博士論文

Implementation of Flying Robot Projects in Aircraft Design Education and its Evaluation of Effectiveness
（飛行ロボット活動の航空機設計教育への応用とその分析に関する研究）

by

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Abstract

Recent changes of needs to engineering education and growth of student-centered teaching and learning activities accompany an educational reform of aircraft design at university. This dissertation focused on an implementation of flying robot projects applied development of one kind of unmanned aerial vehicles. The research also discussed an evaluation of educational effectiveness of the student flying robot activities through the projects. Chapter 1 explained these motivations of the research.

Chapter 2 presented stakeholder requirements about university aircraft design education and flying robot projects through review of industry examples, qualitative and quantitative surveys with aircraft industry stakeholders and an interview to an aircraft designer. The investigations explained a necessity of understanding and experiences of real world practice related to aircraft design for university engineering students. The surveys also indicated requirements of team activities and project management under aircraft design contexts.

Chapter 3 showed prior experiences of the project students about design through field works, qualitative and quantitative surveys, interviews, and video observations. The chapter also compared perceptions in design of the project students with other participants, using quantitative surveys. The result of the surveys indicated that the project students lacked experiences of aerospace design practices. Their design perceptions of applying knowledge to real world design and confidences with design were also insufficient in the comparison with other students. The results were combined with the stakeholder requirements and elicited educational intervention specifications.

In Chapter 4, the specifications that derived from the former studies produced two kinds of flying robot projects in which student design, build and fly original unmanned aerial vehicles through a backward design. The method developed learning objectives and criteria of summative assessment of the flying robot projects. The design demonstrated two teaching and learning activities relevant to flying robot activities. One activities was teacher-centered design activities of three-view drawings of flying robots in a conceptual design phase. The other focused

on constructivism and contained student-centered design activities applied the Kolb's learning cycle.

Chapter 5 demonstrated the two projects and evaluated the student design activities through a comparison of three-view drawings. Criteria of the evaluation which was produced through analyses of assessment sheets of project staffs and video observations of educator meetings produced consistent evaluation of the student products. The results indicated the similarity of the products through the two learning activities.

Chapter 6 explained summative assessment including student self-evaluations and staff post-evaluations with all student design activities of the projects. KJ method categorized student self-evaluation results. The staff assessments were applied to the assessment criterion derived from the curriculum design. The results indicated that though the constructivism learning activities didn't have distinct characteristics through the staff assessments, the self-evaluations demonstrated differences of the student perceptions in design and team activities. The research also referred that many students who engaged in student-centered activities pointed out importances of applying aeronautics knowledge to real world design and consciousness with team activities and project management.

This dissertation ended with conclusions in Chapter 7. The paper illuminated the aircraft stakeholder requirements with flying robot projects and the prior experiences and knowledge of the project students and designed the flying robot projects, using the curriculum design method. The research concluded that the project was able to activate the student educational perceptions in design and team activities through the constructivism learning curriculum of designing flying robots.

Chapter 1 Introduction

1.1 Motivation

Recently a revolution of higher engineering education and an immediate developing of aeronautics demand university innovation about aircraft education. Aircraft design education is also required to change its educational system and learning outcomes. Students required acquiring not only fundamental knowledge of engineering but also team activities skills, including project management, communication skills through real world engineering practice such as team activities related to industrial aeronautical design works, and developing real world unmanned aerial vehicles or flying robots. This background makes evaluations of educational effectiveness more critical with more pedagogical and objective methods. Accumulations of information about student design processes and assessments of student activities and evaluations of education system can give positive effects the next engineering educations. However many aircraft design education have taken in many universities and some isolated design courses out of aeronautics try to evaluate the student activities, only a few research showed the detailed assessment of student aircraft design activities (Butler, 2012; Coso, 2014).

This research showed an implementation and an evaluation of one kind of aircraft design education through developing unmanned aerial vehicles by multidisciplinary student teams: the Flying Robot Project at The University of Tokyo. In this project student teams design, build, and fly an original flying robot which conformed to the competition regulation through one semester curriculum. The research consisted of three phases. The first phase included quantitative and qualitative surveys of an industrial engineers and an interview of a professional aircraft designer. The objectives of aircraft design education in higher education faculty was summarized and the learning outcomes of developing flying robot activities through aeronautical curriculum was defined. At the second phase, I analyzed concrete student design activities of flying robots of each semester. At first, I compared student perceptions about design through qualitative and quantitative surveys. Differences of three categories students was shown. The first group consisted of students who have received the curriculum of developing original flying robots, the second is a group of aeronautical students who have not experienced developing flying robots, and the third is students participated in the contest of developing flying robots. Then concrete student design activities of developing flying robots under the curriculum was designed. accumulation of data about student activities could be acquired through field observations, student documentation including mail documents, deliverables, student blogs, products, and presentations. Comparisons of several student design activities of flying robots were shown and good processes of how to design the vehicles were apparent. I also conducted the qualitative and quantitative surveys and instructors evaluation of student learning outcomes. These works illuminated the effective ways of student developing flying robot activities from the standpoint of design education.

1.2 Literature Review

Aircraft design is a critical discipline in aeronautics and many aerospace department of university adopted as contents in the curriculum. Some university conducted curriculum which focus on understanding conceptual design, it is a main stream of university engineering education in aeronautics fields, and others tried to include experiences of fabrication, detail design, operation, and maintenance through developing unmanned aerial vehicles (Brodeur et al., 2002; Crawley et al., 2011). The latter one is developing through student club activities and design competition managed by national aerospace conferences or institutions (Bovais et al., 2006; Roberts, 2010; Suzuki and Kanegawa, 2013; Cole et al., 2011). Recently some universities tried to add these contents into their curriculum (Mason, 2010; Crawley et al., 2011; The University of Tokyo and Boeing, 2016; KIT, 2015), dealing with requirements from engineering industry (ABET, 2015; Stephens and Richey, 2013; Stephens, 2013). However these educational activities had problems of faculty burden in order to prepare different things related to develop real world aircraft (Mason, 2010), and the educational research is developing relatively.

One of the causes of difficulties of these practical aircraft design curriculum which come form the difficulties of evaluating student design activities correctly is that aircraft design is large and complicated and student need a lot of time even if the problems are to develop UAVs (Mason, 2010). In addition, aircraft fabrication depended on mainly knowledge and experiences of expert designers and there were no deductive absolute solution (Raymer, 2012). Therefore faculty had to depend on their own subjective thoughts with students. These problems are implicit in design education generally (Dym et al., 2005) but recently design education study illuminated several evaluation methods for design (Atman et al., 2008; Mosborg et al., 2005; S.Adams and Fralick, 2010) and Butler (2012) applied these methods to conceptual aircraft design and compared simulation-based learning class with teacher centered class in aircraft design. (Coso, 2014) designed educational interventions in which student could integrate stakeholder consideration into aircraft design. These research characteristics was to evaluate student activities in aircraft design curriculum objectively and discuss them. However analysis of crafting something were insufficient in aircraft design education. This research focused on student activities of developing real world unmanned aerial vehicles as a team, we called them flying robots, investigated meanings of conducting these activities from both aspects of industry and student consciousness. Then this research designed the project in which student design, build, and fly original flying robots as a team under university curriculum and evaluated its effectiveness.

1.3 Paper Overview

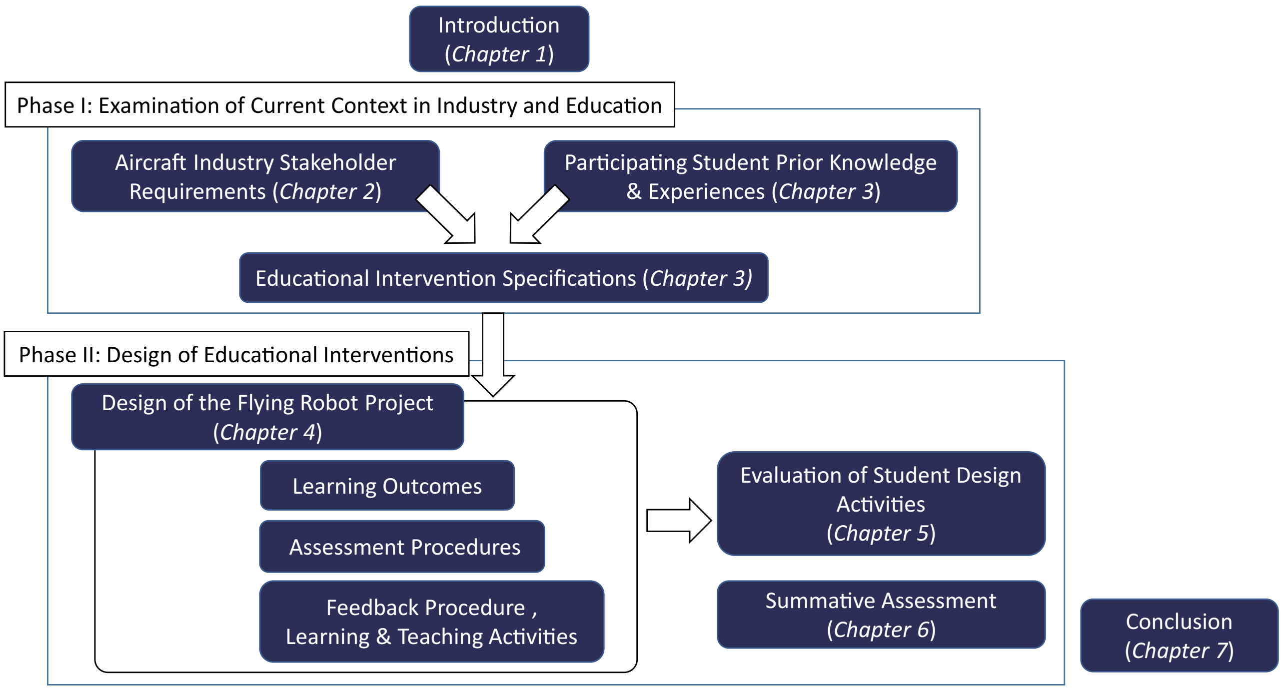


Fig. 1.1: Research Overview

The flow of this dissertation is subject to Fig. 1.1. This paper is organized as follows. Chapter 2 presented the learning objectives of aircraft design education through surveys of industrial stakeholders and an interview of an aircraft designer. Chapter 3 showed the context of the Flying Robot Project and indicated student prior perceptions in design through field observations and qualitative and quantitative surveys. It also brought out educational specifications of this dissertation. In Chapter 4, curriculum design methodology applied to developing flying robots and learning outcomes, feedback and assessment procedures, and teaching and learning activities were indicated. In Chapter 5, concrete student activities of developing flying robots under curriculum were compared and evaluation of student outcomes were explained through student artifacts. In Chapter 6, each team activity was compared and redefined through student self-assessment and staff summative assessment. This dissertation ended with conclusions and future works of the research in Chapter 7.

Chapter 2 Skill Requirement for Aircraft Design and Developing Flying Robots

This chapter answers the following research questions about engineering education demand from aircraft industry.

RQ#1: What learning outcomes does aircraft industry think are needed for university graduates?

Fig. 2.1 showed an overview of this chapter. The research started from industry examples according to literature review. The survey included aircraft stakeholder requirements with flying robot activities and interview with an aircraft designer. The results were analyzed by statistical methods and the conclusion included specifications of educational interventions in which this research focused on.

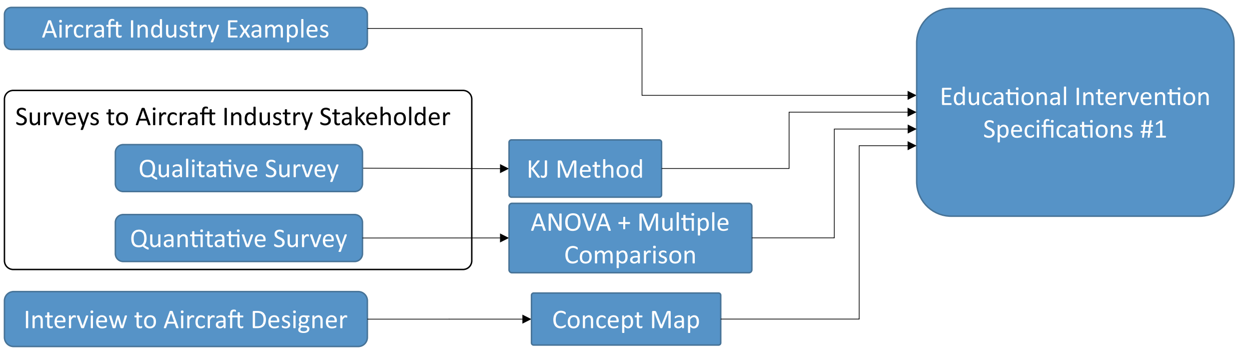


Fig. 2.1: Overview of Aircraft Stakeholder Requirement Surveys

2.1 Industry Examples

This section indicated several examples of recommendation of practical engineering education in aircraft industry.In 2013, Rick Stephens and Mike Richey explained about growing the business leader especially in industry (Stephens and Richey, 2013; Stephens, 2013). In the past 2 years, the Boeing Company hired 33,000 new employees, and they observed important phenomena, e.g. these new employees were generally quite good at using digital tools, however, they had rarely had the experience using their knowledge and skills to create a product of value. Consequently, the Boeing Company now spends 13 weeks training employees for manufacturing job. They were also alarmed that “engineering majors who fail in industry are those who have all the right technical competencies but not the soft or people skills to be successful ” (Stephens, 2013). They also insisted that they should create more internship opportunities and promote more hands-on problem-solving activities in universities.

EMBRAER, the largest aerospace industry in Brazil which had been leading one aspect of industrial aircraft design was pressed for a decision of a revolution of educating engineers for the company right after a large success of ERJ-145 at 1999. It established a systematic and strategic program named EMBRAER’s Engineering Specialization Program (PEE) which trained selected students who want to entire the company with 18 months. This program brought some profit for the industry, however its costs became very high because the company hired all the full-time students as EMBRAER employees who were receiving their salaries and all the social benefits. After all, the managers looked for a different approach for education and concluded with the establishment of Master Program with the Technological Institute of Aeronautics (ITA) and the Casimiro Montenegro Filho Foundation (FCMF) (de Andrade et al., 2003; EMBRAER, 2016).

This program was similar with ordinal master degree programs, but the contents were advanced. The class included contexts of real engagement for aircraft development in the company, so the students was highly selected through several examinations and interviews. The program consisted of four phase. Phase 1 was a basic class of fundamental aeronautics. Phase 2 was a career program of distinct major of real world aircraft development. In Phase 3, student engaged in the real work of aircraft conceptual design as one of design team members. In the last phase, they prepared and presented a dissertation.

It is critical through all the program that “besides the technical competence, students be constantly observed on their planning, controlling and organizing skills (de Andrade et al., 2003)”. Especially in Phase 3, real world design activities, “a whole set skills are observed: technical, behavioral, teamwork, leadership (de Andrade et al., 2003)”.

2.2 Engineering Education Guideline

2.2.1 Roadmap for promotion of research and development of aeronautical science and technology

On August 21, 2012, Ministry of Education, Culture, Sports, Science and Technology in Japan published a roadmap for promotion of research and development of aeronautical science and technology which described guidelines of Japan's aeronautical faculty, institution, and industry (MEXT, 2012). The roadmap was considered by the aeronautical science and technology committee including Japan's aeronautical industry, institution, and university. This roadmap summarized doctrines of Japan's aviation in 10 years and technology and priority that Japan should strengthen and realize.

This roadmap also explained images of human resources and cultivation of human resources for the aeronautical science and technology which included "general things", "conceptual design", "technology development", "management", "certification", "manufacture", and "operation". Tab. 2.1 was summarized the categories which was thought related to aircraft design education.

Tab. 2.1: Roadmap's Category Related to Engineering Practice [1]

Categories	Images of human resources	Examples of efforts
Conceptual design	(I):Engineers who can design aircraft concept	(I-1) Lectures, practices, and contests of aircraft conceptual design
Technology development	(Ⅱ)Practical engineers and researchers	(Ⅱ-1) Aircraft design project and flight demonstration
	(Ⅲ) Avionics and soft engineer of aircraft	(Ⅲ-1) Develop domestic avionics industry
Management	(Ⅳ) Who can cope with project management of aircraft development	(Ⅳ-1) Management education and acquisition of a qualification of project management
		(Ⅳ-2) phasing from experiences of a design leader to an assistant project manager and a project manager
		(Ⅳ-3) Acquire fundamental knowledge about aircraft, Comprehend of correlation of multiple disciplines and acquire sense of their balances
		(Ⅳ-4) Improve communication skill and accommodation capability
Manufacture	(Ⅵ) Engineers who acquaint with high rate and low cost manufacturing	(Ⅵ-1) Interaction with interdisciplinary human resources
	(Ⅶ) Who can guarantee quality of products which fulfill design requirements	(Ⅶ-1) Develop and manage logical and rational qualifications of products

This guideline also referred training and improvement of excellent young researchers, certifiers, engineers who would be responsible for the next generation in the field of aviation technology as a common activity for human resources development. It mentioned construction of a systematic specialized education program and implementation of education linked to aircraft development as an example of efforts of the improvements.

After all not only in acquiring basic knowledge in each field but also developing human resources who had practical project management skills was critical in aircraft design. In order to solve the problem facing the modern society, it is necessary to apply the knowledge to actual problems and derive solutions. At the same time, the challenges in the current aircraft are

[1] Translation by the author.

not solved by individual and it was important to know how to achieve good performance as a team, interact different human resources with multiple disciplines, experience as a design leader, experience in project management , improve communication and adjustment skills.

2.2.2 JABEE

This section also indicated one stream of engineering practices at university education. The Ministry of Education, Culture, Sports, Science and Technology in Japan convened Cooperative Conference on Practical Engineering Education at University and discussed what engineering education systems and structures were suitable for the country with faculty leaders (MEXT, 2010). The discussion ended at June 4 on 2010 and the following concrete activities has been taken over in JABEE (Japan Accreditation Board for Engineering Education). JABEE created criterion for engineering university program as the following, referring to the ABET criterion (ABET, 2015).

Tab. 2.2: JABEE Criterion

(a) An ability of multidimensional thinking with knowledge from global perspective
(b) An ability of understanding of effects and impact of professional activities on society and nature, and of professionals' social responsibility
(c) Knowledge of and ability to apply mathematics and natural sciences
(d) Knowledge of the related professional fields, and ability to apply
(e) Design ability to respond to requirements of the society by utilizing various sciences, technologies and information
(f) Communication skills including logical writing, presentation and debating
(g) An ability of independent and life-long learning
(h) An ability to manage and accomplish tasks systematically under given constraints
(i) An ability to work in a team

This criterion also included abstract concepts and concrete teaching and learning activities or assessment procedures were committed to each faculties.

2.3 Industry Engineers' Perceptions

2.3.1 Methodology

2.3.1.1 Aircraft Stakeholder Survey for Developing Flying Robot Activities

The survey investigated with participants of two workshop of aeronautical innovation for aeronautical stakeholders. The first seminar was on January 1, 2014 and the second was on February 4, 2014. The participants included aircraft manufacturers, airlines, commercial firms, university and research institutes, governments, and other affiliates relating to aeronautical industry. The investigation contained six questions. The four questions was about developing flying robots and the others was about project management which was explained in the next subsection.

Tab. 2.3: Survey List for Aircraft Stakeholders about Developing Flying Robots

#	Question	Format
1	Have you experienced developing real world products like model airplane and small satellites at your university age?	Yes/No
2	Do you think developing aerospace vehicles at university age is useful for your business experiences?	5:strongly agree ～ 1: strongly disagree
3	Describe your opinion about university student activities of developing real world products like student competitions of flying robot.	free
4	Describe any projects you want students engage in.	free

2.3.1.2 Aircraft Stakeholder Survey for Project Management

The two questions about project management was asked to the seminars' participants. The survey contained two Likert questions in which participants selected with the given question from 5: strongly agree to 1: strongly disagree.

Tab. 2.4: Survey List for Aircraft Stakeholders about Project Management

#	Question	Format
5	Do you think the below skills are important for your business work?	5:strongly agree ～ 1:strongly disagree
6	Do you think the below skills are what students should learn at university? • Progress management • Budget management • Human resources management • Negotiation • Communication skill • Internationality • Problem solving skill	5:strongly agree ～ 1:strongly disagree

2.3.1.3 Aircraft Chief Designer Interview

This section indicated one example of aircraft designer perception. I interviewed an aircraft designer who have experienced more than two aircraft design as a chief. The interview was performed over one and a half hours and main contents of questions were as follows (Tab. 2.5).

Tab. 2.5: The Interview Contents

Interview protocols
What abilities or skills do you think aircraft designers have to have?
What abilities or skills for aeronautics do you think aircraft designers have to have?
What abilities or skills for teamwork do you think aircraft designers have to have?
What are the differences between a good aircraft designer and a not good designer?

2.3.1.4 Limitations

This examination only illuminated limited perceptions of an aircraft chief designer. The well-experienced aircraft designer like a chief designer was relatively limited in this research, comparing the prior-research circumstances (Coso, 2014). More concrete and collect surveys should be required. However this investigation could unwrap the mindset of real world aircraft design and indicate the way to go for future researches.

2.3.2 Results

2.3.2.1 Aircraft Stakeholder Survey Results

Ninety-three participants answered the seminar surveys. Fifty-three respondents were on the first survey and the others were on the second.

2.3.2.1.1 Participant Background

This investigation also examined participant affiliations at the Tokyo's session and ages in the both surveys. Fig. 2.2 showed the result. Fig. 2.3 also indicted the age distributions of the respondents.

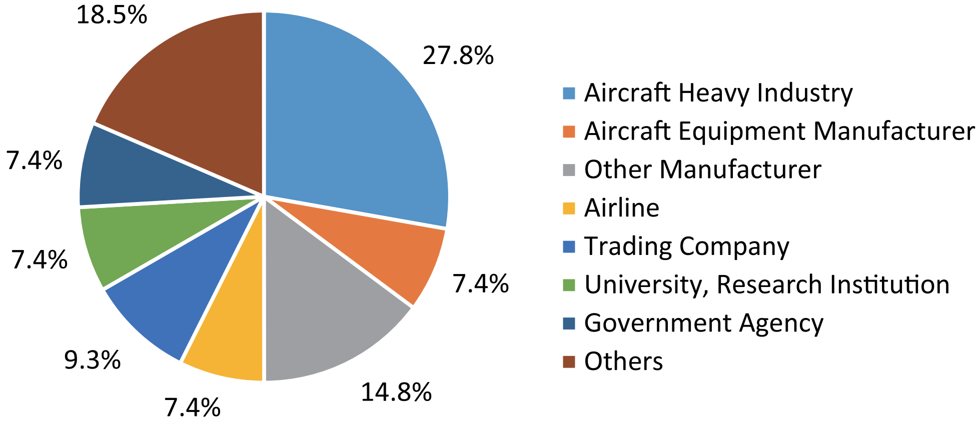


Fig. 2.2: Participant Affiliations at the first seminar (n=53)

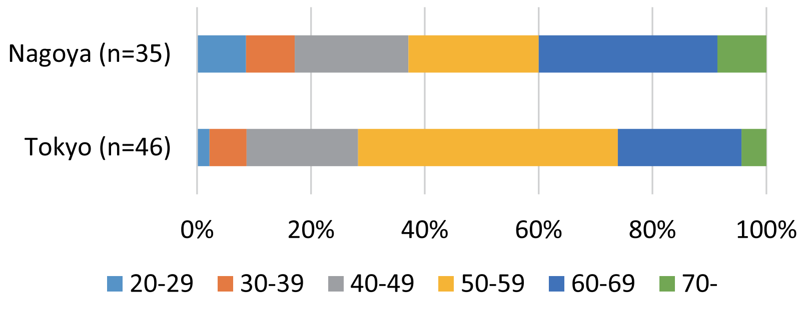


Fig. 2.3: Participant Ages at the first seminar (n=53)

These responses of the respondents of the second seminar could not acquire in the surveys.

2.3.2.1.2 Relationship between University Experiences and Perceptions in Developing Flying Robot Activities

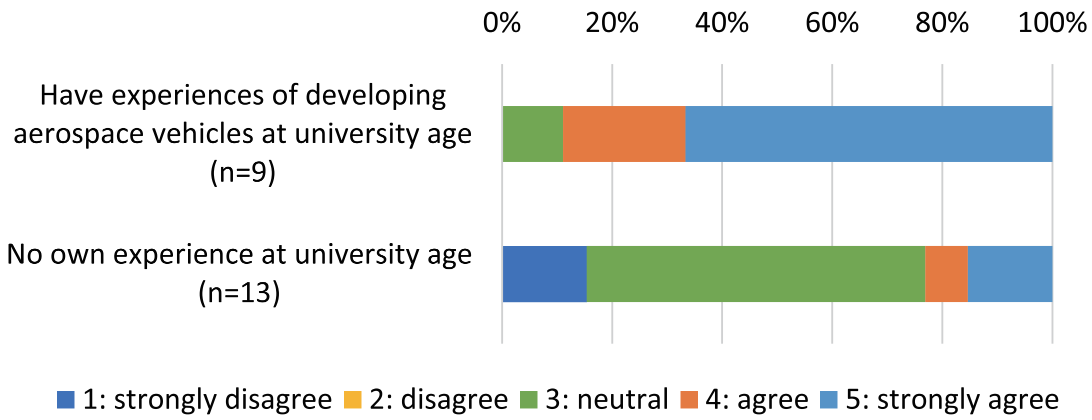


Fig. 2.4: Results of the second question: *Do you think developing aerospace vehicles at university age is useful for your business experiences?*

Only nine of ninety participants engaged in developing aerospace vehicles like model airplane and satellites at their university age. However thirteen of participants who answered "No" at the first question replied the second question and this survey could refer to the relationships of experiences of developing real world products with perceptions in the activities at university level.

Fig. 2.4 showed the result of the second question. Over 60 % of the participants who had experiences of developing the aerospace vehicles at university age selected "strongly agree" whereas half of no own experience people answered item 3:"neutral". However the results of the experienced group ($M = 4.6$, $SD = 0.7$) did not show a statistically difference with the no-experience group ($M = 3.1$, $SD = 1.1$) with the MannWhitney U-test, $p = 0.591$, partly because this research did not acquire enough number of respondents.

2.3.2.1.3 Society Perceptions in Student Activities of Developing Flying Robots

Forty participants answered open-ended third question: *Describe your opinion about university student activities of developing real world products like the Flying Robot Contest.* These respondents were distinguished three groups from the contexts: 1) these activities was thought as very useful or important for students, 2) these activities was thought as useful for students but needed some improvements, and 3) these kinds of activities was thought as useless for students. Fig. 2.5 indicated

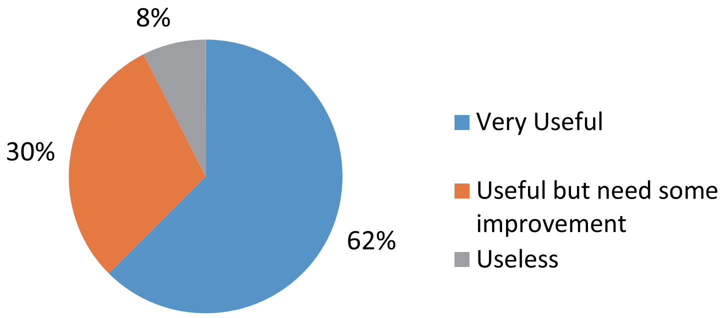


Fig. 2.5: Grouping comments of the open-ended third question: *Describe your opinion about university student activities of developing real world products like the Flying Robot Contest.*(n=40)

In order to describe more clearly, I categorized all comments of respondents. Thirty-one respondents of the third question includes not only words like “it’s splendid” or “That is useless” but also the contexts relating to reasons or improvement points of concrete activities about the Flying Robot activities. Some comments also include both positive and negative impacts of the contest, so I extract key components of each comments and categorized them eight groups as Fig. 2.6. Eighteen respondents of those contains reasons of positive effects and fifteen participants explained the improvement points of the contest.

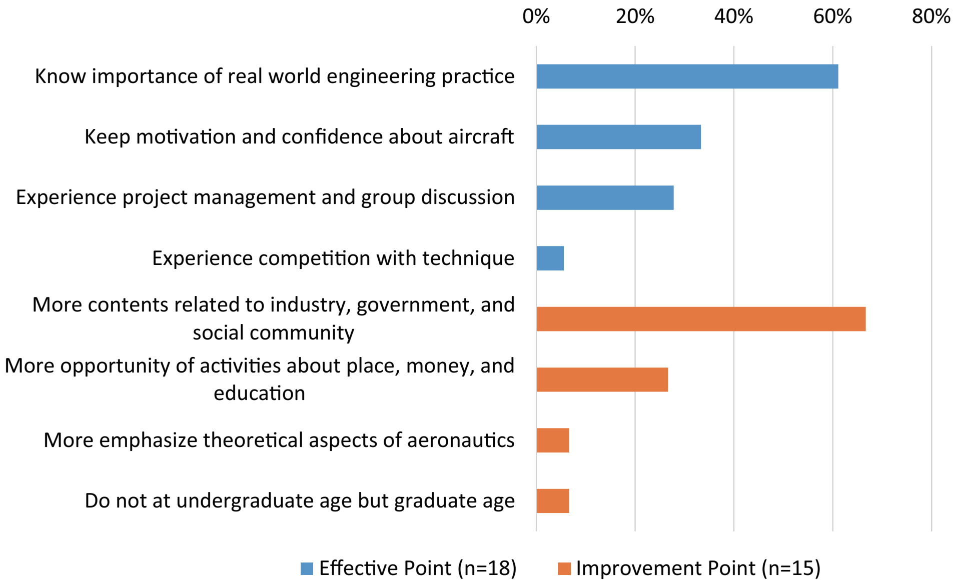


Fig. 2.6: Grouping comments of the open-ended third question: *Describe your opinion about university student activities of developing real world products like the Flying Robot Contest.*(n=31)

Effective points which eighteen participants responded were categorized four groups. First was that students will be able to know importance of real world engineering practice. They thought in-class lectures were not sufficient learning real world products. They guessed these activities can improve student perceptions in design or development through touching and considering real world things. Secondly, students will be able to keep motivation and confidence about aircraft. Designing real world aircraft and watching its flight could make student more motivated to aeronautics, they thought. Some respondents focused on an aspect of experiences of failures. Students acquire authentic engineer minds through their own mistakes of engineering design, and conquering problems help students grow up. In contrast, who have not experienced crafting real world things were more likely to overestimate their own abilities, and they might frustrate when they met the difficulties, the respondents referred.

Third category is that students will be able to experience project management and group discussion. Many industry activities consisted of numbers of teams and project management is indispensable. Group discussion also needed in real world activities on industry. Engaging in these behaviors at university age was very critical in order to grew authentic engineers, they insisted.

The last point of positive effects the respondents thought is that students will be able to experience competition with technique. In real industry works, many things consisted under competition like a price war and considering superiority of each design and engineering behaviors was critical.

On the contrary, fifteen of respondents included improvement suggestions about the Flying Robot Contest activities. First is that it needed more contents related to industry, government, and social community. They thought that developing flying robots could be only hobby if students are not aware of the social needs of them. Therefore, some structure in the contest needed in order to connect students with real industry works. Some participants insisted that university should promote internships alternatively.

The second point they suggested was that it needed more opportunity of activities about place, money, and education. They basically agreed with the contest, but these days supports by management committee of the contest were insufficient. Many students were interested in these activities, but they don't have enough knowledge and experiences about managing their activities in aspects of design technique, test place, and money. Therefore university and government should help student activities more actively, they suggested.

The third and forth points were minority opinion. The former is that it need more emphasize theoretical aspects of aeronautics and the latter is that these activities should promote not at undergraduate age but at graduate age.

2.3.2.1.4 Society Perceptions in Project for University Students

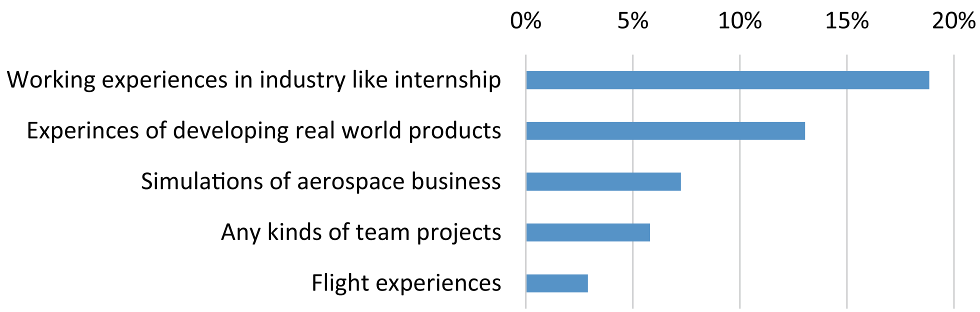


Fig. 2.7: Grouping comments of the open-ended fourth question: *Describe any projects you want students engage in.*(n=69)

Fig. 2.7 showed the result of the fourth question: *Describe any projects you want students engage in.* Sixty-nine respondents expressed other project they want students engage in. The most numbers of answers was about working experiences in industry like internship. They held an importance of knowing industrial circumstances of research and development of products. Some participants noted experiences of developing real world products same as the Flying Robot Contest. Others referred to the simulations of aerospace business at university.

2.3.2.1.5 Summary

In this surveys, many aircraft stakeholders thought developing flying robot as positive. The stakeholders who had experiences of developing aerospace vehicles at university age argued that developing real world products were effective activities for learning aeronautics. In addition most of the no experience participants referred positive aspects of these activities. After all many respondents supported developing real world aerospace products with the objective of both effectivenesses and improvements. However, the statistical test did not indicate a significant difference of experiences of developing real world products at university age and future works need more participants.

Many respondents included the merit of the contest and they insisted an importance of experiences of practical engineering, keeping motivation and confidence with aircraft, and experiences of project management and group discussion.

Some participants answered some improvements about contests, including necessity of more contents related to industry, government, and social community. They also suggested that the committee of the contest gave students more opportunity of these activities and prepared place, money, and education for students.

The respondents also referred other project of working experiences in industry like internship and some comments also included necessity of experiences of developing real world products and simulations of aerospace business.

2.3.2.2 Aircraft Stakeholder Survey for Project Management

Results of aircraft stakeholder surveys for project management (Q5 and Q6) were shown. Eighty-eight respondents of the participants

Tab. 2.6 showed the results of the two quantitative questions.

Tab. 2.6: Results of Stakeholder Perceptions in Project Management Skills

	Q5.Importance (n = 73)			Q6. Necessity for student learning (n = 80)		
	MEAN	S.D.	MEDIAN	MEAN	S.D.	MEDIAN
Progress	4.25	0.75	4	3.33	1.02	3
Budget	3.99	0.69	4	3.08	0.92	3
Human Resources	3.77	0.77	4	2.85	0.90	3
Negotiation	4.64	0.61	5	4.14	0.81	4
Communication	4.77	0.45	5	4.68	0.54	5
Internationality	4.52	0.58	5	4.47	0.69	5
Problem Solving	4.71	0.54	5	4.42	0.70	5

One-way ANOVA using R indicated statistically differences in the seven groups of Q.5 ($F(6, 504) = 26.66$, $p = 2.2e-16$). Multiple comparison using Tukey HSD method showed that the result of *Progress* ($M = 4.25$, $SD = 0.75$) was statistically different from *Human Resources* ($M = 3.77$, $SD = 0.77$) with $p < 0.001$, *Negotiation* ($M = 4.64$, $SD = 0.61$) with $p = 0.004$, *Communication* ($M = 4.77$, $SD = 0.45$) with $p < 0.001$, and *Problem Solving* ($M = 4.71$, $SD = 0.54$) with $p < 0.001$ respectively. It also argued that there were differences statistically between the result of *Budget* ($M = 3.99$, $SD = 0.69$) and *Negotiation* with $p < 0.001$, *Communication* with $p < 0.001$, *Internationality* ($M = 4.52$, $SD = 0.58$) with $p < 0.001$ and *Problem Solving* with $p < 0.001$. The analysis also indicated that *Human Resources* was statistically different from *Negotiation* with $p < 0.001$, *Communication* with $p < 0.001$, *Internationality* with $p < 0.001$ and *Problem Solving* with $p < 0.001$.

After all the multiple comparison result supported the statement aircraft stakeholders thought importances of *Negotiation*, *Communication*, and *Problem Solving*, rather than *Progress*, *Budget*,and *Human Resources*.

One-way ANOVA analysis with the results of Q.6 also showed statistically differences between sets of data ($F(6, 546) = 66.20$, $p = 2.2e-16$). A Multiple comparison with Tukey HSD method indicated that the result of *Progress* ($M = 3.33$, $SD = 1.02$) was statistically different from *Human Resources* ($M = 2.85$, $SD = 0.90$) with $p = 0.004$, *Negotiation* ($M = 4.14$, $SD = 0.81$) with $p = 0.004$, *Communication* ($M = 4.68$, $SD = 0.54$) with $p < 0.001$, *Internationality* ($M = 4.47$, $SD = 0.69$) with $p < 0.001$, and *Problem Solving* ($M = 4.42$, $SD = 0.70$)

with $p < 0.001$ respectively. It also presented statistically significant difference between the result of *Budget* ($M = 3.99$, $SD = 0.69$) and *Negotiation* with $p < 0.001$, *Communication* with $p < 0.001$, *Internationality* with $p < 0.001$ and *Problem Solving* with $p < 0.001$. The analysis also indicated that *Human Resources* was significantly different from *Negotiation* with $p < 0.001$, *Communication* with $p < 0.001$, *Internationality* with $p < 0.001$ and *Problem Solving* with $p < 0.001$ statistically. In addition, the result showed that there were a significant difference of *Negotiation* with *Communication*, $p < 0.001$. In conclusion, the analyses insisted on the existence of the significant differences of the results of *Negotiation*, *Communication*, *Internationality*, and *Problem Solving* with *Progress*, *Budget*, and *Human Resources* as contents which the stakeholders want students learn before they graduate university.

2.3.2.2.1 Summary

The aircraft stakeholders relatively thought that communication skill, problem solving skill, and negotiation skill were important rather than managements of progress, budget, and human resources. They also considered the former skills were learned and taught students at university level. On the contrary, concrete management skills were not the first priority for university students, they thought. Though internationality was not the most important skills for project management, the participants thought it as what students should learn at university age.

After all this surveys illuminated partly the necessity of teaching project management skills , especially communication skill, negotiation skill and problem solving skill to students at university age.

2.3.2.3 Aircraft Chief Designer Interview

Tab. 2.7 showed the result of the industrial aircraft designer perceptions through this survey.

Tab. 2.7: Aircraft Designer Skills

Category	Content
Aircraft Design Skill	Fundamental Knowledge of Engineering Knowledge of Design Solutions and Experiences of Design Logical Thinking Ability Determination
Teamwork and Management Skill	Confidence Interdependence Responsibility and Ownership Progress Management Risk Management Role Sharing Scheduling

2.3.2.3.1 Aircraft Design Skill

Aircraft design skill included four kinds of abilities broadly. First was fundamental knowledge of engineering. Industrial conceptual aircraft design was based on scholarly conceptual design. Aircraft designers had to understand the fundamental of aeronautics in order to decide each parameter of aircraft such as weight estimates, body shape determination, estimation of wing area, and so on. Preliminary phases of aircraft design also needed the designers' theoretical knowledge relating to structures and aerodynamics in order to analyze aeronautical phenomena about aircraft. In addition, these analysis was produced in design teams through documentations or presentations, aircraft designers had to work well using linguistic things.

The second was to have knowledge of design solutions and experiences of design. Aircraft designers should comprehend existing aircraft design solutions and design methods by the prior designers. There were often no general solutions in real world aircraft components. There were also not sufficient time and cost for designing products, so many design solutions depended on experiment rules through the existing design. Therefore aircraft designers had to acquire many cases of aircraft design solutions including design objectives, design methods, troubles, and products through observing existing aircraft materials or real things and experiences of design. They also had to get knowledge of aircraft design but also selected and applied each design solution to their own problems in each case. The designer who had many experiences of design and knew rich knowledge of aircraft could decide about design with confidence.

The third one was logical thinking ability. The aircraft designers had to plan the effective and appropriate analyses and experiments, compare results of experiment with solutions of analyses correctly, and recognize and explain the essence of problems accurately. Especially, a development of real world product often contained specific issues and the designers needed abilities of illuminating the matters authentically, using convinced theoretical knowledge. In addition, deciding design solutions was a role of the designers, and they had obligations of their own decisions logically.

The last ability was determination. Aircraft designer had to appropriately and immediately determine what solutions were adopted in the problem mostly, considering phenomena logically. They also had to select methods of experiment or test and analyses in order to develop real world products under limited circumstances such as cost and time.

2.3.2.3.2 Teamwork and Management Skill

The first skill for teamwork and management skill was interdependence. Interdependence with reliance each other was critical character of aircraft designers. Aircraft design needs more than a few thousand engineers for developing aircraft and it is impossible that only one designer comprehend the all situations of engineering activities related aircraft design. Aircraft design need teamwork and management of it. Required management skills are not to know other engineer concrete activities or detailed results of analysis precisely but believe the correctiveness of results which others bring. Team leaders also need skills to trust the work results and to judge whether they can trust. Works of the leader is to judge the good or bad of the conclusion given by each team and to believe the members in order to make a decision on development. Conversely, teammates also need to believe each team leader's judgment and proceed with development of aircraft.

The second one was responsibility and ownership. the leader has to take care of member work progress and keep their motivations and make sufficient results. Therefore, the leader must bear the fear and anxiety to fail and have patience and ability to wait for the result of teamwork. At the same time, it is necessary to be able to give members the sense of relief. On the contrary, team members have to keep responsibility of their own works containing understanding of the task objectives, outputs, deadlines and constraints, deeply thinking work progress, risk management, and explaining conclusion simply and logically. They also have to have some kinds of courage to deny what is technically impossible in reality. The leader of the design team need to consider for money, time and customer requirements and don't have allowance with making a technically realistic decision in some cases. In this situation, team members concentrated on the aspects of decisions from the aspects of reality and technological conclusions. The team members have to make claims based on real facts.

The third was role sharing. The team leader also had to know and determine members' ability, motivations and potential for their tasks, and define each roles in a team. They are required to identify each characteristics of members and distribute the works for members to raise their performances.

Fourthly, confidence was critical thoughts in aircraft design. The team members could use their ability under a convinced leader.

The last skill was about planning. Aircraft designers has to define objectives of products appropriately, select technology, design instruments, experiment methods and systems, detailed schedule, and costs.

2.3.2.3.3 Discussion

This subsection redefined the concepts of aircraft designer skills. Fig. 2.8 was the new concept maps of the necessary skills.

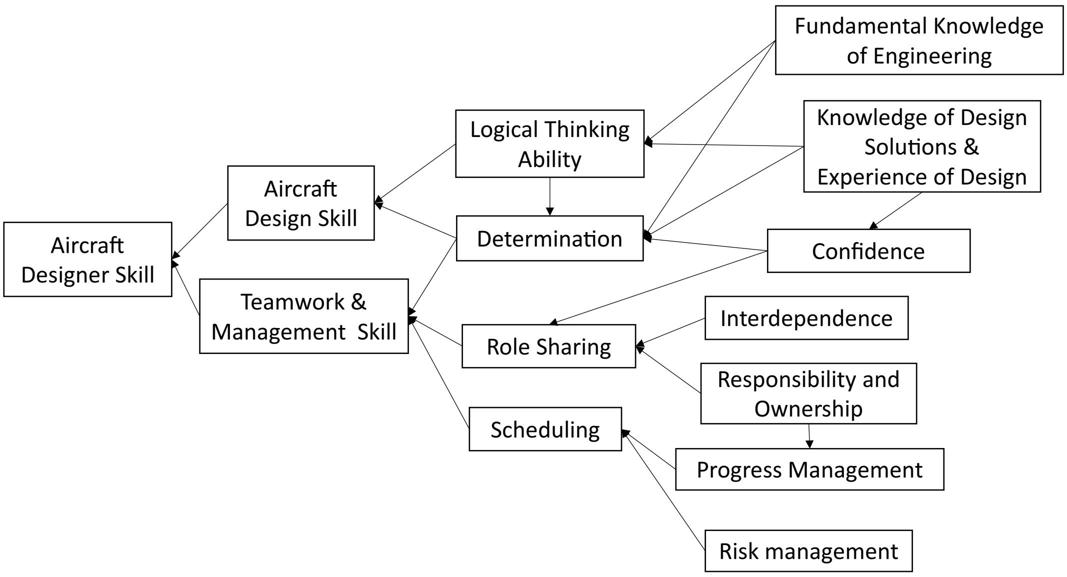


Fig. 2.8: Industrial Aircraft Designer Perceptions

Fundamental Knowledge of Aeronautics Industry aircraft designers need to know fundamental aeronautics in order to not only acquire specialized skills and knowledge for aircraft design but also cultivate logical thinking abilities. It also leads to acquire confidence for designing and it is useful for teamwork.

Application of Aeronautics Skills This skills is to determine things about developing aircraft with confidences, basing fundamental knowledge of aeronautics, logical thinking skills and experiences of real world engineering practice related to design. At same time.

Teamwork and Management Skill This item is needed for team activities. Aircraft design is a teamwork and management is one of the core skills. It also includes role sharing skills and scheduling skills. Role sharing is required to do activities with dependence to team members and have a reliance for other works (*Interdependence*.) It is also important to have responsibilities of their own roles (*Responsibility and Ownership*.) These team activities consisted of each member who have sufficient confidence based on knowledge and experiences (*Confidence*). Especially, in environments requiring interdisciplinary collaboration, like aircraft design, people need interdependence and collective ownership for prominent outputs (Bronstein, 2003). In addition, scheduling is an important factor in order to design under limited circumstances of human resources, time, and costs. The team has to manage its progress and make enough products for deadline. Aircraft designers have to prepare a well-thought plan at start of the design and take good risk management.

2.4 Specifications of developing Flying Robots through Industry Surveys

Through above two surveys with aeronautical stakeholders in industry, this section summarized specifications or requirements of activities of developing flying robots which industrial people stated to engineering university. Tab. 2.8 showed the summary of specifications of developing flying robots as engineering higher education through industry surveys.

Tab. 2.8: Specifications of Developing Flying Robots as Engineering Higher Education through Industry Surveys

#	Category	Educational Intervention Specifications	Derived from
1	General	Shall improve student confidence and motivation about engineering design.	Stakeholder Survey, Aircraft Designer Interview
2	General	Shall experience real world engineering practice.	Stakeholder Survey
3	General	Shall provide students with opportunities to engage in engineering activities related to industry works.	Stakeholder Survey
4	Applying Knowledge to Design	Shall introduce creating theoretical solutions of engineering design, applying fundamental knowledge.	Industry Survey, Aircraft Designer Interview, Student Survey
5	Teamwork	Shall make students identify their own roles and have responsibility in a design team of a flying robot.	Aircraft Designer Interview
6	Teamwork	Shall provide students with opportunities to discuss design solutions and persuade others theoretically.	Aircraft Designer Interview, Industry Survey

Six items were included in the table and it also contained the reasons of deriving each contents from. These contents was based on three categories of engineering practices: “Genera” which influenced every aspects of projects, “Applying Knowledge to Design” was a key thought of real world engineering practice, and “Team work” which was critical element of complicated engineering design.

2.5 Conclusion

This chapter focused on the industry consciousness about aircraft design and student activities of developing flying robots at university level. The industry examples and official guidelines explained improvements of engineering higher education in aspects of its objectives and educational methods. Two surveys with aircraft stakeholders illuminated industry perceptions in university level aircraft design concretely. They stressed students the importances of experiences of engineering practices under real world circumstances at university age from their rich experiences of industrial engineering. After all, not only acquiring fundamental knowledge of aeronautics but also applying it to real world engineering problems and create appropriate solutions through team activities were critical under these days engineering situations.

Chapter 3 Student Prior-Perceptions in Developing Flying Robot

The last chapter explained one the stream of incorporating developing flying robot activities into higher engineering education in Japan. In this chapter, what kind of students participated in these activities was illuminated.

What are differences between students who want to develop flying robots and other students? Some faculties would guess that they had good performances of crafting originally or were interested in the real world products strongly because of the elective class.

In order to investigate the effectiveness of educational program or curriculum clearly, knowing the prior-knowledge of addressing students is important because learners acquired and systematized their knowledge and skills through transfer based their prior-knowledge and experiences (Bransford et al., 2000, Chapter 3). If teachers misunderstand the student capabilities of that time, they could not convince the contents of the class and acquisitions of skills which are defined in the curriculum may suggest. Therefore instructors have to take care of students prior-knowledge and experiences carefully.

This chapter answers the following research questions about student background and perceptions of aircraft design.

RQ#2: What background do students who participate in developing flying robots activities through engineering curriculum have?

- *RQ#2.1*: What major and prior-experiences of design do students who participate in developing flying robot activities through engineering curriculum have?
- *RQ#2.2*: What are differences of perceptions about design between students who participate in developing flying robots activities through engineering curriculum and who don't have experiences of developing flying robots and don't take part in the curriculum?

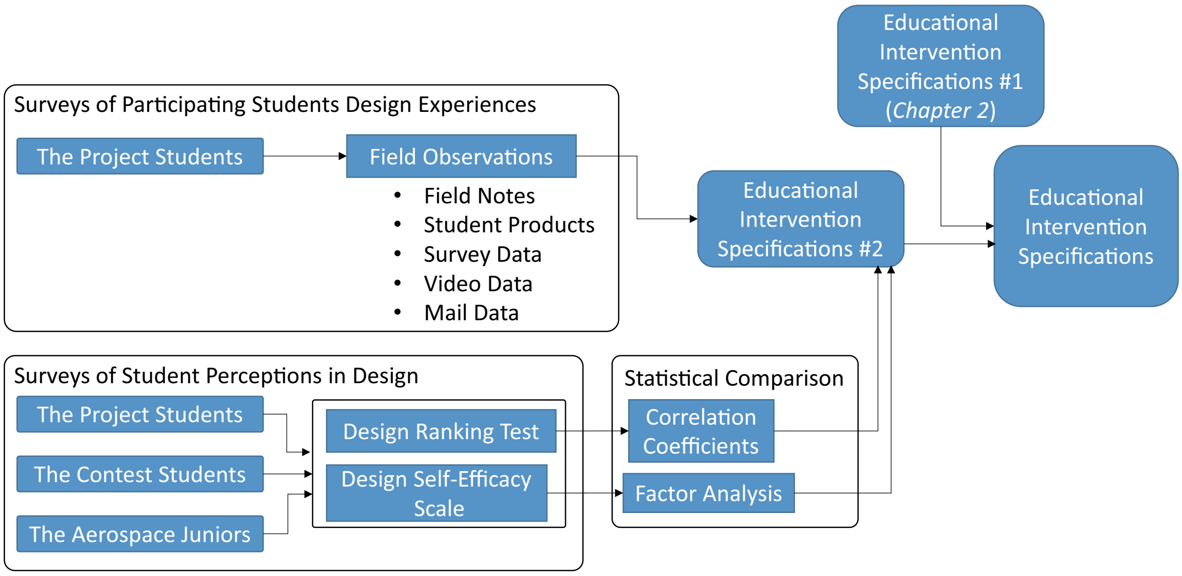


Fig. 3.1: Overview of Participating Student Surveys

This chapter mainly focused on the question of knowledge and experiences which students have before developing flying robot activities through curricula. First research question is about background including student major and grade. Student prior-knowledge are mainly influenced by belonging department. I also explained student design experiences related to develop flying robots. Second is about student perceptions in design. It scoped student consciousness of design like "what points do you think are important for designing aircraft?" or "do you have any confidence of design flying robots?"

3.1 Context - Flying Robot Project and Flying Robot Contest

3.1.1 Subjects and Settings

3.1.1.1 The Flying Robot Project

The context of this study is a project-based learning class in which students design, build, and fly real world flying robots as a team - the Flying Robot Project in the School of Engineering of The University of Tokyo and a robot competition of original flying robots student teams develop - the All Japan Student Indoor Flying Robot Contest.

The Flying Robot Project began as one of the project-based learning classes of the Creative Engineering Project under the Institute for Innovation in International Engineering Education at the School of Engineering of The University of Tokyo on 2010 (IIIEE at the School of Engineering of The University of Tokyo, 2016) in order to give students opportunities of experiencing real world engineering practices and learning not only fundamental disciplines but also teamwork skills and project management skills. The Flying Robot Project also have belonged to the Boeing Higher Education Program since 2013 (The University of Tokyo and Boeing, 2016) and one of the objectives is to grew students who may become practical aircraft engineers through practical engineering education.

In this project, student teams design, build, and fly original flying robots which subject to meet the regulations and rules of the Flying Robot Contest inserted later. Through these activities they would be able to learn some of fundamental knowledge of aeronautics, application method of the knowledge to developing real world flying robots, and soft skills including communication skills and project management skills.

Over 150 students participated in the project from 2010 and they came from different majors and grades. (This is a cumulative total number and some students took the class twice or more in different semesters.) The main goal of this project is to develop real world flying robots, so about half of the members were aeronautics and astronautics students motivated by or interested in aircraft. The department of aeronautics and astronautics of The Univ. of Tokyo recommended student independent extracurricular activities historically, and a few students tried to build original model aircraft with classmates. However not a few students failed to make original aircraft by themselves because of the shortness of experiences of building real world products. For these kind students, this class was thought as exciting and useful to satisfy their curiosity.

Also many junior students attended this class. This phenomenon was caused by the schedule of this university curricula. Freshmen and sophomore students of this university belonged to the College of Arts and Sciences and received wide general education. They received most of the classes at Komaba Campus apart from Hongo Campus in which this project took and most of the students. So, they received the project when they became junior and moved the campus because not only they have motivations of making aircraft but also knowing informations about living in the campus and learning from elder students attended the project such as teaching assistants. Also a start of new semester of new grade stimulate student curiosity of challenging new works, and three-quarters of all the students received this project at summer semester. (Japan's school begin the curriculum on April in general.)

On the contrary, senior students were busy to prepare graduate study. They also tackled job findings or entrance exams of graduate school, so they rarely take this project in this grade.

This project was not a mandatory class, and most of the students don't know this lesson especially at the beginning of the semester if we staff members did nothing. Before a semester began we were preparing introducing the project partly like an inducement of club activity. We made leaflets and posters describing the class activities and student past products and display and distribute them every place in university.university (of course under permission of each department). Sometimes we presented the project between an interval of department orientations and other times took presentation sessions of Creative Engineering Project. Through these "scrupulous" introduction, the students who can have any kinds of motivations about developing real world aircraft participated in the class. After all some kinds of staff's efforts of inviting students to the class confirmed the participants and sustained the activity. If instructors failed the encouragement, the number of students who keep relatively high motivations reduced and the project meet the crisis of disappearing.

3.1.1.2 the Flying Robot Contest

This contest was established in 2006 by the Japan Society for Aeronautical and Space Sciences (JSASS). This is one of the robot competition in Japan and over 60 teams from different high schools, colleges and universities participate in recent years. Student teams develop original indoor UAV and compete the performances and concepts. In this contest, there are some regulations about UAV in order to accomplish missions. The same regulation is applied in our Flying Robot Project. The main regulations are as follows: 1） UAV has to control by radio control, 2） The maximum empty weight of UAV is 200g (manual control section)/ 250g (auto control section), 3） The maximum flight time is 4 minutes, and 4） The main mission is to transport objects to targets. More details were shown in the website (JSASS, 2016).

3.2 Students background and design experiences

First section of this chapter mainly focused on the student prior-knowledge and experiences before developing flying robot activities and answered the *RQ#2.1*.

3.2.1 Data Collection

3.2.1.1 Student Major and Grade

Student major and grade could be evident through the student lists of each semester from 2010 Summer Semester to 2016 S Semester.

3.2.1.2 Student Design Experiences

This research also has a aspect of a trial of gathering useful information effectively under the curriculum, so several methods were adopted on the basis of class circumstances. Tab. 3.1 showed each method of acquiring data of student prior-experiences. The implementation of the project in this research began from 2012 Winter semester and this section included on that time activities.

Tab. 3.1: Data Collection ways of Student Design Experiences Related to Flying Robots

Semester	Data Collection
2012 Winter	Hearing and field notes
2013 Summer	Hearing and field notes and qualitative surveys
2013 Winter	Hearing and field notes
2014 Summer	Hearing and field notes
2014 Winter	Hearing and field notes and qualitative pre-survey
2015 S	Hearing and field notes and qualitative post-survey
2015 A	Hearing, field notes, and video observation
2016 S	Hearing, field notes, video observation, and qualitative pre-survey

3.2.2 Findings

3.2.2.1 Student Major and Grade

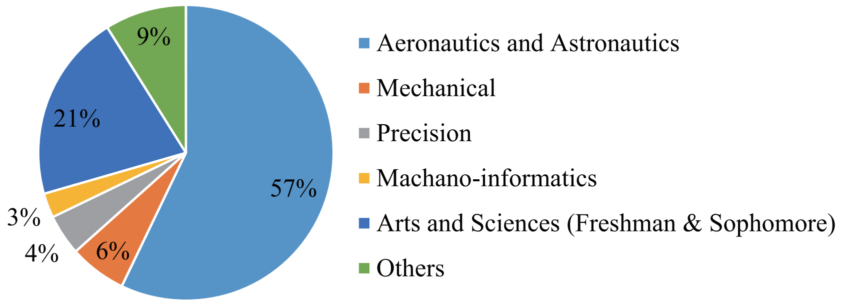


Fig. 3.2: Student Major Distribution from 2012 Winter Semester to 2016 Summer Semester (n=112)

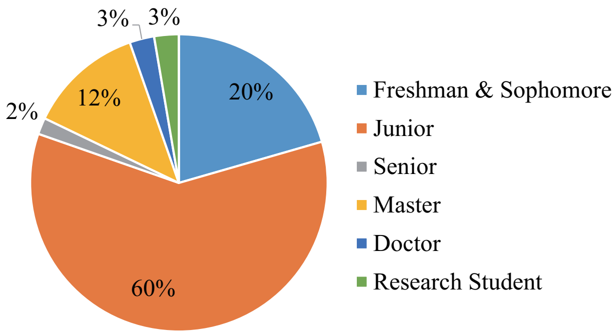


Fig. 3.3: Student Grade Distribution from 2012 Winter Semester to 2016 Summer Semester (n=112)

Over 150 students participated in the project from 2010 and they came from different majors and grades. (This is a cumulative total number and some students took the class twice or more in different semesters.) Fig. 3.2 and Fig. 3.3 showed the student distribution of majors and grades reflectively. The main goal of this project is to develop real world flying robots, so about half of the members were aeronautics and astronautics students motivated by or interested in aircraft. The department of aeronautics and astronautics of The Univ. Tokyo recommended student independent extracurricular activities historically, and a few students tried to build original model aircraft with classmates. However not a few students failed to make original aircraft by themselves because of the shortness of experiences of building real world products. For these kind students, this class was thought as exciting and useful to satisfy their curiosity.

Also many junior students attended this class. This phenomenon was caused by the schedule of this university curricula. Freshmen and sophomore students of this university belonged to the College of Arts and Sciences and received wide general education. They received most of the classes at Komaba Campus apart from Hongo Campus in which this project took and most of the students. So, they received the project when they became junior and moved the campus because not only they have motivations of making aircraft but also knowing informations about living in the campus and learning from elder students attended the project such as teaching assistants. Also a start of new semester of new grade stimulate student curiosity of challenging new works, and three-quarters of all the students received this project at summer semester. (Japan's school begin the curriculum on April in general.)

On the contrary, senior students were busy to prepare graduate study. They also tackled job findings or entrance exams of graduate school, so they rarely take this project in this grade.

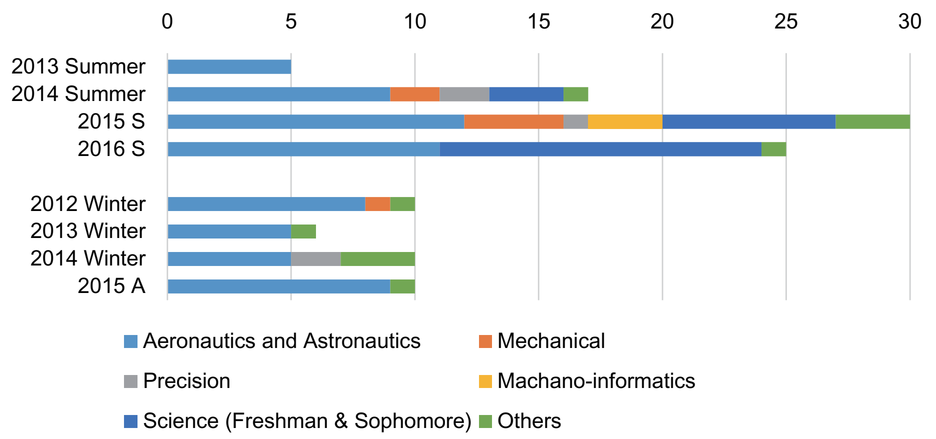


Fig. 3.4: Student Major Distribution at Each Semester (Summer & S: n=77, Winter & A: n=36)

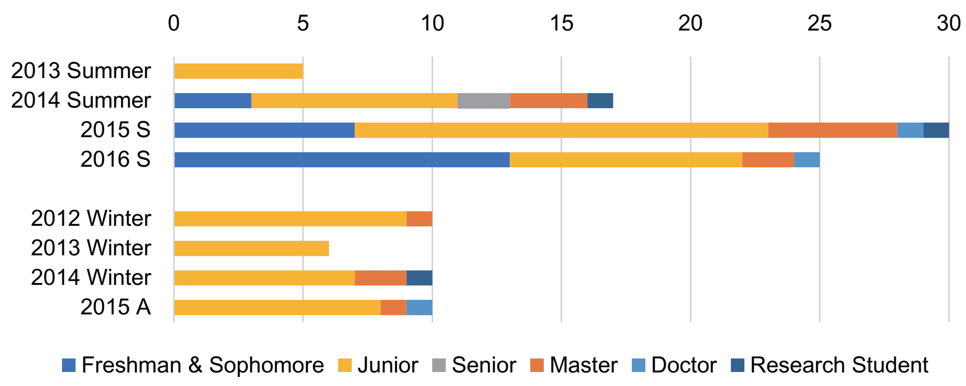


Fig. 3.5: Student Grade Distribution at Each Semester (Summer & S: n=77, Winter & A: n=36)

3.2.2.2 Student Design Experiences

Tab. 3.2: Student Design Experiences Related to Flying Robots

Semester		FR Project	FR Contest	Human Powered Airplane	CanSat	Electronic Kit
2013 Summer	(n=5)	0%	0%	0%	20%	40%
2014 Summer	(n=17)	0%	0%	12%	0%	35%
2015 S	(n=30)	10%	7%	20%	17%	47%
2016 S	(n=25)	8%	4%	8%	0%	-
Total (Summer & S)	(n=77)	6%	4%	13%	8%	*42%
2012 Winter	(n=10)	30%	40%	10%	20%	10%
2013 Winter	(n=6)	67%	67%	0%	17%	33%
2014 Winter	(n=10)	60%	80%	10%	0%	50%
2015 A	(n=10)	10%	0%	10%	50%	10%
Total (Winter & A)	(n=36)	39%	44%	8%	22%	25%
Total	(n=113)	17%	17%	12%	12%	*35%

*Not include 2016 S students.

3.3 Student Perceptions in Design

This section focused on student perceptions in design and answered the *RQ#2.2*. Some people imagined that students who tried to participate in flying robot projects have originally high motivations about engineering design and good-skills of engineering, like students attempting to entry the flying robot competitions or design contests. On the contrary, others guessed that they came the curriculum of developing real world products because they were not interested in projects originally, but some problems or circumstances around them make the students more curious about designing flying robots on that time. The research in this section could reply these kind of questions based on the information acquired through the several surveys.

3.3.1 Participants

In this section, I compared three groups relating to this research. First group was the Flying Robot Project students on 2016 S semester. The survey took at the beginning of the project (2nd class) and twenty-four students replied the questions.

Second was junior students belonging to the department of aeronautics and astronautics of The University of Tokyo. Thirty-nine students participated in the survey after another class. The reason I selected the junior students of this department was that about half of the students participated in the Flying Robot Project were junior students, and this research also compared in the aerospace faculty contexts.

The last group was participant students of the Flying Robot Contest on 2016. The survey took through two methods. First was Web-based survey using Google Form. The pre-survey managed under the Contest committee and I asked the participant registered the entry form of the contest participate in the survey. Second was The committee hold a technical workshop for supporting student learning of aeronautics and techniques about instruments before the contest and I surveyed the students came to the conference.

Tab. 3.3 showed each survey information.

Tab. 3.3: A List of Design Conceptions of the Design Ranking Test

Participants	Day	Remarks
The 12th FR Contest Participants (n=32)	4/9～7/14	Eighteen students: on Web-based, fourteen students at technical workshop (on 6/25)
2016S the FR Project Students (n=24)	4/13	
2016S Junior AeroAstro Students at UT (n=39)	4/11	Except nine students of the FR Project

3.3.2 Data Collection

Several respondents was exclude because they mistook the answer, did not complete the all questions, or rated same scores each item in one section and answers. Finally we got the answers as followings.

3.3.2.1 Prior Experiences

This section discussed mainly through surveys, and the first question about illuminating the student prior design experiences was the following.

- How long have you experienced engineering design or project including on campus and out of campus activities, club activities, and internships?

3.3.2.2 Design Ranking Test

Design Ranking Test is an assessment method of participant perceptions in design. In this test participants selected the six most important and six least important design conceptions from the following twenty-three conceptions about design (Tab. 3.4) (Mosborg et al., 2005). This instrument could be applied in various engineering design situations (Atman et al., 2008; S.Adams and Fralick, 2010; Oehlberg and Agogino, 2011; Hohner et al., 2012) and some researchers adopted this tool for evaluations of aircraft conceptual design contexts(Butler, 2012; Coso, 2014).

Tab. 3.4: A List of Design Conceptions of the Design Ranking Test

Abstracting	Identifying constraints	Seeking information
Brainstorming	Imagining	Sketching
Building	Iterating	Synthesizing
Communicating	Making decisions	Testing
Decomposing	Making tradeoffs	Understanding the problem
Evaluating	Modeling	Using creativity
Generating alternatives	Planning	Visualizing
Goal setting	Prototyping	

In this research all of the participants were Japanese students and some of who don't have enough design knowledge and English knowledge. I tried to test it to some Japanese students before adopt it to this research participants, but some students did not know the word *Brainstorming* and others could not understand differences of *Building*, *Prototyping*. Design study is not general in Japan and this research needed some detailed descriptions of each English conception. Therefore I translated this list for Japanese students as follows. First I categorized each conception based on original papers' meanings (Newstetter and McCracken, 2001; Mosborg et al., 2005), using the KJ method which is a kind of grouping theory (Kawakita, 1975, 1991) with several native English faculties majoring aeronautics. The categories were *Problem Scoping*, *Generating Solutions*, *Problem Solving*, *Project Management*, and *Implementation* and I described each word corresponding with the five categories. Next I pretested it to university and college students who had experiences of developing flying robots and repaired the translations. The final translation of the Design Ranking Test was shown in Tab. 3.5.

Tab. 3.5: Japanese List of Design Activities

Category	Japanese Description (Original Design Activity)
Problem scoping	1. 情報を探す (Seeking information) 2. 課題を分割する (Decomposing) 3. 課題の制約条件を考える (Identifying constraints) 4. 与えられた課題を理解する (Understanding the problem)
Generating solutions	5. チームでアイデアを出しあってブレインストーミングを行う (Brainstorming) 6. 新しいアイデアを生み出すために想像力をはたらかせる (Using creativity) 7. 代わりになる案を生み出す (Generating alternatives) 8. 複数の相反するものごとのバランスを考える (Making tradeoffs)
Problem solving	9. 想像する (Imagining) 10. 最も重要な考えを抜き出して，他は除く (Abstracting) 11. 複数の技術や考えを組み合わせる (Synthesizing) 12. スケッチを描く (Sketching) 13. 考えやアイデアを絵や模型，図面など，目に見える形にする (Visualizing) 14. 物をつくる (Building)
Project Management	15. 計画を立てる (Planning) 16. 目標を設定する (Goal setting) 17. 意思決定を行う (Making decisions) 18. 自分の考えを言葉や文章，図などを用いて他人に伝える (Communicating)
Implementation	19. 本番の作品の前に，数学的なモデルをつくる (Modeling) 20. 本番の作品の前に，試験用のプロトタイプをつくる (Prototyping) 21. プロトタイプやモデルを用いて試験を行う (Testing) 22. 試験結果を用いて評価する (Evaluating) 23. 設計をくり返し行って，設計結果を調整する (Iterating)

This list also included the original English word (like *Brainstorming*) and the five categories were hidden with participants of this surveys.

3.3.2.3 Design Self-Efficacy Scale

Design Self-Efficacy Scale is one of the quantitative surveys which measured participant confidence level in design by Likert scale from 0 to 10 (Carberry et al., 2010). The reason of using eleven choices is to measure participant perceptions more sensitive. This method also applied to aircraft design context (Coso, 2014) and it was simple and effective way of describing student confidence about design. The scale consists of nine items as Tab. 3.6. Using factor analysis, latter eight items (#2: *Identify a design need*〜#9:*Redesign*) have explained as one factor which contains equivalence with item 1:*Conduct engineering design* through further analysis ((Carberry et al., 2010; Coso, 2014)).

Tab. 3.6: Design Self-Efficacy Scale

	Item	Item (in Japanese)
1	Conduct engineering design	工学的な設計を行う
2	Identify a design need	設計ニーズを認識する
3	Research a design need	設計ニーズをリサーチする
4	Develop design solutions	設計解をつくる
5	Select the best possible design	実現可能な最適解を選ぶ
6	Construct a prototype	プロトタイプをつくる
7	Evaluate and test a design	設計をテストし評価する
8	Communicate a design	設計内容を他の人に伝える
9	Redesign	再設計する

In addition, participants in this research were Japanese and I translated them as the table and pretested before applied it to the participants.

3.3.2.4 Limitations

In this research survey was taken in the class time and some students were influenced by others. Some students could take care of others' atmosphere and hesitate talking their own opinions. For example, one student had experienced designing auto control system by himself, however he was strongly concerned a difference of aircraft autopilot system and on-ground robot system, and he did not talk about his skills at start of the project. This example showed limitations of class interviews.

In addition, our students did not always have sufficient time of concentrating on the project some students because they engaged in other mandatory class. The observers had to check the student characteristics and the opinions in limited interval times between class. The observer also had an obligation of managing the project, time for surveying student behaviors completely objectively was insufficient.

This survey discussed with a comparison of research students with aerospace junior students mainly and more detailed surveys about other major students should be needed.

3.3.3 Results and Discussions

3.3.3.1 Prior Experiences

All of the participants wrote their answer in this section. Fig. 3.6 indicated design levels of each group. Most of the Flying Robot Project Students have not had experiences of design in comparison of the junior students of aeronautics and astronautics at the beginning of the semester. On the contrary, the Flying Robot Contest participants included many students who had design experiences. Over half members had designed something in more than one year.

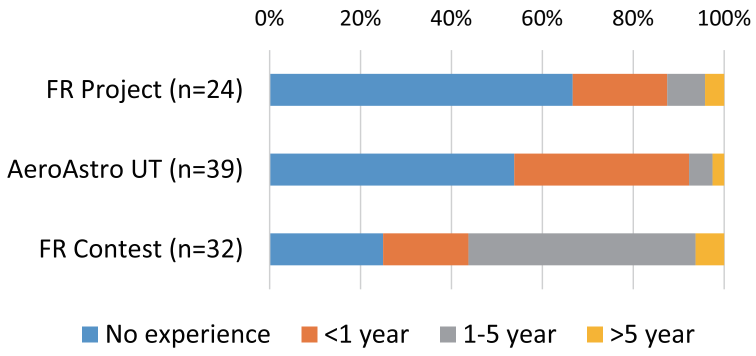


Fig. 3.6: Comparison of Student Design Level

3.3.3.2 Design Ranking Test

Several student respondents were excluded because they mistook the numbers of items they have to select or did not fill it. showed the result of the three groups.

First, a discussion of the differences of Flying Robot Project Students with the Aeronautics and Astronautics Junior Students was shown. The Project student results included high ratio of the number of *Seeking information*, *Visualizing*, *Goal setting*, *Testing*, and *Evaluating*. In contrast, most of the aerospace junior students selected *Testing*, *Visualizing*, *Iterating*, *Identifying constraints*, *Understanding the problem*, and *Planning* as important design activities.

Over two groups, the flying robot project students had high differences especially, comparing to the junior students about *Seeking information* and *Goal setting*. On the contrary, the junior student results selected more number of *Understanding the problem*, *Testing*, *Brainstorming*, *Generating alternatives*, and *Iterating*.

Although *Scketching*, *Visualizing*, *Prototyping*, and *Iterating* took the central role of real world engineering design and practice curriculum like the Flying Robot Project ((**?**)), both group didn't select *Sketching* （FR=0.0%, AAJunior=0.0%). *Visualizing* accounted in high ratio for both groups （FR=50.0%, AAJunior=47.2%）. (One of the reason was that most of the students *Sketching* included in *Visualizing* in Japanese atmosphere.) By contrast, *Prototyping* and *Iterating* were not selected by the Flying Robot Students relatively （*Prototyping*: FR=18.2%, AAJunior=30.6%, *Iterating*: FR=27.3%, AAJunior=41.7%).

After all this survey explained that the students who participated in the project concentrated on acquiring the many information about design at first（*Seeking information*↑） rather than understanding given problems correctly （*Decomposing* → *Understanding the problem* ↓） in comparison with thoughts of other aeronautics and astronautics junior students. They also thought an importance of building real world products as what they could watch actually （*Visualizing*↑）, however they did not emphasize testing products and repair design repeatedly （*Testing*↓ *Iterating* ↓）.

Next a distinction of consciousness of the project students and the students who addressed to the entry of the Flying Robot Contest was discussed. The latter group especially focused on the concepts of *Seeking information*, *Building*, *Planning*, *Testing*, and *Understanding the problem*. The high rate could be shown in the project students for *Making tradeoffs* and *Modeling* and the high rate could be shown in the contest students for *Understanding the problem*, *Building*, and *Sketching*.

The Flying Robot Project students thought gathering information as important as the contest entry students considered (Seeking information →). They also ranked down to understanding given the problem correctly （Understanding the problem ↓）. In addition, the project students took care of visualizing as building what they could look at, though the contest students also guessed sketching as important activities in design （*Sketching*: FR=0.0%, Contest=26.9%, *Visualizing*: FR=50.0%, Contest=38.5%). They also thought building real world products actually was not more critical in design than the contest students（*Building*: FR=18.2%, Contest=46.2%, *Prototyping*: FR=18.2%, Contest=38.5%, *Iterating*: FR=27.3%, Contest=34.6%）.

These results showed perceptions in design of the project students lacked with understanding the problem correctively and building real world products relatively with the contest students.

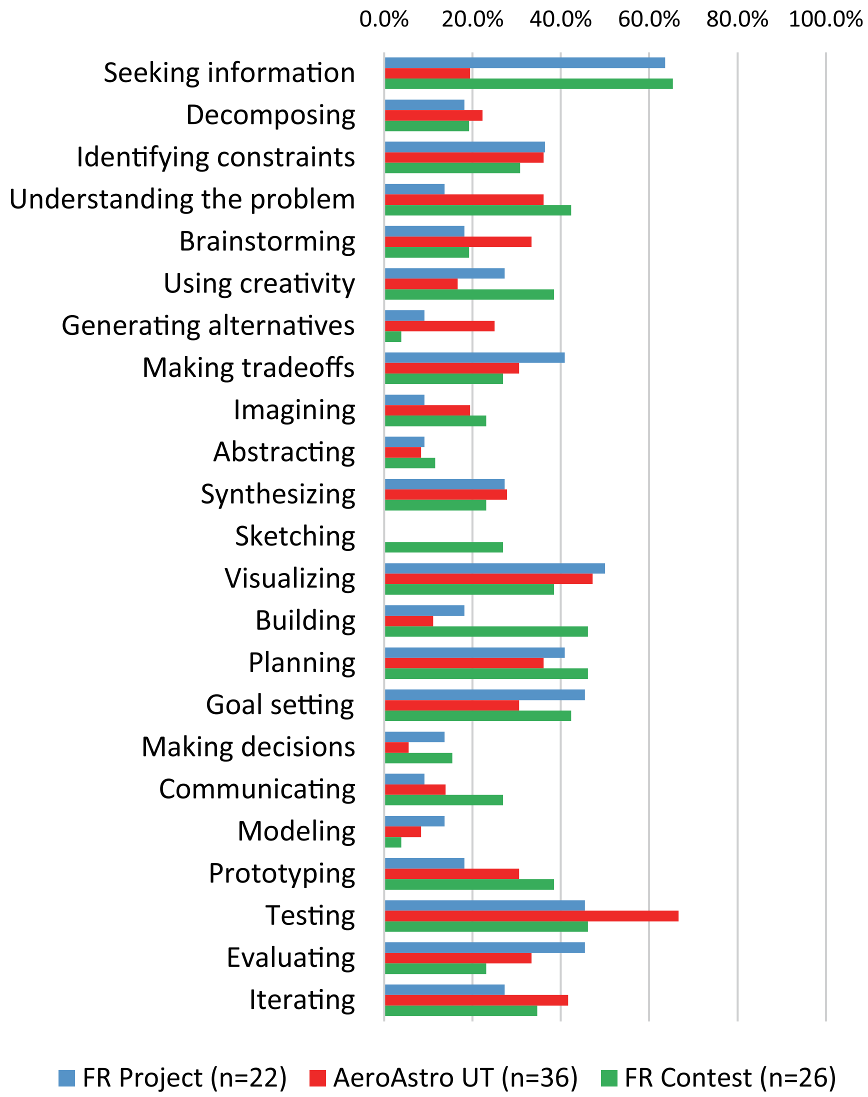


Fig. 3.7: Comparison of the Results of the Most Important Activities in Design Ranking Test

Tab. 3.7: Comparison of Results of Design Ranking Test

	(a) FR Project (n=22)	(b) AeroAstro UT (n=36)	(c) FR Contest (n=26)	GAP ((a)-(b))	GAP ((a)-(c))
Seeking information	63.6%	19.4%	65.4%	44.2%	-1.8%
Decomposing	18.2%	22.2%	19.2%	-4.0%	-1.0%
Identifying constraints	36.4%	36.1%	30.8%	0.3%	5.6%
Understanding the problem	13.6%	36.1%	42.3%	-22.5%	-28.7%
Brainstorming	18.2%	33.3%	19.2%	-15.1%	-1.0%
Using creativity	27.3%	16.7%	38.5%	10.6%	-11.2%
Generating alternatives	9.1%	25.0%	3.8%	-15.9%	5.3%
Making tradeoffs	40.9%	30.6%	26.9%	10.3%	14.0%
Imagining	9.1%	19.4%	23.1%	-10.3%	-14.0%
Abstracting	9.1%	8.3%	11.5%	0.8%	-2.4%
Synthesizing	27.3%	27.8%	23.1%	-0.5%	4.2%
Sketching	0.0%	0.0%	26.9%	0.0%	-26.9%
Visualizing	50.0%	47.2%	38.5%	2.8%	11.5%
Building	18.2%	11.1%	46.2%	7.1%	-28.0%
Planning	40.9%	36.1%	46.2%	4.8%	-5.3%
Goal setting	45.5%	30.6%	42.3%	14.9%	3.2%
Making decisions	13.6%	5.6%	15.4%	8.0%	-1.8%
Communicating	9.1%	13.9%	26.9%	-4.8%	-17.8%
Modeling	13.6%	8.3%	3.8%	5.3%	9.8%
Prototyping	18.2%	30.6%	38.5%	-12.4%	-20.3%
Testing	45.5%	66.7%	46.2%	-21.2%	-0.7%
Evaluating	45.5%	33.3%	23.1%	12.2%	22.4%
Iterating	27.3%	41.7%	34.6%	-14.4%	-7.3%

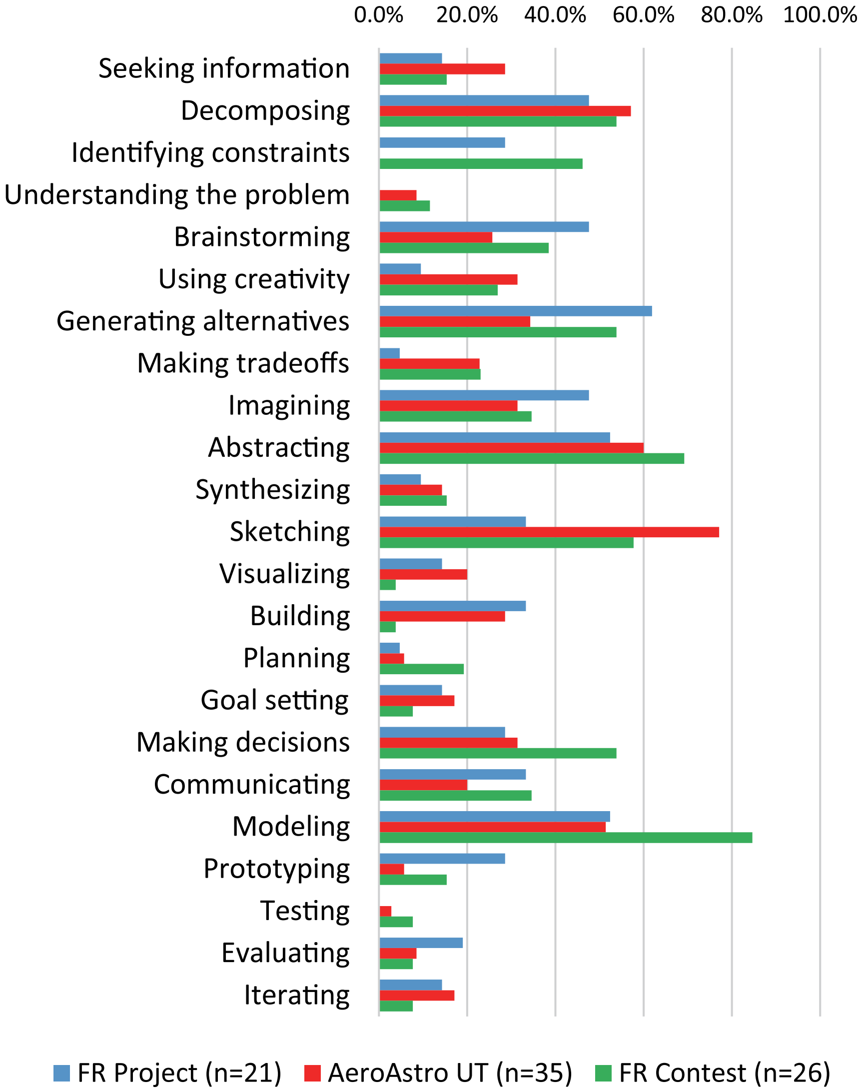


Fig. 3.8: Comparison of the Results of the Least Important Activities in Design Ranking Test

In order to examine more clearly, Kendall rank correlation coefficients was used. Tab. 3.8 showed each coefficients between the three group results. The results indicated a significant correlation between the most important design activities of the Flying Robot Project students and of the aeronautics and astronautics junior students at The University of Tokyo ($\tau = 0.480$, $p = 0.003$). A correlation between the Flying Robot Project students and the Contest students also had a statistical significance ($\tau = 0.311$, $p = 0.049$) and it was lower than the former.

About the least important design activities, the Tau between the Project students and the aeronautics and astronautics junior students was also statistically significant. In addition, the results of the Project students had a statistically significant correlation with the Contest students.

Tab. 3.8: Kendall Rank Correlation Coefficients among Populations for (a)the Flying Robot Project Students, (b)the UT Aeronautics and Astronautics Junior Students, and (c)the Flying Robot Contest Students (p-values are in the parentheses)

	(a)/(b)	(b)/(c)	(c)/(a)
Most Important Activities	0.480 (0.003)	0.439 (0.006)	0.311 (0.049)
Least Important Activities	0.480 (0.002)	0.469 (0.003)	0.463 (0.003)

This result supported the statement in which the perceptions in design of the students who entry to the Flying Robot Project was not completely different from the other aeronautical students. The project students had similar consciousness about design with the aeronautics junior students. They also had similarity with the Flying Robot Contest participants, however the correlation was lower than that with the aeronautical students.

3.3.3.3 Design Self-Efficacy Scale

Several respondents was exclude because they mistook the answer, did not complete the all questions, or rated same scores each item. clearly mistaken replies and answers. Finally we got the answers as followings. Factor analysis was applied to the results of the survey and the resulting factor scores was shown in Fig. 3.9. This results were corrected by the methods by DiStefano et al. (2009); Starkweather (2012). Detailed analysis of validity and reliability were described on Appendix A.1-A.3.

The Mann-Whitney test did not show a significant difference between the Flying Robot Students ($M = 4.38$, $SD = 1.37$) and the Aeronautics and Astronautics students ($M = 5.03$, $SD = 1.16$), $p = 0.0719$. The Mann-Whitney test show a significant difference between the Flying Robot Students ($M = 4.38$, $SD = 1.37$) and the Flying Robot Contest students ($M = 5.52$, $SD = 1.36$), $p = 0.0070$. This results indicated no distinct confidences between who participated in the Flying Robot Project and other aerospace junior students. On the contrary the project students did not have strong confidences relatively than who addressed the entry to the Flying Robot Contest.

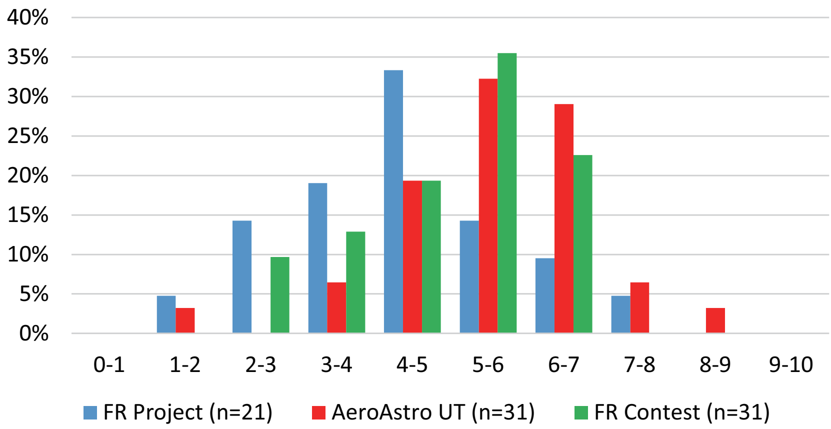


Fig. 3.9: Resulting Factor Scores of Three Groups (Pre-test)

Then each item for design self-efficacy scales was compared. The lowest level of self-efficacy could be shown in the item #4 *Develop design solutions* with the project students. Its highest level of self-efficacy was found at *Communicate a design*. By contrast, the aeronautics and astronautics junior students selected the lowest efficacy with *Research a design need* and the *Evaluate and test a design* and *Communicate a design* was the highest. The Flying Robot Contest students selected *Develop design solutions* and *Select the best possible design* as the lowest items and *Construct a prototype* and *Redesign* as the highest.

The Mann-Whitney test showed a significant difference between the results of *Construct a prototype* the Flying Robot Students ($M = 4.14$, $SD = 2.03$) and the Aeronautics and Astronautics students ($M = 6.42$, $SD = 1.96$), $p < 0.001$. The Mann-Whitney test didn't show a significant difference between the results of *Communicate a design* the Flying Robot Students ($M = 5.57$, $SD = 2.13$) and the Flying Robot Contest students ($M = 5.94$, $SD = 2.05$), $p = 0.603$. The Mann-Whitney test indicated a significant difference between the results of *Redesign* the Flying Robot Students ($M = 4.62$, $SD = 2.15$) and the Flying Robot Contest students ($M = 6.61$, $SD = 2.10$), $p = 0.002$.

In conclusion, the project students at start of the class was different from the student who wanted to take part in the contest in the aspect of real world design confidence especially in making prototype and redesigning.

Tab. 3.9: Results of Design Self-Efficacy Scale among Populations for the Flying Robot Project Students, the UT Aeronautics and Astronautics Junior Students, and the Flying Robot Contest Students

		FR Project (n=21)			AeroAstro UT (n=28)			FR Contest (n=31)		
		MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN
1	(Conduct engineering design)	(0	8	3)	(0	8	5)	(0	10	5)
2	Identify a design need	0	8	5	0	7	5	0	9	5
3	Research a design need	0	9	3	0	8	4	0	8	5
4	Develop design solutions	0	7	3	1	7	5	0	9	4
5	Select the best possible design	2	8	4	2	9	5	0	9	4
6	Construct a prototype	0	7	4	2	8	5	3	10	7
7	Evaluate and test a design	1	9	4	2	8	6	3	10	6
8	Communicate a design	1	9	6	2	9	6	2	10	6
9	Redesign	0	8	5	2	9	5	0	10	7

3.4 Conclusion

3.4.1 Summary

In conclusion, the above analysis could answer the Research Questions #2.1and #2.2. With the first question: [*RQ#2.1*:]What major and prior-experiences of design do students who participate in developing flying robot activities through engineering curriculum have?,

The survey examined that about half of the students came from the aeronautics and astronautics department and almost all of the students were junior. The participants was about three times of the winter semester in the summer semester. The student prior design experiences were also distinct with summer and winter, and most of the summer students have not experienced design of a complicated system like aircraft and spacecraft. By contrast, about half of the winter students have participated in some aerospace design projects or similar design activities.

[*RQ#2.2*:]What are differences of perceptions about design between students who participate in developing flying robots activities through engineering curriculum and who don't have experiences of developing flying robots and don't take part in the curriculum?

The survey illuminated the summer student consciousness in design and the project students lacked design experiences in comparison with aerospace junior students and the contest students at the start of semesters.

The conceptions in design of the Flying Robot Project students were moderately correlated with the junior students, though they were not highly correlated with the contest students. The qualitative survey of conceptions in design also illuminated that the project students also concentrated on acquiring information but did not focused on understanding the given problems. They also thought visualizing, building what they could look at actually, was important in design, however testing and iterating were not critical for design they guessed relatively.

In addition, they also lacked the confidence with design, compared with the contest entry students, and the survey show a no significant but moderate difference with the aeronautics and astronautics junior students. Especially the project students lacked their confidences with constructing a prototype and redesigning.

After all the Flying Robot Project students have not had rich experiences of a complicated aerospace system at the start of the summer semester and they did not have sufficient confidence with design. Most of them were unfamiliar with dealing with real world problems and developing aerospace products actually.

3.4.2 Rethinking Specifications of Developing Flying Robots

This section also rethought the specifications of developing flying robots defined at Chapter.2 because some characteristics was illuminated by the surveys in this section. First, students who wanted to participate in developing flying robots as engineering curricula did not have confidences of engineering design relatively. This result supported the specification 1. In addition, the original specifications did not show the importances of applying fundamental knowledge to real world engineering design and the project participants of developing flying robots lacked these aspects, so I added two items of objectives into the specification lists. Tab. 3.10 showed revised version of the specifications of developing flying robot curricula.

Tab. 3.10: Revised Specifications of Developing Flying Robots as Engineering

#	Category	Educational Intervention Specifications	Derived from
1	General	Shall improve student confidence and motivation about engineering design.	Stakeholder Survey, Aircraft Designer Interview, Student Survey
2	General	Shall experience real world engineering practice.	Stakeholder Survey, Student Survey
3	General	Shall provide students with opportunities to engage in engineering activities related to industry works.	Stakeholder Survey
4	Applying Knowledge to Design	Shall introduce creating theoretical solutions of engineering design, applying fundamental knowledge.	Industry Survey, Aircraft Designer Interview, Student Survey
5	Applying Knowledge to Design	Shall promote the importance of identify problems related to real world products.	Student Survey
6	Applying Knowledge to Design	Shall promote the importance of prototyping and iterating design.	Student Survey
7	Teamwork	Shall make students identify their own roles and have responsibility in a design team of a flying robot.	Aircraft Designer Interview
8	Teamwork	Shall provide students with opportunities to discuss design solutions and persuade others theoretically.	Aircraft Designer Interview, Industry Survey

Chapter 4 Design of the Flying Robot Project

Chapter.2 and Chapter.3 showed the specifications of activities of developing flying robots as engineering education. The next step was to integrate them with real world activities of developing flying robots by students and create curricula which were able to manage under university situations. It is very important that some educators pointed out that it will be just a hobby unless educational facilitators take care of educational effects of student activities (Mason, 2010). So this chapter also concentrated on the educational theory of acquisitions of student skills and curriculum design techniques. The flow of this chapter was following as Fig. 4.1

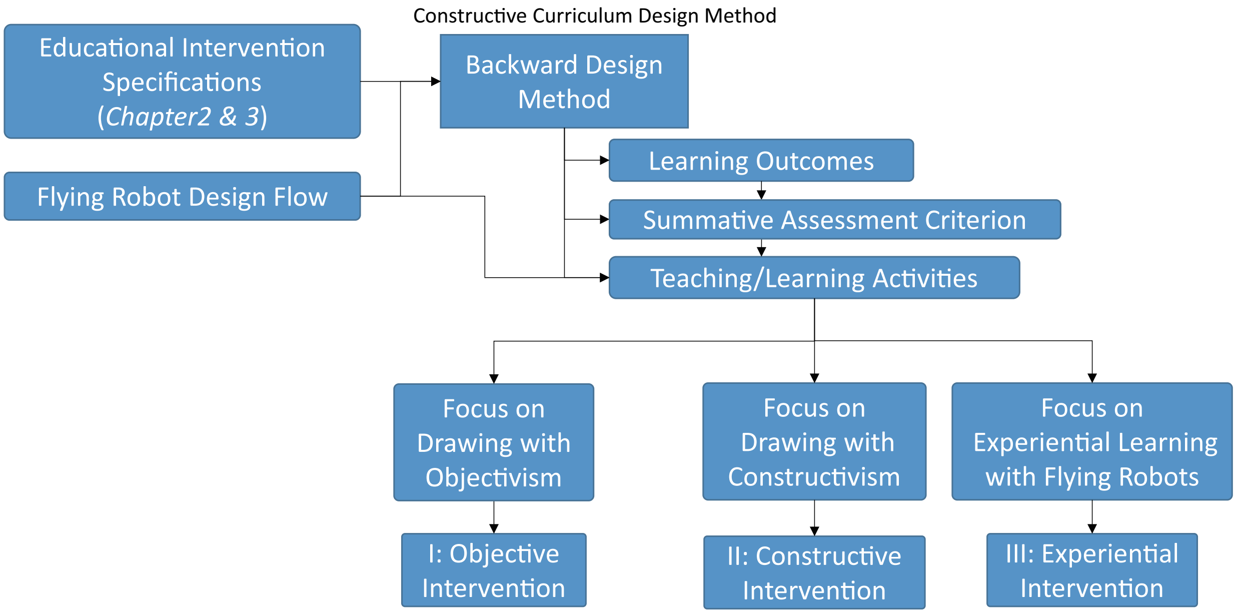


Fig. 4.1: Overview of Project Design

4.1 Development Flows of a Flying Robot

This section explained a flow of developing a flying robot. It is very similar to ordinary aircraft design process which includes several phases, such as identifying market needs, conceptual design, preliminary design, detail design, fabrication, ground test and flight test, and maintenance

(Raymer, 2012; Rinoie, 2011; Nicolai and Carichner, 2010).

Distinct characteristics of design of flying robots is relatively simpleness of development size. It needs low cost, human resources, and time by comparison with large circumstances of real world aircraft design processes in which thousands of employees have to produce millions of parts in decades. The process of design of a flying robot needs only a half year time, about five members, and thirty thousands yen for creating one product. In addition, it is educational. The flying robot activities must be simple because it was managed in university as curriculum. Real world aircraft industry should concentrate on make big results as business for contributing national economy, however the flying robot activities have to contribute to student growth in engineering. Although some unmanned aerial vehicle could contribute to aeronautical research such as demonstrations of control thesis and optimization methods in some research institutions (Iqbal and Sullivan, 2012), it is very critical things for developing aeronautical technology of course, this paper context focuses on the educational aspects of flying robot developments.

4.1.1 Research of Prior Flying Robots

Research of prior design was shown before progressing concrete designs of products.

General aircraft design needs different kind of design requirements like what customers are imagined (Customer Requirements (Torenbeek, 1982; Roskam, 1986))), what operation situations designers have to consider about (Operational Requirements (Roskam, 1986)) and what missions are required (Mission Requirements). It also includes cost, maintenance and support, scheduling, contractor demands and airworthiness. In order to know the appropriate request, it is necessary to investigate what kind of aircraft is present and how it is operated and to conduct a market research on what type of product is required in the future (Roskam, 1986; Torenbeek, 2013; Rinoie, 2011).

In the Flying Robot Project, prior research includes a comparison of prior flying robot addressed in the past Flying Robot Contest, an investigation of the competition regulations and rules. The designers also considered about competition circumstances and what concept was suitable for the contest.

4.1.2 Design Requirements

It is necessary to decide the design requirement after the rules and the direction of the existing aircraft are concretely known. The design request is a more technical and specific request list which summarizes the specifications and performance required for the airplane and the performance of each component level. Choose which ones you have presented so far, and put them into elements of a specific airplane. In the flying robot, the design requirement includes the following: 1) specifications (empty weight, payload weight, span, length etc...), 2) performances (maximum speed, cruise speed, take-off, landing, etc...), 3) body shape, 4) materials, 5) body structures, 6) propulsion system, 7) other components, and 8) operation, maintenance, and reliability.

This phase also includes thinkings of what technology could be applied.

4.1.3 Conceptual Design

Conceptual design is a phase in which "the designers look at a wide range of aircraft configuration concepts, perform trade studies of both the designs and the requirements, and ultimately settle on a single best design and, with significant customer input, select a well-balanced set of requirements (Raymer, 2012)." This phase is to decide the concept of aircraft from the viewpoint of design requirements and design methods. Raymer (2012) referred that "can any affordable aircraft be built that meets the requirements? (p.14)" and making aircraft that meets the design requirement with any form of the concept is important. The designers are required to think about various types of aircraft concept at the beginning, gradually narrow it down and put it in one concept.

The details in the Flying Robot Project are following as 1) general arrangement of aircraft components (wing, motor, stabilizer, landing gear, etc...), 2) sizing, 3) design of wing parameters , 4) design of empennage parameters, 5) design of fuselage parameters, 6) landing gear, 7) position of a center of gravity, 8) positions of wing and empennge, 9)initial three-view drawing, 10) control surfaces, 11) stability analysis, 12) performance analysis, 13) resizing, and 14) repair the initial three-view drawing.

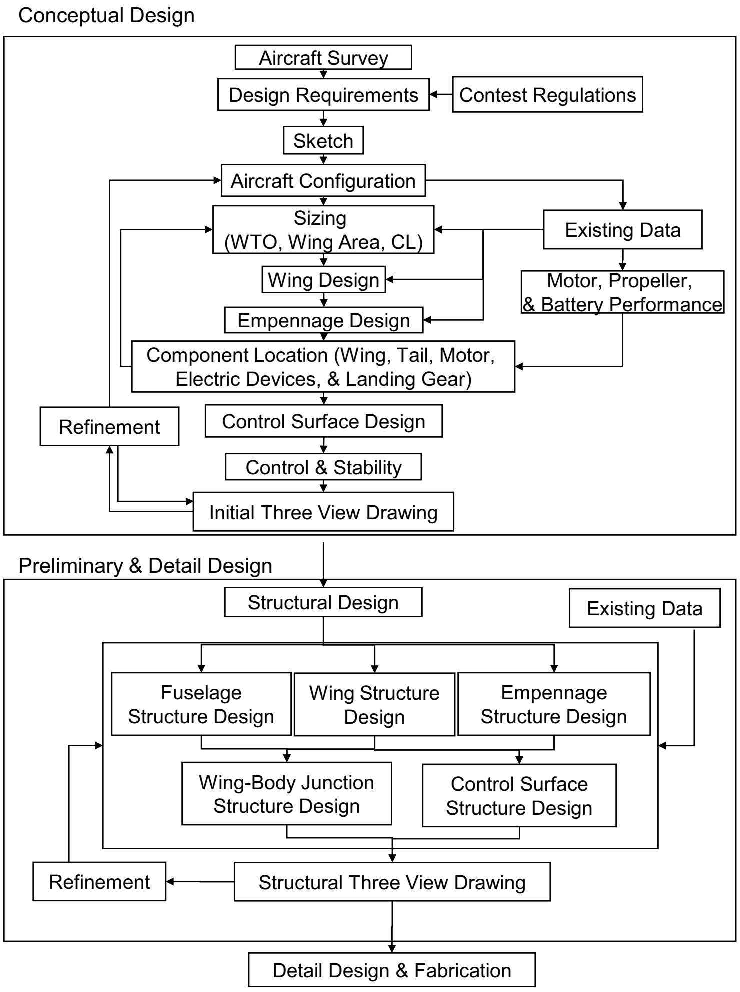


Fig. 4.2: Conceptual, Preliminary and Some of Detail Design Flow Chart of a Flying Robot

By the way, in the Flying Robot Project, limitations of class time made some students engage in only one concept.

4.1.4 Preliminary Design

Preliminary design phase is applied conceptual design results to decide details of aircraft parameters more concretely through aerodynamics analysis, wind tunnel test, computational fluid dynamics, structure analysis, and component design. In this phase, major changes of aircraft shape is refused. For example, whether the empennage is a canard or whether it is attached to the fuselage are already determined by conceptual design (Raymer, 2012). The goal of this phase is preparation before making full scale products. The details follows as: 1) definition of shapes of flying robots, 2) definition of motion diagram of control surfaces, 3) structure arrangement, 4) select materials, 5) select propulsion systems, 6) component arrangements, 7) structural three-view drawing and detail figures, and 8) redesign.

4.1.5 Detail Design

The step of detail design is to design all parts that are manufactured actually. This phase includes not only design of structural parts but also requirements of manufacturing process, quality assurance, consideration of distribution, management method of production. This phase is the most personnel and expensive and thousands of employee are required. Detailed design is usually done even during assembly and Raymer (2012) wrote "Detailed design ends with fabrication of the aircraft (p.18)." The details are following as: 1) design of manufacturing process, 2) determination of production procedures 3) creating a flowchart of manufacturing plan, 4) determination of production location and time, 5) preparation of drawing for building, 6) design of jig, 7) distribution of materials, 8) strength test partly, 9) management of large parts, 10) management of small parts, and 11)specification of test methods.

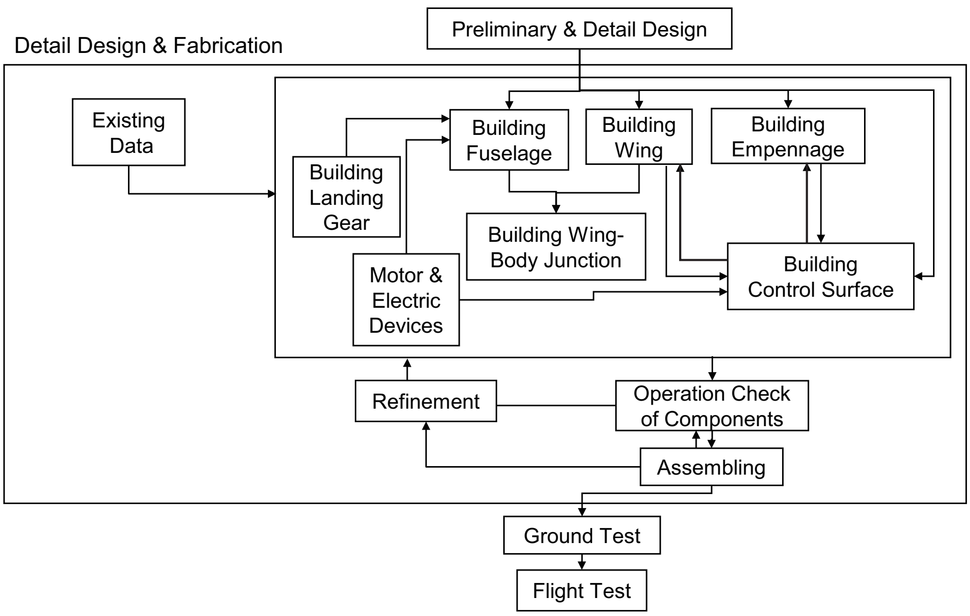


Fig. 4.3: Detail Design and Fabrication Flow Chart of a Flying Robot

4.1.6 Fabrication/Building

Based on the design content confirmed up to the basic design, it is done concurrently with detailed design. Since the placement of the spars and ribs of the wing has been decided to some extent so far, each team works from the part that can be manufactured. Also, if CAD and laser cutter can be used, tool accuracy and efficiency can be greatly improved in many cases. Rough component placement has been decided to some extent at the stage of three view, but for small parts such as motor mounts and legs, there are many cases that are not designed at this stage and there are many cases of making while looking at the real thing. Particularly when designing for the first time, it is often that you can not successfully create parts that are not considered in the basic design. For example, the details are various, such as the skeleton being stuck at the edge and glued, or not designing the wing cylinder joint part in the first place. Important thing is to feed back the contents to the design contents and the drawing properly and rebuild the design according to purpose when there is a problem by looking at the actual thing.

4.1.7 Test

Test the finished product. There are two types of tests performed on a flying robot, the first one is a ground test and the second is a flight test. In the ground test, after installing the battery and the payload and the completed vehicle just before the actual takeoff, activate various movable parts (moving blades, propulsion machines) and check whether there are any defects. In this case, when vibration does not work, as well as vibration that may affect flight, distortion of the aircraft, etc., it is necessary to take appropriate measures such as reinforcement and replacement of parts. Next the flight tests are usually conducted at the gymnasium. Batteries and payloads are loaded, and the aircraft actually fly. For beginners, first perform a ground run and a takeoff and landing test on a straight line. First of all, it is top priority to check whether the aircraft takes off properly. At this time, experts can confirm stability and transverse stability of the aircraft only from takeoff behavior. If the stability is not sufficient, adjust the position of the center of gravity and make it fly again. Normally, if sufficient examination is made on the ground test, adjustment of the center of gravity will be the main treatment here. Subsequently, turn flight is performed on both sides, and it is confirmed that it can fly freely. If you can confirm that you can fly to a certain extent, adjust the thrust of the motor. If the adjustment is not sufficient, if you increase the thrust, it may become head lift or head down, it may be easy to turn in the direction opposite to the direction of rotation of the propeller, so it is necessary to consider measures such as down thrust and side thrust Will come out. In some cases it may be necessary to review the mounting angle of the wing. What is important in the flight test is to practice how better the flight can be by changing any parameters of the fuselage and to find useful information for the next design. It is important to feed back the skipped results to the next design.

4.2 Design the Flying Robot Project as a University Curriculum

4.2.1 Methodology

4.2.1.1 Backward Design (Initial Design Phase)

This research applied integrated course design method especially of a backward design method (Wiggins and McTighe, 2005) to design the Flying Robot Project. A backward design method is one of the curriculum design methods and its initial design phase is subject to the following steps as Tab. 4.2.

Tab. 4.1: Initial Design Phase of Curriculum Using a Backward Design Method

Step 1	Identify Important situational factors
Step 2	Identify Important learning goals
Step 3	Formulate appropriate feedback and assessment procedures
Step 4	Select effective teaching/learning activities
Step 5	Make sure the primary component are integrated

Generally educators plan the lesson under an axis of textbooks and constitutions of class tasks are limited. In backward design, teachers decide learning objectives, assessment methods, and teaching and learning methods clearly and these things make complicated contents of learning subjects be applied to realistic curriculum logically. The methods focused on the relationships of each content and each objectivity and promote student learning.

Tab. 4.2: Initial Design Phase of Curriculum Using a Backward Design Method

Positive	It could be applied to a complicated subject logically.
Positive	It focuses on student learning processes and is suited to practices.
Positive	It is easy to contain active learning techniques as teaching methods and could contribute on increasing student motivations.
Positive	It could make lesson plans which don't depend only on educator teaching skills by using student centered learning environment.
Negative	It needs more time for designing curriculum.
Negative	It is difficult to hand over the lesson plans to other educators.
Negative	It needs specific places or conditions according to each class task.
Negative	It needs facilitating skills and management skills for educators.

This design method is based on constructive alignment. Constructive alignment is one conceptions about curriculum design. It focuses on that learners construct meaning from what they do to learn.

4.2.2 Situational Factor

Chapter 3 defined necessary specifications of educational interventions at university, however all of specifications could not include flying robot activities as curriculum. The Flying Robot Project had only one term class a week and facilitator preparation time was limited. In addition, many students who want to participate in the project were less confident about design and this project had to have an aspect of introduction class of aeronautics which could give students motivations for future study. It is very important to make a practical class, considering balances of objectives and teaching and learning activities.

Interdisciplinary students from different majors and different grades attended this class. However most of the participants had not only less knowledge of aircraft but also no experiences of building or crafting something by their hands. They also don't have any engineering team activities in many cases.

Based on the prior experiences of managing the project, this project was under the following assumptions.

- Flight tests are conducted at least once in a semester, but do not conduct excessive tests beyond student abilities and motivations.

- Most of the students participated in the project have no knowledge of aeronautics, crafting techniques, team skills.
- The content of the task corresponds to the number of units.

4.2.3 Learning Objectives

Learning objectives were defined from combinations of educational intervention specifications with flying robot development flows.

Tab. 4.3: Learning Outcomes of the Flying Robot Activities

#	Categories	Learning Outcomes	Derived from
1	Motivation	Students will be able to have confidence and motivation with engineering design.	#1
2	Applying Knowledge to Design	Students will be able to experience real world engineering practice.	#2
3	Applying Knowledge to Design	Students will be able to create flying robot concepts suitable for accomplishing missions theoretically.	#4, #5
4	Applying Knowledge to Design	Students will be able to describe drawings of flying robot satisfying concepts.	#4, #5
5	Applying Knowledge to Design	Student will be able to describe drawings of a flying robot which are suitable for real world practice.	#2, #4, #6
6	Applying Knowledge to Design	Students will be able to sketch or prototype flying robots and iterate their own drawings, rethink them and build more practical and good products.	#5, #6
7	Applying Knowledge to Design	Students will be able to discuss flying robot performances through flight test, using aeronautical fundamental knowledge.	#5, #6, #8
8	Teamwork	Students will be able to plan a schedule of developing a fling robot and manage member roles appropriately.	#7, #8
9	Teamwork	Students will be able to communicate their own opinions, work progresses, and outcomes about flying robots to other people.	#8
10	Teamwork	Students will be able to hear other members ' opinions, work progress, and outcomes about flying robots appropriately.	#8
11	Teamwork	Students will be able to select appropriate solutions theoretically through discussion with others.	#5, #8

Tab. 4.3 excluded the specification #3 because it was difficult for beginners to use specific tools which also were used in industry only in one semester elective class actually.

There were two opportunities for students knowing relationships of industry in developing flying robots. First was to apply specific tools using in industry for student design like specific CAD and calculation software, however in many cases, these kinds of instruments could be over performance with developing a simple flying robot. The students could spend more time learning not understanding aeronautics but concentrating on how to use software effectively, and they could be exhausted not in main contents of the class. Actually many designers of flying robots under this regulations did not use these kinds of softwares. Recommending only tools that were used in industry beyond its necessity involves leading to education in which many technological experts who did not focus on soft skills were brought in this context (Stephens and Richey, 2013).

Second is to make the new design requirement which contribute directly to present industry needs like researches in unmanned aerial vehicles. For example, autopilot system with image processing and vertical takeoff and landing system were very useful for setting the unmanned aerial vehicle business boundaries (). However these kinds of concepts was extremely difficult for beginners who have not experienced engineering practices to complete only in one semester. This objective is very critical in future aeronautics and distinct from objectives of introduction classes.

These opportunities should be recommended under systematic organized circumstances. I thought that it is meaningful to make excellent educational programs if these concepts were involved systematically and strategically. However, as a result of examination in the current environment of this research, we placed it as not being the first priority.

4.2.4 Feedback & Assessment Procedures

This section made feedback & assessment procedures based on learning outcomes. Finally this project adopted five items as assessment procedures for the purpose of avoiding of preventing student self activities with elaborate evaluations.

Tab. 4.4: Learning Outcomes and Feedback & Assessment Procedures of the Flying Robot Activities

#	Categories	Learning Outcomes	Feedback to Students	Assessment
1	Motivation	Students will be able to have confidence and motivation with engineering design.	N/A	Design Self-Efiicacy Scale
2	Applying Knowledge to Design	Students will be able to experience real world engineering practice.	N/A	Summative Assessment 1
3	Applying Knowledge to Design	Students will be able to create flying robot concepts suitable for accomplishing missions theoretically.	Make concept sketches and descriptions	
4	Applying Knowledge to Design	Students will be able to describe drawings of flying robot satisfying concepts.	Make three-view drawings and the corrections	
5	Applying Knowledge to Design	Student will be able to describe drawings of a flying robot which are suitable for real world practice.	Make three-view drawings and the corrections	Summative Assessment 2 & 3
6	Applying Knowledge to Design	Students will be able to sketch or prototype flying robots and iterate their own drawings, rethink them and build more practical and good products.	Build products based on the drawings and repair them	
7	Applying Knowledge to Design	Students will be able to discuss flying robot performances through flight test, using aeronautical fundamental knowledge.	Take flight tests and final presentation	
8	Teamwork	Students will be able to plan a schedule of developing a fling robot and manage member roles appropriately.	Make a team schedule & a role sharing table	
9	Teamwork	Students will be able to communicate their own opinions, work progresses, and outcomes about flying robots to other people.	N/A	Summative Assessment 4 & 5
10	Teamwork	Students will be able to hear other members ’ opinions, work progress, and outcomes about flying robots appropriately.	N/A	
11	Teamwork	Students will be able to select appropriate solutions theoretically through discussion with others.	N/A	

From the above discussion, assessment procedures were following as Tab. 4.5.

Tab. 4.5: Summative Assessment Criteria and Score Distribution

#	Item	Criterion	Score	Derived from
1	Participation Rate	Participate in the class	10	LO2
2	Knowledge	Get sufficient knowledge of developing flying robot	20	LO3～LO7
3	Implementation	Develop flying robot using their skills and knowledge effectively	20	LO3～LO7
4	Scheduling	Spend activity time effectively and keep the schedule	20	LO8
5	Team Activity	Take a contribution with the team	30	LO8～LO11

4.2.5 Main Activities

Concrete teaching and learning activities were defined. Constructive alignment supported this project learning activities and the project contents focused on student-centered learning. Details was based on Kolb's learning cycle (Kolb and Kolb, 2009).

Kolb's learning cycle is a model of learning. People could learn something through four conceptions: 1) concrete experience, 2) reflective observation, 3) abstract conceptualization, and 4) active experimentation. This theory insisted that students could learn through their experiences and it needs some feedback their own experiences detailed.

Tab. 4.6: Learning/Teaching Activities with Kolb's Learning Cycle

Phase	Concrete Experience	Reflective Observation	Abstract Conceptualization	Active Experimentation
Experience Crafting Phase				
Build Rubber Powered Airplane Kit		Flight Test	Performance Evaluation	Make a Concept (Next Phase)
Build Radio Controlled Airplane Kit		Flight Test & Performance Evaluation	Performance Evaluation	Make a Concept (Next Phase)
Introduction for Crafting	Observe Experiencers' Methods		Building Phase (Next Phase)	
Design Flying Robot Phase				
Know Flying Robots	• Build Rubber Powered Airplane Kit	Flight Test	Performance Evaluation	Make a Concept (Next Phase)
Know Flying Robots	• Review of Previous Flying Robots	Class Discussion	Class Discussion	Make a Concept (Next Phase)
Make a Concept	• Read Handouts & Write a Concrete Concept	Class Discussion	Class Discussion	Repair Concept
		Informal Communication		Make an Initial Drawing (Next Phase)

Tab. 4.6: Learning/Teaching Activities with Kolb's Learning Cycle

Phase	Concrete Experience	Reflective Observation	Abstract Conceptualization	Active Experimentation
Make an Initial Three View Drawing	• Read Handouts & Make Conceptual design & an Initial Three View Drawing	Feedback from Facilitators & Class Discussion	Feedback from Facilitators & Class Discussion	Repair Design
		Informal Communication		Make an Structural Drawing (Next Phase)
Make an Structural Three View Drawing	• Read Handouts & Make structural design (partly) & an Structural Three View Design	Feedback from Facilitators & Class Discussion	Feedback from Facilitators & Class Discussion	Repair Design
		Informal Communication		Make Detail Drawings for Building & Building (Next Phase)
Materials or Parts Supply	• Read Handouts & List up parts	Feedback from Facilitators & Class Discussion	Feedback from Facilitators & Class Discussion	Purchase & Move to Building Phase (Next Phase)
Make Detail Drawings for Building & Building	• Detail Drawings for Building	Feedback from Facilitators & Class Discussion	Feedback from Facilitators & Class Discussion	Repair Design
		Informal Communication	Informal Communication	
Make a Building Schedule	• Make Concrete Schedule & Member Roles & Promote Building Task	Self Reflection, Feedback from Facilitators and Class Discussion	Self Reflection, Feedback from Facilitators and Class Discussion	Repair Schedule & Each Role

Tab. 4.6: Learning/Teaching Activities with Kolb's Learning Cycle

Phase	Concrete Experience	Reflective Observation	Abstract Conceptualization	Active Experimentation
Ground Test	• Take a Test	Observe a test	Performance Evaluation	Repair Flying Robots
Flight Test	• Take a Flight Test	Observe a Flight Test	Performance Evaluation	Repair Flying Robots
Achievement Presentation Phase				
Flight Competition				
Final Presentation				

The project ended with final presentations. The students were given an opportunity to review their own activities, present them appropriately and get feedback from external experts who had different perspectives with the project facilitators.

4.2.5.1 Objectivism vs Constructivism

Objectivism is an original teacher-centered philosophy of education in which teachers's teaching activities is important. Under objectivism teachers lecture techniques had the most critical components because learning contents was based on universal knowledge, so teachers or instructors concentrate on how they could tell the essences of the knowledge students effectively. On the other hand, constructivism focused on individual student prior knowledge and understanding of phenomenon (Jonassen, 1991). It's student-centered approach and teacher concentrated not on teaching but on facilitating which help student own activities (Kubota, 1995). Tab. 4.7 indicated the characteristics of both approach in educational fields.

Tab. 4.7: Differences of Objectivism and Constructivism

	Objectivism	Construcutivism
Perceptions with knowledge	Knowledge could understand objectively and universal knowledge which isn't influenced by personal situations exists.	Knowledge is subjective conceptions and depends on individual situations of learners.
What is learning ?	Acquisition of universal knowledge	Process of constructing deepen knowledge based on prior knowledge of learners
What is education?	Activities in which teachers tell students structured and segmentalized universal knowledge	Facilitations of learners' process of constructing systematized knowledge based on prior-knowledge
Teaching/learning activities	Aim to produce universal teaching system based on clear quantitative criterion	Aim to produce student-centered learning system in which students could focus on understanding new phenomenon with qualitative criterion which could help student meta learning.
Improvement of lesson	Aim to produce effective teaching system which is teacher-centered.	Aim to produce student-centered learning system effectively
Area of specialty	Learning fundamental knowledge and doing experiment	practice and meta learning

4.2.5.1.1 *Objective Intervention*

From above discussion, resulting project was mainly situational and political factors and one semester project was adopted ordinary lesson concepts: lecture & implementation. This intervention focused on objectivism and concentrated on first lesson in teacher-centered method. This class also contained the discussion section of student drawings at the latter part of the project but the teacher more took care of how to communicate students with optimized one way lectures. The detailed of the intervention was subject to Fig. 4.4.

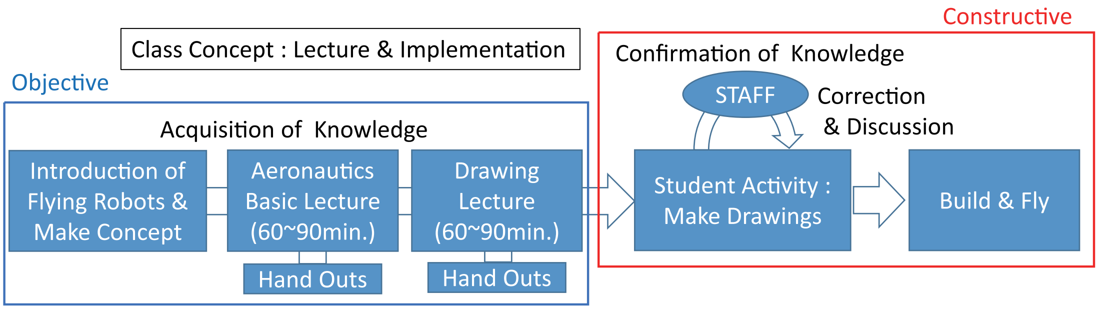


Fig. 4.4: Objective Intervention (2012W)

Of course the staff members understood both positive and negative aspects of this teacher-centered approach, and next semesters other concept projects were been taking.

4.2.5.1.2 *Constructive Intervention*

Constructive intervention was the most popular approach in the Flying Robot Project. The class was subject to Fig. 4.5. This class' flow was often subject to the former approach like beginning with introduction and aeronautics lecture class and letting students create original drawings of flying robots. However this was constructive approach with having students understand aeronautics and drawing techniques. The project focused not mainly on the lectures, in which the staff only had students understand using learning materials, always on the student activity phase, especially on correction and discussion of student drawings. The discussion phase based on Kolb's learning cycle (Kolb and Kolb, 2009), in which student had an opportunity of concrete experience with making original drawings with learning handouts the staff prepared. Next they met reflective observation and abstract conceptualization with correction and discussion phases of drawings with the instructors. Finally they rethought their drawings as active experimentation.

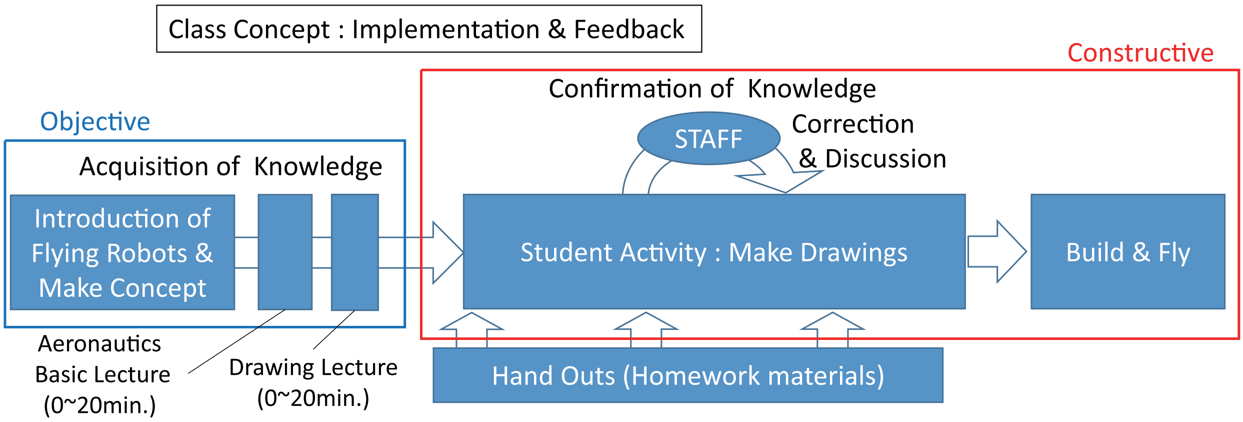


Fig. 4.5: Constructive Intervention (2014S～)

4.2.5.1.3 Experiential Intervention

Another constructivism approach was adopted at one semester as Fig. 4.6. This project shape was experiential intervention, made under constructivism, more concretely Kolb's experiential learning (Kolb and Kolb, 2009). The students received introduction of flying robots at first. Next they had opportunity of group works related specific flying robot components: learn building and aircraft dynamics session and learn flying robot structure session. The first phase had student make a radio control airplane kit with a team and flied it. They also compare the aircraft flight performance with another airplane which the staff created and discussed the differences of specifications and characteristics. The second phase focused on flying robot structures, experiencing wing destruction test. The students reviewed destruction test with different website and textbooks and planned wing destruction test of a prior flying robot wing through small lecture of structure & material with the staff. Then they destructed the wing actually and discussed strength and rigidity of the aircraft structures. Relations of each contents and each meaning were summarized in Tab. 4.8.

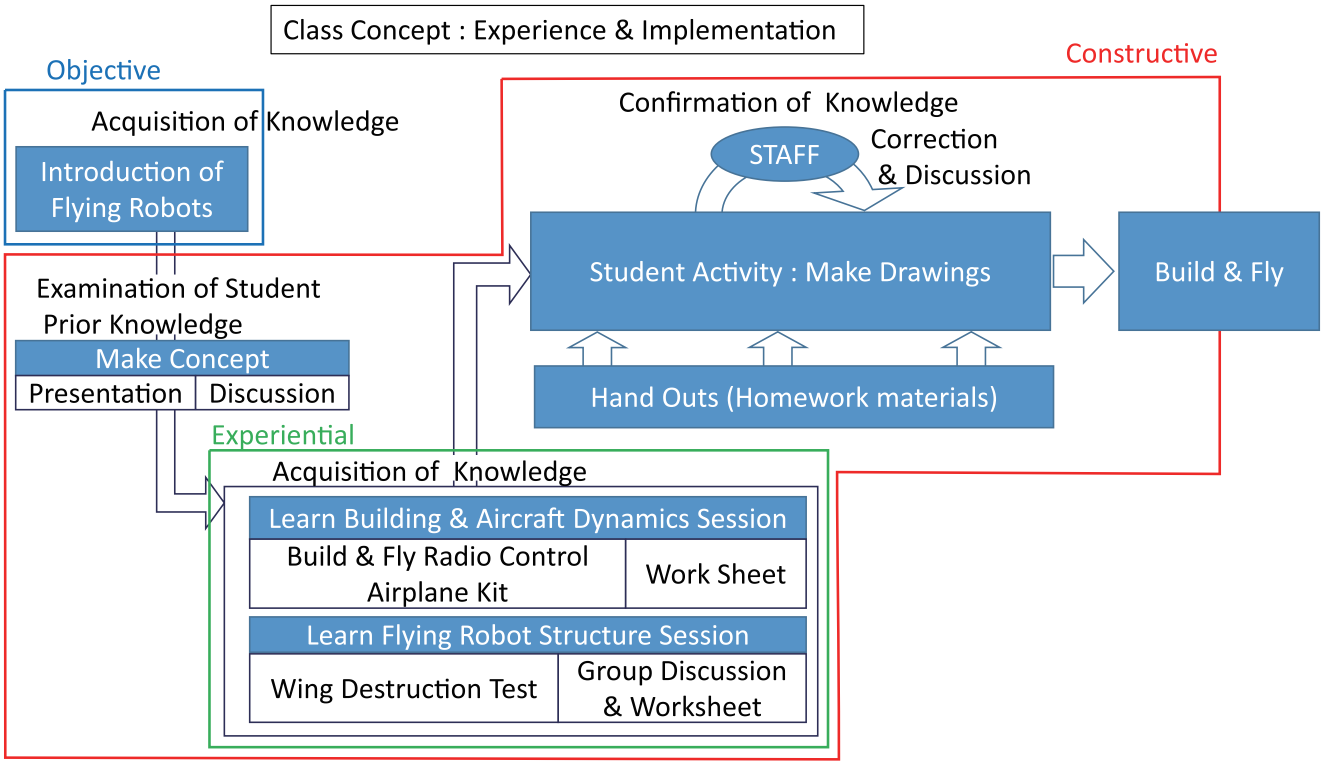


Fig. 4.6: Overview of Experiential Intervention (2013S)

Tab. 4.8: Concrete Student Activities and Educational Meanings of Experiential Intervention

Kolb ' s Learning Cycle	Learn Building & Aircraft Dynamics Session	Learn Flying Robot Structure Session
1. Concrete Experience	Build & Fly Radio Control Airplane Kit	Review and Experiment Wing Destruction Test (with Lecture & Worksheet)
2. Reflective Observation	Build & Fly Radio Control Airplane Kit	Group Discussion
3. Abstract Conceptualization	Worksheet	Group Discussion & Worksheet
4. Active Experimentation	Original Flying Robot Design (Building and Aircraft Dynamics)	Original Flying Robot Design (Structure and Material)
Learning Outcomes	Assessment Criterion 2. Knowledge (Building & Aircraft Dynamics)	Assessment Criterion 2. Knowledge (Structure)

4.2.6 Representative Schedule

There were limited class hours for completing all of the contents actually and concrete project schedule depended on each semester's situational factors (student background, student motivation, class time, workshop and gymnasium schedules). In some cases, some contents was omitted like Tab. 4.9.

Tab. 4.9: Representative Schedule (2015 Summer Semester)

No.	Contents	Deliverables	Place
1st	Introduction		Classroom /Workshop
2nd	Fix team distribution		Classroom
3rd	Observe workshop room, Basic lecture of aeronautics	Concept sketch	Workshop /Classroom
4th	Initial three-view drawing	Initial three-view drawing ver.1 (by the day before the next class)	Classroom
5th	Structural three-view drawing	Structural three-view drawing ver.1 (by the day before the next class)	Classroom
6th	Lecture about workshop room and instruments	Structural three-view drawing ver.2 (by the day before the next class)	Classroom /Workshop
7th〜11th	Build a flying robot		Workshop
12th	Flight Test		Gymnasium
13th	Final presentation	Final presentation slides	Workshop

Student design process of developing flying robots has various shape by their aircraft type and design methods like different subsonic aircraft design methods caused by different aircraft designers (Raymer, 2012; Roskam, 1986; Torenbeek, 2013; Rinoie, 2011). Correspondingly designing flying robots also vary by student designers. However, this project was also introduction class of aircraft design and almost all of the students don't have sufficient knowledge of aeronautics. Also we don't have enough class time (only 14 terms of 90 minutes class each), so we indicated students a "simple method" of designing a flying robot through the project class times.

Tab. 4.9 showed the representative project schedule. The class began with an orientation, next the class took a lecture of aeronautics introduction and fixed team distribution. Then students worked as a decided team, wrote concept sketch, designed initial 3-view drawing, made structural 3-view drawing, created how to make each parts and assemble them to flying robot, built and tested them, and took flight test at a gymnasium finally. Students also explained their activities and products in the final presentation session at the end of the semester.

4.3 Summary

This chapter focused on the curriculum design. The design flow of flying robots was explained and backward design connected the flying robot design with learning outcomes which brought from educational intervention specifications in prior chapter. The design method illuminated the relationships of learning outcomes and program specifications. The learning outcomes leaded to each assessment and feedback methods. Finally concrete teaching and learning activities was defined based on Kolb's learning cycle. This chapter also showed one example of actual project schedule in which the gathered students' situational factors was considered and appropriate contents was selected.

Chapter 5 Evaluation of Each Student Design Activity in the Flying Robot Project

In this chapter, I redefined the outcomes of these projects through qualitative criterion and evaluate and compare them. Specifications of each project were arranged into the first phase of this chapter. In the project different kind approach for learning aeronautics and engineering practice, and what contents became effective was discussed. This chapter also explained student design activities through their drawings. An arrangement method using rubric theory was applied to each semester outputs and results were discussed. After all this chapter explained the following research questions.

RQ#3: What kinds of design outputs did students bring out through developing flying robots through university curriculum?

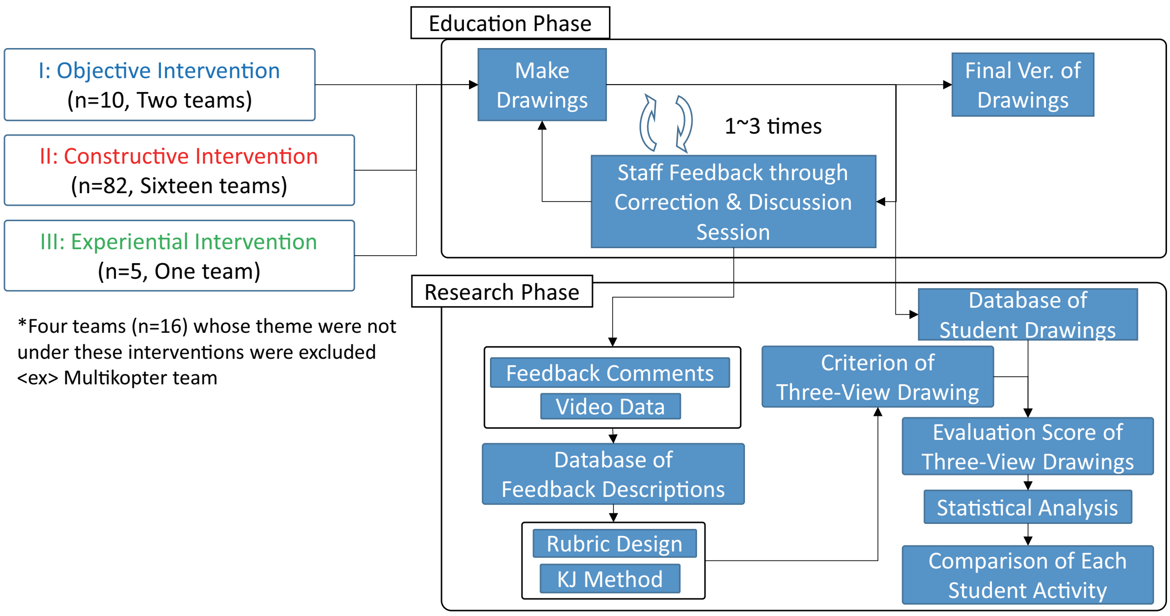


Fig. 5.1: Overview of Evaluation and Comparison of Student Design

5.1 Specifications of Each Project

Though the basis of the project follows the theory of Chapter 4, each project schedule also depended on situational factors at each semester, such as a schedule of the classroom, the workshop, and the gymnasium. It also was influenced by the motivation of the students and the skills of the facilitators and we staff did not have sufficient time for completing all the above contents at same semester in some cases because the class was elective subject. This section aligned specifications of each project and helped the next evaluation and comparison steps be indicated.

Tab. 5.1: Specific Contents and Deliverables of Each Semester Project (The number of deliverable showed the submitted times of each subject.)

	Specific Contents						Deliverables						
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)
Conventional Flying Robot													
2012W A	-	-	-	✓	✓	✓	-	1	1	-	2	-	-
2013S	✓	✓	✓	-	-	✓	1	1	2	-	1	-	1
2014S A	✓	-	-	✓	-	✓	-	-	1	-	3	-	-
2014S B	✓	-	-	✓	-	✓	-	-	2	-	2	-	-
2014S C	✓	-	-	✓	-	✓	-	-	2	-	2	-	-
2015S A	-	-	-	✓	-	✓	-	1	1	1	2	1	-
2015S B	-	-	-	✓	-	✓	-	1	1	1	2	1	-
2015S C	-	-	-	✓	-	✓	-	1	1	1	2	1	-
2016S A	-	-	-	✓	-	✓	1	1	1	1	3	3	-
2016S B	-	-	-	✓	-	✓	1	1	2	2	2	2	-
2016S D	-	-	-	✓	-	✓	1	1	2	2	2	2	-
Unconventional Flying Robot													
2014W A	✓	-	-	✓	-	✓	-	1	1	-	1	-	4
2015S E	-	-	-	✓	-	✓	-	1	1	1	2	1	-
2016S C	-	-	-	✓	-	✓	1	1	3	3	1	1	-
Flying Robot with an Autopilot System													
2015S D	-	-	-	✓	-	✓	-	1	1	1	2	1	-
2016S E	-	-	-	✓	-	✓	1	1	3	3	1	1	-
2012W B	-	-	-	✓	✓	✓	-	1	1	-	2	-	-
2014W B	-	-	-	✓	-	✓	-	1	1	-	1	-	4
2015W A	-	-	-	-	-	✓	-	1	1	1	1	1	2
Improvement of Previous Flying Robot													
2013W	-	-	-	-	-	✓	-	1	-	-	-	-	1
2015W B	-	-	-	-	-	✓	-	1	-	-	-	-	2
Others													
2015S F	-	✓	-	✓	-	✓	-	1	1	1	2	1	-
2016S F	-	-	-	✓	-	✓	1	1	-	-	2	1	-

(a): Build Rubber Powered Airplane Kit
(b): Build Radio Controlled Airplane Kit
(c): Wing Destruction Test
(d): Basic Aeronautics Lecture
(e): Flight Competition
(f): Final Presentation

(g): Individual Concept
(h): Team Concept
(i): Initial Three-View Drawing
(j): Specification Report for (i)
(k): Structural Three-View Drawing
(l): Specification Report for (k)
(m): Schedule and Member Role

5.2 Methodology

5.2.1 Development of Rubric

Rubric is a effective method of assessing complicated learning outcomes of students. A widespread definition of rubric states that “a scoring tool for qualitative rating of authentic or complex student work”(Jonsson and Svingby, 2007, p131). More detailed description is “a simple assessment tool that describes levels of performance on a particular task and is used to assess outcomes in a variety of performance-based contexts from kindergarten through college (K-16) education”(Hafner and Hafner, 2003, p1509). Rubric can not only take reliable scoring of student performance assessment but also promote student learning and self-assessment and/or improve instructor facilitations (Jonsson and Svingby, 2007).

Recently, rubric was developing in engineering design curriculum especially in a complicated design process. Rubric divided into analytic and holistic one. Holistic rubrics may judge overall performance of students by one criterion. Teachers rearranged students’ performances and give a depiction that best describes the results (Bailey et al., 2004). This method needs less time of evaluation, and it has a merit of applicable to a wide range of contents. However the assessment could be stereotypical and it could lack objectivity and reliability (Jonsson and Svingby, 2007). On the contrary analytic rubric is to segment student performances into several components, make evaluation criterion with each part. It could evaluate student activities objectively, promote student self-learning and activities. It also could be useful to look back teachers’ activities (Jonsson and Svingby, 2007). Teachers will describe the best activities of the students, result details, also refer to the lowest activity. Then they divide these activities into several item and several levels.

5.3 Team Specifications at the Beginning of the Project

5.3.1 Member Composition

Tab. 5.2 shows the summary of the member composition of each team. Each team compositions include two kinds of differences with the objective of communication. First difference is a difference of majors. This is one of the causes of the difficulty of communication in team because of the lack of the opportunity of meetings and the difficulty of getting in touch with each other. The team which had a large number of class needed some efforts of acquiring discussion places and time. For example, the team D of the 2016 S semester included five junior students of department of aeronautics and astronautics, who received same curricula. They attended the same class in the same place and it was easy to talk each other before and after of their lessons. On the contrary, the team D in the 2015 S semester contained five kinds of majors. It is difficult for them to adjust a team schedule because all of them got different curricula.

Second difference is a difference of grades. It also give teams some kinds of tension. For instance, the team B in the 2015 S semester consisted of junior students and sophomore students. The two junior students belonged the department of aeronautics and astronautics and both oh them had relatively richer knowledge about of aircraft than the other sophomore students. In this case, the sophomore students had some kinds of respect and modesty with the junior students such as ”they had more familiar with the flying robot so I want to comply with their activities and assist it”. By contrast, the junior students had some kinds of leader ship or ownership just because they belonged to the aeronautics. These things brings up the difficulty of keeping deep communication.

Tab. 5.2: Member Compositions

Team	Members	Category
2012 W A	Four AeroAstro Junior, Mechanical Junior	Ⅱ
2012 W B	Four AeroAstro Junior, One Electrical Research Student	Ⅱ
2013 S	Five AeroAstro Junior	I
2013 W	Five AeroAstro Junior and One Electrical Junior	Ⅱ
2014 S A	Two Precision M1, One Mechanical M1, One Mechanical B4, & Two AeroAstro Research Student	Ⅲ
2014 S B	Three AeroAstro B3, One System Innovation B3, & Two College of Arts and Science B2	Ⅲ
2014 S C	Four AeroAstro B3, & One College of Arts and Science B2	Ⅱ
2014 W A	Five AeroAstro B3, & One Precision Research Student	Ⅱ
2014 W B	Two Precision M1, One Material B3, One AeroAstro Research Student	Ⅲ
2015 S A	Two AeroAstro B3, One Biological Sciences B3, & Two College of Arts and Science B2	Ⅲ
2015 S B	Two AeroAstro B3, & Three College of Arts and Science B2	Ⅲ
2015 S C	Two AeroAstro B3, One Mechanical M1, One College of Arts and Science B2, & One College of Arts and Science B1	Ⅲ
2015 S D	Two AeroAstro B3, One Mechanical B3, Three Mechano-Informatics B3, One AeroAstro M1, & One Research Student	Ⅲ
2015 S E	Three AeroAstro B3, & One Chemistry and Biotechnology D1	Ⅱ
2015 S F	Two Mechanical M1 and One Precision M2	Ⅲ
2015 A A	Four AeroAstro B3, One System Innovation M1 and One AeroAstro D1	Ⅲ
2015 A B	Four AeroAstro B3	I
2016 S A	Three College of Arts and Science B2, & One College of Arts and Science B1	Ⅲ
2016 S B	Four College of Arts and Science B2	Ⅱ
2016 S C	Five College of Arts and Science B2	Ⅱ
2016 S D	Five AeroAstro B3	I
2016 S E	Four AeroAstro B3	I
2016 S F	One Electrical M1, One AeroAstro M2, and One AeroAstro D1	Ⅲ

I categorized these teams into three groups like Tab. 5.3 in the light of the differences. Category I is the easiest to communicate each other. It consists of same major and same grade students and has relatively a lot of opportunities of communication in team. Category Ⅱ includes the team which consists of same grade students from different departments and they have some kinds of difficulty of keeping in contact with others. Category Ⅲ contains the team whose members consist of different grade and different department students. These teams need some kinds of efforts in order to keep in contact with each member.

Tab. 5.3: Category of Member Compositions

Category	Criterion
I	It consists of same major and grade students and has a lot of opportunities of communicating
Ⅱ	It consists of same grade students from different departments and has some kinds of difficulty of keeping in contact
Ⅲ	It consists of different grade students from different departments and needs some efforts of keeping in contact

5.3.2 Prior Knowledge

Prior knowledge which was necessary in developing flying robots divided into two categories. First is about flying robots, second is about auto control system. This research summarized results form aspects of knowledge and application of knowledge. The data collections included video observation of class activities (2015S, 2016S), quantitative surveys (2013S, 2015S, 2016S). Then, comparing the students who gave the same items to the same level, the data and the criterion was adjusted into Tab. **??** and Tab. 5.5.

the score of the students who can judge that the same level of ability can be expected is the same, so that the score of the students who apparently seems to differ in ability is different , And revised the standard at the same time. This was repeated several times, and each score was decided.

I divided the teams into three Level as Tab. 5.3.2.

Tab. 5.4: Level of Prior Knowledge and Experiences of Each Student

		Level	Criterion	Related Activities
Aircraft	Knowledge	3	Have enough aeronautics knowledge and can deeply discuss problems of aircraft	• with more than a year in aeronautics major • sufficient club activities related to aircraft

Tab. 5.4: Level of Prior Knowledge and Experiences of Each Student

		Level	Criterion	Related Activities
		2	Have partial aeronautics knowledge and participate in a discussion about problems of aircraft	• with more than a half year in aeronautics major
				• club activities related to aircraft
		1	Don't have sufficient knowledge about aircraft	
	Implementation	3	Have enough experiences of developing real world aeronautical products like flying robots, unmanned aerial aircraft, and human-powered aircraft or equivalent products	•with more than a year in aeronautics major
				• sufficient club activities related to aircraft
		2	Have experiences of developing real world aeronautical products or some special skills of building engineering products	• with more than a half year in aeronautics major
				• club activities related to aircraft
		1	Don't have enough experiences or skills of developing real world aeronautical products	
Auto Control System	Knowledge	3	Have enough knowledge about control theory and electrical theory and can deeply discuss problems of control system and electrical devices	• with more than a year in specific major
				• sufficient club activities related to auto control system
		2	Have partial knowledge about control theory and electrical theory and can participate in a discussion about problems of control system or electrical devices	• with more than a half year in specific major
				• club activities related to auto control system
		1	Don't have sufficient knowledge about control theory and electrical theory	
	Implementation	3	Have enough experiences of developing real world electrical control devices or equivalent products	• with more than a year in specific major
				• sufficient club activities related to auto control system

Tab. 5.4: Level of Prior Knowledge and Experiences of Each Student

Level	Criterion	Related Activities
2	Have some kinds of experiences of developing real world electrical control devices or equivalent products	• with more than a half year in specific major
		• club activities related to auto control system
1	Don't have sufficient experiences of developing real world electrical control devices or equivalent products	

Tab. 5.5: Prior Knowledge Level of Each Team

	Flying Robot			Auto Control System		
	Knowledge	Implementation	Total	Knowledge	Implementation	Total
2012W A	2.2 (0.4)	1.6 (0.5)	1.9 (0.3)			
2012W B	2.4 (0.5)	2.4 (0.8)	2.4 (0.4)	2.2 (0.4)	1.4 (0.5)	1.8 (0.4)
2013S	2.0 (0.0)	1.0 (0.0)	1.5 (0.3)			
2013W	2.8 (0.4)	2.8 (0.0)	2.9 (0.1)	1.0 (0.0)	1.3 (0.5)	1.2 (0.1)
2014S A	1.7 (0.7)	1.7 (0.7)	1.7 (0.6)			
2014S B	1.5 (0.5)	10. (0.0)	1.3 (0.2)			
2014S C	1.8 (0.4)	1.0 (0.0)	1.4 (0.2)			
2014W A	2.8 (0.4)	2.8 (0.4)	2.8 (0.1)			
2014W B	2.0 (0.0)	2.5 (0.5)	2.3 (0.2)	2.0 (0.7)	2.0 (0.7)	2.0 (0.5)
2015S A	1.6 (0.5)	1.8 (1.0)	1.7 (0.6)			
2015S B	1.8 (0.4)	1.4 (0.5)	1.6 (0.2)			
2015S C	1.4 (0.5)	1.0 (0.0)	1.2 (0.2)			
2015S D	1.5 (0.5)	1.1 (0.3)	1.3 (0.2)	2.1 (0.3)	1.4 (0.5)	1.8 (0.3)
2015S E	1.8 (0.4)	1.0 (0.0)	1.4 (0.2)			
2015S F	2.0 (0.8)	2.3 (0.9)	2.2 (0.8)	2.3 (0.5)	2.3 (0.5)	2.3 (0.2)
2015A A	1.7 (0.5)	1.5 (0.5)	1.4 (0.2)	1.3 (0.5)	1.3 (0.5)	1.3 (0.3)
2015A B	2.0 (0.0)	2.0 (0.0)	2.0 (0.0)	1.5 (0.5)	1.5 (0.5)	1.5 (0.3)
2016S A	1.0 (0.0)	1.6 (0.0)	1.3 (0.1)			
2016S B	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)			
2016S C	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)			
2016S D	2.0 (0.0)	1.2 (0.4)	1.6 (0.2)			
2016S E	2.0 (0.0)	1.0 (0.0)	1.5 (0.3)	2.0 (0.0)	1.3 (0.4)	1.6 (0.2)
2016S F	2.0 (0.8)	2.0 (0.8)	2.0 (0.7)	2.3 (0.5)	2.0 (0.8)	2.2 (0.5)

This was only ordinal scale and had no more than order. It just could show dispersion of prior-knowledge in a team and what team was relatively superior.

5.4 Three-View Drawings

5.4.1 Criterion of Drawings

This survey get 37 drawings of 11 teams. The correction sentences and staff discussion contents using video observations was categorized 334 sentence units, using verbal protocol coding techniques (Atman et al., 1999). KJ method made the sentences divide into 9 categories from 29 items.

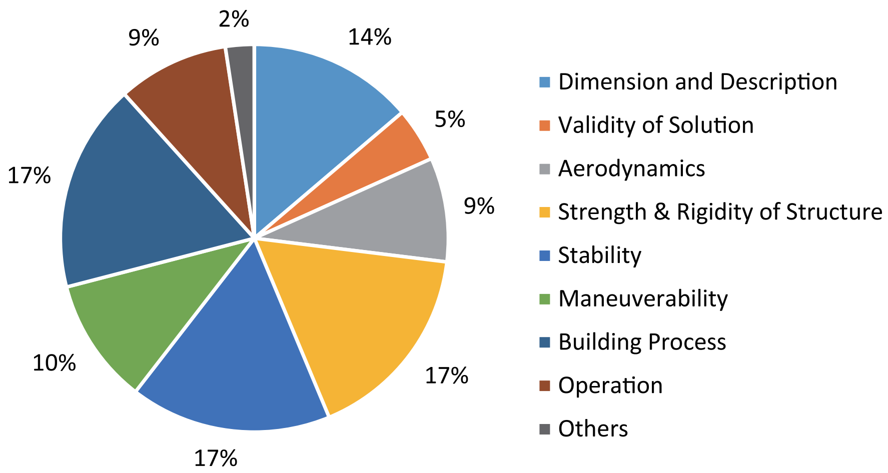


Fig. 5.2: Rate of Comments of Three-View Drawings

Some items were little difficult for using as criterion of detail drawings because of its ambiguity, eight categories from 25 items were selected as criterion Tab. 5.6.

Tab. 5.6: Criterion of Drawings (#2〜#6: Theoretical Aspects, #7 & #8: Practical Aspects)

#	Category	Item
#1	Dimension and Description	Insufficient description
#2	Validity of Solution	Insufficiency of weight estimation
		Inconsistency of body shape or specifications with concepts or design requirements
#3	Aerodynamics	Insufficiency of wing shape
		Insufficiency of consideration with airfoil
		Insufficiency of wing angle of incidence
		Insufficiency of consideration with wing area
#4	Strength & Rigidity of Structure	Low strength of wing or wing-body junction
		Low strength of empennage or tail-body junction
		Low strength of control surface or surroundings
#5	Stability	Insufficiency of consideration with a position of center of gravity
		Insufficiency about longitudinal stability
		Insufficiency about longitudinal stability
#6	Maneuverability	Insufficiency of consideration with control surface shape
		Insufficiency of consideration with operation of control surfaces
		Insufficiency of consideration with position of propellers or motors
		Insufficiency of consideration with propulsion performances
#7	Building Process	Insufficiency of consideration with positions of electric equipments
		Insufficiency of significant figures in dimensions of drawings
		Insufficiency of consideration with materials
		Insufficiency of consideration with building process
		Insufficiency of consideration with arrangement of structural parts as three dimensional figures
#8	Operation	Insufficiency of positions of landing gears
		Insufficiency of structural consideration with landing gears
		Insufficiency of consideration with transportation for flight test

The new criterion were applied to all drawings of the project. Sixty-three drawings from 18 teams was evaluated, using the new criterion and the results were shown in Tab. 5.6. The more items checked, the larger the score. Generally rubric was created based on level distributions, however, this criterion needed more detail and concrete descriptions of figures, and this research did not show each level.

Tab. 5.7: Evaluation Score of Each Drawing

Drawing	#1	#2	#3	#4	#5	#6	#7	#8	SUM
2012WA1	1	1	0	0	1	1	3	0	7
2012WA2	0	1	0	0	0	0	2	0	3
2012WA3	0	1	0	0	0	0	2	0	3
2012WB1	0	1	0	1	1	2	4	1	10
2012WB2	0	0	0	0	0	2	2	1	5
2012WB3	0	0	0	0	0	0	2	0	2
2013S1	0	0	0	1	3	2	3	0	9
2013S2	0	0	0	1	2	1	3	0	7
2014SA1	0	1	3	0	1	1	5	1	12
2014SA2	0	0	1	0	2	1	4	1	9
2014SA3	0	0	1	0	1	1	0	0	3
2014SA4	0	0	1	0	0	1	0	0	2
2014SB1	1	2	1	1	3	2	5	1	16
2014SB2	1	0	1	1	1	0	5	1	10
2014SB3	1	0	0	2	1	0	4	1	9
2014SB4	0	0	0	2	1	0	1	0	4
2014SC1	0	1	0	0	1	2	3	1	8
2014SC2	0	1	0	0	1	0	3	0	5
2014SC3	0	1	0	1	1	0	2	0	5
2014SC4	0	1	0	0	1	0	1	0	3
2014WA1	0	0	0	1	1	2	1	0	5
2014WA2	1	0	0	0	1	0	1	0	3
2014WB1	0	1	0	0	1	0	0	1	3
2014WB2	0	0	0	0	0	0	0	1	1
2015SA1	0	1	2	1	3	1	5	0	13
2015SA2	0	1	0	2	3	2	3	2	13
2015SA3	0	0	0	0	0	1	2	1	4
2015SB1	0	0	0	2	2	1	3	1	9
2015SB2	0	0	2	2	0	1	3	1	9
2015SB3	0	0	0	1	0	0	2	1	4
2015SC1	1	1	1	1	2	1	2	2	11
2015SC2	0	0	1	1	3	1	4	1	11
2015SC3	0	0	1	0	2	0	2	0	5
2015SD1	0	1	3	1	3	3	4	1	16
2015SD2	1	0	0	2	0	0	3	2	8
2015SD3	0	1	0	1	1	0	3	0	6
2015SE1	1	0	1	1	3	3	3	1	13
2015SE2	0	0	2	3	3	0	3	1	12
2015SE3	0	0	1	1	3	1	2	1	9
2015AA1	0	1	1	1	1	0	3	1	8
2015AA2	0	0	0	2	0	0	3	1	6
2016SA1	1	1	2	1	3	2	4	0	14
2016SA2	1	0	1	3	1	1	4	0	11
2016SA3	1	0	1	1	0	0	1	0	4
2016SA4	0	0	0	0	0	0	1	0	1
2016SB1	1	1	2	0	2	2	4	1	13
2016SB2	1	0	2	1	2	2	2	2	12

Tab. 5.7: Evaluation Score of Each Drawing

Drawing	#1	#2	#3	#4	#5	#6	#7	#8	SUM
2016SB3	1	1	0	2	1	0	3	0	8
2016SB4	0	0	0	1	1	0	3	0	5
2016SC1	1	0	2	1	3	1	4	2	14
2016SC2	1	0	1	1	2	1	4	1	11
2016SC3	0	1	0	1	2	1	4	0	9
2016SC4	0	0	0	1	2	1	4	0	8
2016SD1	1	1	2	0	2	2	4	1	13
2016SD2	1	0	0	1	0	0	5	0	7
2016SD3	0	0	0	2	0	0	3	0	5
2016SD4	1	0	0	1	0	0	2	0	4
2016SE1	1	1	2	0	3	1	5	2	15
2016SE2	0	1	1	1	3	0	6	2	14
2016SE3	1	0	2	1	1	1	3	1	10
2016SE4	1	0	0	1	1	0	3	1	7

Tab. 5.7 indicated each drawing and Fig. 5.3～Fig. 5.14 showed the results of practical aspect scores of each intervention. The differences from the initial version of drawings to the final version could be indicated. Some team submitted more sufficient drawings than other teams and the third version and the final version of the teams were substituted by the last one.

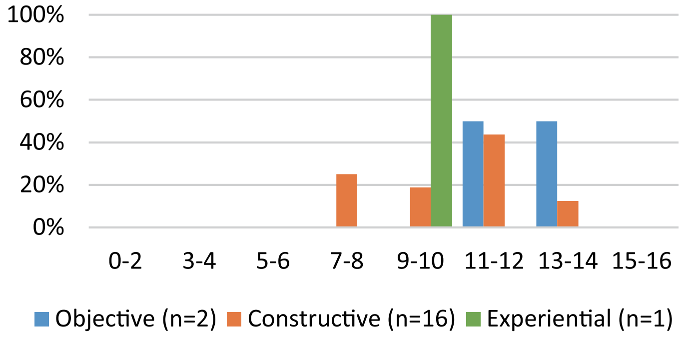


Fig. 5.3: Results of Evaluation Scores of Initial Version of Student Drawing (Theoretical Aspects)

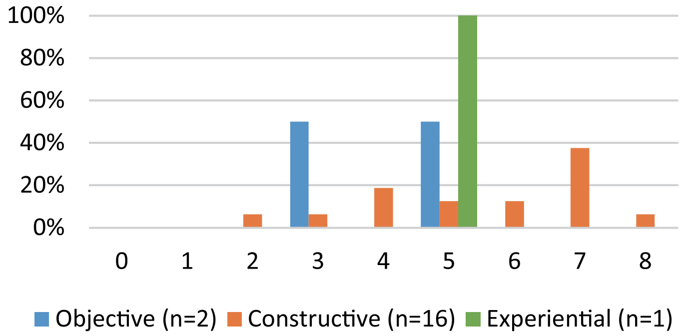


Fig. 5.4: Results of Evaluation Scores of Initial Version of Student Drawing (Practical Aspects)

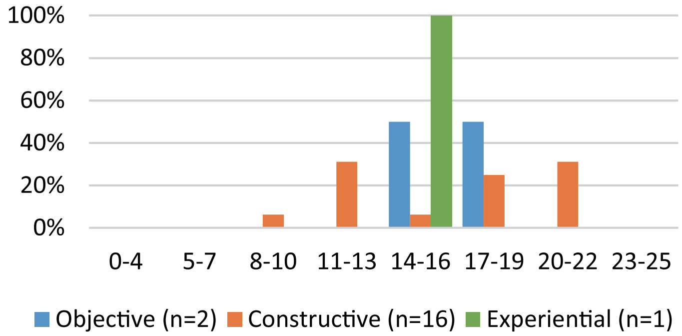


Fig. 5.5: Results of Evaluation Scores of Initial Version of Student Drawing (Total)

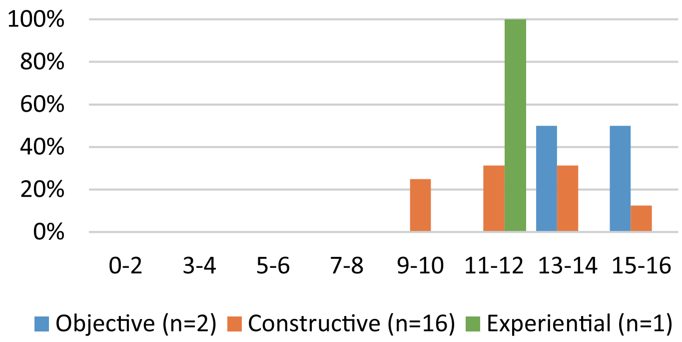


Fig. 5.6: Results of Evaluation Scores of Second Version of Student Drawing (Theoretical Aspects)

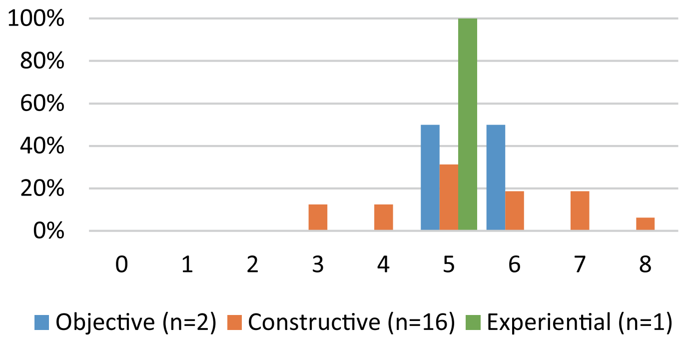


Fig. 5.7: Results of Evaluation Scores of Second Version of Student Drawing (Practical Aspects)

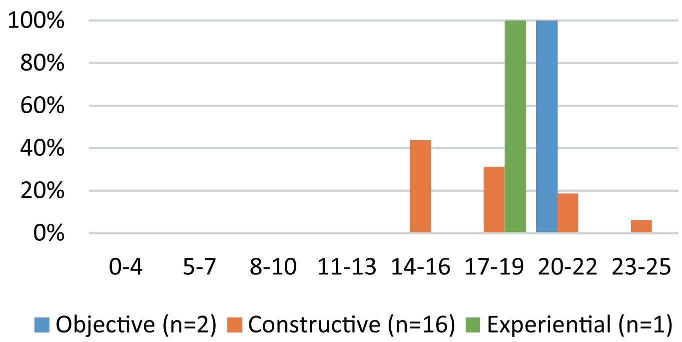


Fig. 5.8: Results of Evaluation Scores of Second Version of Student Drawing (Total)

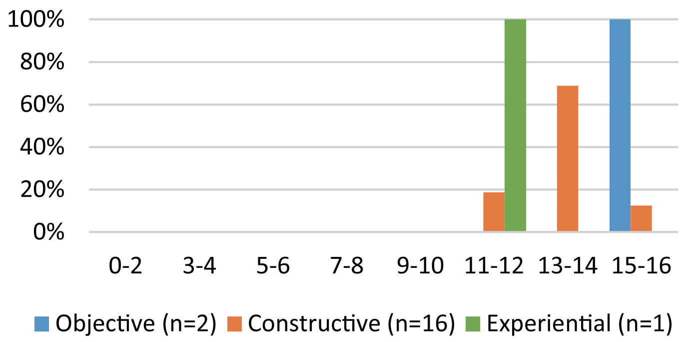


Fig. 5.9: Results of Evaluation Scores of Third Version of Student Drawing (Theoretical Aspects)

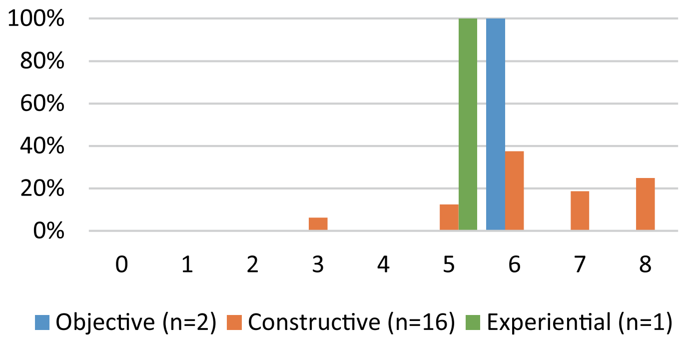


Fig. 5.10: Results of Evaluation Scores of Third Version of Student Drawing (Practical Aspects)

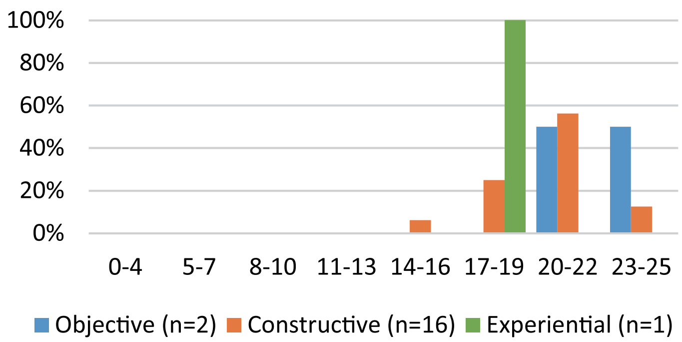


Fig. 5.11: Results of Evaluation Scores of Third Version of Student Drawing (Total)

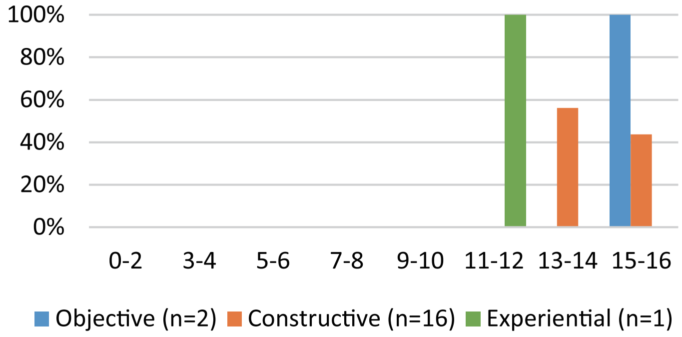


Fig. 5.12: Results of Evaluation Scores of Final Version of Student Drawing (Theoretical Aspects)

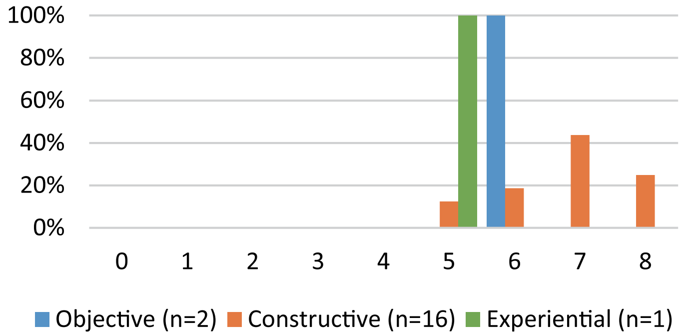


Fig. 5.13: Results of Evaluation Scores of Final Version of Student Drawing (Practical Aspects)

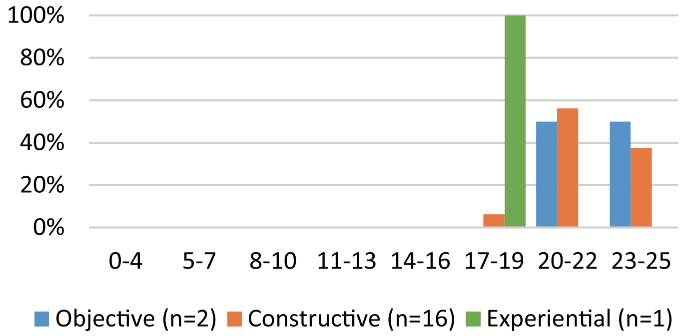


Fig. 5.14: Results of Evaluation Scores of Final Version of Student Drawing (Total)

5.4.2 Final Product

Student team final products were also compared, based on a criterion as Tab. 5.8. The criterion consisted of both of theoretical and practical items which were similar with the drawing criterion. The staff get scores to each items with from 1 to 3 scores respectively.

Tab. 5.8: Criterion of Final Products

#	Category	Item	Score
#1	Theoretical	Originality	3
#2		Validity of Solution	3
#3		Aerodynamics	3
#4		Strength & Rigidity of Structure	3
#5		Stability	3
#6		Maneuverability	3
#7	Practical	Building	3
#8		Operation	3

Fig. 5.15～Fig. 5.17 indicated the evaluation scores of student final products.

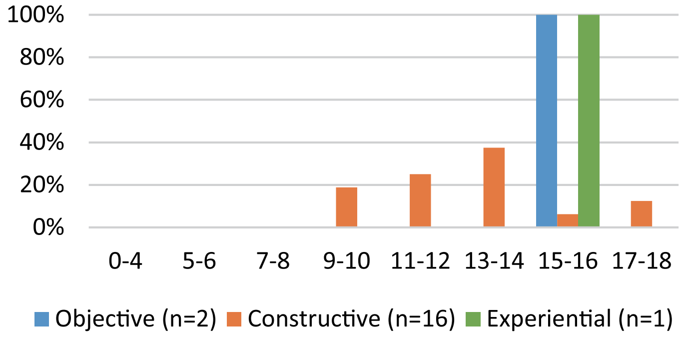


Fig. 5.15: Results of Evaluation Scores of Final Products(Theoretical Aspects)

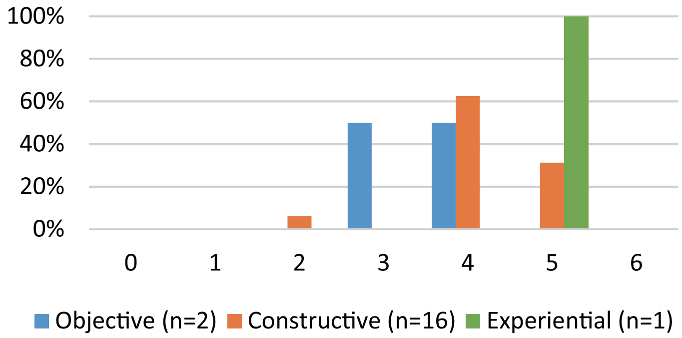


Fig. 5.16: Results of Evaluation Scores of Final Products (Practical Aspects)

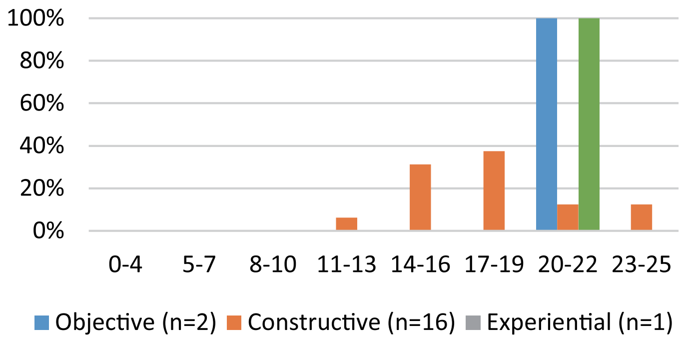


Fig. 5.17: Results of Evaluation Scores of Final Products (Total)

5.4.3 Discussion

5.4.3.1 Differences of Interventions

Each intervention characteristics can be compared from the results of drawings and products. Though the all intervention correction and discussion session had influenced student activities appropriately and the students improved their drawings consistently. The significant differences between objective intervention and constructive intervention cannot be shown with the initial version (p = 0.890) and the final version (p = 0.710). One of the reason was about student prior knowledge. Tab. 5.9 indicated prior knowledge level of each intervention student, evaluated under the prior knowledge criterion. The results showed the significant differences in aircraft (total) could be shown between objective intervention and constructive intervention by multiple comparison test using Tukey HSD method (p = 0.006).

Tab. 5.9: Prior Knowledge of Each Intervention Student

Intervention		Objective (n=10)	Constructive (n=82)	Experiential (n=5)
Aircraft	Knowledge	2.3 (0.5)	1.7 (0.6)	2.0 (0.0)
	Implementation	2.0 (0.8)	1.4 (0.7)	1.0 (0.0)
	Total	2.2 (0.6)	1.5 (0.6)	1.5 (0.0)
Intervention		Objective (n=5)	Constructive (n=41)	Experiential (n=0)
Auto Control System	Knowledge	2.2 (0.4)	1.7 (0.6)	N/A
	Implementation	1.4 (0.5)	1.4 (0.6)	N/A
	Total	1.8 (0.4)	1.5 (0.5)	N/A

5.4.3.2 Each Team Characteristics

Many teams redesigned their own drawings of flying robots and they were improved through communication with staff members. However several teams left some insufficiency of consideration especially in building processes. Seven teams in the eighteen teams checked more than five items in the last drawings before building phases.

The 2013S team was excluded because of no-obligation of submissions of more detailed drawings.

The teams which planned relatively complicated concepts which included some difficulties in crafting such as inverted gull wing, elliptic, large area wing, 2015SC, 2016SB, 2016SC, did not discuss with building processes in detail before fabrication phases. During the process, they met some problems of crafting wing spar or leading and trading edge parts, and needed many hours building main wing parts. However, these teams relatively planned good schedules in staff summative assessment and they completed the products without any big problems. These teams asked staff members to advice actively or passively at the star of the building phase and dealt with the problems, integrating knowledge of experienced persons. In addition, through video observations, they planned schedule included risk managements, in which they could cope with insufficiency of considerations of drawings. As a result, they completed their tasks more early than other teams at the same semester.

The team of 2015SE, 2015AA, 2016SE also did not consider deeply drawings before they started the fabrications otherwise they challenged to relatively difficult and complicated problems such as no-tail plane, gull wing, hybrid of aircraft and multicopter. Video observations showed that they spent more time discussing and being confused with their drawings during class time in which they had to concentrate on building activities. Thy also struggled with the problems by their own skills and efforts and they did not ask for help to the other members relatively. After all, their works could not go ahead effectively or include some problems such as mistakes in detail figures, and lead to necessity of more hours at the last phase of building.

The flying robot in the team of 2015SD was ordinary type of airplane and technological severe problems were not found in building phases. Rather, they was struggling with an adjustment of their schedule, they tried to deal with the problems at same periods, however they could not meet each schedule appropriately. In conclusion, they were not able to prepare enough time for crafting and their schedule became too late for deadline direct before the flight test.

5.5 Summary

This chapter explained student activities through their prior-knowledge and their products. Many cases indicated the necessity of preparation for effective building activities of flying robots before the team started the fabrication phase. The teams that could consider production details before practice could complete development without any big problems. On the contrary the teams that could not image building process appropriately met some big problems in their building phase. However some teams that was successful for discussing with other members, especially staff or experienced members, could deal with problems effectively at the initial steps of building in front of their prototypes, could plan better schedule including risk managements and complete their problems met the deadline. After all, consideration with building process practically at the start of building phases could bring positive results of the products and total schedule management.

The teams could stop their tasks if they met some unforeseen problems in building processes if they neglected detail thinking of the processes because of lack of knowledge and experiences and difficulties of the problems beyond their abilities. However they could reschedule their plans after the start of fabrications if teachers facilitated their problems appropriately. Making opportunities of metacognition with their own activities in building methods and schedules could lead students to complete the tasks appropriately.

If they kept their task as original imagined schedule and developing way, their works could fail somewhere and result to complete tasks with some problems. Some cases they could achieve relatively good outcomes by supports of specific members tremendous efforts, but other cases leaded to break up the team and get down student motivations remarkably. The project had to include these points and teachers should take care of the programs which did not depend on the student prior-skills, preparing circumstances and teaching and learning activities sufficiently.

Chapter 6 Summative Assessment

Teamwork and schedule were also discussed in this chapter. It also described what kind of educational effect the students self-assessed and how the educators evaluated student activities. The result of each project was compared and what kind of activities had the educational effects were explained.

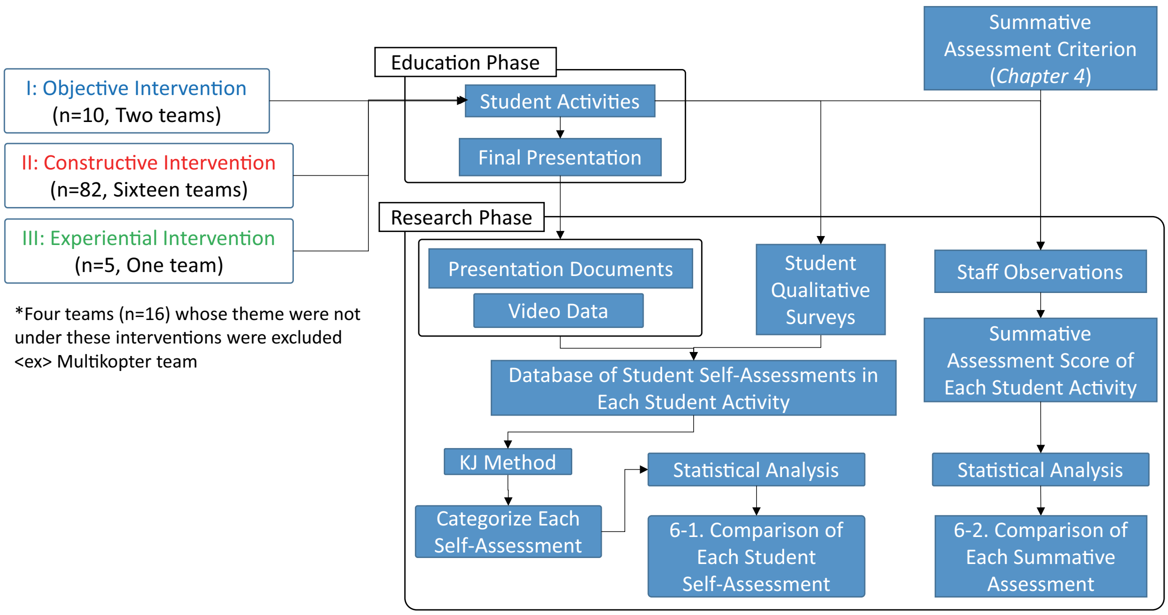


Fig. 6.1: Overview of Summative Assessment

6.1 Student Self Assessment

6.1.1 Methodology

This study was also conducted experimentally and the measurement of the educational effect was done in various forms according to each term. This section aimed to compare student educational effect in each team of each semester, collecting and analyzing artifacts that are considered to be expressing opinions on the educational effect of the project. The data was acquired through the questionnaire conducted at the end of the project and the video observation at the final presentation. The details was shown in Tab. 6.1

Tab. 6.1: Data Collection Methods of Each Semester

Date	Num	Semester	Question
3/4/2013	7	2012W	Q12. Describe impressions about this project.
7/17/2013	5	2013S	Q3. & Q4. Are you satisfied with this project contents? If not, describe the reason. Q5. If you have something which help your future jos or research, describe it. Q6.Describe other contents you want to learn more in this project. Q7.Descrobe your impressions or opinions about this project.
1/9/2013	5	2013W	Q5. Describe positive effects of the project freely.
		2014S	NoData
1/28/2015	10	2014W	Q3.1. How successful was your activities for achieving your goal? Describe them and their reasons. Q3.2 Describe your learning through this project freely. Q3.3 What contents do you want to learn using this experience? Q3.4 If you have other opinions like new project theme, improvements, and requests, describe them.”
7/15/2015	28	2015S	Video Observation (Describe your impressions of the project at the end of your final presentation.）
1/27/2016	8	2015A	Video Observation (Describe your impressions of the project at the end of your final presentation）
7/13/2016	24	2016S	4.2.Describe your learning through this project freely. 4.3.Describe your experiences which you didn’t like or didn’t work well in the project freely. 4.4.Describe other contents you want to learn more, improvements of the project, and requests.

This survey also excluded 2014 S semester data because this did not include individual data corrections at the end of the semester.

6.1.2 Results

This investigation acquired data from 89 students from 20 teams of 7 semesters. The comments of student self-evaluations were scripted (15116 words in Japanese) and coded into several items. Each item included one meaning of educational effects. The 52 items contained requirements for the class which did not have meanings of educational effects. The other 173 items were divided into 7 categories from 26 groups, using KJ method (Kawakita, 1991). The four categories related to applying knowledge to design, one category was teamwork and project management, and one was motivations (the other was another content).

Tab. 6.2: Category of Student Self Assessments

Learning Outcomes(Chapter 4)	Category	Item
	I was able to	
Applying Knowledge to Design	learn applying knowledge to practice	learn real world practice did not go according to theory, I could learn from practice rather than theory
		learn deeper knowledge through engineering practice
		I want to learn more theory relating to practice
		learn importances of both theory and practice
Applying Knowledge to Design	experience crafting	learn technology and making model airplane
		experience design
		learn auto control system or electric kit
Applying Knowledge to Design	learn theoretical knowledge	
Applying Knowledge to Design	learn something related to design process	learn an importance of understand the problem
		learn an importance of defining objectives
		learn an importance of making solutions
		learn an importance of trade-offs
		learn an importance of creativity
		learn an importance of iterating and redesigning
Teamwork	learn about teamwork or project management	learn an importance of schedule management
		experience project

Tab. 6.2: Category of Student Self Assessments

Learning Outcomes(Chapter 4)	Category	Item
	I was able to	
		learn an importance of information sharing with team members and others
		learn an importance of interdependence
		experience about budget
		learn an importance of leadership
		learn an importance of risk management
		Others
Motivation	raise my motivation for learning engineering	It was enjoyable or interesting
		I wan to acquire more knowledge
		I want to experience more engineering practice
		Others
Others		

Tab. 6.3: Results of the Surveys of Student Self Assessment of Their Activities

	(α)	(β)	(a)	(b)	(c)	(d)	(e)	(f)
2012W A (n=5, 100%)	60%	20%	20%	60%	20%	40%	0%	0%
2012W B (n=5, 40%)	0%	0%	0%	20%	0%	0%	0%	0%
2013S (n=5, 100%)	80%	100%	0%	40%	80%	40%	40%	0%
2013W (n=6, 83%)	33%	67%	0%	17%	17%	17%	0%	17%
2014W A (n=6, 100%)	33%	17%	33%	33%	33%	17%	67%	0%
2014W B (n=4, 100%)	75%	100%	0%	25%	50%	50%	0%	0%
2015S A (n=5, 100%)	60%	0%	0%	40%	60%	20%	0%	0%
2015S B (n=5, 100%)	100%	0%	0%	60%	40%	0%	20%	20%
2015S C (n=5, 100%)	100%	20%	0%	60%	40%	40%	0%	0%
2015S D (n=8, 100%)	50%	50%	0%	25%	13%	13%	25%	0%
2015S E (n=4, 100%)	75%	50%	0%	25%	50%	50%	0%	0%
2015S F (n=3, 100%)	100%	0%	0%	67%	33%	0%	67%	0%
2015W A (n=6, 100%)	50%	17%	0%	33%	17%	17%	0%	0%
2015W B (n=4, 100%)	75%	50%	0%	50%	25%	25%	0%	25%
2016S A (n=4, 100%)	75%	25%	50%	0%	25%	25%	50%	0%
2016S B (n=4, 100%)	100%	0%	25%	25%	50%	50%	25%	0%
2016S C (n=5, 100%)	60%	0%	20%	0%	0%	20%	40%	0%
2016S D (n=5, 100%)	80%	40%	0%	0%	60%	0%	40%	0%
2016S E (n=4, 100%)	100%	0%	0%	0%	75%	75%	0%	0%
2016S F (n=3, 100%)	100%	0%	0%	0%	0%	33%	33%	0%

(α): Learn about flying robot design ((a)～(f))

(β): Learn about teamwork and project management

(a): Acquire basic knowledge of aeronautics

(b): Increase motivations of aeronautics

(c): Apply aeronautics knowledge to real world products

(d): Experience technology or crafting

(e): Think about design process

(f): Have other impacts (budget, easiness of flight, etc.)

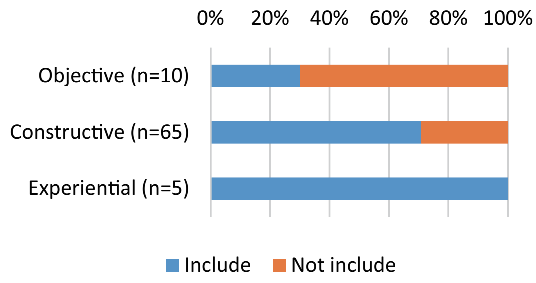


Fig. 6.2: Student Self-Assessment for (α): Design

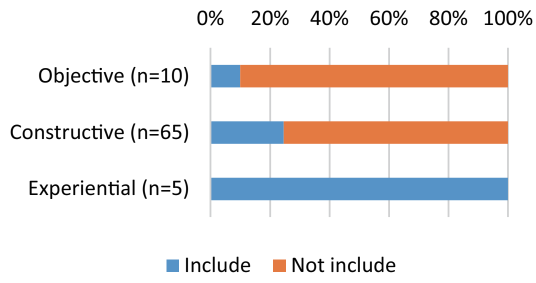


Fig. 6.3: Student Self-Assessment for (β): Team Activity

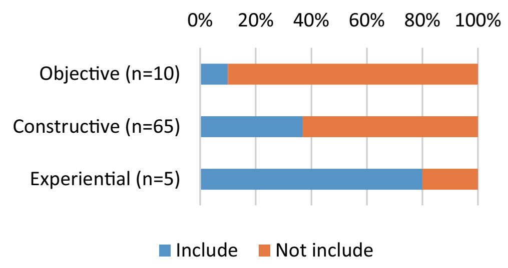


Fig. 6.4: Student Self-Assessment for (a): Aeronautics Knowledge

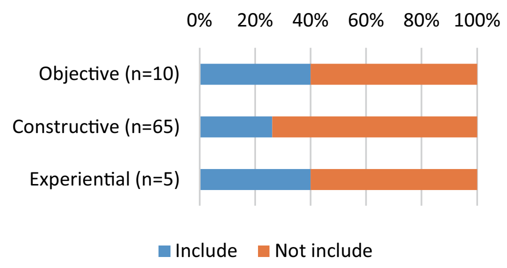


Fig. 6.5: Student Self-Assessment for (b): Motivation

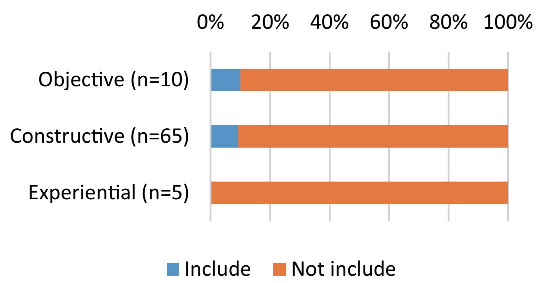


Fig. 6.6: Student Self-Assessment for (c): Applying Knowledge

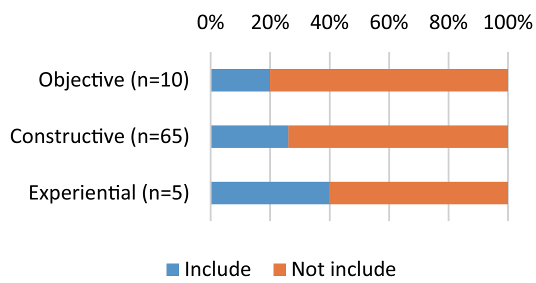


Fig. 6.7: Student Self-Assessment for (d): Experience Crafting

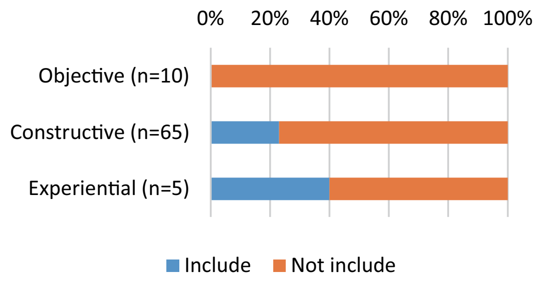


Fig. 6.8: Student Self-Assessment for (e): Design Process

Fig. 6.2～Fig. 6.8 showed the differences of student perceptions in each intervention. Each category was subject to the category of student self assessment comments. X^2-test showed a significant difference of student opinions about learning flying robot design between objective intervention and constructive intervention ($X^2(1) = 4.69, p = 0.030$) and between objective and experiential ($X^2(1) = 4.05, p = 0.044$). The test also explained significant difference about applying aeronautics knowledge between objective intervention and constructive intervention ($X^2(1) = 1.75, p = 0.187$) and between objective and experiential ($X^2(1) = 4.54, p = 0.033$). However there was no significant difference about confidences and motivations between objective intervention and constructive intervention ($X^2(1) = 0.28, p = 0.596$) and between objective and experiential ($X^2(1) = 0.00, p = 1.000$). A significant difference about team activities could be shown between objective intervention and experiential intervention ($X^2(1) = 7.81, p = 0.005$), but could not be indicated between objective and constructive ($X^2(1) = 0.39, p = 0.534$).

6.2 Summative Assessment

6.2.1 Facilitator Criterion

Teachers summative assessment was made for each criteria and evaluation was conducted by several staff members who supervised student activities.

6.2.2 Results

Tab. 6.3 indicated the results of the assessment. 2012W and 2013S was little different in criterion scores and corrected. The evaluation of 2013W and 2015A were not conducted by staff teams with this method and excluded in the following discussion. The results showed each team score in each item. The percentage along the participant numbers in the parenthesis indicated response rate in team.

Tab. 6.4: Results of Staff Summative Assessments

Team (Response Rate)	#1	#2	#3	#4	#5	SUM
2012W A (n=5, 100%)	8.2 (2.2)	16.2 (1.8)	16.0 (2.2)	18.0 (0.0)	21.8 (7.6)	80.2 (13.7)
2012W B (n=5, 100%)	9.3 (1.3)	17.0 (1.7)	16.3 (0.8)	18.0 (0.0)	26.3 (3.6)	86.8 (7.4)
2013S (n=5, 100%)	10.0 (0.0)	18.4 (0.8)	19.0 (0.0)	17.2 (1.0)	27.4 (0.8)	92.0 (1.4)
2014W A (n=6, 100%)	10.0 (0.0)	18.0 (1.8)	16.8 (1.8)	20.0 (0.0)	26.7 (2.9)	91.5 (4.3)
2014W B (n=4, 100%)	10.0 (0.0)	17.5 (1.8)	17.5 (1.8)	20.0 (0.0)	27.3 (2.2)	92.3 (3.3)
2014S A (n=6, 100%)	10.0 (0.0)	16.5 (1.9)	16.3 (2.2)	17.0(0.0)	22.5 (7.8)	82.3(10.1)
2014S B (n=4, 67%)	10.0 (0.0)	17.0 (1.4)	16.0 (0.0)	17.0 (0.0)	26.0 (0.0)	86.0 (1.4)
2014S C (n=4, 80%)	10.0 (0.0)	17.8 (1.8)	18.0 (2.1)	18.0 (0.0)	26.8 (1.6)	90.5 (5.0)
2015S A (n=5, 100%)	9.6 (0.8)	17.2 (1.9)	17.8 (1.3)	18.0 (0.0)	27.0 (1.7)	89.6 (3.7)
2015S B (n=5, 100%)	9.8 (0.4)	16.8 (1.9)	16.8 (1.9)	17.0 (0.0)	26.8 (1.9)	87.2 (5.6)
2015S C (n=5, 100%)	9.8 (0.4)	17.2 (1.9)	17.0 (1.8)	20.0 (0.0)	27.2 (1.9)	91.2 (5.7)
2015S D (n=8, 100%)	9.9 (0.3)	17.6 (1.5)	17.0 (1.4)	10.0 (0.0)	20.3 (1.7)	74.8 (3.9)
2015S E (n=4, 100%)	10.0 (0.0)	19.0 (1.2)	17.8 (0.4)	15.0 (0.0)	28.0 (1.6)	89.8 (2.6)
2015S F (n=3, 100%)	9.7 (0.5)	18.7 (1.2)	18.7 (0.9)	20.0 (0.0)	28.7 (0.9)	95.7 (1.9)
2016S A (n=4, 100%)	9.8 (0.4)	17.5 (2.1)	17.5 (1.7)	20.0 (0.0)	27.0 (0.7)	91.8 (3.3)
2016S B (n=4, 100%)	10.0 (0.0)	17.5 (0.9)	17.3 (0.4)	20.0 (0.0)	27.3 (0.4)	92.0 (1.7)
2016S C (n=5, 100%)	8.8 (1.5)	18.8 (1.6)	18.6 (1.7)	17.0 (0.0)	25.6 (2.2)	88.8 (6.8)
2016S D (n=5, 100%)	10.0 (0.0)	15.2 (0.4)	17.4 (0.5)	20.0 (0.0)	26.6 (0.5)	89.2 (1.0)
2016S E (n=4, 100%)	10.0 (0.0)	19.3 (0.8)	17.5 (0.5)	15.0 (0.0)	27.3 (1.3)	89.0 (2.2)
2016S F (n=3, 100%)	10.0 (0.0)	18.0 (0.8)	17.7 (1.7)	18.0 (0.0)	27.0 (0.0)	90.7 (2.4)

#1: Participation Rate (10 Points)

#2: Knowledge (20 Points)

#3: Implementation (20 Points)

#4: Scheduling (20 Points)

#5: Team Activity (30 Points)

Tab. 6.4 indicated the results of staff summative assessment results. The results was summarized in each intervention as Fig. 6.9～Fig. 6.11.

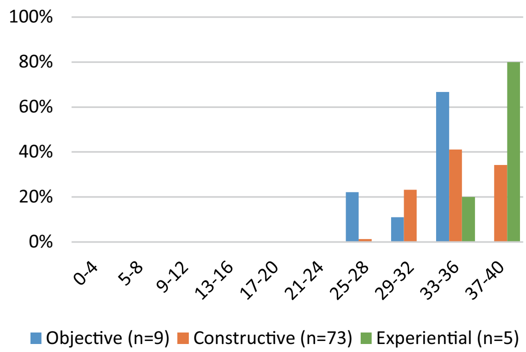


Fig. 6.9: Results of Evaluation Scores of Staff Summative Assessment (Design)

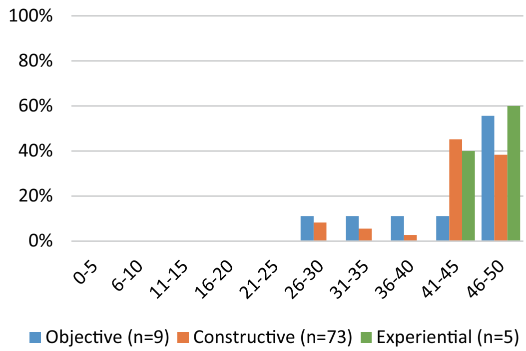


Fig. 6.10: Results of Evaluation Scores of Staff Summative Assessment (Team Activity)

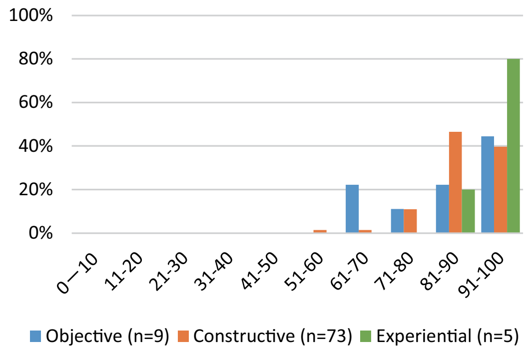


Fig. 6.11: Results of Evaluation Scores of Staff Summative Assessment (Total)

6.3 Discussion

6.3.1 Difference of Constructive Intervention and Experiential Intervention with Objective Intervention

The staff assessment scores were the highest in experiential intervention at both of design and team activity. On the other hand objective intervention results were the lowest in all aspects of the scores. However, the Mann-Whitney test did not show a significant difference with the total scores between the objective intervention students ($M = 83.1$, $SD = 11.8$) and the experiential intervention students ($M = 92.0$, $SD = 1.4$), $p = 0.106$. The test only showed a significant difference between the design score of objective intervention ($M = 32.7$, $SD = 3.4$) and experiential intervention ($M = 37.4$, $SD = 0.8$), $p = 0.004$. The constructive and experiential intervention were strong technique for promoting student-centered learning in developing flying robots contents, but one of the reasons of the results came from the limitations of participants.

Tab. 6.5: Results of Staff Summative Assessments with the Students of Each Intervention

	Design (40 Points)	Team Activity (50 Points)	Total (100 Points)
Objective Intervention (n=9)	32.7 (3.4)	41.8 (6.6)	83.1 (11.8)
Constructive Intervention (n=73)	34.7 (3.0)	43.1 (5.8)	87.6 (7.3)
Experiential Intervention (n=5)	37.4 (0.8)	44.6 (1.7)	92.0 (1.4)
The Mann Whitney U-test (O vs C)	p=0.195	p=0.864	p=0.577
The Mann Whitney U-test (O vs E)	p=0.004	p=1.000	p=0.106

6.3.2 Each Team Characteristics

This section discussed the results of student self-assessment and staff criterion assessment. The two teams (2013W and 2015AB) were excluded because they did not design original vehicles but improved the prior flying robots with adding new auto pilot system and the activities was different with other teams. This section discussed with the teams which designed original vehicles. Eighty-six students from eighteen teams were intended in the following explanations.

6.3.2.1 Educational Effectiveness for Flying Robot Design

Sixty-six students replied that they learned something related to aircraft design, knowledge or technology about flying robots. All teams whose respond rate were 100%, except 2014 WA and 2015SD, showed that more than 75% of team members answered that they acquired some educational effects related to design and development of flying robots.

6.3.2.1.1 From Teamwork

The team 2015SD was the hugest team and the most difficult team with scheduling and teamwork. They could not prepare sufficient time for building until the deadline approached and finally some students were forced to engage in a lot of work at once. In this team, about half of members commented about teamwork, some statements included positive effects about teamwork, the others came from reflections of each work. They became more sensitive with teamwork rather than engagements in design activities or engineering practice finally. In addition, the staff assessment scores of scheduling and teamwork with this team were relatively low, nevertheless they assessed the student technical design outcomes relatively good. The students concluded their activities was insufficient with teamwork and most of them reflected it. After all, their reflections were concluded that the cause of failure was attributed to instability and internal things in attribution theory of Weiner et al. (1971). Actually they thought more efforts for good teamwork could improve outputs and some students had motivations. Improving their consciousness with teamwork might be educational effects like unfortunate happiness.

6.3.2.1.2 From Creative Design

The team 2014WA consisted of students who had superior prior-knowledge and experiences and had high motivations of creating new ornithopter which most of students have not involved. They engaged in the project with initiative and get appropriate feedback through advices from technical supervisors and several flight tests. The staff members assessed their activities as prominent with both of design and development activities and teamwork and scheduling. However the results of all flight test ended with failure and their products could not fly and some students were disappointed with their own activities. They replied to the surveys that they could not have understood theory of flapping wings till the end and not learn anything. This case showed the failure due to decisive ability attribution caused by repetition of serious breakdown (Ichikawa, 1996). They scheduled three day for flight tests and continued the test over twenty times, however they could not get only one success. However, some students referred that they did not think it could fly easily, and were satisfied with their activities because they could experience how to approach new unforeseen problems.

Similarly the case where the flying robot with a new concept (for students) could not fly was the team of 2015SE. They made no-tail airplane and all of them also had high motivations at the start of the project and worked hard with enthusiasm. The staff found their activities not so good for scheduling but superior for design process and teamwork otherwise their could not fly because of longitudinal unstability. However they experienced only one day flight test and the number of failures were less than the ornithopter team. Finally more than 75% of them replied to get some educational effects of design nevertheless they could not be satisfied with the results. These results showed that though a few failure experience could give students motivations came from regret, repetitions of failures could hurt student motivations. Whether the flying robots could fly or not has significant meanings for students.

Same phenomena could be shown in 2012 WB team though it was not appeared on the data clearly. They engaged in flight tests five days and the objectives was to develop an autonomous flying robot which was new concept for the students. The results did not satisfied student first motivations. The airplane could fly by manual control precisely, but the autocontrol system was not able to work accurately and it could not prevent the aircraft fall into a spiral. One of the reasons was role sharing and only one student engaged in design of the auto control system. Another student tried to help him but he had less knowledge about control theory and practice and the output became insufficient. After all some students commented that they could not learn avionics theory. In this case, the team continued failure several times and their motivations decreased markedly.

One of the causes of these results came from specific characteristics of the Flying Robot Project whose main learning outcomes were promoting to understand aeronautics through engineering practice and project management. Creative activities was also important but not the first priority and many students participated in the project with motivations of learning fundamental aeronautics. However some students also insisted on design of creative things and we staffs wanted to recommend this kinds of motivations and concluded into the above examples. In order to deal with these problems, we made new another curriculum treating creativity as main subjects in the project based learning class.

In conclusion, failure experiences were critical for learning generally, however it also could become some kinds of shocking for students. Therefore facilitators had to focus on student efforts and take care of learning aspects such as what outcomes they could acquire and what future works they could engage in actually. If they neglected these kinds of encouragements, student motivations could decrease gradually and leaded to break up the project. The roles of facilitators was to encourage students and guarantee their activities was equivalent to what they could get indeed, monitoring their motivations, vitality, skills and growth through their behaviors.

6.3.2.2 Applying Knowledge to Practice

Twenty-eight students replied to this educational effect. The students consisted of eighteen aeronautics and astronautics junior students and ten other discipline students.

6.3.2.2.1 Differences between Aerospace Students and Others

This category result was different between aeronautics students and other discipline students. Thirty-six percentages of teh aeronautics and astronautics junior students answered that they had learned relationships of theoretical aeronautics and engineering practice, but only 16% students who majored other fields replied about applying theory to practice. A chi-squared test showed the significant difference between the two groups （$X^2(1) = 4.609, p = 0.032$）. In addition, many aerospace juniors referred that they could acquire aeronautics knowledge confirmed by engineering practice rather than others insisted that they understood difficulties of real world practice which could not go according to theory. A few sophomores also replied that airplane could fly even if they did not apply theoretical things sensitively.

In addition, four of the students answered that they want to study aeronautics in engineering practice more in future. The three of them was belonging to the team of 2016SE and they could sublimate the cause of failure as attribution to instability and internal things like their own efforts. Their scheduling was not so superior but design activities and teamwork was evaluated as high performances by teachers. Their objective was to design an autonomous flying robot and the airplane could fly by manual but the auto control system could not work well and leaded to a spiral mode through two flight tests. They felt a little disappointment with the failure and also thought their skills was not so insufficient that could make the products wrong. As a result, they acquired high motivations of self-learning. Actually they received next semester class and struggled with design of a new flying robot.

After all, skills of applying knowledge and theory to real world design and engineering practice through flying robot activities could grew correctly based on fundamental knowledge of aeronautics. When it was applied to aerospace students, its educational effectiveness was sufficiently brought up. In order to teach the other discipline students, the project needed more contents about theoretical aspects and some works in which students could deepen understanding theory useful for engineering practice.

6.3.2.3 Design Process

Conceptions related to design process like goal setting, identifying constraints, and making tradeoffs was often replied to rich experience team like 2014WA and 2015SF. Most of them had experienced the project and achieved great outcomes. They were some kinds of experts and concentrated on key components of design as a result. Although student consciousness went to what they created for the first time and they took care of aeronautics theory and engineering practice, the experts had rich knowledge systematized through experiences and understood how to design flying robots. Therefore their motivations of learning would go to improve their design methods and processes.

6.3.3 Teamwork and Project Management

6.3.3.1 Interdisciplinary Team vs Non-interdisciplinary Team

Interdisciplinary team consisted of several majors and grades could bring out great outcomes if they managed the team appropriately. In order to keep adequate teamwork, monitoring student activities and identifying their own roles in the team.

The team of 2014WB could bring out great outcomes with both of design and teamwork. One of the reason of success was that facilitators leaded team motivations of developing auto control system as realistic way. One of the students referred at first that he wanted to learn building aircraft, however class discussions found his other interest in auto control system. In addition, facilitators let them decide student each role concretely as subject and prohibited biased activity. As a result, the beginner had strong motivation for understanding auto control system clearly in order to play his role. They made their consciousness of the roles by reporting the progress in a concrete way like presentations. Finally all of them engaged in appropriate roles in the team and the team brought the superior outcomes.

This case showed four important things of project facilitators. First, they could lead student motivation deeply and connect them with the team motivation. Second, they let students state and identify concrete role concretely with responsibility and collective ownerships. Third, the facilitators knew concrete steps for progressing tasks for completing the products and student roles could occur periodically. Fourthly, they monitored and supported the student roles they stated at first and let them identify the situations periodically.

In another case, 2015SD team, the team consisted of interdisciplinary team included both of aeronautics department student and other students who knew control theory and auto control system well like the former team, but their motivations were not illuminated clearly at the beginning of the project. The project also did not let student state each role at first. In addition, they had to report only team outcomes weekly and facilitators did not examine individual student works appropriately. After all, their teamwork and scheduling did not bring so great outcomes. Although some students considered importances of project management and they could imagine good teamwork as a result, other students complained about the teamwork and his motivation was declined.

The team of 2016SE brought the great outcomes and the staffs evaluated it as positive however student self-consciousness did not show strong improvement about teamwork. One student mainly engaged in development avionics, however this semester also did not let them state clear roles of the students individually. Therefore teamwork and scheduling were not considered by them as critical things. Besides, this team consisted of same classmates and they could discuss easily. They also did not take care of training team skills originally.

In 2015AA team, they were interdisciplinary, facilitators let them state their roles and schedule but they could not keep their motivations as team motivation. They also decided only small team activities (like wing group, program group) and did not define individual tasks periodically. In addition, facilitators did not keep monitoring individual activities weekly. As a result, many students belonged to the wing group left the team after completing only wings. The scheduling was conducted after completing the three view drawings and chief wing designer became program group member at the start of building. After all some members of wing group did not have high motivations because it was not their own design and their motivations could not become collective ownership. They also did not consider difficulties of adjustment of electrical perts and components after completing wing shape and finally the leader and the designer concentrated on the tasks with limited number members.

The team of 2013S, individual homeworks was taken regularly by different tasks like a presentation of individual concept, building radio control airplane kit, and a destruction test. These activities also leaded to their team motivations. They completed only wings of a flying robot in the semester and they stated individual role and a schedule at the beginning of building phase. In this case, the problem was only building wing, it was relatively small problem and the statement of role sharing was enough in one time. In addition, the introduction activities could let them engage in the design of the product with enthusiasm and they achieved the great outcomes relatively the staff team evaluated.

The team of 2014WA, it was little interdisciplinary, they did not assess by self of learning good teamwork. This team engaged in unforeseen problems, continued enthusiastic teamwork and get several failures with flight tests. One of the reason was that every members of the project including the facilitators could not imagine the results. As a result, nevertheless they stated individual roles concretely at first and reschedule them several times, their tasks were not evaluated in aspects of whether it was realistic, every members could not evaluate it correctly, and their learning motivations were not satisfied. However this team participated in the last contest together and had good teamwork originally.

The mixed member team of sophomore students and junior students, like 2015SA and 2015SB, the junior students leaded the team frequently. The sophomore students could be reserved because of low confidence with aeronautics and engineering. Some of the sophomores replied in the end of the semester that they could not contribute to the team because they did not have rich knowledge. These teams also did not stated individual activities at the start of the project and reported only team progresses and outcomes. Therefore it was difficult for sophomore students to work with collective ownership or responsibilities. If they could engage in task with responsibilities, they could bring by themselves like 2016S semester examples.

6.3.3.2 Summary of Interdisciplinary Team

Interdisciplinary team could bring out great outcomes if it was under good management. These team activities showed four important things of project facilitators. First, they could lead student motivation deeply and connect them with the team motivation. Second, they let students state and identify concrete role concretely with responsibility and collective ownerships. Third, the facilitators knew concrete steps for progressing tasks for completing the products and student roles could occur periodically. Fourthly, they monitored and supported the student roles they stated at first and let them identify the situations periodically.

Interdisciplinary team needed sensitive scheduling and collaboration with different people who had different backgrounds in order to engage in the problems and aim to achieve objectives. It also forced student carry out struggling difficult tasks excessively and facilitators had to monitor student activities frequently and correctly.

6.4 Summary

This chapter explained two summative assessments. First was student self-assessment and the second was staff assessment using criterion. The student self-assessment indicated the effectiveness of student-centered interventions especially in design perceptions. The experiential intervention also showed the educational effect of team activities because it contained many group works in different contexts related to development of flying robots. On the other hand, the staff assessment did not show strong effects of student-centered approach, partly because of limitations of participants. In addition, the staff assessment only evaluated student activities and sometimes excluded student subjective opinions. If someone recognized an importance of leadership after strict failure in a team, the student self-assessment was relatively stressed in the aspect of teamwork, but the staff assessment could be going to fall according to the student failures in the semester. This phenomenon also indicated an importance of observations not only in student physical outputs but also in student processes of thoughts.

Chapter 7 Conclusion & Future Works

7.1 Summary of Findings

Aircraft Development have rapidly changed these days and aeronautics education in university need to cultivate students who could contribute to engineering practice and project management. This dissertation aims to 1) understand contribution of developing flying robots under university curriculum from the point of view of aeronautical stakeholders, and 2) illuminate what contribution do student flying robot activities through implementation and evaluation of activities of the Flying Robot Project.

Chapter 2 explained todays needs of practical aircraft design education from the qualitative and quantitative surveys and the interview to aircraft stakeholders. The investigation illuminated stakeholder requirements for engineering education and several specifications which educational intervention should have were determined. The specifications included both aspects of design activities and teamwork.

Chapter 3 showed the student perceptions in design activities through field observations and the qualitative and quantitative surveys. The surveys compared several groups of students who related to developing flying robots. It also indicated that students who wanted to participate in the university project in which designed, built, and flied original flying robots were unfamiliar with real world engineering practice. They also lacked confidence with engineering design. These examination results also added to the specifications of next educational intervention design.

Chapter 4 showed the design methodology of curriculum in which student could design, build, and fly original flying robots, based on the above discussion about educational specifications needed for university engineering education. Backward design based on constructivism suggested systematic way for designing programs including learning outcomes, feedback and assessment procedures, and teaching and learning activities. This chapter also showed one example of the concrete schedule of the Flying Robot Project.

Chapter 5 reflected student design activities in eight semesters and compared them with rubric systematically. The prior knowledge level and team specifications were arranged using the criterion and the evaluation of the three view drawing with consistent criterion explained characteristics of each student learning outcomes from the aspect of design. The assessment showed the necessity of appropriate feedback and opportunities of reflections before fabrication phase become complicated.

Chapter 6 indicated that summative assessment of student activities by both of student themselves and facilitators. Educational effects about design could be shown in all of the team which could success the flight test however the team which continued failures several times could be frustrated and lost their motivations extremely. The surveys also illuminated the possibility of interdisciplinary team. Interdisciplinary team could bring out great outcomes if it was under good management. These team activities showed four important things of project facilitators. First, they could lead student motivation deeply and connect them with the team motivation. Second, they let students state and identify concrete role concretely with responsibility and collective ownerships. Third, the facilitators knew concrete steps for progressing tasks for completing the products and student roles could occur periodically. Fourthly, they monitored and supported the student roles they stated at first and let them identify the situations periodically.

In conclusion, this dissertation explained the educational effectiveness of developing flying robot under university curriculum.

7.2 Future Works

This project contributions were belonging to grew student skills of applying knowledge to engineering design under real world circumstances and project management with interdisciplinary members. Some problems happened when the students challenged new concept of flying robots such as flapping wing aircraft. Creativity was a next subject of engineering design but this project could not focus on the characteristic because the regulation and rules was following the Flying Robot Contest one. In order to make creative things and give students opportunities of meeting unforeseen problems, the project redesigned by arranged learning outcomes into one which had the first priority at conceptual design and mission requirements.

Engagement in real business circumstances was to be another future work. The stakeholder surveys showed a necessity of industry-academia-government collaboration in university engineering education. However it was difficult under this project circumstances because of limitations of class hours and necessity for characteristics of aeronautics introduction contents. The curriculum design method which this dissertation showed also could apply to new objectives of making educational interventions which could contribute to industry needs directly through developing flying robots in the future.

Appendix A Reliability and Validity of Design Self-Efficacy Scale

A.1 Pre-test with the Flying Robot Project Students (Team A ～F)

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level ($\alpha = 0.900$). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.1). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.733 and 1.074). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

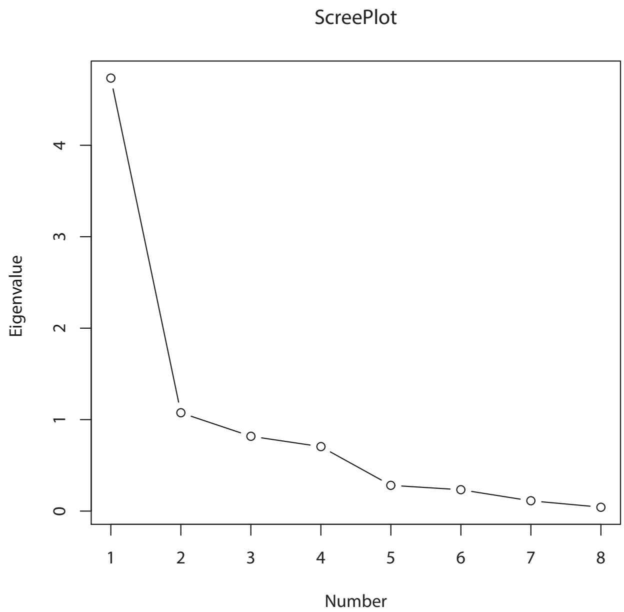


Fig. A.1: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.1. All of the factor loadings were above 0.5

and cumulative contribution ratio was 0.536. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed statistical significance (r = 0.742, p < 0.001）.

Tab. A.1: Factor Loadings for Design Self-Efficacy Items at the Pre-test with the Flying Robot Project students

#	Item	Factor Loading
2	Identify.a.design.need	0.709
3	Research.a.design.need	0.680
4	Develop.design.solutions	0.728
5	Select.the.best.possible.design	0.524
6	Construct.a.prototype	0.825
7	Evaluate.and.test.a.design	0.818
8	Communicate.a.design	0.730
9	Redesign	0.799

A.2 Pre-test with the Aeronautics and Astronautics Junior Students at The UT

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level (α = 0.867). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.2). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.330 and 1.514). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

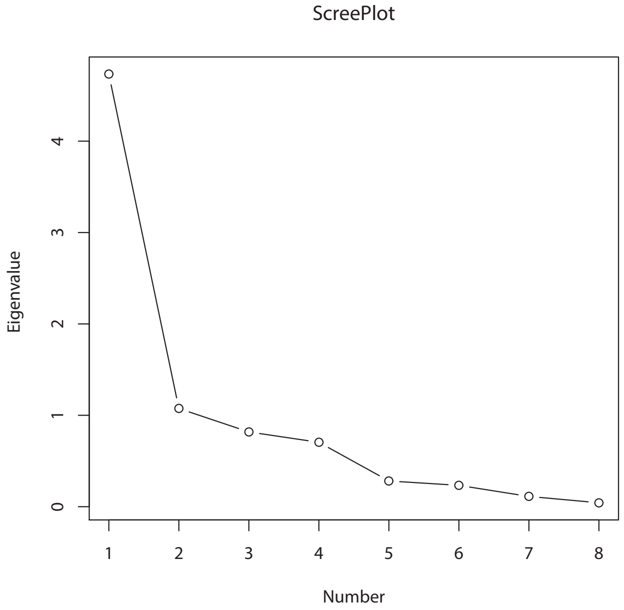


Fig. A.2: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.2. Some of the factor loadings were above 0.5 and Item #2, #3, and #5 were below 0.5. In addition, cumulative contribution ratio was 0.482. This ratio was relatively low but this research respect the prior-research result and adopted this value. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed shortly statistical significance ($r = 0.392$, $p < 0.03$).

Tab. A.2: Factor Loadings for Design Self-Efficacy Items at the Pre-test with the Flying Robot Project students

#	Item	Factor Loading
2	Identify.a.design.need	0.382
3	Research.a.design.need	0.324
4	Develop.design.solutions	0.714
5	Select.the.best.possible.design	0.451
6	Construct.a.prototype	0.879
7	Evaluate.and.test.a.design	0.959
8	Communicate.a.design	0.729
9	Redesign	0.814

A.3 Pre-test with the Flying Robot Contest Students

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level ($\alpha = 0.838$). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.3). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.139 and 1.439). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

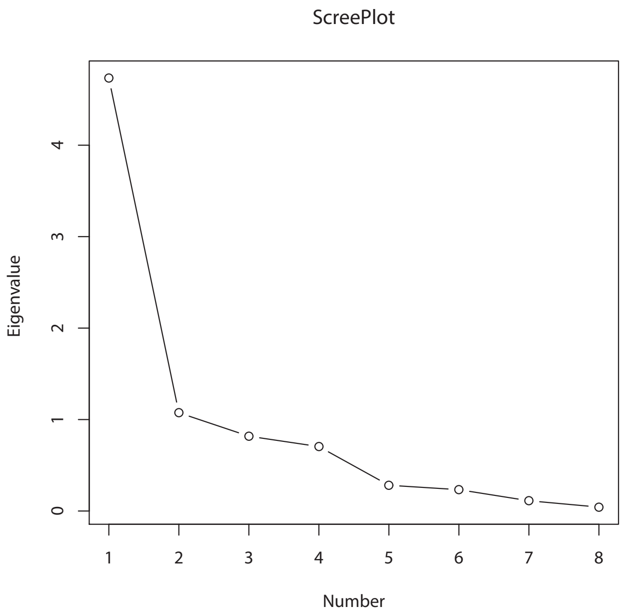


Fig. A.3: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.3. Almost all of the factor loadings were above 0.5 but Item #8 was negative. Cumulative contribution ratio was 0.456. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed statistical significance ($r = 0.923$, $p < 0.001$) and this value was one of the causes of utilizing this result in the discussion.

Tab. A.3: Factor Loadings for Design Self-Efficacy Items at the Pre-test with the Flying Robot Contest students

#	Item	Factor Loading
2	Identify.a.design.need	0.879
3	Research.a.design.need	0.729
4	Develop.design.solutions	0.836
5	Select.the.best.possible.design	0.742
6	Construct.a.prototype	0.518
7	Evaluate.and.test.a.design	0.622
8	Communicate.a.design	-0.017
9	Redesign	0.660

A.4 Pre-test with the Flying Robot Project Students (Team A ～E)

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level ($\alpha = 0.893$). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.1). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.590 and 1.147). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

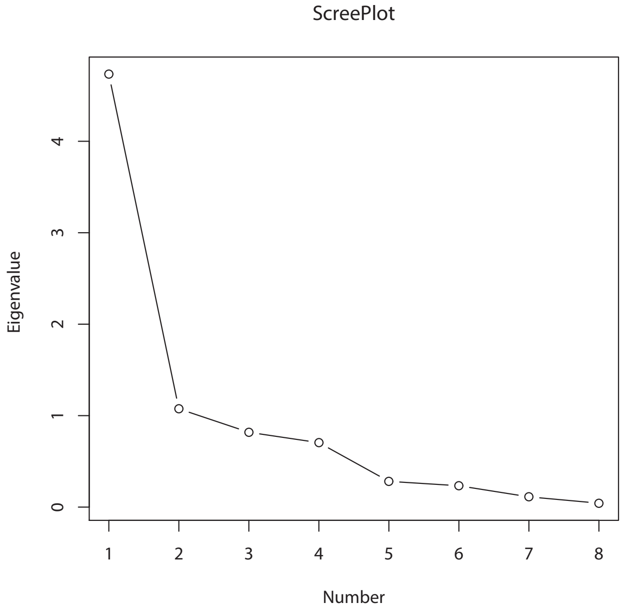


Fig. A.4: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.4. All of the factor loadings were above 0.5 and cumulative contribution ratio was 0.536. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed statistical significance (r = 0.731, $p < 0.001$）.

Tab. A.4: Factor Loadings for Design Self-Efficacy Items at the Pre-test with the Flying Robot Project students from Team A to E

#	Item	Factor Loading
2	Identify.a.design.need	0.695
3	Research.a.design.need	0.657
4	Develop.design.solutions	0.704
5	Select.the.best.possible.design	0.507
6	Construct.a.prototype	0.793
7	Evaluate.and.test.a.design	0.801
8	Communicate.a.design	0.716
9	Redesign	0.821

A.5 Post-test with the Flying Robot Project Students (Team A ～E)

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level ($\alpha = 0.811$). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.5). It might mean an existence of two factors based on Kaiser-Guttman Rule because three of eigenvalue were more than 1.0 (3.563, 1.361 and 1.163). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the only first factor was selected from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

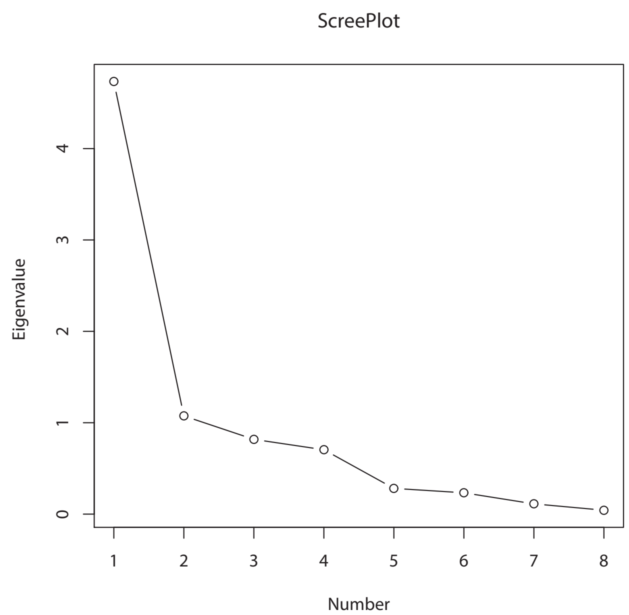


Fig. A.5: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.5. Cumulative contribution ratio was 0.371. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* didn't show statistical significance ($r = 0.221$, $p < 0.336$）, so there was a possibility of discussing other factors, however this research respected the prior-research results and promoted a discussion of the first factor.

Tab. A.5: Factor Loadings for Design Self-Efficacy Items at the Post-test with the Flying Robot Project Students from Team A to E

#	Item	Factor Loading
2	Identify.a.design.need	0.211
3	Research.a.design.need	0.283
4	Develop.design.solutions	0.882
5	Select.the.best.possible.design	0.906
6	Construct.a.prototype	0.513
7	Evaluate.and.test.a.design	0.488
8	Communicate.a.design	0.356
9	Redesign	0.786

A.6 Post-test with the Aeronautics and Astronautics Junior Students at The UT

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level (α = 0.900). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.6). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.909 and 1.318). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

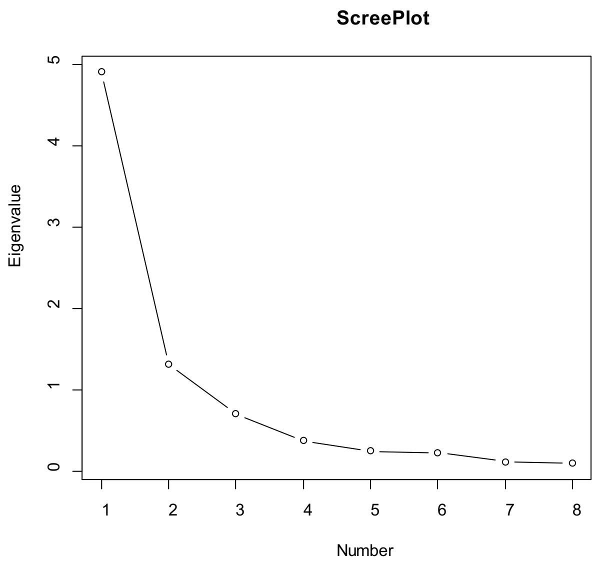


Fig. A.6: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.6. Cumulative contribution ratio was 0.559. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed statistical significance (r = 0.606, p = 0.001）.

Tab. A.6: Factor Loadings for Design Self-Efficacy Items at the Post-test with the Aeronautics and Astronautics Junior Students

#	Item	Factor Loading
2	Identify.a.design.need	0.592
3	Research.a.design.need	0.268
4	Develop.design.solutions	0.736
5	Select.the.best.possible.design	0.779
6	Construct.a.prototype	0.947
7	Evaluate.and.test.a.design	0.877
8	Communicate.a.design	0.636
9	Redesign	0.913

A.7 Post-test with the Flying Robot Contest Students

Before the Design Self-Efficacy Scale was applied to discussions of the research, evaluating consistency of the student respondents of the test. Cronbach's alpha showed the internal consistency of the respondents of the eight items was good level (α = 0.885). Eigenvalues of the correlation coefficient matrix were indicated at Scree Plot (Fig. A.7). It might mean an existence of two factors based on Kaiser-Guttman Rule because two of eigenvalue were more than 1.0 (4.491 and 1.196). However, the Scree Plot showed the number of eigenvalues from a point where the inclination of graph changes greatly was one. In addition, prior research analyzed the second factor was discarded from further analysis (Carberry et al., 2010; Coso, 2014), so this research concluded one factor existed on the test result.

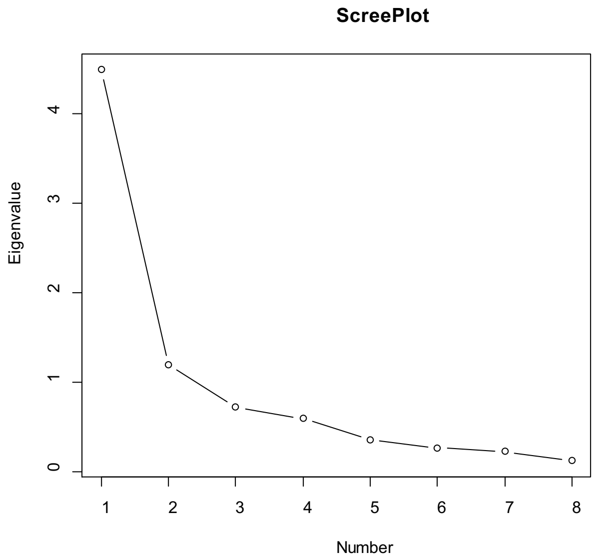


Fig. A.7: Scree Plot of Design Self-Efficacy Scale

Factor analysis using R leaded the result as Tab. A.7. All of the factor loadings were above 0.5 and cumulative contribution ratio was 0.491. The resulting factor scores were calculated using a least square regression approach. After all, Spearman's correlation coefficient between the resulting factor scores and the result of Item #1 *Conduct engineering design* showed statistical significance (r = 0.915, p < 0.001) .

Tab. A.7: Factor Loadings for Design Self-Efficacy Items at the Post-test with the Flying Robot Contest Students

#	Item	Factor Loading
2	Identify.a.design.need	0.872
3	Research.a.design.need	0.803
4	Develop.design.solutions	0.672
5	Select.the.best.possible.design	0.808
6	Construct.a.prototype	0.538
7	Evaluate.and.test.a.design	0.620
8	Communicate.a.design	0.595
9	Redesign	0.624

Appendix B Leaflets for Introduction

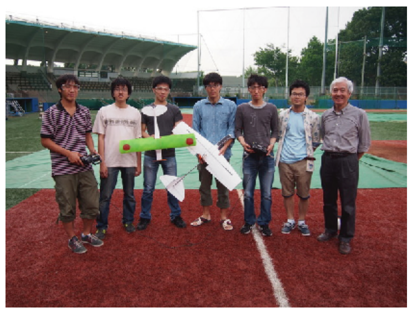
Leaflets for introduction of the Flying Robot Project at some semesters are included from the next pages.

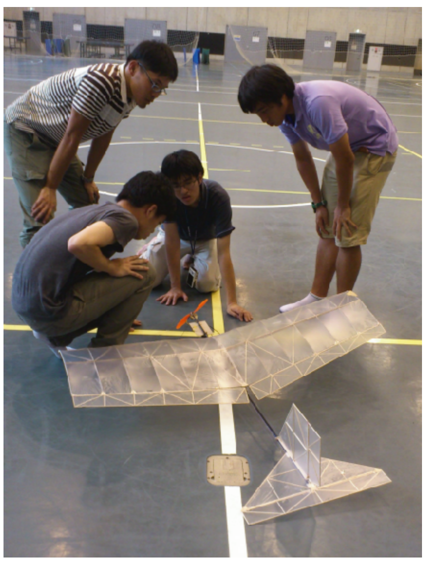
2013年度冬学期　工学部・工学系研究科共通科目
工学部『創造的ものづくりプロジェクトⅡ』
工学系研究科『創造性工学プロジェクトⅡ』

飛行ロボットプロジェクト

～オリジナルの機体を設計して飛ばしてみませんか？～
担当教官：工学系研究科航空宇宙工学専攻教授　鈴木真二

このゼミでは、屋内で飛行可能な飛行機、ならびにその制御装置の設計・製作を通して、航空工学の実践、および課題発見・解決能力、プロジェクトのマネジメント能力を培うことを目指します。
航空宇宙工学専攻でなくても設計、製作、プログラム、操縦、チーム運営などあなたの力を待っています。

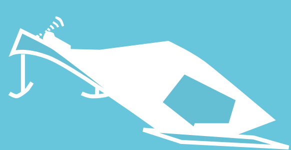




飛行ロボットプロジェクト ガイダンス
日程：１０月１６日（水）１６:４０～１８:２０
場所：工学部７号館２階７２講義室

ゼミ
日程：毎週水曜日１６:４０～１８:２０を予定していますが、参加者と調整します。
場所：工学部７号館２階７２講義室

上記の日程で都合がつかない場合は、直接下記までお問い合わせください。

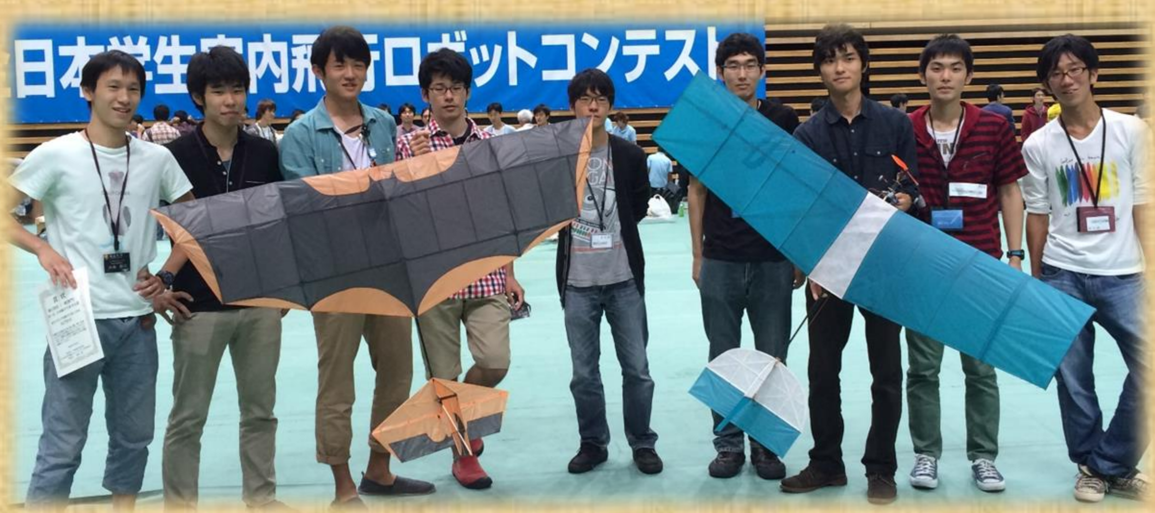


工学系研究科 国際工学教育推進機構
（工学部２号館９階９１C）
担当：三木（k.miki1023@gmail.com）

2014年度冬学期　工学部・工学系研究科共通科目
工学部『創造的ものづくりプロジェクトⅡ』（03-047512）
工学系研究科『創造性工学プロジェクトⅡ』（3799-023）

飛行ロボットプロジェクト

みんなで飛行機をつくりませんか？



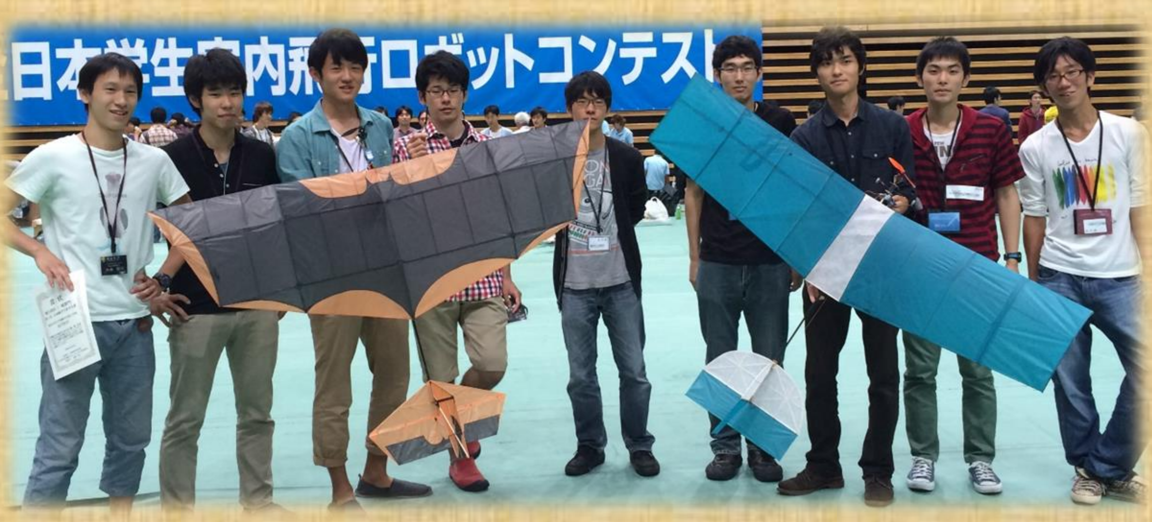
ゼミ
日程　：毎週水曜日5限目（16:40～18:20）
初回　：10月22日（水）
場所　：工学部7号館2階70講義室

問い合わせ先
三木功次
工学系研究科　国際工学教育推進機構（工学部2号館9階91C）
E-mail：k.miki1023@gmail.com

2014 Winter Semester Dept. of Engineering Common Courses
Creative Engineering Project Ⅱ
Course Code : Undergraduates 03-047512 / Graduates 3799-023

Flying Robot Project

Let' s make an aircraft together!



CLASS

DAY : Wednesday 5th period (16:40 ～ 18:20)
ROOM : School of Engineering 7th Building 2F Room 70
1st CLASS : 22 Oct.

CONTACT ADDRESS

Koji Miki
School of Engineering,
Institute for Innovation in International Engineering Education
ROOM : School of Engineering 2nd Building 9F Room 91C
E-mail : k.miki1023@gmail.com

Appendix C Sessions in Experiential Interventions

This chapter introduced two sessions original worksheets (in Japanese) of the experiential interventions for future research and education.

C.1 Learn Building & Aircraft Dynamics Session

Q1. 飛行試験を行う前についてお聞きします。トラクター式のラダー機である Skypuppy について、どのように飛行するだろうと考えていましたか?姿勢や速度などの飛行特性（操縦特性）を自由に記述してください。

Q2. 飛行試験を行う前についてお聞きします。プッシャー式のエルロン機である SAVANNA について、どのように飛行するだろうと考えていましたか？姿勢や速度などの飛行特性（操縦特性）を自由に記述してください。

Q3. 飛行試験を行った結果、Skypuppy はどのような飛行特性を持っていましたか。自由に記述してください。

Q4. 飛行試験を行った結果、SAVANNA はどのような飛行特性を持っていましたか。自由に記述してください。

Q5. 飛行試験を行った結果、自分たちの設計製作している機体について役に立った点、改良すべきだと思った点があれば自由に記述してください。

C.2 Learn Flying Robot Structure Session

C.2.1 Pre Work 1: Review of Destruction Test

主翼破壊試験の調査これから数週の間に主翼の破壊試験を行いたいと考えています。試験用の主翼（飛行ロボコン参加機体のもの）はこちらで用意しています。これに対して実際に破壊試験を行なってもらいたいと思います。まずは破壊試験とは何か？を各自調べてください。その上で以下の内容をまとめてください。

１）破壊試験を行う上で重要となるキーワード（目的、推算、考慮すべき事項）

６つくらい？、もっと多くても良いです。それぞれについて簡単に概要が分かるようにまとめてみてください。

２）キーワードを踏まえて、どのような順序で試験を行うか。

破壊試験の目的はなにで、それを達成するためにはまず何を考えて、どういう試験が必要か、という一連の試験計画を考えてみてください。５ステップくらい？になると思います。まだ詳細な計算は求めません。

１）２）についてまとめて、来週火曜 23：59 までに提出してください。

調べるのは旅客機などでも良いですし、鳥人間サークルのブログなども参考になると思います。

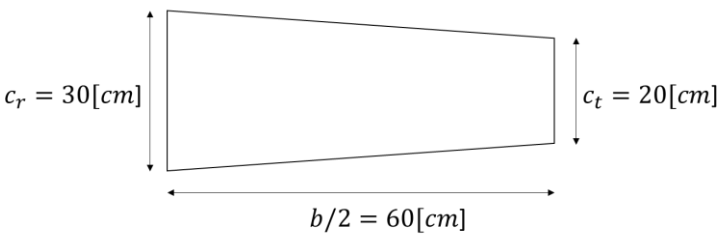
※１　課題の意味としては、計算自体よりも、試験をどのように計画していくか、という過程を考えてもらうことです。もちろん最終的には工学的な推算もしてもらいたいと思いますが、まずは全体像を把握していくところから。

※２　最終的な試験はグループで行なってもらいますが、まずは下調べからなので今回は各自提出をお願いします。

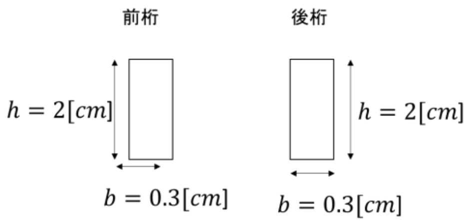
C.2.2　Pre Work 2: Preparation for Wing Destruction Test

主翼の破壊試験　事前課題

１．速度$\mathrm{V}=7[\mathrm{m/s}]$ で旋回半径 $\mathrm{R}=5[\mathrm{m}]$で宙返りするときの最大荷重倍数を求め，そのとき主翼翼根に働くモーメントを求めよ．ただし，大気密度$\rho=5/4[\mathrm{kg/m^3}]$とし，主翼形状は以下のとおりとする．また，翼の揚力係数は翼内で一様とし，$\mathrm{C_L}=0.8$とする．主翼全体（両翼）の重量は30[g]，重力加速度$\mathrm{g}=9.8[\mathrm{m/s^2}]$とする．

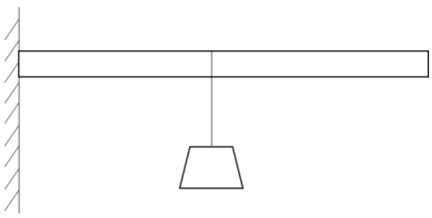


２．桁の翼根部における断面二次モーメントを求めよ．桁は図のように前桁，後桁からなり，2 本まとめた値を断面二次モーメントIとして計算せよ．



３．桁翼根部に働く最大応力を求めよ．求めた最大応力を許容応力と比較し，安全率を求めよ．ただし，桁の材質はバルサとし，許容応力を$\sigma_b=25[MPa]$とする．

４．１．で求めたモーメントを再現する荷重のかけ方を考察せよ．また部材を破壊させるには，どの位置に何 g のおもりをつければ良いかを考察せよ．なお，主翼の質量は無視してもよいが，実験の考察に含めること．
<ex>桁 1 ヶ所に錘をぶらさげ，翼根に同じモーメントを働かせる．



C.2.3 Post Work

1. 破壊試験により，部材が破壊するモーメントをもとめ，そのときに働いていたであろう翼根部の応力を推算し，事前に計算した桁翼根部に働く最大応力の結果と比較せよ.（実際の安全率を計算すること.）
2. 破壊試験を通して理解することのできたこと、設計に利用できそうなことがあれば記述してください.

Appendix D Handouts of Developing Flying Robots

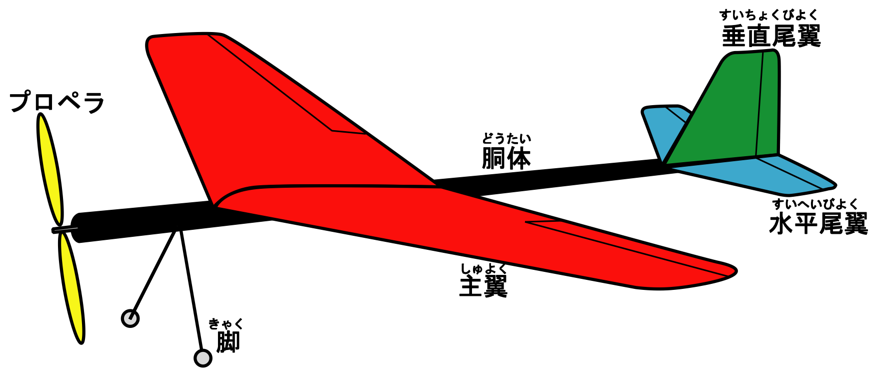
This chapter included learning materials of the Flying Robot Project. These materials are developing and other staff members also improved them according to student prior knowledge and class situations. The following pages showed one of the hand outs (in Japanese) in some semesters for future education and research.

飛行ロボットPro.

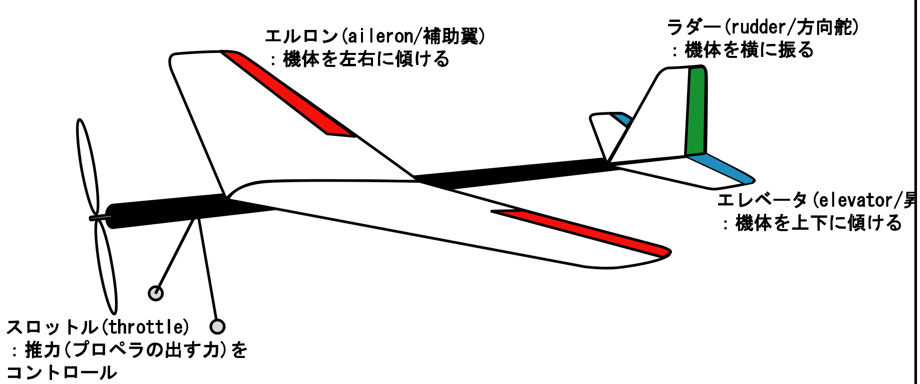
2012/10/24

用語集

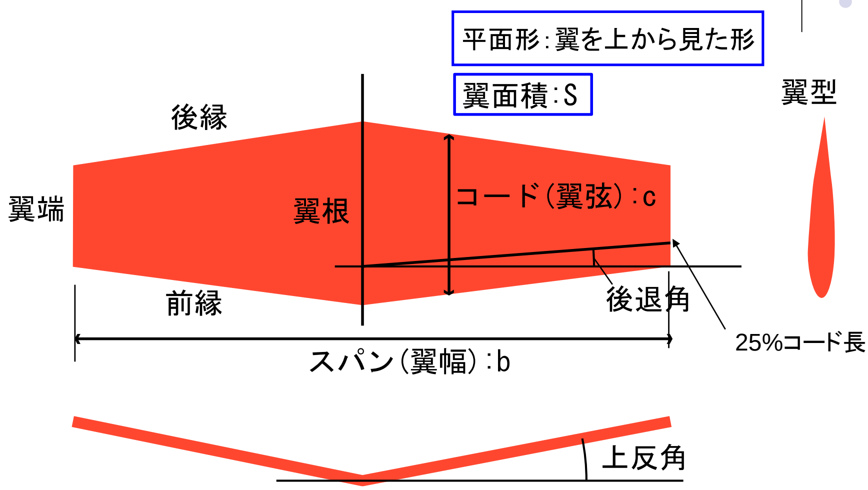
飛行機の各部名称



飛行機の舵の名称



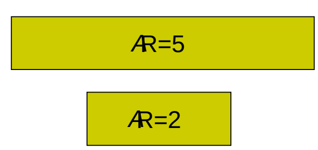
翼の名称



翼の名称2

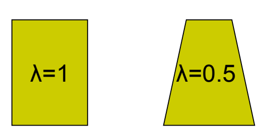
アスペクト比AR :翼がどれだけ細長いか

$$\text{アスペクト比}AR = \frac{(\text{スパン}b)^2}{\text{翼面積}S}$$

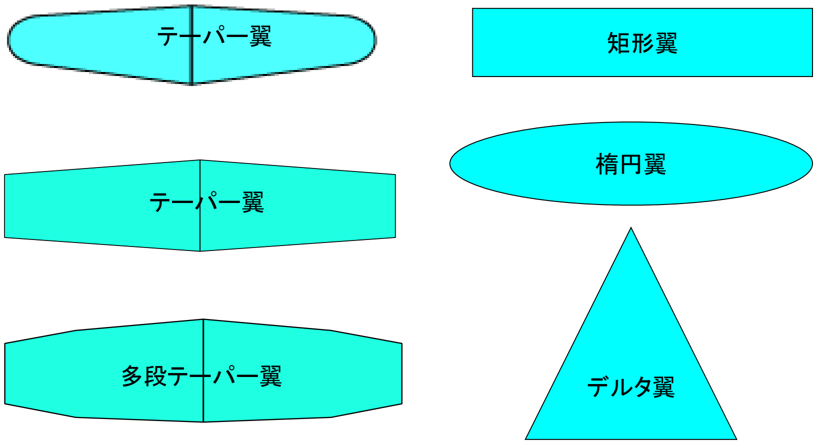


テーパー比λ :翼がどれだけとがっているか

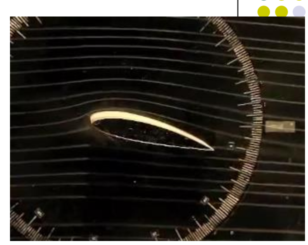
$$\text{テーパー比}\lambda = \frac{(\text{翼端の長さ})}{(\text{翼根の長さ})}$$

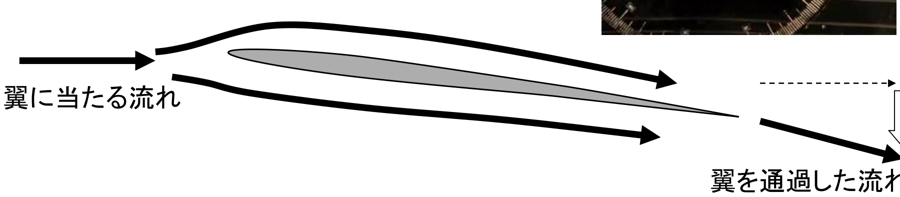


翼の平面形



翼に働く空気力





流れが下に曲げられる ←→ 翼は上向きの力を受ける

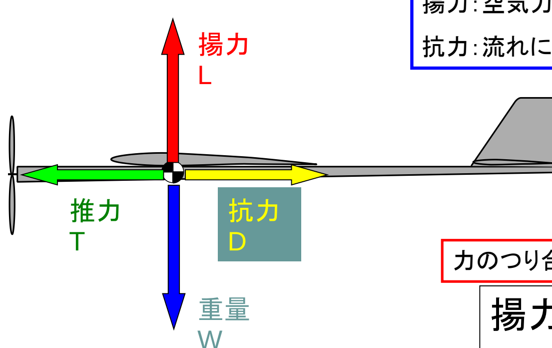
反作用

翼に働く空気力

飛行機に働く力

揚力：空気力のうち、流れに垂直な成分

抗力：流れに平行な成分



力のつり合い

揚力L=重量W

推力T=抗力D

揚力

- 翼に空気が当たると生じる上向きの力

$$揚力L=\underbrace{\frac{1}{2}\rho V^2}_{動圧}SC_L$$

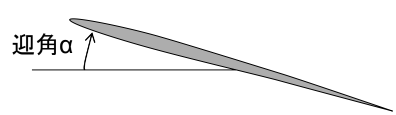
動圧：流れの運動エネルギー

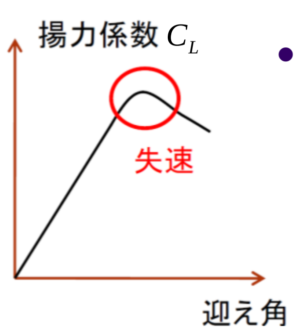
ρ：大気密度
V：流れの速度
S：翼面積
C_L：揚力係数

⇒低速で飛ぶには、翼面積大か揚力係数大

揚力係数 C_L

- 空気の流れと翼がなす角度（迎角）で決まる係数

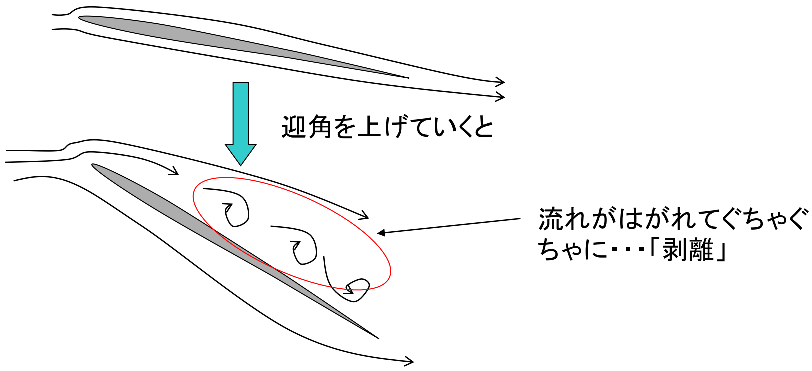




- 迎角に伴い、揚力係数は増加する
  - はじめは一定の割合で増加
  - 迎角が大きすぎると、急激に減少
    失速

失速

- 翼表面の流れが乱れて、揚力が急に減少する
- 抵抗も一気に増える



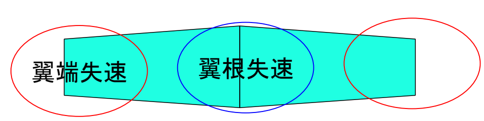
⇒余裕を持って設計する

いろいろな失速

- 翼端失速

:翼端が翼根より先に失速する

⇒重心から遠い部分で失速するので、モーメントが一気に変わる
⇒ 機体が傾きやすい、危険



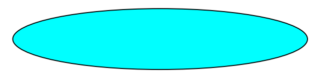
- 翼根失速

:翼根が翼端より先に失速する
⇒あまり傾かない、安全

平面形と失速特性

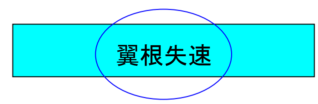
- 楕円翼

どこも同じ失速しやすさ



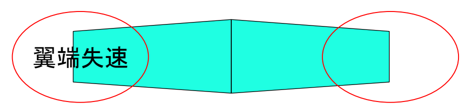
- 矩形翼

翼根から失速しやすい



- テーパー翼

翼端から失速しやすい



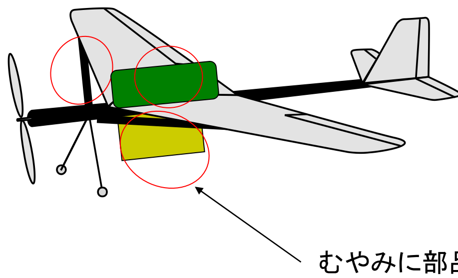
抵抗(主に主翼について)

抵抗=(有害抵抗)+(誘導抵抗)

有害抵抗:翼に空気が当たるだけで発生
・・・翼の翼型、その他構造物による

誘導抵抗:揚力とともに発生する抵抗
・・・翼の平面形による

有害抵抗



誘導抵抗

- 揚力に依存する抵抗

$$\text{誘導抵抗} = \frac{1}{2}\rho V^2 S \frac{{C_L}^2}{e\pi AR}$$

π: 3.14

e : 飛行機効率
・・・翼の平面形による

AR:アスペクト比

$\frac{1}{2}\rho V^2$:動圧

S :翼面積

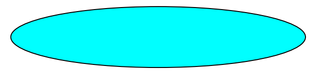
C_L :揚力係数

⇒平面形、アスペクト比によって抵抗が変わる

平面形による誘導抵抗の違い（飛行機効率e）

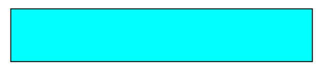
- 楕円翼

e = 1 (理論上飛行機効率最大)



- 矩形翼

e ≒0.93

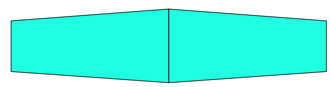


- テーパー翼

テーパー比0.5程度で最大(e ≒0.98)

以降減少し

テーパー比0で(e≒0.85)

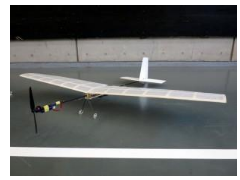


いろいろな翼の性能

矩形翼

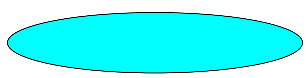
- メリット
  - 作りやすい
  - 翼根失速しやすく安全
- デメリット
  - 飛行機効率よくない
  - 翼端が重いので、頑丈に作る必要あり。

アルバトロス（東京大学）



Libellen-12(日本大学)

楕円翼



- メリット
  - 飛行機効率最大
  - 角がないため、上手く作れば壊れにくい
- デメリット
  - どこで失速するか分からない
  - 作りにくい

ほばQ（明石高専）

FLEMING（東京大学）

アスペクト比の大きい翼

Ibis(日本大学)

あめんぼ（東京大学）

- メリット：誘導抵抗小
- デメリット：

～これまでの参加機体～

2014冬　飛行ロボットPro.

第１０回全日本学生室内飛行ロボットコンテスト

- 9/27(土)～9/28(日)　@大田区総合体育館
- 参加チーム数： 57 チーム（1チームあたり 2～5人）
- 自動操縦部門21チーム
- 一般部門36チーム

自作室内用UAV（無人航空機）の性能、コンセプトを競う

第10回競技概要

- メインミッション
  - 救援物資輸送：お手玉（3～5個）を目標地点に投下
- 追加ミッション
  - 手放し飛行：3秒間
  - ゲート通過：3回まで
  - 無動力滑空：10秒以上
  - 自動操縦：水平旋回、8の字飛行
  - 物資回収
- その他
  - 時間点、離着陸点
- 機体の制約
  - 自動操縦搭載機：重量250g以下
  - 無搭載：200g以下

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これまでの参加機体

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- 高アスペクト比の主翼
- 高度制御装置搭載
- ブログ、動画
  - http://agoomakers.blog23.fc2.com/blog-entry-48.html

あめんぼ（第５回、東京大学）

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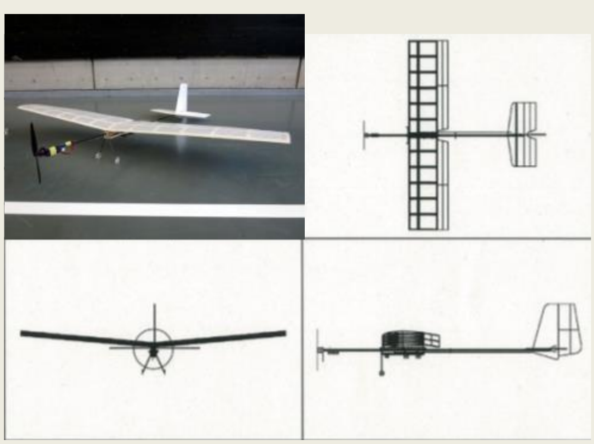
Albatrus（第８回、東京大学）



- 高アスペクト比の主翼
- 自動制御搭載

Length 1140mm
Span 1200mm
Height 313mm
Wing Area 30 dm^2
Aspect Ratio 4.8
Weight 180g

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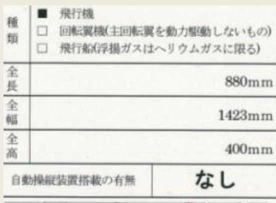
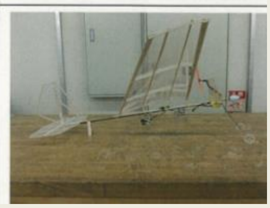
イーグル５（第８回、金沢工業大学夢考房）



種類	■ 飛行機 □ 回転翼機(主回転翼を動力駆動しないもの) □ 飛行船(浮揚ガスはヘリウムガスに限る)
全長	880mm
全幅	1423mm
全高	400mm
自動操縦装置搭載の有無	なし



- 高アスペクト比
- 高い滑空性能
- プッシャータイプの
  プロペラ

Length 880mm
Span 1423mm
Height 400mm
Wing Area 31 dm^2
Aspect Ratio 6.5
Weight 137g

Ibis（第8回、日本大学）

- 高アスペクト比
  - 誘導抵抗小
  - 旋回半径大
- 翼端形状
- CAD使用

- ブログ、動画
- http://www.youtube.com/watch?v=Ime5cNo7xQ8
- https://www.youtube.com/watch?v=09T7ARJroG8&feature=youtu.be

Length 865 mm Span 2100 mm
Height 240 mm Wing Area 38dm^2
Aspect Ratio 11.6
Weight 184.5g

Swing（第4回、金工大夢工房）

- 複葉機
  - 運動性大
  - 頑丈、重量
  - 抵抗大

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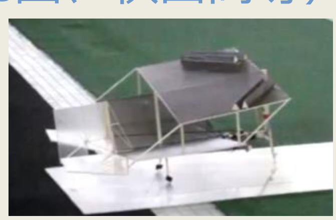
M-Revolution（第8回、秋田高専）

Length 770mm
Span 680mm
Height 360mm
Wing Area 48.8 dm^2
Aspect Ratio 0.95
Weight 199g

Golden eagle Ⅰ（第8回、秋田高専）

Length 860mm
Span 740mm
Height 390mm
Wing Area 59.8 dm^2
Aspect Ratio 0.92
Weight 215g



- ブログ、動画

http://www.youtube.com/watch?v=5TOyFo-gIh4

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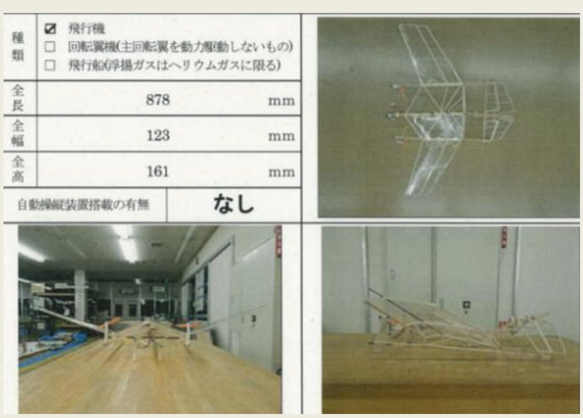
リンリン号（第５回、久留米工業高等専門学校）

- 双胴双発機
- 大推力
- 左右バランス

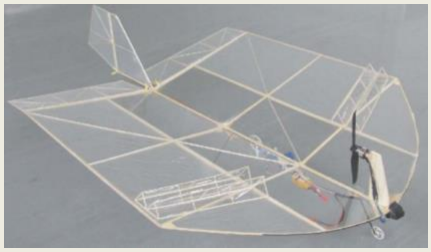
イーグル６（第８回、金沢工業大学）



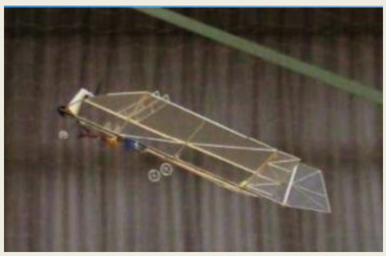
- 双発
- 前進翼

Length 878mm
Span 1230mm
Height 161mm
Wing Area 32 dm^2
Aspect Ratio 4.7
Weight 189g

Mayfly（第3回、秋田高専）



- 無尾翼機
- 低アスペクト比



Length 965mm
Span 640mm
Wing Area 42.3 dm^2
Aspect Ratio 0.97
Weight 93g

飛悠人Ⅲ（第4回大会、東京大学）

ひゅーまん

- 結合翼機
  - 誘導抵抗小
  - 胴体全体を翼として使用
  - 頑丈

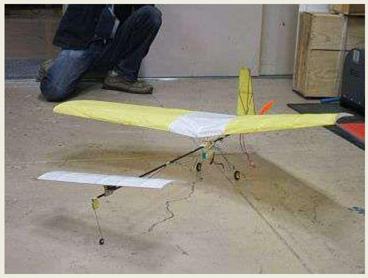
Travolta（第3回、名古屋大）

Span 500mm
Wing Area 17.5 dm^2
Aspect Ratio 1.43
Weight 145g

- http://www.indoorflight.t.u-tokyo.ac.jp/old/
- http://www.youtube.com/watch?feature=player_embedded&v=Tv-438Bf__M

Poop（第5回、名大）

もっぱら（第5回大会、東京大学）



- カナード機
  - 重心を前にしたい
  - 前進翼
- 捩り翼

Length 1050mm
Span 1010mm
Wing Area 32.0 dm^2
Aspect Ratio 3.2
Weight 148g

Booing 717 EnJoy（第4回、中日本航空専門学校）

- カナード機
- 揚力アップ

とるねーだー3119K（第4回、名大）

- マグナス効果
- 主翼を回転させて揚力発生

DELTA-CCV（第7回、神奈川工大 航空研究部）

- ロガロ翼
  - 軽量
  - 低速性
  - 高速性
- http://www.youtube.com/watch?v=-1j29R8pygg

Ladybird（第８回、神奈川工大 航空研究部）

- 翼面積増大
- 滑空性能

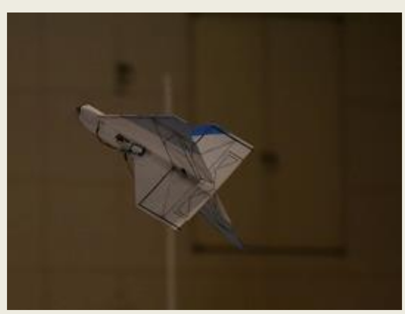
Length 950mm
Span 1320mm
Height 445mm
Wing Area 73.8 dm^2
Aspect Ratio 2.36
Weight 157g

FLEMING（第8回、東京大学）

- 膜翼機
- 大翼面積、軽量
- 滑空性能
- 自動操縦（姿勢制御）装置搭載：水平旋回、８の字飛行可能

Length 1240mm
Span 1110mm
Height 320mm
Wing Area 71.3 dm^2
Aspect Ratio 1.7
Weight 207g
Air Speed 2.5m/s

欣（第8回、東京大学）



- VTOL機
  - ホバリング
- EPP使用
  - 衝撃に強く壊れにくい。

Length 650mm
Span 800mm
Height 380mm
Wing Area 27 dm^2
Aspect Ratio 2.37
Weight 168g

ほばQ（第8回、明石高専）

- VTOL機
  - ホバリング
- カーボンロッド

Length	680mm
Span	600mm
Height	600mm
Wing Area	26.8 dm^2
Aspect Ratio	1.34
Weight	194g

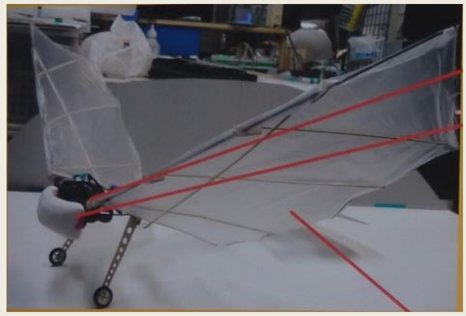
- http://www.youtube.com/watch?v=NwY7XJJy5_M
- http://www.youtube.com/watch?v=ZQ4Hv_SQ-io

カナリア116（第６回、大阪府立大学）

- 可変翼機

エルニエッタ（第９回　東京農工大学航空研究会）

- オーニソプター
（羽ばたき機）



- https://www.youtube.com/watch?feature=player_embedded&v=LZ28ZuHC4s0

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ポアソン（第９回　東京農工大）

- http://www.youtube.com/watch?v=u48mE5Qroks
- https://www.youtube.com/watch?v=wuXQEbXRbq4
- フラップ付き
- 重量：まさかの143g（自動操縦装置含む）
- とんぼっぽい

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Scoparia（第9回　東京農工大）

- 飛行船と飛行機のハイブリッド機体
- http://www.youtube.com/watch?v=b1UOD_Rh3Oo

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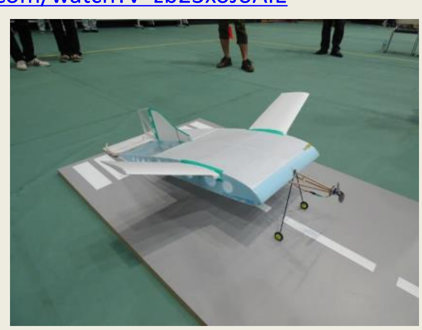
サーフボード（第10回　東京農工大）

- 胴体も翼になっている
- 自動操縦搭載
- https://www.youtube.com/watch?v=zb23xoJoAIE



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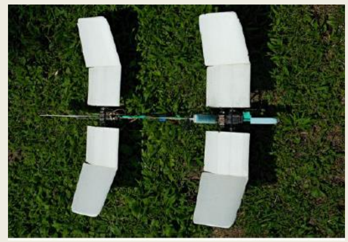
Haworthia(ハオルチア)（第10回　東京農工大）

- タンデム翼機
- http://youtu.be/YybptPkjeNc



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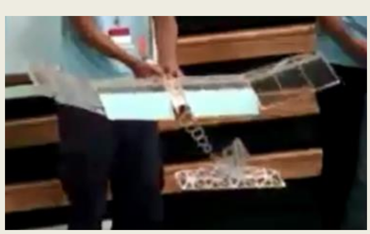
Schmetterling-14(第10回　日大)

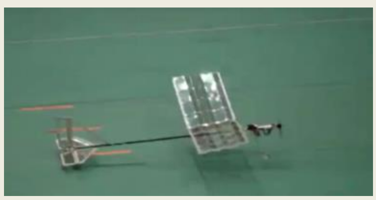
- カーボンロッド、木材による胴体構造（フレーム、ストリンガ）
- 可変キャンバー翼



2014/10/22　　30

DRAGONFLY（第10回　産業技術高専）

- とんぼの羽を模した翼型
- 可変ピッチプロペラで
  バック可能
- https://www.youtube.com/watch?v=kSmYUjDpp-w



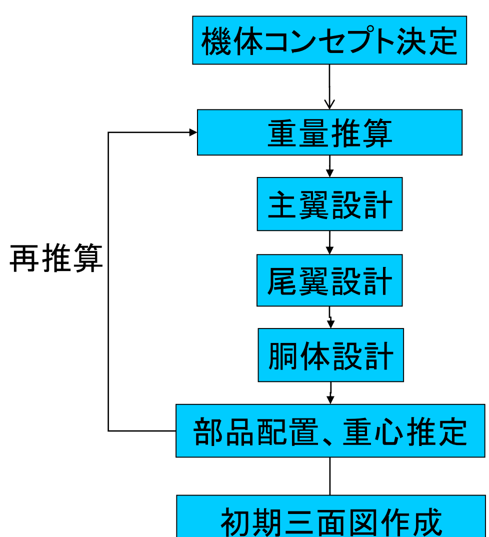
飛行ロボットの設計

～コンセプト決定から初期三面図まで～

2014/05/14

木村壽里

概念設計の概要



1. 機体コンセプト（速度、安定性などの性能や、デザイン等）を決定
2. コンセプトから必要部品を考え、機体重量を推算
3. 機体重量を支えるだけの主翼を設計
4. 機体を安定させる尾翼を設計
5. 備品を搭載できる胴体を設計
6. 部品配置を決定、重心位置を推算し、不具合がある場合は前項に戻って修正する
7. 初期三面図作成

コンセプトの決定

機体コンセプト

- 「どんな飛行機を作りたいか？」を決める。
  - 速い飛行機？小回りの効く飛行機？
  - 多くの荷物（ペイロード）を運べる飛行機？
  - 新しい技術を使って飛ぶ飛行機？（例えばオーニソプターを作ってみるとか・・・）
- 制約条件
  - お手玉を5つ積む必要がある⇒搭載スペースを確保しないといけない
  - 制作場所の制限「大きすぎる機体は作るのが大変」
  - お金と時間

⇒作る目的に合わせて、機体の選定が必要！

設計要求の設定

- その名のとおり「設計に要求される事項」
- 例えば

巡航速度：3m/s以下 ペイロード：お手玉4個以上 滑走距離：10m以内　　　　など

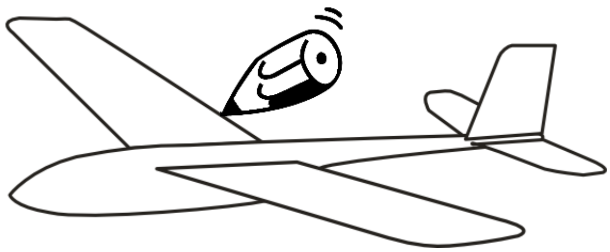
- 飛行ロボコンの場合はミッションを達成することが必要条件の一つになる
- その他に、作りやすさや運びやすさも吟味する必要あり

機体の制約～一般的な機体が載せている物～

- 機体を飛ばすために最低限のせないといけないもの
  - 翼
    - 主翼
    - 尾翼
    - 舵面：エレベータ、ラダー等
  - 胴体
    - 脚：たまにないのもあるが・・・
  - ラジコンメカ
    - モータ＋プロペラ：プロペラ回すため
    - スピードコントローラー ：モータの制御装置
    - サーボモータ：舵を動かすモータ
    - バッテリ：ないと動かない
    - 受信機：ないと動かない
  - アビオニクス
    - 自動操縦部門はあり
  - 他にもあるかも・・・考えてみよう！

ラフスケッチ～まずは書いてみよう！～

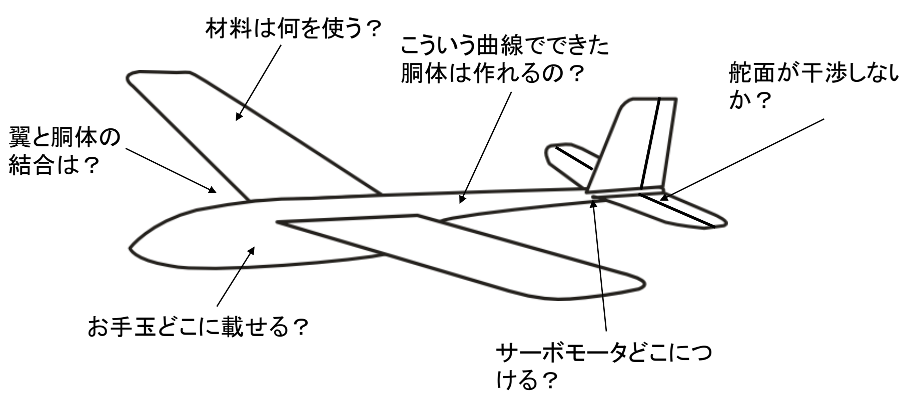
- コンセプトを決めるためにも、だいたいの案を思いついたら実際に絵に書いてみよう！



ラフスケッチ～書いてみると見えてくること～

- 疑問が色々でてくるはずなので･･･

マッチングポイントを探す



重量推算

概念設計における注意

- コンセプトが決まったら
- これから設計を進めるにあたり、さまざまな数値データが必要になる。（揚力係数C_L、重量Wなど）
- しかし詳細のまだ決まっていない概念設計（コンセプト決定～初期三面図）の段階では、正確なデータは得ることができない。

↓

1. 統計データや文献データを参考に仮定してアウトプットを作る。
2. 簡易的に計算してみて、おおまかな値をつける。

- 簡易的にでも、おおまかな形が決まってくると詳細な計算ができるようになる。

重量推算

- 機体重量を推算するため、必要部品を洗い出す。
- 主要部品の大まかな重量の目安
  - 主翼：30～40g
  - 水平尾翼：6～10g
  - 垂直尾翼：4～6g
  - 胴体：20g～30g
  - モータ＋プロペラ＋スピードコントローラー :20～25g
  - サーボモータ（1個あたり）：5～10g
  - バッテリ（2Cell, 350~450mAh）：25～32g
  - 受信機：4～12g
  - 脚：7～12g
  - その他（配線等：10g程度、アビオ：20～30g）

  ⇒全備機体重量Wを計算

主翼設計

主翼設計概要

① 機体重量Wから必要揚力Lを推算

② 翼面積Sを推算

- 機体速度Vを仮定
- 揚力係数C_Lを仮定

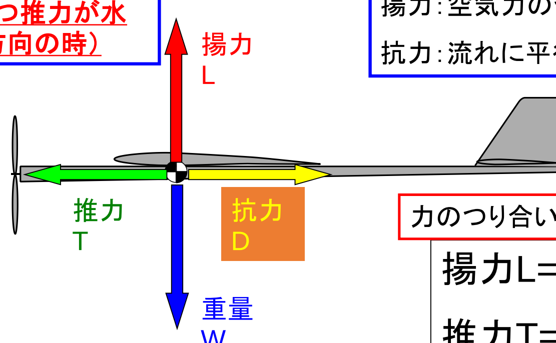
③ 主翼の形状と諸元を決定

機体に働く力

水平定常飛行時（かつ推力が水平方向の時）

揚力：空気力のうち、流れに垂直な成分

抗力：流れに平行な成分



力のつり合い

揚力L=重量W・・・(1)

推力T=抗力D・・・(2)

⇒できる限り重量小かつ抗力小にしたい

① 機体重量Wから必要揚力Lを推算

揚力

- 翼に空気が当たると生じる上向きの力

$$揚力L = \frac{1}{2}\rho V^2 S C_L \cdots (3)$$

動圧：流れの運動エネルギー（$\frac{1}{2}\rho V^2$）

ρ：大気密度
V：流れの速度
S：翼面積
C_L：揚力係数

⇒低速で飛ぶには、翼面積**大**か揚力係数**大**

翼型に依存（揚力係数）

② 翼面積Sを推算

翼面積の決定

(1)と(3)より

$$W = \frac{1}{2}\rho V^2 S C_L$$

$$\therefore S = \frac{2W}{\rho V^2 C_L} \cdots (4)$$ ←機速V、揚力係数C_Lを決めれば求まる

- 機速V

  →設計要求から仮定、通常2m/s〜4m/s

- 揚力係数C_L

  →仮定するだいたい0.5〜0.7くらい

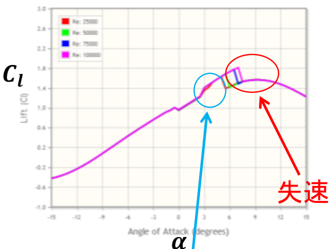
  →仮定するのが気持ち悪い人は $C_l - \alpha$曲線 から計算

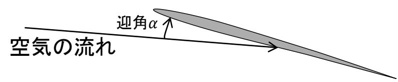
② 翼面積Sを推算

揚力係数C_Lの決定（$C_l - \alpha$曲線 から）

- $C_l - \alpha$曲線・・・二次元翼型のグラフ、風洞試験等から得られる
（参考文献参照）

<ex>EPPLER 58





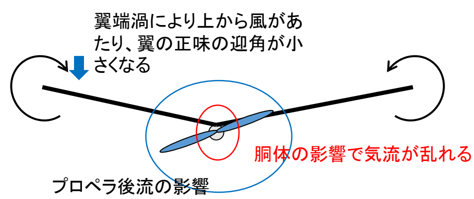
失速しないようにこの辺を水平飛行時の設計値としたい

1. 設計要求よりレイノルズ数を仮定。
→$Re = 60000$を仮定
2. レイノルズ数の近いグラフを選択
→ ■$Re = 75000$と■$Re = 50000$の間を選択
3. 失速する点より前の点を選択
→ $\alpha = 3\text{deg}$で$C_l = 1.4$を選ぶ
4. 三次元揚力係数の補正分を加味
だいたい$C_L \cong C_l \times 0.6 \sim 0.8$

② 翼面積Sを推算

二次元翼（C_l）と三次元翼（C_L）

- 翼型データは二次元翼（スパン長無限の翼）だが、実際に設計するのは三次元翼である。
- →翼端渦により、三次元翼の揚力係数は二次元翼より小さくなる。
- さらに、胴体の影響や、構造材、プロペラ後流、なども揚力係数に影響を与える。

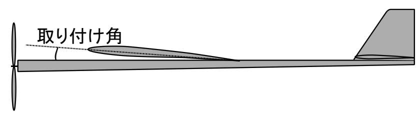


② 翼面積Sを推算

主翼取り付け角i_w

- 翼は機体に水平につけても思った揚力が出ないことが多い。
- 胴体に対する主翼を取り付ける角度＝取り付け角i_wが必要。

→翼型が決まれば、取り付け角により巡航時のC_Lが決まる



- →C_Lを仮定した人・・・取り付け角も仮定　だいたい2~4deg
- →$C_l - \alpha$曲線を使用した人・・・設計点の迎角$\alpha = i_w$

③ 主翼の形状と諸元を決定

主翼形状の決定

- (4)よりSが決定したので、主翼形状と諸元を決める

1. アスペクト比ARを決める

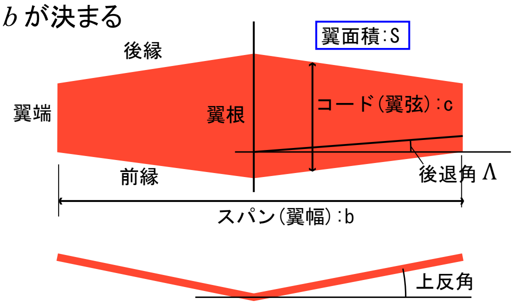
　　→$AR = \frac{b^2}{S}$よりスパン長 b が決まる

〈ex〉テーパー翼の場合

2. テーパー比λを決める

　　→コード長 c が決まる

3. 後退角Λを決める
4. 上半角Γを決める



主翼設計値の“めやす”

- テーパー比 λ･･･0.5～0.85
- アスペクト比 AR ･･･3～6
- 上反角 Γ･･･10deg程度
- 主翼取り付け角 i_w ･･･2～4deg

注）あくまで目安、実際には製作してからの変更も必要。

- 翼型データ

・Airfoil Investigation Database

http://www.airfoildb.com/: $C_L - \alpha$曲線、極曲線

・栗沢　獏　の　活動紹介　公表座標データ (Official Ordinates) Index

http://www.ds-cats.com/~kurisawa/aeronautics/Airfoils/ : 形状のみ

尾翼設計

尾翼設計概要

水平尾翼

① 水平尾翼容積比V_h^*の推定

- 平均空力翼弦$\bar{c}$の計算

② 水平尾翼面積S_hの計算

③ 水平尾翼形状の決定

垂直尾翼

① 垂直尾翼容積比V_v^*の推定

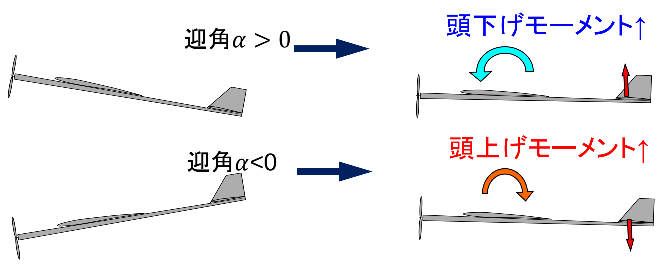
② 水平尾翼面積S_vの計算

③ 水平尾翼形状の決定

復習

水平尾翼の役割

- 迎角の変化に対し逆向きのモーメントを発生させる



- つまり、迎角αが正になれば、頭上げモーメントが小さくなるように、迎角が負なら、頭上げモーメントが大きくなるようにすれば良い。

数式で表すと、モーメントの迎角微分が負：

$$\frac{\mathrm{d}M}{\mathrm{d}\alpha} < 0 \Rightarrow \text{航空機では無次元化して、} \frac{\mathrm{d}C_m}{\mathrm{d}\alpha} \equiv C_{m_\alpha} < 0$$

この状態が安定！

水平尾翼容積比 V_h^*

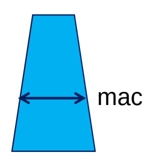
- 水平尾翼の効きを表すパラメータ
  - 水平尾翼が大きいほど効きが良い
  - 重心位置から遠いほど効きが良い
  - 機体が小さいほど効きが良い→代表長としてmacを使う

$$V_h^* = \frac{l_h S_h}{\bar{c} S} \cdots (5)$$

l_h : 機体重心ー水平尾翼の空力中心の距離
S_h: 水平尾翼の翼面積
$\bar{c}$: 主翼mac(平均空力翼弦)
S : 主翼翼面積

- →統計データから適当な値を選ぶ、機種によりかなり幅があるので注意

平均空力翼弦(MAC)
(Mean Aerodynamic Chord)



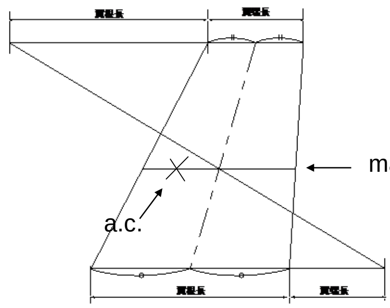
- 翼全体の特徴を代表するコード長
  - =翼全体の空力中心
  - 重心位置は、これとの相対位置を考える
  - 実際には風洞試験等にて求めるが、
    - ・ 翼型、風圧中心、モーメント係数等が全翼にわたって一定である
    と考えると次の式で求められる。

$$\bar{c} = \frac{1}{S} \int c^2 \mathrm{d}y \cdots (6)$$

  - ・ 単テーパ翼の場合は、幾何学的に求めることも可能
  →主翼設計より$S, \bar{c}$は既知なので、l_hを決めれば(5)式より尾翼面積が決まる
- → S_hを決めれば水平尾翼の形状を決めることができる

復習

空力中心を作図で求める方法



※mac上の位置について
機体の各位置を　25%mac　などとmac上の前縁から何パーセントの位置にあるかで表記することがある。（重心位置など）

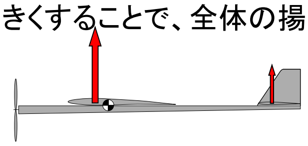
S_h を大きくするかl_hを大きくするか

- S_hが大の時、水平尾翼の抵抗も面積に比例して大きくなる。

また、尾翼が重くなるので、重心位置のバランスにも注意が必要となる。

- 水平尾翼にも揚力をもたせる揚力尾翼の場合、

S_hを大きくすることで、全体の揚力を大きくすることができる。



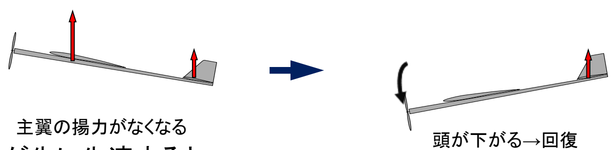
水平尾翼のアスペクト比

- 通常の機体の場合

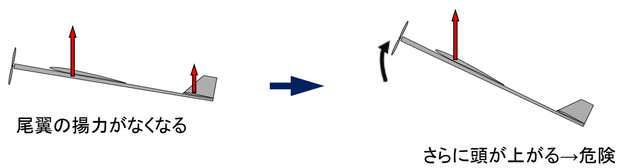
（水平尾翼のアスペクト比）＜（主翼のアスペクト比）

[理由]

  - 主翼を先に失速させるため



  - 尾翼が先に失速すると･･･



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垂直尾翼の設計

- 垂直尾翼の効き
  - 垂直尾翼が大きいほど効きが良い
  - 重心位置から遠いほど効きが良い
  - 機体が小さいほど効きが良い→代表長としてスパン長を使う
- 垂直尾翼容積比：垂直尾翼の効きを表すパラメータ

$$V_v^* = \frac{l_v S_v}{bS} \cdots (7)$$

l_v：機体重心ー垂直尾翼の空力中心の距離

S_v: 水平尾翼の翼面積

b：主翼スパン長

S：主翼面積

- 水平尾翼同様に既存機体データから仮定して、S_vを決定する

　→水平尾翼形状を決定

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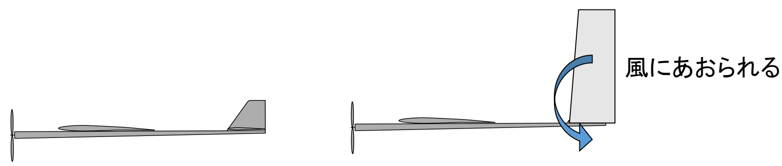
垂直尾翼のアスペクト比

- アスペクト比は小さめに設計（1～2程度）
  - 失速しにくくするため
  - 大きいと、横風にあおられやすい



〈cf〉第8回飛行ロボコン参加機体データ

大学	機体名	全長(mm)	全幅(mm)	全高(mm)	機体重量(g)	Vh*	Vv*
東京大学	FLEMING	1240	1110	320	206.8	0.23	0.07
秋田高専	M-Revolution	770	680	360	198.6	0.14	0.018
名古屋大学	NAVIX-α	920	900	280	230	0.15	0.067
秋田高専	Golden eagle-Ⅰ	860	740	390	215.3	0.15	0.047
秋田高専	MayflyⅩ	810	790	300	215	0.07	0.023
東京大学	Albatrus	1140	1200	313	180	0.58	0.066
神奈川工科大学	Ladybird	950	1320	445	155	0.02	0.016
明石工業高等専門学校	ほぼQ	680	600	600	194	0.12	0.105
金沢工業大学	イーグル5	880	1423	400	136.4	0.39	0.031
東京大学	欣	650	800	400	167.9	0.10	0.136
金沢工業大学	イーグル6	878	1230	161	188.8	0.25	0.051
横浜国立大学	YAL-Ⅲ	950	850	300	198.9	0.14	0.032
新居浜工業高等専門学校	BBK	650	780	180	176	0.53	0.081
中日本航空専門学校	Booing 747 Nike2	790	1200	290	193	0.24	0.028
早稲田大学 基幹理工学部 機械科学航空学科	WASA Aegeo	620	1085	165	192	0.53	0.034
北九州工業高等専門学校	Flight	550	675	222	187	0.20	0.027
鳥取大学	エグゾセ	810	985	220	195	0.33	0.06
久留米工業高等専門学校	Flying Squirrel	1190	873	335	198.5	0.48	0.029
東京都立産業技術高専	飛鵠Ⅱ	1036	1220	242	194	0.37	0.063
東海大学	SSP	790	1090	97	194	0.42	0.024
東京農工大学	GON	1220	1125	355	191.1	0.32	0.022
九州工業大学	CanarBo	762	710	270	180	0.31	0.025
中日本航空専門学校	ダイダロス3	823	1116	302	194.7	0.29	0.039
鳥取大学	T-sparrow	840	830	135	195	0.30	0.035
日本大学	Ibis	865	2100	240	169.5	0.26	0.008

⇒詳しいデータを知りたい人はhttp://flyingrobot.t.u-tokyo.ac.jp/より

舵面について

- めやす
  - エルロン：主翼面積の10〜20%
  - ラダー：垂直尾翼面積の20〜30%
  - エレベータ：水平尾翼面積の20〜30%
- 注意
  - 大きすぎると、ゆがみやすい（特にエルロン）
    →丈夫に作る必要
  - 小さすぎると効きが悪くなる

胴体設計

胴体

- ペイロード、飛行に必要な機材を搭載する場所
- 主翼や尾翼にはたらく力を伝える「構造部材」

- 長さの制約
  - 尾翼のモーメント･アームを満たす長さ
  - 機器、ペイロードを搭載できるだけの長さ

- 幅の制約
  - 機器、ペイロードを搭載できるだけの幅

- 形状
  - 空気抵抗をできるだけ減らす
  - 作りやすさ

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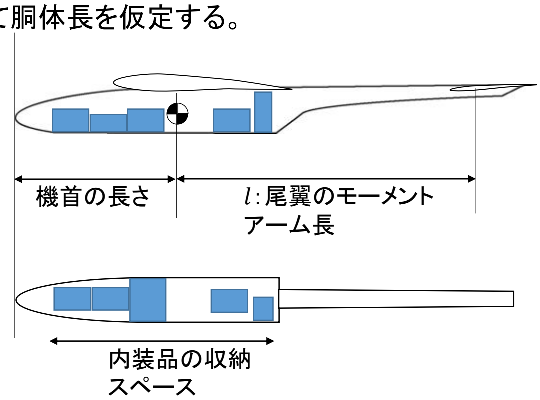
長さの制約

- 尾翼のモーメントアームl_h, l_v、機首、内装備の収納スペース、

を考慮して胴体長を仮定する。



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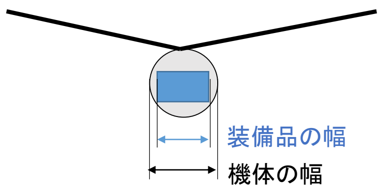
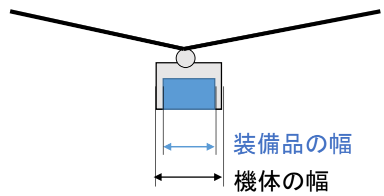
幅の制約

- 装備品を搭載出来るだけの幅が必要

機内に搭載する場合



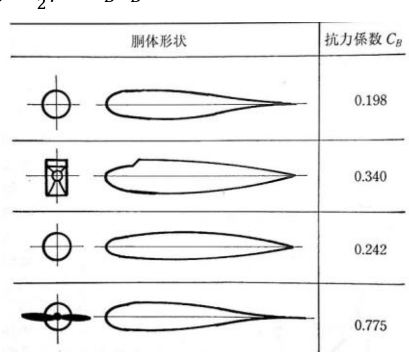
懸架する場合



- 搭載するもの
  - バッテリー、受信機、スピコン、投下装置、お手玉、etc…

胴体形状

- 抗力をできるだけ少なくしたい
  - 胴体の生む抗力
  - $D_B = \frac{1}{2}\rho V^2 F_B C_B$

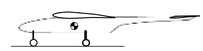


模型飛行機の科学－フリーフライト機の理論と設計－
和栗雄太郎 養賢堂

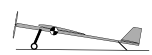
模型飛行機では、棒材、カーボンパイプ等を活用することも多い

脚

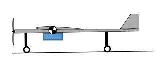
- 重心位置との兼ね合い
  - 重心より片側に集中すると転倒する
  - 前輪式
    - 機体重心付近に主脚（後脚）、前部に前脚をつけたもの
    - 現代の航空機の主流



  - 尾輪式
    - 機体重心付近に主脚（前脚）、尾部に後脚（尾輪）をつけたもの
    - 構造が簡単
    - グラウンドループの発生に注意



  - 自転車式
    - 機体の前部、後部に脚をつけたもの
    - 機体中央に脚をつけるスペースのない機体が使用



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部品配置、重心推定

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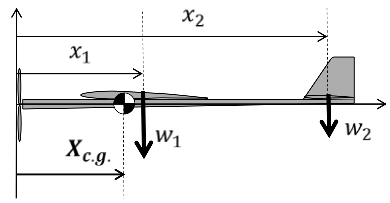
重心位置推定

- 尾翼モーメントアーム長が求まっているので、代替の機体長さは見えているはず。これを元に部品配置を検討し、重心位置を推定する。
- 部品iの(重心の)位置をxiとすると、機体全体の重心位置は

$$X_{c.g.} = \frac{\sum_i w_i x_i}{W}$$

W:全備重量



- 上式から各部品のだいたいの配置を決める
- 主翼空力中心位置とのバランスが重要
- 重心位置の“めやす”:25～33%mac

“前過ぎても後ろ過ぎてもダメ”

注意点

- 計算結果はあくまで“めやす”でしかない。明らかに機体形状がおかしい場合は、“見た目が良くなるように”修正すること。(特に尾翼、舵面の大きさなど)
- 考えた部品配置で実際に製作できるかどうか検討すること。(モータやサーボをどこどうにつけるのか、リンケージをどう通すかなど)
- 製作に入った後に再設計することも必要。

機体初期三面図

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初期三面図

- 機体の外形を外側三方向から書いたもの。

〈注意点〉

- 計算により、機体諸元を決定すること
- 記入する事項
  - 全長、全幅、全高、重心位置、おおまかな部品配置
  - 製作に必要な寸法（尾翼の大きさ、胴体長、プロペラ径など）
  - 機体諸元･･･図面の端に表を作成すること
  - 構造部材の記入は求めない（書いてもOK）

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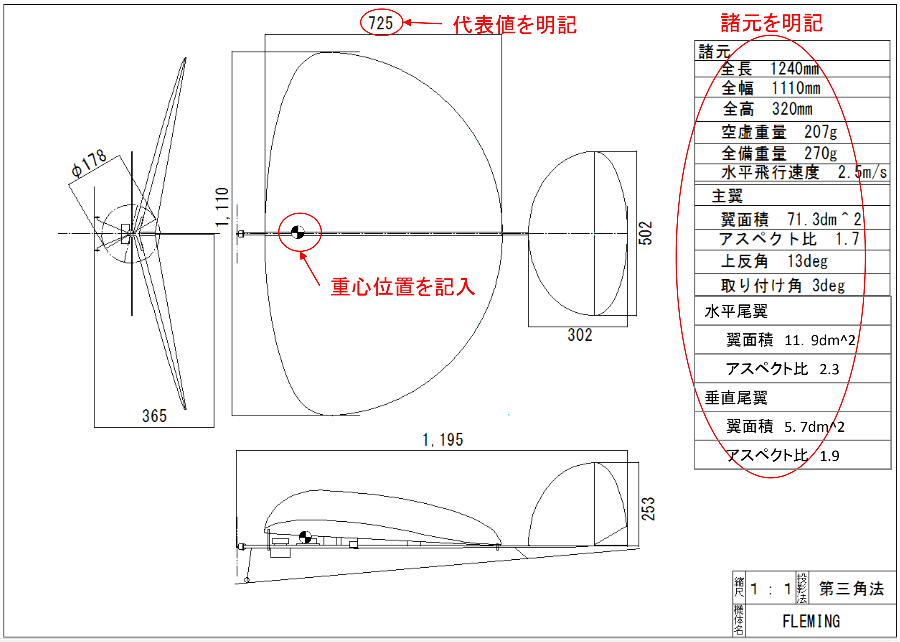

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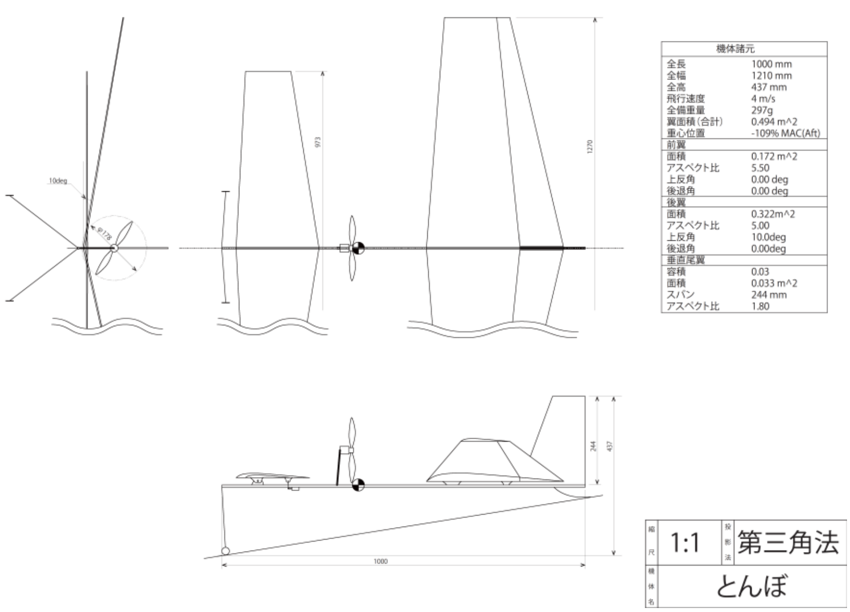

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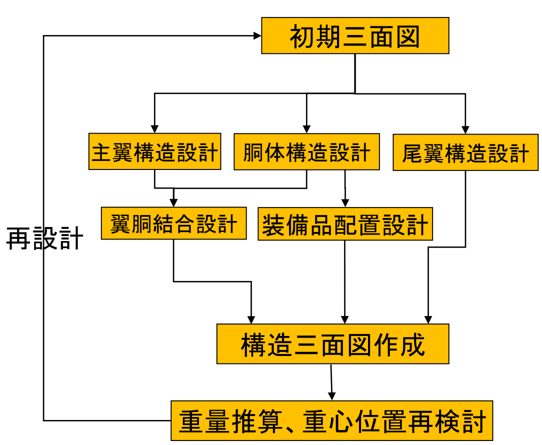
- 模型飛行機[理論と実践] 木村秀政、森 照茂 電波実験社
- 模型飛行機の科学ーフリーフライト機の理論と設計ー
  和栗雄太郎 養賢堂

- 模型飛行機の空力特性とレイノルズ数依存性
  米本浩一（九工大） 第13回スカイスポーツシンポジウム
- Airfoil Investigation Database
  http://www.airfoildb.com/
- 栗沢 獏 の 活動紹介 公表座標データ (Official Ordinates) Index
  http://www.ds-cats.com/~kurisawa/aeronautics/Airfoils/
- 翼設計と製作方法 (翼の外皮の張り方)
  飛行ロボットコンテストHP 製作のノウハウ
- 航空宇宙工学便覧 日本航空宇宙学会
- 飛行ロボットコンテストHP http://flyingrobot.t.u-tokyo.ac.jp/

構造部材三面図作成資料
～構造設計～製作の前まで～

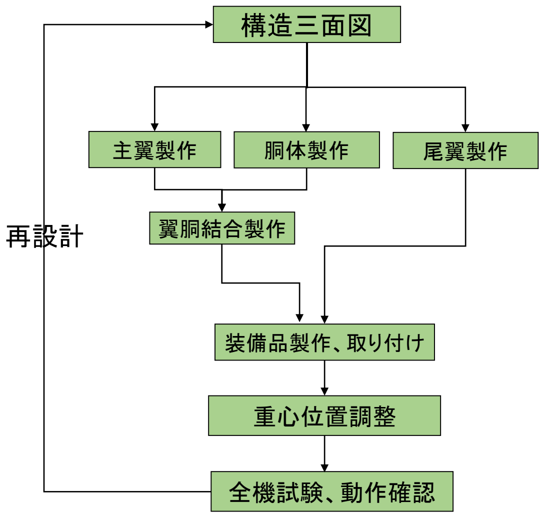
飛行ロボットPro.
2014/05/21
木村壽里

詳細設計（構造設計）の概要



1. 主翼構造設計
   桁、リブ等の構造配置、寸法の計算
2. 胴体構造設計
   外枠の構造、寸法の検討
   装備品の配置、取り付け方法の検討
3. 翼胴結合設計
4. 尾翼構造設計
5. 構造三面図作成

製作



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4. 尾翼構造設計
5. 構造三面図作成

使用材料

- バルサ
- シナベニヤ
- 航空ベニヤ
- ヒノキ
- タケ
- カーボン
- ピアノ線

→ 構造部材、軸材、骨組み

- EPP
- スチレンペーパー
- デプロン
- 和紙
- フィルム（ポリ袋等）
- ケブラー糸
- etc...

→ 外板、翼膜、補強部材

他にもいろいろあるはず！

木材の強度

- 木材の材料許容値

材質	密度 ρ[kg/m^3]	許容応力 σ_b[MPa]	比強度 σ_b/ρ[m^2/s^2]
バルサ(軟質)	86 140	6.7~6.9 7.5~26	$7.8\text{~}9.4 \times 10^4$ $5.3\text{~}18.4 \times 10^4$
バルサ(硬質)	282 354	35~46 43~61	$12.7\text{~}16.2 \times 10^4$ $12.3\text{~}17.3 \times 10^4$
航空ベニヤ	607	62~83	$10.2\text{~}13.7 \times 10^4$
ヒノキ	445 490	78~82 92~115	$17.7\text{~}18.5 \times 10^4$ $18.8\text{~}23.3 \times 10^4$
タケ(角材)	815	170~176	$20.9\text{~}21.6 \times 10^4$
タケ(丸材)	634	166~176	$26.2\text{~}27.6 \times 10^4$

- 材質によって強度が様々であるので、同じ材質でも使用場所に応じて選定が必要になる。
- 特に主翼部材など、左右対称のものは予め同程度の強度の部材を選定しておくこと。

構造部材

〈参考〉http://flyingrobot.t.u-tokyo.ac.jp/wp-content/uploads/2012/05/Airplane-Design.pdf

主翼構造

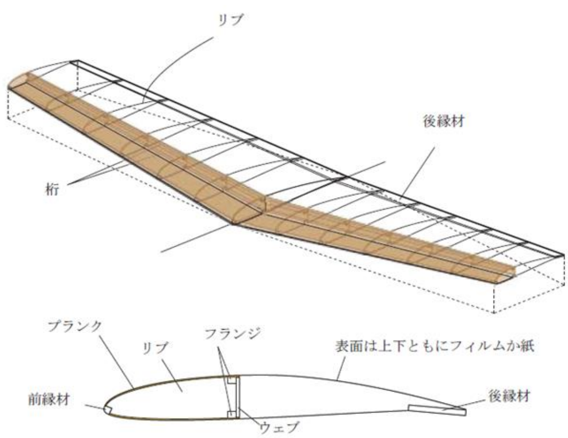
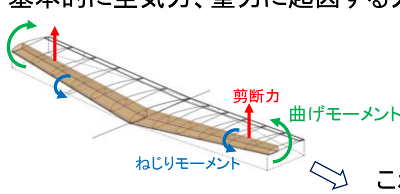


図6　Dボックス構造の例

主翼構造

- 基本的に空気力、重力に起因する力が働く



⇨ これらを胴体に伝える構造材が必要

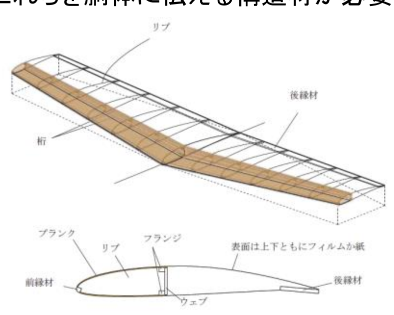
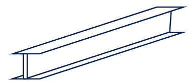


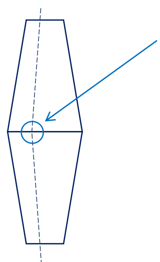
図6　Dボックス構造の例

桁



- 曲げモーメントを受け持つ
- 全揚力のかかる風圧中心位置に作るのが定石→迎角によって変わるため、高運動能力機では注意が必要。
- 通常は前縁から30~40%位置

〈ex〉前縁から30%位置に桁を置いた時



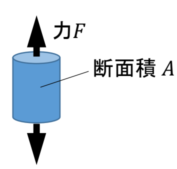
桁を斜めに配置すると、
結合するのが難しくなる（方法が無い訳ではない）

1. 主翼の後退角をずらす
2. 主桁の位置をずらす

応力

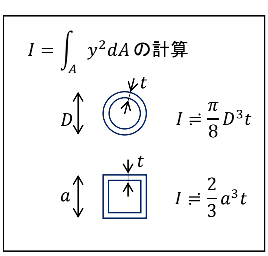
- 物体内部にかかる、単位面積あたりの力

応力 ： $\sigma = \frac{F}{A}$

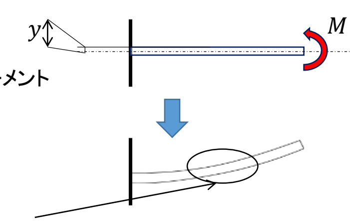


- 曲げに対する応力

応力 ： $\sigma = \frac{M}{I} y$



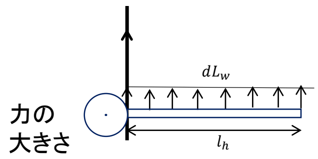
σ :曲げ応力
M :曲げモーメント
I :部材の断面二次モーメント
y :基準軸からの距離



上面は押し縮められる→圧縮応力を受ける
下面は引っ張られる→引っ張り応力を受ける

曲げモーメントの大きさ

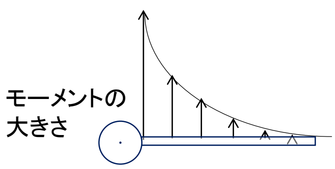
- 曲げについて



主翼にかかる力は大きく分けて空気力、分布力の二種

→いずれも分布力

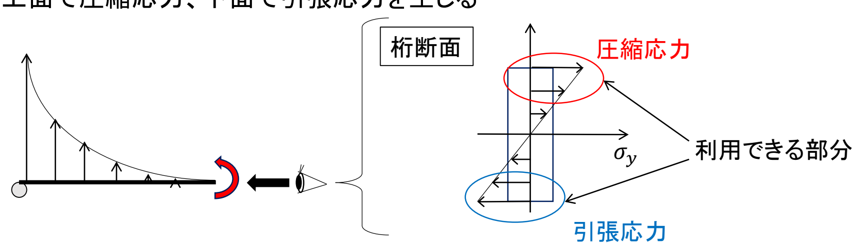
これの作るモーメントが応力を与えるので、図のように、翼根に近づくほど、モーメントが大きくなり、同時に応力が大きくなる。



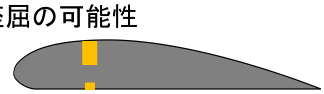
→翼根側ほど、頑丈に作る必要がある
※曲げモーメントを受ける場合、部材の強度は高さの3乗できいてくる。つまり、二倍の太さの桁を作ると、8倍のモーメントを受けることができる
→部材を太くしすぎないように注意

桁の受け持つ曲げモーメント

- 揚力、重力(慣性力)による
- 上面で圧縮応力、下面で引張応力を生じる



- ※一般に棒材は圧縮に弱く、引張に強い:座屈の可能性
  →圧縮を受ける上面を太く、下面を細くする

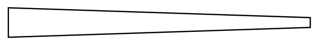


(棒材や糸の性質を考えると引張のみで持たせると軽くできる)

- 下面は引張しか持たないので、翼膜だけにする手法もあり
- 200g級の機体では、板材一本だけでも十分もつ

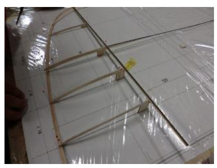
桁構造(応用)

- テーパーさせた桁

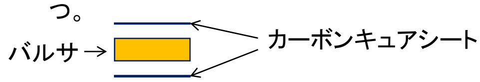


- サンドイッ

桁に働く応力はスパン方向長さに依存するため、テーパーさせることで余分な強度を減らし、軽量化可能。その分製作難易度は上がる。



厚さ2mmのバルサ板の上下に厚さ0.1mmの程度のカーボンキュアシートを貼りつけたもの。元の部材と同程度の重さで数倍の強度を持つ。



リブ、前縁材、後縁材

- 翼型を保つための部材
- 基本的に荷重は受けないのが普通だが、模型飛行機では全体を軽量にするために荷重をもたせる場合もある(前縁、後縁)。

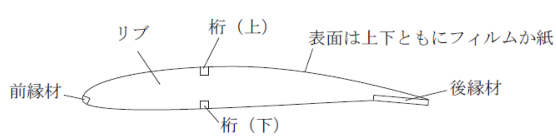
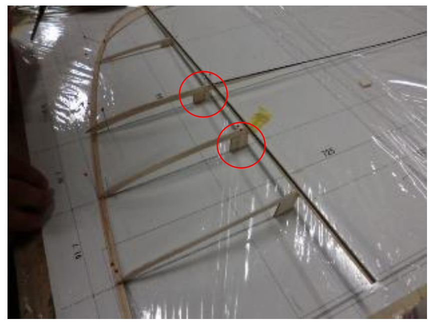


図5　桁を持つ構造の例

←FLEMINGの後縁材は翼形状を保つと同時に曲げモーメントも受け持つ

主翼組立

- 底面が平でないリブは、リブに予め足をつけておくと製作の時に配置しやすい



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センターリブ

- 最も力のかかる翼根部は頑丈にしておく

←断面がI字のFLEMINGのセンターリブ

縦に入っているのはカーボンキュアシート。軽減孔（リブの穴）は丸型のほうが強度が高い（材料力学参照）→

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ねじりモーメント

- 翼の風圧中心は迎角によって変動するので、機体の飛行状態によって主翼には強力なねじりモーメントがかかる。

→構造が弱いとダイバージェンスやフラッターの原因になる。

- **対策**:曲げに比べて、少ない部材で受け持つのが難しい。桁を太くすればなんとかなるがそれ以外で。

・Dボックス構造

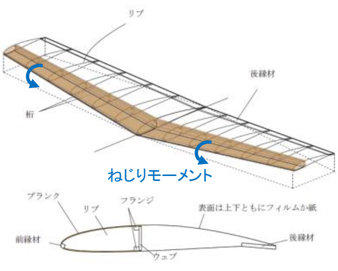


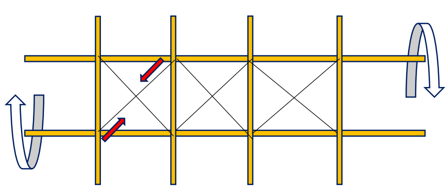
図6　Dボックス構造の例

実機同様に、薄板で囲んだ閉断面を作り、ねじりをもたせる構造。強固だが重い。

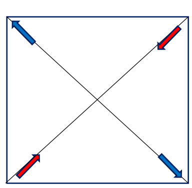
※実際の航空機では前桁後桁の2本の間にボックス構造を作って、ねじりを受け持たせていることが多い。

ねじりモーメント

・リブ間に糸を十字に張る



翼にねじりが働くとき、桁と桁の間に図のように圧縮力が働く。これと点対称の位置に糸を張っておけば、圧縮力を引張力で受け持つことが可能。

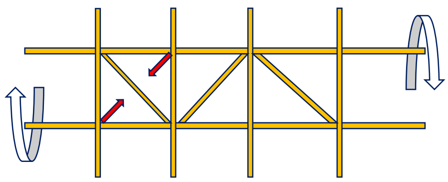


←圧縮でできた剪断を引っ張りでもつ方法

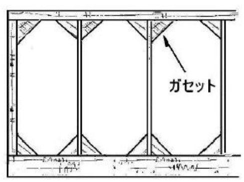
翼端から翼根に2本糸を張った主翼→

ねじりモーメント

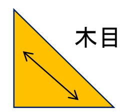
・角材を交互に入れても可



・ガゼットを入れる方法



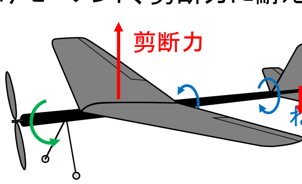
←ガセットがリブと桁の変形を防ぎ、結果強度が増す。
また、そもそもの接着面積が増える。
※ガセットは45°方向に繊維が向くようにすること(最大応力方向)

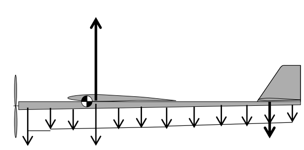


木目方向

胴体構造

- 主翼と尾翼、その他各部品を搭載する部位。
- 主翼、尾翼の空気力、重力、モータトルク等によるねじりモーメント、曲げモーメント、剪断力に耐える必要。



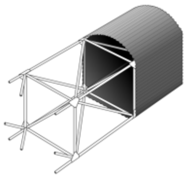


- →胴体外側ほど大きな応力がかかるため、普通は中空構造。
- 尾翼のモーメントアームが稼げればそれ以上の長さは不要。

胴体構造

- トラス構造

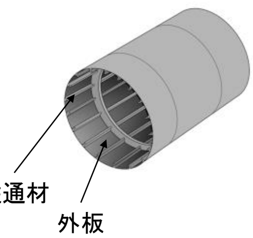
棒材で組んだ構造、部材の引張りで各応力を持たせる



←ねじりによる剪断力を持たせるには斜め方向に部材を入れる。
（最大引張応力方向は45度）

- セミモノコック

外板＋フレームの構造、圧縮引張を縦通材が受け持ち、剪断を外板が受け持つ



胴体構造

- セミモノコック（続き）

← DELTA-CCV（第7回、神奈川工大 航空研究部）
これもおそらくセミモノコック

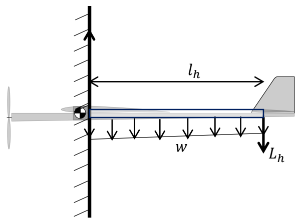
- パイプ、棒材 ・・・ 東大はこれはが多い

カーボンパイプやひのきの棒材をそのまま利用

←90度方向に繊維を入れたクロスタイプ（上）、斜めに巻いた巻きタイプ（中）、縦一方向のみの縦繊維タイプ（下）
200gクラスの機体だと直径5mm~8mm程度
当然斜めに繊維が入っている方がねじりに強い

胴体にかかるモーメント

- 曲げモーメント



- 主翼同様、重力と空気力がかかる。
  →端ほどかかるモーメントは少なく、
  重心付近ほど大きなモーメントがかかる
- 曲げモーメントを受けても尾部が揺れない程度の強度が必要（揺れると、飛行に影響しやすい）

- 振りモーメント
  - 最も強力なのはプロペラ反トルク
  これをモータ～主翼の間で吸収するのがベスト
  →機首は太く、尾部は細くするのが普通

  - 定量的評価： 曲げと同様に太さの4乗できいてくるのは変わらない。

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剪断力：翼胴結合部

- 主翼から胴体へ荷重を伝える部位
主翼の揚力、重力を応力として胴体に伝える
- 揚力の方向は機体上向きなので、下から押し上げる形が良い。

←FLEMING翼胴結合部
胴体に下からはめ込んだV字の翼胴結合部。
ベニヤとバルサのサンドイッチ構造を用いている。両端を輪ゴムで固定。

- 胴体にかかるねじりモーメントに耐える必要性がある。
- 主翼と胴体を分割できるようにしておくと運搬に便利

←あめんぼの翼胴結合部。
ベニヤで竹ひごをはさみ、これに
輪ゴムを引っ掛けて胴体に縛り
付ける。

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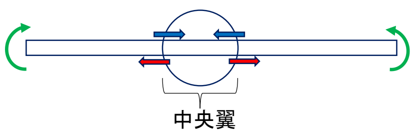
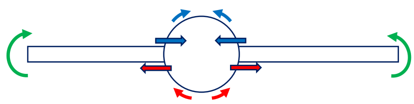
翼胴結合部

- 揚力による曲げモーメント、剪断力を受け持つ
  - 左右の桁をつなぐ方法



揚力による曲げモーメントが強力
→“中央翼”により両翼の桁をつなぎ曲げモーメントをキャンセルさせ、圧縮力と引張力を桁内で持たせる。
特にアスペクト比の大きい翼はこうしないと危険

  - 分割する方法

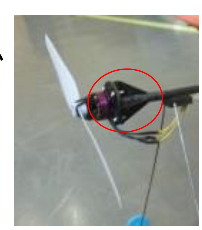


胴体に桁を接合し、胴体フレームに応力を伝える。
胴体に穴を開ける必要がないため、胴体から見ると有利。また、機体をコンパクトに分割できる利点がある。
小型ながら胴体スペースを確保したい小型飛行機などに多い。

モータマウント

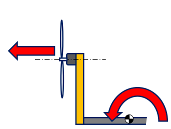
- 重心位置と推力方向によってマウントは大きく異なるが、強固に作るのが基本

胴体との接着は必ずエポキシ系→



- モータの型番によって取り付け方は異なるが、外側から簡単に外せるようにしておくと便利

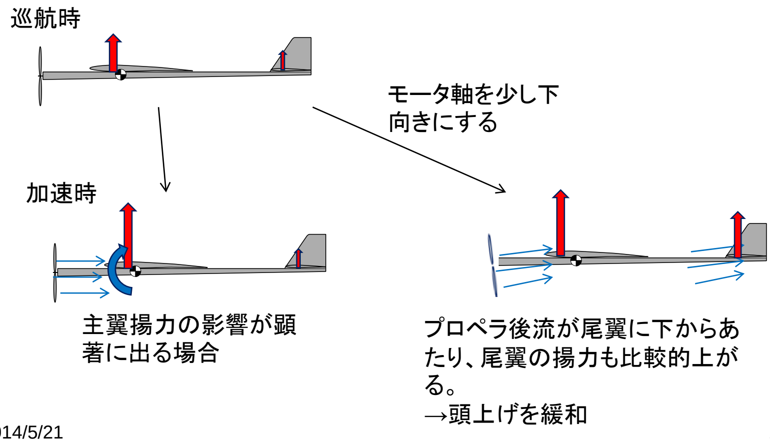
Hacker A10-12S モータ裏四ヶ所を→ネジ止めする方式。ネジの間にワッシャをはさめば、モータの取り付け方向をある程度ずらすこともできる。



←図のように推力線と重心とがずれる場合は、強力な曲げモーメントが働くので注意が必要。

ダウンスラスト

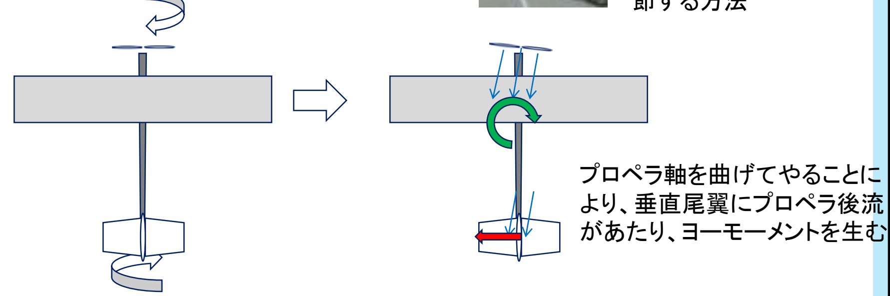
- モータ取り付け角を水平よりやや下向きにつけること
- 通常の機体は、巡航時に水平になるように水平尾翼をつけている。
- →巡航時よりも加速するとバランスは崩れる。特に主翼の揚力が増大し、頭上りになることが多い。



サイドスラスト

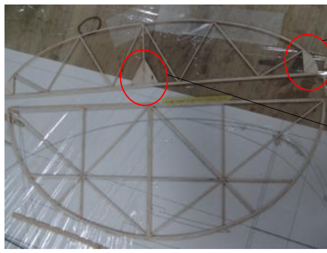
- モータ軸をやや斜めにつける
- モータもプロペラも回転体であり、その反力により機体はロールする。

←モータの取り付け
ネジとナットの間に
ワッシャを挟んで調
節する方法



尾翼（バルサ細工）

- 基本構造は主翼と同じ
- 平板翼の場合、バルサ細工で十分



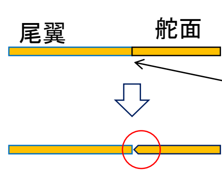
結合部分をバルサ板で補強

エレベータホーンの取り付け部：荷重部なので、バルサ板で補強

- 尾翼部分は重心位置より一番遠いため、
少しの重量変化でも大きな影響が出るので注意が必要。

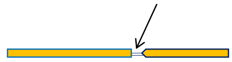
舵面

- スムーズに動くようにヒンジをつける



四角いままだとひっかかって動かない

← 片側を削ってとがらせる：可動域が増える

- 手法
  1. 糸で縛る
  2. 薄いプラ板を挟む  薄いプラ板
  3. テープ
  4. 丸棒、針金等で軸を作る

構造部材三面図及び 構造部材配置図

構造部材三面図

- 初期三面図を元に桁やリブ配置など、構造部材をどのように配置するか書き込んでいく
- 計算である程度の定量的評価は可能だが、木材は強度の幅が広く、また詳細な計算は困難なため、詳しく解析する必要はない。
- ただし、
  - 簡単な計算によるオーダーの評価（部材の太さを2倍にするとどの程度強くなるか等）
  - 定性的な部材の力の受け持ち方：どの位置にどのように部材を配置すればその応力を受け持つことができるか

は考慮する必要あり。

- 構造によっては外形（初期三面図）を変える必要もあり。

構造部材配置図（製作方法）

- 構造部材の製作方法を絵に描いたもの
- 実際に製作にあたる前に以下の図面の検討が必要になる
  - 組み立て方を描いた図面
  - 切り出しようの図面

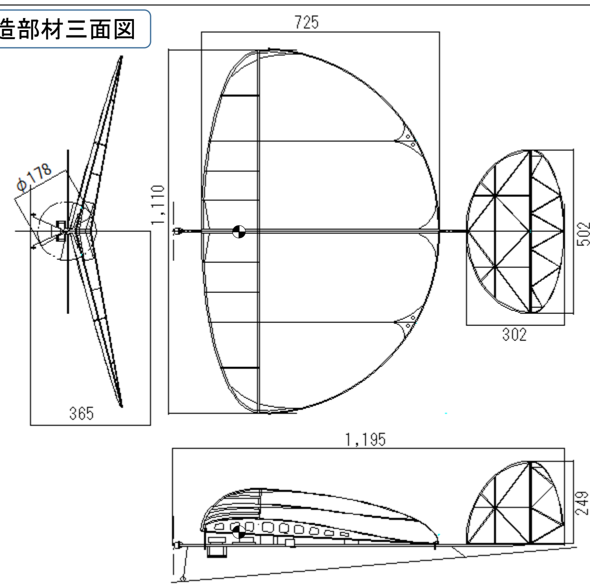
※注意点

- どこに何の材料を使うか
- 部材の厚さ、硬さ
- 各部品が干渉しないか、きちんと作れるか？

をあらかじめ検討しておくこと。

- 図面通りに作れることはまずないので、製作過程で変更、修正、補強が必要。

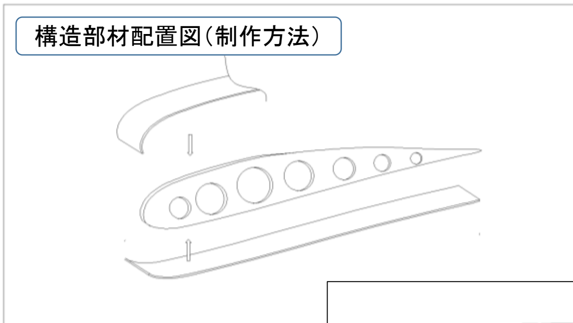
構造部材三面図



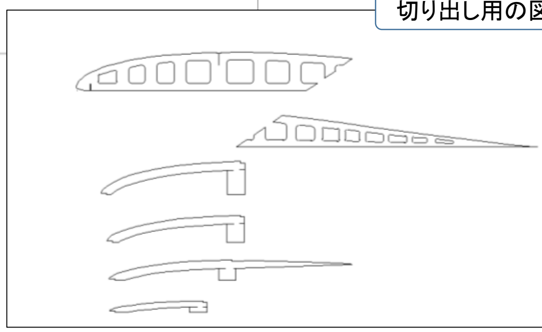
諸元	
全長	1240mm
全幅	1110mm
全高	320mm
空虚重量	207g
全備重量	270g
水平飛行速度	2.5m/s
主翼	
翼面積	71.3dm^2
アスペクト比	1.7
上反角	13deg
取り付け角	3deg
水平尾翼	
翼面積	11. 9dm^2
アスペクト比	2.3
垂直尾翼	
翼面積	5. 7dm^2
アスペクト比	1.9

縮尺	1：1	投影法	第三角法
機体名	FLEMING		

構造部材配置図(制作方法)



切り出し用の図面



参考

- 模型飛行機[理論と実践] 木村秀政、森 照茂 電波実験社
- 模型飛行機の科学ーフリーフライト機の理論と設計ー
  和栗雄太郎 養賢堂
- 基礎から学ぶ材料力学
  臺丸谷政志、小林秀敏 森北出版株式会社
- 飛行ロボットコンテストHP 製作のノウハウ

- http://www.geocities.jp/iamvocu/Technology/kousiki/kousikidanmen.htm
- http://www.geocities.jp/moridesignoffice/torsion-stiffness.html

構造設計の補足、部品選定

飛行ロボットPro.

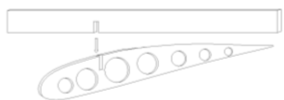
2014/05/28

木村壽里

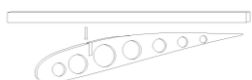
構造設計補足

桁とリブの組み方

- 桁とリブは交差するので、どのように作るのかがポイントになる。
- 例1：桁、リブともに“切りかき”を作っておき、はめ込む。
  - うまく作れれば、リブの位置を測らなくて良いので、製作が楽
  - 桁に切れ目があるので、強度が落ちる、折れる際はたいていこの切れ込みから折れる。



- 例2：リブのみに切りかきを作る
  - 桁を傷つけないので、頑丈
  - 製作するとき、リブの位置を適宜測って決めなければならない。



設計した構造の重さ

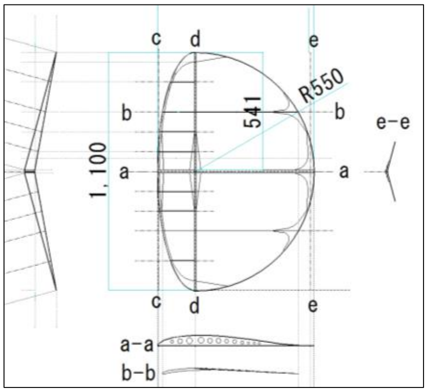
- 構造を設計できれば、パーツの大きさが分かるので、およその程度の重さになるか推算できる。
- 部材の密度

材質	密度 $\rho[\mathbf{kg/m^3}]$
バルサ（軟質）	86～140
バルサ（硬質）	282～354
航空ベニヤ	607
ヒノキ	445～490
タケ（角材）	815
タケ（丸材）	634

→重すぎるようであれば、設計しなおす必要がある。

実際の製作について

- 部材の配置の“下書き”となる原寸大の図面があるのが望ましい



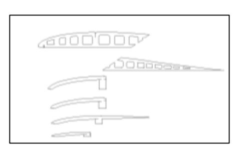
印刷した図面の上で作業をすると製作がしやすく、きれいに作れる

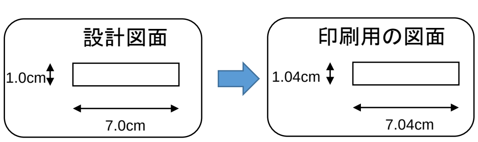
バルサ細工を作るときは必須→

レーザープリンタ（2D）を使用する上で

- レーザープリンタ
  - VD7050（commax）
  - 切れるもの・・・木板、ボール紙

- レーザーの“焼きしろ”
  - レーザーで焼ききるので、切った分だけ部材は減り、小さくなってしまう。→はめ合い等がうまくいかなくなる可能性あり。
  - 通常0.15mm～0.3mm程度の焼きしろをつけてプリントする。できれば、大きめに焼きしろをとっておき、後でサンディングブロックで整形するのがよい。





焼きしろを0.2mmとった場合、両側が削られるので注意

部品選定

カーボン材

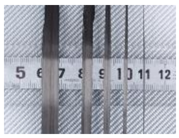
- カーボンパイプ
  - 繊維の入れ方によって強度が大幅に違うので注意。

←90度方向に繊維を入れたクロスタイプ（上）、斜めに巻いた巻きタイプ（中）、縦一方向のみの縦繊維タイプ（下）
200gクラスの機体だと直径5mm~8mm程度
当然斜めに繊維が入っている方がねじりに強い

- カーボンキュアシート
  - カーボンの繊維を樹脂で固めたシート。木材側面に瞬間接着剤で圧着するだけで強度が何倍も増える。0.1mm以下のものがあるとベスト。

カーボン材

- ロービング材
  - カーボン繊維を束ねたもの。専用のエポキシ系接着剤で型紙に貼り付けて使用。



K ： 1束に含まれる繊維の本数1000本をKとして表す。
6K=6000本、ということ。

- カーボンクロスシート
  - カーボン繊維を交互に編んだシート。ロービング材と同じく、接着剤を含浸させて型に押し当てて固定することで、カーボン製のいろいろな部品が製作できる。

- 購入場所
  - ウインドラブ http://www.windlove.net/e-shop/c01.html
  - Sano Factory http://www.sano-factory.jp/index.html
  - 東急ハンズ、その他ラジコン店舗等でも購入可能

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翼膜

- 翼面に貼る紙やフィルム
  - 厚ければ剪断応力をもたせることができる。→重くなる可能性
  - 薄ければ軽い→構造はもたせられない可能性
- 主翼の下面に貼れば、揚力を引張応力としてもたせられる。

- 購入場所
  - ウインドラブhttp://www.windlove.net/e-shop/a03.html
  - レモン画翠http://www.lemon.co.jp/
  - 東急ハンズ：薄手のポリ袋を開いて使用するなど
  - 近所のスーパー：生鮮品の袋も薄手なので使用可能

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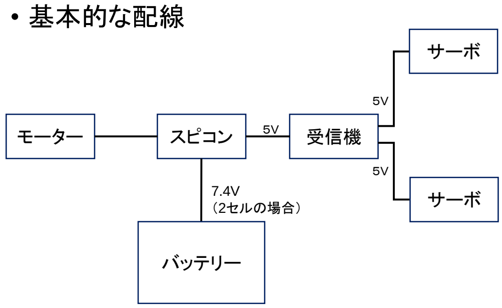
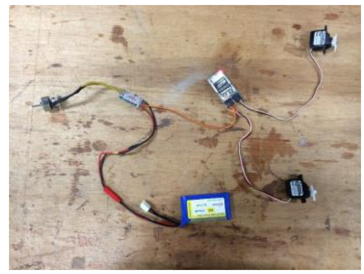
電子部品配置

- 基本的な配線

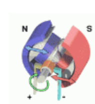




スピコンによっては一個でモータ、受信機、サーボの電源すべてを賄うタイプ（BEC）と、受信機の電源は別バッテリーから取るタイプ（OPTO）とがある。上図はBECタイプのもの。
→サーボの接続個数に制限があるので注意。
※スピコンから受信機への接続部分が5Vでないこともあるので、仕様書をよく読むこと。

モータ

- ブラシモータ



回転子の回転角に応じてコイルに流れる電流の向きを変える必要がある。これを整流子（ブラシ）のによって機械的に行うもの。ブラシの摩擦による損失が大きく、高速回転には向かない。

- ブラシレスモータ

コイルの電流の向きを電子回路によって行う。

- アウターロータ式
回転子が外側のもの
大きな半径のコイルを使用でき、高トルク

- インナーロータ式
回転子が内側のもの
回転子が小さい分、低トルク高速回転

飛行ロボコン用の機体だと、トルクを考えてアウターロータが多い。

モータ諸元

〈ex〉HACKER A10-12S

①	KV値	2900rpm/v, 最高回転数25000
②	対応セル数	2Li-Po
③	連続電流値	4A
④	最大電流値	6A
⑤	シャフト径	2.0mm
⑥	重量	15g
⑦	サイズ(直径x全長)	21x21mm
⑧	最適タイミング	20-25度
⑨	スイッチング周波数	8-16Khz

①**KV値**:モータにかける電圧1Vあたりのモータ無負荷回転数(モータに何もつけてない状態における回転数)。
最高回転数は物理的に壊れない範囲での回転数の上限。
②**対応セル数**:対応するバッテリーの種類とセル数、この場合2セルのLiPoバッテリー
③**連続電流値**:巡航時など連続して流しても構わない電流許容値。
④**最大電流値**:離陸時など瞬間的にかけても良い電流許容値。定義はメーカーによる。
⑤**シャフト径**:プロペラを取り付ける軸の径
⑥**重量**:モータの重さ
⑦**サイズ**
⑧**最適タイミング**:ロータのどの回転角に対し、コイルの電流を切り替えるかのタイミング、スピコンに依存
⑨**スイッチング周波数**:モータを効率よく回せる周波数、スピコン依存

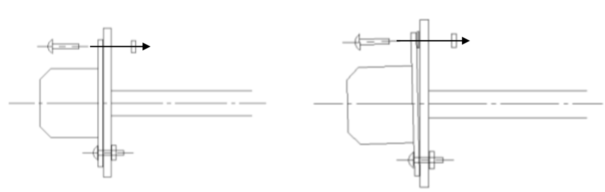
- Hacker motors

http://www.hacker-motor-shop.com/e-vendo.php?shop=hacker_e&SessionId=1763x49e6b4489f4290df22a31e85abb0f844

※まともに検索するとドイツ語のサイトがヒットするので注意。

モータの取り付け方補足

- 非常に負荷のかかるところなので、ネジ止め必須
- サイドスラスト、ダウンスラストがつけられるようにしておくと良い



- 図のようにモーターとマウント(基盤)の間に片側だけワッシャーを入れることで、モーターの向きを傾けることができる。

→ サイドスラスト、ダウンスラストの調整に使える

スピコン

- スピードコントローラー（別名：アンプ、ESC）
  - モータに送る信号の制御
  - 受信機とバッテリーの間の電圧変換
- スピコン諸元

①	サイズ	27x17x5mm
②	重量	7g
③	電流値	連続8A,最大10A(30秒)
④	対応セル数	Li-Po 2-3セル
⑤	タイプ	ブラシレス専用
⑥	プログラム	ブレーキ・オン/オフ切り替え可能。
⑦	使用可能サーボ数	最大4個

①サイズ
②重量
③電流値：巡航時など連続して流しても構わない電流許容値。最大は瞬間的に出しても構わない電流許容値。定義はメーカーによる
④対応セル数：対応するバッテリーの種類と電圧
⑤タイプ：対応モータの種類
⑥プログラム：スピコンで設定できる内容、詳しくは説明書
⑦使用可能サーボ数：そのスピコンで扱えるサーボの数。BECタイプのみ。

※スピコン、モータはバッテリーの種類（電圧、電流）、各々の許容電圧、許容電流を合致させて使用すること。許容電流以上の電流をスピコンやモータに流すと、最悪ショートして燃える可能性もある。

2014/5/28　15

必要推力と揚抗比

- 通常の機体において、水平定常飛行状態を考えれば

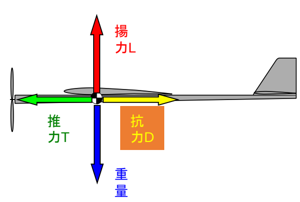
$$T = D$$
$$W = L$$

より

$$T = \frac{W}{(L/D)}$$

つまり、機体重量と揚抗比を仮定すれば、ある程度の必要推力は想定できる。

- 揚抗比の推算
- 翼データからは数十程度のものもあるが、胴体の抵抗や誘導抵抗があるので、実際はもっと低い。結局のところ飛行ロボットでは風洞試験から求める以外信頼できる求め方がない。
- が、競技に滑空があるので、ここではこれを元に推算してみる。



2013/6/12　16

滑空と揚抗比

- 図のように滑空状態の機体を考える。ここでは簡単のため、少し時間がたって定常状態になった時を考えよう。（つまり、減速も加速もしない状態）
- 三力のつりあいより

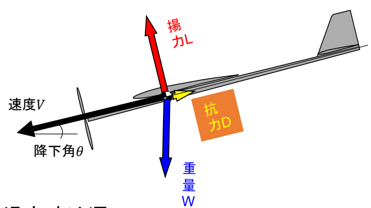
$$L = W\cos\theta$$
$$D = W\sin\theta$$
$$\therefore L/D = 1/\tan\theta$$
$$\cong 1/\sin\theta \quad \cdots(1)$$

ここで、$\theta \ll 1$と仮定した。

すると縦方向の速度（沈下率）v'は

$$v' = V\sin\theta$$

(1)式より$L/D \cong V/v' \quad \cdots(2)$



- さて、飛行ロボット機体の巡航速度が4m/sとすると、滑空時は遅くなると見て、V＝2.5[m/s]と仮定する。実際の競技では高さ10mから20秒程度で地上に到達するので、v'＝0.5[m/s]
- よって$L/D \cong 5$程度と推算できる。（ただし、かなりざっくりとした仮定なので、オーダーが分かったぐらいのつもりでいること）
- →巡航時の推力は以上からもとまるが、これはMinの限界の話。たいていは、最大推力がもっと大きいので、モータ選定はそちらをもとに行う

モーターとプロペラ、スピコンの決め方

一対一対応があるので、モータにあったプロペラ、スピコンを選ばないといけない

〈方針〉
設計要求から必要推力を仮定
→その推力を出せるモータとプロペラを選定
→そのモータ性能に見合ったスピコンを選定」

- モータ
  - （巡航時の必要推力を推算→必要推力が最低限必要な値となる。）
  - 最大推力→空力推算が困難なので、推重比（T/W）を仮定して計算。
  - カタログから適したモーターとプロペラを選定。　←当然、大出力のモーターは重いので注意。
- プロペラについて
  - 選ぶ対象は形状、径、ピッチ
  - 径は大きいほど推力が大きいが、その分消費電力が大きくなる。
  - ピッチはプロペラの翼の傾き具合を表す。ピッチが大きい物は高速機向け
  - 形状は用途に応じてさまざまなものがある。モーターに取り付け可能かどうか確認すること

モーターとプロペラ、スピコンの決め方

・スピコンについて
次の4点を確認
・使用するバッテリーの電圧
・使用するモータに流れる連続電流値以上の連続許容電流値を持っていること。
・使用するモータに流れる最大電流値以上の最大許容電流値を持っていること。
・使用可能サーボ数

- モータカタログには通常、瞬間に流れる可能性のある電流値（例えば30秒だけOKなど）と、連続して流して良い電流値とを分けて書いてある。

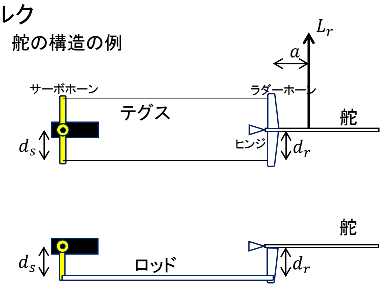
この両者をスピコンの許容電流値と照らしあわせる。
「モータが連続6A、最大8Aなら、スピコンは連続8A、最大10A」といったようにスピコンのほうが上回るように選定する。
どの程度、マージンを取るかは設計者の判断によるが、過去の例を見ると許容電流値が1.5～2倍程度のものを選ぶことが多い。（要確認）
カタログによってはモータに対して推奨するスピコンが出ているものもあるので、利用しよう。

- BECタイプのものは使用可能サーボ数も確認すること。これは、サーボの駆動電流をスピコンを介して供給しているので、スピコンによって駆動できるサーボの数に限界があるため。

- モータとスピコンはセットで考える必要があるので、もしスピコンが大きくなり重量が気になる場合は、推力の仮定とモータ選定をやり直すことになる。

サーボモータ

- 入力に応じた偏差分稼働するモータ
- 舵面の制御に使用
- トルク、動作速度、重量によって選択
- トルク
  - 舵の構造の例



- 応答性
  - 同じトルクでも応答の速い、遅いものあり。

〈ex〉TahmazoのTS-1002
重量 4.7g トルク 1.1kg 動作速度 0.14sec. /60°
長さ 21.6mm 高さ 17.7mm 幅8.0mm

サーボにかかるトルクは

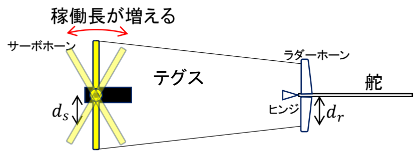
$$M_s = L_r \cdot a \frac{d_s}{d_r}$$
$$= \frac{1}{2}\rho S_r V^2 C_{Lr} \cdot a \frac{d_s}{d_r}$$

(S_r：舵面面積 , C_{Lr}: 舵面の揚力係数)
で概算できる。
これを十分余裕を持って満たすトルクの出せるサーボを選ぶ。

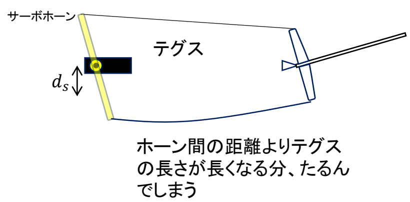
→例えばTamazohなど、製作メーカーのサイトを見れば諸量が分かる。
http://www.tahmazo.jp/

サーボモータの舵角

- 図のようにサーボホーンを長くしてやれば、操舵範囲を広げることができる。



ただし、リンク機構の性質上片側の糸がたるむ可能性があるので注意



過去に使用してきたサーボ

- Tahmazo http://www.tahmazo.jp/12.html
  - TS-1002
  - TS-1006
  - TS-1008
- JR http://www.jrpropo.co.jp/jpn/products/propo/search2.php?he7=sv
  - JR316
  - JR306
- Futabahttp://www.rc.futaba.co.jp/servo/index.html
  - S3114

- だいたいは大きなトルクがかかることはないので、小さめのもので十分事足りる。
- チャイナサーボ注意

購入場所（オンラインショップ）

〈ラジコンショップ〉

ラジコン店は縮小化の傾向にあり、ネットショップの方が内容が充実している

- リトルベランカ http://www.little-bellanca.com/
  - 外国メーカーの物が多い。
- Futaba http://www.rc.futaba.co.jp/index.html
  - 日本のラジコンメーカー
- Tahmazo http://www.okmodel.co.jp/shincyaku/TAHMA-servo-FM.htm
  - サーボなど

〈構造材料など〉

- ウインドラブ http://www.windlove.net/e-shop/c01.html
  - 凧用品のメーカーだが、飛行ロボットに流用できるものも多い。
  - テーパードフェザー等、テーパーしたカーボンパイプあり、軽量なものもそろっている。
  - 凧用の和紙あり。薄手のものは翼膜に使用可能
- Sano Factory http://www.sano-factory.jp/index.html
  - カーボン材の専門店、パイプは一方向材のものが多いので注意。

購入場所（オンラインショップ）

〈電子部品〉

- RSコンポーネンツ http://jp.rs-online.com/web/
  - 電子部品、大抵のものは揃っている。在庫がなければ海外から取り寄せるため、一週間ほど必要。
- ストロベリー・リナックス http://strawberry-linux.com/catalog/
  - 電子部品
- チップワンストップ http://www.chip1stop.com/

〈基板制作〉

- P板.com http://www.p-ban.com/
  - 電子部品の基板を作りたいときに利用、eagle→http://www.cadsoftusa.com/等で設計した基板を製作してもらえる。

購入場所（東大周辺の店舗）

オンラインショップもあり、そこで販売品を調べておくのが吉

〈電子部品〉

- 千石電商http://www.sengoku.co.jp/shop_01.html
  - 電子部品ほか、モータやキット等も販売
- 秋月電子通商http://akizukidenshi.com/catalog/default.aspx
  - 電子部品

〈ラジコンショップ〉

- ラジコンチャンプhttp://www.rc-champ.co.jp/
  - 東大にもっとも近い、品数豊富、店の人も愛想が良いのでおすすめ（主観）。
- フタバ産業http://www.f-sangyo.co.jp/
  - 品数はそこそこ
- スーパーラジコンhttp://www.super-rc.co.jp/rc/index.html
  - 上記2店に比べると品数はやや少なめ

〈その他〉

- レモン画翠http://www.lemon.co.jp/
  - 画材屋だが、和紙、バルサ等の木材、接着剤なども販売。
- タウンドイトhttp://www.doit.co.jp/search/shop_detail.php?st_store_id=249
  - ホームセンター：工具、ネジ類など

購入場所（東大周辺の店舗）

- 東急ハンズhttp://www.tokyu-hands.co.jp/shoplist.html
  - ホームセンター、池袋店が最寄り、他渋谷店、新宿店が大型でおすすめ。

バッテリー取り扱いについて ver2

2015/01/15 修正
文責：木村壽里

1. リポ

正式名称：リチウムイオンポリマー蓄電池。現在のラジコン飛行機バッテリーの主流。
電解質にゲル状のポリマーを使用することからネーミングされている。

- メリット
  1. 小型・軽量
  2. 高起電力（1 セルあたり 3.7V）・大容量
  3. エネルギー密度が高い（リチウムイオン電池の役 1.5 倍程度）
  4. メモリー効果が無い
- デメリット
  1. 可燃性（過充電・過放電・衝撃等により発熱、炎上のおそれがある。
  2. 充放電の制限（放電電流に限界がある。）
  3. 高価

1.1. 可燃性について

リポは非常に燃えやすく危険なので、取り扱いには注意が必要。

- **燃える可能性のあるタブー**
  1. **1 セルあたり 4.2V 以上充電してしまう（過充電）**
  2. **過剰な電流を流す**
  3. **過放電（1 セルあたり 2.6V 以下になると電池機能が消滅）**
  4. **物理的な破損によるショート（落とす、分解する等）**

飛行中に落下して変形した、あるいは膨らんだリポは使用しないように。

1.2. セル数

通常ラジコンで使用するリポは、パック内でいくつかのセルに分かれている。単セルあたりの公称電圧は3.7V である。接続は乾電池同様に直列、並列の 2 つがあり、S が直列（Series）、P が並列（Parallel）接続数を表す。実際の電圧は S の数で決まる。

〈ex〉3S 2P の場合

セル数：3(直列接続数 S) × 2(並列接続数 P) = 6(セル数)

電圧：3.7V × 3(直列接続数 S) = 11.1V

1.3. 放電容量

バッテリーの放電容量。mAh(ミリ・アンペア・アワー)。大まかには放電電流値×放電時間＝放電容量で計算可能。

4000mAh なら、4000mA の電流を 1 時間、2000mA なら 2 時間出せるということ。ただし、実際は放電の仕方によって容量は変動するので一概には言えない。（ふつう、放電電流

が大きいほど容量は小さく、つまり放電時間は短くなる傾向にあるようだ。)

1.4. 充放電許容量 CmA(C):シー・ミリ・アンペア

最大どの程度放電または充電できるかを表す量。mAh にこの値をかけたものが、最大電流量。普通「C」と省略される。C は capacity の意味。

〈例〉20C　4000mAh のバッテリーの最大電流は

$$4000 \times 20 = 80000\text{mA} = 80\text{A}$$

1.5. 過充電

リポの単セルの公称電圧は 3.7V だが、 満充電時の電圧は 4.2V になる。この値を超えて充電すると過充電となってリポは壊れてしまう。

1.6. 過放電

バッテリーを使用して放電すると電圧が降下し、 各セルが 3V よりも下回ると過放電となる。この過放電では、バッテリの性能が落ちて、寿命も極端に短くなる。更に放電して、2.6V まで電圧が降下すると電池機能が消滅する場合もあり。

1.7. 新規購入時

リポバッテリーを購入して最初の数回は、50%放電程度で使用すること。いきなり 20%まで使用すると、容量が減少する。

1.8. メモリー効果

ニッケルマンガン電池やニッケル水素電池では、バッテリーを十分に放電し切らないうちに、継ぎ足し充電することを繰り返すと、十分に放電していないのに起電力が低下する現象が起きる。結果として容量が減少したように見える。これをメモリー効果と呼ぶ。リポの場合は、充放電により電池構造が崩れる事が起こりにくいので、良好な繰り返し充電が可能で、実質的にメモリー効果はない。

1.　充電方法について

HYPERION　EOS0606i　AC/DC
研究室でメインで使用している充電器

1.1.　接続方法

図 1　バッテリーの接続

図のように、バランサコネクタをバランサボードに、充電コネクタを充電コードにそれぞれつなぐ。

1.9.　バランサボード

バランス充電をするために必要。研究室で使用しているバッテリーは基本的に複数セルなので、必ず使用すること。JST EX 端子用、JST XH 端子用、Hyperion 端子用など、端子によって異なるので、バッテリーコネクタによって適したものを使用すること。
各コネクタについて、セル数ごとにコネクタがわかれているので、バッテリーのセル数に応じてその端子につなぐ。

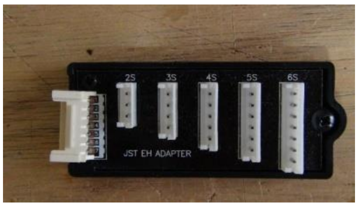


図 2　JST EH ADAPTER

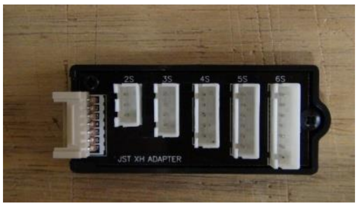


図 3　JST XH ADAPTER

図 4　Hyperion Adapter

1.10. 充電モード

起動時デフォルトはこのモード

- BATTTYPE

　　バッテリー種類変更

　押すたびに対応バッテリーの種類が変わる。

　→使用可能バッテリーLiPo,LiFe,Pb,NiCd,NiMH

- Enter Start/Stop

　一度押すと一箇所が点滅する。押すたびに点滅する場所が変わる。点滅している部分を DEC 、INC によって変更できる。これにより C,S を充電するバッテリーに合わせる。充電電流は普通 1C(mAh の値と同じ A 値)で行う。

- バッテリータイプ、C、セル数を合わせたら、Enter Start/Stop を長押し→充電が始まる。

1.11. モード変更

デフォルト状態から DEC 、INC を押すと CHARGE、DISCHARGE、STORE、BALANCE と切り替えることができる。

各モードについて

　DISCHARGE : 放電モード、放電電流は基本 1C で行う。他は充電モードと同じ。

　STORE : 長時間使用せずに保管するときはこのモードで電圧を調整しておく。

　保管するときは、過放電しないように 50%程度充電した状態で保管すること。

※片付ける時は必ず各コードを外してから箱にしまうこと。コード根本が曲がり、ちぎれる場合あり。また、コネクタを外すときはコネクタを持ち、決してコードを引っ張らないように。

1.12. バランス充電

　セル単位でバッテリーの電圧を監視し、充電完了電圧（リポは 4.2V）を超えないように各セルの電圧を揃える充電方法。バランサボードをつないで充電する理由がこれ。通常の充電方法は直列したセル全体の電圧を監視して充電する。例えば 2 セルだと全体で 8.4V になるまで充電するので、1 セルが 4.4V、もう 1 セルが 4.0V まで充電される場合もあり、過充電になり危険。複数セルのあるバッテリーは必ずバランス充電させること。

　リポは自然放電しにくいが、それでも何らかの理由で各セルの電圧が変わることがある。そのようなときはバランス充電、あるいは充電器のバランス機能で、各セルの電圧を調整すること。

1.13. セルメータ

リポの状態を測定する機器。バッテリー残量やセルのバランスを一瞬で確認することができる。セルの電圧が低すぎたり高すぎる場合は、警告が表示されアラームが発生される。

図 5　セルメータで各セルの電圧を測定

接続は必ずバランス端子を接続すること。図のように「GND」と表示されている側に GND（黒色のコード）を接続する。

2.　廃棄方法

バッテリーは使用していくと容量、セル電圧等劣化してくるので廃棄する。100 回ほど充電させれば十分長く使えたと評価できる。寿命のきたバッテリーは以下のように放電処理をしてから廃棄すること。

1.　**電源コードをニッパーで根本から切断**

必ず正極負極一本ずつ切ること。一度に切ろうとするとショートさせる可能性あり。二本目を切る場合にも一本目と少しずらして接触しないよう十分注意すること。

図 6　長時間使用して膨らんだバッテリー
（バッテリーコード切断後）

2.　**5%程度の食塩水につけて数日放置**

バケツ等に海水より少し濃い程度の食塩水を作り、そこにバッテリーをひたす

3.　**取り出してセルメータで電圧を測定**

セルメータが反応しなければ完全に放電していると分かる。バランサコネクタを塩水にひたしてしまっているので、セルメータには別のコードを介して接続するのが良い。

4.　**燃えないゴミとして廃棄**

完全放電させたあとなら、燃えないごみとして処理できる。必ず放電させてから捨てること。東大内では生協で回収できる（らしい）

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http://winsafe.jp/rc/setumei/Lipo-choice.htm#1「LiPo バッテリーの使い方」

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