AN UPDATING PROGRAM FOR UNDERGRADUATE AIRCRAFT CONCEPTUAL AND PRELIMINARY DESIGN COURSE

Hu Liu*, Zhe Wu*
***School of Aeronautic Science and Engineering, Beihang University, Beijing 100191, China**

Keywords: *design education; aircraft design; conceptual design; course project*

Abstract

To improve an aircraft conceptual and preliminary design course that faces such problems as large-scale class, limited class hours and students with different majors, an updating program has been developed. Presented contents include the philosophy, program arrangements, competitive projects, application of design codes, and concepts accomplished by student design teams. The lessons and possible solutions are also discussed.

1 Introduction

Education of aircraft conceptual and preliminary design has always been an important topic for aeronautic community, and many experience and lessons can be learned from the design courses in worldwide universities, including Virginia Polytechnic Institute and State University[1,2], California Polytechnic State University[3,4], Embry Riddle Aeronautical University[5], University of Limerick[6], and etc.[7~9]. In China, this course is not only important to major aeronautic related universities, such as Northwestern Polytechnical University and Nanjing University of Aeronautics and Astronautics, but also attracts interests of other universities where aerospace schools have been found in recent years, i.e., Tsinghua University and Shanghai Jiao Tong University.

In Beihang University (formerly Beijing University of Aeronautics and Astronautics, BUAA), the Aircraft Conceptual and Preliminary design course has a history of about 50 years, and plays an important role in the education of undergraduate aeronautics engineers. However, due to such limitations as insufficient class hours and lacking of proper design facilities, the course has been taught just by lectures for a long period of time, which is not ideal for a design course.

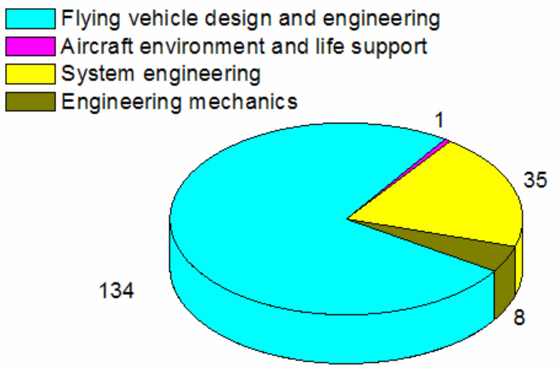
From 2006, a teaching team consists of 7 faculty members was formed to develop updating program for this course. This paper introduces the specific issues faced by the team, the philosophy, features and arrangements of this program, as well as the lessons gotten from the first and second years.

2 Specific issues of the design course in BUAA

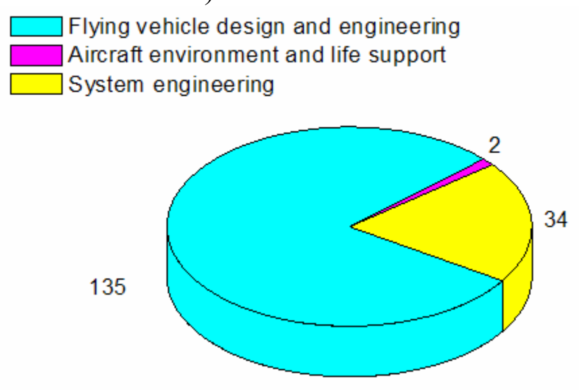
In BUAA, there are some specific problems that seems not be frequently encountered in other universities. The first problem is the large-scale of course: more than 170 senior students from about 8 classes participated in this course at each semester, which not only makes it difficult to ensure all students are concentrate on the course, but also challenges teachers' capability of making this design course in perfect order.

Second, there are only about 36 class hours for the course, which is quite limited because there are too many contents in aircraft conceptual and preliminary design.

Third, although most students belong to School of Aeronautic Science and Engineering, and most students' major is just flying vehicle design and engineering, there were about 40 students come from other departments or learn other majors in School of Aeronautic Science and Engineering each semester(Fig. 1), so they did not have some required fundamental knowledge, e.g., aircraft aerodynamics and flight performance.



a) 2006 fall semester



b) 2007 fall semester

Fig. 1. Number of Students with Different Majors

3 Philosophy of the course

To make the updating program reasonable and effective, the teaching team firstly discussed and proposed some basic points of the philosophy for this course:

1) The course should emphasize basic features of aircraft conceptual and preliminary design in limited class hours, including synthetic thought, the request for both mastering existed data and exerting creativity, the importance of collaboration, and etc. These features should not only be introduced in lectures, by also be strengthened through practice, which is vital in learning this design course.

2) This course should make the students learn and improve basic capabilities that can help them to make ready for their future study or career – *even some students will not be in the aviation industry after graduation*, including collaboration, creativity, presentation, intelligence collection, making use of up-to-date design tools, and etc.

3) The course must be customer-oriented, i.e., teachers should not only teach knowledge, but also intimate students' design passions, and help them to turn their imaginations into reasonable concepts.

Based on these points and the practical issues mentioned above, the old way of teaching solely by teachers' lectures is abandoned. Instead, the updating program is organized as a combination of lectures, course projects, presentations, discussions, and invited lectures. Moreover, according to the feedbacks and learned lessons, the program is kept on adjusting and improving.

4 Adjustment of course contents

Since aircraft conceptual and preliminary design is complex system engineering, it is very difficult to give detailed introductions to each aspect of this phase during limited class hours. In the past, contents of this course are mostly concentrated on configuration and layout design, which are listed as follows:

- Introduction: process and features of design;
- Design requirements;
- Selection of configuration;
- Initial sizing;
- Major components deign;
- Layout and center of gravity estimation;
- Design features of special aircraft;
- Computer aided aircraft design.

It can be seen that although these contents are quite important, they can not cover the general process of conceptual and preliminary design, and students can not learn how to analyze and evaluate their concepts. Consequently, at 2006 fall semester, the contents were adjusted as follows:

- Introduction: process and features of design;
- Design requirements;
- Sizing from a conceptual sketch;
- Selection of configuration;
- Initial sizing;
- Layout of cabin and payloads;
- Propulsion and fuel system design;
- Landing gear design;
- Layout of other components;

- Weight and center of gravity estimation ;
- Aerodynamics and performance analyses
- Special topic: design case of a light fighter aircraft;
- Special topic: application of Conceptual Aircraft Design System (CADS)

At 2007 fall semester, multidisciplinary design optimization is added into the list. By these means, the course contents can form a basic design process.

In addition to the adjustment of contents, about 8 hours were used for presentations and discussions at 2006 and 7 hours were used at 2007, because each student team should present their work more than once to let others know their progresses.

Because the total hour keeps the same, increase of items means some of the contents must be removed or simplified. For example, at the "Wing design" section in "Selection of configuration", the former program gives detailed discussions of the affects of major wing parameters, such as taper ratio and sweep angle, to aerodynamic characteristics, weight and stiffness. In the updating program, these discussions are simplified, not only because of time limitation, but also due to the fact these contents are hard for students from other departments to understand. Instead, the ranges of initial value for each parameter are emphasized, which aims at help students start their initial concepts for both course projects and future work.

As a matter of fact, detail introduction of the tasks at preliminary design stage is not involved in either the former program or the updating program, because these tasks are too trivial and complex. As compensation to the simplification of contents, supplementary materials and a list of references are supplied through course's website http://jpk.buaa.edu.cn/2007jpk/bjsjpk/fjztsj/index.htm. More importantly, the students are encouraged to learn and exploit more knowledge through their design practice. Take selecting the value of a design parameter as example, students should change parameters' values of their designs, and then analyze the aerodynamic, weight and other characteristics to find out the affects of parameters, which not only useful for them to understand the reason of selecting a value, but also help them make trade off in aircraft design.

Lectures on examples are also very important and useful in the updating program. As mentioned above, there are two special topics, and the design case of a light fighter aircraft is just a part of Dr. Raymer's DR-3[10], which is explained after the "Initial sizing" section, so that students can easily understand how such knowledge as sizing methods and principles for selecting components' parameters are applied.

The other topic is related to the application of a design code called CADS, which is the improved version of SEACD that is originally developed for aircraft conceptual design[11]. In this topic, one hour is used to introduce the basic functions of this code, and another hour is used to explain the detail steps of constructing the three-dimensional model of a aircraft from scratch, which not only help them understand corresponding knowledge in textbook, but also inspire their interests to up-to-date design technology.

In addition to the examples introduced in class, some other materials are recommended to students, such as the "Storm Shadow" concept designed for AIAA design competition[12], as well as Ref. [13] that contains examples of passenger aircraft, military trainer aircraft, and etc.

To widen students' outlook, the teaching team tries to invite a well-known design expert to give lecture in class every semester. These experts are always experienced designer from industry, so that students can have precious opportunities to know what's real in industry and the leading edge technology in this field.

4 Course projects

4.1 Projects and arrangement of the first year

2006 is the first year that course project, i.e., Aircraft Conceptual Design (ACD) project, is applied, and two topics are given at the beginning of that semester: conceptual design of a jet passenger aircraft and a light fighter aircraft. To each topic, simplified design requirements are given, including performance, mission profile, payload, as well as a baseline aircraft. The students are asked to perfect the requirements, and then conduct their work according to the progress of the course, including drawing sketches, sizing, components design, layout, performance analyses, and etc.

For the purpose of making every student get benefit from this design practice, all students were divided into ACD teams in the first year. Since there are too many students, we finally got 17 teams, and each team has about 10 members – which leaded to quite 'large' teams. A team leader is elected in each team, and the responsibility and contribution of each member should be written in the finally design report, which is the basis of giving their scores.

Although the design work of ACD teams is conducted after class, it is very important to know their progress in time, so presentation and discussion sessions are arranged in class. As shown in Fig. 2, there was 3 rounds of presentations during the semester, and each round were about two hours.

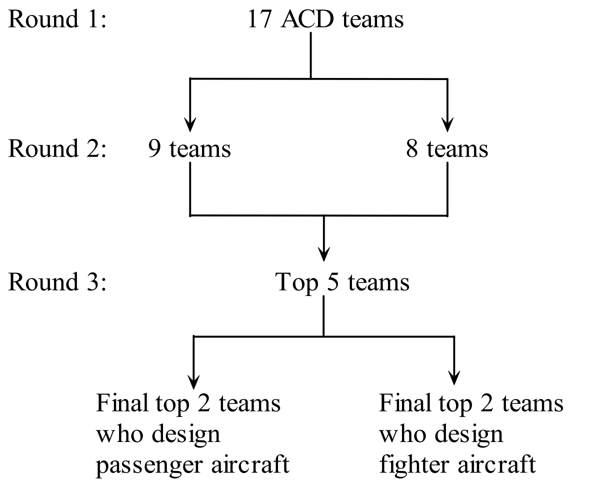


Fig. 2. Process of Presentation and Discussion Sessions in 2006 Fall Semester

In the first round, each team was given 5 minutes to introduce their initial concepts; The second round was arranged near the end of semester, the design teams are divided into two groups, and each team had about 10 minutes to introduce their latest progress; In the final round, 5 teams were elected based on presentations of the previous round: three of them designed light fighter aircraft, and the other two teams designed passenger aircraft. According to the votes of both students and teachers, the final top 2 teams for each topic were selected and awarded in class.

4.2 Projects and arrangement of the second year

The first semester of applying new program leads to significant progress that has never been expected before: all design teams accomplished their projects and brought us various design concepts. However, some problems did exist. For example, the "large" design teams lead to the fact that less than half members afforded most work, whereas the others do not exactly know what to do and afford a small part of the project.

To address the above problems, the course projects were adjusted at 2007 fall semester. On the one hand, ACD project is also the most important type, and two topics are given: large military transport aircraft and unmanned combat air vehicle (UCAV). On another hand, Professional Literature Survey project (PLS) was applied, which means students should collect and analyze latest information, especially academic papers, on certain topics related to aircraft conceptual and preliminary design, and fulfill a survey report at the end of semester. To ACD project, 10 design teams were formed, and each team has about 9 students; To PLS project, because each team has only 3-4 students, there were 18 PLS teams at 2007.

Since the member's number of a PLS team is limited, it is much easier to assign clear task to each member, e.g., translate and analyze one or two specific papers. However, this is not the major reason of launching PLS project. In fact, according to the authors' research experience, mastering up-to-date information and data in a specific area is one of the most important capabilities that a qualified researcher should have. Moreover, to graduate students and Ph. D. candidates, literature survey is a required part in their thesis. Consequently, the PLS project supplies a chance for undergraduate students to exercise what they will experience in future.

To facilitate PLS teams' work, some online literature databases are introduced to students as major data source. Owing to the information supplied by BUAA's library, abundant databases are accessible to PLS teams, including AIAA papers, NASA reports, AD reports, Elsevier journals, IEEE journals and meeting papers, and etc.

Presentation and discussion session is also an important link in class. Due to the increase of the total team number and the new project, the arrangement was different from that of 2006 semester. As shown in Fig. 3, there were 2 rounds of presentations for PLS teams and 4 rounds for ACD teams.

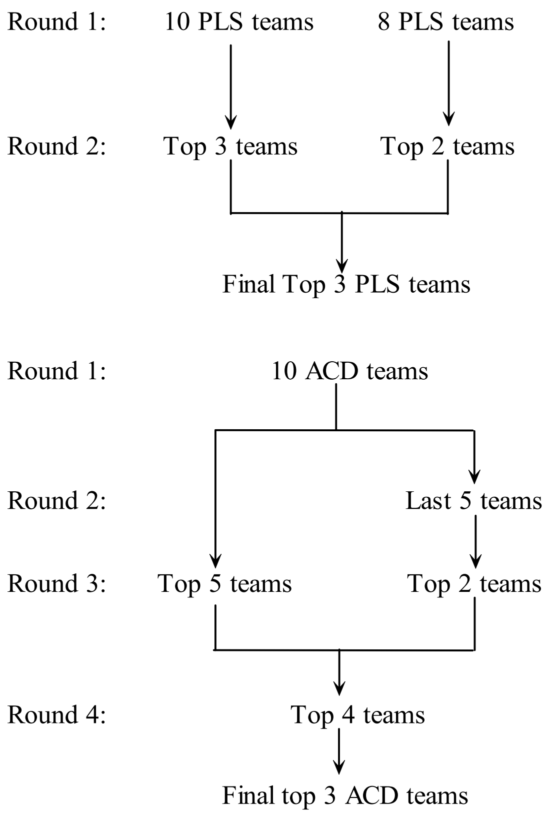


Fig. 3. Process of Presentation and Discussion Sessions in 2007 Fall Semester

In round 1 for PLS teams, they were firstly divided into two groups randomly, and each team was given 5 minutes to introduce their topics and literatures. According to the remarks and votes of students, 5 teams were elected and promoted into the second round. Based on each team's future analyses and survey to literatures (the second presentation was also limited to 5 minutes per team), the final 3 top PLS teams were elected and awarded.

To ACD teams, the competition was much more "cruel": they were divided into two groups according to the results of first round; the second round was just applied to the last 5 teams, and the top 2 teams "revived" from this round, which lead to 7 teams that entered into the third round. In the final round, according to the votes of both students and teachers, final top 3 ACD teams were elected and awarded.

4.3 Application of design codes

To ensure the ACD teams can accomplish their designs within a semester, the students were encouraged to use design codes and facilities in an open laboratory of School of Aeronautical Science and Technology. One of the most important codes used by students is just CADS. The function modules of CADS include graphical input of design requirements, preliminary sizing, components design and three dimensional modeling, estimation of major performances, optimization, and etc. Since CADS can basically cover major tasks in conceptual design and has user-friendly interface, it can be used as a suitable conceptual design tool for design education.

Although only about 8-10 hours is available for training and guiding each team to use CADS, we were quite glad to see that 17 teams accomplished the layout and three-dimensional model of their final designs with CADS in the past two years. The other teams modeled their designs by using CATIA (which is the No. 2 widely used tool), SolidWorks, RDS[14], and etc. It's quite great because the team members just learn to use most of these codes by themselves! As a matter of fact, some ACD teams used more than one tools to accomplish their project, which helped them understand benefits and shortcomings of each tool, so that they can make better choice in practical work.

In addition to improve efficiency and quality of the design projects, CADS was also used in class. As mentioned above, the case of applying it to model a concept is explained. Moreover, some design knowledge can be visually demonstrated and then understood by students much easier. For example, when basis principles of reducing radar cross sections (RCS) in configuration design are introduced, RCS of an F-15 like model is firstly estimated by using CADS, and then its twin-tail is interactively adjusted to make it inclined. From results of estimating the adjusted model, the effect of this principle to reduce RCS can be evidently shown.

5 Concepts and topics of student teams

In 2006 semester, 8 ACD teams chose to design a civil passenger aircraft, and the other 9 teams chose the light fighter aircraft project. Although Boeing 737-700 and Lockheed F-35A were given as baselines, some teams preferred to develop novel concepts to meet the given requirements, which lead to joint-wing, flying wing, three surface configuration, and etc. It should be noted that the elected final top team who design passenger aircraft really built a flyable model of joint-wing configuration at the prior semester, and this course gave they the chance of turning it into a full-scale concept.

In 2007 semester, 6 ACD teams designed large military transport aircraft concepts and the others developed their UCAV concepts. Similar to what happened in 2006, most teams did not follow the baselines, i.e., C-17 and X-45, and the proposed novel concepts include blended wing body transport (a flyable model was built by some members of team at the prior semester), ground effect aircraft, and etc.

Fig. 4 shows 10 of the concepts accomplished by design teams, which include all of the elected final top teams. Naturally, other teams also did good design and accomplished their project, and their concepts can be found on the course website.

To PLS teams, more than 100 references were collected and surveyed according to 18 topics, and the list of references is supplied on the website, so that a “literature database” can become more and more abundant year after year. In fact, some topics selected by students are just

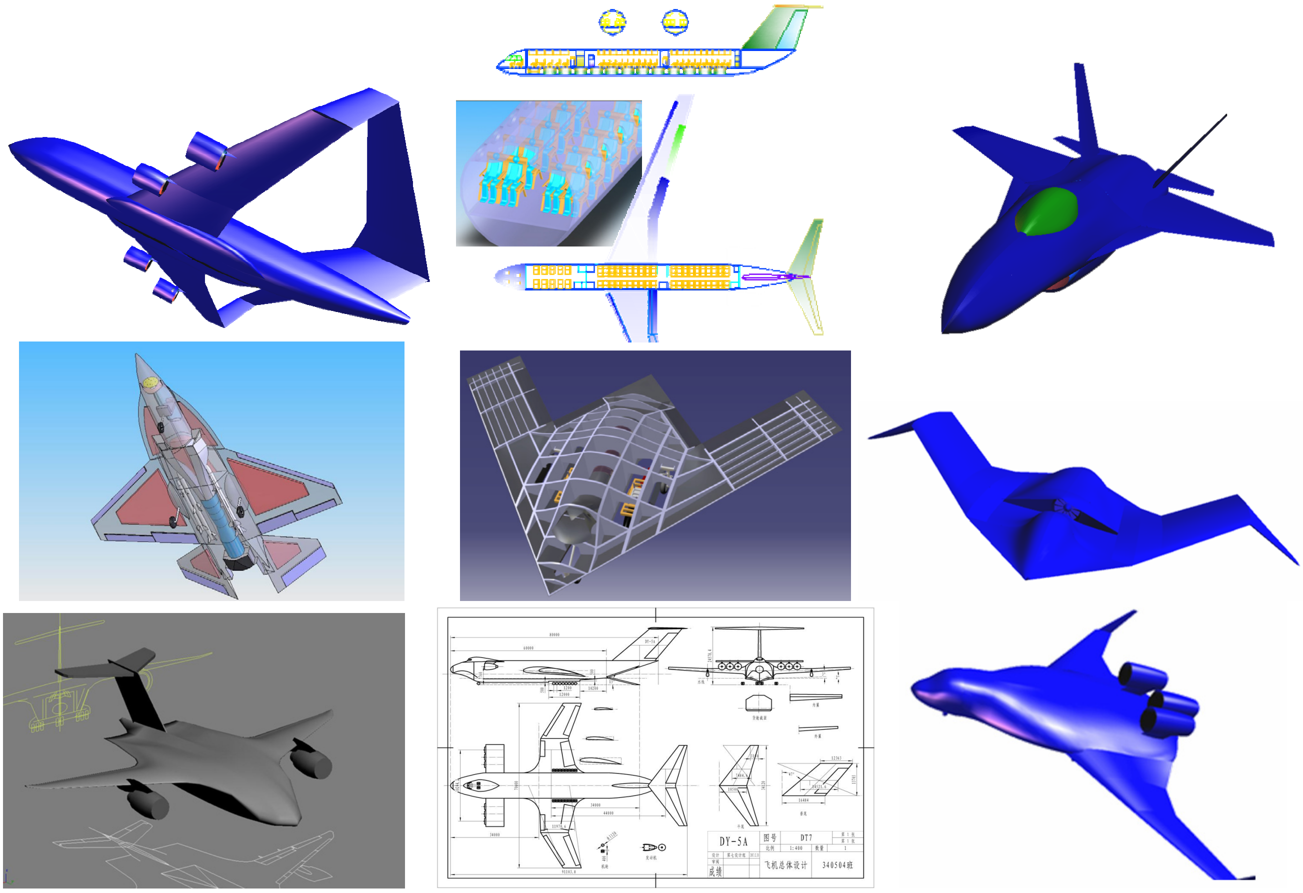


Fig. 4. Typical Concepts Designed by ACD Teams

hot points in aircraft design, e.g., topics of the final top PLS teams include “Conceptual design of micro air vehicle (MAV)”, “Importance of advanced composite material to aircraft design”, and “Application of multidisciplinary design optimization and decoupling methods”.

6 Lessons learned and upcoming solutions

From the first two years of applying new program, a lot of feedbacks were received from students. We are glad to know that most students like the various contents supplied by the course, especially the way of conducting course projects. For example, a student remarked: “It is quite impressive to conduct aircraft design like those famous designers! Although our tasks are just limited to conceptual design phase, I believe such an experience can be very useful to my future work.” Students also regard course projects as an important and effective measure to help them understand the vital role of collaboration to successful design.

Although the teachers tried a lot to arrange the course, limitation of time and “large” design teams still brought many problems. For example, we were not capable of guiding each team’s detail work from beginning to end, and we could not give enough time to each team for their presentations. In fact, we do plan to improve ACD project to be a university-wide conceptual design competition, which will inevitably increase scale of the course. Consequently, if the total class hour can not be further added, we should make better balance among lectures, presentations, discussions and requirements of projects, as well the balance between number of ACD teams and that of PLS teams.

In addition, although the students were encouraged to develop novel concepts, it is difficult to analyze and evaluate these concepts properly with available methods and tools. Consequently, it is necessary to supply more design and analyses tools to students, e.g., proper computational fluid dynamics codes, so that the design quality can be further improved.

7 Conclusions

As the students are told in class, it is the teaching team’s responsibility to show them one of the most impressive courses during their college life, not only because of the importance of conceptual and preliminary design to aircraft development, but also because they have been studying in a university with well tradition in aircraft design and aeronautical engineering. As emphasized in the paper, the philosophy of course is vital for teachers to choose what to teach and how to teach. Course projects and other arrangements adopted in the updating program enable us to turn abstract philosophy into measures that are beneficial to students. The first two years brought us important experiences and lessons, and helped us to improve the program for the future.

Acknowledgement

The authors are grateful to other members of the teacher team, including Prof. Chao Yang, Prof. Jun Huang, Prof. Yun Fei Zhang, Mr. Qi Xiang Jiao and Dr. Pei Lin Huang for their contributions to the new program. The students giving precious feedbacks and advices to this course are also appreciated. In addition, the authors would like to acknowledge Dr. D P Raymer for his help in supplying specific design code.

References

[1] Mason W H. Aircraft design at Virginia Tech - experience in developing an integrated program. 1st *AIAA Aircraft Engineering, Technology and Operations Conference*, Los Angeles, CA, AIAA Paper 95-3893, 1995.

[2] Marchman J F III. International-multidisciplinary aircraft design education - a ten year experience. *43rd AIAA Aerospace Sciences Meeting and Exhibit*, Reno, Nevada, AIAA Paper 2005-281, 2005.

[3] Sandlin D R and Riet R. The Cal Poly aircraft design program. *AIAA/AHS/ASEE Aerospace Design Conference*, Irvine, CA, AIAA Paper 93-1111, 1993.

[4] Soban D. Aircraft design education - a student's perspective. *AIAA Aircraft Design, Systems and Operations Meeting*, Monterey, CA, AIAA Paper 93-3993, 1993.

[5] Rodriguez J L. Teaching aircraft preliminary design - The first three years. *AIAA Aircraft Design Systems Meeting*, Hilton Head, SC, AIAA Paper 92-4275, 1992.

[6] Young T M. Aircraft design education at universities: benefits and difficulties. *Aircraft Design*, Vol. 3, No. 3, pp. 207-215, 2000.

[7] Nevill G. Integrating principles and multidisciplinary projects in design education. *1992 Aerospace Design Conference*, Irvine, CA, AIAA Paper 92-1041, 1992.

[8] Bowman W J and Snyder D O. A minimalist approach to teaching aircraft design. *43rd AIAA Aerospace Sciences Meeting and Exhibit*, Reno, Nevada, AIAA Paper 2005-282, 2005.

[9] Perkins J N, Hall C E Jr and Worsham M J. An update of aircraft design education at N.C. State University. *37th AIAA Aerospace Sciences Meeting and Exhibit*, Reno, Nevada, AIAA Paper 99-0801, 1999.

[10] Raymer D P. *Aircraft design: a conceptual approach*. 3rd edition, American Institute of Aeronautics and Astronautics Inc., Reston, 1999.

[11] Liu H, Wu Z, Wang G L and Wang X L. Implementation of a sketch based approach to conceptual aircraft design synthesis and modeling. *Chinese Journal of Aeronautics*, Vol. 20, No. 4, pp. 129-136, 2004.

[12] http://www.aerospaceweb.org/design/ucav/. 2001.

[13] Jenkinson L R and Marchman J F III. *Aircraft design projects: for engineering students*. American Institute of Aeronautics and Astronautics Inc., Reston, 2003.

[14] Raymer D P. *RDS-STUDENT: Software for aircraft design, sizing, and performance*. American Institute of Aeronautics and Astronautics Inc., Reston, 1999.

Copyright Statement