Aircraft design education at Linköpings University

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Abstract: Aircraft design is a complex multi-disciplinary task and teaching can easily tend to be too theoretical, not providing the students the tools they need to successfully participate in industrial projects. The approach chosen at Linköping University is intended to create the right balance between theory and practice, and to place the student in the centre of the problem, in order to achieve an overall perspective of the aircraft design process. This article presents in brief layout of the courses, and in more detail, the aircraft design project course given in the last year of the aeronautical masters program, where flying hardware is designed and build, in response to a design challenge.

Keywords: aircraft design, education, student project

1 INTRODUCTION

Aircraft design at LiTH is a comparatively young education; it started in full-scale in 1997. The initiative came from SAAB and LiTH with Saab, with SAAB personnel giving a helping hand from the very start in building up education as well as in creating a positive research environment in aircraft design.

Aircraft design is a part in mechanical design and runs over the 3rd and 4th year. In the 4th year, education is centred on an aircraft project. The main goal of the project is to provide means for practical application of theoretical aeronautical knowledge being gathered over the years. The aircraft projects centre on designing, building, and flying aircraft models of different sizes and for different applications. The students work together covering the whole process of 'real' aircraft design, i.e. conceptual design, detail design, analyses, manufacturing, and flight tests.

2 EDUCATION CHALLENGES

Over the years, there has been a dramatic reduction in ongoing aircraft projects.

Today's aircraft design engineers are lucky if they are involved in one or two complete projects during their entire careers. This is in sharp contrast to the golden age, when an engineer was likely to be part of several projects during his career (Table 1).

This situation creates an issue regarding the education of aircraft design engineers. When they start their professional life they will be integrated into an ongoing project and may be involved in that process for a long time before anything new appears. The teaching approach as proposed by Linköpings University is to allow future aircraft design engineers to participate in a complete aircraft project, from requirements to flight testing as a preparation for their very first steps in industry.

The other main challenge in aircraft design education is changing demands from the industry regarding the type of knowledge the yet to be engineers should be educated for. Almost all the educational systems, in aeronautical engineering, are focused to develop the analytical skills of students and to a lesser degree develop the synthesis capability or the innovative perspective need for design. Recent changes in educational perspective such as the CDIO (*Conceive, Design, Implement, Operate*) initiative [**1**], initiated by the Aerospace Institute at MIT and tree Swedish university, Linköping's university being one among them, try to apply a more synthetic view on engineering education, by introducing some portion of practical work into the regular courses. This approach is adopted in a larger scale for the aircraft design education at Linköping's University, and was even adopted before the creation of the

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Table 1 Design careers length versus military aircraft designs by decade (adapted from Scott [**7**])

Time span	Aircraft projects
1950–1980	XP-5Y, A-2D, XC-120, F-4D, F-3H, B-52, A-3D, X-3, S-2F, X-2, F-10F, F-2Y, F-100, B-57, F-102, R-3Y1, A-4D, B-66, F-11F, C-130, F-101, T-37, XFY, F-8U, F-6M, U-2, XY-3, F-105, X-13, C-133, F-107, B-58, F-106, F-5D, X-14, C-140, T-2, F-4, A-5, T-39, T-38, AQ-1, X-15F, F-5A, X-1B
1960–1990	A-6, SR-71, SC-4A, X-21, X-19, C-141, XB-70, XC-142, F-111, A-7, OV-10, X-22, X-26B, X-5, X-24
1970–2000	F-14, S-8, YA-9, A-10, F-15, F-18, YF-17, B-1B, YC-15, YC-14, AV-88, F/A-18
1980–2010	F-117, F-20, X-29, T-46, T-45, B-2, V-22
1990–2020	YF-22, YF-23, JSF, C-17
2000–2030	UCAV, B3, ?

CDIO initiative. In the same spirit Young [**2**] argued in favour of design project in engineers' education.

Nowadays, it is more important to work together in teams and the new engineer needs to be able to perform as an individual in that team. Being able to present results and ideas in a selling manner is also becoming increasingly important. Another important aspect is to be able to convert his/her own ideas into something practical and useful. This is something which Universities seldom care very much about, but which is no doubt important, i.e. to bridge the gap between a previously mostly theoretical life, into a more practical one in industry. One of the most important issues for an engineer is to be able to gain a holistic viewpoint from the very start in working life, with regard to the product, or project the engineer is involved in. Possessing this holistic view makes life easier for everyone and saves time as well as money in the long run for industry. One way of preparing for that insight is to carry out projects like the aircraft design project in Linköping. This directly corresponds to the type of engineer McMaster [**3–6**] forecasts for the future of aircraft design, as described in the series of article 'The demise of aerospace- we doubt it'.

3 EDUCATION PLAN

The aircraft design curriculum covers the two last years of the Mechanical Engineering Master program, illustrated in Fig. 1, note that only the courses explicitly related to aeronautics are showed. In the second semester of the last year, the students work on a project. The aim of the project is to design and

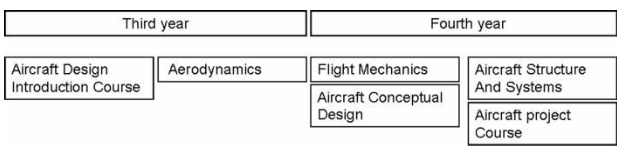

Fig. 1 Process flow during the project

produce a flying object of some sort that have to be flown, thereby combining theory with hands-on practical work. The project finishes up with evaluation by means of test flying and comparison with the calculated performances. Compared to other similar approach around the world, Linköping's University tries to adopt a unique approach, contrary to other university where manufacturing of the projects is realized only in some cases, all projects have to be build and flown. The other differences compared to some UK-based universities, for example the approach proposed by Cranfield University [**8**], is that the conceptual design is entirely done by the student, out from a requirement list, and that all manufacturing must be done inhouse at the university by the students. A large part of the project is dedicated to conceptual design in order to stimulate the creative and multi-disciplinary thinking. The lectures can only advice the student, and try to keep an open mind to every proposed solution as long as the student proves that he or she has fully analysed the proposed concept. Doing an aircraft design and then building and testing it, means that the student has to focus on realistic designs that can be produced in the limited time with limited resources. Furthermore, the experience that also the details can be difficult, and needs to be solved is also enlightening.

Since time (and student skill) is limited, only model sized aircraft are considered. This constraint is in reality no set back, since model aircraft design involves many steps in real aircraft design. The emergences of many small-scale UAVs and growing interest in subscale flight testing legitimates the fact to design build and test fly smaller scale aircraft in the same manner as performed in industry. In order to represent a real project and not only build a simple RC model the different project proposed each years is technically challenging and are trying to explore new concept types, and not just reproduced a miniature version of an existing aircraft.

The project courses allow the student to integrate and use all theoretical knowledge acquired in earlier courses. This integration reduces the gap between theory and practical product development for real life.

4 STUDENT PROJECT

The project course covers one full semester and represents half time work for that semester. The number of students varies from year to year. Generally there are about 12–14 students involved in the project. Very often there are participants of four or five different nationalities. This more or less mirrors the national mix in today's European aircraft industry.

4.1 Project structures

The main goal of the project course is to allow the students to integrate their previous knowledge, and search for any other need, in order to complete a given task. The education method can be related to project-based learning (PBL) in reference [**9**], a pedagogical theory where the students need to solve a problem by their own and the project supervisor (the lecturer) guides the student towards the project by indicating where the needed information can be found. Typical literature used in the course is Raymer [**10**], Pamadi [**11**], Roskam [**12**], Stevens [**13**], Torenbeek [**14**], and the AIAA and NASA paper data base.

The project structure is very compact since the course covers everything from conceptual design to flight test; the process is illustrated in Fig. 2.

In order to fulfil the requirements the student must come up with a time plan, and they are in charge of the advancement and on respecting of the time line. The supervisors are acting as the customer and the owner of the project. Time planning and advancement of the project are presented by the students in a weekly meeting.

As the project covers the entire design process from concept to flight testing the students are divided into different groups during the different phases of the project. Typically, during conceptual design different small groups, up to four students, compete for the best concept proposal. At the end of the conceptual design study, all groups should come with a proposal based on the concept generated in each group. The final decision is up to the project supervisor. When the project moves onto preliminary and detail design a more conventional group formation is adopted: the groups are in charge of one discipline such as aerodynamics, structure, flight mechanics, configuration management, etc. During the manufacturing, the roles are divided into parts to be manufactured.

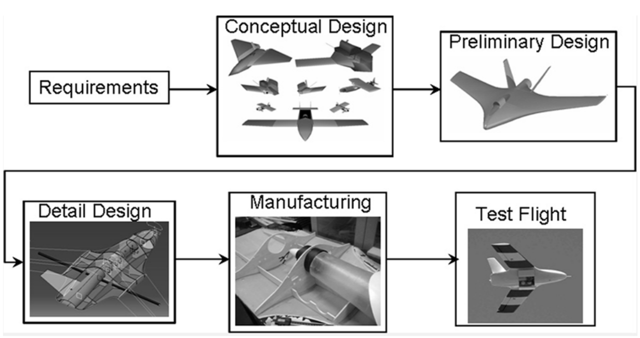

Fig. 2 Process flow during the project

4.2 Tools used

Since the time schedule for the entire project is so short, there is no time for the use of advanced computational tools such as: CFD or FEM. The students use rather conventional and efficient tools such as lifting line theory for the aerodynamics and advanced CAD software for the design and modelling of the aircraft. In order to collect all the obtained data from the different calculation methods, the students use an in-house developed sizing program.

An exhaustive list of tools is presented here.

1. The aerodynamic calculation are performed with vortex lattice program, Tornado [**15**].
2. The three-dimensional modelling, inertia, and weight estimation are realized in CATIA V5.
3. The flight simulation are realized with an open source software, Flight Gear [**16**].
4. Flight mechanics are computed in a Matlab code.
5. All sizing and preliminary calculations, as well as performances are realized with an in-house developed Excel-based sizing program.

5 PROJECT EXAMPLES

In 1999, R/C controlled 'Sunrazor', (Fig. 3) which was built in the sole purpose to test, if it would be possible to design, build, and fly a sun powered aircraft of an in-house design. The model had an electrically powered motor, which ran solely on sun power. The model was able to fly on 15 W of sun power only, which means flying was possible on partly cloudy days as well. To minimize structural weight the flying wing concept was chosen. The aircraft was built using mainly balsa for the main structural items and plastic for covering. It was designed for an all up weight of 1.5 kg, but came out lighter at 1.1 kg when actually built. The mid-part of the wing was covered with 256 very brittle silicon solar cells, which were soldered together manually (very time consuming) in series and in parallel, to provide the needed voltage and current to the motor. The

Fig. 3 Sunrazor a sun power flying wing

motor was designed to run on 30 W maximum, which put the limit to the number of solar cells needed, although the model was designed to fly on 50 per cent power (15 W) to ensure flying would be possible on a partly clouded day, i.e. a typical relevant Swedish weather condition. The aircraft was controlled by means of a pair of ailerons, i.e. a combined aileron and elevator function, mixed in the ratio. The aircraft had no landing gear. It was hand launched and landed on its belly. A foldable propeller ensured structural integrity. During initial flight tests the aircraft performed extremely well, climbing away at quite steep angles. Unfortunately, the aircraft was later lost beyond repair due to a flutter incidence, which broke the wing in half. Presumably, a much too low structural stiffness finally paid its price.

Local Hawk was built in 2000 and illustrated in Fig. 4. It was dedicated to flight testing and therefore needed to be quite conventional and simple in its layout. The difference between an ordinary model plane and the local Hawk was essentially the number of control surfaces (the same as on an ordinary aircraft) and the ability to be able to carry flight test equipment and a number of built-in sensors. The Local hawk presented a wingspan of 3 m and a maximum take of weight of 4.5 kg, including 1.5 kg of instrumentation. Flight test data were fed into a data logger during flight. After landing the information was unloaded into a laptop for further analysis.

The Lucas project of year 2001 (Fig. 4) was built with the same purpose as for the previous local Hawk, i.e. flight testing. The difference was its more advanced layout due to the built-in Stealth appearance in the former and thus less predictable handling qualities. The aircraft could carry flight test equipment and sensors on board. To enhance the Stealth and jet-like appearance the motor was an electric driven fan, hidden in the fuselage. Lucas was R/C controlled and had a motor producing 1200 W. Engine installation and stability issues were the main difficulties encountered during the project. The engine installation complexity was dependant on the stealth requirements and the fact that it was hidden into the body without a direct line-of-sight from the front. The stability issues were due to the shined forebody and the difficulties to determine the forebody influences and characteristics. In order to improve the lateral behaviour thrust vectoring was implemented in one dimension.

In 2002, something very different was the scope of the project. It was the design of an ornithopter, baptized ‘The Crow’ (Fig. 5). The ornithopter was electrically powered with a motor rated at 7 W, which worked through a gear box to give the 4 Hz flapping frequency required for flight. The model was R/C controlled, weighed 95 g and could carry a small video camera onboard. The ornithopter was built with an exchangeable wing, so that different wing configuration could easily be tested. The ornithopter was built using balsa and carbon fibres. Covering of the wing was made of a very light plastic film. One

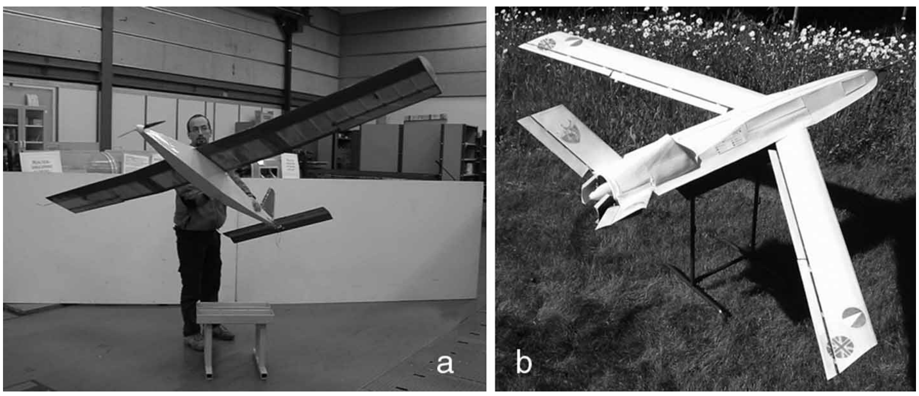

Fig. 4 Student project (a) Local Hawk, (b) LUCAS

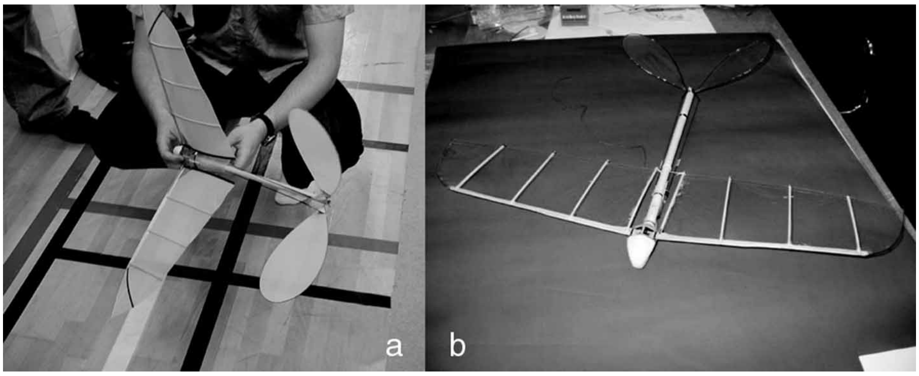

Fig. 5 Flapping wing project (a) The Crow, (b) Woodpecker

of the main challenges, at that time, was to find suitable batteries and components for the mechanism and the control. The resulting airplane is one of the first small scaled flapping wing with a useable payload ever produced.

Inspired by the previous ornithopter project, the project of 2003 also became an ornithopter, which built on the previous experience and the possibility to make the machine even lighter and smaller by using lighter and more effective batteries. The Woodpecker (Fig. 5) thus was born, and was in fact a scaled down version of the Crow. The motor delivered 3 W, which made the machine flyable at an all up weight of 46 g. The Woodpecker was R/C controlled and was able to carry a video camera onboard. By reducing the size from the previous flapping wing concept the student had to deal with weight issues and low Reynolds number aerodynamics.

In 2004 the students worked on a so-called 'backpacker' design, one named 'Black square' and the other one 'Pink widow', illustrated in Fig. 6. The 'backpacker' concept represents an R/C controlled electrically powered aircraft, used for over the hill reconnaissance. Since it was supposed to be used in a difficult and harsh environment, it had to be easy to control, easy to pack, easy to handle, more or less unbreakable, and not too sensitive to gust. The payload was a video camera for laptop flight plus a GPS for position control. The aircraft had to be easy to pack by design and was also required to be housed within the measurement of an ordinary laptop case, $300 \times 400 \times 60$ mm. Two teams worked on the same specification and came out with slightly different solutions. Both were flying wing concepts, due to the package and handling requirements. The Black square concept shown in Fig. 6 had a simple and smart solution to the package problem and proved almost unbreakable due to the material chosen. The wing although slightly denser was made in EPP, extruded polypropylene, offering the same advantage as classical foam material but with extra strength. This material is a shock absorbant and resilient; a person would be able to jump on it without breaking. This project presented interesting issues regarding low Reynolds number, stability, and control of small UAV and piloting by using only the pictures produced by the on-board camera.

In 2005, the project course and design moves back to something bigger than the last years. The full project is presented here in more detail to illustrate the complexity of the project course, and how it covers several aspects of aircraft design.

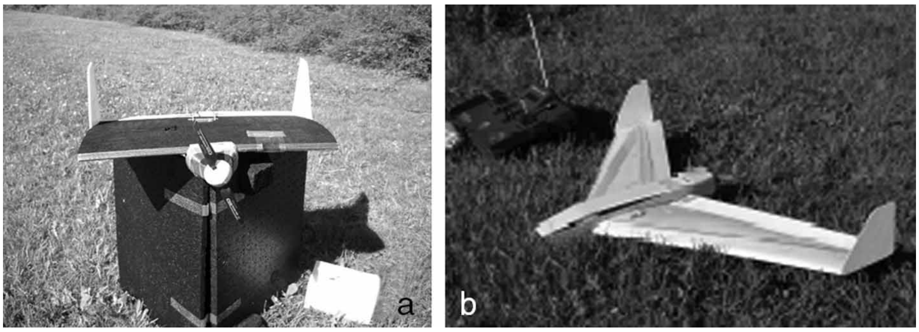

Fig. 6 Mini UAV project (a) Black square, (b) Pink widow

5.1 2005 Project description

The goal with this project is to develop, build, and flight test a demonstrator for an unmanned rescue/ reconnaissance aircraft adapted for civil as well as for military use. The aircraft (from now on called the mothership) should be able to fly in the shortest possible time to the coordinates of observation, loiter to find the target and release, two smaller babies/ micro aerial vehicles ((MAVs) carried internally or partly submerged) equipped with real time video capabilities to provide a better view of the target. The development and manufacturing of those MAVs is also included in the project. Each MAV must be able to carry a payload of 11 g (a camera and video link). In excess of the two MAVs, the mothership must be able to carry an extra internal payload of 400 g, besides internal provisions for a camera. In order to allow for easy transportation, the whole package (mothership as well as carried babies) must be easy to handle, should not break too easily and must be easy to mount as well as dismount.

The overall performance should allow dash speed in excess of 90 km/h at 70 per cent throttle.

The aircraft must also have a good performance at low speed to allow for a long loiter time when searching the desired area/target. In order to meet possible military requirements, aspect such as a reduced radar cross section might need to be included. Trade studies showing penalties due to 'Stealth design' must be presented. In order to meet high as well as low speed requirements, aspect such as a 'morphing wing' studies should be included, but need not be implemented. The project requirements are described below.

The mothership should have the following basic characteristics:

(a) radio controlled;
(b) propulsion based on Wemotec HW750 fan and plattenberg HP 370/30/A2S engine;
(c) designed to minimum weight;
(d) to be housed within a transport volume of: $1 \times 1.7 \times 0.8$ m;
(e) endurance: 15 min at 50 per cent throttle;
(f) stall speed as low as possible;
(g) minimum rate of climb 3 m/s;
(h) payload:
    (i) two small MAVs of max 200 g/each to be carry internally/partly submerged in the fuselage/wing;
    (ii) 400 g extra payload in excess of the above.

Each MAV shall have the following basic characteristics.

(a) radio controlled;
(b) payload of 11 g (a camera).

5.2 Time line

The project runs under the entire spring semester, from mid-January to beginning of June. The student where given the following deadlines to respect.

1. January 19th: start of the project.
2. January 21st: presentation of time plan.
3. 11th February: presentation of conceptual design studies and proposal for the concept to proceed to detail design.
4. 25th February: individual interview (10 min/pers).
5. 11th March: complete drawing set for mould manufacturing.
6. 13th May: first flight.
7. 20th May: individual interview (10 min/pers).
8. 26th May: preliminary report.
9. 10th June: final report.

From these deadlines, the student had to come up with plan for the entire project. The planning was weekly reviewed and adjusted if needed.

5.3 Concept generation

In this stage the students were divided into four groups, all working on conceptual design, some of them are illustrated in Fig. 7.

The project supervisors saw that none of the concepts proposed by the students was feasible. They were given an extra week to come up with a new proposal based on request from the project supervisor. The final proposal is illustrated in Fig. 8.

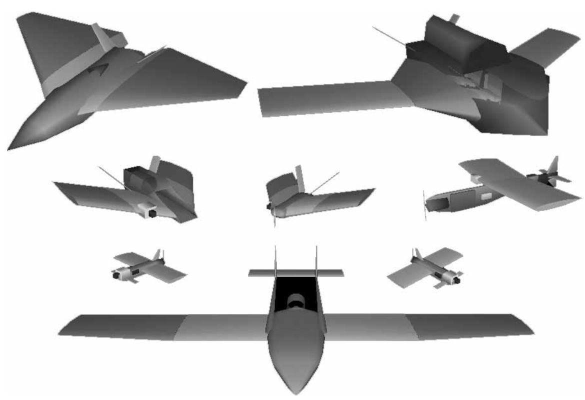

Fig. 7 Concept for the 2005 project

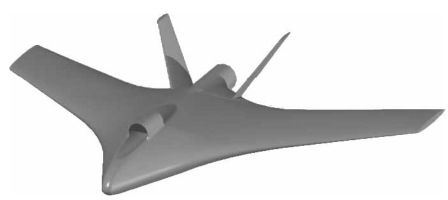

Fig. 8 Final concept accepted by the supervisor

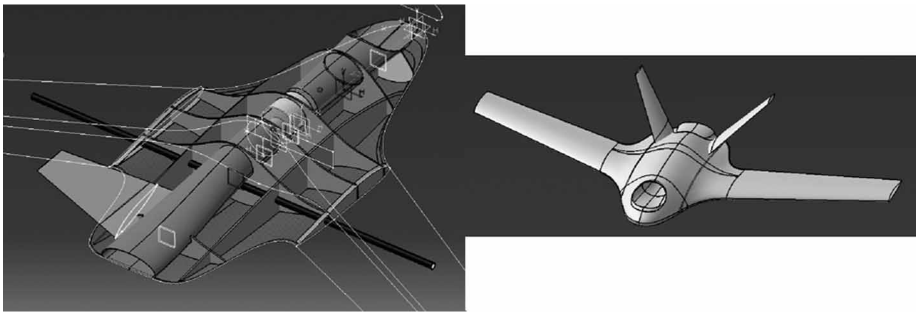

Fig. 9 CATIA V5 modelling and structure layout

Fig. 10 Illustration of the manufacturing process

5.4 Preliminary and detail design

In this stage of the project, the students were divided into different areas, such as, aerodynamics, structures, flight mechanics, etc.

During this stage, an intensive work is realised, and the students learns to work as a team, since several disciplines are linked and dependent on each other, the students are forced to interact and to understand what the others are working with, and each week they have to present what they are working on to each other.

Figure 9 illustrates the detail design work realised in CATIA V5. The model is parametric such that changes will automatically propagate through the design. The mothership was manufactured in composite. Full documentation and CAD model were needed to send to a mould manufacture. At that point the external layout was frozen and internal structure and system installation entered in its final design phase. The students decided to build a simple structure mock-up prior to the manufacturing of the final structure. This was performed in order to assure that no last minute change will be necessary.

Manufacturing is illustrated in Fig. 10. The skin of the aircraft is build in composite. It consists of a sandwich structure, and the curing is realised with bagging and vacuum, with manufacturing techniques fairly close to those ones used in the industries.

By obliging the students to manufacture the aircraft, they realize that drawing an entire structure is time consuming but not so hard, and producing a nice CAD drawing, where everything fits perfectly, is not an easy task. This experience is considered to be very valuable.

The final aircraft is illustrated in Fig. 11. The aircraft performed several flights. Preliminary flight tests partly confirmed the results calculated by the students.

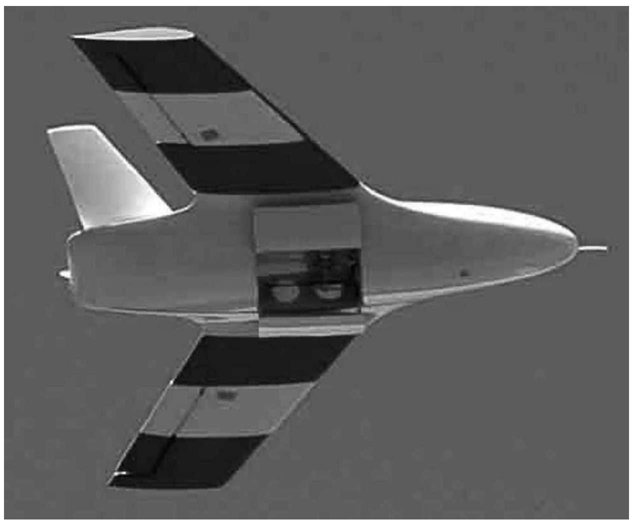

Fig. 11 Final aircraft performing a test flight with bay doors open and dropping of a micro air vehicle

6 CONCLUSION

Many different teaching models exist in aircraft design education. The one used at Linköping University is a mix of theoretical teaching and ‘hands-on’ approach. This allows the future engineers to understand the complexity of aircraft design, by setting themselves in the centre of a project. The students are given the opportunity to work on an entire aircraft project and see the results of their effort flying at the end of an intensive workload. This approach gives the student a broad knowledge of aircraft design, as well as a deeper knowledge in a particular field depending on the area they have been working in the preliminary and detail design phases. Finally, the experience of having successfully participating in a challenging project, build confidence in the student they make good use of as engineers.

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