The EB-2 Fly-Lab of the Warsaw University of Technology

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Abstract

The paper describes a project undertaken at the Warsaw University of Technology (WUT) to develop mobile aerodynamic laboratories to measure the pressure distribution around an airfoil at a natural scale and in the atmosphere. The first phase consisted of the design of the wind-tunnel stand fixed on a car roof. The wing airfoil section with flap to be tested was placed between two side-plates and this configuration was the research element (Element Badawczy in Polish, marked as EB-1). The aim of EB-1 tests was the verification of measurement methods and equipment. To gather airborne data, a similar research element was constructed and fixed to a PW-6 glider and called the EB-2 flying laboratory. The procedure of airworthiness required several tests before the first take-off (in the field of stability, strength and flutter analysis). The first test flight was made in summer 2006 and proved the serviceability of a new flying-lab for aerodynamic investigations. The details of these unique experiments are given in the paper.

Introduction

Designing high quality airfoils for glider wings is closely associated with numerical methods of flow modeling, wind tunnels tests and the investigations conducted in the atmosphere (Fig. 1). The main problems connected with airfoil design are drag minimization, which depends on such issues as boundary layer profile and the phenomena of transition to turbulence flow on the airfoil surface. Several parameters influence the transition especially the Reynolds number and the free-stream turbulence. Also, the aerodynamic characteristics measured in different wind tunnels can be different. Moreover, they can vary from those measured under natural atmosphere conditions. This is due to different spectral densities of turbulence. One can ask why make any wind tunnel tests, since nowadays several tools exist for modeling the airflow (for example XFOIL, Fluent, etc.)? The answer is that results from numerical modeling still need the experimental verification because some 3 or 5 % error in the case of high performance gliders can be significant.

Wind tunnels used for experimental verification of computation results can be divided into two categories: the high Reynolds number devices and the low Reynolds number devices. The cost of airfoil testing strongly depends on which category is used. The Warsaw University of Technology (WUT) aerodynamic laboratory is equipped with the low Reynolds number wind tunnels shown in Fig. 2. They are effective but, in many cases, they do not ensure the required accuracy of measurements for high performance airfoils.

To obtain the required measurement accuracy, a new research-educational project was undertaken: to design and test the mobile aerodynamic laboratories. The laboratories were to be used mainly for pressure-distribution measurements around an airfoil in the atmosphere[1, 2, 3] (Fig. 3).

EB-1 – the mobile wind tunnel

The first phase of the project consisted of the design of the wind-tunnel test stand fixed on a car roof (Fig. 4). The research section is comprised of the airfoil and flap to be tested. The element was fixed between two large perpendicular side-plates and designated EB-1 (Element Badawczy in Polish). The EB-1 was used mainly for testing the hardware for the pressure-distribution measurements. Figure 5 shows some phases of the manufacturing process of the airfoil moulds. The moulds of the wing halves were made from PROLAB on a CNC milling machine. The surface of the moulds was coated by with gel coat and then graphite-reinforced-plastic (GFRP) composite shells were formed. The last step in manufacturing the moulds was the stiffening by means of composite shear webs. The structure of the research element is shown in Fig. 6. In the case of the EB-1, the GFRP composites were applied and the Interglas-symbols of the fabrics used are indicated in Fig. 6.

The details of the internal structure of the wing and the system of wing-drainage necessary for the pressure measurements are presented in Fig. 7. On the surface of the wing, 72 holes were drilled, 0.4 mm diameter each, which later were connected to the electronic pressure sensors. The EB-1 was installed on a special frame to adjust the angle of attack and attached to the roof of a car. The frame was attached high enough to avoid the car's influence on the flow. Figure 8 shows the mobile wind tunnel ready for tests.

Testing mobile wind-tunnel

Experiments were performed on the 3 km long runway at an airfield near Warsaw. A sample of the registered pressure signals (without filtration) measured at chosen points on the wing as a function of time is shown in Fig. 9. The first half of the chart refers to the car acceleration phase (up to 100 km/h), and the second half refers to the deceleration phase. As can be seen, the constant speed phase was small due to the fact that the 3 km long runway was not enough long for this kind of experiment. On the basis of the registered pressure signals, the plots of the pressure distributions around the airfoil were made.

EB-2 – flying wind-tunnel

Based on the knowledge gathered from the EB-1 experiments, the main part of the research program was launched: the design of the fly-lab. It is necessary to mention that the idea of the fly-lab built on a glider is not new. Figure 10 shows two Polish projects conducted as early as the 1960's. Also, previous work includes the well known is the German fly-lab built on a Schempp-Hirth Janus glider (upper part of Fig. 11). Another concept of the fly-lab was developed in Lithuania based on two Blanik gliders.

The authors decided to use the PW-6 glider. It is well known this glider was designed at WUT and the first prototype has been available for research programs at the University. The design concept of the fly-lab is shown in Fig. 12. The new research element of the lab is called EB-2. Figure 13 presents the dimensions of the EB-2. This time the CFRP composites were used for the wing and flap. The flap deflection system was completely hidden inside the wing so the wing surface was free from any obstacles. The wing shells were manufactured using vacuum technology. The internal structure of the wing and side plates is presented in Fig. 14. Inside those plates was stored all the electronic equipment necessary for the pressure distribution measurements.

The design and manufacturing processes were crucial for the project, but they did not take as much time and effort as the airworthiness related tests. The airworthiness procedure required performing a number of calculations and tests (flight stability, strength and flutter analysis) before the first take-off. Figure 15 presents a sample of the strength test and Fig. 16 presents some flutter animations made by Wojciech Chajec, a well-known Polish flutter specialists.

Having encouraging results from all necessary pre-flight investigations, the fly-lab was ready for the first flight. The main aim of the first EB-2 flight was to confirm stability of the glider with the wind tunnel test stand mounted on top. The first take-off was made in the summer 2006 at the same airfield where the EB-1 was tested. Having safety in mind, a car tow was chosen as the launch method. For this purpose, an off-road car, equipped with a special release system and 600 m of polyester rope, was used as the towing machine. This launching method allowed the glider to reach the altitude of 200 m. The first test was successful, i.e. the flight stability was proven as well as a brief fore-design. The pilot reported that the dynamic behavior of the fly-lab was good and the descent rate was only slightly higher than normal.

The EB future

The results obtained during the second (flying) phase of EB project have paved the way for further investigations. The first should prove the safety of the fly-lab operation. The long-term plans are the following applications of the fly-lab:

•Multipoint pressure measurements – pressure distributions over the airfoil
•Noise level measurements within the boundary layer
•Application of the hot-wire technique to velocity time course recording – analysis of turbulent pulsations and turbulence scales
•Determination of the transition point
•Active and passive control of transition
•Flow visualization

It is worthwhile to emphasize the educational aspect of the EB project. In all phases, students of WUT were engaged and their participation was an integral part of their curriculum at the Faculty of Power and Aeronautical Engineering.

Acknowledgements

Figure 8 presents the authors of the article. Piotr Sierputowski (1949 – 2008) was the initiator and promoter of the EB project while Miroslaw Rodzewicz was the chief designer. The successful completion of the project would not have been possible without support provided by the following: J. Gadomski M.Sc. (detailed project and strength calculations); W. Chajec M. Sc. (flutter simulations); K. Kubryński Ph.D. (aerodynamic calculations); T. Grabowski Ph. D. (stability evaluations); W. Fraczek M.Sc. (supervision of the PW-6 glider, and documentation for the aviation authorities); K. Drabarek M. Sc. (logistic assistance); technicians: J. Głuchowski and A. Pruszkowski (structure manufacturing); students: N. Borowiec, M. Cwiek (EB-1), and D. Glowacki, P. Marek (EB-2); the test pilot was J. Kedzierski M.Sc. The assistance of the Polish aviation authorities is appreciated.

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[2] Rewucki P., Rodzewicz M. Sierputowski P., "Aerodynamic investigations of a wing element in a real atmosphere" (in Polish), Proceedings of Conference *Mechanics in Aeronautics*, 2004

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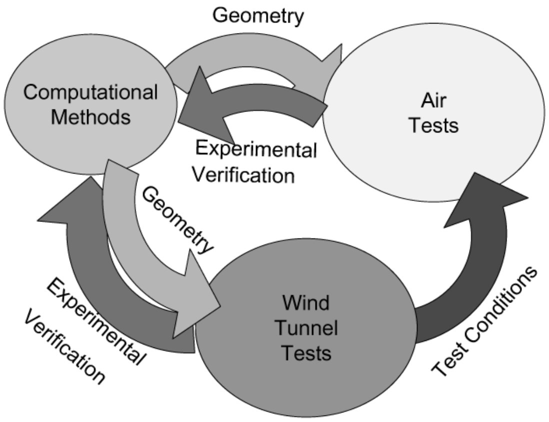

Figure 1 Aerodynamic design of high performance gliders

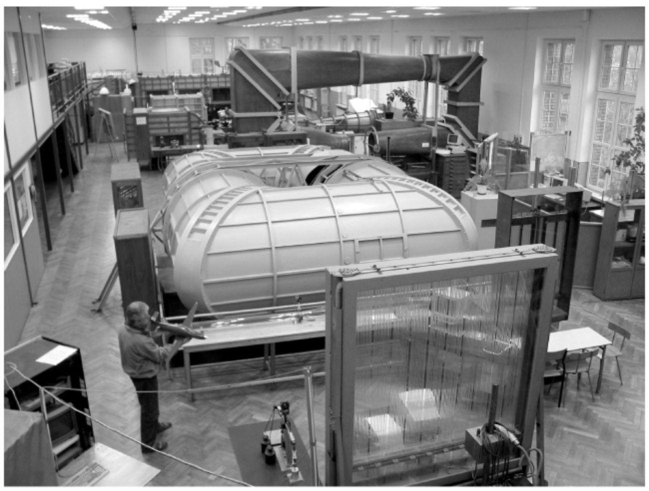

Figure 2 Aerodynamic laboratory at the Warsaw University of Technology (WUT)

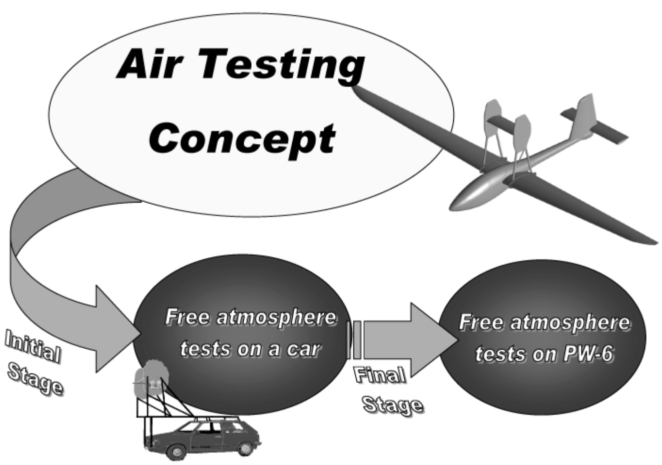

Figure 3 Scheme of experiments

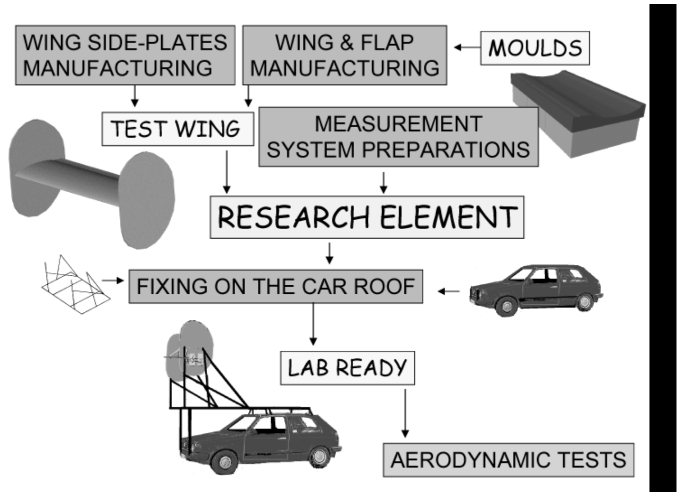

Figure 4 EB-1 project

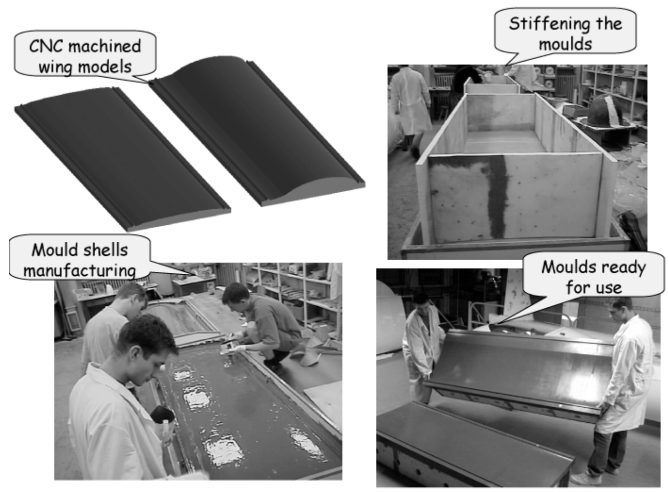

Figure 5 Manufacturing the moulds

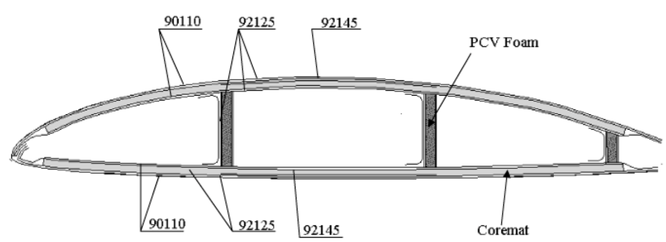

Figure 6 Wing cross section with Interglas-symbols of used fabrics

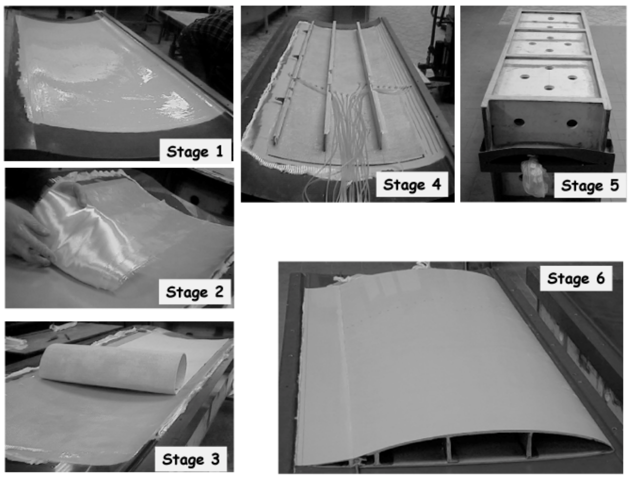

Figure 7 Manufacturing the wing

Figure 8 EB-1 ready for tests. From left to right: Piotr Sierputowski and Miroslaw Rodzewicz

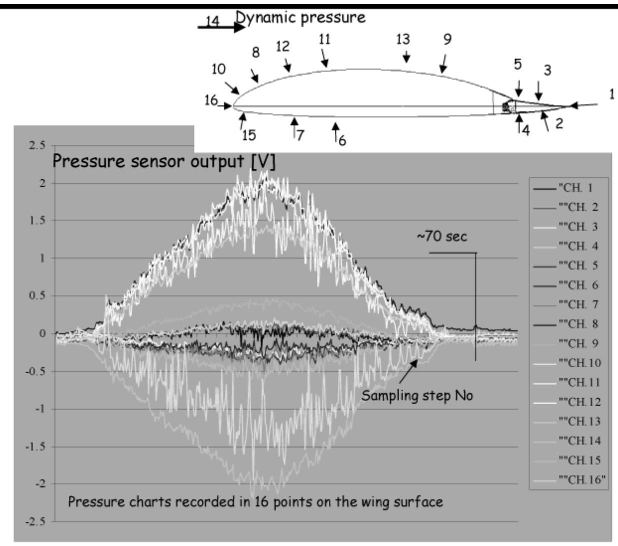

Figure 9 Example of registered pressure signals

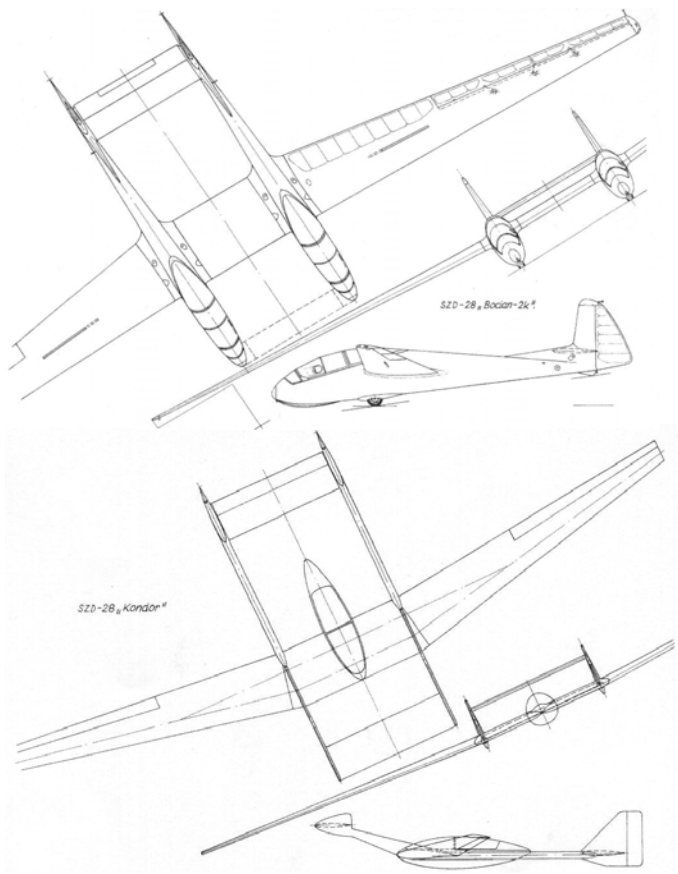

Figure 10 SZD – projects the years 60 of the XX Century

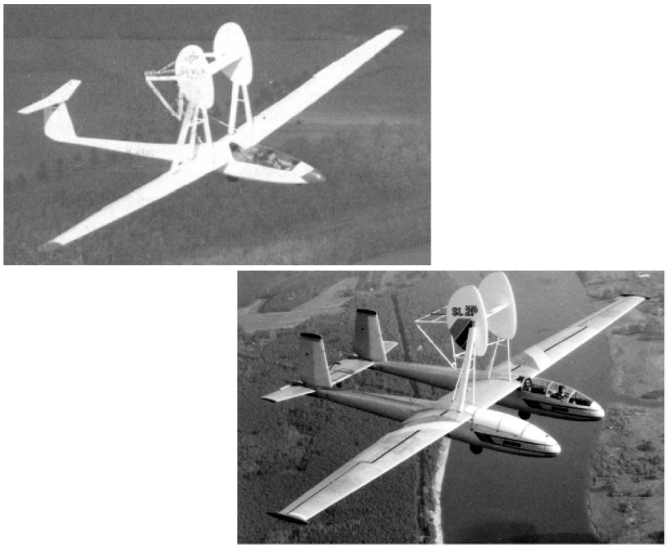

Figure 11 Schemp-Hirth Janus glider as a fly-lab and the Lituanian fly-lab based on the Blanik glider

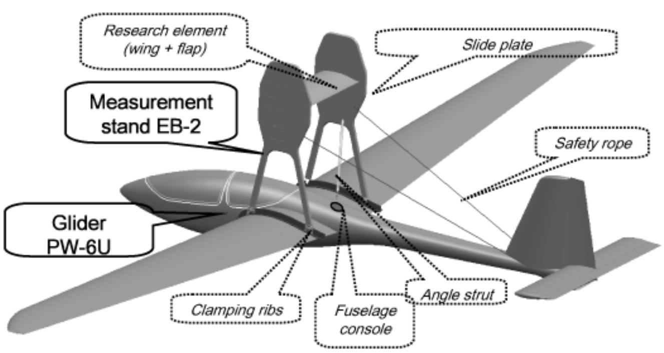

Figure 12 EB-2 fly-lab of Warsaw University of Technology

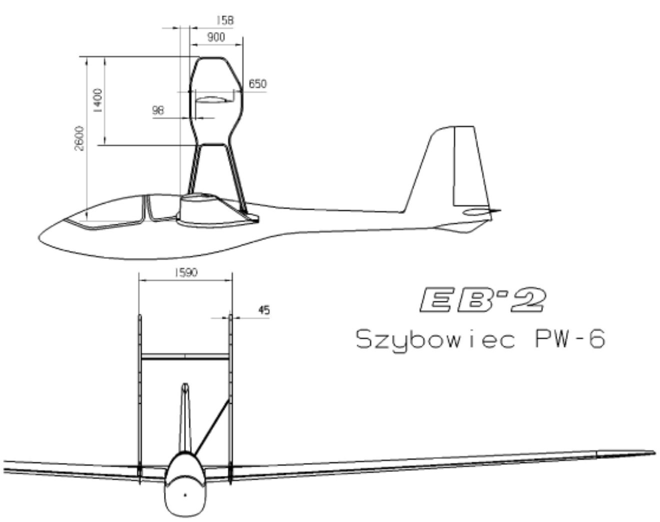

Figure 13 EB-2 dimensions

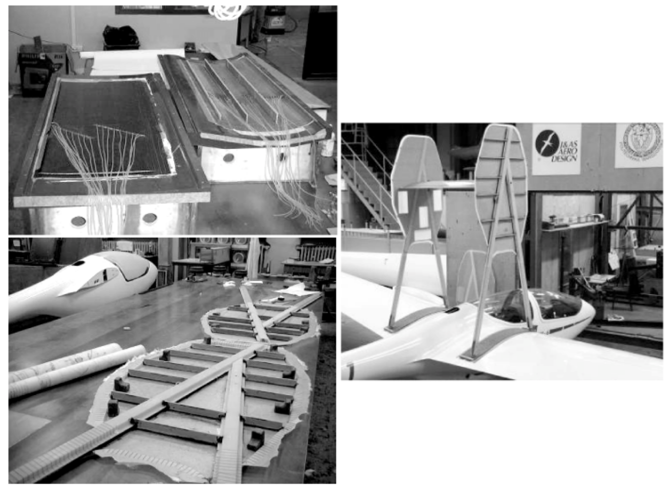

Figure 14 Manufacturing the wing and side plates

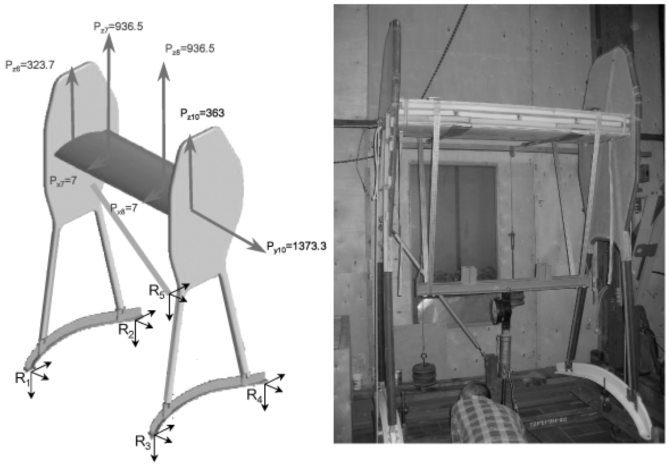

Figure 15 Strength tests

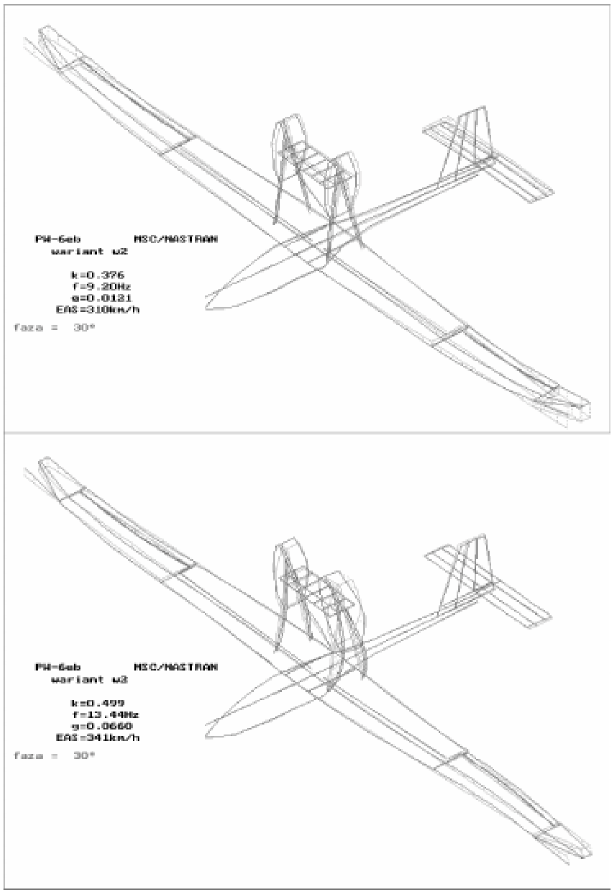

Figure 16 Resonance tests and flutter analysis

Figure 17 First take-off

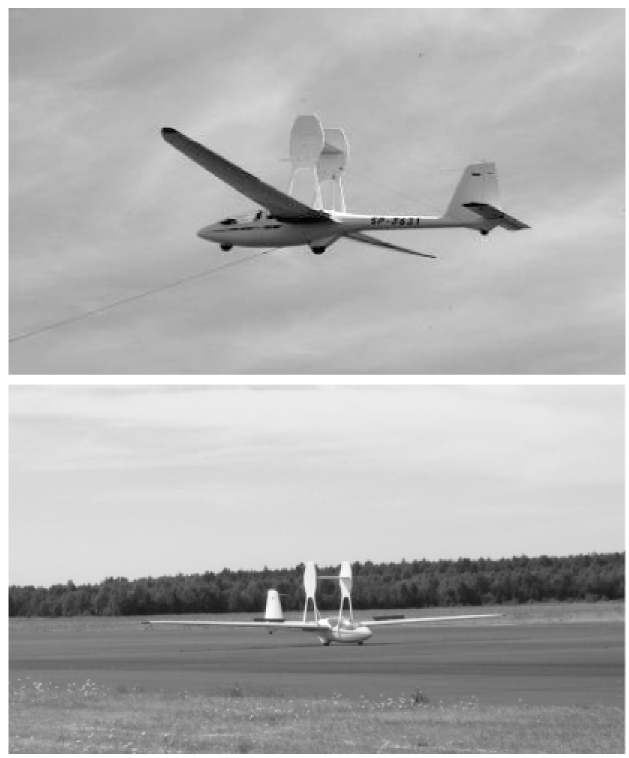

Figure 18 EB-2 in the air and back on the ground