Learning by doing: An innovative laboratory exercise to enhance the understanding of thin-walled Mechanics of Materials

Gillian N. Saunders-Smits, Jan de Vries

Faculty of Aerospace Engineering
Delft University of Technology, Delft, The Netherlands

Introduction

Mechanics is widely considered to be the core of any type of construction engineering course in the world, be it a mechanical, aerospace or naval architecture engineering course. Yet at the same time it also considered by many students as one of the most difficult subjects in the course and something they have great difficulties coming to grips with, as many of us experience on a day-to-day basis. This problem is becoming more and more apparent with the ever-changing focus of high schools. The challenge for Mechanics lecturers is to overcome those shortcomings and to keep students motivated and interested in Mechanics.

This paper reports on the introduction of a laboratory exercise in the second year of our BSc curriculum at the Faculty of Aerospace Engineering at Delft University of Technology in the Netherlands aimed at improving the understanding of the mechanical behavior of structures as well as increasing the student's motivation.

Mechanics education in the BSc Aerospace Engineering

At the faculty of Aerospace Engineering at Delft University of Technology in the Netherlands students have to complete a basic mechanics course of 11 ECTS (European Credit Transfer System, 1 ECTS = 28h, 60 ECTS in a year) in their first year. The course consisting of a Statics (4 ECTS), Mechanics of Materials (4 ECTS) and a Dynamics part (3 ECTS) is based on the well-known books by Meriam & Kraig[1,2] and Gere[3].

In the second year the mechanics courses are more applied to the subject of aerospace engineering and we continue the Mechanics of Materials education in the course aircraft structural analysis, a 3 ECTS course, based on the book Aircraft Structural Analysis for engineering students by Megson[4]. This course is perceived by our students as a difficult course and traditionally has a low pass-rate. In order to try and improve the understanding of aircraft structural analysis and to improve the pass rate a laboratory exercise was set-up allowing students to get a better feel for the subject matter.

Objectives and set-up of the exercise

The objectives of the exercise are:

- To show the validity of the formulae derived in Aircraft Structural Analysis in real engineering practice
- To practice the theory of Aircraft Structural Analysis
- To observe buckling phenomena
- To demonstrate testing of structures and the inaccuracies introduced in measuring

In order to achieve these objectives students are asked to test a wing box with a cutout.

Set-up of the test

For the test two thin-walled aluminum wing boxes were designed each with a cutout. The cutouts were located either on the right side or on the lower side of the box as can be seen in the figures below.

Figure 1: The wing box with a cutout in its side in the test rig

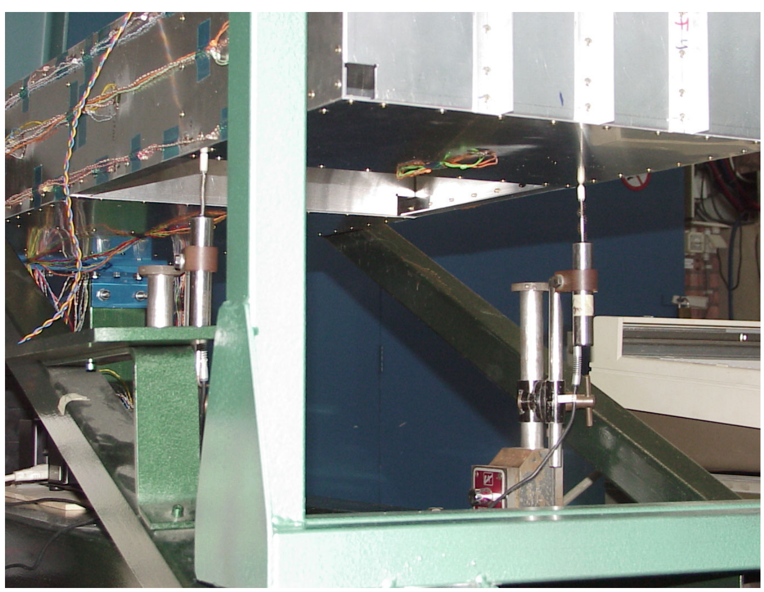

Figure 2: The wing box with a cutout in its lower side in the test rig and the linear voltage displacements transducers

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Each box consists of 5 bays, each separated with an aluminum rib, with a cutout in the second bay from the tip. The box is clamped at the end of bay 5. The box is 1500 mm long, 400 mm wide and 150 mm high. The ribs are spaced 300 mm apart. An L-profile stiffener with a height and width of 20 mm and a thickness of 1.5 mm reinforces each of the longitudinal corners. The box was put together using pop-rivets. The aluminum used was 2024-T6. Appendix B shows the engineering drawing.

Loading is introduced at the tip of bay 1 by hoisting the tip of the wing box using a set of gears. A load cell is attached to the geared hoisting system. In order to avoid fraud and duplication of measurement results the load can be introduced at three different locations on the tip as is shown in figure 3 and 4. A total of rosettes and single strain gauges have been used in the test. On plates in compression strain gauges have been positioned both on the in- and the outside of the metal skin to allow students to correct for bending.

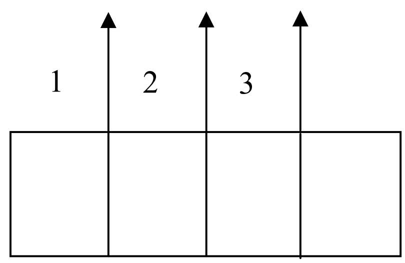


Figure 3: loading options of the wing box

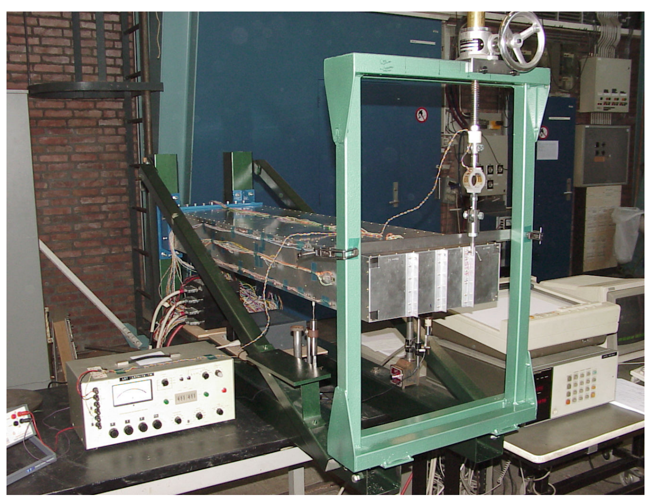


Figure 4: The loading options at the end of the wing box in the loading frame with load cell and jack. The load is introduced here at position 3 thus introducing a torque.

On the first three bays from the tip a large number of strain gauges have been attached to the structure, as well as two linear voltage displacements transducers situated near the tip of the wing box. These are all attached to a data acquisition unit as can be seen from figure 4. After the test the data are stored on Blackboard[7], a commercially available e-learning environment, which is also used during the course. Students can download their data from Blackboard.

Strain Gauges

There are a large number of strain gauges attached on the box. Two of them are glued on the box near the location where the box is attached to the test frame. These gauges will measure the largest strains. Further gauges have been placed on the stringers and on the plates. The plates, which will be in compression during the test, might show some buckling pattern. This means there will be a bending moment in the plates, yielding different strains in the upper and lower side of the plate. At those locations strain gauges are glued on both sides of the panel. The positioning of the strain gauges can be found in Appendix C.

Execution of the exercise

The exercise itself consists of two parts: the execution of the test and the writing of the report. During the test the students increase the load on the wing box in steps of 100 N to approximately 1000N. The test is limited to a 1000N to avoid any possible non-elastic deformation of the wing box. On the computer the students will see a graphical plot of the load versus the displacement of the tip. During the test the students can observe the waving buckling pattern appearing on the wing box during the loading as well as its disappearance when the structure is unloaded.

Reporting

Armed with their observation and their measurements students are now asked to write a report in which they describe the test rig, the test conditions and their observations during the test[1]. The students obtain a text file from Blackboard with in it all the measurements taken. It is up to them to select a suitable load from this file for which they will compare their theoretical results with the measurements. They are asked to work out the data from the strain gauges into stresses and to calculate the theoretical stresses for the idealized structure using the Engineering Bending theory from Megson[4].

The students now compare the measurements data with their analytical results. They will notice some large differences between theory and practice. This needs to be explained by them. The differences are caused by the following:

- The analytical theory the students are using assumes that the plates in the structure only carry shear flows, whereas the stringers carry only normal forces. The cross-sectional area of the plates in the box is not small compared to the area of the stringers. Therefore the plates will carry a large part of the normal load, yielding quite a large difference between theory and practice.
- The concentrated load will cause stress concentrations in the box. Therefore no strain gauges are glued in the vicinity of the load application point. The cutout in the box, modeled by removing a load-carrying panel, is assumed to have an influence on the stress distribution in the box only one whole length before and after the cutout. This is an essential assumption, as this assumption allows the problem to remain statically determined and simple formulas can

[1] Exercise manual is available from the authors upon request (G.N.Saunders@LR.TUDelft.nl or J.deVries@LR.TUDelft.nl).

be used to solve for the stresses. However in reality the influence of the cutout will extend over a larger part of the box, also producing differences between theory and practice.

- When the loading increases, at some point the compressed panels will buckle slightly. The students will use the average value of the measured strains of the lower and upper skin to compare with the theoretic value. The buckling effect will be sort of compensated, however due to this buckling the stiffness of the plate will become smaller as to compared with the stiffness of the panel under tension at the other side of the box. This will generate a change in stress distribution as well.

The latter effect is not mentioned as one of the reasons why theory and practice differ, however it is a challenge for the eager students to look for all possible differences.

Conclusions

The results the students will find show there are large differences between theory and practice. Notice, that this is not a problem, but really an essential feature! The important thing students learn is that although the theory may give you all nice results, in the real world things are often not that beautiful. They will learn that one always has to use more accurate models, more advanced theory, and often needs sophisticated computer codes to get satisfying corresponding results.

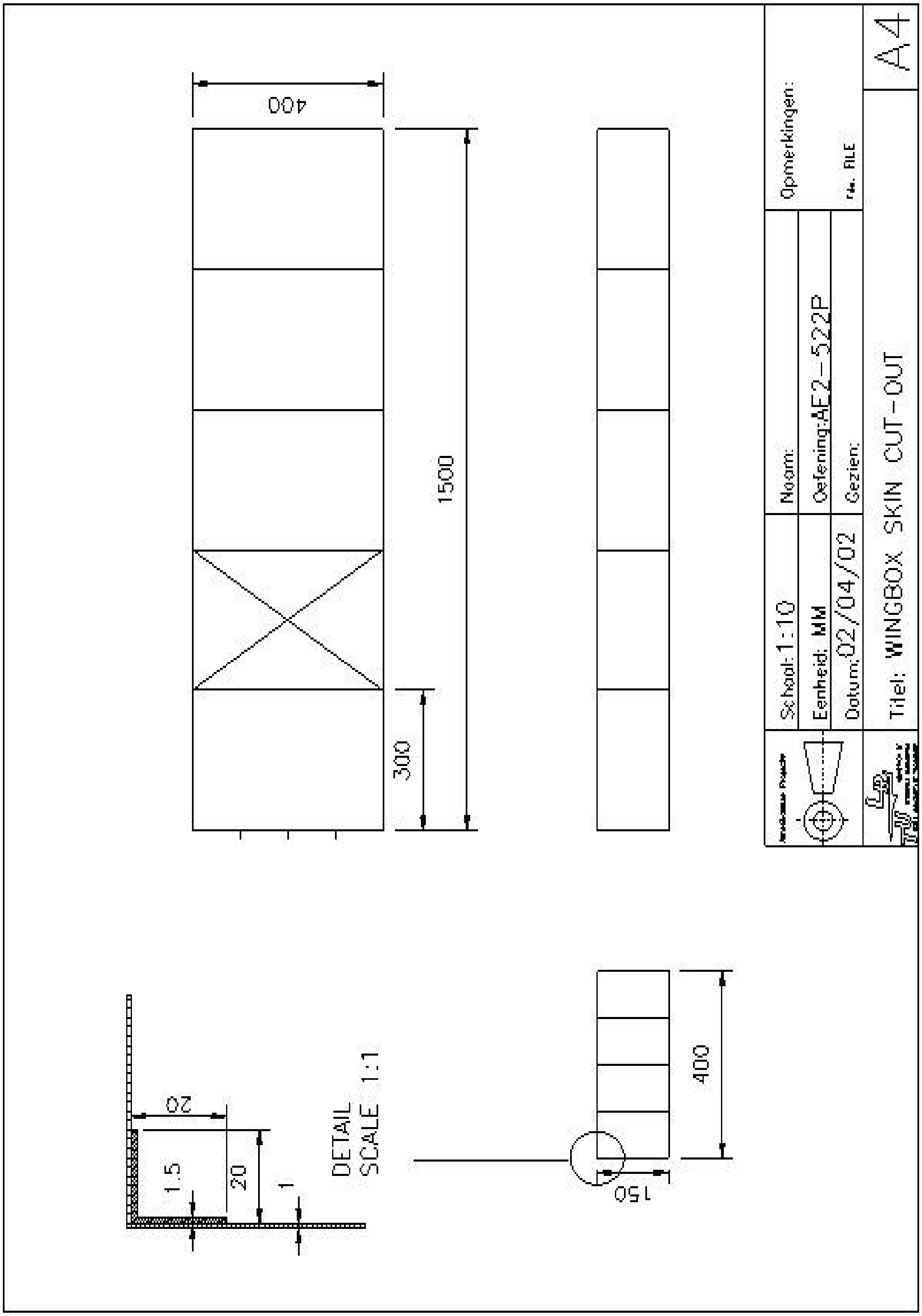
This exercise has now run for 3 years and has received positive feedback from the students in the review committees. They indicated that although it was a lot of hard work it gave them a real sense of how theory compared to practice and also an opportunity to practice modeling of structures and the limitations. Although no direct surge in student pass rate has been noted, students have indicated that it increased their ability to model real structures and their feel for how structures behave. They also feel it motivates them more for the subject of aircraft structural analysis.

Overall it has been a successful exercise, which is motivating to both students and staff. It again proves that if you involve students in the mechanics problems rather then just telling them about it they will gain more ownership of the subject and it will increase their appreciation.

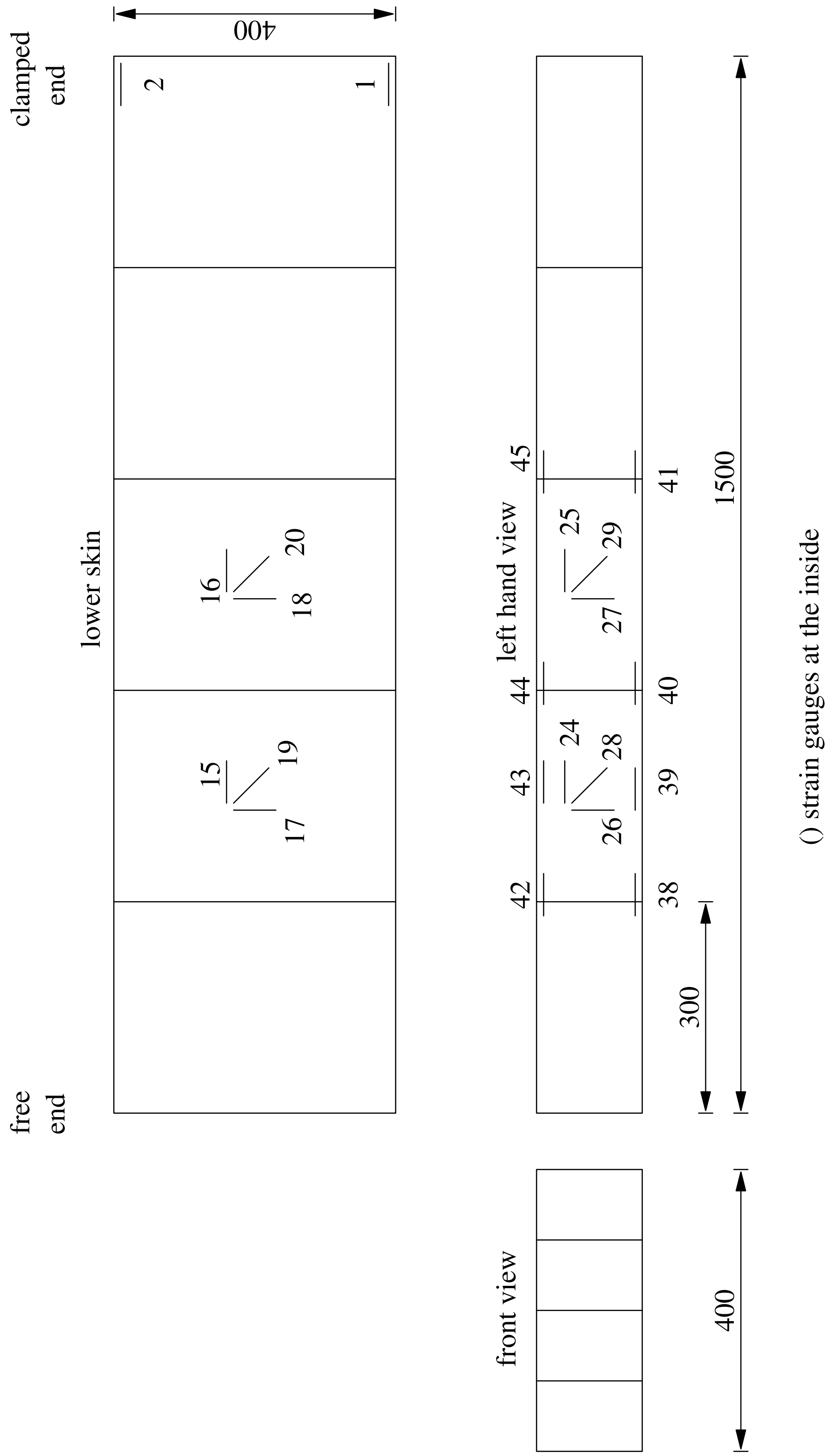
Appendix A: Faculty of Aerospace Engineering at Delft University of Technology

The degree of Aerospace Engineering[5] at Delft University of Technology[6] exists since 1940 and Aerospace Engineering has been an independent faculty since 1975. It currently has some 1700 students enrolled in their Bachelor and Masters programs. Students graduate with a Bachelors of Science degree in Aerospace Engineering, which is internationally recognized (ABET), and many continue on to obtain a Master of Science degree in Aerospace Engineering.

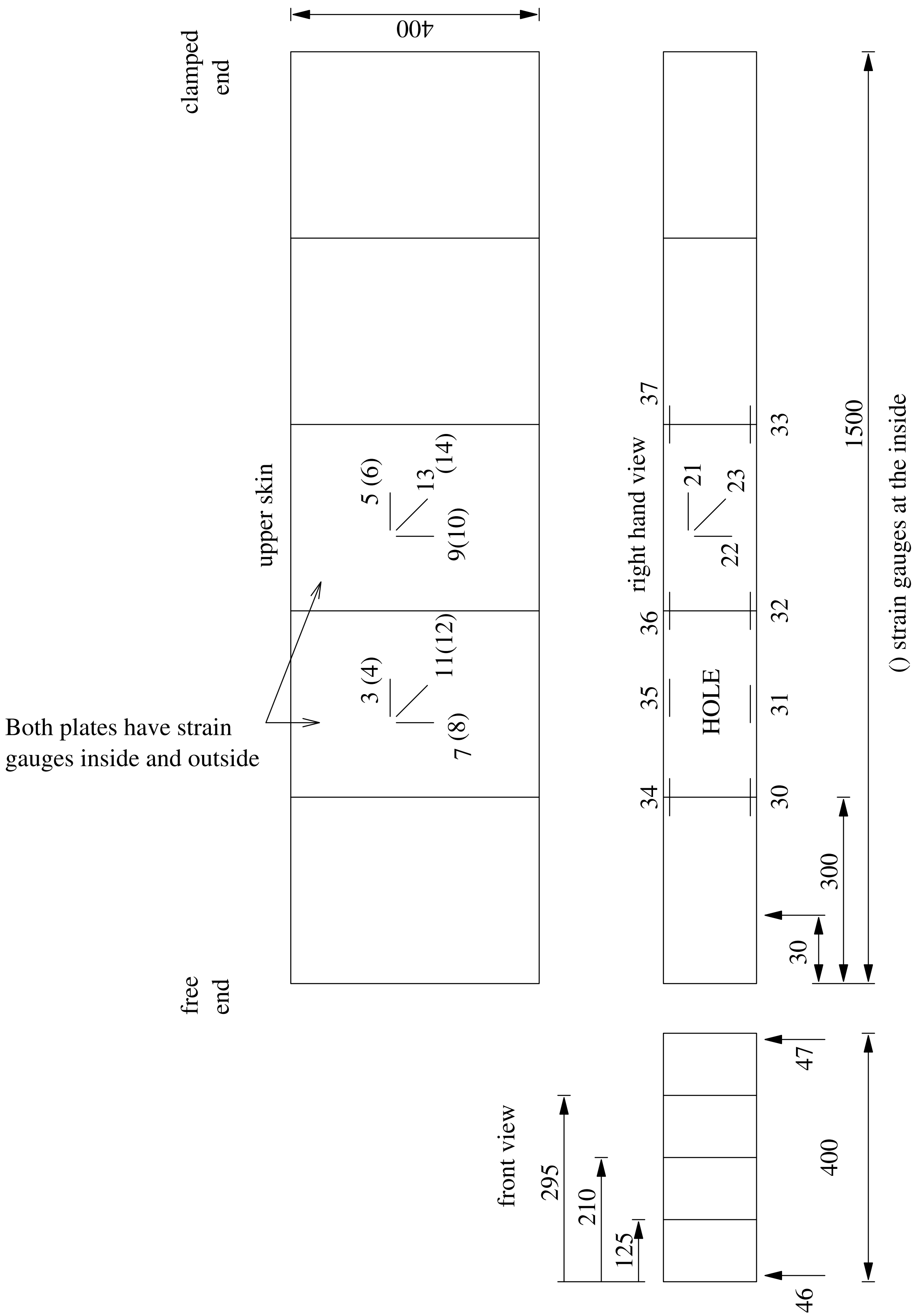
Appendix B: Engineering Drawing of the wing box



Appendix C: Strain Gauge locations



Strain gauges in lower skin



Strain gauges in upper skin

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6. www.tudelft.nl - Official University website
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GILLIAN N. SAUNDERS-SMITS
Gillian N. Saunders-Smits obtained a MSc. in Aerospace Structures and Computational Mechanics from the Faculty of Aerospace Engineering at Delft University of Technology in 1998. After a short period in industry, she returned to the Faculty of Aerospace Engineering in 1999 as an assistant professor. Since 2000 she is the faculty's project education coordinator. She also teaches Mechanics and is currently doing a PhD in engineering education.

JAN DE VRIES
Jan de Vries obtained a MSc. in Aerospace Structures and Computational Mechanics from the Faculty of Aerospace Engineering at Delft University of Technology in 1989. After serving in the army he returned to the faculty to setup a computer assisted learning program for the aircraft structural analysis course. Today he is an assistant professor lecturing this course, among other things and is doing a PhD in stability of thin-walled shells.