SD2810 Aeroelasticity, 9 credits

Course Manual

Pandemic version 2.2, revised schedule, December 7, 2020

1 About this course

This is an introductory course on aeroelasticity, treating the most fundamental aeroelastic phenomena such as static aeroelastic deformation, aileron reversal, divergence, classical flutter and gust loads. Emphasis is put on understanding the mutual interactions causing these phenomena, and the development and application of methods for aeroelastic analysis. For this purpose, it is sufficient to limit the course to slender wing structures in low-speed airflow for which beam theory structural analysis and strip theory aerodynamics are useful.

2 Learning objectives

The overall learning objectives of the course are that you should be able to

- explain how the aeroelastic phenomena aileron reversal, divergence and flutter arise and how they affect aircraft performance,
- formulate aeroelastic equations of motion and use these to derive fundamental relations and solution algorithms for aeroelastic analysis,
- perform a preliminary aeroelastic investigation of a slender wing structure in low-speed airflow to devise suitable modifications, and finally
- explain under what circumstances an aeroelastic analysis can be expected to produce useful results.

Aside from the aims related to your knowledge and skills in aeroelasticity, the course also aims at improving your ability to

- work effectively in a ~~culturally mixed~~ group,
- learn with and from other students,
- approach and solve a complex engineering task,
- present your results and conclusions effectively, and
- review and give constructive feedback on work.

3 Prerequisites

You should preferably have knowledge in calculus, linear algebra, numerical methods, finite element analysis, solid mechanics, fluid mechanics and control theory. Experience of programming in Matlab/Octave is an advantage.

4 Coordinator, teacher and examiner

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5 Literature

Borglund, D. and Eller, D., *Aeroelasticity of Slender Wing Structures in Low-Speed Airflow*. Lecture Notes, KTH Aeronautical and Vehicle Engineering, 2016.

6 Forum

The learning management system canvas will be used in the course. Once registered to the course, you can access the aeroelasticity event at

`https://kth.instructure.com`

using your kth-login. If necessary, it will be demonstrated in class how to use the forum.

This year, part of the course will be on-line using the zoom video conferencing service.

7 Computer resources and Matlab/Octave

No dedicated computer resources are provided in the course. Instead, each team is expected to work out a feasible solution using available computers on campus or your own laptops.

If you have never used Matlab or Octave (interactive systems for numerical computations), it is recommended that you get familiar with it as soon as possible. It will be very useful in the project assignments in this course as well as in many other courses at KTH, and likely in your future career. Matlab will not be taught in class, but some material to get going on your own is provided [1, 2]. Based on this material, you may also complete the course SD1105 Matlab (3 credits) by performing an individual assignment in Matlab.

8 Teaching and learning

In this course, your learning will be facilitated by a peer learning approach similar to the one described in Ref. [3]. The objective is to enable a natural and creative learning environment that hopefully leads to a deeper learning experience and at the same time develops some of your personal and interpersonal skills. You will therefore be part of a team, formed by four to six students. Each team will meet on a weekly basis to engage with the course material and collaborate on different project tasks. The team activities are, as a central part of the course, described in more detail in the following.

Every week in the course constitutes a learning cycle, which is based on suitable parts of the course book. The main task for you and your team is to engage with the content of each cycle in five successive steps:

1. The first step is a two-hour overview session by one of the teachers. The purpose of this session is not to teach all the technical details in the book, but to emphasize principles and concepts and to provide an overview of the current learning cycle.

2. In the second step, you prepare yourself for a team discussion by carefully reading the course literature and carrying out some homework. When you arrive to the teamwork session, you should be able to summarize your reading and explain the main insight you gained and the main difficulty you encountered (in terms of understanding a central aspect of the course).

3. The third step is a two-hour team discussion. The ambition here is to have a fruitful discussion in your team about the insights and difficulties that are brought to the meeting. The meeting should start and end with a round that allows each team member to speak in turn. Finally, the team should agree on a main insight and a main difficulty, that are documented and uploaded to canvas along with the minutes of the meeting. More on team organization, responsibilities and reporting later on.

   Important: This session should focus on the reading and to understand the principles and concepts currently dealt with. You should not solve problems or perform project work at this meeting!

4. The fourth step is a follow-up team session. At this session you have the opportunity to reconsider the difficulties that were spotted at the previous meeting, to see if someone has gained some new insight since then (for example, by doing some research). All teams are also expected to work out some results for a simple aeroelastic wind-tunnel model that is used as a course 'playground'. In addition, some teams may be asked to present their results or a main insight/difficulty to the class at the subsequent workshop. Once the different tasks are completed, you should proceed with work on an appropriate section of the final project.

5. The last step is a project workshop. The teacher will go over and respond to questions that have appeared in the team session notes. Selected teams may be asked to present either some results for the simple aeroelastic model or a main insight/difficulty. Your team may also get the opportunity to collaborate on the given computer tasks and the final project with some assistance from the teachers.

On top of this weekly process, you will perform two lab experiments with your team, where the usefulness of the developed analysis is investigated by comparing theoretical and experimental results.

9 Course program

Learning cycles

The material to be dealt with in each learning cycle (LC) is defined in Table 1.

LC	Topic	Chap.	App.
1	Introduction	1-5	-
2	Structural modeling	6-7	A-B
3	Static aeroelasticity	8-9	C-D
4	Flutter analysis	10	E-F
5	Flight loads	11	G

Table 1: Content of the learning cycles.

Milestones and deliverables

As previously mentioned, you will be responsible for your own learning in the course. However, since the course activities are designed to support your learning, it will not be difficult to monitor your own progress. For example, if you make sure to meet the milestones and deliverables in Table 2, you will always be in good shape! The deliverables as well as the milestones should be met individually, but you are allowed and encouraged to collaborate with your team in order to reach the milestones as efficiently as possible.

Schedule

The overview session (OS), team sessions (TS) and workshops (WS) will take place according to the schedule in Table 4.

This year, the course participants will be split in two classes for the overview sessions to reduce the number of people meeting in the lecture room. The room is also larger since we use Munin and Hugin for these sessions. You should only attend the session for your class as indicated in the schedule. Please make sure to maintain distance to your fellow students and the teacher.

The experimental testing (ET) will be performed in teams in the wind tunnel L2000 at the Department. Sometimes, the experiments will be run over two days, but your team will only attend **one** of the two sessions, ET1 **or** ET2, each one or two hours long.

Week	Milestones	Deliverables
1	All mechanical properties of the wind tunnel model determined. Provided Matlab code reviewed.	Homework. Team rules.
2	Eigenfrequencies and mode-shapes of the wind tunnel model computed.	Homework.
3	Vibration testing completed and structural model updated. Divergence and reversal speeds computed.	Homework. Hand-in of draft I.
4	Flutter speed computed for different mass configurations.	Homework.
5	Flutter testing completed. Study of wind tunnel model concluded.	Upload and peer review of draft II.
6	Flight load analysis and flutter solution for final project completed.	Homework.
7	Course completed. All learning objectives reached.	Upload of final paper.

Table 2: Milestones and deliverables.

Events:	OS	Overview Session
	TS	Team Session
	WS	Workshop
	ET	Experimental Testing
	DL	Deadline

Table 3: Abbreviations in course program.

10 Requirements

To pass the course (grade E) you must

1. participate in the teamwork activities by carrying out homework, participating in the discussions, and sharing your team's responsibilities;
2. perform a final project with reasonable results, that are presented in an individually written paper, and
3. perform an oral presentation with emphasis on the learning objectives of the course.

Your project results and the oral presentation will be used to assess how well you have reached the learning objectives, and your course grade will be set according to the criteria detailed in Appendix A.

The message is simple: focus on the course activities and to learn from them. Once you reach the learning objectives, you will be approved in the course and get a fair grade (that is final). Just like that. If you get the grade Fx you will be given opportunity to improve your project work in order to obtain the final grade E.

If you have a high ambition in the course the following advice is very useful: **the best possible way to prepare for the oral presentation is to participate in the team discussions.** If you help your team to understand different matters, you will at the same time improve yourself and obtain even better results in the course.

Date	Time	Place	Event	Class	Teacher	Topic
Mon 26/10	13-15	Munin+Hugin	OS	1	UR	Introduction
Tue 27/10	10-12	Munin+Hugin	OS	2	UR	Introduction
Tue 27/10	13-15	Munin/zoom	TS		-	Getting started
Wed 28/10	13-15	Munin+Hugin	OS	1	UR	Structural modeling
Fri 30/10	10-12	Munin+Hugin	OS	2	UR	Structural modeling
Mon 2/11	13-15	K53/zoom	TS		-	Structural modeling
Tue 3/11	10-12	D32/zoom	TS		-	Structural modeling
Tue 3/11	14-16	Munin+Hugin	OS	1	UR	Structural modeling
Wed 4/11	14-16	Munin+Hugin	OS	2	UR	Structural modeling
Thu 5/11	60 min	L2000	ET		UR	**Vibration testing!**
Fri 6/11	10-12	zoom	WS		UR	Structural modeling
Fri 6/11	60 min	L2000	ET		UR	**Vibration testing!**
Mon 9/11	13-15	Munin+Hugin	OS	1	UR	Static aeroelasticity
Tue 10/11	10-12	E33/zoom	TS		-	Static aeroelasticity
Tue 10/11	13-15	Munin+Hugin	OS	2	UR	Static aeroelasticity
Wed 11/11	13-15	Munin/zoom	TS		-	Static aeroelasticity
Fri 13/11	10-12	zoom	WS		UR	Static aeroelasticity
Mon 16/11	13-15	zoom	OS	1	UR	Flutter analysis
Tue 17/11	10:15	canvas	DL		-	**Paper draft I**
Tue 17/11	10-12	zoom	OS	2	UR	Flutter analysis
Tue 17/11	13-15	zoom	TS		-	Flutter analysis
Wed 18/11	13-15	zoom	TS		-	Flutter analysis
Fri 20/11	10-12	zoom	WS		UR	Flutter analysis
Mon 23/11	13-15	zoom	TS		-	Flutter analysis
Tue 24/11	10-12	zoom	TS		-	Flutter analysis
Tue 24/11	13-15	zoom	TS		-	Flutter analysis
Wed 25/11	13-15	zoom	WS		UR	Flutter analysis
Thu 26/11	2 hrs	zoom	ET1		UR	**Flutter testing!**
Fri 27/11	2 hrs	zoom	ET2		UR	**Flutter testing!**
Mon 30/11	13-15	zoom	TS		-	Postprocessing test data
Tue 1/12	10-12	zoom	OS	1	UR	Maneuver Loads
Tue 1/12	13-15	zoom	OS	2	UR	Maneuver Loads
Wed 2/12	08.00	canvas	DL		-	**Paper draft II**
Wed 2/12	13-15	zoom	PR		-	Peer Review
Fri 4/12	10-12	zoom	TS		-	Loads
Mon 7/12	13-15	zoom	WS		UR	Loads
Tue 8/12	10-12	zoom	OS	1	UR	Final project
Tue 8/12	13-15	zoom	OS	2	UR	Final project
Fri 11/12	1 hr	Hugin	-		UR	**Oral presentation**
Mon 14/12	1 hr	Hugin	-		UR	**Oral presentation**
Tue 15/12	1 hr	Hugin	-		UR	**Oral presentation**
Mon 21/12	13-15	zoom	WS		UR	Final project
Sat 9/1	17.00	canvas	DL		-	**Final paper**

Table 4: Preliminary course program. (Abbreviations in Table 3)

In summary: you should only take this course if you want to learn something. Get involved in the team activities, have fun and learn a lot. And by the way, you will get some credits for your effort (and a grade too!).

11 About your teamwork

~~In this course you will be part of a cross-cultural team of (nominally) five students.~~
This year, due to the on-going pandemic, the teams will be formed to minimize new acquaintances. As described in the section about teaching and learning, you will for example meet on a weekly basis to discuss the content of the current learning cycle. The teams will be formed by the teacher. To give the teamwork some structure, two of the team members will act as chairperson and secretary. A new chairperson and secretary will be appointed in each cycle, so that all team members are given opportunity

to practice in these positions.

Chairperson

The main responsibilities for the chairperson are to

- initiate the meeting with a round (see the separate note on rounds),
- if necessary, pass the word around during the discussion,
- bring the discussion back on track if too much time is spent on a minor issue,
- make sure that the team agrees on a main insight and a main difficulty to be reported in the minutes of the meeting (see below), and
- conclude the meeting with a final round.

Secretary

The main responsibilities for the secretary are to

- take notes during the session, and
- **upload a set of meeting minutes in the team's log book shortly after the meeting**.

The meeting minutes can be very brief, but should at least cover today's date, the name of the team, meeting participants, a short summary of the discussion in the team, and your main insight and difficulty, and a note on the next meeting. The following lines can be used as a template for the meeting minutes:

```
Meeting minutes of November 8, 2019

Team:
The Smarties

Meeting participants:
Vanessa W. Vortex (chairperson)
Isaac Newton (secretary)
Amelia Earhart
William Thomson, 1st Baron Kelvin
Nabla Phi

Main discussion:
The session was about aeroelastic phenomena and some structural
dynamics. We discussed how the different phenomena arise and
tried to understand the  mechanisms leading to structural
instabilities. Divergence was reasonably easy but flutter
difficult. We also discussed if the typical section can display
these phenomena and how to determine the spring stiffnesses.
Finally, we discussed the physical significance of modeshapes,
in particular for the typical section. We also settled the basic
rules for our team (see below). Overall, it was a good
discussion.

Basic rules:
* The working language is English.
* Everybody should prepare themselves properly before
  the meetings.
...

Main insight:
We understood how to derive the linear equations of motion for
the typical section, in particular the mass coupling terms.
```

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Main difficulty:
Why is the magnitude of the structural modeshapes not unique?

Next meeting:
Chairperson: Isaac Newton
Secretary: Amelia Earhart
Topics:
- Estimate the material properties of the test specimen.
- Figure out how to calculate the spring stiffnesses of the
  typical section.
- Compute the eigenfrequencies and modeshapes in Matlab.
- Download and check the provided Matlab package.
```

The first cycle

In the first learning cycle, you will mainly get acquainted with your home team and how the course works. In the following, some guidelines for the first learning cycle are provided.

The first meeting (TS)

It is suggested that you start the meeting by introducing yourself to one another, and perhaps share some thoughts about the course. Note, however, that the main objective of the meeting is to have your first technical discussion. Be sure to acknowledge the chairperson and secretary of the first week, and that you are all familiar with their responsibilities. Later on, do not forget to allow time for a final round and to agree on your team's main insight and main difficulty in the learning cycle. Note that the main insight/difficulty should preferably be related to the principles and concepts that are discussed in the course (in order to keep focus). Also note that you may be given the task to present your main insight/difficulty to the class at the subsequent workshop (more on this below).

The first follow-up meeting (TS)

Besides from comparing and discussing your results for the simple aeroelastic model (and possible insights gained since the first meeting), you have an additional task to complete at this meeting: to agree on a set of basic rules for your teamwork. Your basic rules should be uploaded in your team's log book! In the subsequent cycles, you need not upload meeting minutes from the *follow-up TS* meeting (only this time).

The first workshop (WS)

The purpose of the weekly workshop is to have a concluding discussion about the work that has been carried out during the week, and to perform project work. To make the workshop more inclusive and interactive, a few teams may be given opportunity to share their progress with the class. Typically, one team will be expected to present their results for the simple aeroelastic model. Other teams may be given opportunity to present a relevant insight or difficulty to the class. In turn, the class is expected to support the team that presents in a respectful and meaningful way.

12 About your paper

The results of the project should be presented in an individually written paper. The paper should be written in English and include a title, your name and a KTH address (see the sample paper), an abstract, an introduction, suitable sections for the technical part, and separate conclusions and references. The length of the paper must not exceed 10 pages, using a legible format.

To support you in this effort, two references is provided (available in canvas). The first is a very good text by Ashby [4] about how to write a paper, and the second is a sample paper written in this format [5]. **Try to use a style that matches the sample paper as closely as possible.** However, the double-column format is not required. Note that a paper does not have a front page, and no table of content. When writing the paper, it is also useful to consider the criteria in Table 5, that will be used in the different reviews of your paper.

Individually written paper?

Your paper should be an individual accomplishment. This means that you are not allowed to share formulations with other course participants, you must use your own words and reasoning. This requirement will not be compromised. If you break it, it will be considered as cheating.

In order to distribute your work throughout the course, the paper is written in three successive steps. Before completing the final paper, you are therefore required to write two draft versions that are described in the following.

First draft

The first draft should include a preliminary title, your name, a KTH address, and an introduction. The introduction should communicate what aeroelasticity is all about and explain the treated aeroelastic phenomena in words (deformation, divergence, aileron reversal and flutter). About one page of text should be enough. The objective here is that you should try to show that you have reached the first learning objective of the course. Of course, you will be able to update your introduction to the final version, based on feedback from your team (more on this below). **Upload a PDF of your first draft to canvas no later than the given deadline. Label your draft as "yourlastname_first.pdf".**

Second draft

In the second draft, the main objective is to show that the second learning objective of the course is reached. You should now add a theory section to your paper, given some guidelines. You can essentially assume that a discrete aeroelastic model of an aircraft operating in the low-speed regime is given, in terms of degrees of freedom, structural matrices, aerodynamic matrices and so on. Write a text with standpoint from the linear equations of motion and then explain how they can be used to derive suitable relations to perform aeroelastic analysis. In this case, the quality of the presentation will likely be improved by using a few subsections. **Your second draft should be uploaded in PDF format on canvas no later than the given deadline. Label your draft as "yourlastname_second.pdf".**

Peer review

The teams will be utilized to perform a peer review of the **second draft**. The main purpose of this is to further consolidate your learning by reading the work of other authors. Another purpose is that you should improve your ability to review the work of someone else, and to provide constructive feedback. To give constructive feedback is not necessarily an easy task [6], but the basic principle is: instead of just pointing out all negative aspects of the work, first highlight the good aspects of it and then deliver the bad news as suggestions for improvement (in a gentle manner).

The first step of this process is an individual review of at least two papers written by other members in your team. First review the papers on your own using the criteria in Table 5. Then write a short feedback with reference to the given criteria, telling what strengths and possible areas of improvement the paper has from an engineering as well as writing point of view. For this, you can, but do not have to, use the provided peer review form. You should also prepare an oral summary of approximately 6-8 minutes (per paper) of your feedback.

In the second step of the process, you should bring your feedback to a peer review session with your team. At this session, it is suggested that you focus on one draft at a time, and give each other oral as well as written feedback (prepared in the first step). Note that the feedback is a personal opinion, that should be respected. It is up to each author to judge the relevance and usefulness of the feedback (and not argue about it).

Management: During the team session **before** the peer review, figure out who is going to review which papers (two each), and put that plan into your meeting minutes. Before the deadline for the 2nd draft, upload your paper to canvas and email a copy of the same to the reviewer. Your homework for this day is writing feedback of the two drafts which you were assigned. Soon after that (usually on the next day) is the peer review session, in which you are to present your feedback orally.

Final version

The final version of your paper should also include sections that account for the final project in the course. Overall, you should describe the approach that has been used to develop the numerical model, how results from the theory section are applied to perform analysis, the main results that you have obtained, and what conclusions you can draw from these. In total, you should have written a neat and digestive paper that covers the background, approach, results and conclusions for a preliminary aeroelastic analysis of an aircraft structure. **A PDF version of your paper should be uploaded to canvas no later than the given deadline. Label your paper as "yourlastname_final.pdf".**

In addition to the paper, please upload the final version of the Matlab code that you used for the project. Make sure that all input data and function files that are needed to run your main scripts are included and upload a compressed archive (zip, 7z or tgz).

13 About the oral presentation

The course is concluded with a short oral presentation with emphasis on the overall learning objectives. It is not a secret what the oral presentation will be about. On the contrary, we will talk about the fundamentals of aeroelasticity that you have already discussed with your team or dealt with in the project. Consequently, if you have performed the preparatory homework, participated actively in the team activities and performed the project, it should be straightforward.

A frequently asked question concerns the 'level of detail' at the oral presentation. Well, extensive equations that you 'plug and chug' are soon forgotten about. It is much more important that you understand the principles and concepts, and are able to derive and explain the most important results from these. For example, it is not meaningful to remember all the details in a derivation of a particular element of the mass or stiffness matrix. However you should readily be able to use the discretized equations of motion to derive, for example, an eigenvalue problem that can be used to compute the divergence speed. Thus, what you have learned about the fundamentals from the course activities is the most important factor at the oral presentation.

The oral presentation is meant to be an *opportunity* for you to show what you have learned in the course. Therefore, the presentation does not have the traditional format of a teacher asking questions and a student answering them. Instead, you will perform the session together with another student (and the teacher). At the oral presentation, each candidate should give a 10 minutes presentation about one of the main topics that we have treated in the course, such as structural dynamics, unsteady aerodynamics, aeroelastic divergence, reversal, flutter or modal analysis. It is suggested that you choose a topic that you understand well, but also find challenging. You must also communicate with your partner so that you do not select the same topic. Each presentation will be followed by a 15 minutes discussion, where the presenter should be able to answer questions from the partner and the teacher. By asking relevant and insightful questions and participating in the discussion that follows, each participant will thus be able to show that a particular topic is well understood. Of course, both candidates should be able to answer questions about any of the main topics in the course. In order to document each participant's contributions, the teacher will take notes during the session. Finally, the teacher will summarize his impression and inform the participants about their performance at the oral. In total, the session will take 1/2 to 1 hour.

No other aids than a whiteboard and a pen are allowed. Please respect the slot that you have been assigned (see schedule in canvas) and show up in time!

14 Homework

First cycle

- Read Chapter 1-5 in the Lecture Notes as well as the teamwork handouts.
- Explain the basic mechanisms of divergence, flutter and reversal.

- Give a physical interpretation of eigenfrequencies and modeshapes.
- Derive the linear equations of motion for the typical section.
- Where is the elastic axis located on the wind tunnel model?
- How can the material properties E, G and ρ_m (elastic modulus, shear modulus and density) be estimated from the test specimen?
- Compute the center of mass and moment of inertia of the typical section model.
- Estimate suitable values for the spring stiffnesses of the typical section model (some creativity may be required here).
- Complete the typical section model and compute (by hand or using Matlab) the eigenfrequencies and modeshapes.
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Second cycle

- Read Chapters 6-7 and Appendices A-B in the Lecture Notes.
- Pose the differential equations of motion of a beam.
- Explain the basic concept of a weighted residual method.
- Give a simple physical interpretation of a finite element model.
- Derive the inertial forces due to a concentrated mass.
- Explain the null space method for constrained motion.
- Derive the properties of the wind tunnel model that are required for the beam finite element model in Matlab.
- Develop some ideas for the vibration testing based on the lab instructions in the Notes.
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Third cycle

- Read Chapters 8-9 and Appendices C-D in the Lecture Notes.
- Explain the approximations made for the aerodynamic forces.
- Explain the physical significance of the reduced frequency.
- Explain what strip theory means.
- Pose the differential equations of motion including aerodynamic forces.
- Give a physical interpretation of the aerodynamic matrix and vector.
- Pose a force equilibrium to compute the static aeroelastic deformation.
- Derive the divergence eigenvalue problem and give a physical interpretation of the eigenvector.
- Derive the rolling moment coefficient taking elasticity into account.
- Derive the reversal eigenvalue problem and give a physical interpretation of the eigenvector.
- Derive the rolling moment derivatives in the finite element framework.
- Estimate the divergence and reversal speeds using the typical section model.
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Fourth cycle

- Read Chapter 10 and Appendix E-F in the Lecture Notes.
- Explain how the frequency-domain equations of motion can be interpreted as a nonlinear eigenvalue problem. In what sense is p the eigenvalue?
- Give a physical interpretation of an aeroelastic eigenmode. What does a complex modeshape mean?
- Explain how the flutter and divergence eigenvalue problems are related.
- Explain why the aerodynamic forces due to undamped vibrations can be used for flutter analysis.
- Explain the basic principle of the p-k method.
- Outline the algorithm of the p-k method.
- Explain the basic principle of modal flutter analysis.
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Fifth cycle

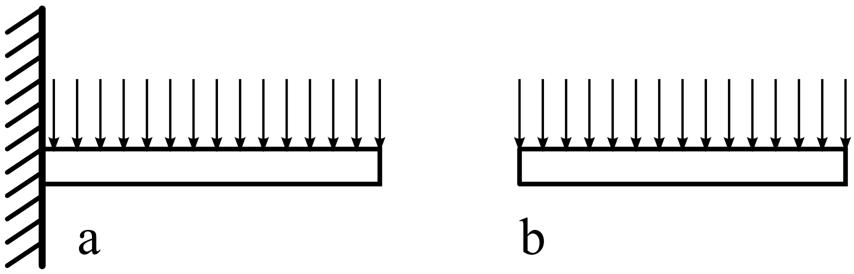

Figure 1: Constrained and free-flying beam.

- Read Chapter 11.1 in the Lecture Notes.
- Which general aircraft loads from the list in Chapter 11 must be treated as dynamic loads?
- Propose a criterion to decide whether a certain load case can be handled with a (simpler) quasi-steady approach or needs a fully unsteady solution.
- Determine the normal stress distribution $\sigma(y)$ for the cantilever beam (a) and the free-flying beam (b) subjected to a constant line load q, shown in Figure 1. Both beams have identical dimensions, width w, height h and length L and a material of the same homogeneous density ρ.
- Why can we not introduce the rigid-body constraint $\mathbf{B} = \mathbf{Z}_r^T$ in the full equation of motion for quasi-steady maneuvers (233)?
- Your company wants to modify an existing business jet design for maritime surveillance. As part of the modifications, a rather heavy box with electronic equipment needs to be placed somewhere inside the wing. As the person responsible for aeroelasticity and loads, explain where you want the box to be installed.
- Can you point out an example aircraft configuration where the described solution procedure for maneuver loads will generate severe errors?
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Sixth cycle

- Read Chapter 11.2 – 11.3 in the Lecture Notes.
- Explain how a quasi-static aeroelastic maneuver problem and a gust response analysis are different. Focus on physical effects, not equations.
- Investigate how the gust response problem (253) is related to the flutter problem.
- In discrete gust analysis, the gust velocity field can be prescribed in different ways. One particularly dangerous case is called the *tuned gust*. Can you imagine what this could be?
- When traversing a gust, will the maximum shear stress and the maximum normal stress at each monitoring point always occur at the same time?
- Your colleague suggests that a continuous turbulence analysis alone is all that needs to be done because it already includes the information that could possibly be gained from a discrete gust solution. In what sense is she right about that?
- Using continuous turbulence analysis, we can determine a probability of failure P, which unfortunately never becomes exactly zero. How would decide whether a certain probability is acceptable?
- Prepare for the team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.

Acknowledgments

The course in Aeroelasticity was very actively developed and improved by Dan Borglund until 2010 and David Eller until 2016. A large fraction of the course material, including this manual, was originally written by Dan and David and then continuously updated by the current teacher(s).

References

[1] Griffiths, D. F., *An Introduction to Matlab*. With additional material by Ulf Carlsson, KTH Aeronautical and Vehicle Engineering. The University of Dundee, 2005.

[2] Carlsson, U., *Miscellaneous Exercises in Matlab*. KTH Aeronautical and Vehicle Engineering, 2009.

[3] Borglund, D., "A Case Study of Peer Learning in Higher Aeronautical Education," *European Journal of Engineering Education*, Vol. 32, No. 1, 2007, pp. 35–42.

[4] Ashby, M., "How to Write a Paper," Engineering Department, University of Cambridge, Cambridge, 6^{th} Edition, April 2005.

[5] Borglund, D., "Robust Eigenvalue Analysis Using the Structured Singular Value: The μ-p Flutter Method," *AIAA Journal*, Vol. 46, No. 11, 2008, pp. 2806–2813.

[6] Gibbs, G., *Learning in Teams: A Student Guide*. The Oxford Centre for Staff Development, Oxford Brookes University, 1998. (This reference can be purchased in the student expedition at KTH Aeronautical and Vehicle Engineering for 20 SEK).

A Grading criteria

A You can readily derive and explain the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You are also, to some extent, able to develop the theoretical models on your own. You have participated in the teamwork activities in an active and meaningful way. Your project work is characterized by a discernible, creative and thorough approach that is based on correct principles. Your results and conclusions are focused and relevant in relation to the project description. Your approach, results and conclusions are presented in a complete, concise, coherent and well structured paper.

B You can readily derive and explain the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You are also, to some extent, able to develop the theoretical models on your own. You have participated in the teamwork activities in an active and meaningful way. Your project work is characterized by a discernible and thorough approach that is based on correct principles. Most of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a complete and well structured paper.

C You can derive and explain most of the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You have participated in the teamwork activities in an active way. Your project work is characterized by a discernible approach that is based on correct principles. Most of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a complete and well structured paper.

D You can derive and explain most of the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You have participated in the teamwork activities in an active way. Your project work is characterized by a valid but not so well explained approach. Most of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a partially complete and fairly well structured paper.

E You can explain most and derive some of the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You have participated in the teamwork activities in an active way. Your project work is characterized by a valid but not so well explained approach. Most of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a partially complete and fairly well structured paper.

Fx You can explain most and derive some of the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You have participated in the teamwork activities, but perhaps only to some extent. Your project work is characterized by an approach that is poorly explained or not valid. Only some of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a partially complete paper.

F You can only explain some and hardly derive any of the fundamentals of aeroelasticity that are referred to in the learning objectives and the homework assignments, respectively. You have participated in the teamwork activities, but perhaps only to some extent. Your project work is characterized by an approach that is poorly explained or not valid. Only some of your results and conclusions are relevant in relation to the project description. Your approach, results and conclusions are presented in a partially complete paper.

B Paper review criteria

Technical work
Are all major aspects of the project description treated? Is there a valid reasoning used, and does it show an apparent understanding and grasp of the subject? Does the work even show some originality and imagination? Are conditions, approximations and assumptions clearly stated? Are governing equations included, and are they valid for this problem? Are appropriate methods used for solving the equations, and are they suitably explained? Does the technical work appear to be correct, or at least reasonable? If some results are obviously not realistic, have the author commented on this? Are the validity and accuracy of the results motivated? Are an appropriate number of figures used when presenting numerical or experimental results? Are the conclusions reasonable and relevant in relation to the project description?
Content
Is the title meaningful and brief? Does the abstract cover the motive, method, key results and main conclusions of the work? Does the introduction communicate why the topic is interesting or important, who have contributed what in the past, and the purpose of the present paper (alternatively, a historical background and/or important applications of the technology)? Does the paper have an apparent and natural structure that helps the reader to keep track? Are theory/methods and results presented in separate sections? Are the section headings meaningful and brief? Is the content relevant and concise, or can some parts even be omitted without loosing quality? Does the level of detail stand in reasonable proportion to the results and conclusions that are reported? Are the most important results drawn together in a separate section with conclusions? Finally, are sources of previous work, theories, methods or data cited in a concluding list of references?
Style
Is the paper written in commendable English and does it present the material in a clear and apparent form? Does the introduction have a good first sentence? Is the spelling correct? Are figures and tables clear, easy to read and properly integrated in the text? Are figure and table captions meaningful and brief? In graphs: are axes properly labeled, units well defined and a decent fontsize used? Are equations suitably formatted and properly presented in the text? Are all properties in the equations defined in the text? Are pages, figures, tables and equations numbered? Is the list of references complete and properly used in the text?
Overall impression
What is your overall impression of the paper? What was the main point that the author tried to convey? What did you like the most about the paper? What did you like the least? If the author have additional time to work on the paper, what would you mainly recommend him/her to improve?

Table 5: Criteria for the review of your paper.