AE3212-II SVV
Structures Assignment 2020

This document outlines the Structural Analysis assignment used in the 2019-2020 edition of the AE3212-II Simulation, Verification & Validation (SVV) course. The first part of this document provides a general overview of the assignment. The second part outlines the high-level tasks that you ought to perform.

Introduction

The aileron of an aircraft is located close to the tip of the wing as indicated in Figure 1. Correct operation of the aileron is critical to flight safety. A critical loading scenario ensues for the aileron when the aileron is at maximum upward deflection, the aerodynamic loading on the wing is at limit load and one of the two actuators of the aileron is jammed. Under these conditions the aileron will be subjected to torsion, bending and shear.

The cross-section of the aileron under consideration consists of a semi-circular leading edge, a spar and a triangular trailing edge, see figure 2. The aileron is symmetric about the z-axis. Stiffeners are uniformly distributed along the circumference of the aileron and run over the full length of the aileron. The aileron is made of aluminium 2024-T3. The aileron is hinged at three points, as shown in figure 3. The hinges are numbered 1 to 3. In the middle two actuators are attached to the aileron, numbered I. and II.

As a group of stress engineers, you will create a preliminary, numerical structural analysis tool to compute the deflection of the hinge line, the twist of the aileron, as well as the maximum stress experienced by the aileron. The latter will be evaluated using the Von Mises stress.

The precise loading conditions can be described as follows. The middle hinge point is kept fixed. The two other hinge points are subjected to a vertical displacement that corresponds with the bending displacement of the wing under limit load, see figure 4. Actuator I. is kept fixed in the z-direction. A force P acts on actuator II. in negative z-direction. An aerodynamic force acts perpendicular to the symmetry plane of the aileron, varying both with the spanwise and chordwise direction. Furthermore, the aileron is loaded in its maximum upward deflected position, see figure 5.

The aerodynamic loading perpendicular to the symmetry plane is known. Your model should thus incorporate this loading (which will be given to you) to compute the actual deflections and stresses of the aileron. In order to help you verify and validate your model, you will be given the following:

- A verification model. You will be given access to an already written model of the aileron. Although the source code of this model will be protected, you will have access to nearly all of its intermediate results, allowing you to verify your own code by comparing your results with this verification model.
- The results of finite element simulation, which can be considered to be a numerical experiment. This numerical experiment has been performed using well validated

software. Therefore, it can be used to validate new numerical models. It must be noted that assumptions and simplifications were made in generating the finite element model, e.g. the aerodynamic loading has been simplified to a uniform distributed load.

During the analysis, the following assumptions hold:

- The aileron can be modelled as a beam.
- Reaction loads at the hinges and actuators can be modelled as point loads.
- The hinges only restrict translations, but allow rotations.
- Attachments of the stiffeners to the skin of the aileron do not have to be analysed.

Group Aircraft Allocation

Each project group is allocated one of four aircraft types:

- Airbus A320
- Bombardier CRJ700
- Dornier Do 228
- Fokker 100

The allocation of aircraft type to each group is given in table 1. Groups must use the aircraft type allocated to them for the SVV structures assignment. The relevant data for each aircraft is provided in a separate document.

Table 1: group aircraft allocation

Group	Aircraft	Group	Aircraft	Group	Aircraft
A01	A320	A18	CRJ700	A35	Do 228
A02	CRJ700	A19	Do 228	A36	F100
A03	Do 228	A20	F100	A37	A320
A04	F100	A21	A320	A38	CRJ700
A05	A320	A22	CRJ700	A39	Do 228
A06	CRJ700	A23	Do 228	A40	F100
A07	Do 228	A24	F100	A41	A320
A08	F100	A25	A320	A42	CRJ700
A09	A320	A26	CRJ700	A43	Do 228
A10	CRJ700	A27	Do 228	A44	F100
A11	Do 228	A28	F100	A45	A320
A12	F100	A29	A320	A46	CRJ700
A13	A320	A30	CRJ700	A47	Do 228
A14	CRJ700	A31	Do 228	A48	F100
A15	Do 228	A32	F100	A49	A320
A16	F100	A33	A320	A50	CRJ700
A17	A320	A34	CRJ700	A51	Do 228

Load case

- Hinge 1 is fixed in z-direction and displaced in y-direction by a predefined amount, d1.
- Hinge 2 is fixed in x-, y- and z- direction.
- Hinges 3 is fixed in z-direction and displaced in y-direction by a predefined amount, d3.
- Actuator I. is kept fixed in z-direction.
- **Discrete load P** acts in negative z-direction at actuator II.
- **Distributed load** q due to aerodynamic forces on aileron, points downwards in the direction perpendicular to the symmetry plane of the aileron (and remains constant irrespective of aileron deformation). A more elaborate description of this distributed load follows in the section "Aerodynamic load".
- **No other than the aforementioned loads working on the aileron**

Aerodynamic Loading

The aerodynamic loading on the aileron is known and will be given to you in a simple .dat-file. As typical with aerodynamic loadings, you do not have access to an explicit function describing the loading. Rather, you are given a data set, describing the aerodynamic loading perpendicular to the symmetry plane. Let $x' - y' - z'$ represent the reference frame corotated with the aileron, such that z' is still aligned with the symmetry plane and points towards the leading edge. This data set is given in a simple .dat file, containing 81 rows and 41 columns. Each row corresponds to a spanwise station, and each column corresponds to a chordwise station. The ith row has a z-coordinate equal to

$$\theta_{z,i} = \frac{i-1}{N_z}\pi, \qquad 1 \leq i \leq N_z + 1$$

$$z_i = -\frac{1}{2}\left\{\frac{C_a}{2}\left[1 - cos\left(\theta_{z,i}\right)\right] + \frac{C_a}{2}\left[1 - cos\left(\theta_{z,i+1}\right)\right]\right\}, \qquad 1 \leq i \leq N_z$$

with $N_z = 81$. Similarly, the ith column has a x-coordinate equal to

$$\theta_{x,i} = \frac{i-1}{N_x}\pi, \qquad 1 \leq i \leq N_x + 1$$

$$x_i = \frac{1}{2}\left\{\frac{l_a}{2}\left[1 - cos\left(\theta_{x,i}\right)\right] + \frac{l_a}{2}\left[1 - cos\left(\theta_{x,i+1}\right)\right]\right\}, \qquad 1 \leq i \leq N_x$$

with $N_x = 41$. The corresponding aerodynamic load is given in kN/m^2. Note that more points are included in the chordwise direction than in the spanwise direction; typically in CFD-simulations the mesh has a finer resolution in chordwise direction as the gradients are larger in that direction.

Note that the aerodynamic data differs for each aircraft, and that each aircraft has its own .dat-file.

Numerical Models

As will be discussed in one of the supplementary documents corresponding to this assignment, you are likely to be needing a continuous function describing the aerodynamic loading. This will mean that numerical interpolation of the gridded data is necessary.

Furthermore, this interpolant needs to be integrated, which may be chosen to be done numerically. As the central focus of this project is to construct your own numerical models and to then verify and validate them, you will have to write your own numerical interpolation and integration scheme. This means that you are not allowed to use existing modules capable of numerical interpolation and integration. This includes, but is not limited to, the following:

- numpy.interp()
- numpy.vander()
- scipy.interpolate
- quadpy
- np.trapz()
- scipy.integrate
- integral() (Matlab)
- interp1() (Matlab)

This list should not be considered to be a complete list of modules that are not permitted; use of any existing module / function that violates the spirit of writing your own numerical interpolation and integration schemes is forbidden.

It should be noted that the use of numpy as a whole is *not* forbidden; using numpy arrays and numpy.linalg.solve to solve a system of linear systems of equation is perfectly allowed, for example. Only functions that clearly violate the spirit of writing your own numerical interpolation and integration schemes should be avoided. Note that your code will be checked for this. In case of doubt whether you are allowed to use a certain function from NumPy or SciPy or similar modules, you are advised to consult the course staff.

Additionally, the verification of your numerical interpolation and integration schemes may not rely on any existing modules and functions either, and you will have to verify your numerical schemes independently from them.

Report Outline

Generally speaking, your simulation plan and final report will both include technical discussions about the following topics:

- Description of loading case.
- Numerical model.
- Verification model.
- Verification.
- Validation.

Each of these topics will be discussed in more detail now. Unless otherwise noted, the described items should be included in both the simulation plan and final report.

Description of loading case

The loading case acting on the aileron should be unambiguously clear from your report without having to consult this assignment. Therefore, as a minimum, provide the following:

- Verbal description of the load case.

- Free body diagram of the aileron.
- Table containing all input parameters.

Numerical model

As mentioned previously, you are tasked with constructing a numerical model. This numerical model should be capable of computing the deflection of the hinge line, the twist of the aileron, as well as the maximum stress experienced by the aileron. The latter will be evaluated using the Von Mises stress. All these calculations should be based on the load case and the input parameters.

Based on your knowledge from the AE2135-I Structural Analysis & Design course, you have sufficient information to compute any desired stiffness properties and stress distributions in the aileron. A supplementary document is provided to you that serves to refresh your knowledge on computing deflections for a statically indeterminate beam. Although you are free to use another method based on your own liking, note that this project places a significant emphasis on verification and validation. The reason why you are given this supplementary document in the first place is to enable you to spend more time on verification and validation. In any case, you are not allowed to construct a Finite Element (FE) model. Furthermore, as your numerical model needs to be sufficiently different from the verification model, you are not allowed to compute the deflections based on a Rayleigh-Ritz method or a close derivative, and you are not allowed to compute the shear flow distributions by integrating the shear flows analytically; instead, you should make use of either structural idealisation or numerical integration, whichever you prefer.

As mentioned previously, you should write your own numerical interpolator and integrator whenever you wish to interpolate or integrate; use of scipy, numpy and similar packages is not allowed for these purposes.

You should discuss the assumptions you have made in your model (be sure to describe both its effect and its validity), as well as the numerical model itself, in such detail that the reader would be able to program the numerical model on their own. To that end, you should also provide a flowchart to aid the reader in understanding the flow of your program. Finally, for the final report only, you should naturally produce plots of the requested output (for the maximum stress, provide a plot of the stress within the cross-section at the most critical spanwise station). You should also produce plots showing your interpolant of the given aerodynamic load.

In conclusion, as a minimum, provide the following:

- Discussion of the assumptions made in your numerical model.
- Description of your numerical model. This should include a flowchart of your program (flowchart is for simulation plan only).
- Results of your numerical model (final report only). These should based on the data corresponding to the aircraft your group has been assigned.

Verification model

In order for you to more easily verify your own model, a verification model of the aileron will be provided to you. This verification model produces nearly the same output as your model (rather than computing the deflections of the hinge line, it computes the deflections of the flexural axis).

A supplementary document is provided to you in order to help you understand the verification model. Based on this description, you should discuss the assumptions (implicitly) made in the verification model, and why this model can be used to verify your numerical model. Furthermore, you should discuss the verification model itself, explaining the main steps taken by the program and the governing equations that lie at the basis of it.

Thus, as a minimum, provide the following:

- Discussion of the assumptions made in the verification model.
- Description of the verification model.
- Results of the verification model (final report only).

Verification

Your numerical model should be verified before it can be validated. An excellent opportunity for system tests is naturally to compare the results of your numerical model with the verification model. However, this does not guarantee that the numerical model is correct, since it has not been established yet that the verification model is correct. Therefore, you should also verify your own numerical model itself by performing independent unit and system tests. The verification model may be assumed to work correctly (as long as the assumptions made by the model are valid) and thus does not necessarily need to be checked. Nonetheless, you are encouraged to be critical of the verification model and to report any checks you have performed, although you are not required or expected to do so.

As mentioned previously, the verification of your numerical interpolation and integration routines should not rely on any existing modules that offer the same capabilities; the verification should be performed independent of any existing functions and modules.
Thus, as a minimum, provide the following:

- Independent verification of your own numerical model including unit tests and possibly system tests (results only for final report).
- Comparison between the results of the verification model and your numerical model, including appropriate system tests (results only for final report).

Validation

Finally, your numerical model should be validated. To this end, you will be given the results of a numerical experiment. This numerical experiment has been performed using well validated software, allowing it to be used to validate new numerical models. A supplementary document is provided to you in order to help you understand the validation data.

The numerical experiment will provide access to the displacements and Von Mises stresses at a large number of predefined points in the aileron (in the order of 10,000 points). It is your task to process this data, and provide meaningful comparisons to your numerical model. It is your responsibility to interpret the test data correctly.

Thus, as a minimum, provide the following:

- Comparison between the results of your numerical model and the validation data, including appropriate validation tests and associated plots (results only for final report).
- Reasoning for discrepancies found.

Miscellaneous notes

Reference Material

- Megson, 'Aircraft Structures for Engineering Students' 4th or 5th edition
- 2nd year Structural Analysis & Design course (AE2135-I), lectures + lecture notes
- S.J. van Elsloo, Dr. ir. J.M.J.F. van Campen, Dr. ir. W. van der Wal, 'A primer on deflections of statically indeterminate structures'
- S.J. van Elsloo, Dr. ir. J.M.J.F. van Campen, Dr. ir. W. van der Wal, '3212-II SVV Structures Assignment Aircraft Allocation & Data'
- S.J. van Elsloo, Dr. ir. J.M.J.F. van Campen, Dr. ir. W. van der Wal, 'Description of the Verification Model Used in the AE3212-II Project'
- S.J. van Elsloo, Dr. ir. J.M.J.F. van Campen, Dr. ir. W. van der Wal, '3212-II SVV Structures Assignment Description of Validation Data'

Useful guidelines

- Be consistent with the use of your coordinate systems!
- The aileron cross-section can be assumed to be constant throughout its length, and the *xz*-plane in undeflected position may be considered a symmetry plane of the aileron.
- Actuators I. and II. connect at the same y- and z-coordinate to the wing. They are placed at the same x-distance from hinge 2.
- Note that not *all* parts of your numerical model need to be numerical. It is fine if parts of it are done exactly (an example of this is the MacCaulay step functions, which is in principle an exact method).
- When discussing your assumptions, specify *why* it is valid to make this assumption, and what its effect is (what error does it introduce).
- Statement of facts are *not* assumptions. As an example, hinge 3 being fixed in z-direction and displaced upwards in y-direction is *not* an assumption, it is just a given fact.
- Make sure that you are specific in describing your verification and validation strategies (particularly for the simulation plan). You do not have to explain what verification and validation mean as a concept; you may assume the reader to be well aware of this. Rather, you should detail how *you* plan on verifying and validating your model. Thus, avoid vague descriptions such as "The results of the validation data and the numerical model will be compared", without specifying

how you will compare them (how do you define the error between them, for example).

Diagrams Aileron Geometry

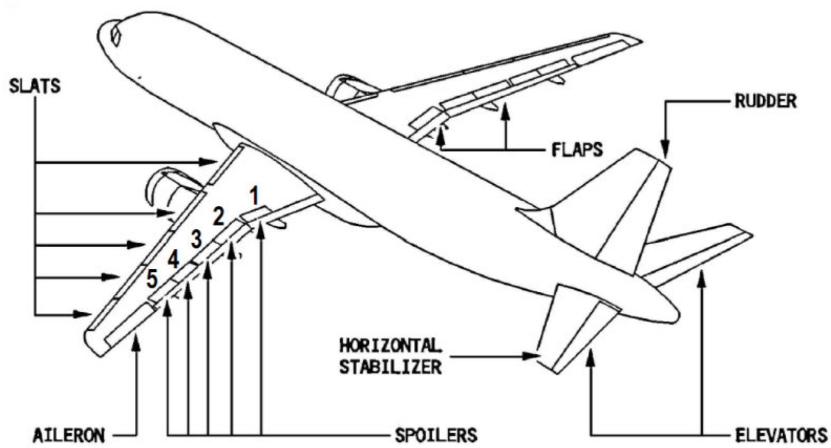

Figure 1: Aileron [http://theflyingengineer.com/tag/alleviation/]

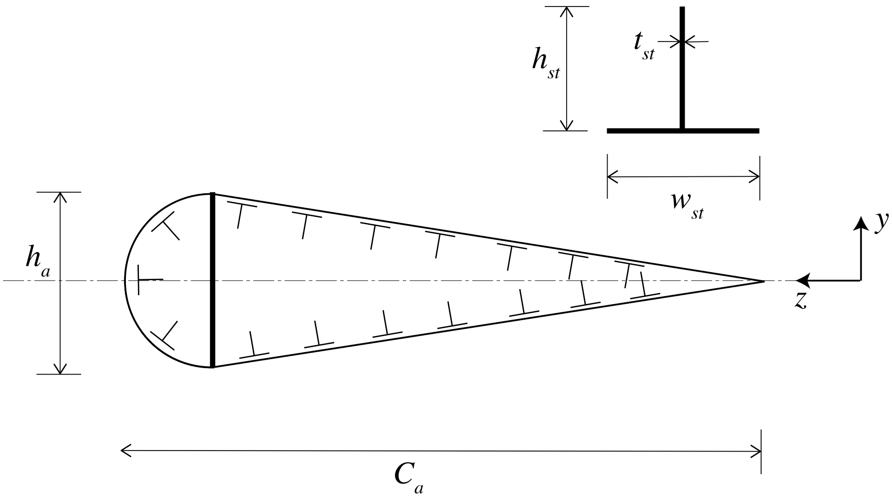

Figure 2: Cross-section of aileron

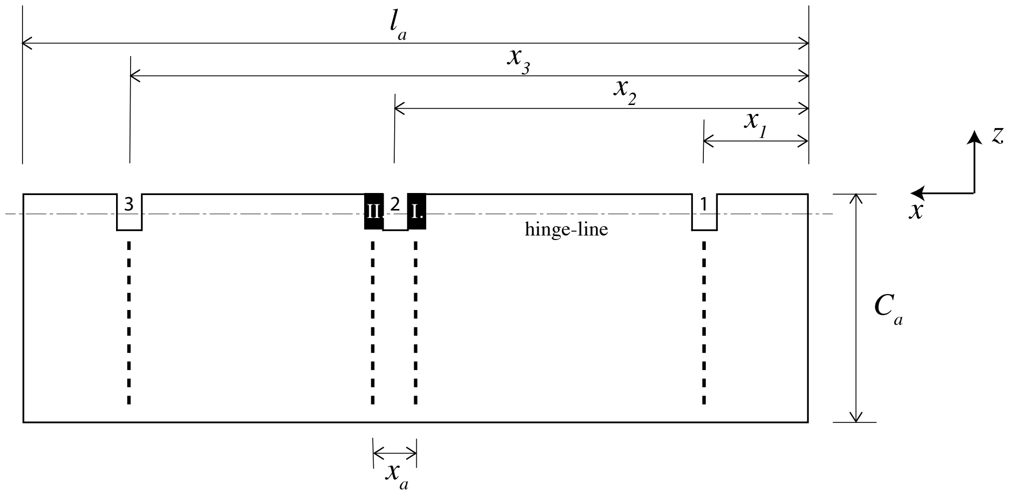

Figure 3: Hinge points and actuator attachment of aileron

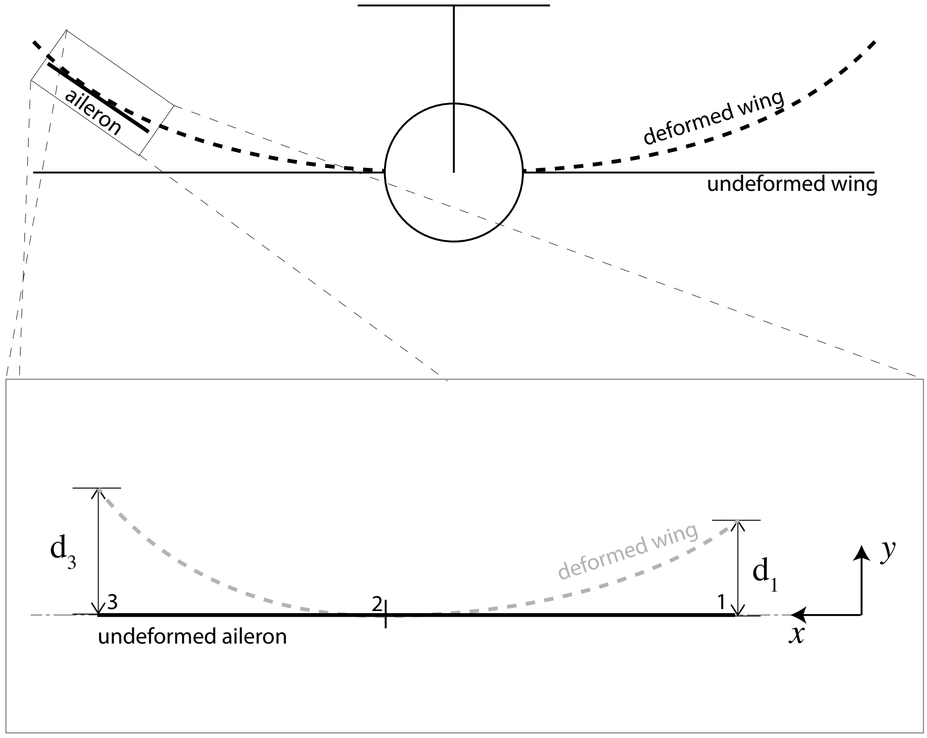

Figure 4: Wing deformation under limit load and required aileron deformation to match wing deformation. The test fixture mimics this deformation state by fixing hinge 2 and by moving hinges 1 and 3 in positive y-direction.

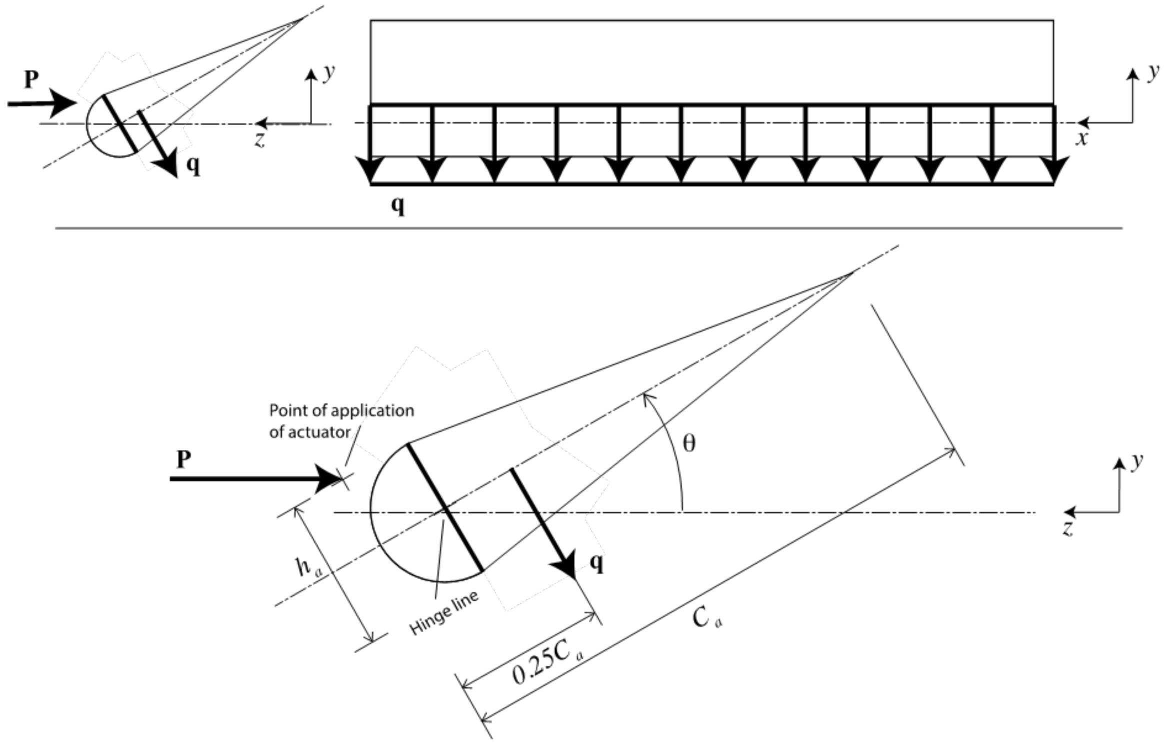

Figure 5: Deflected aileron, rear and side view with loading