AE3212-II SVV
Structures Assignment 2021

This document outlines the Structural Analysis assignment used in the 2020-2021 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 be provided with 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 is evaluated using the Von Mises stress. This model, to be referred to as the **developer model**, has already been developed and programmed by a fellow engineer; it will be your primary responsibility to verify and validate this model.

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 q acts perpendicular to the symmetry plane of the aileron, varying both with the spanwise and chordwise direction (not shown in figure 5). Furthermore, the aileron is loaded in its maximum upward deflected position, see figure 5.

The aerodynamic loading perpendicular to the symmetry plane is known. The developer model thus incorporates this loading (which will be provided to you as well, see page 4) to compute the actual deflections and stresses of the aileron.

In conclusion, your main objectives in this project will be the following:

- **Verify the provided developer model.** This should rely on a variety of tests that cover all of the simulation and are developed to find errors or inaccuracies in different parts of the code. As a start, you should develop your own numerical model that is able to calculate (in a simplified way) the deflections and stresses in the aileron. However, you should also perform verification tests that do not rely only on comparison of the developer model with your numerical model and which can be developed in parallel with the development of your own model. Therefore, you are advised to simplify your numerical model compared to the fidelity of the developer model, to allow you sufficient time for other verification tests. In the second part of this document you are provided with some suggestions on what simplifications can be made in your own numerical model.

- **Validate the developer model.** To aid you in this, you will be provided (via Brightspace) with the results of a finite element simulation, which can be considered to be a numerical experiment. This numerical experiment has been performed using well validated software. It can therefore be used to validate new numerical models, including the developer model. Note that assumptions and simplifications were made in generating the finite element model, e.g. the aerodynamic loading has been simplified to a number of discrete loads and the stiffeners are smeared out over the skin of the aileron..

In the developer model, the following general assumptions have been made:

- The aileron can be modelled as a beam.
- Reaction loads at the hinges and actuators can be modelled as point loads.
- The hinges 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	Group	Aircraft
A01	A320	A18	CRJ700	A35	Do 228	A52	F100
A02	CRJ700	A19	Do 228	A36	F100	A53	A320
A03	Do 228	A20	F100	A37	A320	A54	CRJ700
A04	F100	A21	A320	A38	CRJ700	A55	Do 228
A05	A320	A22	CRJ700	A39	Do 228	A56	F100
A06	CRJ700	A23	Do 228	A40	F100	A57	A320
A07	Do 228	A24	F100	A41	A320	A58	CRJ700
A08	F100	A25	A320	A42	CRJ700	A59	Do 228
A09	A320	A26	CRJ700	A43	Do 228	A60	F100
A10	CRJ700	A27	Do 228	A44	F100	A61	A320
A11	Do 228	A28	F100	A45	A320	A62	CRJ700
A12	F100	A29	A320	A46	CRJ700	A63	Do 228
A13	A320	A30	CRJ700	A47	Do 228	A64	F100
A14	CRJ700	A31	Do 228	A48	F100	A65	A320
A15	Do 228	A32	F100	A49	A320	A66	CRJ700
A16	F100	A33	A320	A50	CRJ700	A67	Do 228
A17	A320	A34	CRJ700	A51	Do 228	A68	F100

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.
- Hinge 3 is fixed in z-direction and displaced in y-direction by a predefined amount, d3.
- Actuator I. is kept fixed in z-direction.
- **A 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 act 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 chordwise station, and each column corresponds to a spanwise 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.

Report Outline

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

- Description of loading case.
- Developer model.
- Numerical 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.

Developer model

As mentioned previously, you are provided with a developer model that is the focus of all your activities in this project. This model produces the output listed at the beginning of this assignment.

A supplementary document is provided to you to help you understand the developer model. Based on this description, you should discuss the assumptions (implicitly) made in the developer model (be sure to describe both their effect on the final result and their validity). Furthermore, you should discuss the developer model itself, explaining the main steps taken by the program and the governing equations that lie at the basis of it. To that end, you should also provide a flowchart to aid the reader in understanding the flow of the developer model code.

For the final report, 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).

Thus, as a minimum, provide the following:

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

Numerical model

A good basis for the verification of the developer model will be to work out your own (simplified) numerical model of the load case providing the same outputs. Comparing the results of the numerical model with the developer model will then provide a good starting point of the complete verification. However, as mentioned before, you should not rely solely on your numerical model to verify the developer model as there can be errors and inaccuracies in many parts of the model, so you should simplify your own model sufficiently to allow you for enough time to also perform other tests.

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 developer 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 before, it is vital that you do not spend too much time writing a high-fidelity model of the load case and ending up not having time to do independent tests on the developer model. Therefore, you are recommended to make the following simplifications in your numerical model:

- For the deflection calculations, assume that deflections due to twist are negligible compared to the deflections caused by bending, and replace the boundary condition at the jammed actuator with a fictious boundary condition on the twist
- For the deflection calculations, replace the provided the two-dimensional, varying aerodynamic loading with a simplified loading, e.g. a one-dimensional, uniformly distributed load located along the hinge-line.
- For the stress and shear center calculations, ignore the presence of stiffeners in your calculations.

You should still discuss the effects and validity of these assumptions (as well as those of any other assumption you make in your numerical model) as they will explain discrepancies between your own model and the developer model. However, you can be assured that these simplifications will lead to results that are sufficiently accurate that they can be used to help verify the developer model. In the supplementary document, you can find some additional information on the two of these assumptions.

In relation to this, you should motivate why your numerical model is a suitable model to verify the developer model, in light of the differences between the models.

Finally, for the final report only, you should 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). In conclusion, as a minimum, provide the following:

- Discussion of the assumptions made in your numerical model and their effect on results.
- Description of your numerical model.
- Motivation why your numerical model is suitable to verify the developer model.
- Results of your numerical model (final report only). These should based on the data corresponding to the aircraft your group has been assigned.

Verification

The developer 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 developer model. However, this does not guarantee that the developer model is correct, since it has not been established yet that your numerical model is accurate (and likely your numerical model is of lower fidelity than the developer model), and errors and inaccuracies can be in different parts of the development model. Therefore, you should also verify the developer model by performing independent unit and larger tests.

Thus, as a minimum, provide the following:

- Verification of the developer model including appropriate unit tests and system tests and explanation of discrepancies (results only for final report).
- Comparison between the results of the developer model and your numerical model for a variety of cases and explanation of their discrepancies (results only for final report).

Validation

Finally, the developer 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, including the developer model. A supplementary document is provided 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 the developer model. It is your responsibility to interpret the test data correctly.

Thus, as a minimum, provide the following:

- Comparison between the results of the developer 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 Developer 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 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 for the load case.
- 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 developer model will be compared", without specifying *how* you will compare them (how do you define the error between them, for example).

Diagrams Aileron Geometry

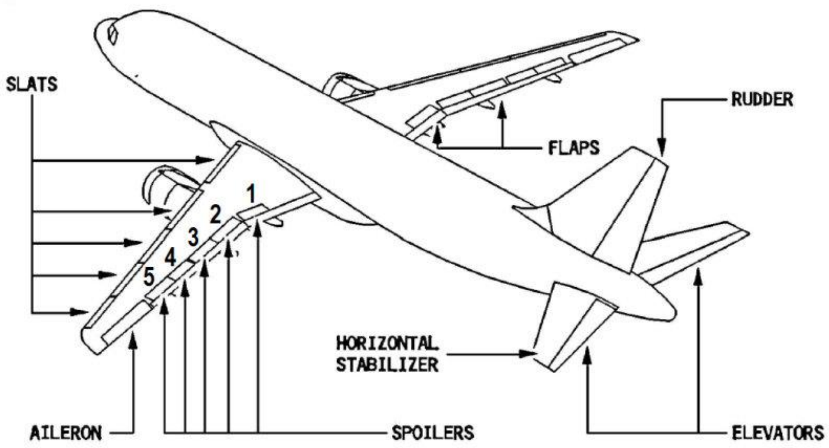

Figure 1: Aileron [http://theflyingengineer.com/tag/alleviation/]

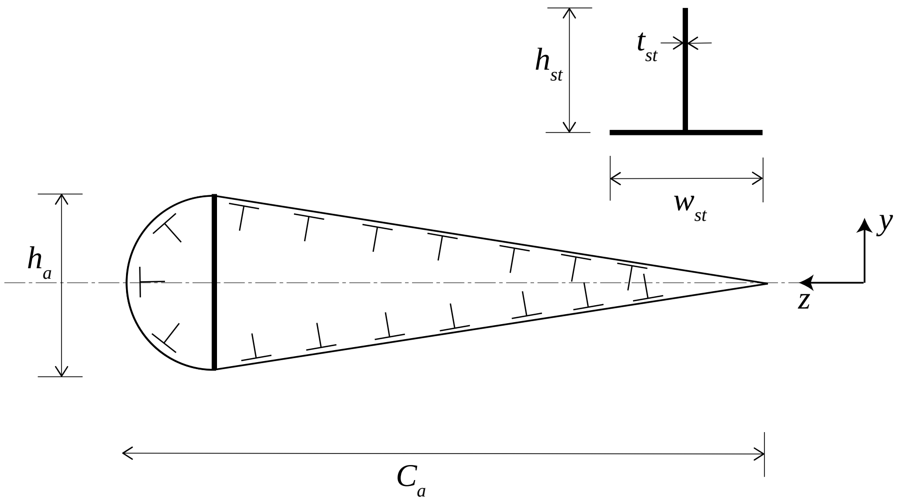

Figure 2: Cross-section of aileron

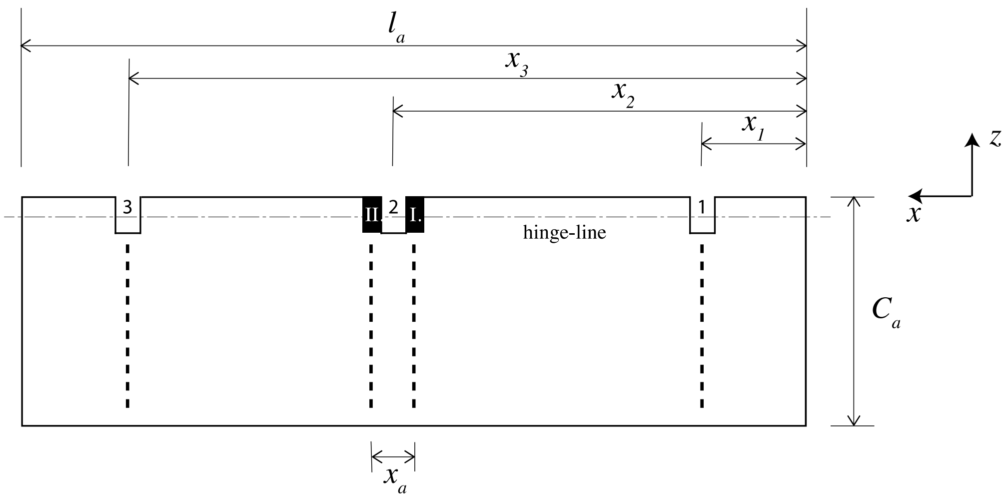

Figure 3: Hinge points and actuator attachment of aileron

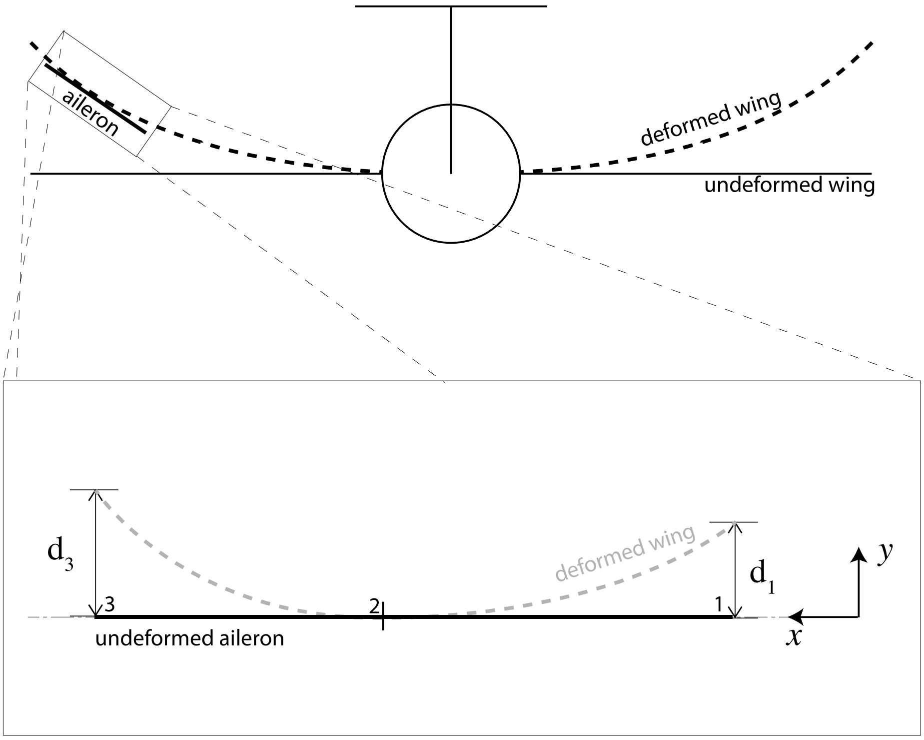

Figure 4: Wing deformation under limit load and required aileron deformation to match wing deformation. The provided load case mimics this deformation state by fixing hinge 2 and by moving hinges 1 and 3 in positive y-direction.

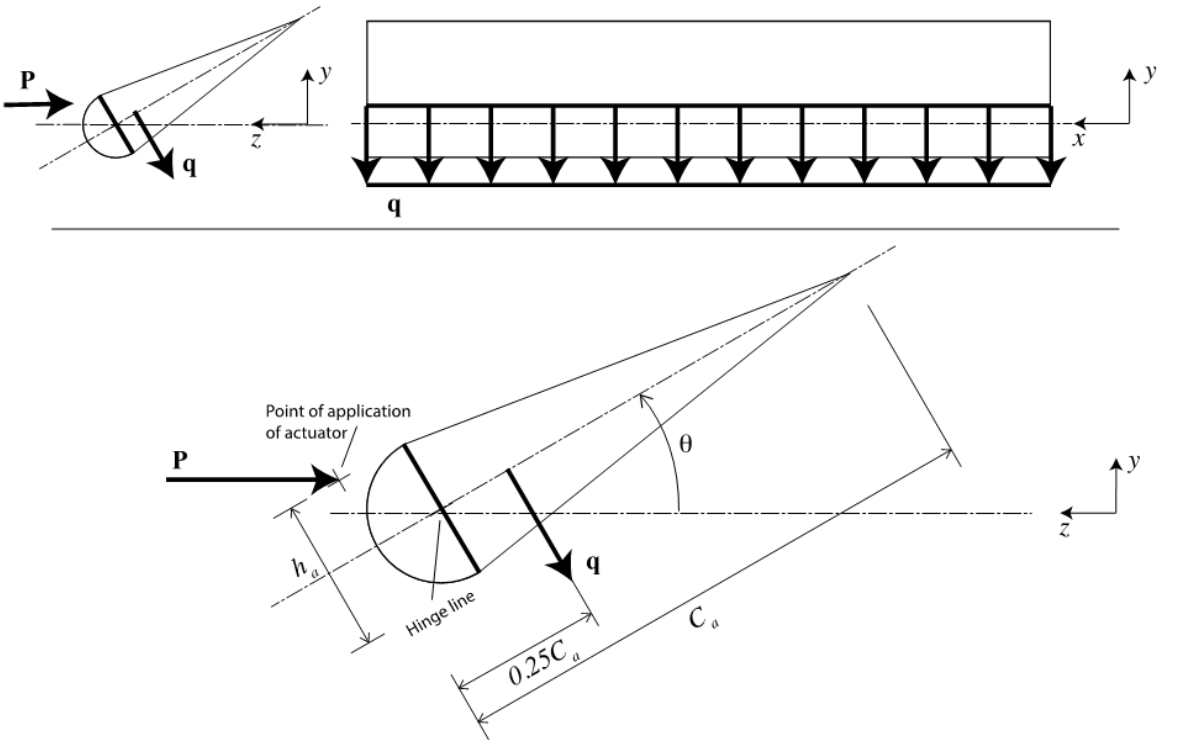

Figure 5: Deflected aileron, rear and side view with loading