AE3212 SVV
Extra Structures Assignment 2020

This document outlines an extra Structural Analysis assignment used in the 2019-2020 edition of the AE3212-II Simulation, Verification & Validation (SVV) course. This assignment has been created to give you another opportunity at passing the SVV course this academic year, as was decided by the Board of Examiners of the faculty of Aerospace Engineering.

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

During landing, the fuselage of the aircraft as described in the figures below, e.g. the moment when the landing gears touch the ground, a critical loading scenario ensues, as the fuselage is under torsion, bending and shear.

The loads on the fuselage are reacted at the location of the landing gears. Due to local disturbances, the pilot uses the rudder to balance the aircraft, causing a constant torque T in the fuselage.

As a group of stress engineers, you have the responsibility to check if the structure does not fail under the given loads. Furthermore, you are to check if the frames that introduce the point loads from the landing gears into the fuselage do not fail in shear.

In order to get you on started on the assignment you will be provided with a document containing the following:

- A guideline on how to set up a verification model for this problem.
- A suggestion on how to set up a numerical model for this problem.

During the analysis, the following assumptions hold:

- The fuselage can be modelled as a beam
- The attachment of the floor and the stiffeners to the fuselage do not have to be analysed.
- Reaction loads at the location of the landing gear can be modelled as point loads. No reaction moments are present.
- Frames can be modelled as very stiff open “rings” and are loaded in pure shear only.

Aircraft Allocation

Your group has been assigned the Boeing 737, for which the following data are given (refer to drawings at the end of this document):

Property	Symbol	Value (Unit)
Length of the fuselage	L	30.0 (m)
Length parameter	L_{f1}	4.0 (m)
Length parameter	L_{f2}	12.5 (m)
Length parameter	L_{f3}	5.2 (m)
Fuselage radius	R	2.0 (m)
Floor height	h_f	1.8 (m)
Skin thickness	t_s	3.0 (mm)
Floor thickness	t_f	2.0 (cm)
Thickness of stiffener	t_{st}	1.2 (mm)
Height of stiffener	h_{st}	1.5 (cm)
Width of stiffener	w_{st}	2.0 (cm)
Number of stiffeners (equally spaced along the periphery of the cross-section)	n_s	36 (-)
z-distance of aerodynamic centre of the tail to the back of the fuselage	$d_{tail,z}$	2.8 (m)
y-distance of aerodynamic centre of the tail to the back of the fuselage	$d_{tail,y}$	5.0 (m)
y-distance between bottom of the fuselage and the landing gear	$d_{\mathrm{lg},y}$	1.8 (m)
Lateral force on the tail	S_x	$1.7 \cdot 10^5$ (N)
Design landing mass	W	65.000 (kg)

Load case

- Lift and drag forces during landing are negligible.
- Lateral force S_x works on the tail of the aircraft.
- The total weight (structure + payload) can be modelled as a uniformly distributed load q.
- Vertical deceleration during “touch-down” is 3g.
- Federal Aviation’s Authority (FAA) requires a safety factor of 1.5 during the asymmetric landing.
- **No other than the aforementioned loads working on the fuselage**

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 fuselage 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(s) of the fuselage.
- 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 fuselage, the twist of the fuselage, as well as the maximum stress experienced by the fuselage. 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 fuselage. 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.

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 suggestion on how to set up a verification model of the fuselage will be provided to you. Your verification model should produce nearly the same output as your model.

A supplementary document is provided to you in order to help you set up your 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 fuselage. 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, chapter 22 on Fuselages and charpter 24 on Frames.
- 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’
- F. Esrail, Dr. ir. J.M.J.F. van Campen, Dr. ir. W. van der Wal, ‘Pointers to set up a verification model for the 2020 extra structures assignment’

Useful guidelines

- Be consistent with the use of your coordinate systems!
- The fuselage cross-section can be assumed to be constant throughout its length.
- 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, the vertical deceleration being 3g 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 Fuselage Geometry

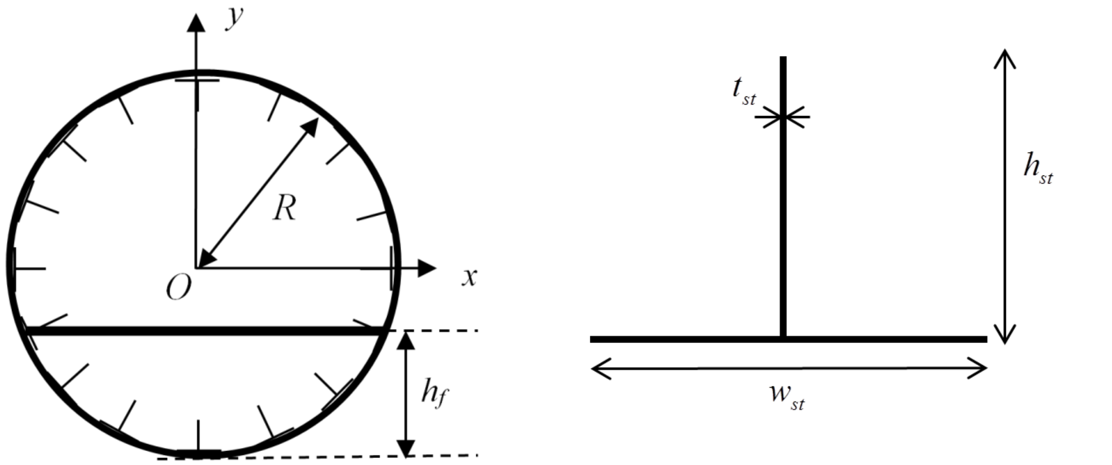

Figure 1: Fuselage cross-section (left) and stiffener geometry (right)

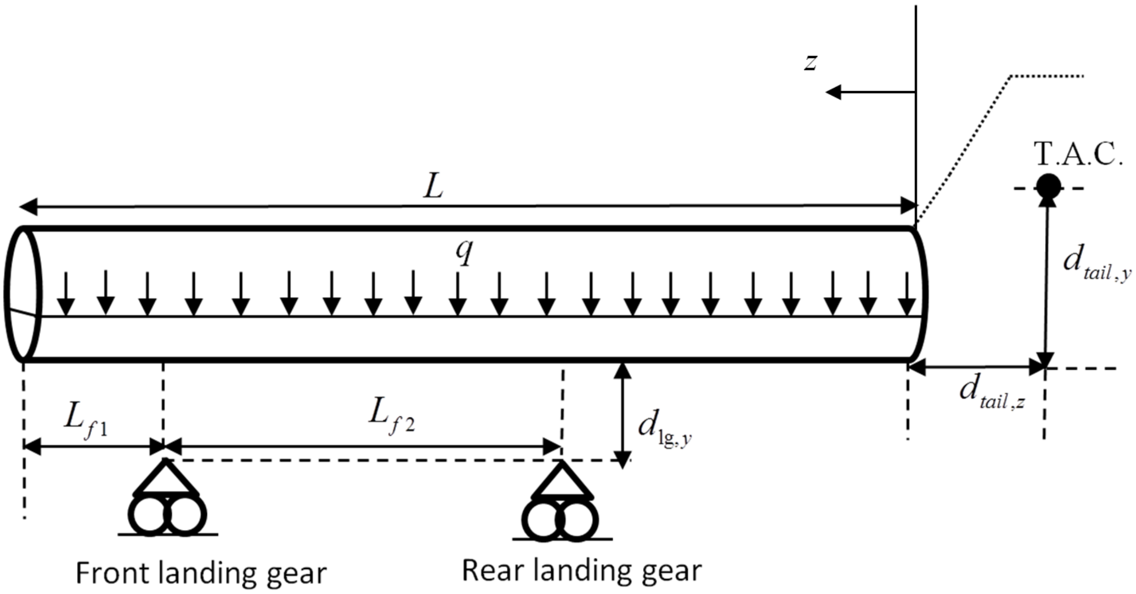

Figure 2: Fuselage modelled as a beam, q = distributed inertial load, T.A.C. = Tail Aerodynamic Centre

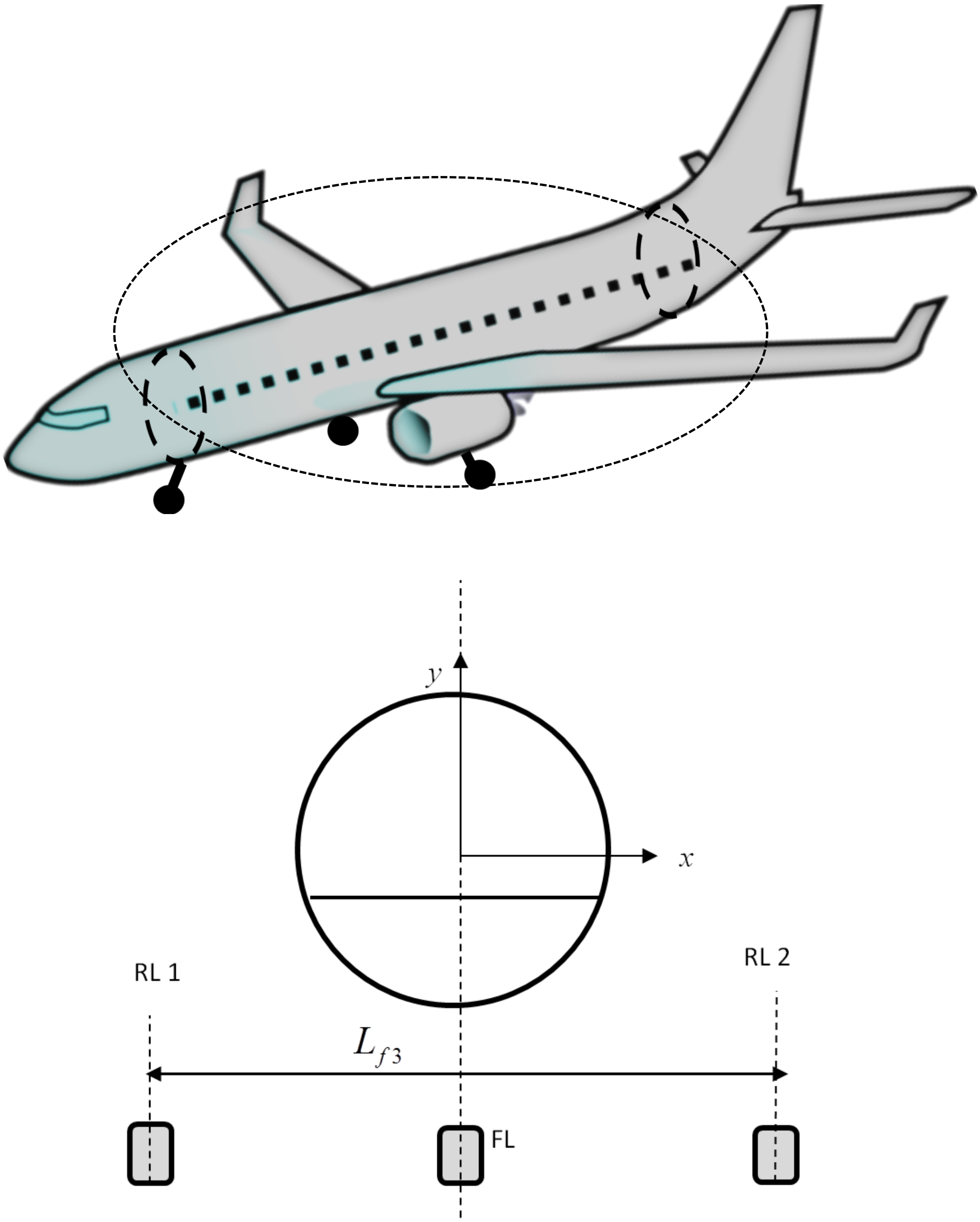

Figure 3: Isometric view of fuselage (top) and arrangement of landing gear front view (bottom), RL = rear landing gear, FL = front landing gear

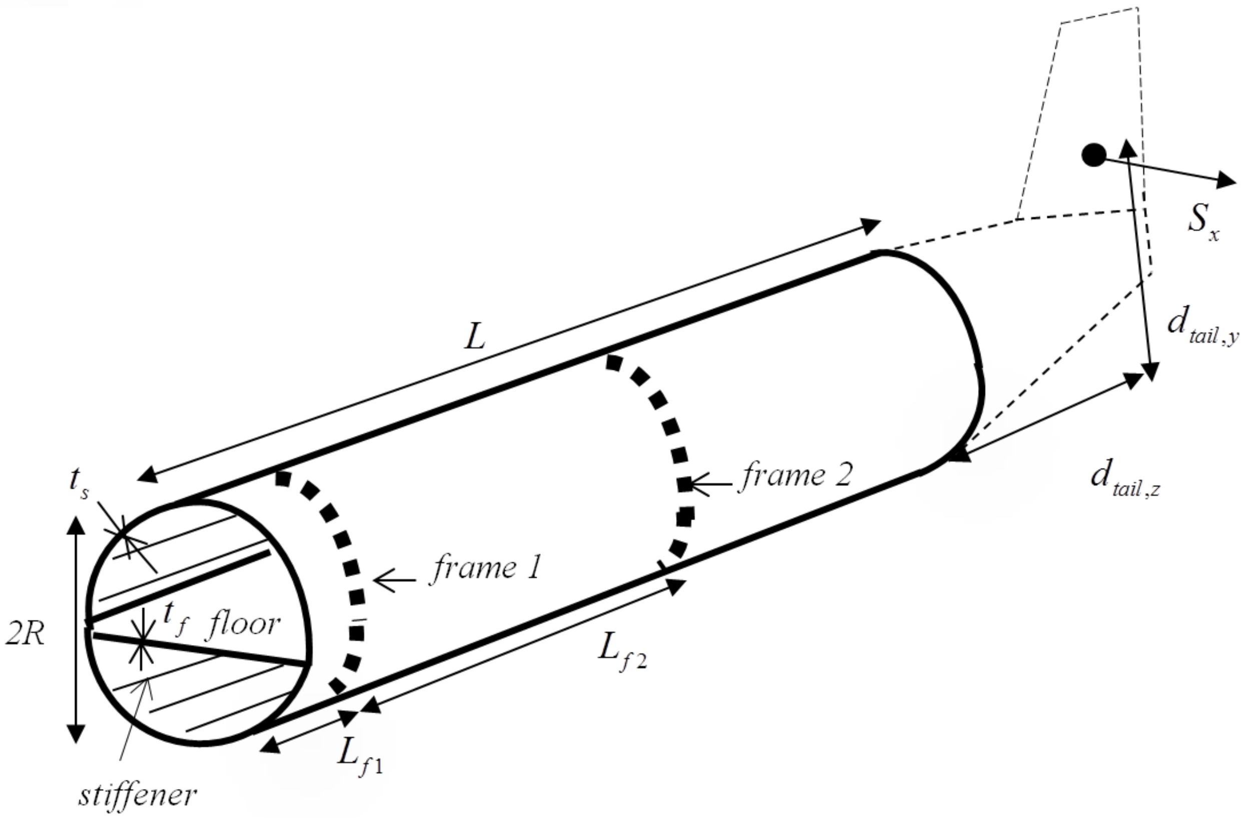

Figure 4: Isometric drawing of the fuselage, note: the aft tail section drawn with dashed lines does not have to be analysed.