Department of Aerospace Engineering
University of Bristol

Structures & Materials 3

Metallic Wing Torque Box Assignment Report

STRESS ANALYSIS USING MSC PATRAN/NASTRAN

STUDENT:	Your name
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TUTOR(S):	Tutor name
ACADEMIC YEAR:	2018-19

Academic Year 2019-19

Structures & Materials 3 (AENG31200)

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Department of Aerospace Engineering

University of Bristol, January 2019

Summary

Summary should be written in simple language (avoiding core technical terms) clearly stating the objective of the analysis, main conclusions and recommendations. It is meant for managers, decision makers and team members involved in the project who either do not have sufficient time to go through the complete report or are not familiar with FEA terminology.

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1 Format of technical report

The final report will be submitted online via SAFE as a PDF, no hardcopy necessary! A report template is available on Blackboard. You may use either Microsoft Word, or LaTeX. Technical report should include:

1. **Title or front page of report:** The title of the project, a nice small figure of the component, a report number, date of submission, name of supervisor, name of analyst (student), student contact details and affiliation.
2. **Summary (maximum 1 page) of the project:** A summary should be written in simple language (avoiding core technical terms) clearly stating the objective of the analysis, main conclusions and recommendations. It is meant for managers, decision makers and team members involved in the project who either do not have sufficient time to go through the complete report or are not familiar with FEA terminology.
3. **Main body of work:**
   a) Aims/Scope of project.
   b) Brief description of component, basic design details, functionality.
   c) Methodology or strategy of analysis.
   d) Mesh details (element types used, number of elements etc.), quality checks.
   e) Material and sectional properties.
   f) Boundary conditions details with separate figure corresponding to the appropriate load case.
   g) Tabular results and clear figures of appropriate load case.
4. **Conclusion and future work**

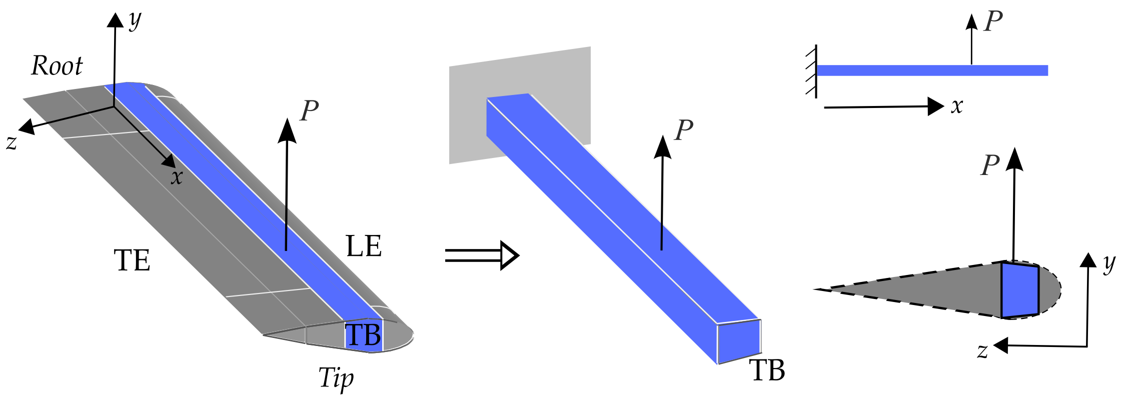
Documentation and local data storage/backup of all relevant models and results are essential.

2 Introduction to StM3 Assignment

2.1 Aims/Scope of project

1. Explain in a few paragraphs the motivation for carrying out this work.
2. Discuss relevance of 2nd year AVDASI2 course module.

> ...the aim of this assignment is for you to broaden your FE skills and have practical experience tackling a **real-world exercise** by using an aerospace industry-standard, FE software package; MSC Patran/Nastran. A useful reference is a peer-reviewed journal paper by Ostegaard et al. on the application of virtual testing of aircraft structures using non-linear finite element models [1]...
>
> ...to realise this goal, a finite element model of a wing torque box is developed based on a generic design from AVDASI 2, see Fig. 2.1, and perform a linear static stress analysis to assess its structural performance (by calculating deflections and stresses)...



* Wing profile defined according to standard NACA 2418 coordinates.
* Profile constant along the span.

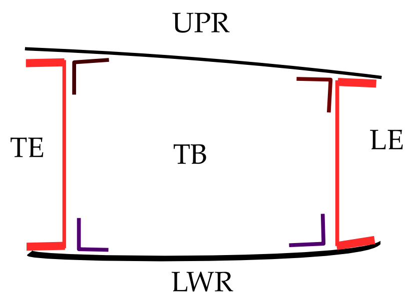


Figure 2.1: Schematic of a typical wing torque box - NACA 2418 profile. (LE) - Leading edge, (TB) - Torque box, (TE) - trailing edge - *(Ian Farrow 2013)*.

2.2 Description of wing torque box

1. Provide a brief description of component, basic design details, and functionality.

...a representative CAD model of a generic torque box (TB) prototype is shown in Fig. 2.2. Key structural features are:

- **Spars** Vertical elements running along the wingspan. They have the main function of carrying the shear force;
- **Stringers** Slender beams attached to the skin. They have the main function of carrying the axial force (thus balancing the wing bending moment) and stabilizing the skin against buckling;
- **Skin** Thin shell covering the wing. It has the main function of carrying the wing torsional moments and providing the aerodynamic shape;
- **Ribs** Elements located in the cross-section plane. They have the main function of maintaining the shape and redistributing the external loads.

Although several simplifications have been made (e.g. absence of LE droop-nose and TE flap), the proposed structure contains sufficient detail for an initial FE analysis to capture the phenomena of interest. The CAD that has been prepared for this exercise is a reduced version of this wing torque box, containing only surfaces and curves (lines) to represent the main geometric features (see Fig. 2.3)...

2.2.1 Boundary and loading conditions

The torque box is idealised as a cantilever beam with an offset load, as illustrated in Fig. 2.4. Only one load case shall be considered, where the value of $P = 1.0$ kN. To best mimic the structural root attachments from AVDASI2, the following boundary conditions (BCs) are suggested:

1. Trailing Edge spar: To represent the TE bending reaction joint plates, assign fully constrained boundary conditions at the TE, see Fig. 2.4.

2. Baseplate: Entire wing root is constrained in the global X (span-wise) direction. Note that this BC implies that all of the sections are active at the root.

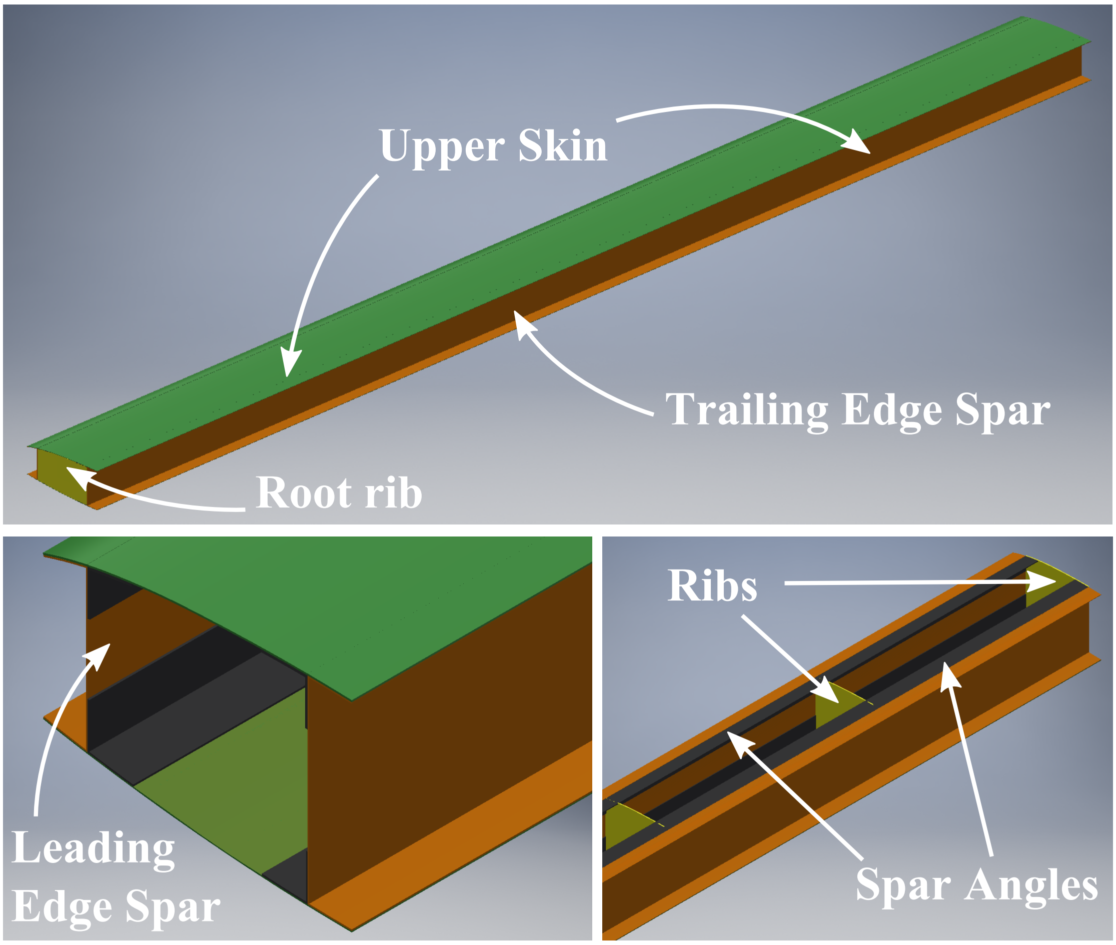


Figure 2.2: Representative CAD model of torque wing box highlighting key structural features.

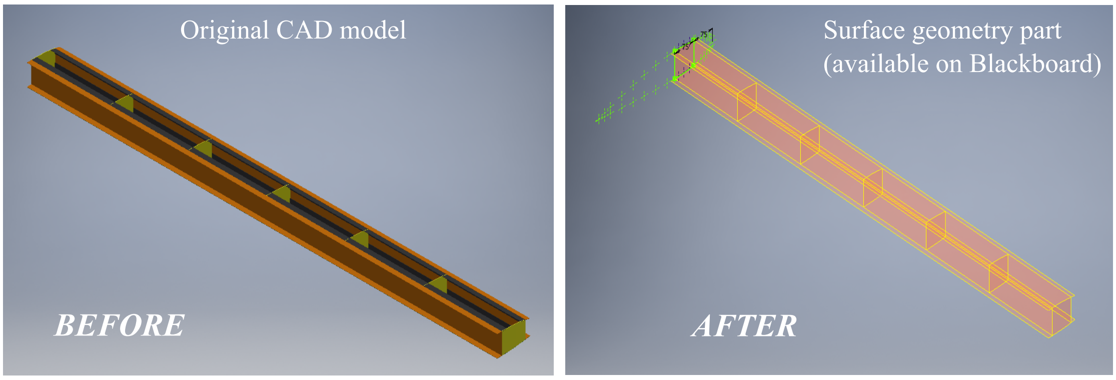


Figure 2.3: Final IGES file available on Blackboard after CAD clean-up and repair.

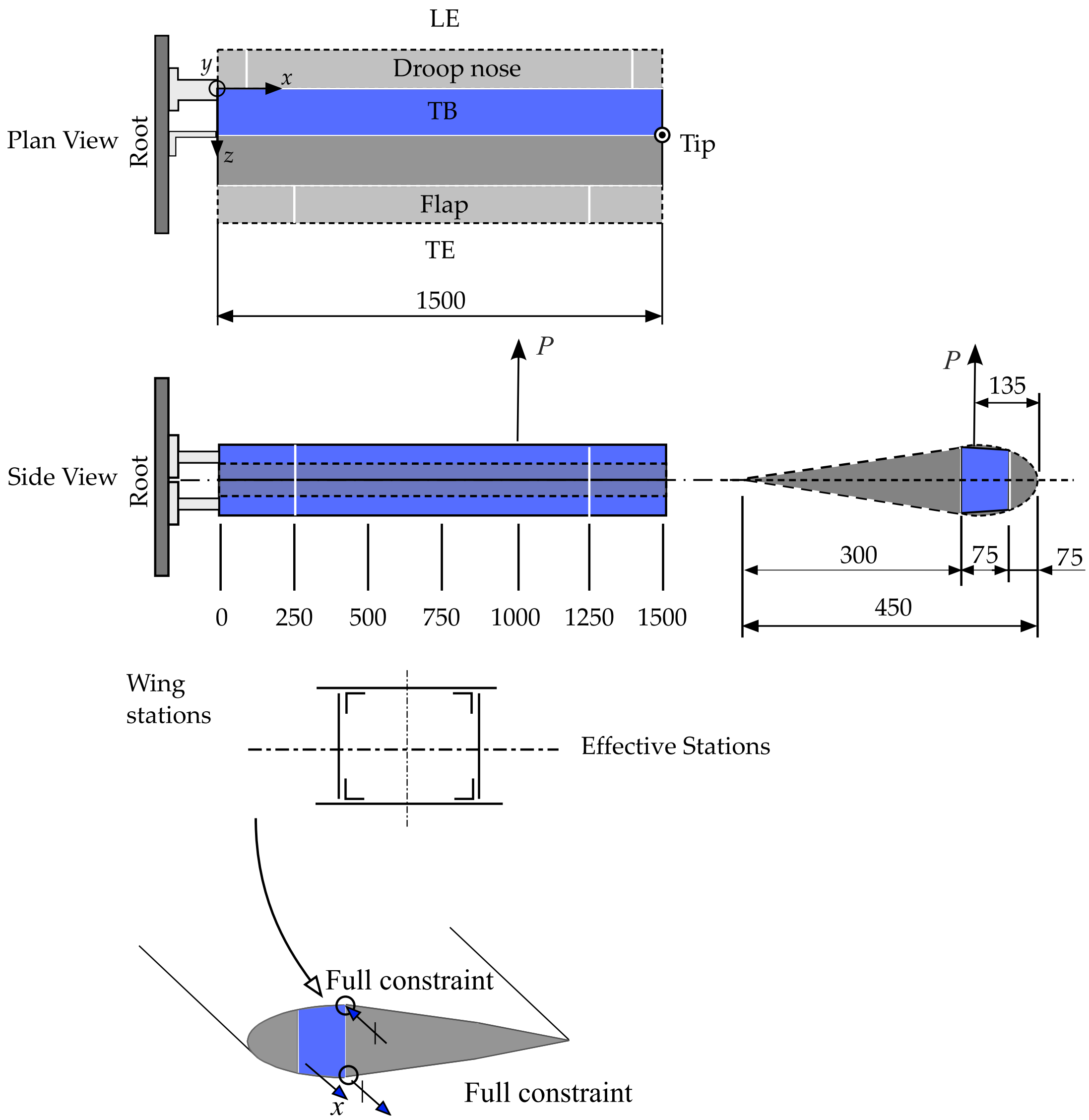


Figure 2.4: Schematic of boundary (restraint) and loading conditions applied to wing torque box *(Ian Farrow 2013)*.

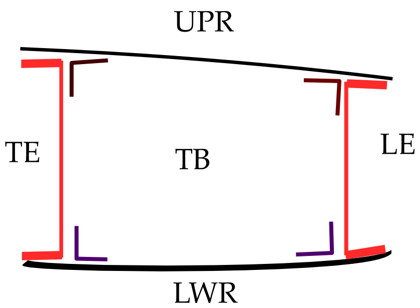


Figure 2.5: Cross-section of the wing torque box showing key structural features: skin, stringers and spars.

2.2.2 Geometric properties of structural elements

Table 2.1 gives the dimensions of key structural elements of the torque box that should be employed in the sectional properties definition of the finite element model, as illustrated in Fig. 2.5.

Spar cap angles are composed of L profiles cross-sectional areas.

All structural elements are manufactured from the aerospace standard clad aluminium alloy 'Aluminium 2014a-T3'[1]. Typical material properties for 2014 aluminium alloy are given in Table 2.1.

Table 2.1: Dimensions and sizes of the wing and its structural elements.

Element	Thickness [mm]	Additional comments
UPR skin	0.8	
LWR skin	0.5	
LWR spar cap angle	0.9	All angles: L profile
UPR spar cap angle	0.7	15×15 mm
LE spar	0.5	
TE spar	0.5	
Ribs	1.0	
Material : Aluminium 2014a-T3 E = 73 GPa, ν = 0.3, ρ=2800 kg/m^3 Tensile and compressive allowable limit: 245 MPa		

[1] Recall temper notation : T3 - Solution heat treated, cold worked and naturally aged

3 Finite Element Model

3.1 Pre-processing steps

Discuss very briefly the pre-processing steps:

1. Geometry (import of CAD geometry, topological congruency, partition of surfaces).
2. State unit system.
3. Material type and properties used.
4. Section properties. You may copy and paste relevant sections of .bdf file showing material and sectional properties in Appendix A. **DO NOT COPY THE ENTIRE .BDF FILE!**
5. Boundary and loading conditions with separate figure corresponding to the appropriate load case, show this in a couple of figures.
6. Mesh details - element types and formulations, number of elements, quality checks, see Table 3.1.

Table 3.1: Summary of element types and aspect ratios assigned to each structural entity

Part	Total No. of elements				Element
	CBAR	CBEAM	CQUAD4	CTRIA3	size (AR)
UPR/LWR Skin					
TE/LE Spar webs					
TE/LE Angle caps					
Ribs					
Total					

4 Analytical Wing Sizing Calculations

4.1 Initial wing sizing calculations

1. State all key assumptions, equations and simplifications.
2. Include an annotated sketch of the equivalent torque box and boom idealisation.
3. You may tabulate the results directly from a working excel spreadsheet or Matlab script. However, place key calculations in the Appendix not in the main body of text.

5 Results of Finite Element Model

5.1 Results from Exercise #1

1. Tabular results and clear figures of appropriate load case, see Table 5.1.

Table 5.1: Summary of stress and deflection results as obtained from MSC Nastran linear static model.

Component	Value	Location	Fig. No.
Max. displacement			
Max. von Mises stress (shell)			
Max. shear stress (shell)			
Max. combined axial and bending stress (beam)			
Mass of the wing torque box		n/a	n/a

5.2 Verification against Analytical Solutions

1. Compare and discuss analytical and FE reserve factors.

	UPR TE col. bkl.	UPR skin buckling	TE spar buckling	LWR skin tension	LWR TE tension	Max tip deflect.
FE	RF val	RF val	RF val	RF val	RF val	(mm)
Analytical	RF val	RF val	RF val	RF val	RF val	(mm)

5.3 Discussion of Results

1. Use engineering judgement to comment on the structural integrity of the wing torque box based on your stress results and stress allowable for the aluminium material.
2. Does the FE model fully capture the structural behaviour of the wing torque-box under the loading specified?
3. What are the limitations of the current 'linear static model'?

5.4 Improvements to FE Design - Inspection hole analysis

1. Discuss the geometry creation, namely how to partition the geometry and create the inspection holes cuts.
2. Present images of the von Mises stress field on the lower skin without and with inspection holes. Discuss differences.
3. Calculate the stress concentration factor on each inspection hole. Present results in a table.
4. Present a graph showing the distribution of stress in a chord-wise direction on an inspection hole. Discuss stress concentration around a hole.
5. Discuss the re-distribution of stress after including the inspection holes. How has the stress been distributed in the skin/booms?

6 Conclusions and Future Work

Bibliography

[1] Morten G Ostergaard, Andrew R Ibbotson, Olivier Le Roux, and Alan M Prior. Virtual testing of aircraft structures. *CEAS Aeronautical Journal*, 1(1-4):83–103, 2011.

A MSC Nastran .bdf file

1. Copy of **<u>truncated</u>** .bdf file from Exercise #1.

B Analytical Calculations

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