Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Department of Mechanical and Process Engineering
Institute of Design, Materials and Fabrication

ETH Zurich - CMAS

Leonhardstrasse 21

8092 Zurich, Switzerland

Student:	Valverde, Alejandro	
	ETH-Nr:	Departement: MAVT
	Hochschule (if external student): Cranfield University	
Thesis:	Title: Bending-Twist Shape Adaptation by Compliant Chiral Spar Design	
	Kind of Thesis: MA	Semester: FS2017
Supervisor:	Prof. Dr. P. Ermanni	
Advisor:	Runkel, Falk; Keidel, Dominic; Urban Fasel	

Start of the work:	01/04/2017
Intermediate presentation (Zwischenpräsentation):	tbd
Final presentation (Endepräsentation):	31/08/2017
Deadline delivery final report:	30/09/2017

Introduction

Shape adaptation of aerodynamic surfaces offers great potential for performance improvement across a wide range of flight conditions. In general, morphing structures encounter the challenge of combining the capability of carrying external loads (requiring a particular stiffness) with the need to macroscopically change its shape (requiring high compliance). For achieving purely passive shape adaptation by means of a desired bending-twist coupling, the propsed thesis studies the utilisation of a structurally tailored wing box featuring a unique mechanical response. The wing box is comprised by two flanges and two spars, one of which is designed by chiral periodic elements with curved ligaments, adding an additional geometrical parameter to the chiral design [1]. This significantly augments the tailorability of the mechanical behaviour of the chiral spar under deformation, which – in turn – affects the torsional stiffness and shear centre location of the wing box and, consequently, its torsional response [2,3]. Under shear and bending deformation – resulting from the aerodynamic pressure acting on the wing structure – the microstructural deformation behaviour of the chiral spar design is utilised to affect the global bending-twisting coupling of the wing structure. The attainable change in stiffness of the chiral spar, offered by virtue of the curved ligament design, is therefore exploited to increase the structural efficiency of the wing, e.g. by enabling load alleviation by means of root bending moment reduction.

Objectives

For achieving a buckling-induced twisting of wing structures, we consider a wing profile with a wing box comprised by two spars, one of which is designed with the novel chiral structure introduced at our institute. The initially very large shear modulus of chiral structures – owing to their microstructural deformation behaviour – significantly contributes to the torsional stiffness of the wing box. At a particular external load, the shear flow in the web exceeds the buckling limit, resulting in a drastic reduction of the effective shear modulus of this structural element. As a results, the torsional stiffness and the shear centre is affected, leading to a purely passively induced local twist of the affected wing sections, conceptually shown in Figure 1. For the wing structure, this buckling-induced change in twist results in a spanwise varied effective angle of attack which we aim to exploit for load alleviation purposes.

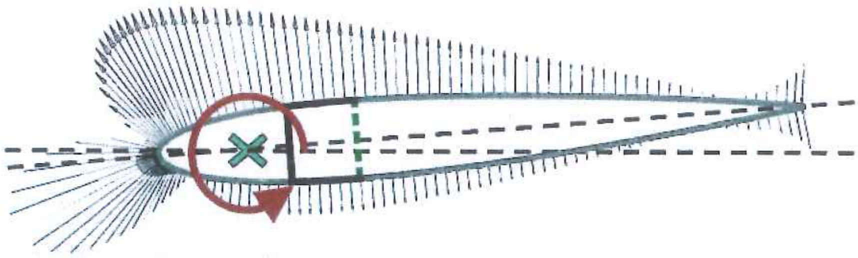


Figure 1- Wing with variable shear stiffness spar. Twisting results due to change in mechanical properties of rear spar under aerodynamic loads

In the first part of the thesis, parametric studies for the existing finite element simulation for a wing box structure with embedded chiral buckling elements are conducted. By means of numerical simulations, we assess the impact of geometrical parameters of the internal structure for the shape adaptation capability of the proposed concept.
These studies aim to find a wing box design that can be utilised for conducting simple preliminary tests, showing that a buckling-induced change in twist of the box structure can be obtained. For this purpose, chiral lattices must be manufactured to be applied for the spar design (Figures 2 and 3). The remaining structural elements of the wing box are manufactured with isotropic material to simplify manufacturing and the analytical calculation of the twisting of the beam. For a realistic wing design, the wing box is implemented in a NACA0012 wing profile, and aero-elastic analyses are conducted, utilising techniques already developed at our institute. The proposed concept is studied for achieving shape adaptation of wing structures under realistic aerodynamic loads, with the aim to reduce the loads on the wing and to improve its aero-elastic behaviour. The results of this study are compared to the state of the art for achieving passive twisting of wing structures and benefits/drawback of the novel design idea are evaluated.

Figure 2 – Chiral elements with curved ligaments, processed by additive manufacturing

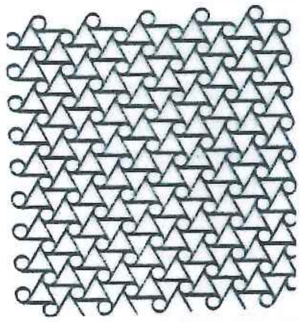
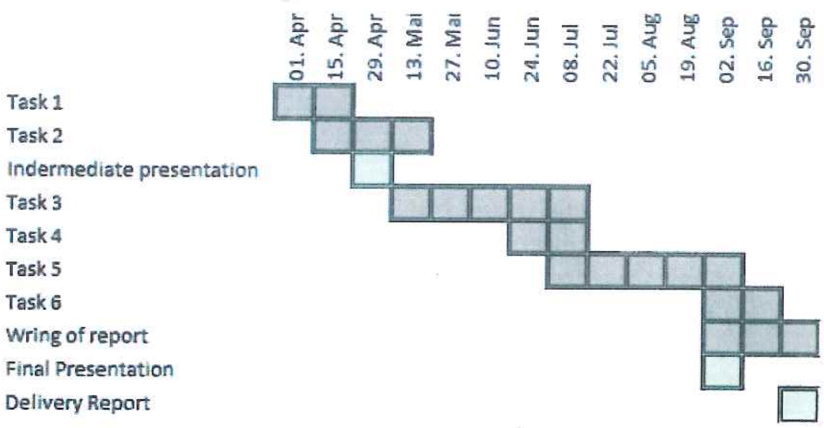


Figure 3 – Periodic chiral structure (taken from Bornengo, 2005)

Work breakdown

1. **Task 1**: Familiarisation with software (Abaqus CAE, XFOIL) and manufacturing techniques (3D printing process) of chiral structures.

2. **Task 2**: Finite elements analysis for assessing impact of geometrical parameters of chiral structure on the shape adaptation capability of simple wing box structure
3. **Task 3**: Manufacturing of wing box demonstrator with chiral elements shear web
4. **Task 4**: Testing of demonstrator for simple load cases
5. **Task 5**: Finite elements study of wing structures with chiral shear webs: aero-elastic analyses
6. **Task 6**: Comparison of results with existing concepts: benefits/drawbacks



Bibliography

[1] Bornengo, Scarpa, and Remillat, Evaluation of hexagonal chiral structure for morphing airfoil concept, 2005
[2] Urs Steiner, Airfoil camber morphing through tailored structural instability
[3] Gilles Ramstein, Experimental validation of chiral structures with controlled local instability

Please consider

- Directives and useful information about Student Projects at the Laboratory of Composite Materials and Adaptive Structures are available online at: http://www.structures.ethz.ch/content/dam/ethz/special-interest/mavt/design-materials-fabrication/composite-materials-dam/Education/Informationen/CMAS_Richtlinien_Studienarbeiten_EN.pdf
- Don't forget to register for the thesis under "My Studies" www.myStudies.ethz.ch at the begin of the semester
- <u>This document has to be included in the final report</u>

Zurich, 22/01/2017

Supervisor:	Advisor:	Student:
Prof. P. Ermanni		Alejandro Valverde