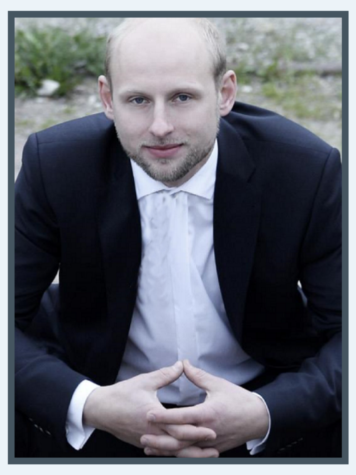

Fluid-Structure-Interaction in kite design

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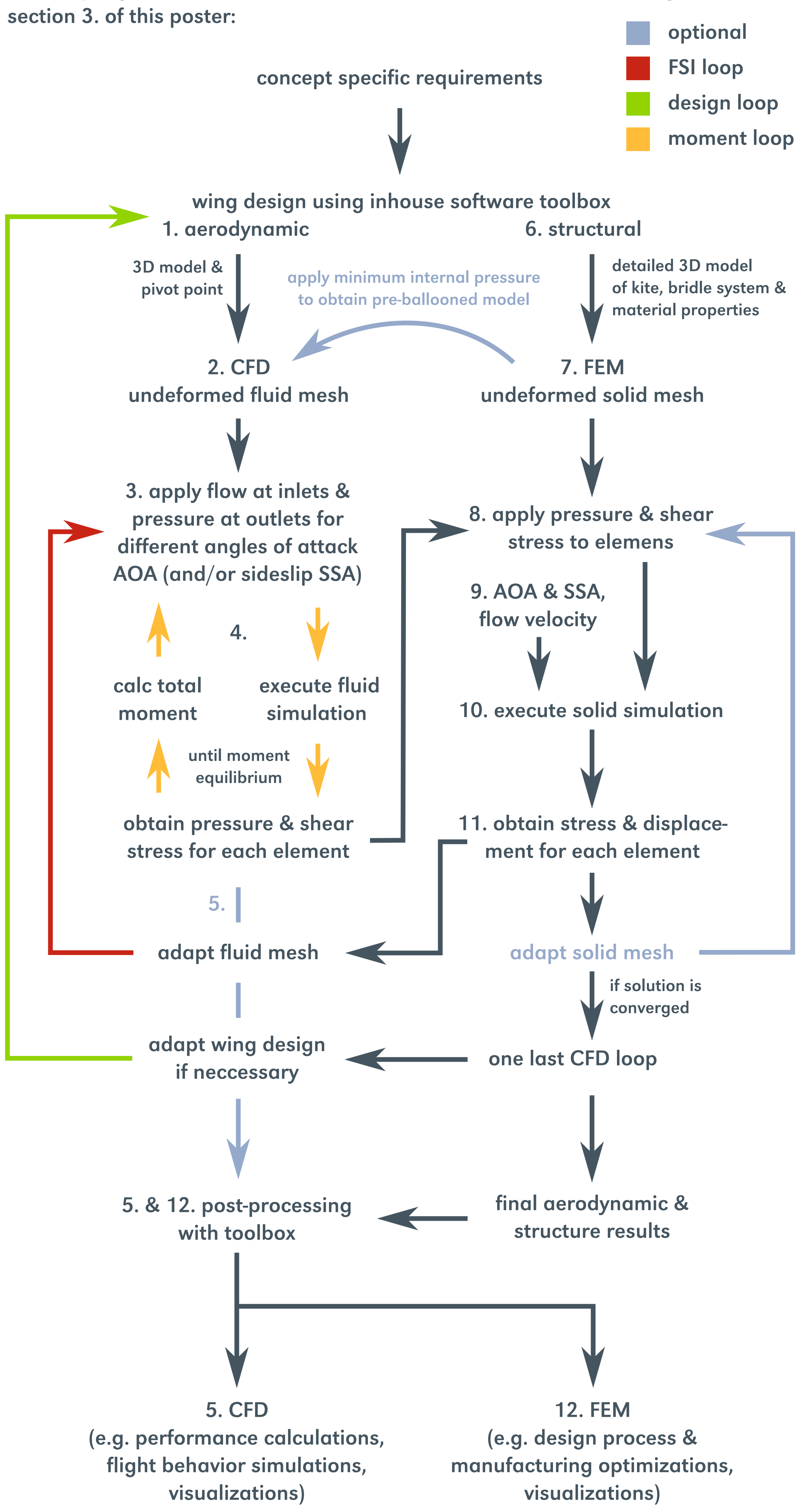
1. Introduction

The aim of reliable and sustainable tethered flight applications makes high-tech simulation, measuring and manufacturing approaches neccessary. To meet the requirements such as high surface load and durability, anurac investigates and develops in the field of kite design. To be able to incorporate the latest scientific findings an inhouse software package is permanently enhanced. This poster will show how the number of cost-intensive prototypes can be reduced significantly and new findings can be achieved by using simulation tools like CFD (Computational Fluid Dynamics), FEM (Finite Elements Method) and FSI (Fluid Structure Interaction).

2. Method

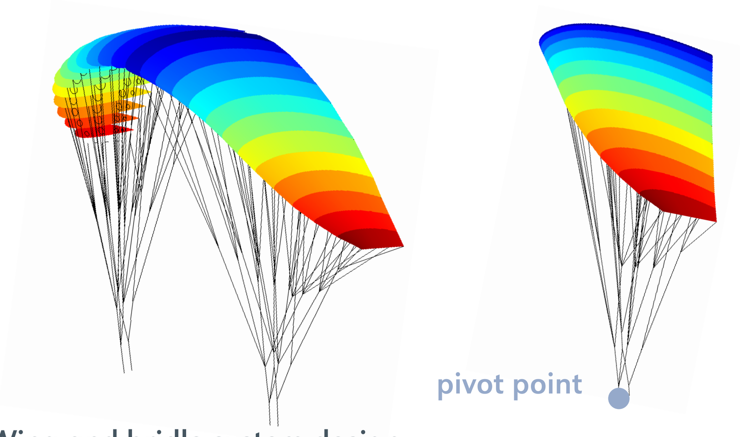
The current status of FSI development is simulating a steady-state flight situation. A snapshot of a straight-ahead transition flight through the power zone as well as a constant spiraling with compensating external forces have already been successfully simulated.
The coupling is done as shown in the flow-chart below. The numbering refers to section 3. of this poster:



3. Process & Results

Depending on the problem to be solved, the simulation process can be cut-off at particular steps. In most cases, the first design iteration will be done for a fixed power setting (e.g. depowered) as follows:

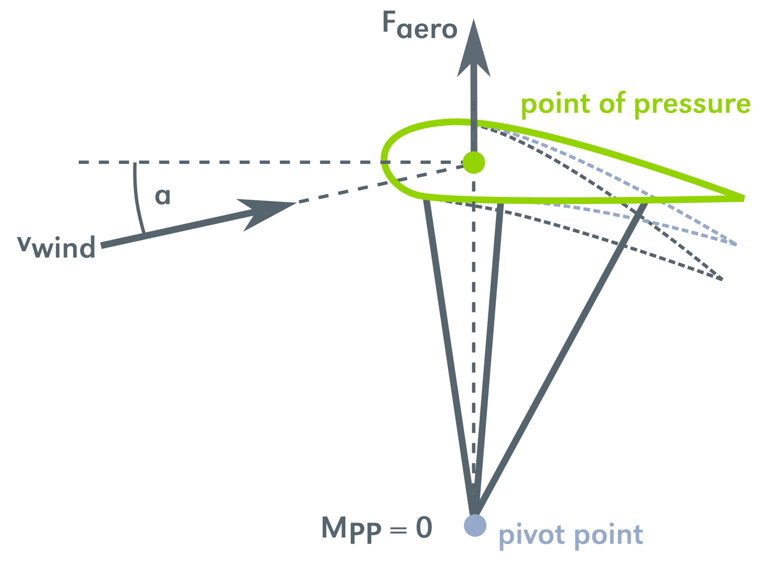
1. Design aerodynamic shape, define bridle system & pivot point (PP)
2. Create CFD mesh
3. Define boundary conditions
4. Running CFD simulation with different angles of attack to determine moment equilibrium (s. Fig. 2 & 3)
5. Post-processing CFD data w.r.t. workpoint angle "a" to optimize shape and/or bridle system (s. Fig. 4)



1. Wing and bridle system design

If structural issues like fabric stress and deformation under high loads are of interest, the whole process of coupled fluid and structure simulations is necessary. Therefore the next steps are:

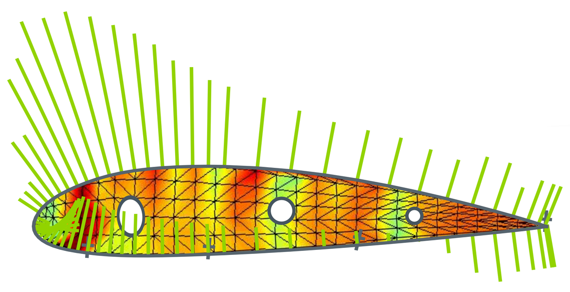
6. Define reinforcements, material types & orientation for wing and bridle system
7. Create FEM mesh
8. Map pressure and wall shear stress data of the wing at working angle of attack (AOA) "a" to the undeformed (or pre-ballooned) FEM model (s. Fig. 4)
9. Since the bridle system is not simulated in CFD, the wind loads on the bridles can be calculated by using the working angle "a" and flow velocity
10. Running FEM simulation
11. Use new deformed model to repeat FSI loop (sequence 3,4,8,9,10,11) until deformations are small and solution is converged (s. Fig. 4 to 7)
12. Post-processing FEM data to visualize deformations (s. Fig. 4 to 7 & flip-book) and optimize e.g. reinforcements, shape, bridle system, material spezifications



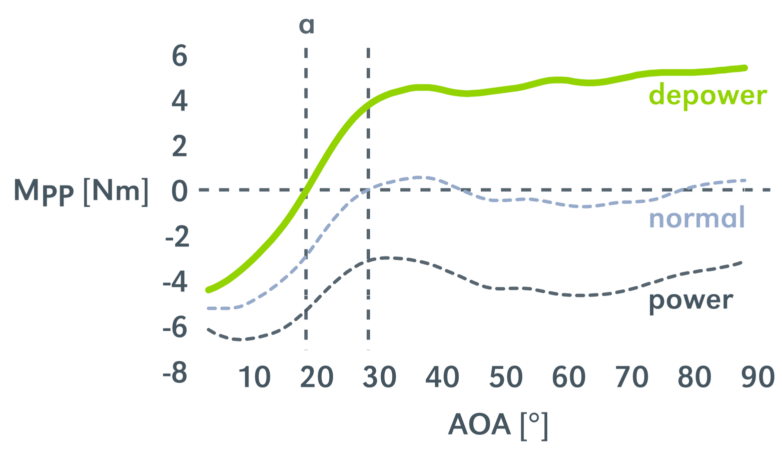
2. Example for moment equilibrium at angle of attack "a"

The CFD results of the simulation process can be fed into a tethered flight simulation (developed for MATLAB/Simulink) to check flight behavior and improve performance estimation. If the simulation mirrors an already manufactured and tested prototyp, the flight simulation can be validated and thus provide neccessary data for autopilot control loops.

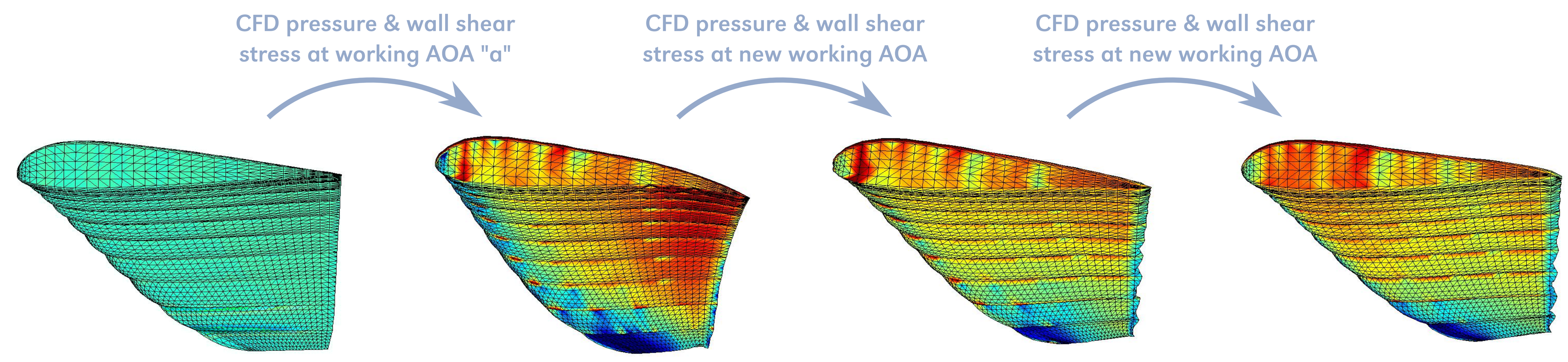
To incorporate the results of the CFD and/or FEM simulations into the design iteration, new flexible tools are necessary to visualize the data and map them to the production data (e.g. sewing pattern as seen in Fig. 8).



8. Pressure distribution at a particular rib



3. Results of moment loop to find working AOA "a"



4. Pre-ballooned FEM model (start point of FSI) [1]
5. Deformed model after first FEM simulation
6. Deformed model after second FEM simulation
7. Final deformed model after n FEM simulations

4. Conclusion

Since most of the altitude wind energy concepts consist of a flying device, one of the main challenges of HAWE is to increase the lift-to-weight ratio while at the same time to minimize the wear and tear. This task requires new innovative approaches in the field of aerodynamics, materials science and manufacturing of resistible light weigt structures. Especially for crosswind concepts, the broad range of aerodynamic loads between steady state and dynamic flight leads to a classical physical conflict in weight and resistance (detailed consideration in [3]). To overcome these challenges a deep understanding of the interaction between pressure related forces (such as aerodynamic flow and/or internal pressure) and structure is essential. The rising computing power together with powerful algorithms and tools help the scientists to develop a new generation of flying devices which harvest energy from high altitudes profitably, while safety and durability are considered from the first drafts. By using numerical simulations such as CFD, FEM and FSI, cost-intensive prototypes can be reduced while new findings are achieved.

Further information

First approaches of Fluid-Structure-Interaction of flexible wings (RAM-Air Kite PULSE1 from Flysurfer) were made in my diploma thesis in 2009 using ANSYS CFX [2]. The results have been validated by wind tunnel tests performed by Mathis Müller. The process explained above is based on an one-way coupling between OpenFOAM CFD results (steady-state solver simpleFoam) and a specialized FEM solver for anisotropic fabrics of an external partner. The FEM data transfer, the whole coupling of forces and deformations as well as the final post-processing is done by anurac's inhouse MATLAB/octave tool box. The presented results were partly validated by force measurement inside the bridles, flight velocity to total force relations as well as optical analysis (e.g. location of wrinkles). Together with partners (e.g. goal-engineering) anurac investigates in the field of 3D meassurement using laser-based and photogrametric approaches to improve the validation quality. Research is also done in the field of 3D printing for individual product development, visualization and prototyping issues.

Acknowledgements

I would like to thank my former employer and still good partner the SkySails GmbH for providing me with the FSI results I worked out in my position as kite designer from 2009 to 2012.

Business Cards

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