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An Integrated STEM Approach for Aerospace Design and Manufacturing

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Abstract

We are developing a course on STEM education to compare computer simulations with experimental measurements for designing and manufacturing efficient airplane wings. The hydraulic analogy is utilized to infer airfoil effects on shock waves and Expansion fans. Manufacturing quality and process chain variation will be quantified with the three pillars of sustainability.

Motivation

The engineering workforce in general has two main problems (NSF Engineering Task Force, 2013):

- "interest in engineering is declining"
- "women and minorities are significantly underrepresented in engineering"

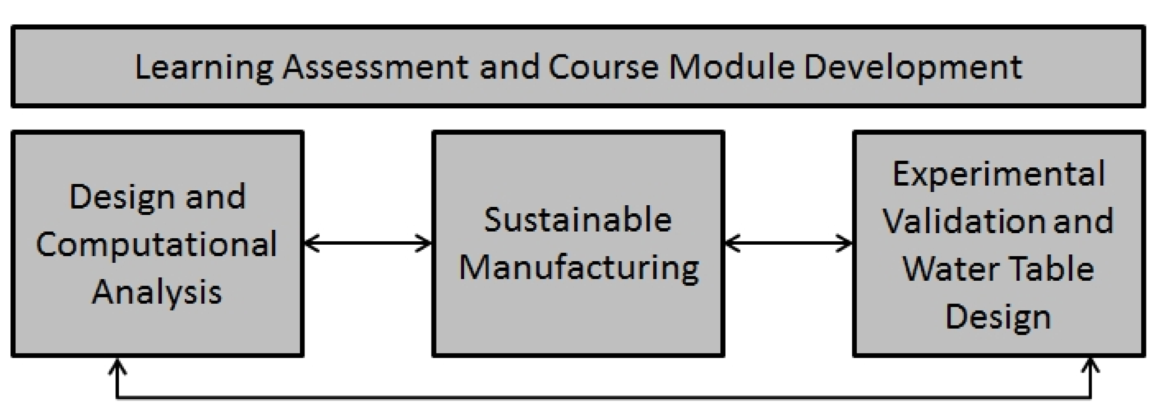
Therefore, students need to be attracted to and retained in the field and we propose to do so through developing interactive, applicable, and fun undergraduate courses.

Overview

The course objective is for mechanical and aerospace engineering students to gain an understanding of how airplanes fly, and the students will do so through the process of designing, modeling, manufacturing and testing a prototype wing. This active, integrated and project-based approach is supposed to foster the development of deep, conceptual learning and greater problem-solving flexibility.

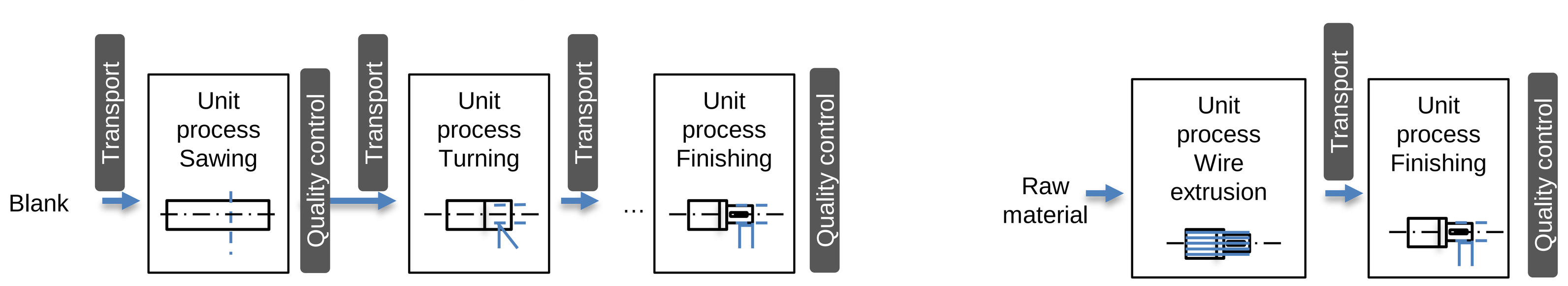
Course Structure

The undergraduate course will integrate design, manufacturing, and validation of airfoils and nozzles within a coherent and meaningful set of activities. All course material is available through the website.

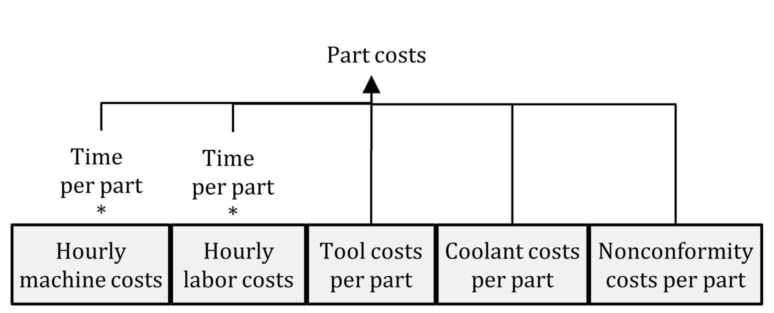


Sustainable Manufacturing

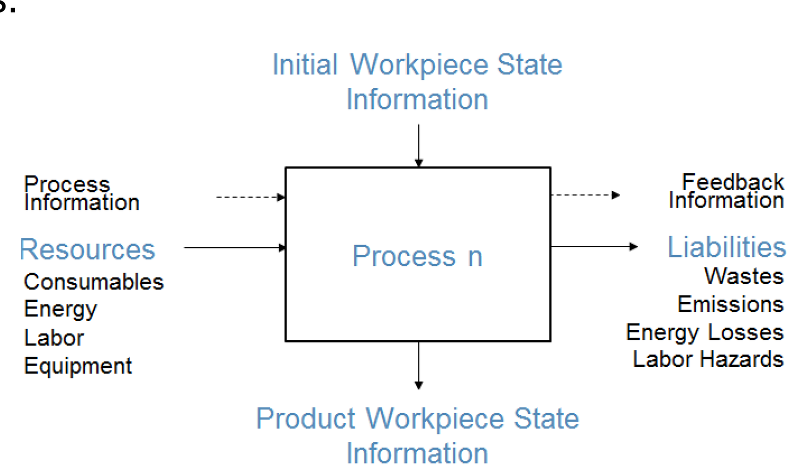
Manufacturing variations through the use of different process chains and variations in component to component quality can result in different sustainability impacts attributable to manufacturing processes.



To capture economic, environmental, and social sustainability impacts from different process chains, calculations can be made using cost assessments, mass and energy balances, and worker injury rate estimations.



(Linke, 2013)

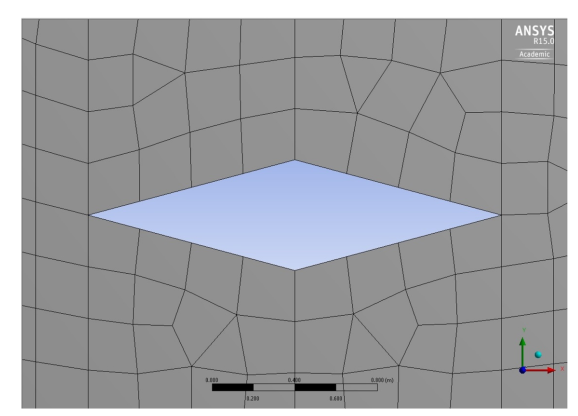


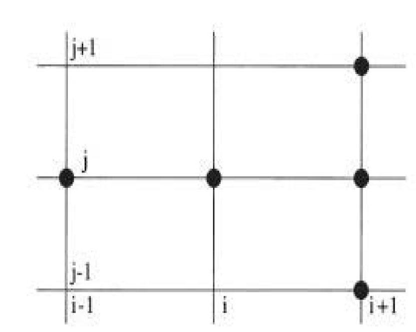
(Garretson, 2015)

Variations in component dimensional accuracy will become apparent during the water table testing causing variation in turbulence and deviations of simulated behavior.

Design and Computational Analysis

The fluid is modeled as a two-dimensional steady compressible flow field around an airfoil, and the control volume around the airfoil is first subdivided into different elements creating a mesh.





(Chattot et al., 2015)

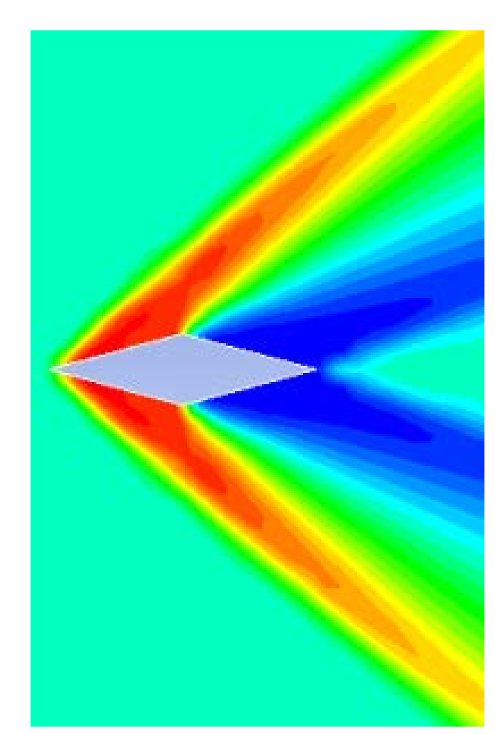
The finite difference method is applied to each element to solve the conservation laws of mass, momentum, and energy for the unknown variable velocity components.

The following equations are used, where M is the mach number, β is the wave angle, and ψ is the stream function.

$$-(M_\infty^2 - 1)\,\psi_{xx} + \psi_{yy} = 0$$

$$\beta = \sqrt{M_\infty^2 - 1} \quad \text{For} \quad M_\infty^2 \geq 1.3$$

$$-\beta^2 \frac{\psi_{i+1,j} - 2\psi_{i,j} + \psi_{i-1,j}}{dx^2} + \frac{\psi_{i,j+1} - 2\psi_{i,j} + \psi_{i,j-1}}{dy^2} = 0$$

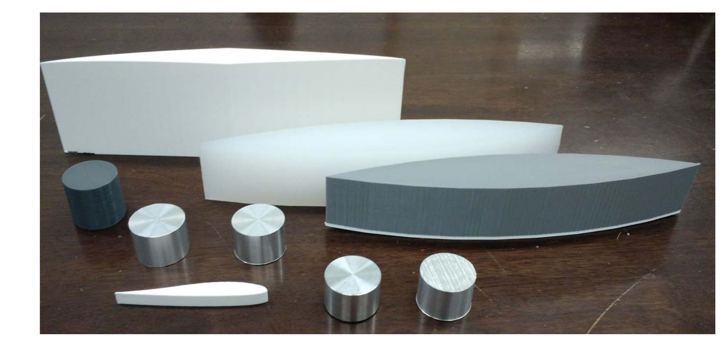


The stream function can then be solved for the velocity components of the flow.

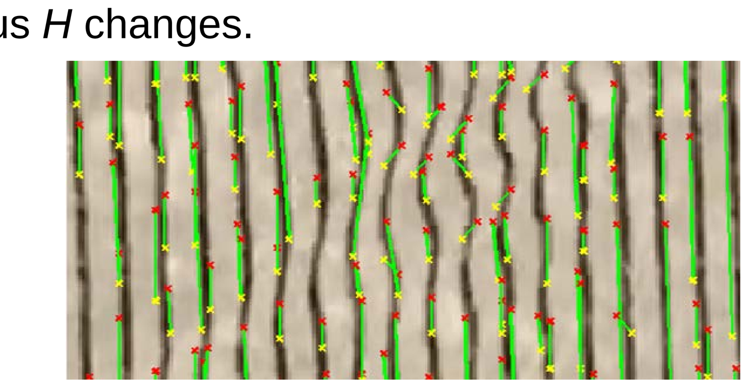
Generally, in the transonic regime shockwaves will appear resulting in wave drag. The goal for the undergraduate students is to minimize the wave drag by designing the shape of the airfoil.

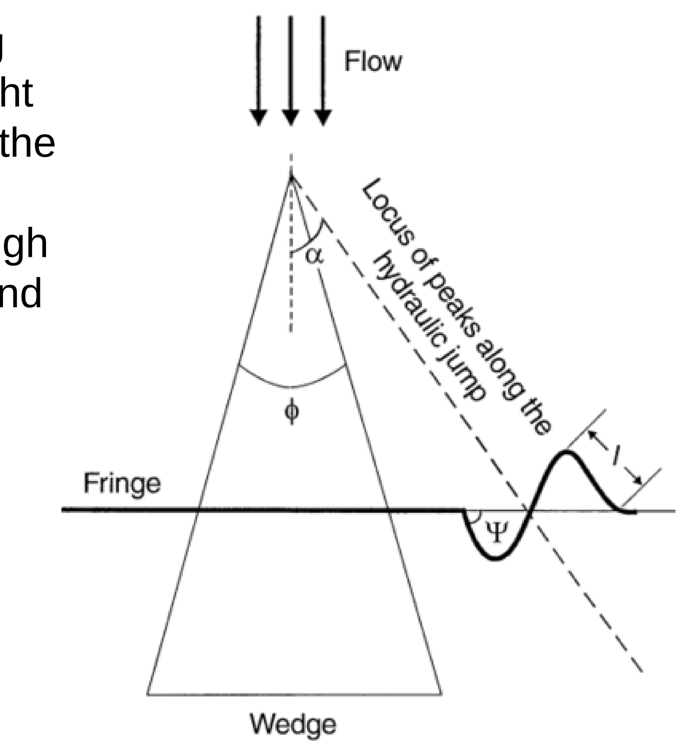
Water Table Design

The water table is of simple construction, utilizing a transparent rectangular tank to contain the water and a linear motion device to control the movement of the airfoils. It is a cost-effective and elegant way to show flow phenomena instead of using a traditional maintenance-intensive wind tunnel.



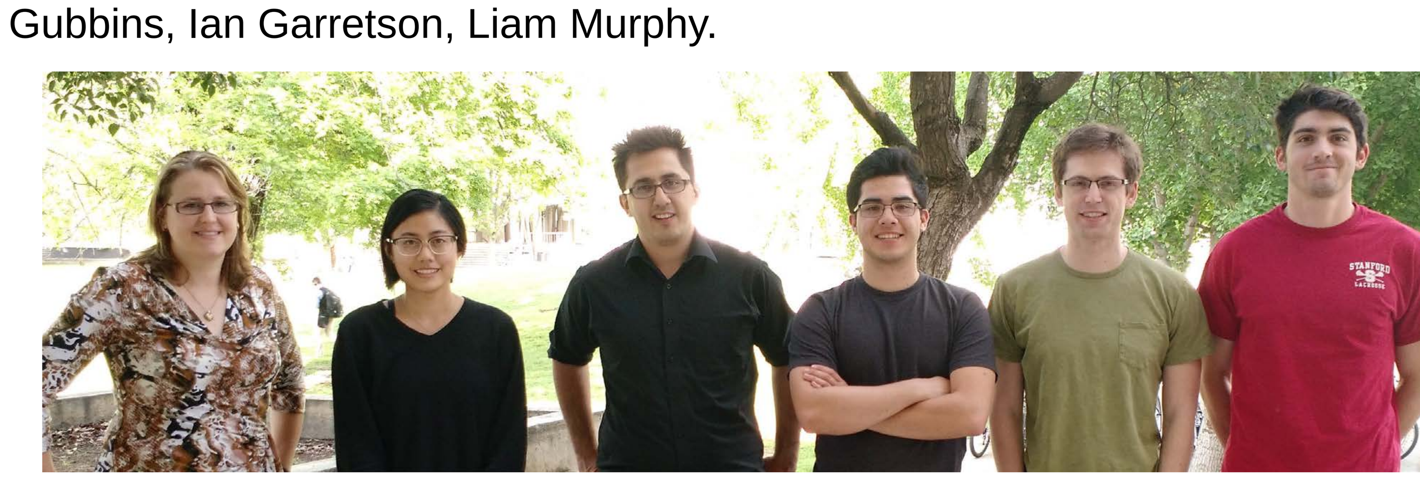
A student undergraduate design team is developing a device for water height measurement. Water height (H) is determined using geometric relationships for the length (l) and angle (ψ) of the deviated fringe at a specific point. Fringes are modeled as prisms. Hough Transformation is utilized to depict line deviations and thus H changes.





Project Team

- From left to right: Dr. Barbara Linke, Michelle Dao, Farhad Ghadamli, Mitchell Gubbins, Ian Garretson, Liam Murphy.



- Dr. Lee Martin, Fahad Jan, Munkhbold Ganbold, and Gurpreet Kaur

- Dr. Mohamed Hafez is pictured with the water table above.

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