Integrating Simulation in the Singapore Institute of Technology-University of Glasgow Mechanical Engineering Curriculum

Christian Della, Arturo Molina-Cristobal, Chen Hao, Jolly Shah, Idris Lim
University of Glasgow Singapore

Alfred Tan, Elisa Ang Yun Mei, Jian Huei Choo, Chong Yok Rue, Desmond, Zhang Linyun, Tay Nam Beng
Singapore Institute of Technology

Enhancing Learning and Teaching of using FEA and CFD

- Modelling and simulation techniques, such as finite element analysis (FEA) and Computational Fluid Dynamics (CFD) have become common in modern engineering workplace[1] ;
- Modelling and simulation have been integrated in teaching mechanical and civil engineering courses to improve learning, such as, basic mechanics[2-5] ;
- Modelling and simulation have been integrated in engineering courses for students to gradually develop their skills and competence in modelling and simulation and prepare them for the workplace.

1. *Magana, A., Fennell, H., Vieira, C., Falk, M. (2019). Journal of Engineering Education, 108(2), 276-303.*
2. *Brown, A. O., et al. (2012), ASEE Annual Conference & Exposition, San Antonio, Texas. https://peer.asee.org/21509*
3. *Navaee, S., Kang, J. (2017), ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/28359*
4. *Steif, P.S. and Gallagher, E. (2004). Proceedings - Frontiers in Education Conference. S3B - 1. 10.1109/FIE.2004.1408752.*
5. *Young, B., Ellobody, Ehab and Hu, Thomas. (2012). 3D Visualization of Structures Using Finite-Element Analysis in Teaching. Journal of Professional Issues in Engineering Education and Practice, 138(2), 131-138.*

Integrating Simulation in the Engineering Programme

Swanson Simulation Program at Cornell University

	Course	Level	Enrollment	Software
1	MAE 3250 Mechanical Structures	Junior	150	ANSYS Mech.
2	MAE 3240 Heat Transfer	Junior	130	ANSYS Mech.
3	MAE 3272 Mechanical Lab	Junior	140	ANSYS Mech.
4	MAE 4272 Thermo-fluids Lab	Senior	160	ANSYS Fluent
5	MAE 4230/5230 Int. Fluid Dynamics	Ugrad/M.Eng	60	ANSYS Fluent
6	MAE 4700/5700 Finite-Element Analysis	Ugrad/M.Eng	50	ANSYS Mech.
7	MAE 4020/5020 Wind Energy	Ugrad/M.Eng	50	ANSYS Mech./ Flu.
8	MAE 4650 Biofluid Mechanics	Ugrad/M.Eng	20	ANSYS Fluent
9	BME 4490 Biomechanics Laboratory	Ugrad	4	ANSYS Mech.
10	MAE 6510 Advanced Heat Transfer	Ph.D./M.Eng	10	ANSYS Mech.
11	MAE 6690 Biofluids	Ph.D.	15	ANSYS Fluent
12	MAE 6640 Mechanics of Bones	Ph.D./M.Eng	15	ANSYS Mech.

Integrating FEA and CFD in the undergraduate and graduate Mechanical Engineering programmes

Source: https://openlearning.mit.edu/events/new-paradigm-engineering-education-using-two-disruptive-technologies-simulations-online

Importance of Integrating Simulation in the ME Curriculum

1. As Visualization Tool to enhance the learning of Mechanical Engineering modules – For example in mechanics of solids, the use of FE models can help the students visualize the deformation and stress contours within the loaded structural member.

2. As Virtual Experimental Tool – Students can conduct “experiments” in a safe environment.

3. To Improve Problem Solving Skills – Visual learning methods can open new ways to solve problems and provide alternative ways of thinking about science and engineering[1]

4. To Develop Industry Relevant Skills – Early exposure of students on modelling and simulation practices to gradually develop their modelling and simulation skills and be ready for the workplace

[1]*M. B. McGrath and J. R. Brown, "Visual learning for science and engineering," in IEEE Computer Graphics and Applications, vol. 25, no. 5, pp. 56-63, Sept.-Oct. 2005, doi: 10.1109/MCG.2005.117.*

Our Purpose

FEA and CFD have been integrated in various modules in the SIT-UofG Mechanical Engineering programme, to be able to:

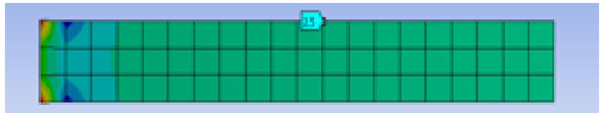
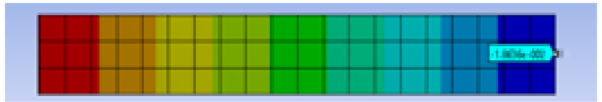
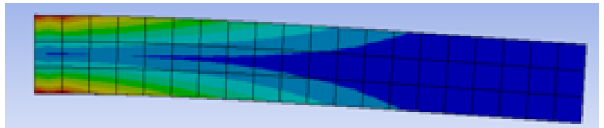
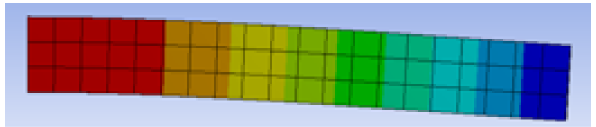
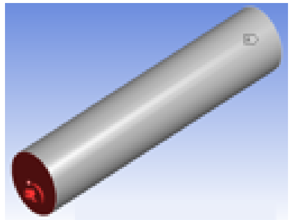
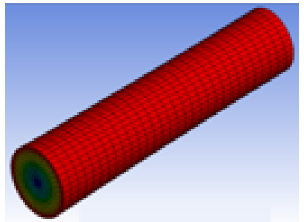
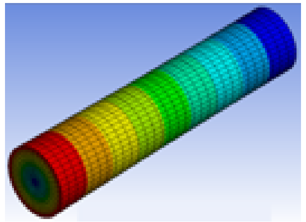
1. Enhance the learning of various mechanical engineering modules;
2. Identify opportunities so students can conduct “experiments” in a safe environment;
3. Improve students’ problem solving skill;
4. Expose the students on modelling and simulation practices early on their engineering education for them to gradually develop industry relevant skills;
5. Identify effective learning strategies for students to successfully acquire modelling and simulation skills;
6. Identify authentic assessments for students to learn and apply simulation to solve engineering problems.

Integrating Simulation in the SIT-UofG Mechanical Engineering

3 Approaches to Integrate Simulation

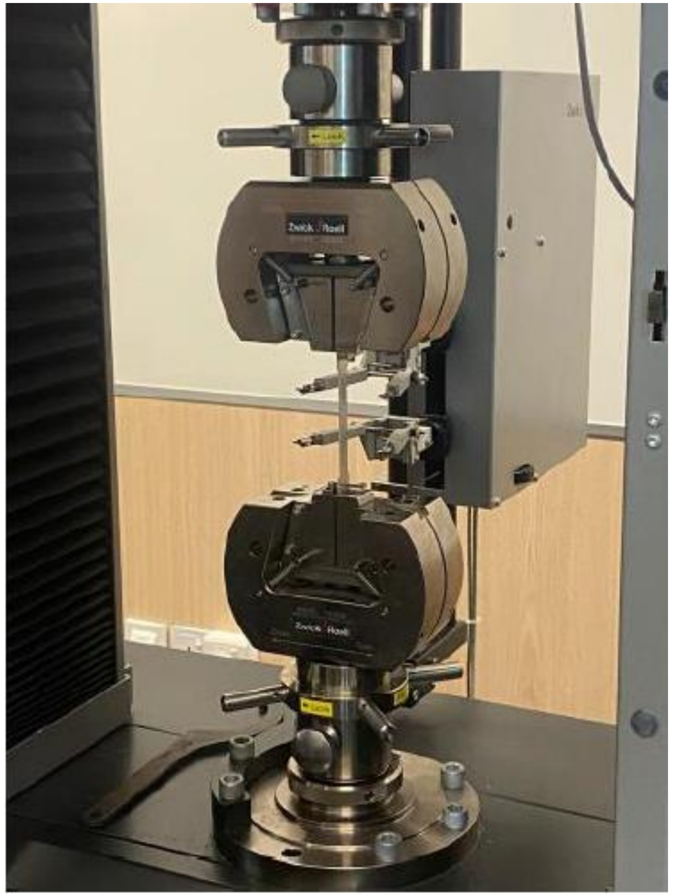
Learning of Fundamental Engineering Concepts	Non-Placement Learning Activities	Work-Integrated Learning
• Engineering Mechanics (FEA) • Mechanics of Solids (FEA) • Dynamics (FEA) • Thermodynamics and Heat Transfer (FEA) • Fluid Mechanics (CFD) • Additive Manufacturing (FEA)	• Mechanical Design • Overseas Immersion Programme (OIP) • Capstone	IWSP/Capstone • Rolls-Royce • CSIM Systems • Experimental Power Grid Centre • Ping Siong International • Genesis Medtech International

Basic FEA in Engineering Mechanics

	Support and Load	Stress	Displacement	Analytical Solutions
Bar in Tension				$\sigma = \frac{P}{A}$ $\delta = \frac{P \times L}{E \times A}$
Cantilever Beam in Bending				$\sigma = \frac{M \times y}{I}$ $\delta_{\max} = \frac{PL^3}{3EI}$
Shaft in Torsion				$\tau = \frac{T \times r}{J}$ $\phi = \frac{T \times L}{J \times G}$

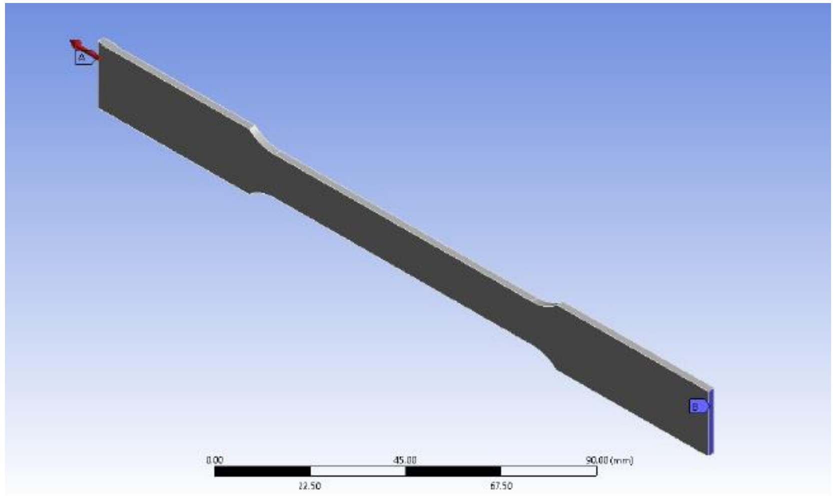
- Workshops on the use of simulation softwares, such as ANSYS, have been conducted to train the students to use the tools to perform FE and CFD analysis.
- Through the use of FE models, the students can visualize the deformation and stress contours within the structural members.

FEA: Tensile Test in Mechanics of Solids

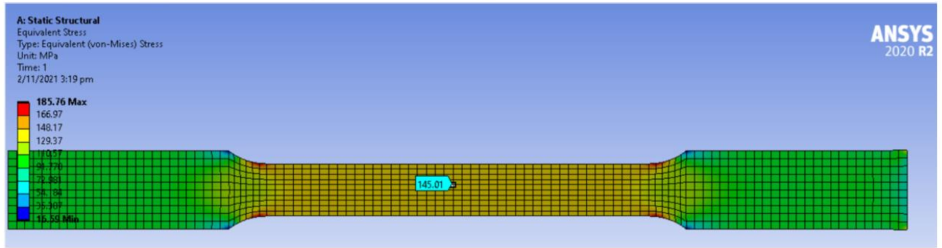


Mild Steel

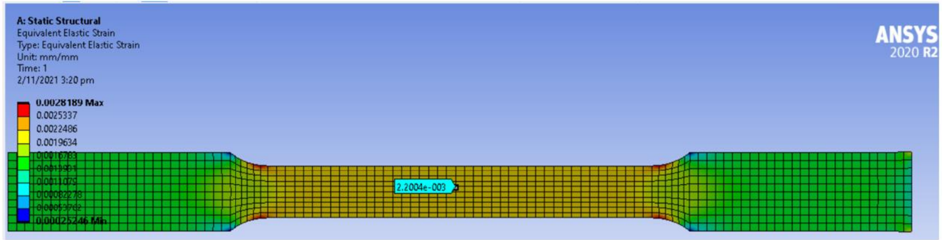
Aluminium Alloy



Aluminium 2mm(best mesh), Force = 3720N, Stress = 145.01MPa



Aluminium 2mm(best mesh), Force = 3720N, Strain = 0.0022

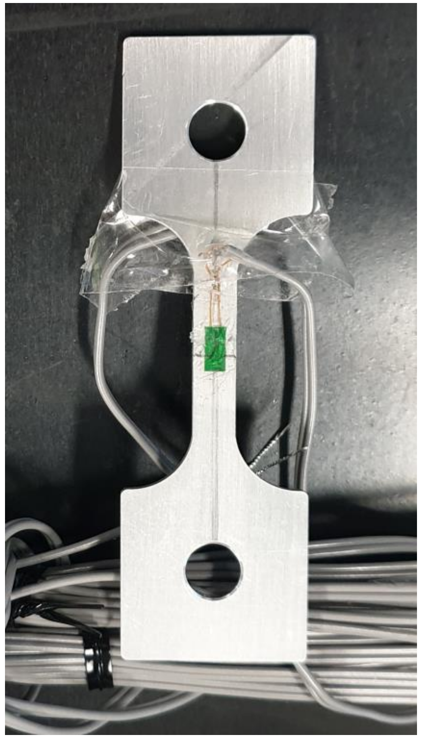


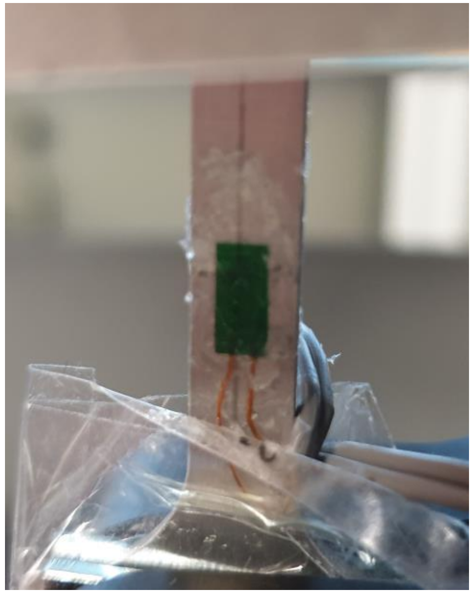
Aluminium

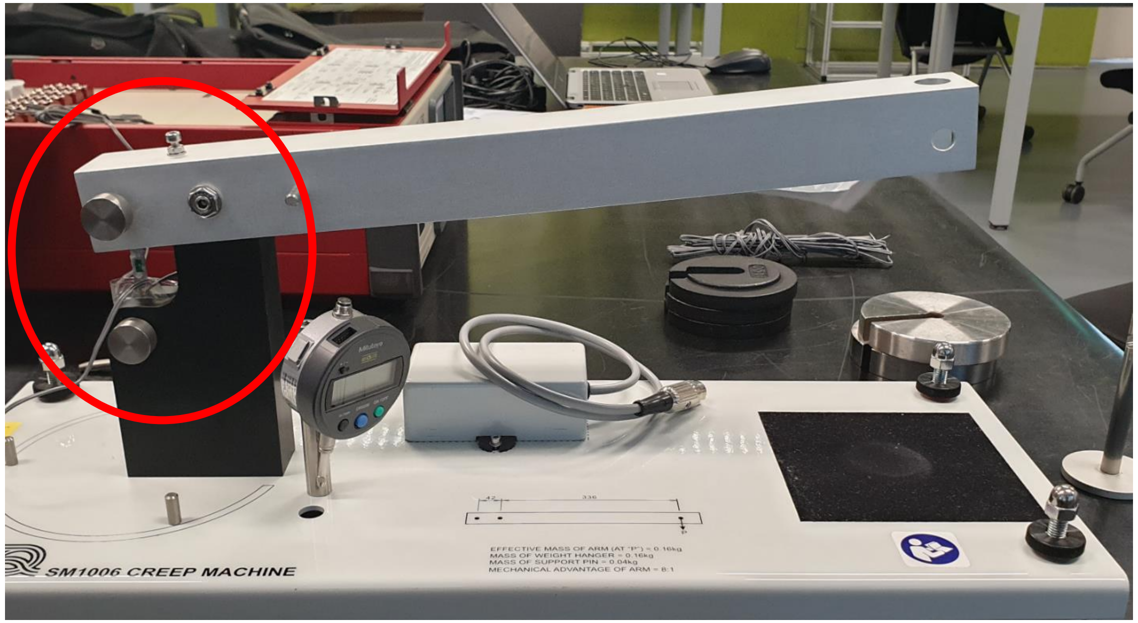
Model	Force Applied, N	FEA Results		Analytical Results		% Difference	
		Stress, MPa	Deformation, mm	Stress MPa	Deformation mm	Stress MPa	Deformation mm
Mesh (2mm)	3720	145.01	0.0022	145.00	0.0022	0.007 %	0%
	7150	278.71	0.0042	278.75	0.0048	0.014 %	12.5%

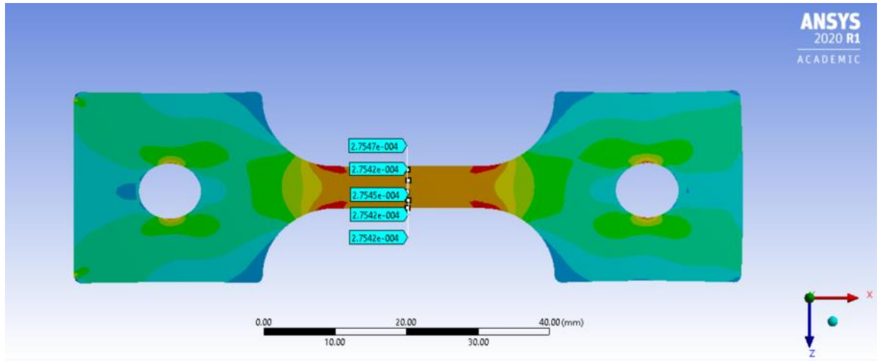
- Students develop FE models and compare FE results with actual tensile test results. Provide students the confidence in developing FE models.

FEA: Strain Measurement in Mechanics of Solids





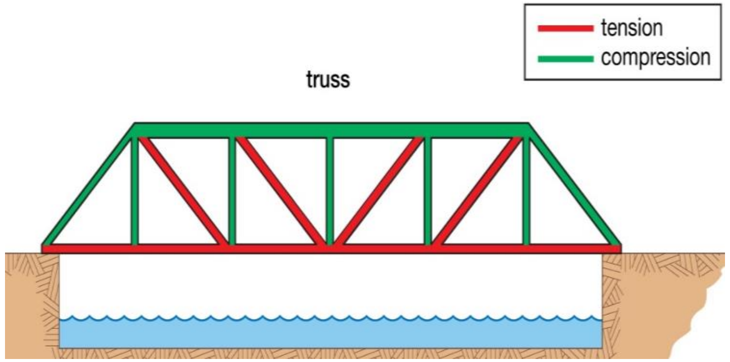


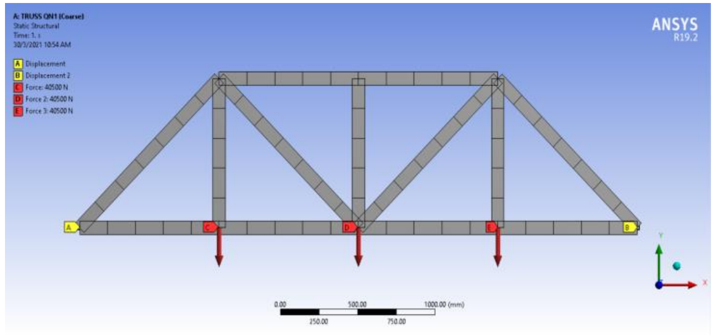


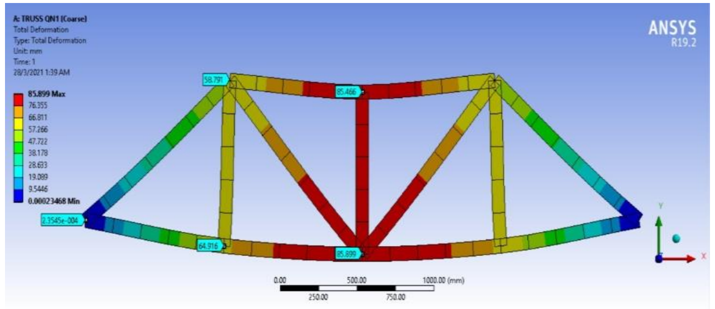
- Students develop FE models and compare FE results with strain measurement results

Modelling and Simulation: Structural and Vibration Analysis

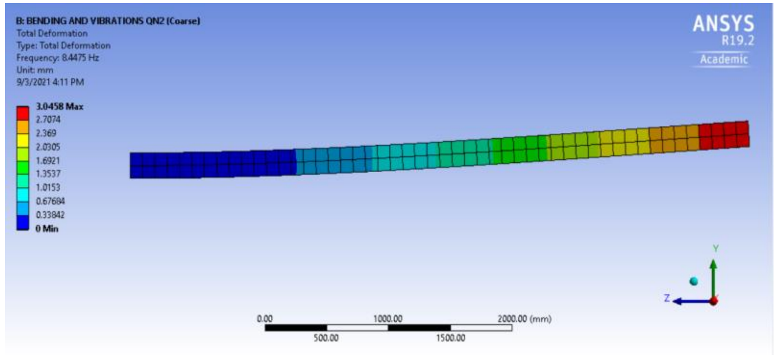
Structural Analysis

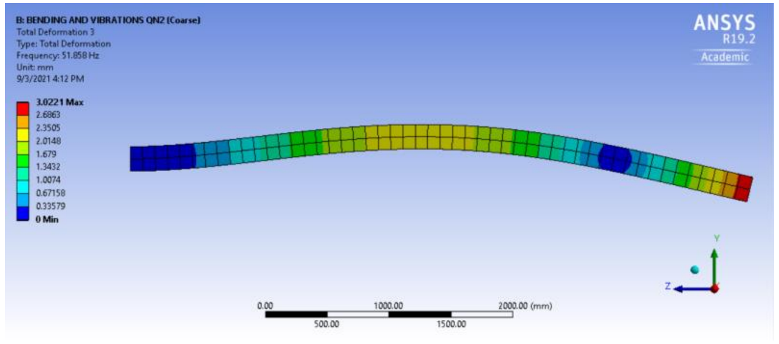


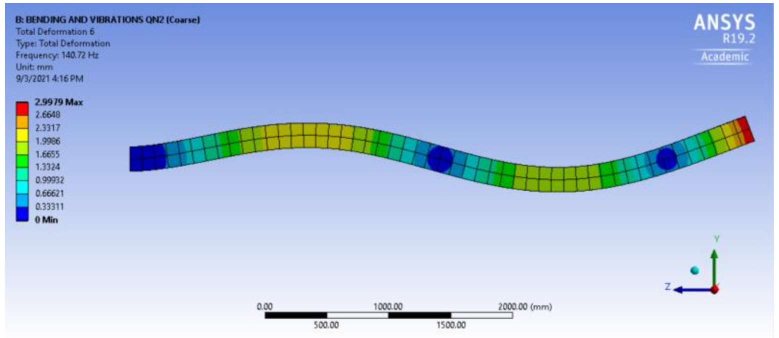




Vibration Analysis



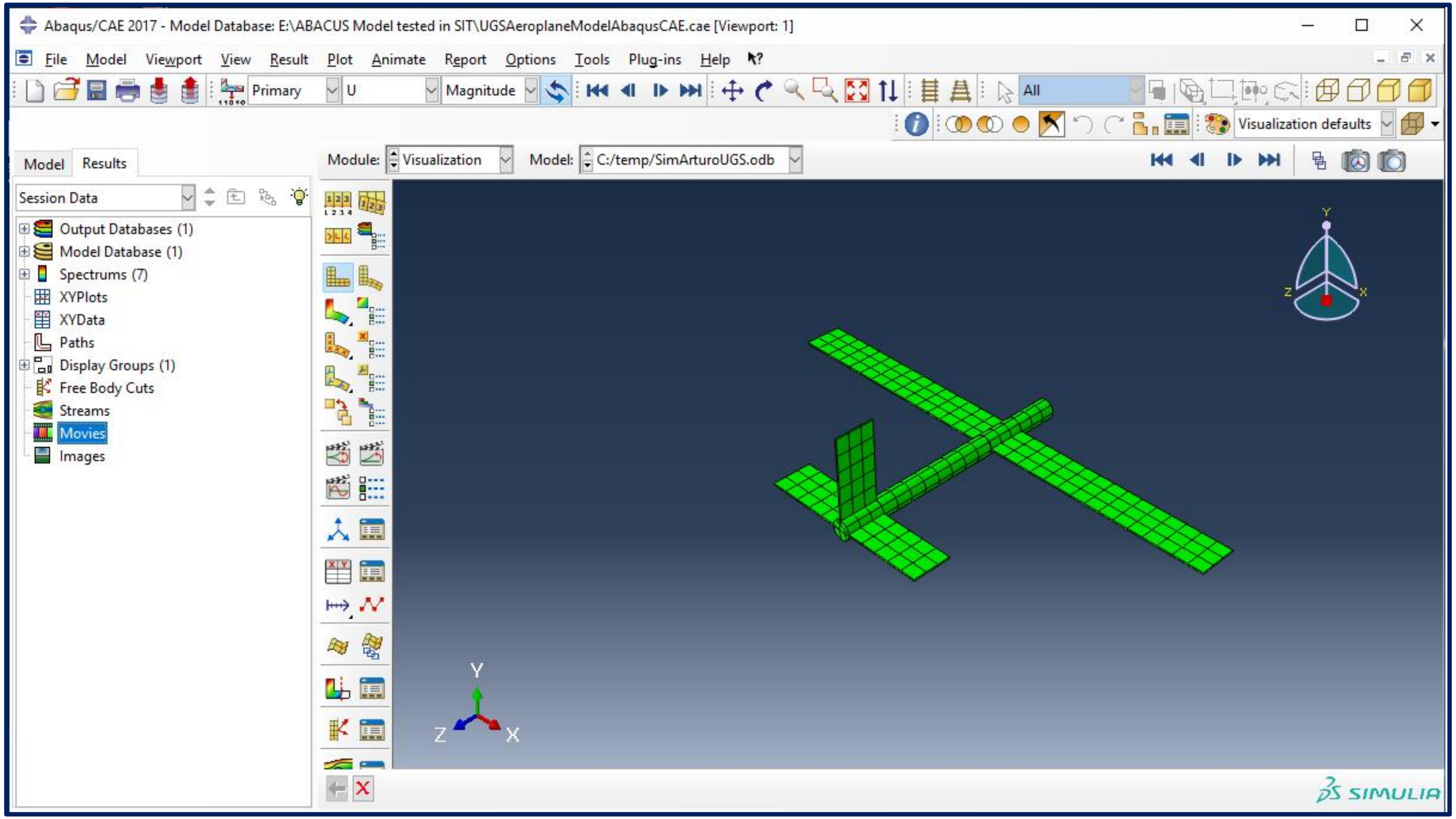




- Students develop FE models and compare FE results with the results of the analytical solutions
- Understand best practices in developing FE models
- Provide students the confidence in developing FE models.

FEA: Dynamics

Vibrational Analysis of an Aeroplane Model



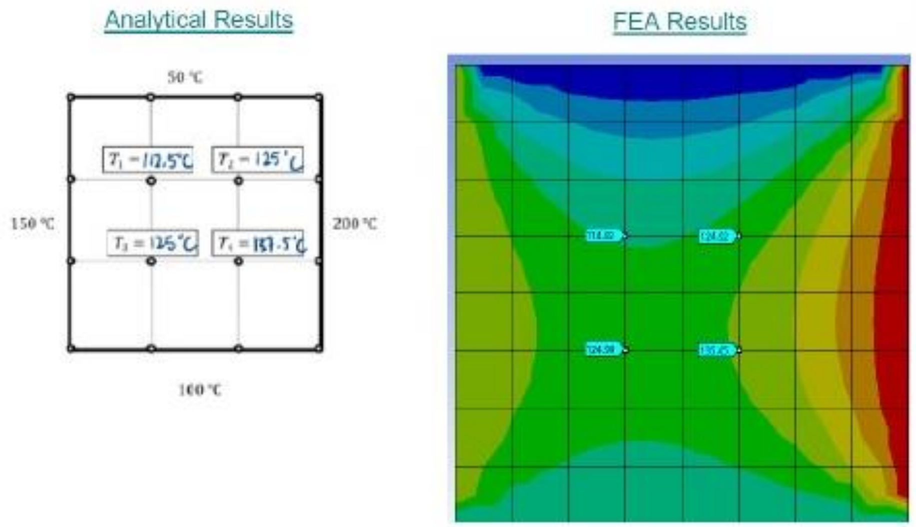
On completion of this lab the student should be able to:

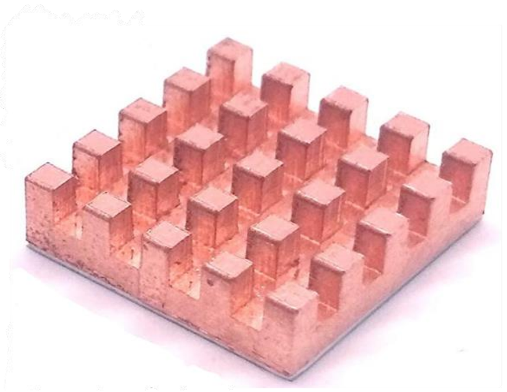
- Extract the natural modes of a structure using computer simulation.
- Relate their dynamics systems theory (skills learnt in the classroom) to a simulation test.

FEA: Thermodynamics and Heat Transfer

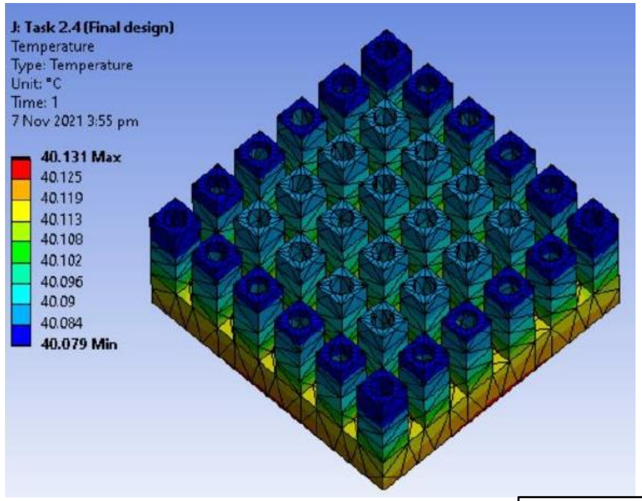
- A **simulation laboratory** is included in the thermodynamics and heat transfer module where students will apply heat transfer concepts learnt to a software simulation assignment.
- The assignment starts with a **simple 2D plate analysis**. Students use this simple problem to appreciate the difference between analytical and numerical solution.
- The assignment ends with a heatsink design task, where the students are given a scenario to optimize and justify the heatsink design.

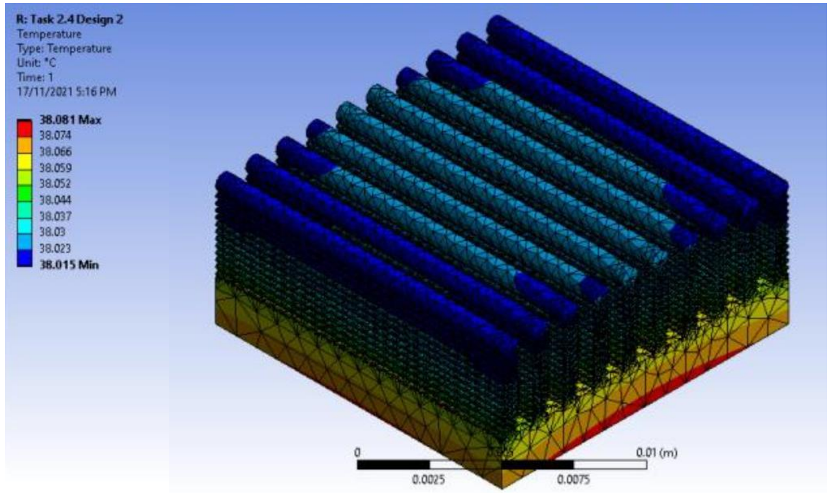
Simple 2D plate analysis





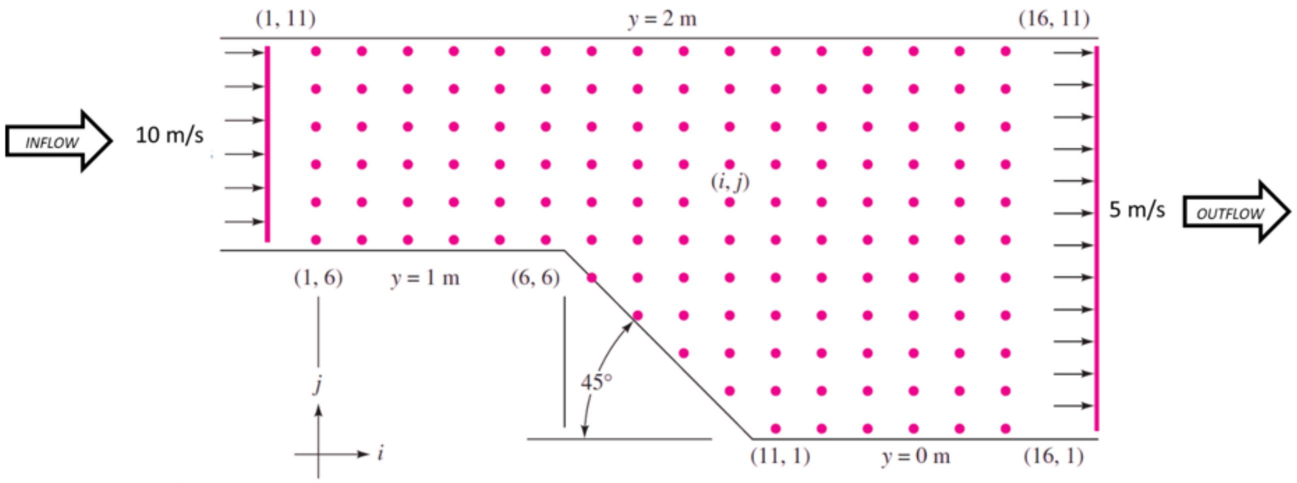
Commercially available Copper Heat Sinks

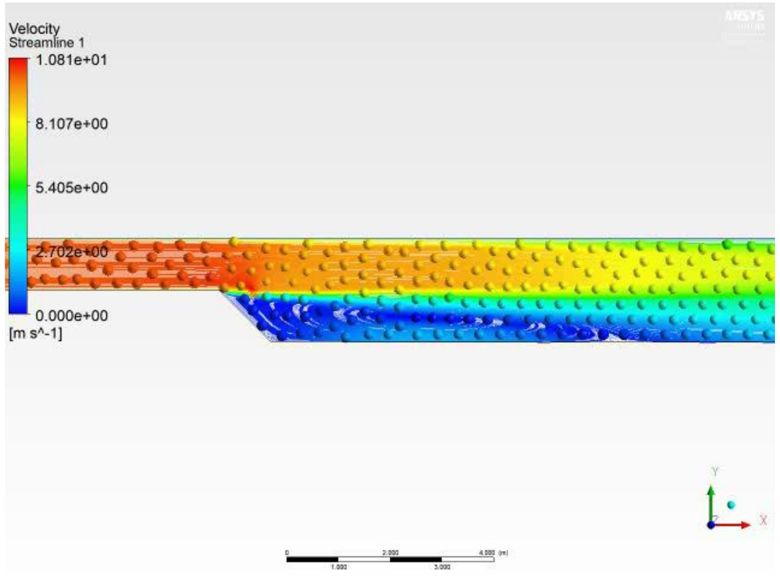


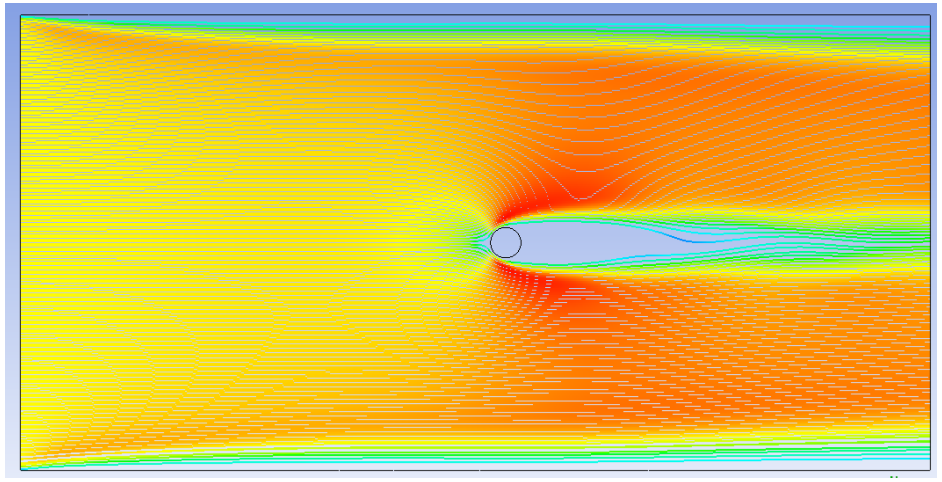


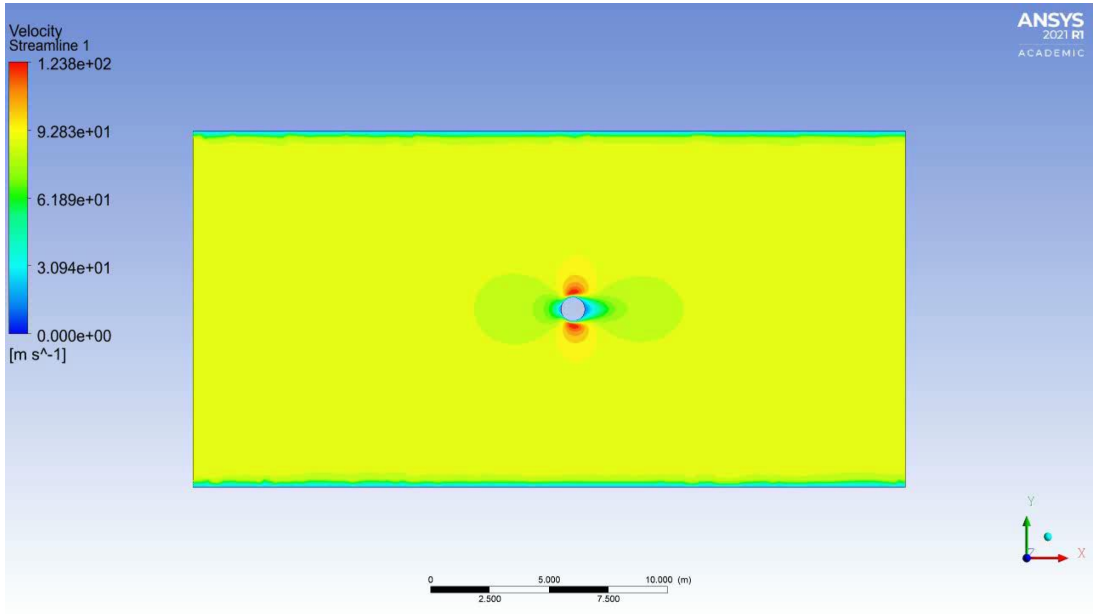
Student's Submission

Computational Fluid Mechanics (CFD): Fluid Mechanics





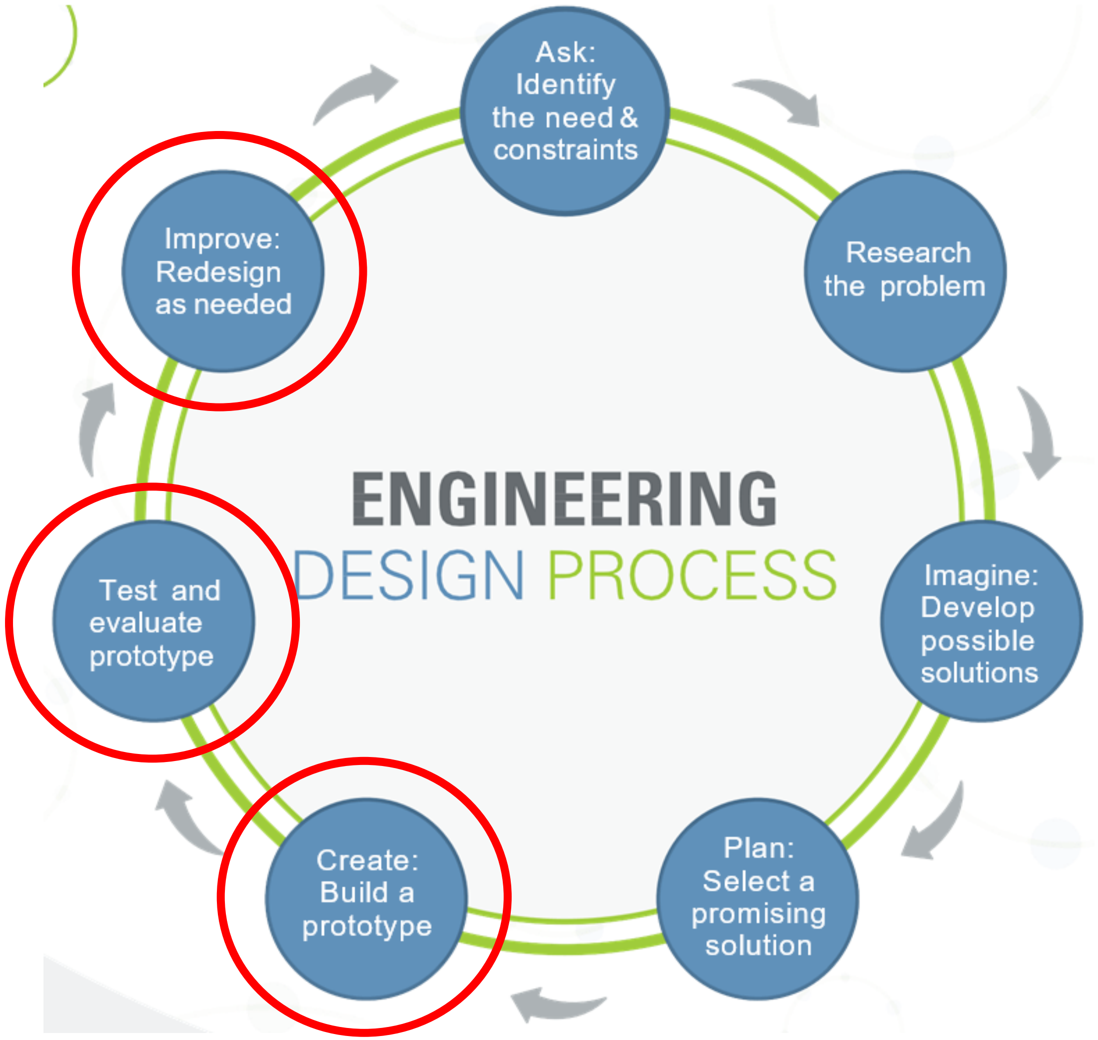




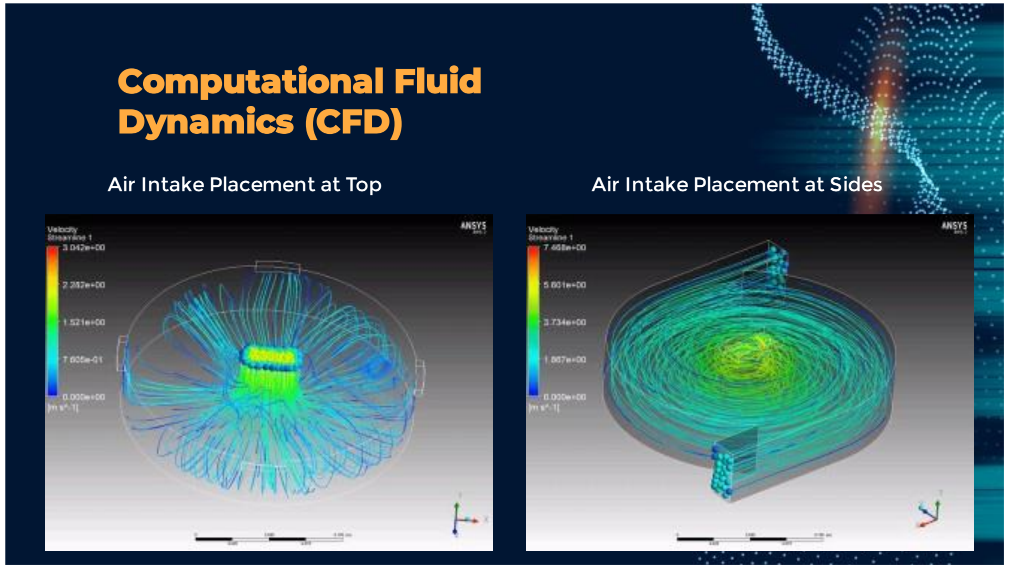
Non-Placement Learning Activities

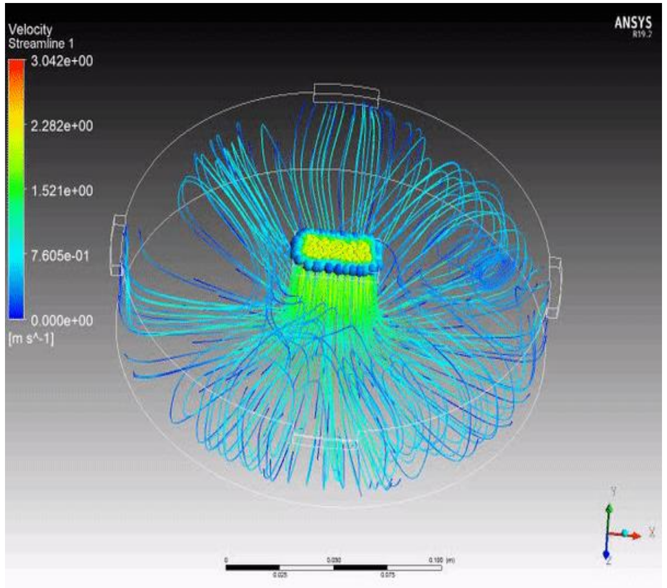
- Mechanical Design
- Overseas Immersion Programme (OIP)
- Capstone

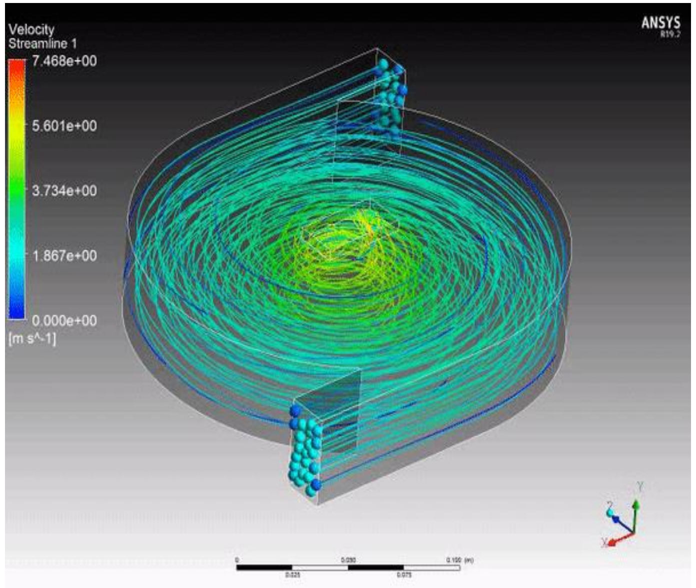
- Students were able apply their knowledge and skills in simulation through project-based modules, such as Mechanical Design and the Overseas Immersion Programme (OIP).
- For OIP, due to the limited opportunities to develop physical prototypes for their designs, the students need to develop simulation models or virtual prototypes.



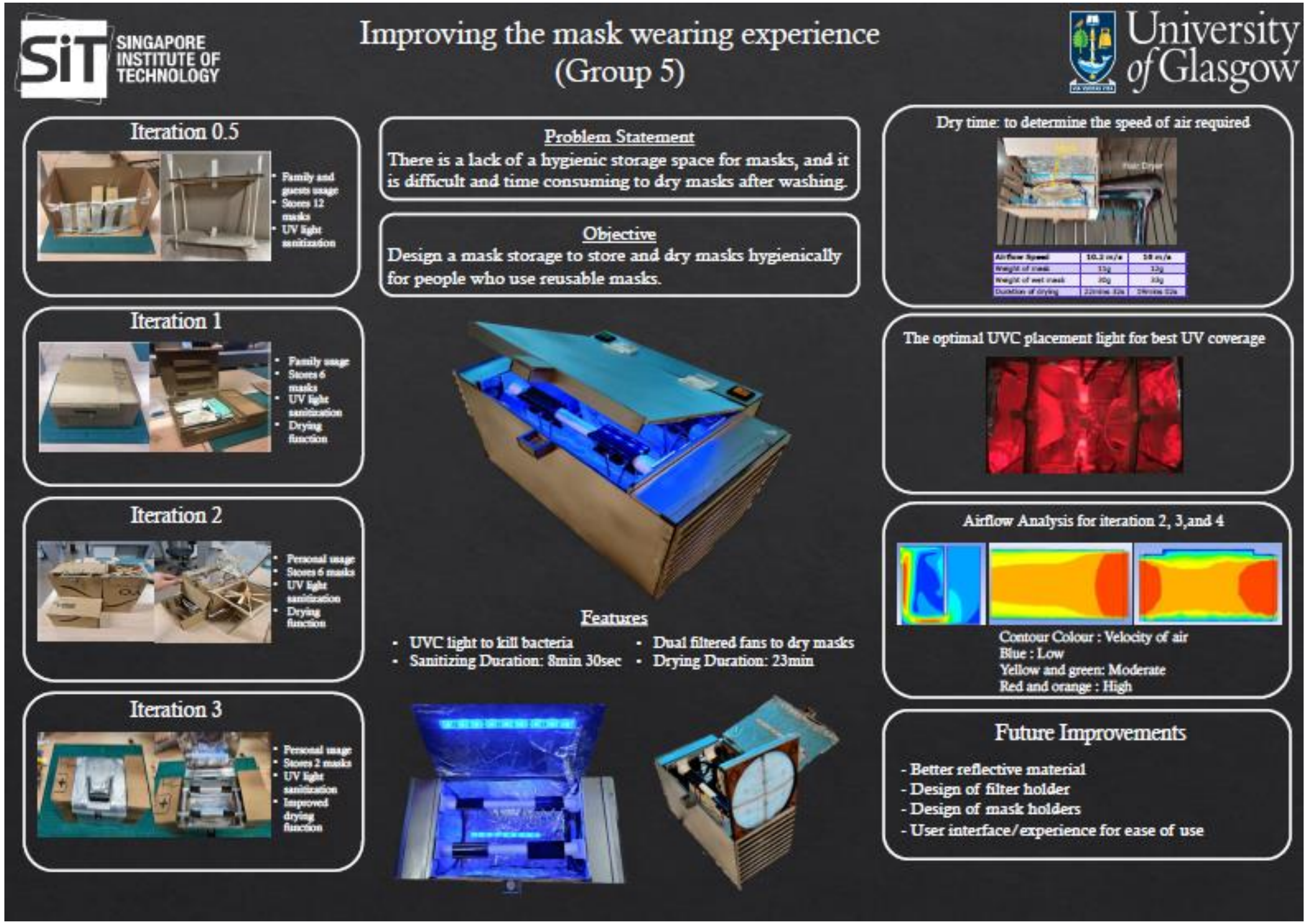
CFD: Mechanical Design





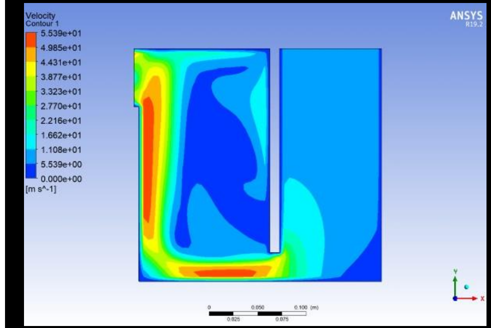


CFD: Mechanical Design

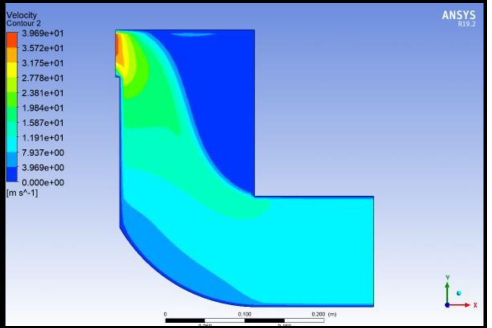


Ansys - Air Flow Simulation

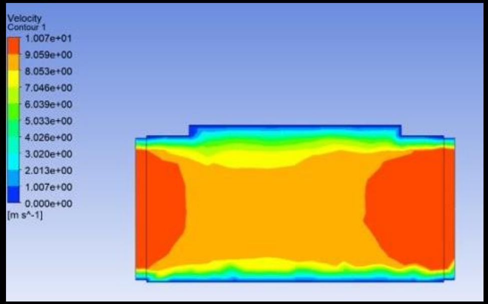
Iteration 2



Iteration 2.5



2 Fans



Work-Integrated Learning: IWSP and Capstone Project

Work-Integrated Learning
IWSP/Capstone • Rolls-Royce • CSIM Systems • Experimental Power Grid Centre • Ping Siong International • Genesis Medtech International

Work-Integrated Learning

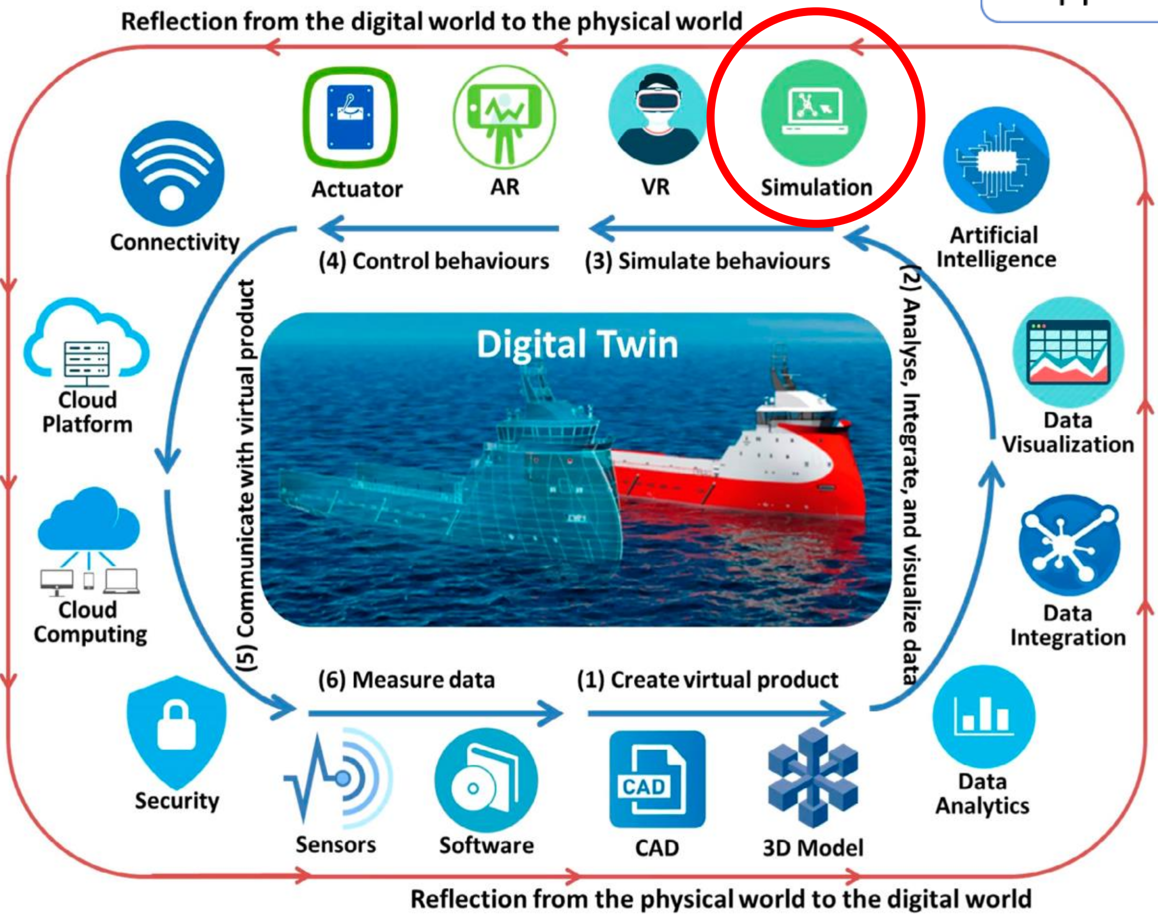
- About 10% of the mechanical engineering IWSP students are currently assigned to projects that requires simulations.
- Opportunities to students to further improve their knowledge and skills in simulation

Further opportunities to evaluate the effectiveness of integrating simulation in the curriculum!

The Digital Twin - The Next Wave in Simulation Technology

Simulation-based Engineering is evolving

- 1960+ Individual Applications
- 1985+ Simulations Tools
- 2000+ Simulation-based System Design
- 2015+ Digital Twin



Tao et al. (2018). Digital twin-driven product design framework. International Journal of Production Research. 1-19. 10.1080/00207543.2018.1443229.

Digital Twin

Seamless integration of Industry 4.0 technologies

The Digital Twin market is expected to grow to over $15B by 2023

https://www.cocop-spire.eu/content/digital-twins

Conclusions: Integrating Simulation in SIT-UofG ME

Learning of Fundamental Engineering Concepts

- Integrated modelling and simulation in various modules mechanics of solids, dynamics, heat transfer, fluid mechanics and additive manufacturing.
- Conducted workshops on the use of simulation softwares, such as ANSYS, to train the students to use the tools to perform FE and CFD analysis.
- Assigned assessments in the form of projects for students to learn and apply simulation to solve engineering problems.

Non-Placement Learning Activities

- Students were able apply their knowledge and skills in simulation through project-based modules, such as Mechanical Design and the Overseas Immersion Programme (OIP).
- Opportunities to develop simulation models or virtual prototypes for realistic engineering problems have been provided to the students

Work-Integrated Learning

- About 10% of the mechanical engineering IWSP students are currently assigned to projects that requires simulations, which provided an opportunity to students to apply the knowledge and skills
- In the future, interviews will be conducted to both the students and the work supervisors to assess the effectiveness of the simulation integrated curriculum.

THANK YOU