Programme

There will be a brief introduction at 09:00 and a closing presentation at 15:15 in the auditorium for all to attend.

Room: LR2		Open presentation	
Start	**Finish**	**Project**	**Title**
09:15	10:00	MAN6	Environmental impact analysis and life cycle analysis for siting of concentrating solar power plants
10:00	10:45	MAN2	Digitalised Solutions of Organisational Learning Capability
11:15	12:00	MAN4	Digital Twin representation of a modified mobile asset in the aerospace and land vehicle context
12:00	12:45	MAN5	Supply Chain Optimisation for Land Vehicles within Babcock International
13:30	14:15	MAN1	Linear actuator monitoring for enhanced productivity in vehicle assembly line
14:15	15:00	MAT9	Ultra-precision laser finishing

Room: LR3		Open presentation	
Start	**Finish**	**Project**	**Title**
09:15	10:00	MAN 7	Factory flow simulation and lean improvements
10:00	10:45	MAN10	Developing sustainable supply chains for UK manufacturing growth
11:15	12:00	MAN11	Shop floor simulation for continuous improvement in a pharmaceutical company
12:00	12:45	MAN12	Reconfigurable microfactories for future vaccines manufacturing
13:30	14:15	MAN8	Augmented reality to improve data usage and increase pilot plant capacity
14:15	15:00	MAN9	Developing the next generation of training at network rail

Room: LR5		Open presentation	
Start	**Finish**	**Project**	**Title**
09:15	10:00	MAN13	Industrial System Pen-Testing
10:00	10:45	MAN14	Towards Digital Aircraft Engineer and Paperless MRO
11:15	12:00	MAT1	Surface Integrity and Performance of Laser Peened Nickel-based Superalloy
12:00	12:45	MAT2	Quantifying Sintering Behaviour of Thermal Barrier Coatings at High Temperatures
13:30	14:15	MAT3	Photoluminescence thin films for improvement of solar photovoltaic performance
14:15	15:00	MAT4	Portable thermal conductivity testing rig for composites

Room: LR6		Open Presentations	
Start	**Finish**	**Project**	**Title**
09:15	10:00	MAT6	Radio Frequency Piezo Electric Tuning Element
10:00	10:45	MAT7	Wire plus arc additive manufacture (WAAM) of 15-5 PH stainless steel using Plasma arc process
11:15	12:00	MAT5	Development of graphene enhanced hydrogen pipelines
12:00	12:45	MAT10	Augmented Reality Equipped Composites Assembly

Room: LR6		Closed Presentations	
Start	**Finish**	**Project**	**Title**
13:30	14:15	MAN3	Demonstrating the benefit of Predictive Maintenance
14:15	15:00	MAT8	3D printing of latex gloves

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Linear actuator monitoring for enhanced productivity in vehicle assembly line

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Mrs. Xiaoyu Zhou, Mr. Yuanfei Zhu

Background

Jaguar Land Rover is aiming to implement Condition Based Maintenance (CBM) to increase productivity, by monitoring the rack-and-pinion linear actuator on marriage station, a machine for joining car body and powertrain. Monitored data can be processed to indicate failure modes and degradation stages, which are vital for subsequent maintenance decision.

Objectives

- Conduct Failure Mode Effect & Criticality Analysis (FMECA)
- Rig Testing with selected failures seeded in
- Digital Twin Simulation by building Simulink model
- Cost Benefit Analysis in different degradation stages
- Develop CBM detection algorithm & sensor selection

Methodology

Rig Testing

Degradation Stages	0	1	2	3	4	5	6
Failure Modes	Healthy Condition	1. Teeth Breakage					
		2. Spalling					
		3. Sand Contamination					
		4. Lack of Lubrication					

At 5 different speed (only for healthy condition) and 5 or 4 different loads (for all conditions)

System Modelling

- Position
- Loads
- Time
- Voltage
- Failures

Stepper Motor ↔ Rack & Pinion

- Current
- Voltage
- Velocity
- Position
- Torque
- Force

Simulink

Algorithm

Estimate system behavior of given conditions for different degradation stages by digital twin simulation

Real-time signal acquisition and processing from sensors implemented on machine

CBM

Cost estimation according to current and subsequent health conditions to guide maintenance

Cost Analysis

Condition Acquisition

Cost Breakdown

Repair Costs	Production Losses	Labour Costs

Cost Estimation

Maintenance Scheduling

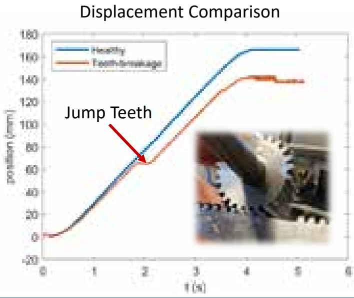
Results

Rig Testing

The rig was tested under 116 conditions and 537 sets of data including Current, Displacement, Acoustic and Vibration were collected and analyzed.

The Figure below shows the difference of rack displacement of teeth breakage stage 6.

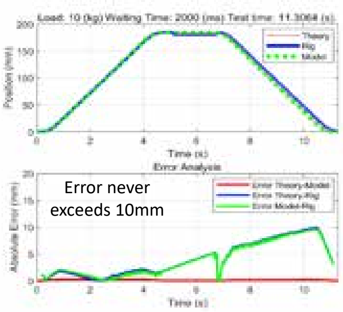
Displacement Comparison



System Modelling

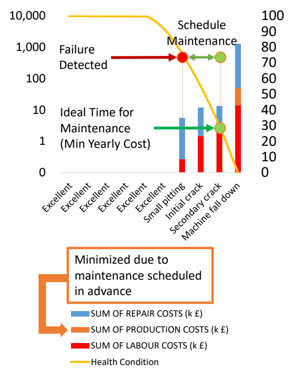
The Simulink model can mimic the kinematic and electronic behavior of rig. The figure below shows its position difference with rig as well as theoretical value.

Position Result Conformity



Cost Analysis

Pitting Health Condition & Maintenance Cost



Conclusions

- On average, changing from corrective maintenance to CBM can half the maintenance cost.
- Production loss is the majority of cost when failure happens while it can be minimized if maintenance is scheduled in advance.
- According to test, vibration could detect failures since early-stage. Displacement can only detect late stages.
- Model simulation has good conformity of a less than 10mm's absolute error with rig result in terms of displacement.
- Model simulation indicates that excessive load would cause severe drop down during extension.

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Digitalised Solutions of Organisational Learning Capability

Mrs. Queen Great, Miss Chloé Gros, Miss Elisa Ptak, Miss Agnieszka Oginska, Mr. Thibault Mastromichele, Mr. Pablo Joly

BACKGROUND

Public service organisations provide different learning programs to their employees in order to enhance their skills and capabilities to provide better services. Digitalised solutions are enabling technologies that this research believes it would help in enhancing employees performances if they are incorporated.

AIM & OBJECTIVES

- Synthesise the best practices of the organisational learning model and capability through literature review & field study.
- Develop a conceptual OLC framework based on digital technologies.
- Facilitate employees' learning through digitalised solutions.

RESEARCH METHODOLOGY

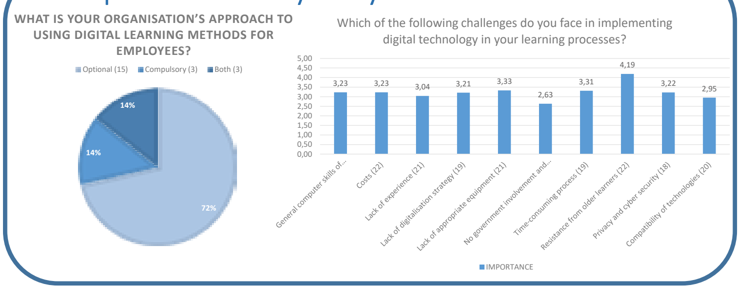
Literature review → Questionnaire & field study → Data analysis → OLC Framework → Expert judgment

Law enforcement & security | Education | Local authorities & social care | Healthcare

OLC Definition :

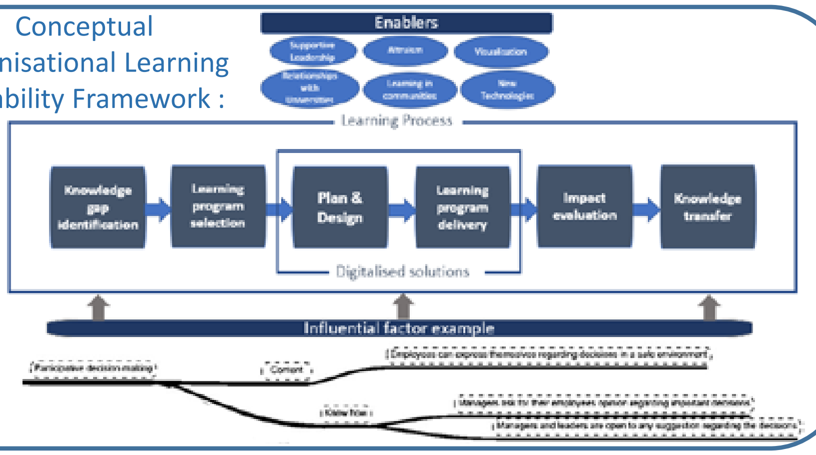
OLC is the facilitation of a process to ensure that the organisation is learning from its operations and the experiences of different projects and initiatives. This learning process is influenced by certain factors that are directly related to the performance of both employees and service provision.

Example of field study analysis :



E- Learning digitalised solution example:

Conceptual Organisational Learning Capability Framework :



CONCLUSION

Enhancing performance in public organisations could not be achieved without a formal initiative of OLC. The impact of learning can be enhanced significantly by employing digitalised solutions of the learning programs.

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Digital Twin Representation of a Modified Mobile Asset in Aerospace Maintenance

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WHAT IS A DIGITAL TWIN?

"A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a complex product & uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin." **(NASA, 2012)**

MOTIVATION

Babcock put technology at the core of their activities continually looking for innovations. Thus they are focusing on developing digital twin technology to extend their competencies in system design, integration and support.

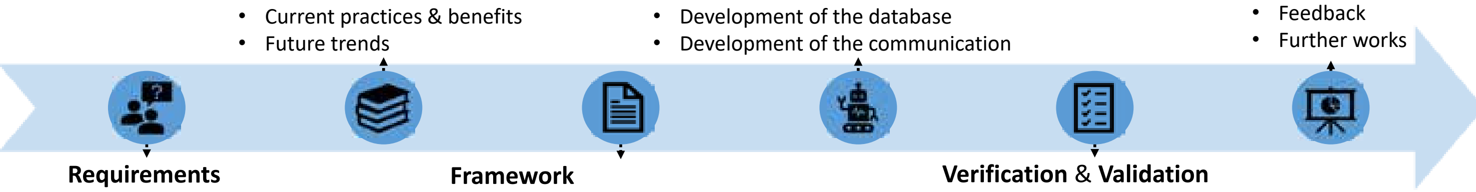
AIM

Develop a framework to build a digital twin & demonstrate the impacts & benefits by applying it.

OBJECTIVES

- Develop a scalable & flexible framework for the design & development of a digital twin.
- Build a functional digital twin prototype for a system integrated onto a modified mobile asset.

METHODOLOGY



Requirements
- Aim
- Scope

Literature review
- Current practices & benefits
- Future trends

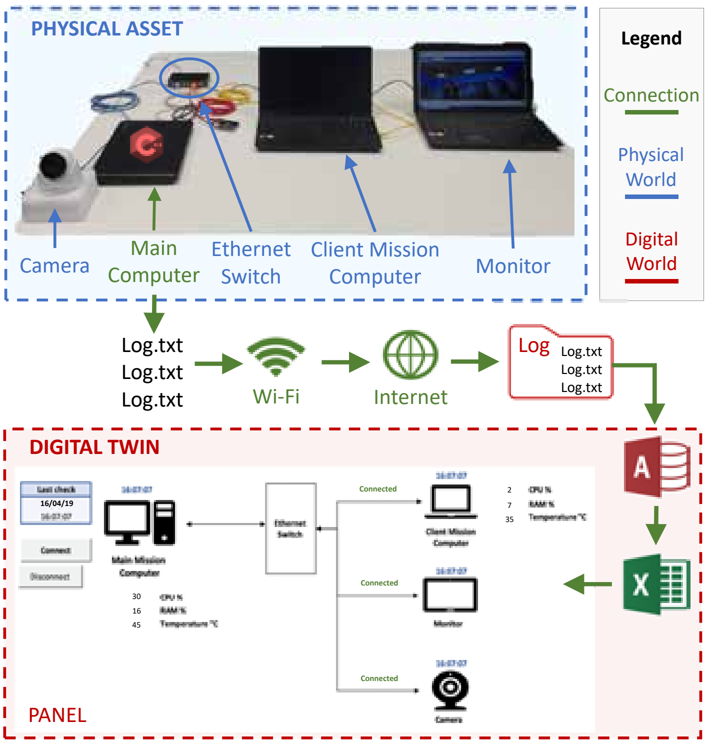
Framework
- What does a digital twin look like?
- How is a digital twin built?

Creation of the digital twin prototype
- Development of the database
- Development of the communication

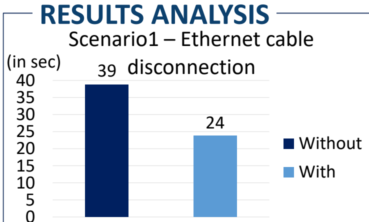
Verification & Validation
- Experiments & results analysis
- Identification of benefits

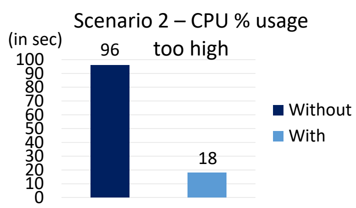
Discussion
- Feedback
- Further works

PROTOTYPE



RESULTS ANALYSIS





39% Reduction of time in scenario 1

81% Reduction of time in scenario 2

89% User-friendliness of the digital twin

85% Data relevancy of the digital twin

VALIDATON FEEDBACKS

Babcock testers
- Upgrade the panel to show the source of the failure.
- Find a way to make the database more robust.

Cranfield testers
- Display only the information linked to the current situation.
- Display a progress bar of the data transmission status.

QUOTE FROM BABCOCK

"We are extremely impressed that the prototype could be adapted and implemented on the actual system we were integrating onto a mobile asset."

J. Sibon, Head of Research and Partnerships,
S. Wedell, Technical Support Manager

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Supply Chain Optimisation Framework for a Service Provider

Cranfield University

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Aim & Background

To provide an implementation framework for the optimisation of the supply chain to an asset management service provided by Babcock International. This framework guides the sponsor to find the best trade-off between maximising assets availability and minimising supply chain costs.

Objectives

- Conduct literature review to identify best practices in Supply Chain Management
- Identify suitable use cases to optimise the existing supply chain
- Establish the appropriate parameters against which the optimisation should be run
- Create a through life optimisation framework

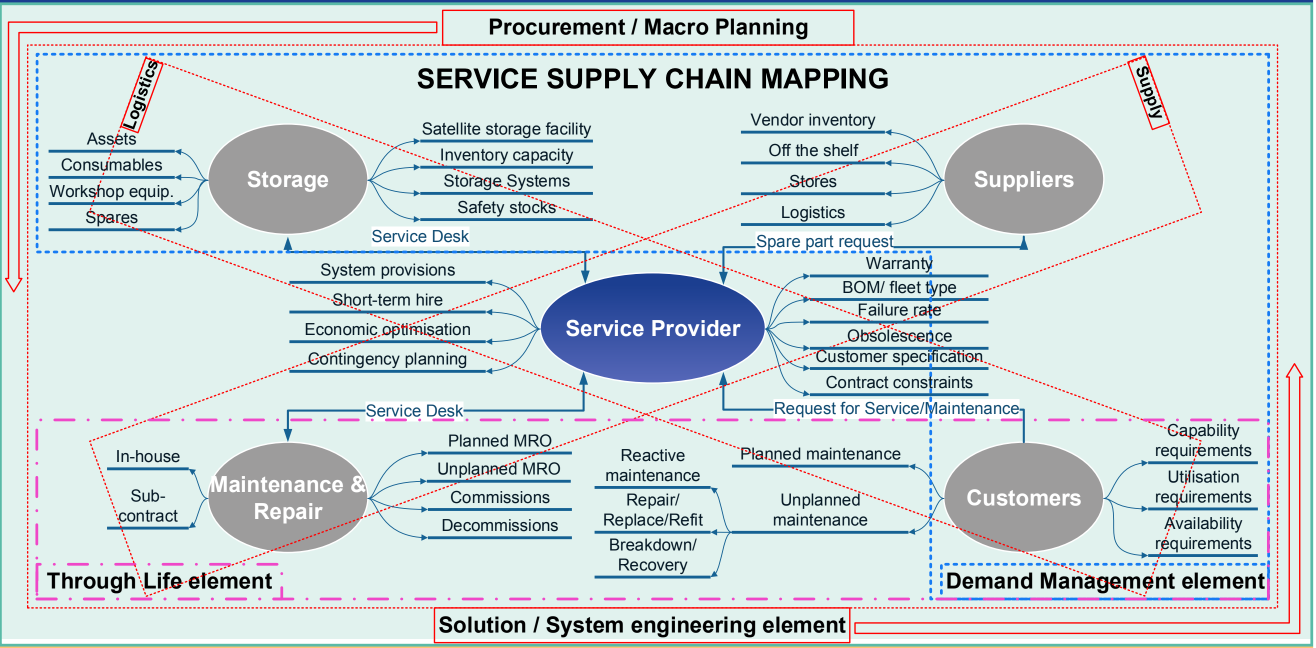
Service Provider Supply Chain Optimisation Framework

DEFINE

Profile

Illustrate

Architecture



MEASURE

KPI

Feature

Evaluate

Key performance indicators: Economic KPI's — Operational KPI's — Service KPI's

Area	Demand management	Procurement	Supply	Logistics

ANALYSE

Method

Decide

Structure

Challenges	Accurate demand forecast Forecast suppliers lead time Buy less (Minimum Order Quantity)	Select adequate suppliers Maximise value for money	Maximise operations efficiency Maximise assets availability	Decrease inventory costs Increase inventory visibility

MCDM & Optimisation Methods

Mathematical methods:
Mixed Integer Programming;
Linear Programming;
Non Linear Programming;

Analytic Hierarchy Process;
Decision-Making Trial and Evaluation Laboratory;
Preference Ranking Organisation Method for Enrichment of Evaluation;

Simulation methods:
Discrete Event Simulation;
Agent Based Simulation;
System Dynamics;

IMPROVE

Tools

Implement

Plan

Expected benefits	Increase demand forecast Reduce downtime costs Improve Just-In-Time	Decrease materials costs Improve supplier selection Better value for money	Decrease service cost Increase asset uptime Increase resilience	Reduce inventory level Decrease inventory cost Improve prediction

CONTROL

Documentation

Monitor

Review

Validate the new process:
- Continuously measure the solution validity
- Create a process monitoring plan: (Agree on Frequency/procedure/manager)

→

Document the new process:
- Create a user guide & trainings
- Communicate the changes
- Align changes to the company's standards

→

Evaluate continuous improvement updates:
- Consider process transfer opportunities
- Implement a permanent control plan/ updating system

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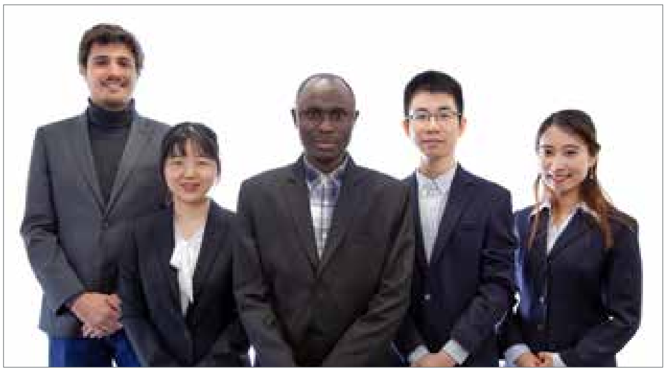

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Environmental Impact Analysis and Life Cycle Analysis (LCA) for the siting of Concentrated Solar Power (CSP) plants

Presented by:

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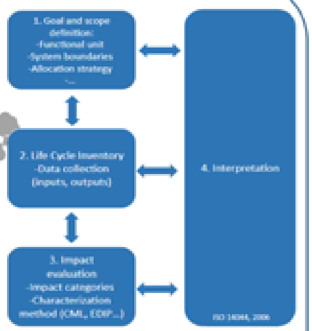
Aim:
This project aims to explore a feasible path to conduct a Life Cycle Analysis on a Concentrated Solar Power plant, and highlights the most influent factors to be taken into consideration.

1.LCA Methodology

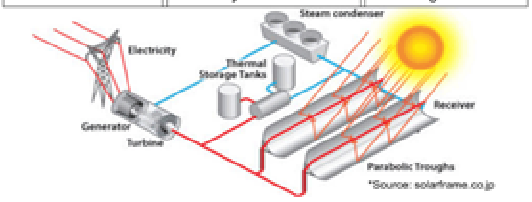
→ISO standardized framework to assess **environmental impact** of a production system for all stages of the CSP plant life cycle

*Source: carbonfootprint.com

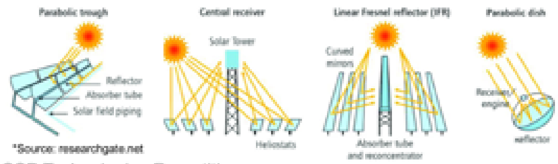


2.Concentrated Solar Power

→ Produces energy by concentrating **solar thermal energy** onto a small area	→ Light is converted into heat that boils water to produce steam to drive **turbines** and generate electricity	→ Excess day-time heat is stored in **molten salts tanks**, hence the plant can run at night

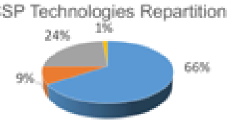


*Source: solarframe.co.jp



*Source: researchgate.net

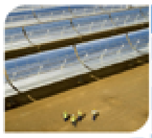
CSP Technologies Repartition



→ The study focuses on **Parabolic Trough** technology as it is the most frequently used in the world to date.

*Source: solarpaces.nrel.gov , 2019

3.LCA on Andasol-1



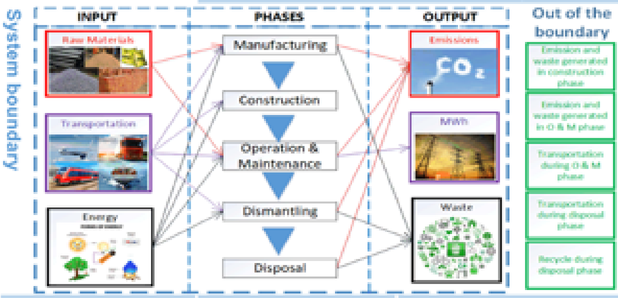
Project Overview	
Location	Aldeire, Spain
Technology	Parabolic Trough
Turbine Capacity	50 MWe
Cooling Method	Wet cooling, Cooling Tower

*Source: Google map

1.Goal and Scope Def.

Functional unit:
1 MWh generated

Objective:
→ To evaluate the environmental impacts of the Andasol-1 Concentrated Solar Power plant



2. Life Cycle Inventory

Inventory data was collected from published report on the Andasol-1	Transformation of the collected data to relate all variables to the functional unit	**Database:** EcoInvent v3.3 **Software:** SimaPro v8.3 **Analysis Method:** Europe ReCiPe E v1.09

3. Impact Evaluation

Water Depletion	Climate Change	Cumulative Energy Demand

4. Result

Analysis Method	ReCiPe Midpoint E & CED v1.09					
Generation	158000 MWh/Year					
Total(25 years)	3950000 MWh					
	Total	Manufacturing	Construction	O & M	Dismantling	Disposal
GHG	47.8	40.3	0.5	6.7	0.2	0.2
[kg/MWh]		84%	1%	14%	0%	0%
Water	4.2	0.6	0.0	3.6	0.0	0.0
[m3/MWh]		14%	0%	86%	0%	0%
CED [MJ/MWh]	562.7	432.6	7.3	116.9	3.2	2.9
		77%	1%	21%	1%	1%

5. Conclusion

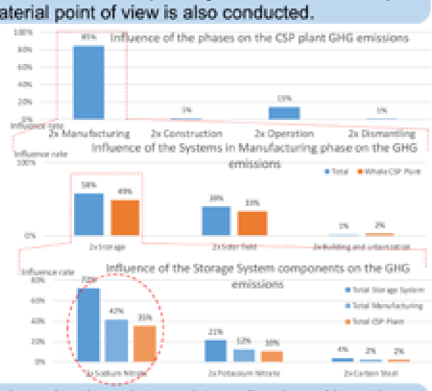
Manufacturing phase contributed 84% and 77% on GHG and CED category respectively. O&M phase is the biggest contributor to the water depletion of 86%, since O&M phase consumes 560 million liters of water per year for cooling down the condenser and cleaning the mirrors.

4. Sensitivity Analysis

(GHG emission as an example)

In order to see which component has greater influence on the system, a top-down analysis of the phases, the systems, and components was conducted. The relevant item is multiplied by 2 to observe the impact. An analysis from material point of view is also conducted.

Phase level → System level → Component level



Sodium Nitrate, which is used as thermal storage intermediary, has a biggest impact on GHG emissions. If double its quantity, the GHG emission of CSP plant will increase by 35%. Sodium Nitrate is also found to be the biggest contributor to the water consumption at a rate of 6% apart from water consumed directly in O&M phase.

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Factory Flow Simulation & Lean Improvements, Saint Gobain

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Mr. Peng Luo

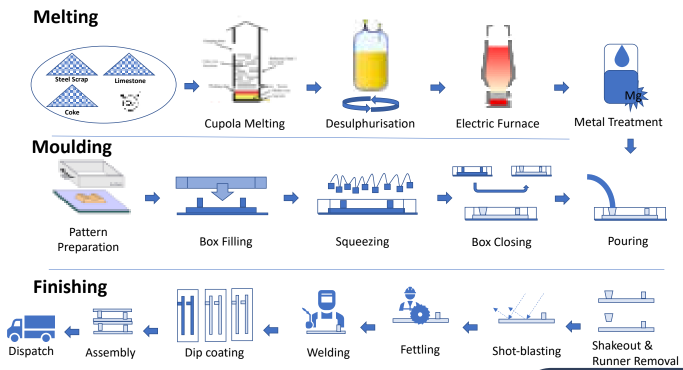
PROJECT AIMS

- **Reduce Work in Process** (WIP) in the **finishing area** at the **PAM Holwell foundry**.
- **Improve line balancing** between moulding and finishing areas
- **Investigate and research technology improvements** in the finishing area of the foundry

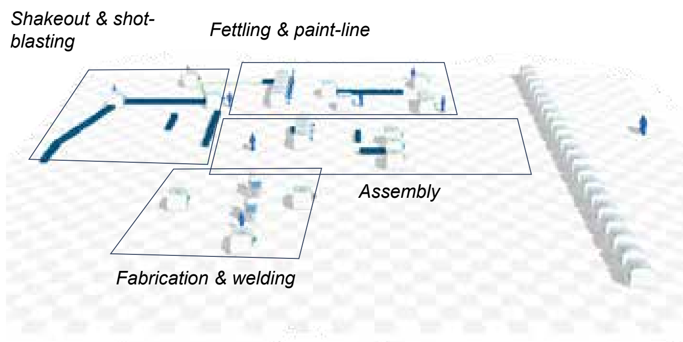
OBJECTIVES

- Create a **virtual model** of the facility, using **WITNESS** simulation software
- **Recommend Lean Improvements** that aim to **reduce WIP** and **improve** day to day **operations**
- Based on research, **recommend technological improvements** to be used at the facility

Holwell foundry process routes



3D WITNESS Model



METHODOLOGY

1: Problem Definition

- Project primarily focuses on the **finishing area** of the Holwell Foundry
- Finishing area consists of automated and manual operations
- Complete understanding into production practices, using **value stream & process maps**

2: Data Collection

- **77 Time measurements** provided distribution for manual finishing processes
- **Routing studies** provided verification into travel time across the floor
- **Pareto Analysis** carried out on product range highlighted top 20% of product that made up 80% of volume processed

3: Model Development

- **Conceptual model** created to verify understanding into production decisions
- **Simulation model** built in the following Work centre - based modules:
  - Moulding
  - Shot-blast & Shakeout
  - Fettling
  - Welding
  - Painting
  - Assembly

Results & Conclusions

- Simulations show **imbalance** between manual and automated work-centres
- **WITNESS** provided a means to experiment with different layouts, moulding strategies & labour configurations to provide recommendations to improve balance between moulding & finishing areas

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AR to Improve Data Usage in Manufacturing Settings

Ms Supriya Gupta. Ms Xin Wang Mr Matthieu Favrot
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1. BACKGROUND

The widespread use of the Internet has supported the creation of "Smart Factories", which have led to the digitalisation of processes. It has caused the creation of abundant and dynamic data which has made interpretation more difficult. AR can help humans to use this data for faster product development and more production. *(Image 1)*

Image 1: AR Interaction

Image 2: Verification on-site

2. PROJECT AIM

Developing an AR app to visualise real-time data of an ice cream pilot plant

- to help the employees to make more data-driven decisions
- to increase efficiency and productivity

3. PROJECT OBJECTIVES

1) Increase Efficiency

- Saving the time an operator spends on a process
- Performing a task in less time without impacting the quality

2) Improve Visualisation

- Real-time data will provide better control over parameters
- Visualise the data in user-friendly way

Image 3: View of the application

4. METHODOLOGY

Phase 1 – Identify problems

- Manufacturing process analysis
- AR functions research
- On-site visits
- Applications proposal
- Application selection

Phase 2 – AR system design

- Software & hardware selection
- Conceptual model
- Use case
- Story map

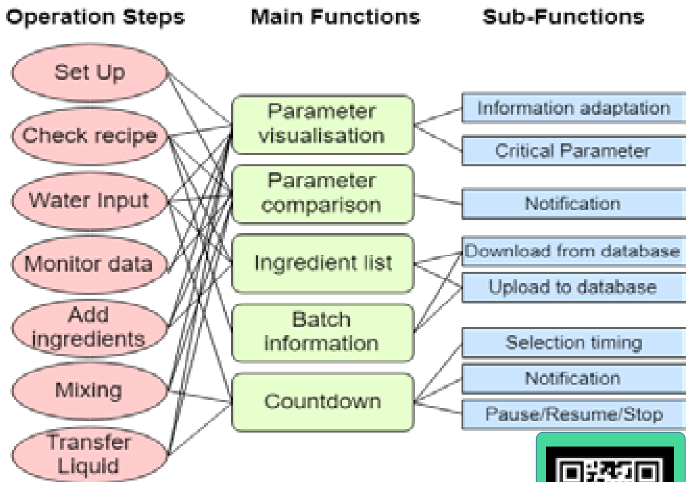
Phase 3 – AR application development

- AR application prototype
- Verification *(Image2)*

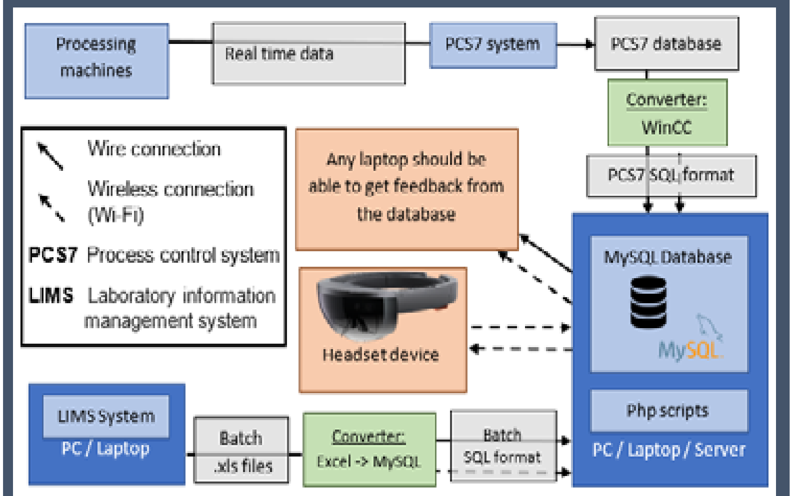
Phase 4 – Validation

- Perform trials *(Image3)*
- Efficiency: program flow analysis of the trials
- Use satisfaction: questionnaire

5. CONCEPTUAL MODEL



6. APPLICATION SYSTEM ARCHITECTURE



TRY AR

7. RESULTS

- Information visualisation
  - Better process control: a quick overview of the process
  - Optimisation of operational procedures: reduce unnecessary WALKING time
- Improve traceability: record information in digital way
- High user satisfaction from users

8. CONCLUSIONS

- A starting point for a change of culture within the company
  - To become more engaged with new data-driven ways of working
  - To introduce an application with high user satisfaction
- Better use of augmented reality in the future
  - Scale-up the application system to the whole pilot plant
  - Apply AR system in commercial factory

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Developing the Next Generation of Training for Network Rail

Luis Azana, Chelsea Camilo Monteiro, Suphanvipha Saydaung, Michael Jason Solis, Mulanga Rosalie Tshimanga, Oyinkansola Yusuff

BACKGROUND

Network Rail employees undergo safety training to empower them to do their jobs efficiently and safely, yet there were incidents where safety protocols were ignored. Network Rail is exploring how new technological innovations could be utilised to improve the effectiveness of trainings and **behavioural safety**.

AIM

To guide Network Rail with assessing how '**new technological innovations**' could be used in increasing productivity and efficiency when delivering training to improve their employees' behaviours, actions and decisions.

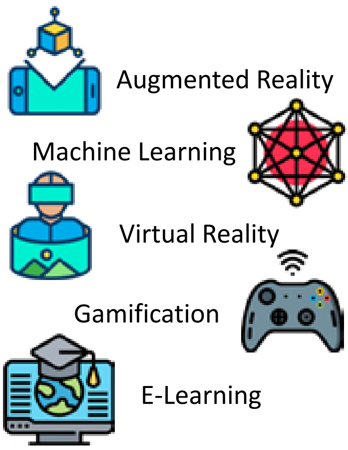
OBJECTIVES

- **Investigate** new technological innovations for training.
- **Analyse** the current training processes, strengths, challenges, opportunities and gaps at Network Rail.
- **Identify** and evaluate which new technological innovation is appropriate for delivering training that complies with training requirements and addresses target behaviours.
- **Prioritise** technological opportunities through the development of a Return on Investment type toolkit.
- **Validate** the research findings in the Network Rail context.

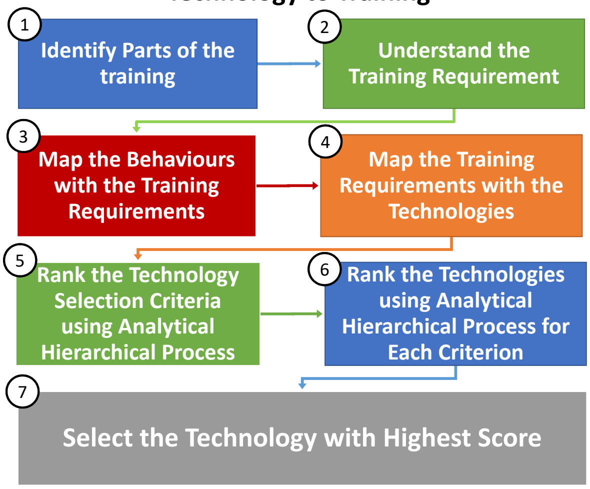
RESEARCH METHODOLOGY

RESULTS

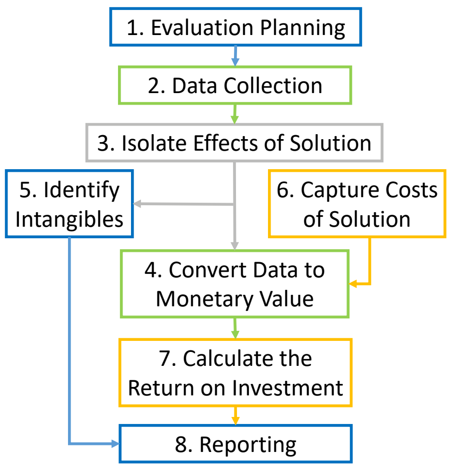
New and Existing Technologies in Training



Framework for Introduction of Technology to Training



Return on Investment Type Toolkit based on Phillips ROI Methodology



CONCLUSION

This project has successfully provided Network Rail with the means of assessing how 'new technological innovations' could be used in increasing the productivity and efficiency when delivering training to improve the workforce's actions, behaviours and decisions through the development of a **Report of New and Existing Technologies**, **Framework for Introduction of Technologies to Training** and a **Return on Investment Type Toolkit** based on the Phillips ROI Methodology.

"These are the kind of deliverables we were seeking when we assigned the group project, and I believe they will help support Network Rail Training in our review of future training and our ambitions to keep our people safe"

Michelle Nolan-McSweeney, Head of Training Strategy, Network Rail

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Developing sustainable supply chains for UK Manufacturing growth

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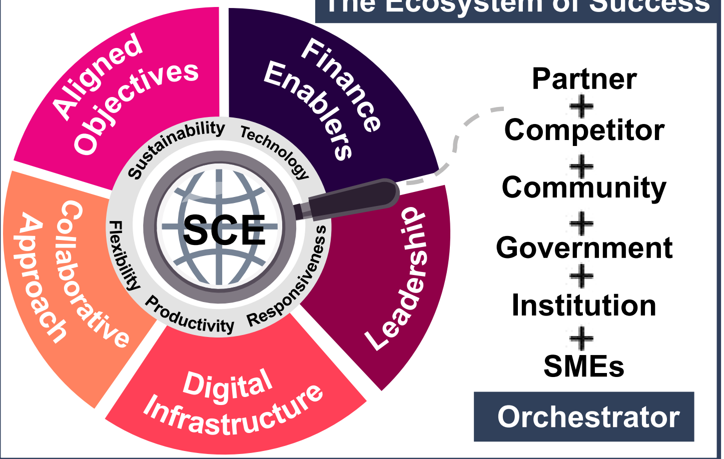
AIM

The aim of the project is to outline a Supply Chain Ecosystem and the actions required to enable the sustainable growth of UK supply chains.

OBJECTIVES

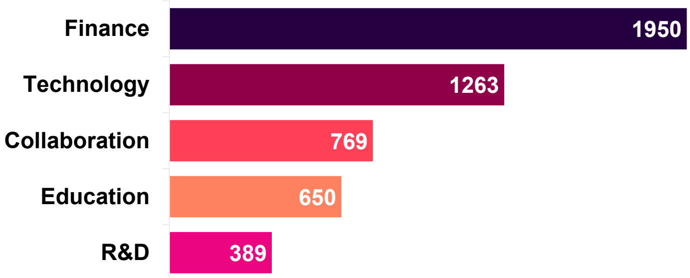
- Conduct a literature review of UK Manufacturing supply chains.
- Lead structured interviews with supply chain experts.
- Perform a qualitative analysis of literature and interviews.
- Present findings in the form of a White Paper for the **National Manufacturing Debate 2019**.

The Ecosystem of Success

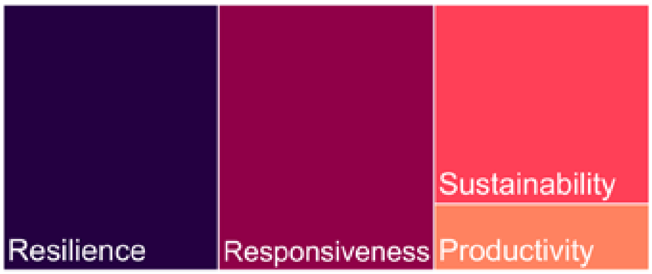


METHODOLOGY

● Topics Identified from Literature Review



● Qualitative Analysis of interviews



● Key Findings

Finance: Issues around late payment and extended payment terms resulting in reduced resilience through the supply chain

Technology: Leadership fears of new technology and the risks it can bring to the supply chain if not implemented correctly.

Collaboration: Lack of awareness among business leaders of the benefits of collaboration and how to implement it.

● Recommendations

It is our recommendation that an ecosystem is developed to encourage sustainable UK manufacturing supply chains. Government involvement in developing the ecosystem is fundamental and should facilitate the underlying infrastructure, policies and skills needed. Collaboration, finance and technology are the key enablers to promote more resilient, responsive, sustainable and productive supply chains. The orchestrating and monitoring of this new ecosystem can be made possible through a central control tower.

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Shop floor simulation for continuous improvement in a Medical Device Company

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Project Aim

The aim of this project is to develop a strategy to increase the capacity of Sterifill and increase the efficiency through the reduction of the downtime of Physioject with the support of a discrete event simulation software (DES).

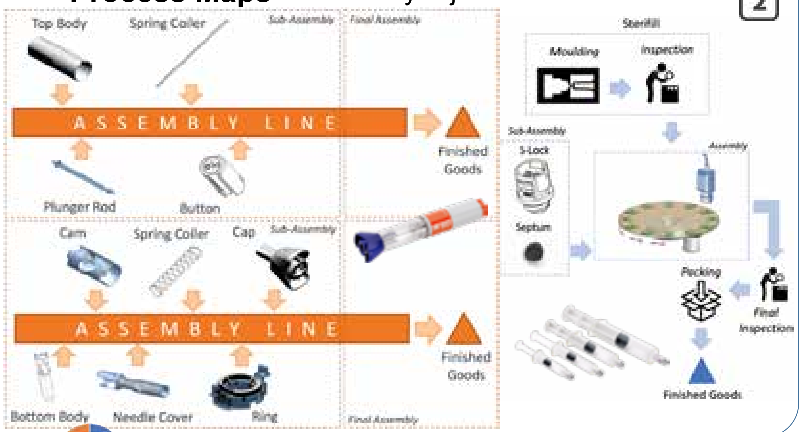
1 Data Collection

Stopwatch

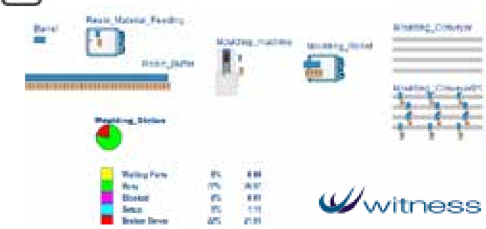
Database

Interview

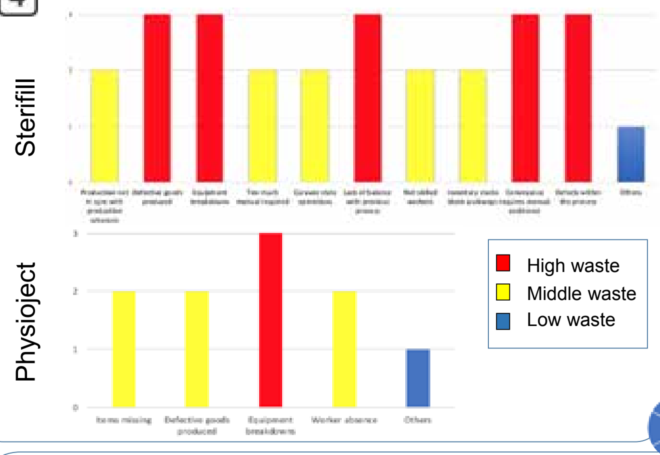
2 Process Maps



3 Modelling

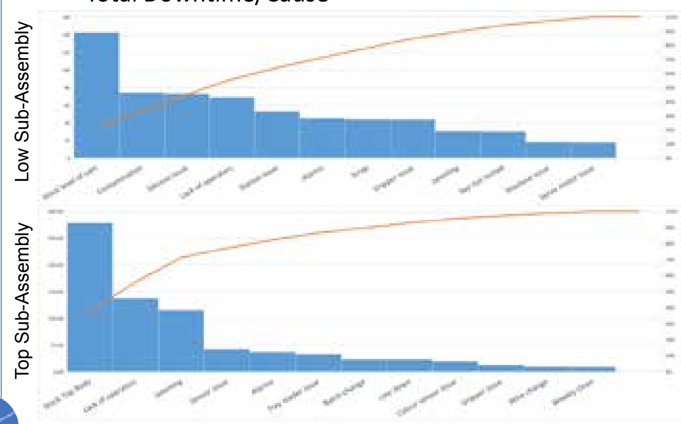


4 Waste Identification



5 Root Cause Analysis

Total Downtime/Cause

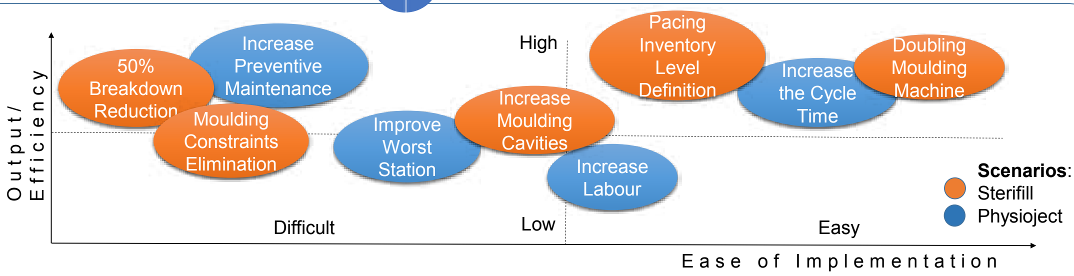


6 Strategy

Validation

Verification

What if Scenarios



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Reconfigurable Micro-factories for Future Vaccines Manufacturing

Mr. Daniel Simon Jimenez Miss Xiaochen Liu Mr. Shahed Md Salahuddin
Mr. Adrien de Soultrait Miss Jingjing Wang Mr. Zhao Yang
Mr. Daheng Zhao

BACKGROUND

Due to increasing threats by emerging pathogens, there is an urgent need for vaccines manufacturing by using RNA platform. Our study part of the EPSRC future vaccines manufacturing hub focusing on making vaccines accessible to everyone especially for LMIC(low and medium income countries) countries by dropping the price at a $1/dose. This is a novel emerging technology and it shall be suitable for fast response to potential epidemics and emergencies at any circumstances.

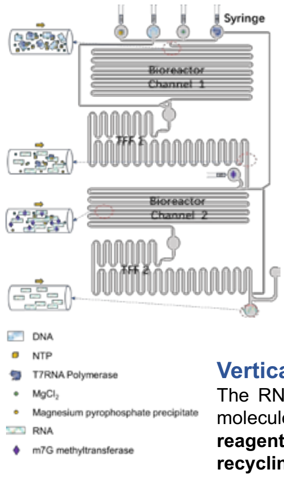
AIMS & OBJECTIVES

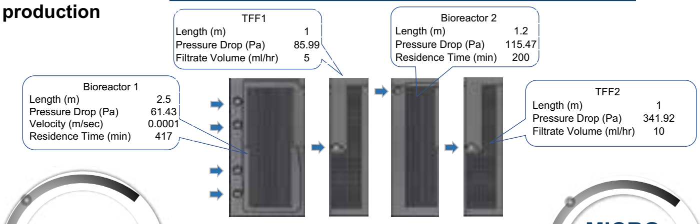
To design and demonstrate a reconfigurable modular micro-factory for vaccines manufacturing.

- Develop concepts of a reconfigurable micro-factory
- Build a prototype with suitable flow and filtration techniques & testing

METHODOLOGY

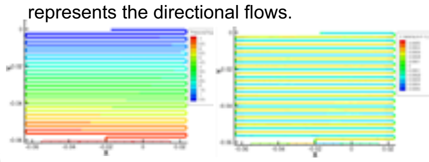
Schematic of the continuous RNA production





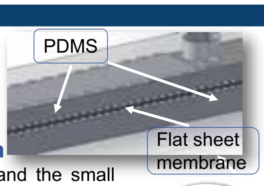
CAD design for whole microfluidics chip

CFD analysis verifies the calculated data according to the velocity profile in the microchannels. Both negative and positive data represents the directional flows.



CONCEPT DESIGN

MICRO-FLUDICS ANALYSIS



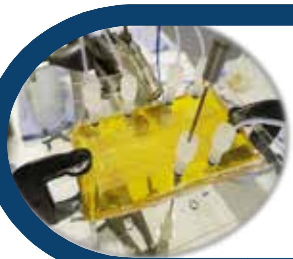
Vertical Tangential Flow Filtration

The RNA goes though the top channel and the small molecules are filtered down. **Those expensive reagents are pushing back to the reactor thanks to recycling channel**

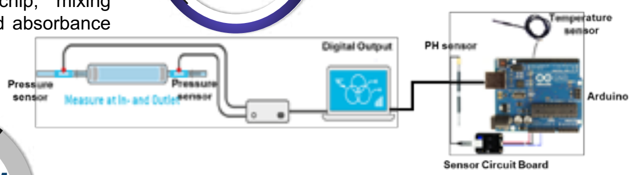
3D printed mask using **soft lithography** (SLA printing)

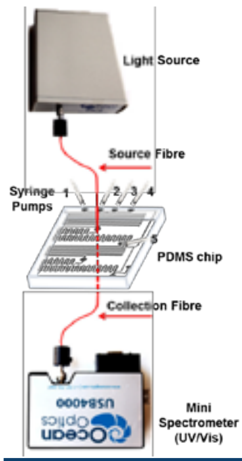
By applying PDMS over the mask and baking it, the PDMS reactor is ready

PROTOTYPE BUILDING



Samples with different colours are introduced in the chip, mixing effectiveness, PH and absorbance can be obtained.





PLATFORM INTEGRATION

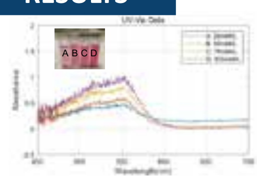
PH Calibration and real-time monitoring

Python reads the Arduino and Ocean Optics spectrometer data

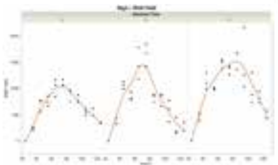
Experimental Integrated Platform Design

TESTING

RESULTS



UV/Vis absorption spectra of samples



Data analysis (RNA yield VS Mg^{2+}) & Optimum reaction time selection (Shattock Group at Imperial College)

FURTHER WORK

- Build and test a continuous flow system with integrated recycling channels
- Appropriate design of filtration processes and testing in the laboratory with reference samples
- Validating the microfluidics calculated data by the experimentation in the lab
- Building the automatic control system to control the pump

REFERENCES

- http://www.imperial.ac.uk/future-vaccine-hub/about-us/
- https://ieeexplore.ieee.org/abstract/document/6487168/references#references

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Industrial System Pen-Testing

Amaury Boxberger, Max Bradford, Theo Drousiotis, Josh Fan, Alexandre Misson

Background

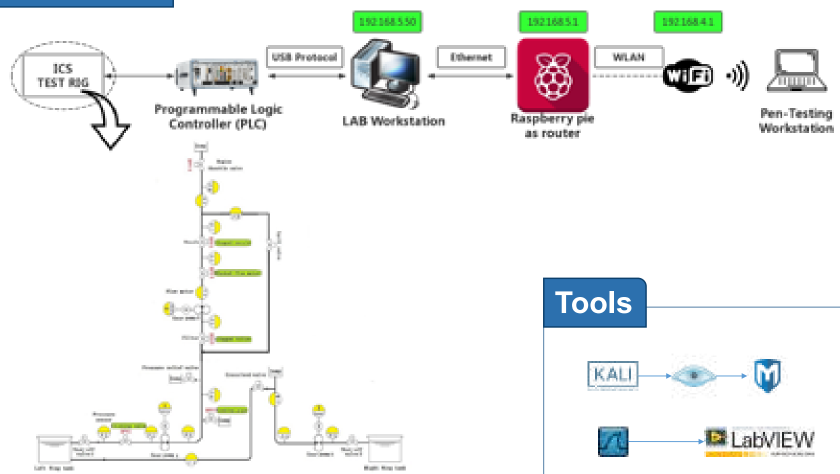
Cybersecurity of industrial systems has become a paramount concern for all organisations across every industry. Most of industrial systems are legacy systems that have been designed a long time ago without any consideration for cyber security. Consequently the need for more secure and easier to defend industrial systems is pressing. Failing that can have huge harmful consequences on a enterprise or country's infrastructure.

Aim & objectives

One way of improving Industrial Automation & Control Systems' cybersecurity is to perform pen-testing on a test rig, disconnected from real systems and realistic in terms of architecture, equipment and functionality. The objectives are to identify and exploit vulnerabilities of the test rig, thus to provide solutions and countermeasures to real life cyber attacks to secure SCADA systems. To implement the goal, three types of attacks, a remote attack, a direct attack and malware infection, are performed to demonstrate the penetrability of the system with vulnerabilities.

Methodology

Architecture



Layout of the Aircraft Fuel System Rig

Tools

Attack demonstration

Scenarios	Preparation		Intrusion			Breach		Recommendation
	Reconnaissance	Weaponization	Delivery	Exploitation	Installation	Command and control	Actions and objectives	
Remote Attack Scenario	Nmap IP & Port Scanning	Metasploit Penetration	Metasploit	Eternal Blue	Invoking Target Shell with Metasploit	DoS attack malware Malicious PLC program attack Remote Desktop interface USB traffic listening & injection	DoS: PC unusable Control the ICS	• NGFW • Up to date OS • Up to date apps • Limit connectivity • VPN • Strong password policy • HIDS
Direct Attack Scenario	Locate target & Find physical weakness	Get physical access	Connect Flash Disk with Dual-boot OS	Brute force account password hash	Log in as Administrator	DoS attack malware Malicious PLC program attack	DoS: PC unusable Control the ICS	• Anti Virus • Disk encryption • BIOS password • Secure physical access • Strong password policy • HIDS
Malware Infection Scenario	Find Employee's Data	Social Engineering	Malware Delivery	Propagation in the Intranet		Malware activation	DoS: PC unusable Control the ICS Steal secret files	• NGFW • Anti Virus • Up to date OS • Back up critical data • VLAN isolation • HIDS

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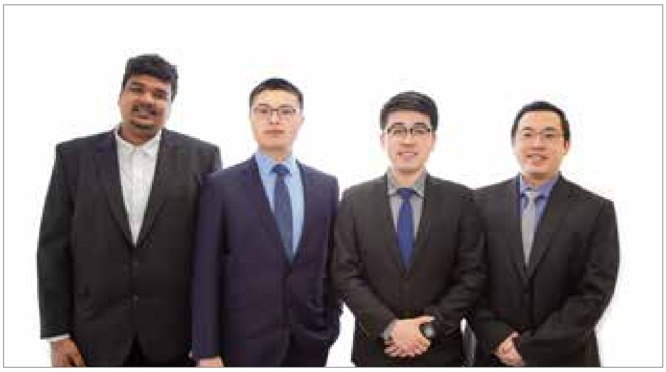

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Towards Digital Aircraft Engineer and Paperless MRO

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Mr Jinghui Wang, Mr Tany Moses Isukapatla

Introduction

- Aircraft Engineers spend unproductive hours on redundant tasks
- High volume of paper documentation

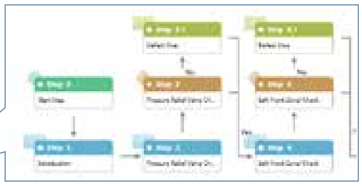
Aim & Objective

Aim – To improve work efficiency and support e-documentation of current aircraft maintenance

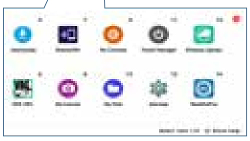
Objective – Explore wearable device (HMT-1) in realistic MRO context using Cranfield's 737-400

Methodology

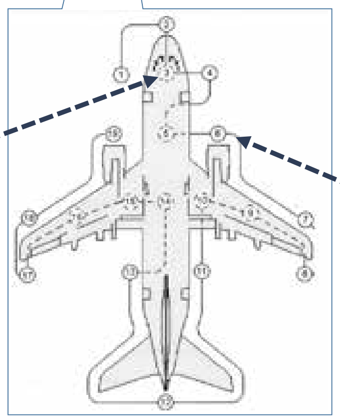
Learning hardware & software → Trial Design → Trial Execution → Data Collection → Data Analysis → Product Improvement



Extract of WorkfloPlus



Interface of HMT-1



Scenario is representative of the pre-flight check before aircraft despatch

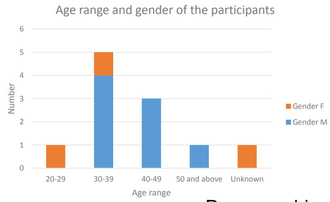
Results & Outcomes

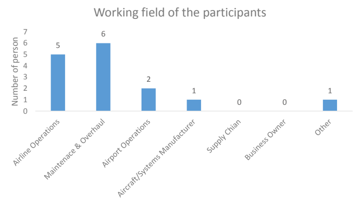
- First trial aims to gather feedback on the use of HMT-1 and the available technical content in device
- 10 participants from Boeing Apprenticeship Programme

Feedback on Usefulness of HMT

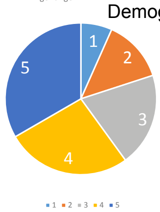
Feedback on Quality of Information

- Second trial aims to evaluate the feasibility of the technology and potential opportunity in real maintenance environment with a group of experienced engineers.
- 15 participants from Human Factors in Aviation Maintenance Course

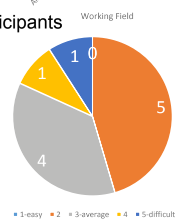




Demographics on the participants



Helpfulness of technology compared to paper manuals



Difficulty to understand instructions

Analysis

- First trial:
  - Feedback on device and associated content have been positive
  - Wearable device has the potential to improve current aircraft maintenance practices
- Second trial:
  - Feedback was negative
  - Experienced engineers are familiar with pre-flight checks, the trial scenario more appropriate for apprentice training
  - Wearable technology could be beneficial in real-life maintenance for complex and unfamiliar scenarios with communication support from remote engineer(s)

Conclusion

- Relatively high acceptance of wearable device
- Technology could improve work efficiency, but need to be utilised in the right work tasks
- Investment in organisation learning and process changes is substantial

Future Works

- Integrate Remote Expert to provide further assistance when complex problems are detected on-site
- Integrate with MRO ERP to acknowledge task completion by digital signature
- Integrate AR technology with Digital Twin to facilitate task execution and error detection

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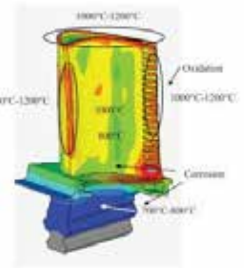
Surface Integrity of a Laser Shock Peened Single Crystal CMSX-4® Nickel-based Superalloy

Aabid Husen Hakeem, Alice Grégoire, Rafael Ruiz Iglesias, Thijaya Sumoreeah, Yuliya Hryshchenko

Background

Laser shock peening can be used to induce deeper surface compressive residual stress in the work piece than other conventional surface treatment processes Combined with the generated dislocation density, it improves fretting, fatigue and stress corrosion cracking resistance. It offers a promising approach for high temperature corrosion-fatigue damage mitigation on the turbine blades root region.



Typical range of temperatures and damages on the surface of a HPT Blade

Ref: Darolia R. Development of strong, oxidation and corrosion resistant nickel-based superalloys: critical review of challenges, progress and prospects. International Materials Reviews. 2018; 6608. Available at: DOI:10.1080/09506608.2018.1516713

Aim and objective

Aim: To investigate surface integrity of a laser shock peened without coating single crystal CMSX-4® nickel-based superalloy for turbine blade root application.

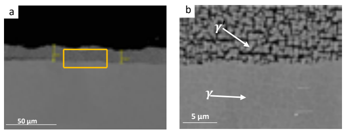
Objective: To evaluate the surface and subsurface characteristics of laser peened CMSX-4® treated with three different laser power densities (4, 7 and 10 GW/cm²), before and after thermal exposure at 700°C for 50 hours.

Methodology

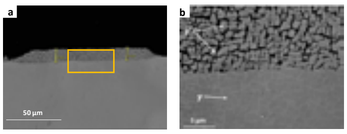
- Microstructural changes
- Surface topography
- Dislocation density
- Hardness distribution
- Residual stress distribution

Results

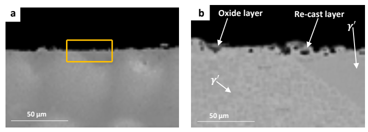
- Microstructural changes by Scanning Electron Microscopy



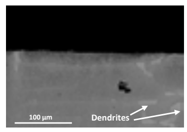
(a) 4 GW/cm² peened sample at low magnification
(b) 4 GW/cm² peened sample at high magnification



(a) 7 GW/cm² peened sample at low magnification
(b) 7 GW/cm² peened sample at high magnification

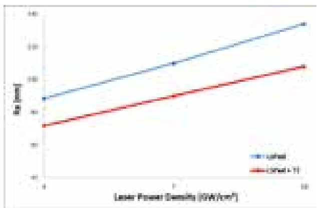


(a) 10 GW/cm² peened sample at low magnification
(b) 10 GW/cm² peened sample at high magnification



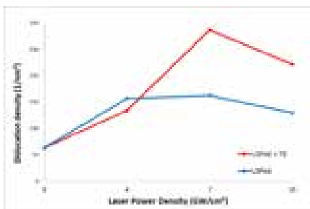
4 GW/cm² peened sample after thermal exposure at low magnification

- Surface topography by Interferometry



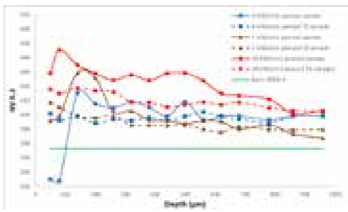
Variation of Ra values over laser power density

- Dislocation density by X-Ray diffraction



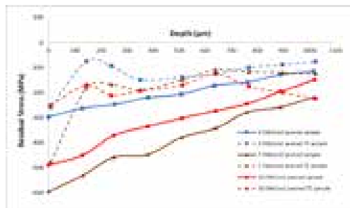
Dislocation density for {200} peak broadening

- Microhardness by Vickers testing machine



In-depth microhardness distribution

- Residual Stress by Central Hole Drilling



In-depth residual stress distribution

Conclusions

- Microstructural changes on sample subjected to 10 GW/cm² had the most severe effect showing an oxide and recast layer.
- After thermal exposure, recrystallisation and an oxide layer have been found in all samples.
- The dislocation density increases in the peened surface with power densities 4 and 7 GW/cm², and declines at higher values.
- The surface roughness increases with respect to laser power density rise and reduces after thermal exposure.
- The compressive residual stress is maximum in the near surface layer with power density 7 GW/cm².
- A significant part of beneficial surface compressive residual stress has been retained after thermal exposure for all LSP samples.
- All LSP samples exhibit an improvement in hardness before and after thermal exposure.

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Acknowledgment

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Quantifying Sintering Behaviour of Thermal Barrier Coatings at High Temperature

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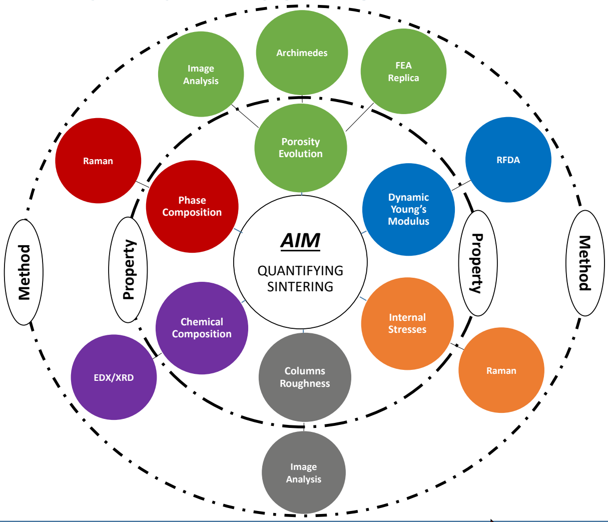


Introduction

TBCs deposited by Electron Beam Physical Vapour Deposition (EB-PVD) are used on high temperature and high pressure turbine blades in aero-engines to protect underlying nickel superalloy substrate from thermal degradation

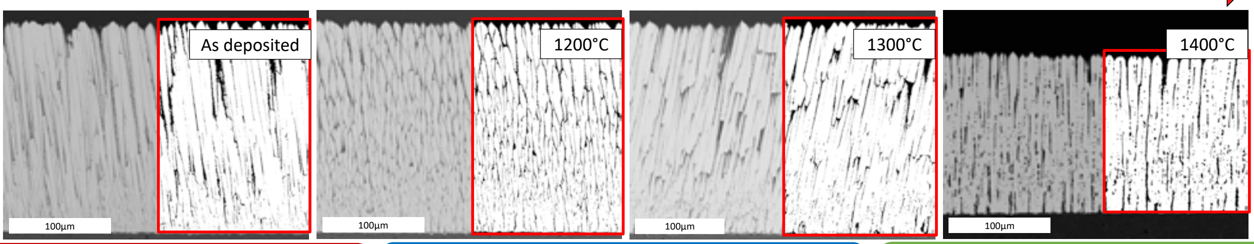
- 7wt%Y_2O_3 stabilised ZrO_2 (7YSZ) is the Industry standard TBC . Newer ceramics include lanthanide dopants to further lower thermal conductivity, 4mol%$Er_2O_3$7YSZ.
- Porous, columnar TBCs obtained from EB-PVD deposition provide low thermal conductivity and superior strain tolerance under demanding service conditions. During prolonged exposure to high temperatures, columnar TBCs evolve towards a bulk state following the sintering process.
- Sintering Processes:
  - Loss of feathery porosity (FP) and internal porosity (IP) – surface diffusion
  - Necking between columns (N) – loss of intercolumnar porosity
  - Phase changes – (t-m) (PC)

Results

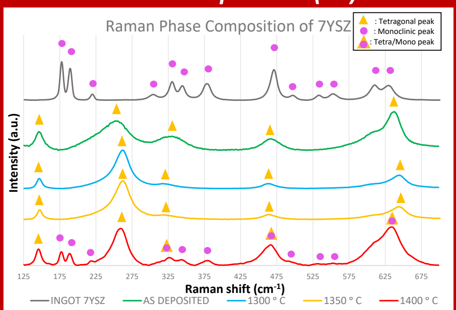
7YSZ, 100 Hours Thermal Exposure, Increasing Temperatures

Left half: SEM image

Right half: Threshold image using Otsu method

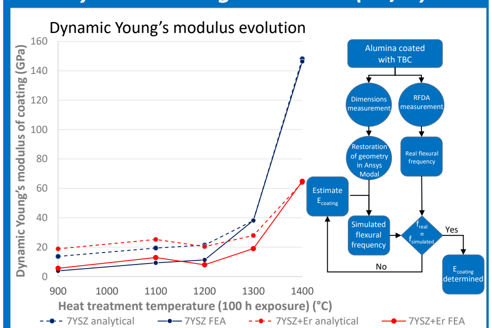


Phase Composition (PC)



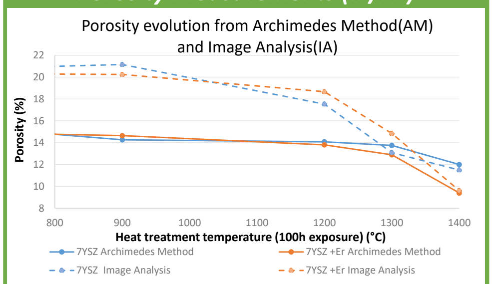
- Surface phase composition assessment shows that monoclinic transformation occurs between 1350°C and 1400°C on 7YSZ samples.
- Peak shift study was inconclusive because of aleatory stress dispersion on 7YSZ samples.
- Spectroscopy of Erbia doped samples was affected by fluorescence, making investigation of phase composition inconclusive.

Dynamic Young's Modulus (PC/N)

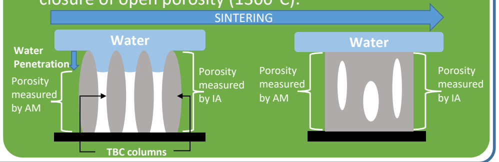


- Young's Modulus starts to increase from 1200°C.
- Rate of increase is higher for 7YSZ than Erbia doped.
- 7YSZ : 10-fold increase from as deposited state to sintered (1400°C).
- 7YSZ+Er 3-fold increase from as deposited state to sintered (1400°C).
- 50% higher activation energy value for Er_2O_3 doped TBC.

Porosity Measurements (IP/FP)



- Porosity study shows a drop around 1200°C.
- Convergence of results for sintered samples indicates closure of open porosity (1300°C):



Conclusion:

- Sintering evolution was successfully studied through quantitative and qualitative methods.
- Surface Raman was proved to deliver insufficient results.
- Cross-section Raman was determined as more conclusive.
- The different methods converge toward similar conclusion: bulk diffusion commences at temperatures above 1200°C for 7YSZ: coating stiffening initiation and porosity drop.
- First increase in Young's modulus (1200°C-1300°C) might be related to intra-columnar porosity decline.
- Second increase in Young's modulus (1300°C-1400°C) might be related to extra-columnar porosity augmentation and necking phenomenon, inducing more significant stiffening.
- Erbia addition impedes sintering process and decreases its rate, enabling extension in maximum service temperature of engines from 1200°C to 1300°C, improving combustion efficiency.

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Photoluminescence thin films for improvement of solar photovoltaic performance

Chenguang Yang, Jocelyn Delansorne, Junfeng Chen, Mylène Leduc

1. Background:

- Fundamental losses in solar PV

Solar PV technologies suffer from inefficiencies in energy conversion due to mismatch between solar radiation spectrum and PV spectral response:
$E_{ph} << E_g$: sub-bandgap transmission loss.
$E_{ph} >> E_g$: thermalization loss.

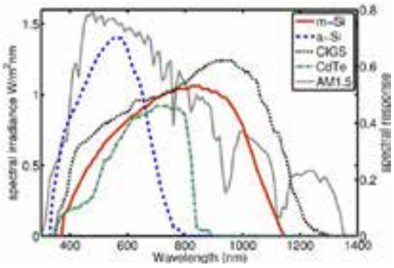


Figure 1. Spectral response of different PVs against AM1.5G solar irradiance [1]

- Quantum dot (QD)

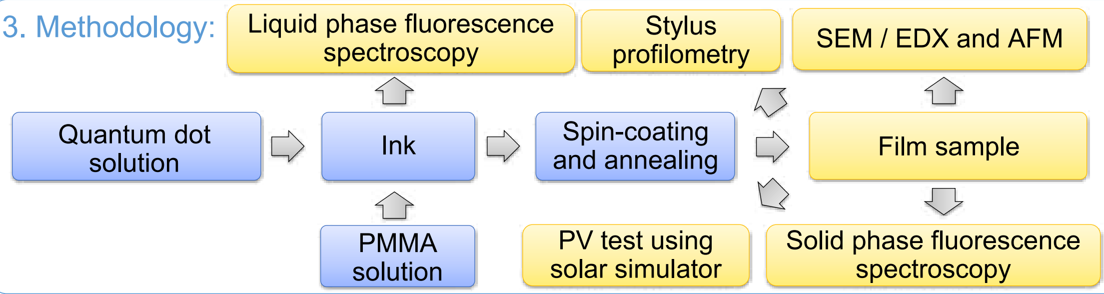
The luminescent film containing QDs can absorb photons in the spectrum region where solar power peaks and shift the photon energy to regions where Si solar PV convert photons most efficiently.

Figure 2. Luminescent ink and film

2. Aim:

Manufacturing and characterisation of photoluminescent downshifting thin films containing various QDs, and assessment of power conversion performance through optimisation of process parameters.

3. Methodology:



Techniques	Parameters
Liquid/Solid phase fluorescence	λ_{ex} and λ_{em}
SEM/AFM	Topography
EDX	Composition
Stylus profilometry	Thickness
PV test	PCE, FF, V_{oc}, I_{sc}

4. Results:

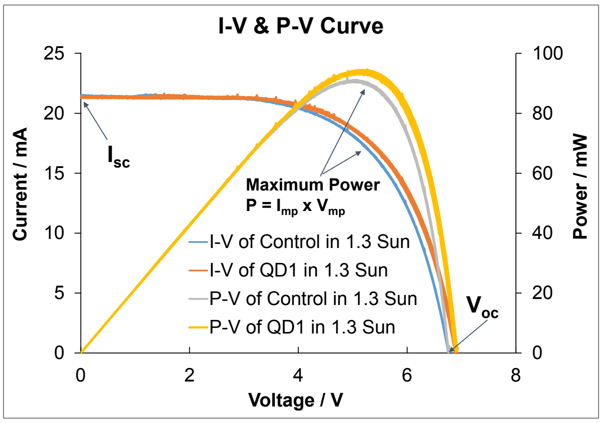


Figure 3. I-V and P-V curve of PV with only PMMA on top (control) and a PV with luminescent film on top under 1.3 sunlight intensity

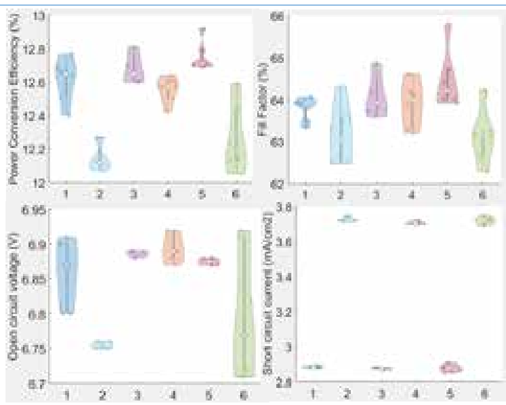


Figure 4. PV performance in presence of luminescent film

1: Control 1 Sun
2: Control 1.3 Sun
3: QD1 50 mg/mL 1 Sun
4: QD1 50 mg/mL 1.3 Sun
5: QD2 25 mg/mL 1 Sun
6: QD2 25 mg/mL 1.3 Sun

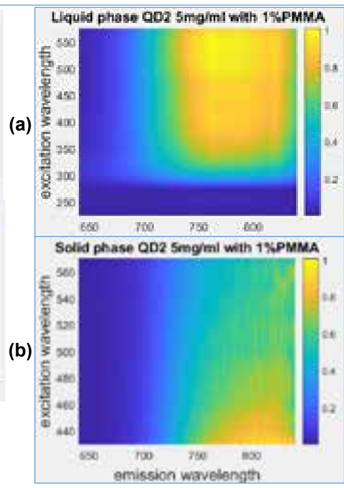


Figure 5. Fluorescence excitation-emission of (a) liquid QD2 ink and (b) solid QD2 film

5. Discussion:

- Overall improvement of PCE for high concentration samples up to 4.96% and fill factor up to 1.98%.
- Luminescent film decreases PV thermalization as observed by an improvement in V_{oc}, which may improve on the longevity of PV.
- Manufacturing process affects the photoluminescence properties of all tested QDs by shifting their λ_{em} of up to 55 nm.

6. Future Work:

- Verify the impact of integrating anti-reflective coating with luminescent film to PV performance.
- Explore the feasibility of replacing PMMA by UV-curable isobornyl acrylate (IBOA).

Reference: [1] Betcke, J et al. (2010) 'Spectrally Resolved Solar Irradiance Derived from Meteosat Cloud Information-methods and Validation', University of Oldenburg, Energy and Semiconductor Laboratory, Energy Meteorology Group

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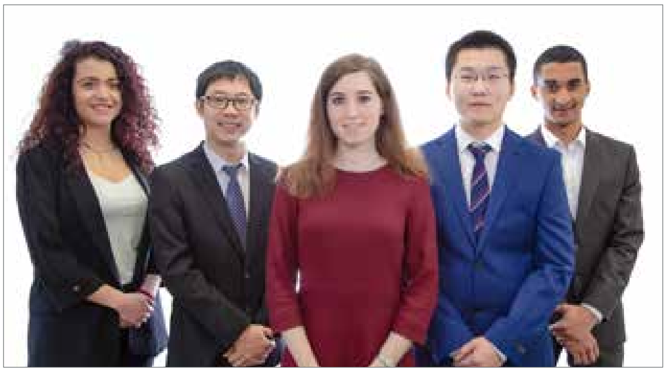

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Portable thermal conductivity testing rig for composites

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Motivation

- Increasing use of composites with tailored thermal properties, e.g. automotive engine casing, chassis
- Need of thermal conductivity measurements of assembled component: one sided access, non-contact, portable, accurate, reproducible measurements

Aims

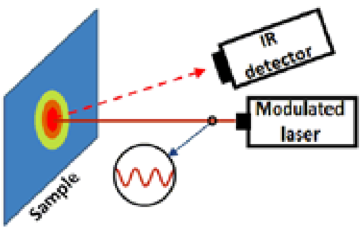
- Feasibility study of thermal conductivity apparatus for composites
- Model development of experimental apparatus

Objectives

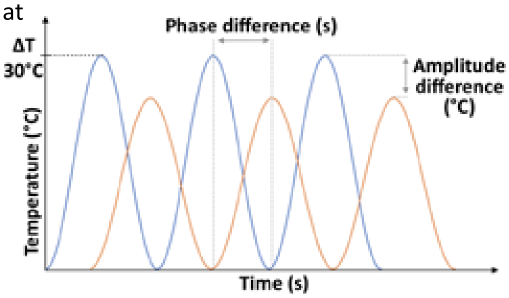
- Develop FEA model
- Investigate optimum set of model parameters
- Define requirements of apparatus components

1. Measuring Technique

- Laser sinusoidal **modulated heat source:** multiple frequencies applied simultaneously



- Top surface temperature measurements at varying distance from laser beam centre
- FFT analysis of multiple frequencies
  - Temperature wave amplitude at varying x-axis points derived
  - Temperature wave phase lag at varying x-axis points derived
- Changes of k → temperature wave amplitude and phase change



2. FEA Model – ANSYS Fluent

Model Parameters

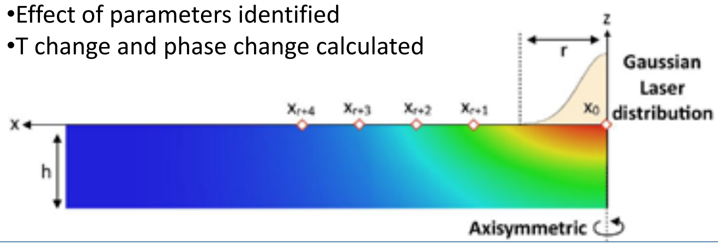
MODEL PARAMETERS		TESTED VALUES	UNITS
Laser Power		Varied for $\Delta T \cong 30°C$ at beam centre	W
Laser Beam Radius		R = 1, 2, 5	mm
Modulation Frequency		f = 1/30, 1/60, 1/100	Hz
Material Thermal Conductivity	Isotropic	k = 0.2	W/m K
	Orthotropic	$k_x = 7$, $k_z = 0.2$	
Sample thickness		h = 1, 10	mm

Procedure of Model Analysis

- Varying combination of model parameters for k and k +5% change
- Post-processing ANSYS results by FFT

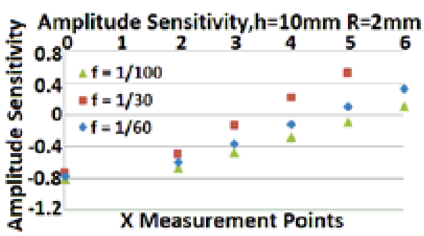
↓

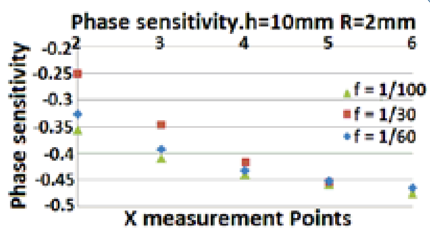
- Sensitivity to k changes of amplitude and phase of T wave obtained
- Effect of parameters identified
- T change and phase change calculated



Results & Conclusions

- Laser power does not affect either temperature or phase change when k varies
- Lower R provide greater phase sensitivity to k
- Higher R increase T change. Higher accuracy for rig measurement expected
- f ≤ 1/60 Hz provide more reliable results and increased sensitivity
- R = 2mm and f = 1/60 Hz give best results for amplitude/phase sensitivity and T changes. Advantage: time efficiency
- Minimum phase lag to be detected 0.01 s
- Minimum T change to detect 0.04 °C
- Linearity applies for FFT to be used in multi-frequency heat source





Future Work

- Investigation of multiple layer composite model
- Research of two-laser model
- Retrieve k values from amplitude and phase temperature data
- Assemble apparatus and test measurement technique

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Development of graphene enhanced composite hydrogen pipelines

Chenkai Zhang, Krutarth Jani, Lakshmi Priya Muthe,
Noor Salam Ghadarah, Xinyi Guan

PROBLEM SPECIFICATION

ADVANCED MATERIALS FOR HYDROGEN PIPELINES

- Low permeability to avoid leakage of hydrogen gas
- Better mechanical properties to enable high pressure pipelines
- Anti static property to eliminate static charge build up in polymer pipes
- Cost effective

MATERIAL SELECTION FOR HYDROGEN PIPELINES

Polymers:	Graphene percentages:
HDPE (High density polyethylene)	0.1%
PET (Polyethylene terephthalate)	1%
PA 6 (Polyamide 6)	

MANUFACTURING PROCESSES

Extrusion

Planetary mixing

Compression moulding

Injection moulding

CURRENT CHALLENGE:- SAFE, RELIABLE, AND COST EFFECTIVE PIPELINE NETWORK FOR HYDROGEN DISTRIBUTION

PROPOSED SOLUTION:- POLYMERIC NANOCOMPOSITES FOR RELIABLE AND AFFORDABLE PIPELINES

CO2 EMISSIONS CAN BE SIGNIFICANTLY REDUCED BY REPLACING NATURAL GAS WITH HYDROGEN

GRAPHENE

- HIGH ELECTRICAL CONDUCTIVITY
- HIGH THERMAL CONDUCTIVITY
- IMPERMEABLE TO MOST GASES
- STRONG AND DUCTILE

GRAPHENE ENHANCED COMPOSITE PIPELINES ENABLE :

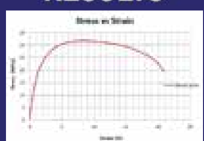
- LARGE DIAMETER POLYMER PIPELINES
- HYDROGEN GAS SAFETY
- ABOVE GROUND PIPELINES
- ANTI STATIC PROPERTIES

TESTING

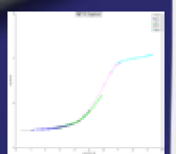
- Tensile
- Creep
- Electrical resistivity
- Gas permeability

RESULTS

PA 6 : At 0.1 wt% Graphene: E increased by 22% and σuts increased by 21%



HDPE: At 1 wt% Graphene: E increased by 26% and σuts increased by 2%



Strain behaviour of PET 1% graphene in time

FUTURE RECOMMENDATIONS

- Aging of pipelines and environmental effects
- Fracture toughness and impact behaviour
- Assess applicability to transmission pipelines (Design pressure > 700psi)
- Fitting and joining techniques

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RF Piezoelectric Tuning Element

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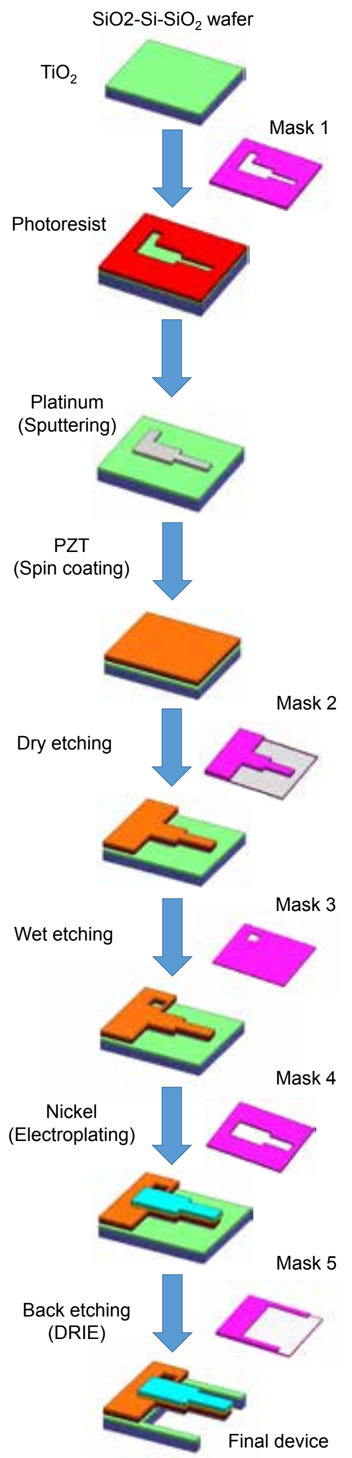
Process Flow



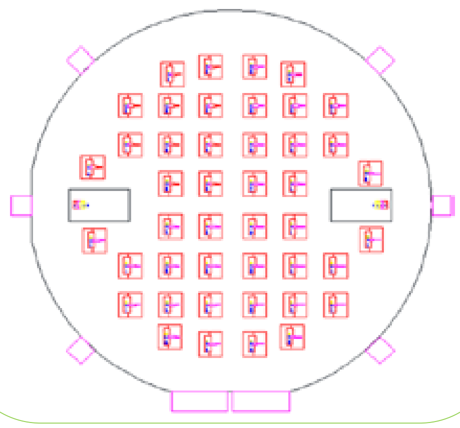
Objectives

- Model a PZT actuator with potential tuneable air gap element for electronic devices to avoid signal interference
- Design a process flow for manufacturing
- Generate photolithography masks for fabrication
- Demonstrate piezoelectric actuation of manufactured cantilever structure devices

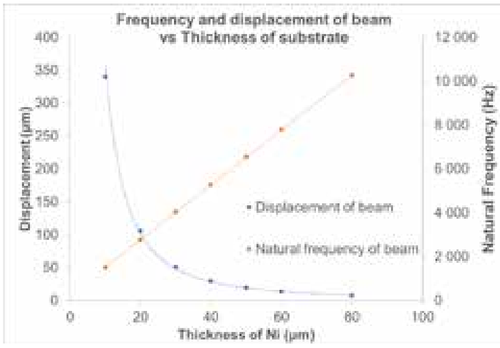
Device Specifications

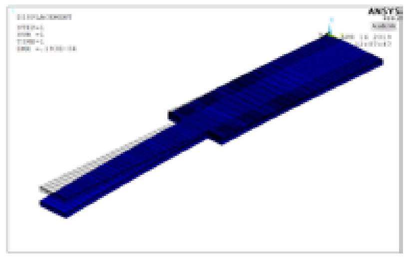
- Resonance free operation range: 10 to 2000 Hz
- Critical beam length: 2.325 mm
- Operating temperatures: -25 to 85°C
- Maximum deflection: 25 µm

5-layer Superimposed Mask Design

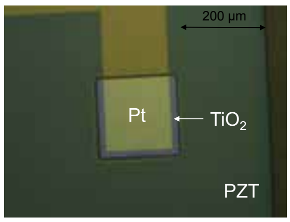


FEA Model of Actuator

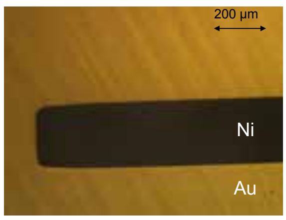




Optical Microscope

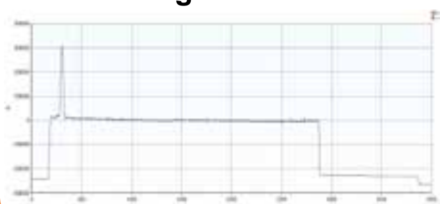


Platinum as bottom electrode

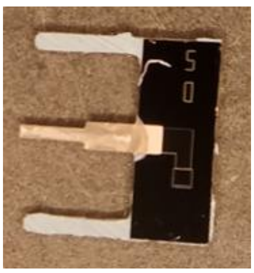


Nickel electroplated on Gold coated wafer

Post-electroplating Nickel Length Profile



Final Device



Conclusion

- Successful manufacturing route has produced intact micro-cantilever structures based on dimensions from modelling results.
- Surface roughness dramatically influences thin film's electrical properties. Improved roughness of nickel plated surface needs to be addressed.
- Desired Nickel thickness was deposited, putting beam's natural frequencies above potential interference application frequencies.

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Wire plus Arc Additive Manufacture (WAAM) of 15-5 PH stainless steel using plasma arc process

Authors: Dao Wang, Yuhan He, Halil Emre Caglar, Felix Otuada.

1. INTRODUCTION

Wire + Arc Additive Manufacturing (WAAM) is an important manufacturing tool for metal AM in aerospace, defence, and transportation industry. The 15-5 precipitation hardening (PH) stainless steel (SS) is one of the advanced alloys and suitable for application in extreme conditions. The present study aims to understand the feasibility of using the WAAM process for manufacturing 15-5 PH SS structures.

2. MATERIAL AND METHODOLOGY

- The 15-5 PH SS wire was used to deposit and manufacture components using the Plasma arc welding based WAAM process to study the response of the metal when subjected to multiple thermal cycles due to successive layer deposition.

Depositing single beads → Optimizing parameters → Building two small walls → Final input selection → Depositing two identical walls → Comparison of mechanical properties and microstructure in the heat treatment (HT) with the as-deposited (AD) condition

Table 2.1 Chemical composition of 15-5 PH SS wire

C	Si	Mn	Cr	Ni	Cu	Nb	Fe
0.02	0.50	0.50	14.8	4.50	3.30	0.28	Bal

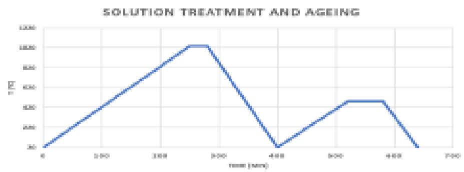

Fig 2.1 Heat treatment temperature vs time graph

3. STATISTICAL ANALYSIS

The bead geometry of each single bead was measured. Then the DoE software was adopted to investigate the effect and interactions of WFS, TS and Current. For the desired bead geometry, two optimised parameters were selected for the small walls, and the wall efficiency was used to determine the parameters for the final wall.

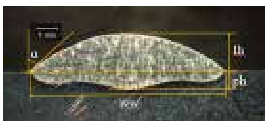

Fig 3.1 Geometry of single bead: α-contact angle, lh-layer height, ph-penetration height, ww-wall width

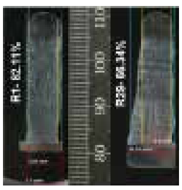

Fig 3.2 Wall efficiency

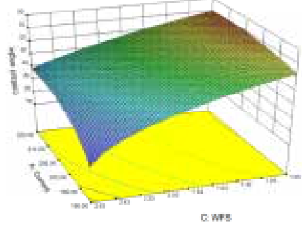

Fig 3.3 Contact angle in 3D surface

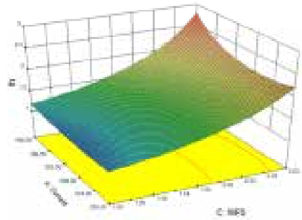

Fig 3.4 Layer height in 3D surface

4.RESULTS

- The overall hardness of the wall (HT) is higher than the wall (AD).
- As for the wall (AD), the hardness value decreases with the increase of layer height.

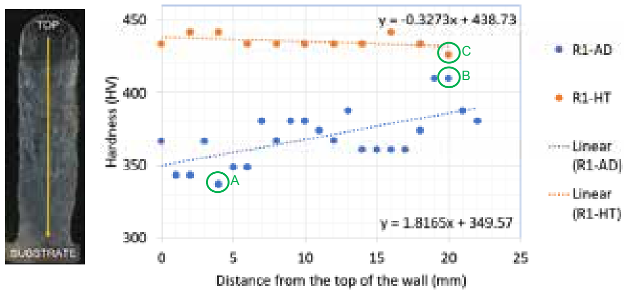

Fig 4.1 Hardness as a function of sample height

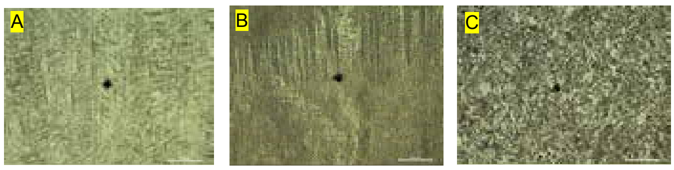

Fig 4.2 Microstructures of selected points (the scale bar is 200 μm)

5. DISCUSSION AND CONCLUSION

- Plasma arc welding based WAAM process can be successfully used to build walls with 15-5 PH SS.
- Partial solutionizing and ageing contribute to the higher hardness of the layers which are closer to the substrate compared with the layers on the top of the wall.
- Solution treatment followed by ageing treatment makes the microstructure uniform and increases the hardness because of the precipitation hardening.
- The tensile test will be carried out later to investigate the influence of ageing on mechanical properties.

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3D Printing of Latex Gloves

Authors: Nicolas Correa, Ségolène Couty, Runze Gong, Eva Peláez

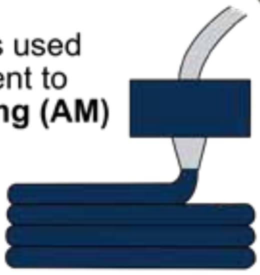
FROM THE RAW MATERIAL ...

LATEX

The latex raw material is extracted from the **rubber tree** and concentrated to form a solution that typically contains 60% of solid rubber latex, that it is later mixed with chemicals to form the **compound** to produce gloves.

3D PRINTING

The term 3D Printing is used extensively as equivalent to **Additive Manufactuting (AM)** and it is the process of joining materials **layer upon layer** to form a 3D object.



A **specialised 3D printer** has been used to develop **novel printing technology** and manufacture latex gloves with **similar mechanical properties and appearance** than those manufactured with conventional methods.

OBJECTIVES

This project stems from the interest of exploring 3D printing technology to create **low cost, sustainable, raw material saving and customised** latex gloves.

- ☑ Obtain a **3D printed latex glove**.
- ☑ For the **medical** field.
- ☑ Viability of the manufacturing process for **customised gloves**.

CONVENTIONAL MANUFACTURING

Latex gloves are currently mass-produced using hand formers and a **dipping process** with several stages. Although it is a process well developed for large scale production, there are important **limitations** regarding the possibility of **customisation,** control over the **quality** of the product and **waste reduction**.

FINAL PRODUCT

... TO THE FIRST 3D PRINTED LATEX GLOVE.

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Optimised process chain for rapid production of CLIC disc

Mr. Hamzah Baqasah, Mr. Jun Xiao, Mr. Jiandong Li,
Mr. Robbie Arhip, Mr. Xiaolong Zhang

MOTIVATIONS

The Compact Linear Collider (CLIC project by CERN) should produce a 100 MV/m accelerating field achieving 3 TeV total energy by 2035.

STATE OF THE ART

2 parts/day
600 euros/part
Diamond machining

Millions of discs
Ra 25 nm
Accuracy A ±4 µm
Accuracy B ±20 µm

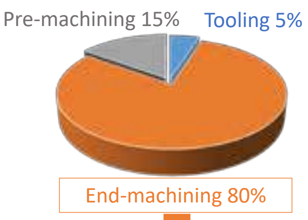
AIM

Optimise the process chain to reduce cost and increase production rate

RESULTS

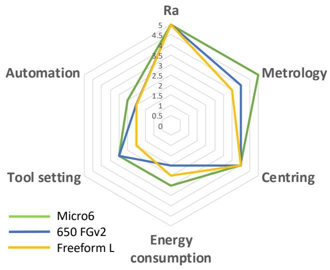
Objective 1: Automation of the current end-machining steps

Cost analysis

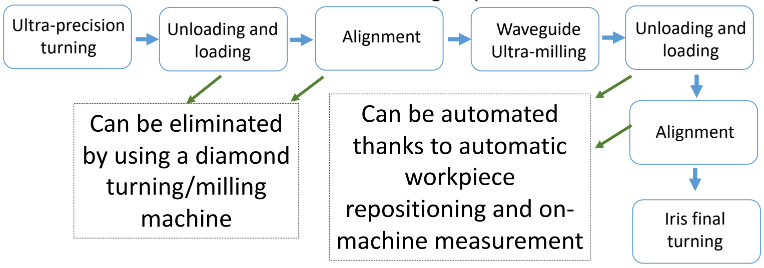


Significant improvements possible

Comparison of 3 diamond turning-milling machines



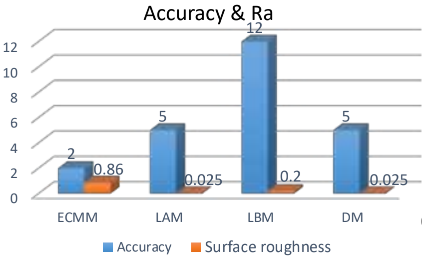
End-machining steps



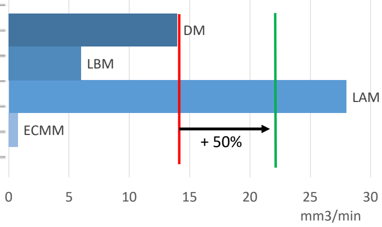
Objective 2: Selection of end-machining process

LBM= Laser Beam Machining
LAM= Laser Assisted Machining
ECMM= Electrochemical Micro-Machining
DM= Diamond Machining

Accuracy & Ra



Material Removal Rate

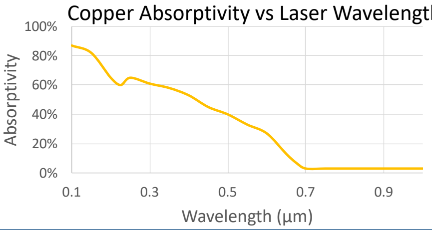


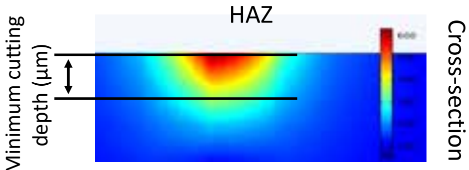
20 processes have been reviewed and evaluated. Only 4 are promising.

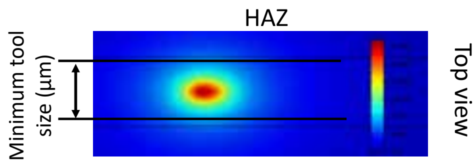
LAM was selected as the cutting depth is increased by heating.

Objective 3: Optimisation of the parameters for the chosen process

Copper Absorptivity vs Laser Wavelength







The impact of wavelength, spot size, scanning speed and power on the cutting depth were investigated.

CONCLUSION

- A new optimised process chain was identified by incorporation of laser assistance to the precision micromachining.
- A comparison of state-of-the-art precision machines reveals that a machine with an automated part loading/unloading will benefit the yield
- An FE analysis was carried out to study the extent of laser heating for evaluating the safe cutting depths during machining.
- Cost can be significantly improved when loading & measurement steps are automated.

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Augmented Reality (AR) Equipped Composites Repair

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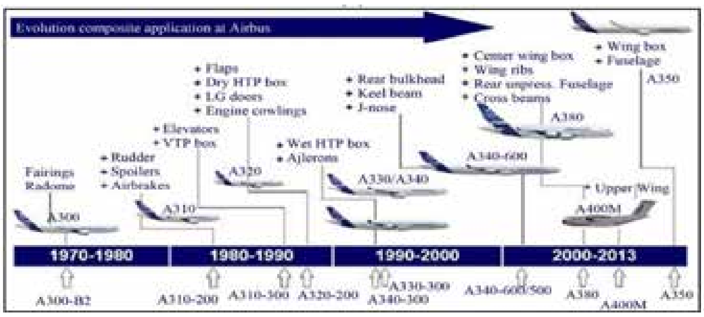
CHALLENGES & OBJECTIVES

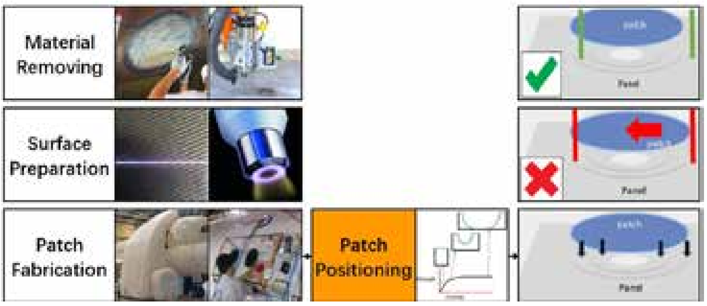


Augmented Reality based toolkit development to facilitate reliable and repeatable aircraft composite repairing processes by providing real-time instructions to operators

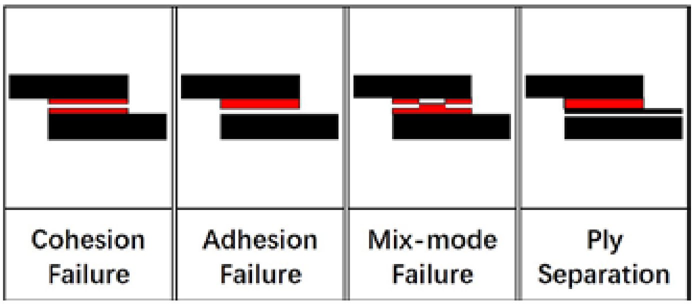
METHODOLOGY

Literature Review	Gap Analysis	Concept Design	Implementation
Defect Type	Demands	Project Scope	Software Selection
Repair Process	State of the Art	Case Design	Terminal Selection
AR Application	Vacancy	Applet Flow	Procedures & Steps

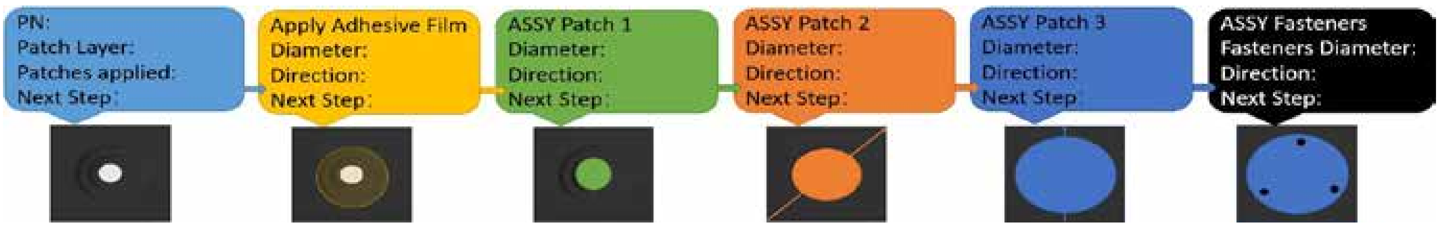
COMPOSITE REPAIR



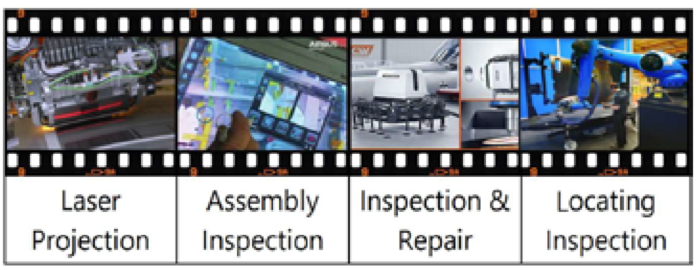
BOND FAILURE MODES



CONCEPT DESIGN



CURRENT AR INDUSTRY APPLICATION



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