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RESEARCH ARTICLE

Engine strip and build lab: a practical approach to learning gas turbine engines

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Abstract
The world is currently undergoing a technological transformation with numerous innovative concepts emerging. This shift is driven by remarkable advancements in artificial intelligence and the urgent need for decarbonisation. With this comes a growing demand for skilled engineers who can actively contribute at any stage within the life cycle of a product. This can be the generation of new concepts at low Technology Readiness Levels or contributing actively to their development and operational safety. This paper explores the integration of a 1-day practical activity to reinforce theoretical concepts learned within a classroom-based environment. Small groups of students were given the opportunity of engaging with a small helicopter engine (Rolls-Royce Gnome engine) through the disassembly and reassembly of the exhaust and power turbine section while following the manufacturer's manual and ensuring industrial norms for safe practice. This hands-on activity included an introduction to tooling, a Gnome familiarisation activity, and an introduction to inspection techniques. Based on the feedback recorded, the students experienced a notable improvement in their basic understanding by effectively reinforcing knowledge acquired within the classroom through active engagement with an actual gas turbine engine.

Nomenclature

PTES	Postgraduate Taught Experience Survey
Engine	gas turbine engine
PBL	problem-based learning
FADEC	full authority digital engine control
IBL	inquiry-based learning

1.0 Background

Traditional learning methods that are based within a typical classroom environment where students are introduced to a significant amount of content, which they are required to assimilate within a relatively short time span. This teaching approach is commonly unidirectional (teacher to student) without major forms of participation from the students which leads to poor information retention, unadaptable to different learning needs and is mostly theory based. However, this approach coupled with alternative learning strategies through class activities which encourages student participation and critical thinking has been shown to promote student engagement and information retention. They were often found to be superior to traditional teaching methods [1]. Laboratory learning is one example of active learning which is particularly crucial in the field of engineering, as it nurtures vital skills like spatial reasoning, innovation and creativity in students before they enter the job market.

This paper is a version of a presentation given at ISABE 2024.

The outbreak of Covid-19 brought about a significant decline in the student experience as teaching styles shifted from traditional face-to-face learning to online platforms. This shift was evident in the Postgraduate Taught Experience Survey (PTES) [2], where students expressed feeling more isolated and less supported compared to previous years. Although overall satisfaction levels eventually returned to pre-Covid standards, this transition provided an opportunity to comprehend and value the impact of in-person learning and promoting student involvement. While digital learning methods and diverse instructional approaches are becoming more popular, it remains imperative to strike a balance by incorporating human interaction and fostering a safe space for students to engage in active learning while being supported, nurtured, and guided through their learning experience. Enabling group activities has the added benefit of encouraging peer bonding, which is quite important at the very beginning. Additionally, pairing groups of students having varying abilities promotes growth mindset which enhances learning and overall experience.

Practical exercises are particularly important in training future gas turbine engineers who often feel the need to see to fully understand and conceptualise theories introduced during classes. The engine strip and build lab was designed with this in mind. It aims at enabling future engineers to inspect and engage physically with an engine. This happens right after the course lectures. Not only does this aid in the improvement of their visual representation of major engine components but also expands their understanding of other aspects of engine design that are not addressed within the classroom such as operability, inspection, maintenance and safety. Safe practice for working within a workshop environment will also be introduced as well as an introduction to tooling. This lab activity aims at filling the gaps between theory and practice and introduce in-service considerations regarding gas turbine operations. The class is split into small groups of maximum four students. This allows less-proactive students to interact with lecturers and provides a safe space for them to explore the inner working and understand the logic that went into the design of an actual engine.

This engine strip and build lab activity takes place over a whole day and follows the taught modules within the MSc in Thermal Power and Propulsion course delivered at Cranfield University. The compulsory modules are listed in Table 1 and happens prior to the group design project and the individual research project. The purpose of placing the engine strip and build lab exercise prior to the start of the engine group design project is to provide the students with the ability to strengthen their understanding of key engine components before being given the opportunity to collaborate in the conceptual design of an actual engine using industrial procedures and in-house engine performance modelling tools (e.g. TURBOMATCH).

The benefits of actively engaging in the learning experience (e.g. class activities, case studies, practical exercises) are well documented. Wrenn and Wrenn summarise well the benefits of integrating theory and practice [4]. They highlight the advantages of active learning in improving student engagement, higher order thinking and providing the opportunity for students to clarify, question, consolidate and appropriate new knowledge and understanding.

Problem-based learning (PBL) is currently addressed during the group design project and individual research project where students actively engage in research activities which includes elements related to the conceptual design of a gas turbine engine. However, most of the students coming from an academic background would not have encountered an actual physical engine. Integrating a real gas turbine engine into the learning environment is not only costly to set up (engine itself and associated specialised tools) but impractical due to its size and weight. Additionally, the overhauling of a whole, small sized, engine would take a specialist teams weeks to complete. This is one of the reasons why it is rare for gas turbine focused courses to include practical activities such as the actual dismantling and reassembly of a gas turbine engine component. A significant number of courses developed choose to provide the students with the means to conceptually design a gas turbine engine using in-house tools [5, 6]. One such 'hands-on' approach was mentioned by Bringhenti et al. where a small industrial gas turbine engine namely the 45 kW Rover IS/60 engine was applied [7]. Students reported that they understood more easily the subjects taught during the lectures after 'seeing and feeling' the hardware. Another laboratory experience involved seeing the running of a Pratt and Whitney PT6A-20 turboprop at a local airfield and after recording key engine parameters, students were asked to model the engine using the various modelling

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Table 1. *Compulsory modules – MSc thermal power and propulsion [3]*

Modules	Aims
Combustors	To make students familiar with design, operation, computation and performance criteria of gas turbine (GT) combustion and reheat systems and to explore issues related to gas turbine pollutant emissions
Engine systems	To familiarise students with engine systems or engine designs for stationary and aero gas turbines and technical reporting by examples and sources systematic analysis
Mechanical design of turbomachinery	To familiarise students with the common problems associated with the mechanical design and the lifing of the major rotating components of the gas turbine engine
Propulsion systems performance and integration	To equip students with background knowledge of aircraft propulsion, component performance integration
Management for technology	Develop interpersonal skills, understand management processes within an organisational context and promote technological innovation and change while remaining within planned parameters of performance
Gas turbine performance simulation and diagnostics	To provide course members with the ability to undertake gas turbine component performance calculations, diagnostics and to perform evaluations of gas turbine performance and deterioration
Turbomachinery and blade cooling	To introduce students to the technology of gas turbine blade cooling through analytical and practical approaches of heat transfer principles, convection cooling, impingement film transpiration cooling and liquid cooling

software available [8]. Although this was less hands-on than the previous case, the students gained an understanding of the differences arising due to theoretical engine modelling compared to actual recorded data.

This paper presents the development a learning activity for future gas turbine engineers aimed at improving their understanding and the overall quality of the course by combining theory and practice. The engine strip and build lab provides a platform to diversify the strategies used in the dissemination of content (problem-based learning, blended learning, active learning) while providing alternative ways of understanding gas turbines. Students can consolidate their understanding of theories learned during lectures and broaden their perspectives to other aspects of engine design, which goes beyond performance and operability. This includes maintenance, inspection, degradation, safety and tooling (naming and usage).

An effective and hands-on method for learning about gas turbines, using the Rolls-Royce Gnome engine, is presented. This learning experience involves actively engaging with the various engine components arranged around the lab. It includes pertinent questions that encourages students to physically investigate and explore the actual engine, followed by detailed instructions and drawings for the disassembly and reassembly of a major component. This practical approach ensures students gain valuable familiarity with gas turbines while enhancing their understanding of the engine's inner workings.

2.0 Engine strip and build lab

The engine strip and build lab consists of a whole day activity where students are introduced to a typical mechanical workshop area and are guided, through a practical activity, to improve their familiarisation of an actual gas turbine engine. The Rolls-Royce Gnome engine, as shown in Fig. 1, is a

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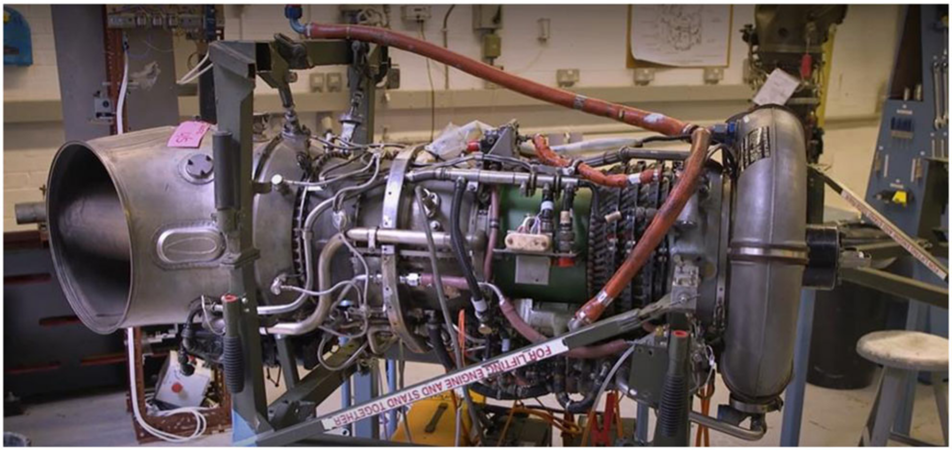

Figure 1. *Rolls-Royce gnome engine installed for demonstration.*

turboshaft engine consisting of a 2-stage turbine driving a 10-stage axial compressor which then powers aerodynamically a single stage free power turbine. The Gnome engine powers the Westland Sea King, Wessex and Whirlwind helicopters. One of its interesting features is that it consists of an axial compressor having one of the smallest manufactured blades within the last stage. Usually, engine manufacturers choose to adopt centrifugal compressors as dimensions reduces due to the impact of tip losses. The students are hence able to get a better appreciation of the impact of compressor tip clearances on engine design and the importance of preventing harsh manoeuvres, which can either lead to compressor tip rubbing or compressor efficiency reduction. It is maybe for this reason that the Gnome engine has a full authority analogue computer as part of the fuel control system to limit fuel flow during harsh acceleration and prevent compressor surge. This analogue computer was the very first developed and is the precursor to the now commonly known full authority digital engine control (FADEC) system.

The advantages of using a Rolls-Royce Gnome engine for this student activity are numerous with the main one being its size (max length of 1.4 m), which enhances accessibility and handling of major components for inspection. For instance, during the engine familiarisation activity, the participants are encouraged to inspect a selection of already disassembled components (e.g. accessory gearbox, driveshaft, combustor liner) to determine their role within the engine and understand design aspects. This includes weight comparison against steel counterparts. Additionally, the integrated analogue computer enables the students to visualise and understand the logic behind the main levers which allows for better engine control and surge avoidance.

2.1 Activities

Before the students come to the propulsion lab, they are provided with pre-work material developed and available within Cranfield's intranet to allow them to assimilate key information which will be used during the activity. It also allows students who have no previous experience within a mechanical workshop to improve their knowledge of safety and tooling. It is also a good opportunity for students who do not speak English as their primary language to have enough time to learn new terms and tool names before coming to the lab. This aims at promoting a culture of inclusivity, allow students of various background to communicate more effectively which leads to more efficient team activities and peer bonding. This also aims at breaking down perceived intercultural boundaries [9]. The online platform also includes a breakdown of the activities included during the day so that students are aware of what to expect. This improves student engagement and attention retention. The online material is provided to students a week in advance and includes a 2 min introductory video about the engine strip and build

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Table 2. *Agenda for the engine strip and build laboratory*

Time	Activity
9:00–9:15	Welcome – H&S brief test area, safety overshoes, feedback form
9:15–9:25	Self-risk awareness
9:25–10:00	Tooling brief
10:00–10:30	Wire locking
10:30–12:20	Familiarisation with the Gnome engine system
12.20–12.30	Planning the strip and build and manual usage
12:30–13:30	**Lunch**
13:30–16:45	Disassembly of exhaust system with power turbine
	Inspection of Gnome and demonstration of borescope inspection
	Reassembly of exhaust system with power turbine
16:45–17:00	Tooling and lab organisation
17:00–17:15	Demonstration, concluding remarks and feedback forms

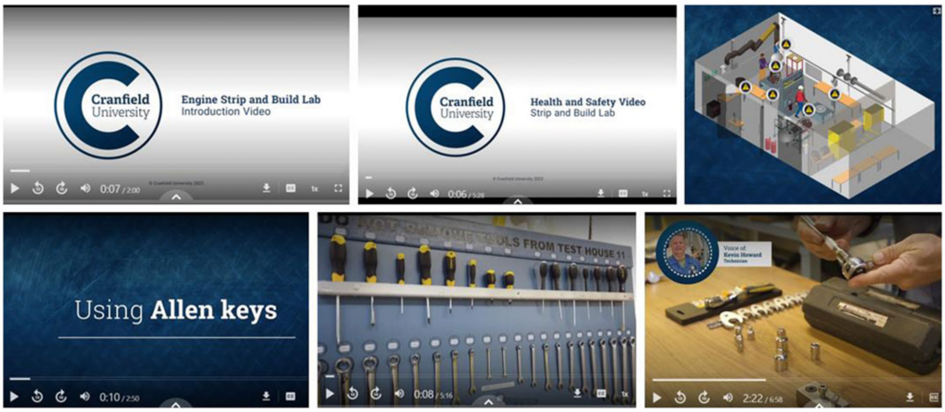

Figure 2. *Snapshots of the online pre-work material.*

laboratory followed by a 5 min video on good health and safety practice while working in a workshop environment. The health and safety segment also includes a small activity, which includes the actual test area where students will be working in and highlighting common hazards. This segment ends with a knowledge check quiz. An introduction to tool use is also included, which not only shows how to properly handle specific tools but also addresses tool naming, units and most importantly identifying the right tool for the job. These are introduced through a series of short videos showing a technical expert explain common tools found in a mechanical workshop. After every short video, knowledge check questions are asked to make sure that students retain the correct information. Although much of the information will be repeated during the day of the activity, it aims at reinforcing this information and allows students to ask questions if they had any while going through the material. An overview of the online content is shown below in Fig. 2. The material itself is broken down into short tasks and a variety of activities as it was shown to retain attention span and improve engagement [10–12].

The day is structured as shown in Table 2. The first half of the day includes going over the online content and making sure that key information was correctly retained. The feedback assessment is separated into two segments. One assesses the improvement in understanding of each student on core theoretical material provided within a classroom-based environment and the other one the overall satisfaction of the activity itself. It also includes a brief risk awareness activity of the lab and tooling brief.

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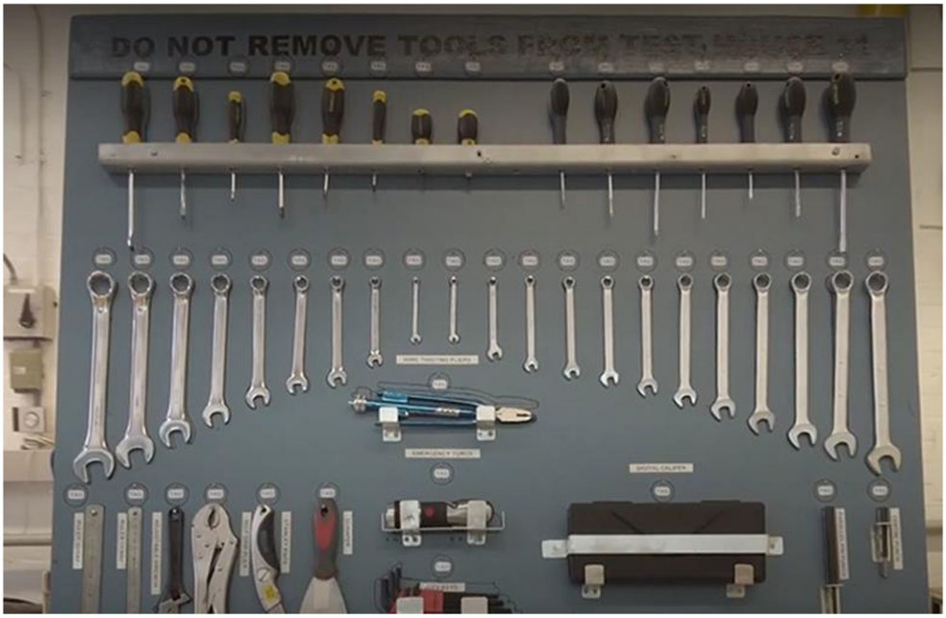

Figure 3. *Tooling stand.*

2.1.1 Tooling brief

This review aims at making sure that each student retained key information from the online material provided. The tooling brief goes even further by introducing small activities that allow everyone to choose the correct tool for the job and handle it properly to avoid wearing and harm. The tools are made available (both metric and imperial) and displayed on a tooling stand as shown in Fig. 3. The main ones explained during this segment includes the following:

1. Types of spanners and determining which one to select for the job
2. Screwdrivers
3. Allen keys and its features
4. Ratchets and sockets including the introduction of selecting the correct size to prevent excessive torque
5. Vernier calliper and using it correctly
6. Mallet
7. Torque meter and importance of selecting the correct torque

This segment is highly interactive as it includes questions based on the online material and small exercises to check whether the correct tool is selected for a specific task. Within this activity, the students will be required to select the correct spanner, which can be done by trial and error or using the digital vernier calliper. They will also be required to use the pliers, wire cutters and wire locking pliers if engaging with wire locking. They might also use the mallet on the bleed pipes (slotted) during the removal and reassembly. The team also introduces the importance of applying bolt locking mechanisms and the different types present within an engine. This paves the way for the wire locking exercise.

2.1.2 Wire locking

Following the briefing on tooling and a summary on how perform wire locking, students are then able to use the different tools available to perform the same exercise. Wire locking is a technique used to

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ensure that nuts remain fastened by securing them with a wire, which passes through two or more nuts and bolts. This is to ensure that if a nut tries to become undone, it will fasten the one attached to it, and vice versa. Based on the location of the wire and bolt size, the choice of material, wire thickness, number of turns per inch all become important design considerations, which are introduced.

The first wire locking trial was attempted manually, using pliers and wire cutters, and the second one using wire-locking pliers. This activity is quite important as it allows students to improve their handling of certain tools but also practice their spatial reasoning ability, which is said to be a significant predictor of overall course grade [13]. Although most students would not be involved in mechanical workshops, it is important to integrate knowledge of tools, limitations and accessibility for ease of maintenance as this an important factor that goes into the design of a new engine. It also allows students to improve their spatial reasoning skills by mentally considering the placement of the wire and the direction of turning of the bolts before performing a specific task as any mistake would reduce the strength of the wire being handled.

2.1.3 Familiarisation with the gnome engine system

Before starting with the disassembling of a major component from the engine, the familiarisation with the Gnome engine exercise was introduced as a form of inquiry-based learning (IBL) activity. This type of active learning strategy encourages students to construct knowledge based on their own understanding while using information acquired during lessons to create subjective realities. Using this form of teaching deep learning is achieved [14]. This is done by encouraging students to improve their understanding of the various components and function of a gas turbine engine by going around the lab and exploring (manual handling and inspection) the scattered Gnome engine parts. This includes the fuel distribution system, electrical harnesses, overspeed trip logic, its connection to the fuel system, rotary and static parts, and inspection of the combustion chamber liner. The students are provided with a comprehensive list of questions to assist their exploration of the Gnome engine. A small extract of is shown in Table 3. The question listed follows a brief description of the main components to provide some useful information to assist with this activity.

During this activity, a staff member is around in case anyone has any questions or to steer the discussion in the correct direction. The answers are reviewed either during the exercise or at the end while ensuring that a clear understanding was achieved. Given that the group of students is small (max 4), this allows for better team learning and fosters a safe environment to ask questions. This not only improves the learning experience but also student understanding of the Gnome engine which will facilitate the actual strip and build activity.

These questions were built to consolidate the individual learning outcomes of the modules presented in Table 1 and integrate aspects related to engine control, inspection, degradation among others. For instance, within the Gas Turbine Performance Simulation and Diagnostics module, the importance of modifying the variable guide vanes to improve part-load operability is introduced and the shift of the operating line on the compressor map is provided. With the familiarisation activity, students are encouraged to manually vary the variable stator vanes, understand how they are mechanically coupled together, see the direct connection to the fuel supply, and finally by looking at the opening angles understand the impact on the engine's flow capacity. Similarly, the different aspects which are introduced within a classroom environment are explored further with the benefit of having actual engine components to visually correlate theoretical concepts. To enable the students to freely explore the lab, it was rearranged in distinct areas namely one for the actual disassembly and reassembly of the exhaust, the tooling stand, the fuel and lubrication components, the components within the main gas path (rotors, stators, combustor), structural elements (disk and casings), a demonstrator engine and space to write.

2.1.4 Quality and documentation

Before each group starts with the removal of the exhaust assembly, they are introduced to the engine's maintenance procedure which includes the procedures and checklist provided by the engine

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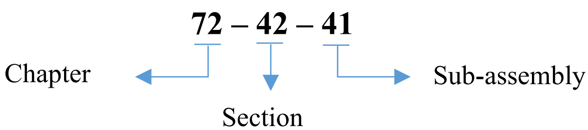
Table 3. *Questions asked during the Gnome engine familiarisation activity*

1. Identify and locate a rotor of the axial flow compressor. Measure the interstage distance between the exit of the 1st stage (trailing edge) and the inlet of the 2nd stage (leading edge). Repeat the procedure between the last stages of the same rotor. Are differences notable? Measure the chord of any blade from the 1st stage and compare it with the chord of any blade from the last stage. Are differences notable?
2. Please identify and locate an accessory drive casing (handle with care). Manually spin the accessory drive shaft and comment on the observed rotational speeds in each outlet. Could you identify which spline output belongs to which subsystem?
3. The variable stator vanes are linked by a scaled rule. What is the purpose of varying stator vane angle settings?
4. Examine the rotor of the power turbine and 2nd stage turbine of the gas generator. Are the differences notable?
5. Inspect the condition of the tips of each turbine rotor (gas generator and power turbine). Can you identify signs of wear? Discuss within your team about the typical mode of failure within a turbine blade.
6. Identify and locate an exhaust casing of the power turbine. Carefully inspect this casing and take note of its weight and internal condition. A central hub is supported by four hollow struts. Can you guess the functionality of this hub?
7. The combustion system of the engine is a single annular-type combustor with simplex burners supplying fuel via two manifold assemblies. How many igniters plugs provide ignition? ____
8. Please select one to Gnome assemblies and carefully observe the air bleed system. The axial compressor of the gas generator has three (3) air bleeds: 4th stage, 6th stage and 10th stage. Following the hoses fitted around the engine, where are each of these air bleeds directed and why?

manufacturer. To this end each group is provided with the technical manual, which includes detailed instructions with exploded diagrams on the disassembly and reassembly of the exhaust nozzle and power turbine. The drawings are labelled according to the ATA 100 numbering system [15], which is a common referencing standard for commercial aircraft documentation.

For example, a basic chapter will be defined as:



In this case,

72 Engine Chapter
42 Combustion Section
41 Combustion Chamber Liner

Based on this, each student can retrace back the item number within the mentioned sub-component assembly. The manual itself has been condensed for ease of use. A designated member of each team is responsible to date and sign a checklist which falls in line with current industrial practice and quality assurance within aviation. That person is responsible in ensuring that every single task on the checklist is done correctly. After completing a specific task, the supervising staff will check the completed task and ensure that it was completed correctly.

The tool tagging system is also used. Each student is assigned a tag number, which needs to be placed at the location of each tool which is removed from the stand. This not only ensures safe practice

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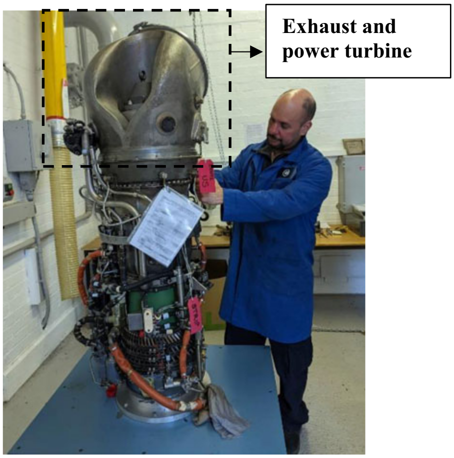

Figure 4. *Gnome engine secured on stand for disassembly.*

but accountability of every piece of equipment used, which is critical within aviation. It is beneficial to inculcate quality assurance and industrial standards at an early stage due to its safety implications. While most of the engine manufacturing process has been automated, overhauls and inspections are still performed manually which are more prone to human errors. Although its reduction is part of the engine design considerations, it cannot be eliminated completely. This is why there are detailed guidelines and procedures put in place to minimise those errors and ensure that the highest levels of rigor and safety is achieved.

2.1.5 Engine strip and build

Within this activity, each student has the opportunity of applying knowledge acquired and described in previous sections. The purpose of this exercise is to provide the experience of engaging with the dismantling, inspection and reassembly of a major component of a gas turbine engine. In this case it is the exhaust and power turbine. It also aims at making each student aware of the practical challenges of this activity in a real life.

The engine is already assembled on a stand as shown in Fig. 4. The exhaust and power turbine assembly are at the very top end. The aim for the disassembly is to safely secure it on a stand before inspection. Before starting any task, the students are prompted to visually match the actual engine with the drawings provided and to identify the main components and pipes attached to the exhaust. Not only does this improves the execution of this exercise but also stirs the team in the correct direction.

Some of the major sub-components that need to be removed are the oil vent pipes, cooling air pipes and overspeed trip governor. The electrical harness cables are also disconnected before the crane is attached to the exhaust system and preloaded. The bolts and nuts surrounding the casing are removed. The lifting operation is performed by the supervising staff and directed by the students to safely secure the exhaust and power turbine on a stand. Inspection is then performed which is further explained within the next section.

Detailed instructions for the reassembly are also included within the manual and students are also expected to fill in the checklist after completing a specific task. Usually, the reassembly is performed faster than the disassembly; however, there are potential areas for errors. For instance, lengths of certain bolts attaching the exhaust to the rest of the engine are of different lengths for a specific reason and their position is provided in the exploded diagram. It is a good learning activity and brings forward the importance of following the instructions provided and the reasoning behind every design choice.

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2.1.6 Inspection

The disassembly of the exhaust allows the inspection of the power turbine rotor and stator blades. Within this segment, students are introduced to various inspection techniques including borescope inspection. Following a brief introduction on the capabilities and usage of a borescope, students are then able to inspect components further down the engine such as the 2nd stage rotor blades and the state of the thermocouples surrounding the inlet of the power turbine. They are also prompted to inspect for any severe discoloration, damage and presence of excessive soot. To accompany this exercise, a video of an actual borescope inspection conducted within a combustor was shown and the various capabilities of the borescope highlighted. This includes the ability to measure the length of cracks and perform quick inspection without the need for significant engine disassembly.

2.1.7 Demonstration

The activity is concluded by a staff member performing the final inspection of the assembled Gnome engine and collecting the checklists. Tools are returned to the rack and a separate Gnome engine is started through the starter motor. The engine goes only through the starting phase and shut off. Combustion is not initiated. This is performed to enhance the experience of students who never saw an engine running in real-life and bring to a nice conclusion the engine strip and build lab.

3.0 Feedback

The feedback activity is performed to assess whether this learning experience consolidated and improved upon previous knowledge acquired during lectures. This is also an opportunity to see if students merged theoretical concepts with actual engine geometry. This is important as being able to mentally visualise a component not only reinforces understanding but also opens the way for creativity and problem solving by improving spatial reasoning skills. The feedback forms were divided into three different questionnaires. One questionnaire assesses the current understanding of basic concepts taught in classrooms, and another questionnaire allows students to add on to their previous responses based on lessons learned during the strip and build lab activity. The third questionnaire is a typical one that gauges the level of satisfaction with the activity itself, online content, delivery, structure and recommendations. The responses are grouped based on the level of experience and age.

The total number of participants totalled 53 with an average of 4 students per group. The activity was held from the end of June to beginning of July 2023. The average age range was between 20 and 25 with students having limited experience within a typical workshop environment. At the end of the strip and build lab activity, 85% of students were pleased with the activity and gave it a score of 5 (max possible) with the rest of those involved giving a score of 4. All the participants reported that their understanding of the inner workings of a gas turbine engine improved during this activity with 77% reporting a great improvement. This was shown within the feedback form 1 where the answers to the same theoretical questions asked improved compared to the form filled during the start of this activity. However nearly everyone reported that one day is not enough to fully explore an engine and retain information. Also, many students showed interest in disassembling more of the engine. Those recommendations will be implemented for later cohorts. Some student comments are shown in Table 4.

4.0 Conclusion and future work

The merging of theories learned within a classroom environment with practical exercises involving a real gas turbine engine not only reinforces knowledge previously acquired but extends it by improving the mental representation of the various components within the engine. Students are introduced to a workshop laboratory environment and understand the safety implications. Most of the future engineers coming to Cranfield to study for a master's degree in thermal power and propulsion have limited

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Table 4. *Student feedback on the engine strip and build lab*

1.	Very well coordinated activity. I appreciate staff support throughout the activity.
2.	Nice activity, keep it going
3.	This session was great but can be done more than once. Overall great experience.
4.	I would recommend providing this lab session often in the future for students to familiarise themselves with all the GT engine components. After every module like compressor and turbine etc, introducing actual engine components is very useful in understanding things and being confident in all the courses.
5.	I recommend the lab for future MSc students.
6.	More practicals like this please!
7.	Great experience!
8.	This course is really amazing, but this workshop made me realise that we need to experience this practical knowledge along with the modules. This helped me understand better the working principles of a gas turbine engine.

knowledge of being in a workshop. This is a good opportunity to introduce them to tool handling and usage which they will need to apply during the strip and build activity. Through the inquiry-based learning, they need to answer key questions which helps build on their current understanding by exploring the various components of the engine, which are scattered around the lab. This includes the fuel distribution and rotary components. By improving their familiarisation with the Gnome engine, they become also aware of the design considerations that are not limited only to improving the performance and emission of an engine but also operability, ease of maintenance and inspection namely borescope. Everyone involved were happy with the activity and reported that it greatly improved their understanding of a gas turbine engine. It is quite rare to integrate this form of learning within a gas turbine course due to the cost and logistics involved. However, it was found to be extremely beneficial in reinforcement learning, improving critical thinking and introducing design for maintainability into the curriculum to provide future engineers with a holistic approach to engine design.

Looking ahead, the strip and build laboratory allows for in-depth exploration of a small gas turbine engine in real-life, which can be beneficial in the future development of continuous professional development courses for both Cranfield and beyond. It is essential to recognise the importance of nurturing a new generation of engineers who can tackle the pressing demands of sustainability and contribute to the continuous development of new engine concepts. The incorporation of practical, hands-on experiences, like the Gnome engine workshop activity, serves as a model for effective education and training methods, laying the foundation for a more sustainable future in aviation. This is crucial as it will bring large and continuous streams of new talent to accomplish changes during aviation's third revolution sustainably while working towards achieving zero carbon emission and meeting the growing demand for air transport.

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