ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #38083

Student Paper: Engine Wash and Sustainability in an Engineering Technology

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Abstract

Aviation has become a trusted forefront and reliable mode of transportation for both people and goods. In recent years, the rapid growth of the air transport industries has also increased International Civil Aviation Organization (ICAO) and the United Nations (UN) attention to sustainable aviation. In alignment with ICAO's promotion of sustainability actions and plans, this paper explores the impacts of aircraft engine washes, not only in terms of technical impacts but also environmental impacts.

This paper describes the education environment and inclusion of engine washing technologies in courses. To enable students to more fully understand aviation sustainability, one way that might be effective is to combine practical and technical knowledge. Therefore, aerospace and aeronautical education environments need to teach students practical engine washing technologies and the sustainability impacts. This paper may be useful in educational environments as a starting point of including both practical and sustainability knowledge in courses.

Keywords: aviation, engine wash, carbon footprint

Introduction

Air transport is taking a significant part of the transportation category. ICAO is a multilateral agency that focuses on global aviation harmonization [1]. In 2010, ICAO adopted two goals: "to continuously improve CO2 efficiency by an average of 1.5 per cent per annum from 2009 until 2020, to achieve carbon neutral growth from 2020 and to reduce its carbon emissions by 50 per cent by 2050 compared to 2005 level" [2], [3]. To fulfill the ICAO projection, there are four main strategies: aircraft technological developments, optimization of aircraft operation plan, adopting sustainable aviation fuel (SAF), and market-based measures to promote aviation sustainability growth [2].

Fuel consumption is directly related to carbon dioxide equivalent (CO_{2e}) impact on the environment in terms of Global Warming Factor. Transport category aircraft are currently dependent on jet fuels such as Jet A and Jet A-1. For Jet A and Jet A-1, the CO_{2e} emissions factor for ICAO is 3.18 kg CO_2 per kg of fuel consumed [4]. Several types and brands of SAF are available, but not at the level needed to replace the demand currently on traditional jet fuel from petroleum sources. Therefore, improvement of the aircraft operation efficiency is needed in the short-term. Engine wash technology is effective in reducing fuel consumption as well as emissions. New fuels and technologies are effective, and require a longer development process, approval and implementation process, and a higher investment cost.

Considering the aggressive goals for aviation, aviation students need to be equipped with theoretical concepts and practical information about environmental sustainability issues.

Problem Statement

The aim of this study is to examine the curriculum in a current engineering technology (ET) program as it relates to engine wash technologies and associated sustainability impacts. A connection to ABET EAC and ETAC criteria are identified.

Sustainability in the Aviation Industry

The term sustainability was very well related to the ecological concept, but now it has developed into many aspects in society and its definition is getting more complex and comprehensive [5]. The United Nations (UN) has set the 2030 agenda for sustainability future in all aspects which consists of 17 Sustainable Development Goals (SDGs) and 169 targets. This SDGs covers 5 main groups; people, prosperity, planet, peace and partnership [6].

Sustainable air transport implies its persistent development, adding benefit to the social-economic impacts while at the same time alleviating its adverse social and environmental consequences costs [4]. It includes taking into account the amount of greenhouse gas emissions (such as CO_2 and NO_x gases) and how efficient the energy consumption is from fossil fuels. ICAO is currently working on issues related to the adaptation to climate change impact which is addressed in UN SDG 13, mainly to meet the global aspirational goals of a 2% annual fuel efficiency improvement, and carbon-neutral growth from 2020 and to reduce the carbon emissions by 50% by 2050 using 2005 as the baseline [3], [7].

ICAO has formulated The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to curb the aviation impact related to CO_2 emission on the environmental in order to achieve goal of carbon-neutral growth from 2020 onwards. ICAO member states in CORSIA necessitate their airline operators to comply with this CORSIA offsetting agreements each three years [7]. According to CORSIA, there are four measures on how to cut international aviation net CO_2 emissions in the aviation sector [2]:

1. Operational Improvements
2. Aircraft Technology
3. Sustainable Aviation Fuels
4. Market-based Measures

Aviation industries and national organizations have highlighted the carbon footprint of engine operations. Improvement of the aircraft operation efficiency is the most feasible effort that can be implemented quickly even though the impact is not as big as the development of new technology and the implementation of Sustainable Aviation Fuel (SAF). One way to reduce the environmental impact is to regularly perform on-wing engine wash because it increases engine efficiency and reduces fuel burn. Engine wash supports sustainability as it is used to improve

engine operation efficiency, extending Time On-Wing (TOW), and reducing engine degradation [8].

Sustainability in Education

Education is crucial in shaping the human mindset and a sustainable future. Reorienting the curriculum and developing the knowledge, values, attitudes, and skills should be included in courses that include the sustainability aspect [5]**.** The role of the university system can be the primary contributor to society's sustainable development by enhancing their social and behavioral impact and decreasing the environmental impact [9]–[12]. The role of the university system can be the primary contributor to society's sustainable development by enhancing their social and behavioral impact and decreasing the environmental impact [5]. The university system is expected to be able to answer these challenges and play an important role in solving key sustainability issues through graduates who have the necessary attitudes to act as agents of change in a global society [13]. In the aspect of sustainability in aviation education, insight can be drawn from various disciplines, however, interdisciplinarity can enhance the ability to solve current problems and complex challenges in the future. Based on the study done in [5], sharing ideas, knowledge, and experiences is the most effective way in delivering sustainable education, followed by creativity, interdisciplinary and multicultural courses.

ABET-EAC has criteria that apply to all accredited engineering programs. ABET student outcomes in [14] criteria 3 part 2 states, "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." This criterion is very aligned with sustainability issues in the aviation industry. In ABET accreditation criteria for Engineering Technology Programs, criterion 5 discipline specific content curriculum states " …must include design considerations appropriate to the discipline and degree level such as: industry and engineering standards and codes; public safety and health; and local and global impact of engineering solutions on individuals, organizations, and society." It is clear that educational programs need to address social and environmental issues in their curriculum as one of the requirements for accreditation assessment [14].

Engine wash plan in Aviation Industry

Aviation Transport Action Group (ATAG), an industry group, stated: "Aviation is responsible for 12% of carbon emissions from all transport sources, compared to 74% from road transport" [15]. In order to contribute to the organization's promotion of a carbon-neutral plan and annual 2% reduction in fuel consumption, the industry has addressed innovative engine wash technology and contracted with specialized engine wash suppliers. Even though the industry is looking to improve engine operations, the actions of each company may not be exactly the same

Table 1. Summary of Industry Perspectives Toward Sustainability

Engine Manufacturer	Action Description	Positive Perspectives

Pratt & Whitney (EcoPower) [16]	“When it comes to maintenance, P&WC offers customers access to the eco-friendly EcoPower Engine Wash system. The system, which was developed as a joint venture between VT Systems and Pratt & Whitney, is a closed-loop process that does not require detergents. The wash cycle restores degraded engine performance, resulting in up to 30°C cooler exhaust gas temperatures and an impressive 1.8% reduction in thrust-specific fuel consumption. EcoPower washes are available for many of P&WC’s engines.”	“P&WC knows that sustainability is a team effort and is playing an active role in encouraging the industry to adopt practices that reduce environmental impacts. One of the company’s priorities is showing its appreciation for suppliers and partners who are embracing sustainability...”
General Electric [17]	“360 Foam Wash is now approved for use on engines including the GE90, GEnx, CF34, and CF6, as well as the Engine Alliance’s GP7200 engines, which serve on large Airbus A380 double-decker jets. At the Dubai Airshow his week, GE Aviation announced the 360 Foam Wash program has reached 1,000 washes of engines in the field since 2017.”	“Now, after a lot of study and testing, GE engineers who designed and built those engines think they’ve hit upon a novel way to reverse the effects of the sands of time. Called GE’s 360 Foam Wash, the powerful approach thoroughly cleans a commercial jet engine, helping to improve its performance and potentially eliminate tons of climate-damaging CO2. “Regular washing can help prevent the buildup of difficult to remove contaminants that often form on the back stages on the compressor”
Rolls-Royce (Cold Jet) [18]	“Rolls Royce, a manufacturer of gas turbine engines, was using a manual cleaning process to remove the buildup from titanium compressor blades. It required workers to scrape and scrub the blades with a combination of water and other cleaning chemicals. This method was time consuming, labor intensive and had the potential to damage the blades. It was also hazardous to the personnel who performed the cleaning. Compressor blades have very sharp corners and the workers were at risk of being injured. As a result,	“By using the Cold Jet automated cleaning process, cost savings on compressor rotor blade cleaning improved by 90% and the module/component turn time improved 84%.” “Rolls Royce eliminated the use of chemicals in the cleaning process and

	Rolls Royce began to explore alternative cleaning methods." "U.S. Rolls Royce tested Cold Jet dry ice cleaning and found that the effect of the process on the material microstructure was minimal. After the successful tests, dry ice cleaning was approved to be used in the cleaning of the compressor blades. Cold Jet's dry ice cleaning system uses non-abrasive media in the form of recycled CO2 pellets that will not damage surfaces or equipment. The combination of dry ice cleaning's kinetic energy and thermal effects break the connection between the dirt and surface, lifting away contaminants."	decreased employee exposure to harmful chemicals. Dry ice cleaning also made the cleaning process safer for their employees. They can stand at a safe distance and clean the blades without directly coming into contact with them. The company also utilizes dry ice blasting to clean the compressor rotor between the blades, the compressor guide vanes, stators and casings."

Summary of Industry Engine Wash Technologies

Engine wash is part of *operational improvement* action to reduce engine emissions. The aviation industry understands that completing engine wash will have positive outcomes such as aircraft operational costs such fuel-savings, eco-friendly-low carbon emissions, and maintenance frequency saving. Engine manufacturers and Maintenance Repair & Overhaul (MRO) have contracted with engine wash equipment providers such as EcoPower and Cold Jet, and General Electric has proprietary engine wash technology, which is called 360 foam wash. In addition, MRO companies are actively researching and testing optimization of engine wash, mainly considering environmental sustainability; Not only the aviation industry (Airlines, Engine manufacturers, MRO) need to consider the environmental sustainability of engine wash, but also consider the safety, reliability, and quality of cleaning that is no side effect to engine operation.

The principal target for engine wash is to remove foulant inside the engine. The engine foulant is a significant attributor around 70-85% of overall performance loss [19]. Depending on the engine's operating hours and regional flight conditions, engines are subject to build undesirable fouled compressors that provide rough surfaces on rotors and stators [20]. The built foulant inside the compressor disturbs the designed isentropic efficiency, lowering the engine's maximum output performance or consuming more fuel to achieve the desired power.

Manual cleaning is an effective way of cleaning; however, the engine has to be shut down. In order to clean with brushes and washing agents, the engine has to come off from the wing and needs to be overhauled and cleaned per the manual. The major disadvantage of manual cleaning is low efficiency, considered time consumption. The Grit Blasting is an old-fashioned engine wash technique known as abrasive cleaning; wash conducted natural resources such as rice, nutshells, and synthetic resin particles. However, abrasive techniques' disadvantages have arisen and gradually disappeared as new cleaning technologies are adopted [20]. Not only does the

development of the new cleaning technologies take over old abrasive technologies, but they also offer adequate skills to advanced engines involving sophisticated design and sensitivity and are responsible for operational safety, reliability, and optimum efficiency [21].

Engine wash effectiveness is widely studied and tested. These positive outcomes that will be expected:

- Engine TOW last longer
- Eco-friendly, environmental sustainability
- Less fuel burn = operator perspective, economy efficient
- Less maintenance

Drawbacks of engine wash performance:

- Considerable consumption of water
- Using a high level of toxic chemicals to dissolve foulants = non-environment friendly in terms of engine wash performance-wise
- A significant amount of safety and reliability tests needed may occur side effects on blades such as corrosion, stress, scratches, and weak spots.
- High cost for engine wash equipment

Aspect Addressed

ABET-ETAC Criterion 3. B (student outcomes) mentions "for baccalaureate degree programs, these student outcomes must include but are not limited to, the following: (1) an ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly defined engineering problems appropriate to the discipline; (2) an ability to design systems, components, or processes meeting specified needs for broadly defined engineering problems appropriate to the discipline; (3) an ability to apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and ability to identify and use appropriate technical literature; (4) an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes; and (5) an ability to function effectively as a member as well as a leader on technical teams" [14].

Aligning the ABET-ETAC Criterion, current aviation industry trends that contribute to reducing carbon footprint, and ICAO's goals toward sustainable aviation, one of the operational improvements efforts to cut net CO2 emissions is by performing aircraft engine wash. Teaching the engine wash method in the ET program class, which aims not only to explain the goal of recovering engine performance loss but also to describe a broader view as a measure to reduce carbon emissions, is essential. This lesson will open students' insights regarding sustainable aviation future.

Current ET Course Objective

According to discipline-specific content point D in "Criterion 5. Curriculum ABET-ETAC", the ET program curriculum needs to address "public safety and health; and local and global impact

of engineering solutions on individuals" [14]. One ET program at a major university has the potential to provide students instruction and development in the area of operational improvements in reducing net CO2 emissions. This program has an aircraft gas turbine engine technology course that covers a basic understanding of turbofan engines and systems, performance evaluations, operational efficiencies, and fault isolation of engines. One of the course goals in the syllabus mentions that "The students will learn to inspect, check, service, troubleshoot, and repair turbine engine airflow, pressure, and temperature measurement systems." In addition, the learning objectives section explicitly states that the students will learn: "Turbine engine condition monitoring and the interaction of engine parameters, troubleshooting, and turbine engine efficiencies." Nevertheless, this course has not explicitly taught how the concept of machine washing is related to sustainability and how to perform engine wash practically yet.

Even though the engine wash task is a paramount practice in terms of aircraft operational improvement to sustainable aviation for the ET program, The university or school has faced some hindrances such as the need for engine wash equipment which is quite costly, resources, and facilities are inadequate. Hence, in this course, practical activities cannot be demonstrated directly to students, and it is necessary to have other methods that are not only effective but also efficient.

Additional ET Course Activity

The ET course activity is designed for junior-senior level undergraduate students in engineering technology programs following to ABET-ETAC educational objectives standard. In the class, lecturer will have two sessions to discuss the concept of engine water wash. The lecturer must be able to explain that the concept of doing an engine wash is an effort to reduce carbon emissions in sustainable aircraft operations. A general overview of ICAO's commitments related to environmental protection can be the opening topic of discussion. Then, it can be continued with a topic about how aircraft operational improvement through an engine wash task can contribute to that commitment. Lecturers can also provide general procedures for performing engine wash on aircraft. The researcher in this study proposes an example of lecture slide that talks about engine wash (see Appendix A).

After lecturers discuss the general concept of engine wash and ICAO's 2050 goal, students will have an assignment to watch on how to perform engine wash videos based on the URL links provided in the slides. These links are from MRO and engine wash equipment manufacturers that released video of procedure to perform engine wash. Students will get indirect experience to know the procedure and what things need to be considered while operating the engine Some of these videos are old-fashioned skills, in which the sustainability aspect is not included. Others will include cutting-edge technology and consider the environmental aspect. These two kinds of videos would help students understand how recent and past engine wash technologies have developed. The assignment is a group project for two weeks during lecturer covering engine efficiencies, propulsive efficiency, cycle efficiency, and combustion efficiency.

A group of 4-5 people assigned to work together on making a maintenance manual based on what they see in the video. Students are allowed to see some older versions of the Aircraft Maintenance Manual (AMM) in the library to help them make their maintenance procedure. The task is intended so that students can increase their critical thinking skills regarding what procedures must be carried out in doing engine wash and what important things are the goals of this engine wash task. After two-week periods, each group will present their maintenance manual, limitations of maintenance manual, and aspect of sustainable aviation. Through this project activity, students would be able to understand the broad concept of greening aviation technology and apply it to their engineering technology skill set. This method is expected to be an effective and efficient learning process to instill a sustainability mindset in students.

Assessment

To assess the group assignment, students' work will be graded based on the project's rubric. The total score will be 100 points which consists of 80 points for maintenance manual completion and 20 points for presentation task. Lecturers will assess the students' work on maintenance manual based on aspects of the accuracy of operational considerations in developing the maintenance manual, sustainability aspect, safety considerations, and rationality aspects of explaining the engine water wash task.

Table 2. Maintenance Manual Rubric

Maintenance Manual Grading Rubric	**Score**
Coherent and sequential steps	20
Addressing environmental issues	20
Safety considerations	20
Procedures are logical and well explained	20
Total	80

Conclusion

The need for sustainable aviation has been being emphasized since 2005 and still needs a significant amount of effort to reduce 50 percent of carbon emissions. The paper proposed the additional activity in the ET course regarding ICAO sustainable aviation goals in 2050 and ABET-ETAC criteria. Engine wash lesson as a measure in operational improvement scheme in CORSIA will need to be included in the current ET curriculum even though it cannot be taught practically. A brief overview of engine wash as an effort toward sustainable aviation and assignments for students to work in groups and study independently, researchers expect the course material will be able to sensitize students' thoughts on the importance of environmental aspects consideration in the future of aviation.

Sustainable Aviation Effort: Aircraft Engine Wash

This presentation is made to show an example of lecture slides

Purpose of Engine Wash Performance

- Clean the external and internal engine airflow components for performance recovery.
- Remove foulant inside the engine. The engine foulant is a significant attributor around 70-85% of overall performance loss [1]
- Common procedure in Aircraft Maintenance Manual (AMM) for aircraft maintenance practice

What is engine wash?

"Gas turbines draw huge amounts of air per unit of time and are thus subject to particles forming an undesirable coating, primarily in the compressor. This reduce compressor efficiency and disturbs the air flow through the engine, causing increases in fuel consumption, temperatures, and emissions" [2]

"The effect of compressor fouling is a drop in airflow and compressor isentropic efficiency, which results in a "rematching" of the gas turbine and compressor causing a drop in power output and thermal efficiency" [1]

Sustainable Aviation

-Aligned with **ICAO** commitment related to environmental protection [3],[4]:

- continuously improving CO2 efficiency by an average of 1.5 % per annum from 2009 until 2020.
- to achieve carbon neutral growth from 2020 and to reduce its carbon emissions by 50% percent by 2050 compared to 2005 levels.
- improving fuel efficiency 2 per cent annum from 2021 to 2050 (volume of fuel used per revenue tonne kilometre performed)

- **ABET-ETAC criterion 5.** curriculum; discipline specific content (D):

Include design considerations appropriate to the discipline and degree level such as: industry and engineering standards and codes; **public safety and health**; and **local and global impact** of engineering solutions on individuals, organizations and society [5].

General Procedures

- Make sure the aircraft is in standard configuration for maintenance
- Prepare the engine water wash cart with water (or cleaning agent solution)
- Install the engine wash equipment probes
- Make sure the aircraft bleed system is turned off
- Dry motor the engine
- Start the water wash pump at a predetermined water rate
- Inject the water until the tank is empty, turn off the water wash pump, then stop dry motoring

*Remarks: highly encouraged to use resources that available in Purdue Airport Library e.g. different manufacturers AMM

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Example Engine Wash Videos

***This slide is just an example. Permission to use these videos in class or online should be obtained before use.**

- P&WC: https://www.youtube.com/watch?v=pPxC83dMnQc
- Lufthansa Technik Group;
  a. Cyclean Engine Wash: https://www.youtube.com/watch?v=nLHFdg8MBS8
  b. cycle 2.0 : https://www.youtube.com/watch?v=YTJp1x1suW8
- Southwest Airlines: https://www.youtube.com/watch?v=JvdK46bcqzc&t=72s
- 737NG engine wash: https://www.youtube.com/watch?v=YAeG2VcTXtg&t=410s
- Cessna: https://www.youtube.com/watch?v=VWX7HU-yGnk

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Group Assignment

1) 4 -5 students in one group
2) Each student should watch engine wash videos
3) Each group will create and develop engine wash procedures (80 points).It should include:
   a) coherent and sequential steps
   b) environmental aspect
   c) safety aspect
   d) Logical and well explained procedures

1) Presentation (20 points), includes:
   a) limit & challenges
   b) other ways to contribute in future sustainable aviation

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