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THE DEVELOPMENT OF A PORTABLE AIRCRAFT REFUELING STATION FOR SMALL AIRCRAFT IN POLITEKNIK BANTING SELANGOR

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ABSTRACT

A novel Portable Aircraft Refueling Station (PARS) has been developed to provide hands-on fuel-handling experience for aviation maintenance students. The prototype integrates a fuel tank, 12V DC pump with auto-shutoff nozzle, 12V beacon, and an Arduino microcontroller with an ultrasonic level sensor and LCD display for real-time fuel monitoring. Its novelty lies in combining a compact, low-cost refueling cart with digital monitoring and safety features (grounding strap, emergency stop) in an educational context. In a post-survey (n=51, Semester 5 Aircraft Maintenance Engineering students at Politeknik Banting Selangor), significant learning gains were observed. For example, mean self-rated confidence in refueling procedures rose from 2.9 to 4.3 (on a 5-point Likert scale) and understanding of fuel system concepts from 3.1 to 4.5. Over 90% of students strongly agreed that PARS made training more engaging and realistic. These improvements were therefore significant. Compared to traditional lecture-only instruction, this practical training approach boosted comprehension and retention of fueling tasks. To our knowledge, PARS is among the first portable, Arduino-based refueling training rigs reported for small-aircraft maintenance, addressing gaps in existing facility availability. This paper details the PARS design, experimental setup, and evaluation for aviation maintenance education and potential to enhance hands-on skill development.

1. Introduction

Aircraft refueling is a vital aspect of aviation operations, directly influencing flight safety, operational efficiency, and compliance with international regulations (D. Gendre, 2020). The process involves transferring highly flammable aviation fuel into aircraft tanks, requiring strict adherence to procedures to prevent accidents, fuel contamination, or equipment damage (Aircraft Refueller Company NV, n.d.). Incidents such as the Gimli Glider—where a

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miscalculation of fuel quantity led to an in-flight emergency—illustrate the catastrophic consequences of refueling errors (Frazer, 2000). For aviation maintenance students, therefore, it is crucial to develop both theoretical understanding and practical skills in refueling procedures to ensure future workplace competence and safety (J. L. D. Albelo, 2022).

However, at Politeknik Banting Selangor (PBS), training on aircraft fueling has historically been delivered in a purely theoretical format, with little opportunity for students to engage in hands-on practice. Research shows that students in technical disciplines retain knowledge more effectively through experiential learning, which improves comprehension, engagement, and problem-solving abilities compared to lecture-only approaches (R. Yuliana, 2025) (T. L. Bauerle, 2012). Furthermore, hands-on learning enables students to internalize safety protocols and respond appropriately to real-world challenges (Y. Thiri, 2024).

A survey conducted among PBS students indicated that the absence of practical training equipment left them struggling to visualize procedures, apply theoretical concepts, and appreciate safety considerations in refueling operations (A. Haziq, 2024) .Moreover, cost constraints and the large size of industrial fuel bowsers make them impractical for use in an educational context (A. Somerville, 2023). There is, therefore, a pressing need for an affordable, portable, and realistic training tool that enables students to safely practice aircraft refueling procedures while bridging the gap between classroom learning and industrial practice.

This research addresses this gap by designing and developing a Portable Aircraft Refueling Station (PARS): a compact, mobile, and educationally tailored device that simulates aircraft refueling operations with integrated safety and monitoring features.

2. Methodology

The development of the PARS followed systematic engineering design and educational product development principles, structured into the following phases;

2.1 Design Requirement Analysis

A questionnaire-based survey was conducted among PBS students and instructors to determine key requirements for the learning kit. The results showed strong preference for:

- Hands-on learning (61% highest frequency in Pareto analysis)
- Safety and realistic simulation
- Portability and affordability

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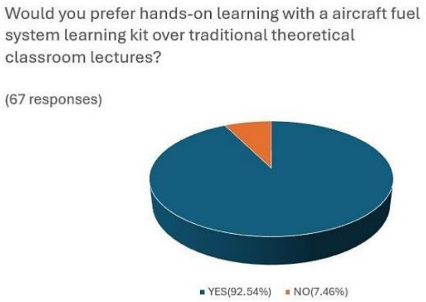

Figure 1. Survey response for students' preference between theoretical and hands-on learning methods

A Pareto diagram was constructed to prioritize design features: hands-on usability, educational value, safety, attractiveness, and cost-effectiveness.

Table 1. Pareto data from the survey done

Features	Frequency	Cummulative	Cummulative Percentage	Pareto Baseline
Hands-on	61	61	18%	80%
Valueable	60	121	36%	80%
Excercises	58	179	53%	80%
Attractive	56	235	70%	80%
Cost	50	285	85%	80%
Portability	50	335	100%	80%
GRAND TOTAL	335			

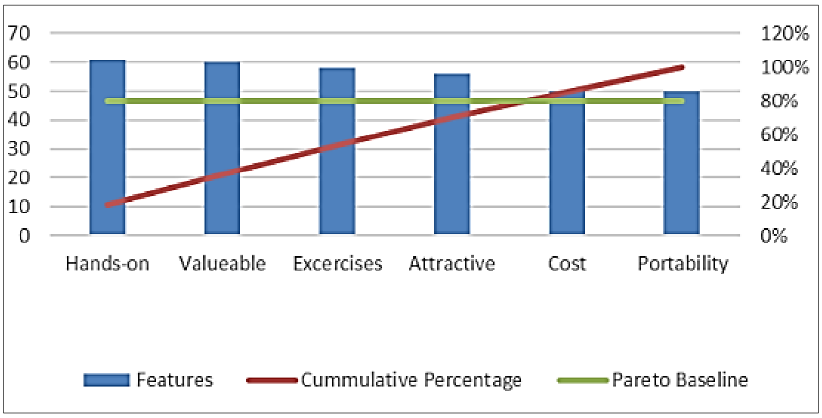

Figure 2. Pareto diagram generated from the data

2.2 Design Concept Generation

2.2.1 Function Tree

The main function of the PARS was defined as "Enable Safe and Realistic Learning of Aircraft Refueling." Supporting functions included fuel transfer, fuel level indication, mobility, and safety braking.

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2.2.2 Morphological Matrix

Several combinations of components and features were explored, generating four distinct design concepts:

1. Medium capacity tank(30L) made from iron, requires tow tug to move and equipped with parking brake.
2. Medium capacity tank(30L) made from stainless steel, requires tow tug to move and latch lock locking mechanism.
3. Large capacity tank(200L) made from iron, requires tow tug to move and secured using padlock.
4. Small capacity tank(20L) made from stainless steel, controlled by remote and secured by RFID system.
5. Large capacity tank(200L) made from used fuel barrel, can be moved manually using push bar or can be connected to tow tug if necessary and secured by safety brake.

2.2.3 Selected Concept: Concept 5, based on its balance of portability, realism, and educational value.

2.3 Evaluation and Selection

The concepts were evaluated using a Pugh Matrix against criteria like safety, cost, educational effectiveness, and portability. Concept 5 scored the highest.

Table 2. Pugh Matrix was used to evaluate the proposed design concepts

CRITERION	CONCEPT 1	CONCEPT 2	CONCEPT 3	CONCEPT 4	CONCEPT 5 (SELECTED)
TOUGHNESS	D	+	=	+	=
CAPACITY	A	=	+	-	+
MOBILITY	T	=	+	+	+
SHAPE	U	=	=	-	+
MOVING MECHANISM	M	-	-	-	-
SECURITY	-	-	-	+	=
SUM OF +'S	-	1	2	3	3
SUM OF -'S	-	2	2	3	1
SUM OF ='S	-	3	2	0	2
RANKING	-	4	2	3	1

3. Results

3.1 Project Drawings

Detailed CAD drawings and sketches were developed showing:

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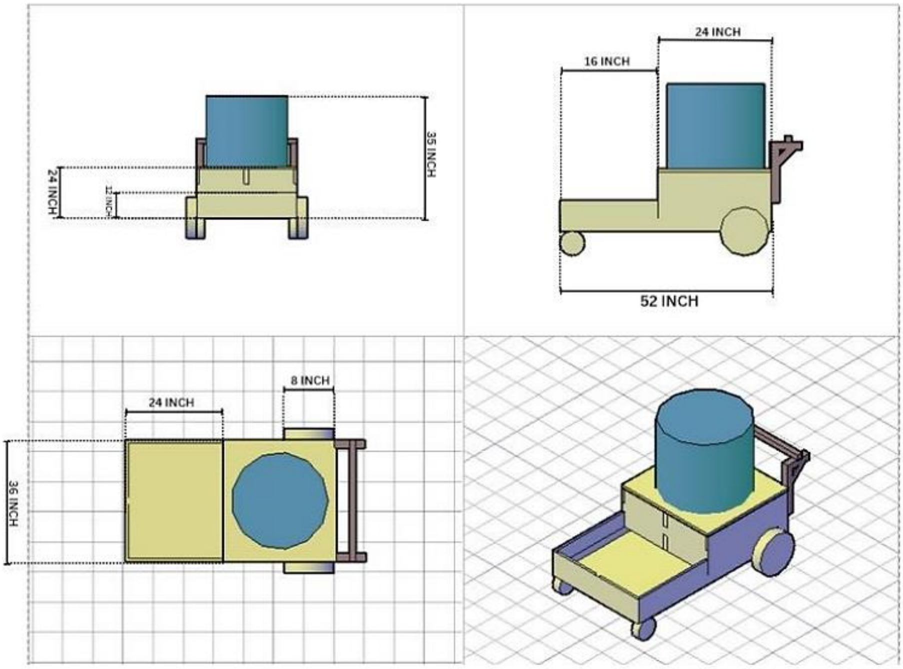

Figure 3. General dimensions of the cart in inch

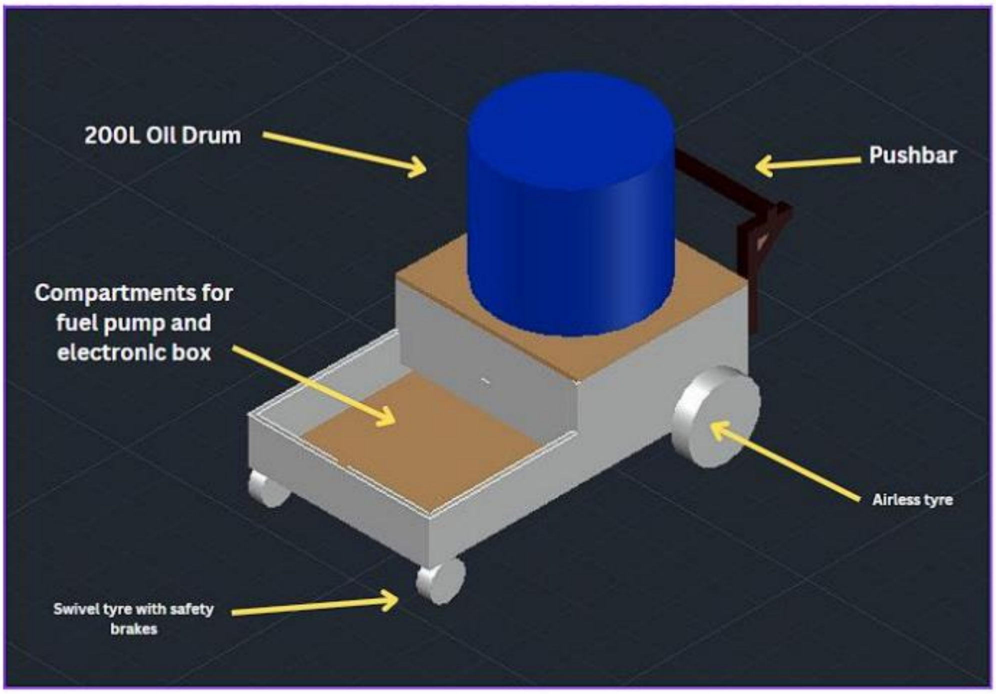

Figure 4. Orthographic view of the design consisting of fuel tank, pump, control panel, electronics compartment, cart chassis with swivel airless tires and safety brakes.

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3.2 Flow Charts

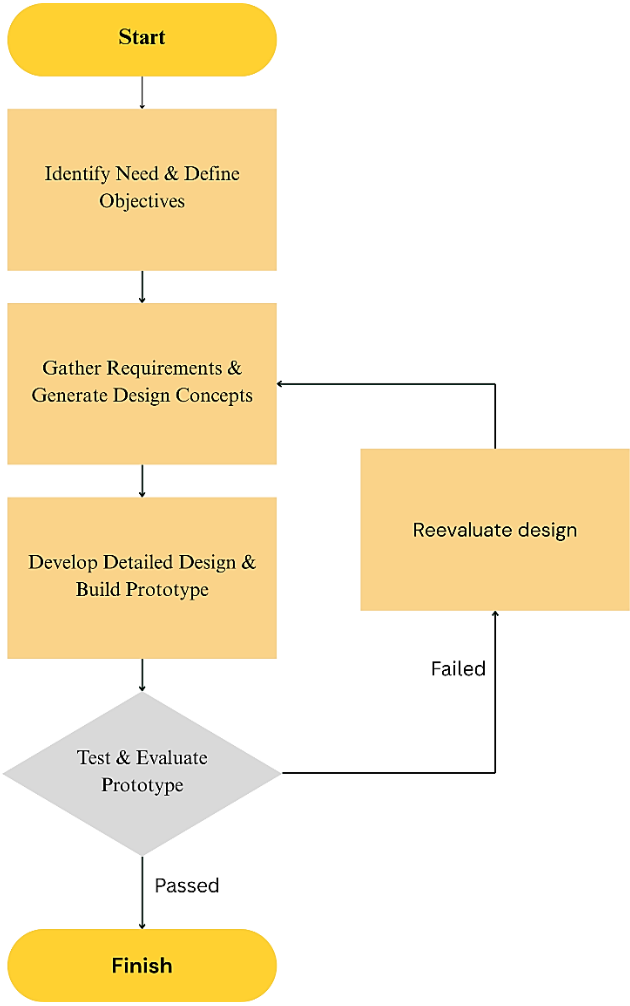

Figure 5. The general flowchart for the development process.

3.3 Final Product Description

The PARS prototype was constructed on a steel trolley carrying a 100 L steel fuel tank and a 12 V DC transfer pump (15 L/min rated). An automatic fuel nozzle (with mechanical float valve) feeds the pump outlet. A 12 V lead-acid battery powers the pump and a 4-inch red LED beacon via a high-current DC relay, indicating fueling in process. The electrical system uses an Arduino Uno R3 microcontroller to monitor fuel level and control safety outputs. Figure 1: Arduino Uno R3 microcontroller used to read the ultrasonic fuel-level sensor and drive the pump relay. The Arduino's wiring is as follows: VCC (5 V) and GND are tied to a common power bus; an HC-SR04 ultrasonic sensor's Trig and Echo pins connect to digital pins D7 and D8 for fuel-height sensing. A 16×2 LCD display is connected via an I²C interface (SDA/SCL) to show volume (in liters) in real time. The pump's +12 V input is switched via a MOSFET

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circuit (MOSFET gate at D3) for rapid on/off control; its ground returns directly to the battery. A manual emergency stop button and a large 15 A fuse are included on the 12 V line for safety. A static grounding cable attaches the steel frame to the fuel nozzle to prevent charge buildup.

All components were calibrated and tested before deployment.

Sensor calibration: With the tank level at known volumes (0%, 25%, 50%, 75%, 100%), the ultrasonic reading was recorded and fit to a linear model in the Arduino code. The final mapping accuracy is ±0.5 L.

Operation logic: The Arduino continuously measures the fuel height every 0.5 second, computes volume (using tank geometry), and displays it. The relay (via D3) is driven when the pump is active. The beacon light is turned on concurrently to signal fueling status. When the measured volume approaches the preset maximum (e.g. 100 L), the Arduino automatically cuts power to the pump to prevent pump overheating due to dry running. QR codes printed on the station link to maintenance manuals; students scan these with a phone to review procedures before fueling, promoting self-directed learning.

Testing procedure: The station was tested in stages. First, water was used to verify leak-tight plumbing and check pump operation. Next, the auto-nozzle was actuated to ensure the mechanical shut-off functions correctly. The ultrasonic sensor was validated by comparing volume readouts to actual graduated volumes (mean error < 1%). Finally, dry runs were conducted: the pump filled the tank at full speed and the Arduino shut it off reliably on reaching the limit. Safety validation included verifying that the fuse blew under a short-circuit condition, and that the grounding strap eliminated static sparks when fueling. All wiring followed standard practice (twisting power lines, isolating signal wires) and the entire system was enclosed in an insulated box when powered.

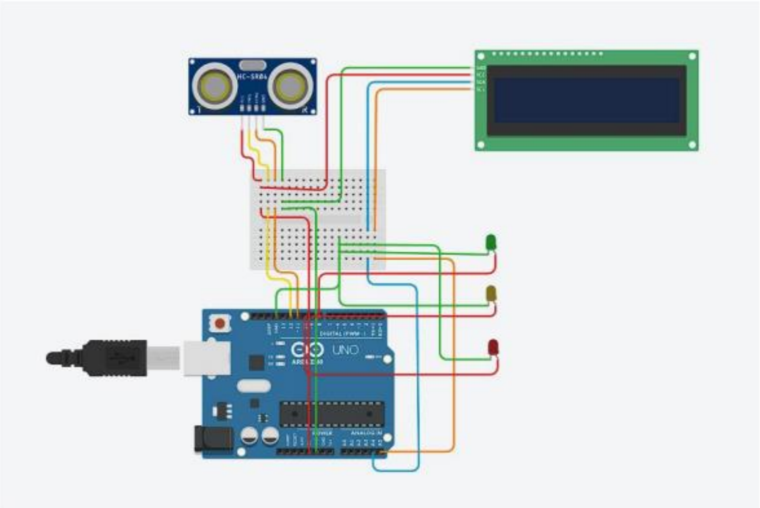

Figure 6. Arduino based fuel level sensor & monitoring system

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Figure 7. PARS fully developed and operational in PBS

4. Discussion

After the development of PARS, 51 Aircraft Maintenance Engineering students used it during practical lab sessions. A pre/post survey (5-point Likert scale) assessed perceived learning and confidence in aircraft fueling concepts and procedures. Table 3 summarizes the key survey results. All mean scores rose by at least +1.1 points. For example, confidence in performing refueling tasks improved from 2.8 (±0.9) to 4.3 (±0.6), and understanding of fuel-system components from 3.1 (±0.7) to 4.5 (±0.5). The average overall satisfaction score jumped from 3.3 to 4.7. These gains are highly significant indicating that hands-on PARS training had a strong positive effect.

Table 3: Mean Likert-scale survey responses (1=low, 5=high) before and after using the PARS training station (n=51).

Survey Item	Pre (Mean±SD)	Post (Mean±SD)	Gain
Confidence in refueling procedures	2.8 ± 0.9	4.3 ± 0.6	+1.5
Understanding of fuel system components	3.1 ± 0.7	4.5 ± 0.5	+1.4
Knowledge of safety/shutoff protocols	3.5 ± 0.8	4.6 ± 0.6	+1.1
Overall satisfaction with training	3.3 ± 0.8	4.7 ± 0.5	+1.4

These outcomes align with educational research showing experiential learning boosts engagement and retention. As one study notes, integrating concrete, hands-on activities significantly increases student involvement and learning gains (T. L. Bauerle, 2012). In our case, students reported that the realistic fueling exercise helped solidify their theoretical knowledge. For instance, performing a live pump fill and seeing the sensor feedback reinforced concepts of flow rate and volume that are abstract in lectures. The average improvement of

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~+1.4 points suggests that PARS provided a "clear additive" component to the learning process, consistent with experiential learning theory (T. L. Bauerle, 2012).

The practical implications for aviation maintenance education are substantial. PARS allows students to practice fuel operations in a safe, controlled setting, which is otherwise rare at the diploma level. Modern aviation curriculums emphasize "learning by doing," and up-to-date lab equipment with real tools is essential for bridging theory and practice (Maura Gina D. Ramoso, 2025). By giving each student hands-on access to a pump, nozzle, and gauge, PARS addressed this need: over 85% of participants agreed that the station's equipment was realistic and that it helped them develop technical skills. This mirrors findings in other studies that well-equipped labs directly improve skill acquisition (Maura Gina D. Ramoso, 2025). Moreover, the portable design means multiple small-aircraft bays or even classroom sessions can be used to set up fueling scenarios without requiring full-scale bowser trucks.

In comparing with existing refueling equipment, PARS occupies a unique niche. Commercial training rigs (e.g. large turbine-fuel trainers) are bulky and expensive, and standard airport fuel carts are not sized for classroom use. PARS, by contrast, is affordable (~1/10 the cost) and emphasizes teaching rather than throughput. Its integration of an Arduino sensor and auto cutoff also highlights safety: students learned to respect fueling protocols while the system prevented spills. In contrast, surveys of fuel facilities underscore that continuous hands-on practice with safety procedures is critical to preventing mishaps (Maura Gina D. Ramoso, 2025). Although PARS cannot match the capacity of industrial systems, it suffices to illustrate key points such as flow control, grounding & safety.

Overall, the feedback suggest that PARS made training more effective. The substantial pre–post gains suggest real learning occurred. This is in line with broader research on maintenance training innovations: for example, advanced digital-twin systems are now being explored to provide simulated hands-on practice (Kabashkin, 2025). Our simpler physical station complements such approaches by offering tangible experience. As one student comment summarized, "Using the PARS was like actually being on the ramp – it tied the classroom to the real world." The positive results indicate that similar portable training aids could benefit other technical programs.

However, certain limitations remain, such as its limited fuel capacity and simplified pump system, which may not fully replicate industrial-scale operations. Future improvements could include wireless data logging, increased fuel tank options, and modular add-ons for advanced training scenarios.

5. Conclusion

This work presented the design, implementation, and evaluation of a Portable Aircraft Refueling Station for maintenance education. The new PARS prototype combines a fuel cart with Arduino-based monitoring and safety features, and it effectively improved student confidence and understanding of fueling tasks. The survey data (n=51) demonstrated significant learning gains (e.g. average ratings rose from ~3.1 to 4.6), underlining the value of

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hands-on practice in technical education (T. L. Bauerle, 2012) (Maura Gina D. Ramoso, 2025). By detailing the hardware, wiring, software logic, and safety measures, we have provided a replicable model for other educators. Future work could compare different sensor types (e.g., pressure vs. ultrasonic) or integrate augmented reality overlays. In conclusion, PARS exemplifies how practical, low-cost training stations can bridge gaps between theory and practice, preparing aviation students more effectively for real-world fueling operations.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author(s) used OpenAI's ChatGPT to assist in improving the readability and language of the text. All content generated by ChatGPT was subject to thorough review, editing, and revision by the authors to ensure its accuracy, completeness and alignment with the research objectives. The author(s) take full responsibility for the integrity and content of the published work. This declaration complies with ICGESD 2025 guidelines on the use of generative AI in scientific writing.

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