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Design and Functional Demonstration of a Miniature Compass Swing Trainer for AMTO Practical Training

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ABSTRACT

Compass swing practical training in Aircraft Maintenance Training Organizations is often constrained by limited access to training aircraft and maneuvering areas. This study designed and functionally demonstrated a portable miniature compass swing trainer produced by fused deposition modeling with a predominantly polylactic acid structure. Mounted on a tripod, the trainer supported controlled rotation and leveling. A single instructional run reproduced correcting-swing and checking-swing procedures and yielded illustrative Make Compass Read outputs (C = -2°, B = +6°, A = -2.67°) together with data for a training Compass Deviation Card. Six subject-matter instructors, purposively selected from 17 AMTO instructors, provided structured feedback (mean = 4.75 ± 0.34; 71 of 72 item-level responses were agree or strongly agree). The prototype is intended as a hands-on procedural and mathematical trainer, not a metrological calibration tool or electromagnetic replica. The findings support preliminary instructional functionality and expert acceptance but do not establish measurement accuracy, repeatability, full-scale equivalence, or student-learning effectiveness.

1. INTRODUCTION

Aircraft maintenance education is part of technical and vocational education and training (TVET), which requires the integration of technical knowledge, practical skills, and compliance with safety standards. Aircraft Maintenance Training Organizations (AMTOs) are responsible for preparing maintenance personnel who can perform tasks in accordance with approved procedures and regulatory requirements. Therefore, learning quality cannot be assessed only through conceptual mastery; trainees must also be able to apply their knowledge to tasks that resemble actual workplace conditions. Recent peer-reviewed TVET studies published in 2025 have reported that contextual, project-based, mobile, and immersive learning approaches can strengthen learner engagement and help connect classroom learning with industrial practice (Sardi et al., 2025; Wulansari et al., 2025).

One practical competency in avionics is aircraft magnetic compass calibration, commonly known as a compass swing. In the basic certificate avionics curriculum under Advisory Circular 147-02, this subject is classified at Teaching Level 3. This level requires comprehensive theoretical instruction and practical training (Directorate General of Civil Aviation [DGCA], 2017; Rifai & Harini, 2022). Technically, a compass swing is conducted to minimize errors caused by the aircraft magnetic field, adjust the compass compensators, and record the remaining deviation on a Compass Deviation Card.

Compass swing practice requires specific operational conditions. The Federal Aviation Administration (FAA, 2017) describes several calibration methods, including a compass rose, master site compass, simulated rotation system, portable magnetic standard, and air swing. Before testing, the selected location and its surroundings must be evaluated and kept as free as practicable from magnetic interference. In conventional procedures, the aircraft must also be placed on a level surface and rotated to specified headings. Consequently, an AMTO requires a training aircraft, a reference instrument, and adequate maneuvering space. At AMTO Politeknik Negeri Batam, the training aircraft can only be moved to the operating area immediately in front of the hangar for routine compass-swing practice. A site assessment showed that this area is closely bounded by campus infrastructure: the maximum separation between the available aircraft operating position and Tower A, a 12-storey building, is approximately 39 m, while the TRAIN Building in front of the hangar is approximately 9 m from the aircraft position. These approximate site separations were estimated from available map imagery and are reported only to characterize the spatial constraint, not as magnetic-clearance criteria. The physical constraints limit the space available for repeatedly positioning and rotating a full-scale aircraft during student training and motivated the development of a smaller portable procedural trainer.

Several technologies have been developed to reduce dependence on operational aircraft and large physical facilities in aircraft maintenance training. Virtual-reality studies have demonstrated advantages for repeatable visualization, safe procedure rehearsal, interactive scenarios, and performance monitoring (Lee et al., 2022; Wu & Vu, 2022; Gómez-Cambronero et al., 2023; Li, 2023). However, these studies primarily validate digital interaction and procedural visualization rather than direct manipulation of a physical magnetic compass. Conversely, Liu et al. (2022) reported that actual equipment remained advantageous for maintenance tasks in which performance depended on direct physical interaction. Taken together, the literature suggests that digital simulation is valuable for repeatability and accessibility, but it does not fully address training activities that require learners to physically align, read, adjust, and record indications from an actual instrument.

Additive manufacturing provides a complementary pathway for competencies that require physical interaction but are constrained by equipment cost or facility size. Three-dimensional printing enables digital models to be converted into tangible components that can be redesigned, fabricated, and assembled for instructional use. Ullah et al. (2020) demonstrated its value for integrating design, visualization, and fabrication in engineering curricula, while Vukašinović et al. (2024) showed that printed components can support understanding of component form and operating principles. Monroy-Peláez et al. (2025) further demonstrated the use of 3D printing for tangible engineering problem solving. These studies validate the educational value of physical printed models, but they do not address a portable trainer that combines a printed airframe-like structure with an actual aircraft magnetic compass for practicing the sequence and calculations of a compass swing.

This distinction defines the gap addressed in the present study. Existing virtual and immersive systems emphasize digital procedure representation, whereas prior additive-manufacturing studies largely emphasize component visualization, design, or general engineering experimentation. Limited attention has been given to reduced-scale physical trainers that allow trainees to manipulate an actual magnetic compass while practicing heading alignment, compensator adjustment, deviation calculation, and Compass Deviation Card preparation. The present prototype therefore combines a predominantly PLA aircraft-like structure, an actual magnetic compass, a portable support system, and controlled rotation. The instrument remains responsive to changes in heading within the local magnetic environment, but the trainer is not intended to reproduce the hard-iron, soft-iron, or electrical magnetic environment of an operational aircraft. Its intended fidelity is procedural and mathematical rather than electromagnetic.

Accordingly, this study aimed to design and demonstrate a miniature compass swing trainer produced by fused deposition modeling using polylactic acid and to obtain preliminary expert-user feedback on its instructional use. Two research questions guided the study: (RQ1) Can the prototype support the principal procedural and mathematical sequence of compass-swing training, including cardinal-heading alignment, Make Compass Read calculations, a 12-heading check swing, and Compass Deviation Card preparation? (RQ2) How do subject-matter AMTO instructors perceive the prototype in terms of technical suitability, ease of use, relevance to practical learning, and implementation? The study was framed as an engineering prototype demonstration and descriptive expert-user evaluation, not as a metrological validation of compass accuracy or an evaluation of student-learning outcomes.

2. METHODS

Research Design

This study used a Research and Development approach focused on the engineering development and preliminary functional demonstration of a physical instructional medium. The development process was organized into four stages: three-dimensional model design, fabrication and assembly, procedural demonstration and compensation calculation, and expert-user evaluation. This sequence was selected because the research output was a prototype training aid intended to demonstrate compass-swing procedures and calculations. The study was not designed as a metrological calibration-validation study and did not aim to establish measurement accuracy or airworthiness suitability.

Population and Sample

The functional demonstration was conducted on the completed prototype using a reference compass as the heading reference and an aircraft magnetic compass installed on the trainer. Current calibration-traceability documentation was not available for either instrument; therefore, the readings were used only to demonstrate the compass-swing procedure and associated calculations, not to establish metrological accuracy. For the expert-user evaluation, six instructors were purposively selected from a total of 17 instructors at AMTO Politeknik Negeri Batam because they had teaching and/or practical expertise in aircraft magnetic compass calibration and compass-swing procedures. The evaluation was therefore descriptive rather than inferential, and the results were interpreted as specialist expert feedback rather than estimates that can be generalized to the full instructor population or to other AMTOs.

Data Collection Procedure

The miniature aircraft was designed digitally using SolidWorks and Blender. SolidWorks was used for components requiring mechanical and geometric precision, including the compass housing, fuselage joints, and mounting adapter connected to a camera-tripod quick-release plate. Blender was used to model the overall aircraft shape and divide the model into printable segments according to the build volume of the available printer.

Fabrication used fused deposition modeling on a Bambu Lab P1S Combo printer with an Automatic Material System. The model was divided into the nose, fuselage sections, wing sections, vertical and horizontal stabilizers, and landing gear. Bambu Lab PLA Basic was selected because it provided sufficient stiffness for the trainer while avoiding the ferromagnetic characteristics associated with conventional metallic airframe structures. PLA is a polymeric material with weak diamagnetic behavior and therefore does not produce significant hard-iron magnetization under normal conditions. Its use was intended to minimize magnetic interference originating from the trainer airframe itself. However, this material choice also means that the trainer does not reproduce the hard-iron and soft-iron magnetic fields normally generated by ferromagnetic aircraft structures and onboard equipment. Accordingly, the developed device was designed primarily as a procedural and mathematical training simulator for compass-swing practice rather than as a full electromagnetic representation of an operational aircraft. The magnetic characteristics of the supporting tripod were not intended to represent aircraft-related magnetic effects. Because the magnetic signature of the commercial tripod and mounting hardware was not independently quantified in the present study, no claim was made that all external magnetic interference was eliminated. After printing, the components were assembled, the aircraft compass was installed in the upper-fuselage housing, and the model was mounted on a tripod equipped with a bubble level for pitch and roll leveling.

The functional demonstration followed the operational sequence commonly used for aircraft magnetic compass calibration. The test site was an open field located more than 50 m from other aircraft and more than 100 m from the hangar, following the internal operational criteria used by the AMTO for procedural practice. A quantitative ambient magnetic-field survey was not performed because a calibrated three-axis magnetometer was not available. Therefore, the site is not presented as a certified magnetic calibration area or as being free from all local magnetic interference. The trainer was aligned using the available reference compass as a heading reference. The demonstration consisted of correcting-swing and checking-swing phases.

During the single correcting-swing demonstration, the trainer was rotated to North (000 degrees), East (090 degrees), South (180 degrees), and West (270 degrees). Deviation was calculated from the difference between the reference heading and the indication of the aircraft compass. The readings were used to demonstrate the calculation of Coefficients B and C and the Make Compass

Read targets for compensator adjustment. In practical terms, Make Compass Read (MCR) is the target compass indication to which the compass is adjusted after applying half of the reciprocal-heading error. Because the instruments were not supported by current calibration traceability and repeated trials were not performed, these numerical results were treated as instructional demonstration values rather than accuracy-validation measurements.

$$B = \frac{[Dev(E) - Dev(W)]}{2} \quad (1)$$

$$C = \frac{[Dev(N) - Dev(S)]}{2} \quad (2)$$

$$MCR\ (transverse) = I_w - B \quad (3)$$

$$MCR\ (longitudinal) = I_S - C \quad (4)$$

In these equations, B and C represent the semicircular deviation coefficients on the East-West and North-South axes, respectively. The terms Dev(N), Dev(S), Dev(E), and Dev(W) represent the initial compass deviations measured at the North, South, East, and West reference headings. Importantly, I_w and I_S denote the actual indicated compass readings observed at the West (270 degrees) and South (180 degrees) reference headings prior to compensator adjustment; they do not represent the absolute reference headings of 270 degrees and 180 degrees. When the coefficients are applied to the indicated readings, their algebraic signs are reversed to remove half of the reciprocal-heading error. MCR represents the target compass indication used during adjustment of the corresponding compensator.

Data Analysis Technique

During the checking-swing demonstration, the trainer was rotated clockwise at 30-degree intervals from 000 degrees to 330 degrees. The 30-degree interval followed the standardized compass-correction sequence presented in FAA AC 43-215 (FAA, 2017). Residual deviations were recorded at 12 headings and used to demonstrate calculation of Coefficient A as the mean deviation and preparation of a Compass Deviation Card. Only one demonstration run was performed; therefore, no repeatability statistics or measurement-uncertainty estimates were derived.

Expert-user feedback was collected using a 12-item structured questionnaire on a five-point Likert scale, where 1 represented strongly disagree and 5 represented strongly agree. The items covered four dimensions: technical suitability and procedural authenticity, design and ease of use, relevance to AMTO learning, and implementation feasibility. Two open-ended questions were included to identify the trainer's main advantages and aspects requiring improvement. The questionnaire was used as a structured prototype-feedback instrument rather than as a psychometrically validated scale. Accordingly, content-validity indices and internal-consistency coefficients were not calculated. Quantitative responses were summarized descriptively using means, standard deviations, and the percentage of agree/strongly agree responses. With only six purposively selected experts, the standard deviations were used only to describe response dispersion and no inferential conclusions were drawn. Open-ended responses were grouped into recurring themes.

$$A = (\Sigma\ Dev(i))\ /\ 12, i = 1, \ldots, 12 \quad (5)$$

In this formula, *A* represents Coefficient A, which indicates the constant index error of the compass installation calculated as the mean of the overall deviations. The variable *Dev(i)* refers to the individual residual compass deviation recorded at each specific 30-degree interval heading during the check swing phase.

3. RESULTS

Mechanical Design and Fabrication

The mechanical design focused on instrument accuracy, reading visibility, and system portability. The completed prototype had a wingspan of 103.32 cm and a fuselage length of 69.09 cm. The wing tip measured 10.8 cm, the wing chord 14.7 cm, the horizontal stabilizer spans 34.00 cm, and the vertical stabilizer height 12.79 cm. These dimensions retained recognizable training-aircraft proportions while allowing the device to be transported and operated in an open field.

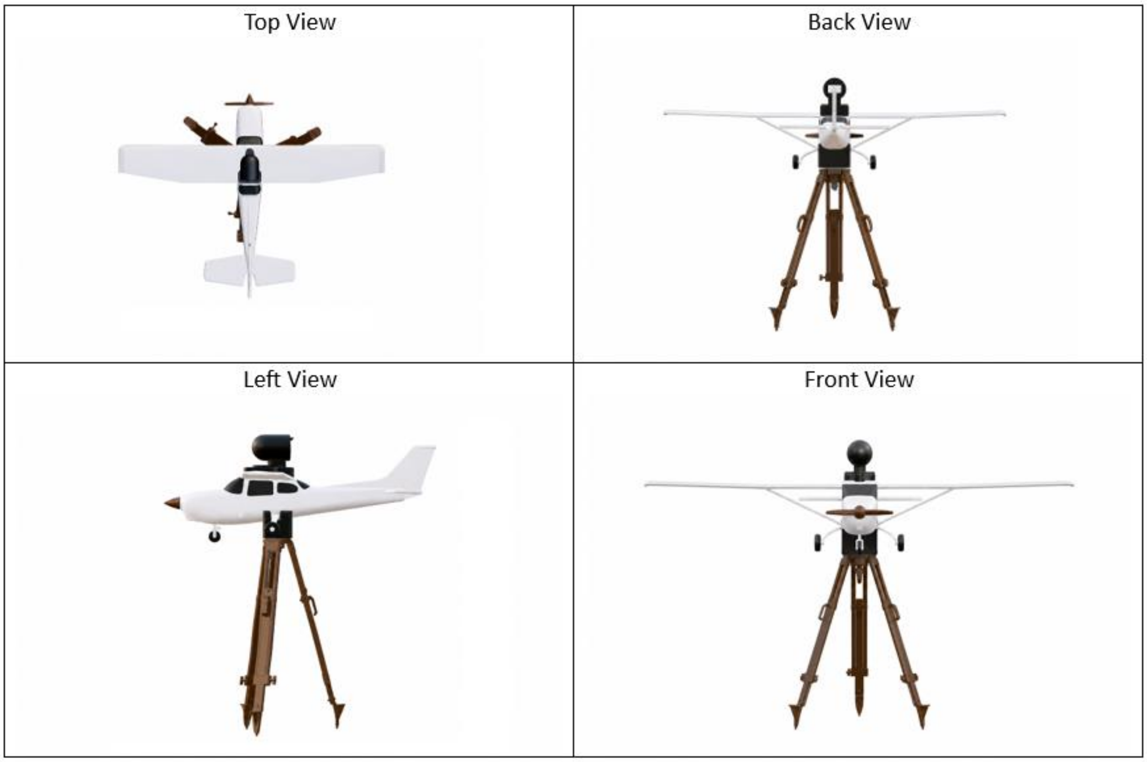

Figure 1. Three-dimensional visualization of miniature aircraft and tripod configuration

Two mechanical interfaces were incorporated into the design. The external compass housing on the upper fuselage improved visibility during heading readings and was designed to follow the longitudinal axis of the miniature aircraft. A mounting adapter on the lower fuselage connected the model to a standard camera-tripod quick-release plate. The tripod pan-and-tilt head supported 360-degree azimuth rotation, while the bubble level assisted with pitch and roll leveling before each demonstration. No independent angular-metrology measurement was performed after assembly; therefore, a numerical tolerance between the airframe longitudinal centerline, compass housing, and compass lubber line cannot be reported. Small assembly or mounting play may consequently introduce systematic angular bias. Future iterations should incorporate visible centerline/index marks and a more positive locking interface to improve alignment consistency.

Fabrication was completed using a Bambu Lab P1S Combo printer. Because the model exceeded the printer build volume, it was divided into the nose, fuselage, wing, empennage, and landing-gear segments. Printing was performed in an enclosed chamber at a speed approaching 300 mm/s, with a nozzle temperature of 190-230 degrees Celsius and a bed temperature of 35-45 degrees Celsius. The assembled components did not show visible warping that affected the compass mounting alignment. Bambu Lab reports a tensile strength of 35 ± 4 MPa, a bending modulus of 2750 ± 160 MPa, an impact strength of 26.6 ± 2.8 kJ/m^2, and a density of 1.24 g/cm^3 for PLA Basic (Bambu Lab, n.d.).

Figure 2. Mounting adapter and compass housing components

Figure 3. Fabrication and assembly stages showing segmented printed airframe components, the assembled airframe, external compass installation, and the final tripod-mounted trainer configuration

Functional Demonstration

A single correcting-swing demonstration was conducted at the four cardinal headings. The instructional readings and calculated deviations are presented in Table 1.

Table 1. Correcting-swing demonstration results at the cardinal headings

Target heading	Reference compass indication	Aircraft compass	Deviation
N (000°)	000°	002°	-2°
S (180°)	180°	178°	+2°
E (090°)	090°	090°	0°
W (270°)	270°	282°	-12°

Using the cardinal-heading deviations, Coefficient B was calculated as +6 degrees and Coefficient C as -2 degrees. Following the half-error compensation principle, the signs of the coefficients were reversed when applied to the indicated compass readings prior to adjustment. The corresponding Make Compass Read targets were therefore 276 degrees on the transverse axis (282 degrees - 6 degrees) and 180 degrees on the longitudinal axis (178 degrees - [-2 degrees]). These values were used as the visual targets when adjusting the compass compensator screws before the check swing.

After the compensator-adjustment demonstration, the trainer was rotated at the standardized 30-degree heading intervals described in FAA AC 43-215 (FAA, 2017). Table 2 presents the 12-heading checking-swing demonstration results.

Table 2. Checking-swing demonstration results at 30-degree heading intervals

Target heading	Reference compass indication	Aircraft compass	Deviation
N (000°)	000°	001°	-1°
030°	030°	033°	-3°
060°	060°	061°	-1°
E (090°)	090°	090°	0°
120°	120°	118°	+2°
150°	150°	147°	+3°
S (180°)	180°	179°	+1°
210°	210°	219°	-9°
240°	240°	250°	-10°
W (270°)	270°	280°	-10°
300°	300°	303°	-3°
330°	330°	331°	-1°

In this single demonstration run, the maximum absolute residual deviation was 10 degrees. The sum of the 12 deviations was -32 degrees, producing a calculated Coefficient A of -2.67 degrees. These values were transferred to the Compass Deviation Card to demonstrate the complete instructional sequence. A descriptive directional comparison also showed clear asymmetry within the single run: the mean residual deviation over 030-090 degrees was -1.33 degrees, whereas the mean over 210-270 degrees was -9.67 degrees. These sector means describe the observed pattern only and are not repeatability statistics. Because only one rotation sequence was performed, no standard deviation across repeated trials or measurement-repeatability metric was generated.

Expert-User Evaluation

All six purposively selected subject-matter instructors completed the structured expert-user questionnaire after observing and using the trainer during correcting-swing and checking-swing activities. Table 3 summarizes the descriptive results.

Table 3. Descriptive expert-user evaluation of the miniature compass swing trainer

Evaluation dimension	Mean ± SD	Positive responses (%)	Descriptive interpretation
Technical suitability and procedural authenticity	4.83 ± 0.41	100.0	High expert rating
Design and ease of use	4.61 ± 0.49	94.4	High expert rating
Relevance to AMTO practical learning	4.78 ± 0.40	100.0	High expert rating
Implementation feasibility	4.78 ± 0.40	100.0	High expert rating
Overall evaluation (12 items)	4.75 ± 0.34	98.6	High expert rating

Note: Results are descriptive expert-user feedback from six purposively selected subject-matter instructors. The standard deviation describes response dispersion only and should not be interpreted as a stable population estimate. Positive responses combine agree and strongly agree selections.

Of the 72 item-level ratings, 55 responses (76.39%) were in the strongly agree category, 16 (22.22%) were agree, and one (1.39%) was neutral. No instructor selected disagree or strongly disagree. The concentration of responses in the highest category suggests a potential ceiling effect and limits discrimination among individual design elements. The technical suitability dimension received the highest mean rating, while design and ease of use received the lowest mean. The lowest individual item concerned the compass position and tripod system, with a mean score of 4.33. Because the respondents were six purposively selected internal subject-matter instructors, these ratings represent specialist prototype feedback and should not be interpreted as evidence of trainee learning effectiveness or as population-level estimates.

Open-ended responses identified portability, limited space requirements, ease of storage, and practical interaction as the main advantages. Recommended improvements included an accurately marked compass rose, protected wiring, a spare compass, and verification of alignment among the nose or propeller cone, vertical stabilizer, longitudinal axis, and compass lubber line.

4. DISCUSSION

The developed trainer addressed a practical training problem by combining physical interaction with a portable configuration. Within the Level 3 practical-training context of Advisory Circular 147-02, it is intended to function as a hands-on bridge between classroom or virtual instruction and practice on a full-scale aircraft. Virtual-reality approaches offer repeatable visualization and low spatial demand, but they do not provide direct manipulation of a physical magnetic compass or compensator. Full-scale aircraft practice provides the highest operational realism, but it requires aircraft availability, larger maneuvering space, and greater resource commitment. The miniature trainer requires substantially less physical space and avoids dedicating a full-scale aircraft during introductory practice while retaining tactile interaction with a real compass and the calculation workflow. A formal capital-cost comparison was not conducted, so this positioning is qualitative rather than economic. The prototype is therefore intended as a preparatory training aid, not a replacement for full-scale aircraft practice.

The use of fused deposition modeling supported rapid fabrication of a geometrically consistent structure. Previous studies have shown that three-dimensional printing can connect digital design with tangible engineering learning and provide physical representations of component form and operation (Monroy-Peláez et al., 2025; Ullah et al., 2020; Vukašinović et al., 2024). In this study, segmentation allowed a model with a wingspan exceeding the printer build volume to be produced and assembled. An important design consideration is the magnetic behavior of the trainer structure. Unlike an operational aircraft, whose ferromagnetic structural components and onboard equipment may generate hard-iron and soft-iron magnetic effects, the present trainer was intentionally fabricated predominantly from PLA. The weakly diamagnetic and non-ferromagnetic nature of the polymer was a design rationale for reducing ferromagnetic contribution from the printed airframe; it was not independently quantified as a magnetic-performance result. Consequently, the baseline deviations observed in the trainer should not be interpreted as reproducing the magnetic signature of an operational aircraft. The prototype is specifically a procedural and mathematical simulator for practicing heading alignment, compensator adjustment, coefficient calculation, and Compass Deviation Card preparation. The commercial tripod and mounting hardware may contain ferromagnetic components. Because a calibrated three-axis magnetometer was not available, the isolated tripod assembly and ambient site field were not quantitatively mapped. Future engineering validation should therefore include baseline magnetic mapping of the support assembly to distinguish mounting-hardware interference from compass-indication effects.

The single functional demonstration showed that the trainer could support the intended calculation sequence: Coefficients B and C were derived from cardinal-heading readings, Make Compass Read targets were applied during the compensator-adjustment exercise, and the subsequent 12-heading checking-swing exercise produced a calculated Coefficient A of -2.67 degrees. The directional pattern was not uniform. For descriptive comparison, the mean residual deviation over 030-090 degrees was -1.33 degrees, whereas the mean over 210-270 degrees was -9.67 degrees, with the largest values reaching -10 degrees at 240 and 270 degrees. Thus, the observed SW-sector values reached the ±10-degree comparison limit referenced in FAA AC 43-215 with no margin below that limit. However, these values should not be interpreted as evidence of regulatory compliance because the instruments lacked current calibration traceability, the ambient magnetic field and tripod signature were not mapped, and the run was not repeated. The asymmetry may reflect mounting or alignment bias, localized magnetic influence, compass condition, or a combination of these factors; the present study cannot isolate the cause. Instructionally, the non-uniform values remained useful because they required trainees to calculate, interpret, and transfer deviations to a Compass Deviation Card. The prototype is therefore a procedural and mathematical trainer rather than a calibration or airworthiness tool.

A further limitation of the current trainer is that it does not reproduce compass disturbances generated by changes in aircraft electrical-system configuration. In operational aircraft, magnetic compass calibration is performed under a defined equipment configuration, and electrical or radio equipment status may affect the local magnetic field around the compass. Although simulation of these effects was outside the scope of the present prototype, a future version could incorporate a low-voltage DC micro-coil positioned near the compass housing and controlled by a simple trainee-operated switch. At the same reference heading, trainees could first record a systems-OFF indication, energize the coil to represent a systems-ON condition, record the new indication, and calculate the resulting delta. The two conditions could then be entered in separate columns of an instructional Compass Deviation Card. This feature has not been implemented or tested in the present study; it is proposed only as a future enhancement to instructional fidelity while preserving the trainer's role as a procedural and mathematical simulator rather than an electromagnetic replica of an aircraft.

The expert-user evaluation complemented the procedural demonstration. The highest mean rating was obtained for technical suitability and procedural authenticity, while design and ease of use received the lowest mean. The latter finding was consistent with the lowest-rated individual item concerning the compass position and tripod system (mean 4.33) and with the open-ended recommendations on compass-rose accuracy and alignment verification. These improvements are important for instructional consistency because misalignment among the nose reference, longitudinal axis, compass housing, and compass lubber line can bias demonstration readings and subsequent calculations. Protected wiring would improve durability and reduce accidental disturbance during repeated practice, while a spare compass would support continuity of training. The response distribution also showed a ceiling concentration, with 76.39% of all item ratings in the strongly agree category, which limits the questionnaire's ability to discriminate among design features. Because the six respondents were purposively selected subject-matter experts, the favorable ratings should be interpreted as specialist prototype feedback rather than as statistically generalizable evidence of feasibility or student learning.

The findings should be interpreted within the scope of a preliminary instructional-prototype study. First, the reference compass and aircraft magnetic compass used in the demonstration were not supported by current calibration-traceability documentation; therefore, the study does not claim metrological accuracy. Second, no independent angular-metrology measurement was performed for the assembled longitudinal axis, compass housing, and lubber-line alignment, so mounting play and systematic angular bias cannot be quantified. Third, the ambient magnetic field at the test site and the magnetic signature of the tripod and mounting hardware were not quantitatively surveyed because a calibrated three-axis magnetometer was not available. Fourth, only one compass-swing demonstration run was performed, so measurement repeatability, trial-to-trial standard deviation, and uncertainty were not evaluated. Fifth, the 12-item questionnaire was used as a structured expert-feedback instrument rather than a psychometrically validated scale; the 76.39% concentration of ratings in the strongly agree category suggests a potential ceiling effect, and the six respondents were purposively selected from 17 instructors because of their compass-swing expertise. Consequently, the questionnaire results are descriptive expert perceptions and cannot be generalized to all instructors, other AMTOs, or trainee learning outcomes. Finally, the trainer was not compared directly with a full-scale aircraft under matched conditions. Future work may address these issues if the research objective is extended from procedural training demonstration to measurement performance or educational-effectiveness validation.

5. CONCLUSION

A portable miniature compass swing trainer was successfully designed and functionally demonstrated using fused deposition modeling and a predominantly polylactic acid structure. The tripod-mounted configuration supported leveling and controlled rotation, while the externally positioned aircraft compass allowed the principal stages of correcting swing, checking swing, Make Compass Read calculation, and Compass Deviation Card preparation to be demonstrated. In the single instructional run, the illustrative calculation sequence yielded Coefficient C of -2 degrees, Coefficient B of +6 degrees, and Coefficient A of -2.67 degrees. These values are reported as demonstration outputs and not as metrologically validated compass-calibration results.

The six purposively selected subject-matter instructors provided favorable descriptive feedback, with an overall mean rating of 4.75 ± 0.34; 71 of the 72 item-level responses (98.6%) were rated agree or strongly agree. The concentration of ratings in the highest category and the specialist sample mean that these findings should be interpreted as expert-user feedback only. They do not demonstrate measurement accuracy, repeatability, equivalence with a full-scale aircraft, population-level feasibility, or student-learning effectiveness. The trainer is therefore positioned as a compact, hands-on bridge between classroom or virtual instruction and subsequent practical work on an actual aircraft, not as an electromagnetic replica or calibration tool. Before broader instructional implementation, alignment references, compass-rose presentation, wiring protection, and availability of a spare compass should be improved. Further research can extend the prototype toward metrological or educational-effectiveness validation if those outcomes become the objectives of subsequent studies.

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