

Design, Fabrication and Preliminary Performance Evaluation of a Locally Manufactured Personal Flotation Device for Calm-Water Applications

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ABSTRACT

This study presents the design, fabrication, and preliminary experimental evaluation of a locally manufactured vest-type Personal Flotation Device (PFD) for adults weighing 75–80 kg under controlled calm-water conditions. The prototype used locally available closed-cell polyethylene foam, polyester fabric, nylon webbing, plastic buckles, mesh fabric, and reinforced stitching. It measured 0.63 m × 0.59 m × 0.06 m. Analytical calculations yielded a bounding volume of 0.0223 m³ and an upper-bound buoyancy estimate of 218.76 N. A simplified stability analysis estimated a metacentric height of 0.40 m, while the fastening system had a calculated design load of approximately 2,280 N. These values were treated as design estimates rather than measured performance or strength. Experimental evaluation involved 10 adult participants at Alovera Hotel Swimming Pool, Minna, Nigeria. All participants maintained flotation for 15 min, with head clearance of 9–11 cm and a mean of 10.2 cm. Mean ratings were 4.60 ± 0.52/5 for buoyancy, 4.40 ± 0.52/5 for stability, and 4.30 ± 0.48/5 for comfort. Following a controlled 90° rotational disturbance, participants could assist recovery using normal arm and body movements; mean recovery time was 2.95 ± 0.16 s. PFD mass increased from 1.85 to 1.92 kg after immersion and draining, representing a 3.78% increase. No visible damage affecting fastening or flotation function was observed. The findings indicate preliminary feasibility for calm-water applications but do not establish certification, standards compliance, or structural strength. Further research should include direct buoyancy measurement, tensile testing, replicated trials, participant-level data, and broader environmental testing.

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INTRODUCTION

Drowning is a major public-health and safety concern, particularly in low- and middle-income settings where exposure to recreational, occupational, fishing, transportation, and flood-related water hazards may be considerable. The World Health Organization has identified drowning as an important cause of preventable mortality and has emphasized the importance of effective prevention measures, including appropriate safety equipment and safer behaviour around water (World Health Organization [WHO], 2021, 2022, 2024). Personal flotation devices (PFDs) are among the engineering measures used to reduce drowning risk by providing buoyancy and assisting the user in maintaining a safer position in water. Their effectiveness, however, depends not only on the availability of a flotation device but also on appropriate buoyancy, fit, retention, stability, comfort, and structural integrity. The performance of a PFD is influenced by its design configuration and the distribution of buoyant material around the user's body. Barwood et al. (2014) demonstrated that the distribution of buoyancy within flotation equipment can influence self-righting performance, highlighting the importance of considering buoyancy location rather than buoyant force alone. Similarly, Lunt et al. (2014) reported that appropriate fitting and retention characteristics can improve lifejacket performance during immersion. User acceptance is also an important consideration because discomfort or restricted movement may affect the willingness of users to wear flotation equipment. Lincoln et al. (2012), in their assessment of PFDs used in the fishing industry,

identified comfort, mobility, and user satisfaction as important factors associated with PFD use. These studies indicate that the engineering evaluation of a PFD should consider several interacting characteristics rather than relying solely on a theoretical buoyancy calculation. Recent developments in flotation technology have introduced advanced materials, smart wearable systems, and technology-assisted flotation devices. Koo and Kim (2021) and Liang et al. (2021) discussed the development of wearable and smart flotation systems for improving water and maritime safety. Pérez-Rosés and Bastida (2022) emphasized the importance of incorporating safety considerations into the engineering design of flotation devices, while Su and Cheng (2023) examined the development of more environmentally conscious materials for PFD applications. Wang et al. (2022) similarly highlighted environmental considerations associated with conventional flotation materials and the need for more sustainable alternatives. Although these developments can improve functionality, the use of specialized materials, advanced components, and smart technologies may increase manufacturing complexity and dependence on components that are not always readily accessible in resource-constrained environments. Consequently, the development of functional PFDs using locally available materials remains relevant, particularly where affordability, reparability, and local manufacturing capability are important considerations. The need for systematic evaluation of flotation devices is particularly relevant in developing and African contexts. Evidence from

Lake Albert, Uganda, illustrates that the availability of lifejackets in local markets does not necessarily guarantee adequate functional performance. Oporia et al. (2024), in an assessment of 22 lifejackets obtained from landing sites around Lake Albert, reported deficiencies in buoyancy and righting performance among the devices evaluated. Such findings highlight the importance of engineering assessment of locally available flotation equipment and demonstrate the need for prototype development supported by reproducible performance evaluation. Similarly, Rahman et al. (2022) emphasized the role of appropriate drowning-prevention measures, including PFD use, in reducing water-related risks. Shattuck and Carhart (2021) also discussed lifejacket use within the broader context of maritime safety and risk reduction.

International standards provide important frameworks for the design and evaluation of flotation devices. ISO 12402-5:2020 specifies safety requirements for Level-50 buoyancy aids intended for sheltered-water applications, while ISO 12402-9:2020 provides relevant evaluation procedures for applicable PFD categories (International Organization for Standardization [ISO], 2020a, 2020b). The International Maritime Organization (IMO) Life-Saving Appliances (LSA) Code provides a broader framework for the testing and approval of life-saving appliances used in maritime applications (IMO, 2022). These standards emphasize the importance of objective performance assessment rather than relying solely on theoretical calculations or subjective observations. In the present study, the relevant standards are therefore used as engineering and methodological benchmarks rather than as evidence of certification or conformity. Despite the available literature on PFD design, user acceptance, buoyancy distribution, wearable flotation technology, and safety requirements, there remains a practical need for locally fabricated PFD prototypes whose design characteristics and preliminary performance are documented using accessible materials and experimental procedures. In particular, there is a need to distinguish clearly between analytical design estimates and experimentally measured performance. A theoretical buoyant force calculated from an

assumed or geometric volume does not by itself establish the actual buoyancy of a fabricated PFD. Likewise, a calculated metacentric height represents an analytical stability estimate and does not replace reproducible human-PFD stability testing. Similarly, a calculated strap design load represents a design requirement and should not be interpreted as the experimentally measured strength of the straps, buckles, stitching, or their attachment points. Addressing these distinctions is important for producing reliable prototype-level evidence and avoiding unsupported claims of compliance or safety. Accordingly, this study focuses on the design, fabrication, and preliminary experimental evaluation of a vest-type PFD manufactured primarily from locally available materials for calm-water applications. The prototype was designed for adult users within the 75–80 kg body-mass range and evaluated under controlled calm-water conditions. The investigation considers both analytical design parameters and experimental observations, with particular emphasis on separating calculated design estimates from measured prototype performance

MATERIALS AND METHODS

Validation Scope and Standards Framework

The validation programme comprised three levels: analytical design verification, prototype-level calm-water testing and standards benchmarking. ISO 12402-5:2020 was used as the principal conceptual benchmark because it addresses level-50 buoyancy aids for sheltered waters. The current ISO publication identifies ISO 12402-5:2020 as the published edition and notes that it is to be revised. The IMO LSA Code was used as a broader maritime safety reference. The IMO framework links life-saving appliances carried under SOLAS to the LSA Code and associated testing and approval procedures. No formal certification or regulatory approval was claimed in this study.

Materials Used

Table 1 presents the comprehensive specification of materials, their technical characteristics, and their respective functions within the PFD assembly.

Table 1: Material Specifications and Functions

S/N	Material	Specification	Function
1	Closed-cell polyethylene (PE) foam	60 mm thick	Primary buoyancy material
2	Polyester fabric	Water-resistant grade	Outer covering of the PFD
3	Nylon lining fabric	Lightweight, breathable	Inner lining for comfort
4	Nylon webbing straps	50 mm wide	Body adjustment and fastening
5	Plastic side-release buckles	Heavy-duty	Securing the life jacket
6	Hook-and-loop (Velcro) tape	Industrial-grade	Auxiliary fastening
7	High-strength polyester sewing thread	UV-resistant	Stitching all fabric components
8	Reflective tape	Marine-grade	Improves visibility during rescue
9	Mesh fabric	Breathable	Ventilation and comfort
10	Fabric edge binding tape	Polyester	Finishing exposed edges
11	Fabric marking chalk	Tailoring-grade	Pattern marking
12	Pattern paper	Brown paper	Development of cutting patterns

Note. S/N = Serial Number; PE = Polyethylene; UV = Ultraviolet.

Equipment and Tools

Table 2 presents the equipment and tools utilized, along with their specific functions in the development process.

Table 2: Equipment and Tools for Fabrication and Testing

S/N	Equipment/Tool	Specification	Purpose
1	Industrial sewing machine	Heavy-duty, multi-needle	Stitching all fabric components
2	Fabric cutting scissors	Professional-grade	Cutting fabric and lining materials
3	Foam cutting knife	Sharp, heated blade	Cutting polyethylene foam
4	Measuring tape	5 m, ± 1 mm accuracy	Measurement of body dimensions and materials
5	Steel ruler	1 m, ± 0.5 mm accuracy	Accurate linear measurements
6	Tailor's chalk	Water-soluble	Pattern marking
7	Pins and clips	Stainless steel	Holding materials before sewing
8	Hand sewing needles	Assorted sizes	Finishing and minor stitching
9	Digital weighing scale	0–150 kg, ± 0.1 kg	Measuring material and user weight
10	Vernier caliper	0–150 mm, ± 0.02 mm	Measuring foam thickness
11	Swimming pool	25 m $\times$ 12.5 m $\times$ 1.8 m	Buoyancy and flotation testing
12	Digital stopwatch	± 0.01 s accuracy	Timing flotation performance
13	Digital camera	High-resolution	Documentation of fabrication and testing
14	Personal computer	Standard specifications	Design calculations, data analysis, and report preparation

Note: S/N = Serial Number; m = Meters; mm = Millimeters; kg = Kilograms; s = Seconds

Closed-cell polyethylene foam was selected because of its lightweight structure, water resistance, buoyancy characteristics, durability, and affordability (Wang et al., 2022).

Design Theory and Engineering Calculations

Design Parameters and Assumptions

Table 3 presents the initial design data adopted for the development of the Personal flotation device.

Table 3: Initial Design Data for the Personal Flotation Device

Parameter	Symbol	Value	Unit
Overall Length	l	0.63	M
Overall Width	w	0.59	M
Overall Thickness	t	0.06	M
User Weight Range	-	75–80	Kg
User Height Range	-	1.80–1.90	M
Abdomen Circumference	-	108	Cm
Water Density	ρ_{water}	1000	kg/m ³
Foam Density	ρ_{foam}	50	kg/m ³
Gravitational Acceleration	g	9.81	m/s ²

Note: The Design Parameters Reflect Calm-Water Recreational Applications with a Safety-Oriented Approach

Average User Mass

The average user mass was calculated as the arithmetic mean of the specified weight range using Equation 1:

$$m_{avg} = \frac{m_1 + m_2}{2} \quad (1)$$

Where the minimum user mass (m_1) = 75 kg and maximum user mass in (m_2) = 80 kg

Substituting these values:

$$m_{avg} = \frac{75+80}{2} = 77.5 \text{ kg}$$

Therefore, the average design user mass is 77.5 kg.

Weight of the User

The body weight of the user was determined using Newton's second law as expressed in Equation 2

$$W = m \times g \quad (2)$$

Where w represents the weight of the user (N), m is the mass of the user (kg), and g is the gravitational acceleration (9.81 m/s²). Substituting the values:

$$W = 77.5 \times 9.81 = 760.28 \text{ N} \approx 760.0 \text{ N}$$

Bounding Geometric Volume

The Bounding geometric volume was calculated from the adopted dimensions using the geometric relationship shown in Equation 3:

$$V_b = l \times w \times t \quad (3)$$

Where l = 0.63m, w = 0.59m, and t = 0.06m. Substituting these values:

$$V_b = 0.63 \times 0.59 \times 0.06 = 0.0223 \text{ m}^3$$

Thus, $V_{\text{bounding}} = 0.0223 \text{ m}^3$.

The calculated 0.0223 m³ is the rectangular bounding volume defined by the overall dimensions. It is not a direct measurement of the actual polyethylene-foam volume incorporated into the shaped prototype.

Foam Mass and Net Buoyant Contribution

The mass of the closed-cell polyethylene (PE) foam used as the primary buoyant material was determined from the foam density and its effective volume. The density of the PE foam was taken as 50 kg/m³, while the effective foam volume was 0.0223 m³.

i. Mass of the Foam

$$m_f = \rho_f V_b \quad (4)$$

Substituting the values:

$$m_f = 50 \times 0.0223 = 1.115 \text{ kg}$$

Using the bounding geometric volume as an equivalent flotation volume, the estimated PE-foam mass is 1.115 kg. This value is an analytical estimate and not the directly measured mass of polyethylene foam in the fabricated PFD.

ii. Weight of the Foam

The corresponding weight of the foam was calculated as

$$W_f = m_f g \quad (5)$$

Where $g = 9.81 \text{ m/s}^2$

Substituting:

$$W_f = 1.115 \times 9.81 = 10.94 \text{ N}$$

iii. Upper-bound Geometric Buoyancy Estimate

The upper-bound geometric buoyancy estimate was determined from Archimedes' principle using the rectangular bounding volume of the PFD. The adopted volume of 0.0223 m³ represents the external geometric envelope calculated from the overall dimensions and does not represent the directly measured volume of polyethylene foam incorporated into the fabricated PFD. Therefore, the resulting buoyancy value is treated only as an analytical estimate of the maximum buoyancy associated with the assumed equivalent volume and is not interpreted as the experimentally measured buoyant force of the prototype. The equivalent flotation volume used in the analytical design was 0.0223 m³. The theoretical buoyant force was calculated from Archimedes' principle:

$$F_b = \rho_w g V_b \quad (6)$$

Where F_b is the theoretical buoyant force, ρ_w is water density, g is gravitational acceleration and V_b bounding geometric volume (m³).

Using the adopted values:

$$F_b = (1000)(9.81)(0.0223)$$

$$F_b \approx 218.76 \text{ N}$$

Thus, the upper-bound geometric buoyancy estimate is 218.76 N. This value is based on the rectangular bounding volume and should not be interpreted as the actual buoyant force generated by the fabricated PFD. Direct measurement of buoyant force would require an appropriate experimental displacement or buoyancy test.

iv. Net Buoyant Contribution of the Foam

The estimated net buoyancy associated with the assumed equivalent flotation volume was obtained by subtracting the estimated weight of the polyethylene foam from the upper-bound geometric buoyancy estimate:

$$F_{\text{net}} = F_b - W_f \quad (7)$$

Substituting:

$$F_{\text{net}} = 218.76 - 10.94 = 207.82 \text{ N}$$

The resulting value of 207.82 N is therefore an analytical net-buoyancy estimate based on the assumed equivalent flotation volume and estimated foam mass. It does not represent a direct experimental measurement of the net buoyancy of the fabricated PFD.

Simplified Stability Analysis

The stability of a person wearing a flexible PFD is governed by the combined human-PFD system rather than by the geometry of the PFD alone. The position of the user's Centre of gravity, distribution of flotation material, Centre of buoyancy, immersion depth, body orientation, and deformation of the flexible vest can all influence the resulting flotation stability. A simplified metacentric model was therefore used only as an analytical design estimate to examine the geometric stability characteristics of the prototype. It was not used as a direct prediction of the self-righting behaviour of a human wearer.

For an idealized rectangular water-plane approximation, the metacentric-height relationship can be expressed as:

$$GM = \frac{I}{V} - BG \quad (8)$$

where GM is the metacentric height (m), I is the second moment of area of the water plane (m⁴), V is the total volume of water displaced (m³), and BG is the distance between the center of buoyancy (CB) and center of gravity (CG) (m). For stable flotation, the condition $GM > 0$ must be satisfied.

Because the prototype has two principal geometric directions, the second moment of area was considered about both principal axes. For the longitudinal-axis approximation:

$$I = \frac{b \times l^3}{12} \quad (9)$$

Where b is the width of the PFD (0.59 m) and l is the length (0.63 m). Substituting:

$$I = \frac{0.59 \times 0.63^3}{12} = 0.0123 \text{ m}^4$$

The volume of displaced water, previously calculated in equation (3) is:

$$V = 0.0223 \text{ m}^3$$

For the simplified geometric estimate, a centre-of-buoyancy-to-centre-of-gravity distance of $BG = 0.15$ m was adopted as a design assumption. This assumption is used only to illustrate the sensitivity of the idealized geometric model and is not presented as a measured property of the human-PFD system. Substituting into the metacentric height equation (Equation 10):

$$GM = \frac{0.0123}{0.0223} - 0.15 = 0.5516 - 0.15 = 0.4016 \text{ m} \approx 0.40 \text{ m}$$

The calculated metacentric height is therefore retained only as a preliminary geometric estimate and should not be interpreted as the experimentally measured stability or self-righting performance of the human-PFD system.

Structural Design and Load-Bearing Assessment

The fastening system comprising the nylon webbing straps, plastic buckles, reinforced stitching, fabric attachment regions, and plastic D-rings was assigned a factor of safety of 3. The adopted average user weight was 760.0 N. The resulting design load was therefore calculated as 2,280 N. This value represents an engineering design requirement rather than an experimentally measured load-bearing capacity.

$$F_{\text{design}} = SF \times W \quad (10)$$

$$F_{\text{design}} = 3 \times 760.0 = 2280 \text{ N}$$

Where F_{design} is the calculated design load (N), SF is the safety factor, and W is the adopted user weight (N). The value of 2280 N therefore represents a calculated design requirement and not an experimentally measured load-bearing capacity. The complete fastening load path consists of the nylon webbing, plastic buckles, reinforced stitching, fabric attachment regions and plastic D-rings. Quantitative verification would require axial tensile testing of the complete assembly using a calibrated tensile-testing or universal-testing machine. Structural failure would be defined as webbing rupture, buckle fracture or disengagement, stitching failure, fabric tearing, D-ring failure or displacement, or permanent deformation that compromises the fastening function. Where an experimentally measured ultimate load F_u is available, the experimental factor of safety is:

$$FS_{\text{exp}} = \frac{F_u}{W} \quad (11)$$

and the load-capacity ratio is:

$$R_L = \frac{F_u}{F_d} \quad (12)$$

No numerical tensile-load measurements were available in the experimental record. Consequently, the ultimate load-bearing capacity, experimental factor of safety, and load-capacity ratio of the complete fastening assembly cannot be reported. The 2,280 N value is therefore retained only as a calculated design requirement.

Hydrostatic Pressure Analysis

The pressure acting on the submerged PFD was determined using the hydrostatic pressure equation as shown in Equation 13:

$$P = \rho \times g \times h \quad (13)$$

Where P is the hydrostatic pressure (Pa), ρ is the water density (1000 kg/m^3), g is gravitational acceleration (9.81 m/s^2), and h is the immersion depth (m). For shallow immersion in a swimming pool environment ($h = 0.30 \text{ m}$):

$$P = 1000 \times 9.81 \times 0.30 = 2943 \text{ Pa} = 2.94 \text{ kPa}$$

The calculated hydrostatic pressure represents the static water pressure corresponding to the assumed immersion depth. It provides a preliminary loading estimate and does not, by itself, establish the compressive stress, deformation behaviour, or long-term buoyancy retention of the foam.

Drag Force Analysis

The hydrodynamic drag force experienced by a swimmer wearing the PFD was determined using the drag equation as expressed in Equation 14:

$$F_D = \frac{1}{2} \times C_D \times \rho \times A \times V^2 \quad (14)$$

Where F_D is the drag force (N), C_D is the drag coefficient, ρ is the water density (1000 kg/m^3), A is the projected area (0.37 m^2), and V is the swimming velocity (m/s). For calm swimming conditions, the velocity was assumed to be $V = 0.5 \text{ m/s}$, and the drag coefficient was taken as $C_D = 1.1$ (Pérez-Rosés and Bastida, 2022).

Substituting the values:

$$F_D = \frac{1}{2} \times 1.1 \times 1000 \times 0.37 \times 0.5^2 = 50.88 \text{ N}$$

The calculated drag force represents an analytical estimate under the assumed swimming velocity, projected area, and drag coefficient. Because drag was not measured

experimentally, the result should not be interpreted as direct evidence of improved swimmer mobility or comfort.

Thermal Insulation Analysis

The rate of heat transfer was determined using Fourier's law of heat conduction as shown in Equation 15:

$$Q = \frac{k \times A \times (T_1 - T_2)}{L} \quad (15)$$

Where Q is the heat transfer rate (W), k is the thermal conductivity of the foam ($0.035 \text{ W/m}\cdot\text{K}$), A is the surface area (0.37 m^2), $(T_1 - T_2)$ is the temperature difference across the foam (10°C), and L is the foam thickness (0.06 m).

Substituting the values:

$$Q = \frac{0.035 \times 0.37 \times 10}{0.06} = 2.16 \text{ W}$$

The calculated heat-transfer rate represents a simplified one-dimensional conduction estimate under the assumed thermal properties and temperature difference. It does not constitute an experimental measurement of the prototype's thermal insulation performance.

Fabrication Method

The fabrication sequence comprised pattern development, material cutting, component assembly, foam insertion, joining, fastening, edge finishing, reinforcement, and quality inspection. The process was guided by engineering drawings to ensure dimensional accuracy and conformity with the specified design.

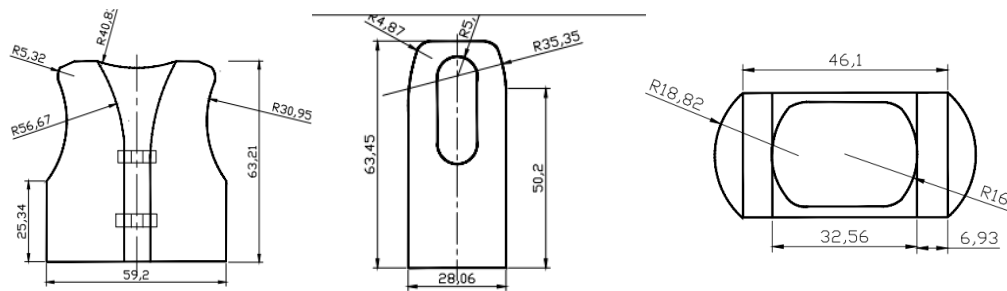


Figure 1: Composite Orthographic Views of the Developed PFD Showing the Front, Top, and Back

Participant Recruitment, Safety and Ethical Considerations

Ten adult participants weighing 75–80 kg and measuring 1.80–1.90 m were recruited for the calm-water evaluation of the developed Personal Flotation Device (PFD). The experimental tests were conducted at Alovera Hotel Swimming Pool, Minna, Niger State, Nigeria, under controlled calm-water conditions. Before participation, all participants were informed about the purpose of the study, test procedures, potential risks, and their right to discontinue participation at any time. Written informed consent was obtained from all participants before testing. The PFD was properly fitted and secured using the adjustable nylon webbing straps and plastic fastening components before each trial. Participants were continuously supervised throughout the water-based tests. Appropriate emergency and rescue arrangements were maintained throughout the testing, and the tests were discontinued if any participant experienced distress, discomfort, or any condition that could compromise safety. The study was conducted as a preliminary prototype evaluation and the results are reported only within the conditions and participant group investigated.

Performance Evaluation

The fabricated PFD was evaluated under controlled calm-water conditions. The testing programme considered

buoyancy, stability, comfort, water absorption and structural integrity. Ten adult participants within the intended design range of 75–80 kg body mass and 1.80–1.90 m height participated in the user-based assessment. Testing was performed in a swimming pool measuring $25 \text{ m} \times 12.5 \text{ m} \times 1.80 \text{ m}$, with an average water depth of 1.50 m and water temperature of $28 \pm 2^\circ\text{C}$. Before each test, the PFD was fitted using the adjustable nylon webbing straps and plastic side-release buckles. The fit and fastening were checked before the participant entered the prescribed test position. Participants were briefed on the test procedure and supervised throughout the water-based assessment.

Buoyancy Evaluation

Each participant wore the PFD and assumed the prescribed natural floating position for 15 min. Successful flotation was defined as maintaining flotation support throughout the test period without complete loss of flotation. Head clearance was measured as the vertical distance between the water surface and the participant's mouth/chin airway region while the participant maintained the prescribed floating position. The measurement was recorded in centimetres. The mean head clearance was calculated as:

$$\bar{H} = \frac{\sum_{i=1}^n H_i}{n} \quad (16)$$

Where $\bar{H}$ is the mean head clearance (cm), H_i is the individual measurements (cm), and n is the number of participants.

Buoyancy was additionally assessed using a five-point rating scale:

- 1—Very poor
- 2—Poor
- 3—Fair
- 4—Good
- 5—Excellent

Buoyancy efficiency was calculated from the mean participant rating using

$$BE = \frac{\bar{B}}{B_{max}} \times 100, \quad (17)$$

Where $\bar{B}$ is the mean buoyancy rating and B_{max} is the maximum rating of 5.

Stability Evaluation

Stability was evaluated based on the participant's floating orientation and recovery behaviour following a controlled 90° rotational disturbance. Each participant wore the PFD, which was properly fitted and secured using the adjustable nylon webbing straps and plastic side-release buckles, and assumed the prescribed floating position before the stability assessment. A controlled 90° rotational disturbance was then applied by the test operator. Recovery time was measured using a digital stopwatch with a resolution of ± 0.01 s. Timing commenced immediately following the disturbance and ended when the participant returned to the predefined upright floating orientation. Participants were permitted to assist their recovery using their normal arm and body movements. Ten recovery trials were conducted for each participant. The participant-level mean recovery time was calculated using:

$$ART = \frac{\sum_{i=1}^n t_i}{n} \quad (18)$$

Where ART is mean recovery time, t is recovery time for trial i , and n is the number of recovery trials.

Stability was additionally assessed using a five-point rating scale: 1 = Very Poor, 2 = Poor, 3 = Fair, 4 = Good, and 5 = Excellent. The mean stability rating was calculated from the participant responses.

Stability efficiency was calculated as:

Mass Change Following Immersion

The water uptake of the complete assembled PFD was evaluated by determining the change in mass before and after immersion. The fully assembled and dry PFD was first weighed using the digital weighing scale, and the initial dry mass was recorded as M_i . The PFD was then immersed in the swimming pool under the same calm-water conditions used for the flotation assessment. Following immersion, the PFD was removed from the water and allowed to drain under the prescribed test procedure before its final mass was measured and recorded as M_f .

The percentage mass increase following immersion was calculated using:

$$\Delta M(\%) = \left(\frac{M_f - M_i}{M_i} \right) \times 100 \quad (21)$$

Where ΔM is the percentage mass increase after immersion, M_i is the initial dry mass of the PFD (kg), and M_f is the mass of the PFD after immersion and controlled draining (kg).

The measured mass of the assembled PFD increased from 1.85 kg before immersion to 1.92 kg after immersion and controlled draining. Therefore,

$$\Delta M = \left(\frac{1.92 - 1.85}{1.85} \right) \times 100$$

$$\Delta M = 3.78\%$$

The 3.78% value represents the measured increase in mass of the complete assembled PFD following the specified immersion and draining procedure. It is reported as an

$$SE = \frac{\bar{S}}{S_{max}} \times 100, \quad (19)$$

Where $\bar{S}$ is the mean stability rating.

The stability results were interpreted as preliminary observations of human-PFD recovery behaviour under the controlled calm-water conditions investigated. Because participants were permitted to assist their recovery using normal arm and body movements, the measured recovery time represents assisted human-PFD recovery behaviour rather than passive self-righting performance. The results should therefore not be interpreted as standardized self-righting performance or as evidence of conformity with a certification requirement. Future replicated testing should standardize and document the disturbance procedure, direction of rotation, starting orientation, degree of participant assistance, recovery endpoint, and environmental conditions to improve reproducibility.

Comfort Evaluation

Comfort was assessed using a structured five-point Likert-scale questionnaire covering:

- i. body fit;
- ii. ease of wearing;
- iii. flexibility;
- iv. breathability; and
- v. freedom of movement.
- vi.

Table 4: The rating criteria were

Rating	Description
1	Very Poor
2	Poor
3	Fair
4	Good
5	Excellent

The comfort efficiency was calculated as:

$$CE = \frac{\bar{C}}{C_{max}} \times 100, \quad (20)$$

Where C_{max} = 5, where $\bar{C}$ is the mean comfort score.

indication of water uptake under the conditions investigated and is not interpreted as a standardized water-absorption or water-resistance efficiency. Because a standardized water-absorption test procedure and acceptance criterion were not applied, the result should not be used to establish compliance with a specific PFD standard.

Structural Integrity Evaluation

Structural integrity was assessed through visual and manual inspection of the nylon webbing, plastic buckles, reinforced stitching, polyester fabric, plastic D-rings and polyethylene foam before and after the flotation tests. The assessment considered:

- i. webbing tearing;
- ii. broken or loosened stitching;
- iii. buckle disengagement;
- iv. fabric tearing;
- v. D-ring displacement;
- vi. permanent deformation; and
- vii. Displacement of flotation components.

The prototype was considered to have maintained short-term structural integrity when no visible damage capable of compromising fastening or flotation function was observed. Following the preliminary flotation evaluation, the assessed components remained intact, with no visible tearing, broken stitching, buckle disengagement, or permanent deformation that compromised prototype function. These observations

provide preliminary evidence of short-term structural integrity under the tested flotation conditions. Because calibrated tensile-load measurements were not obtained, the ultimate load-bearing capacity and experimental factor of safety of the fastening system could not be established.

Engineering and Statistical Analysis

The collected data were analyzed using descriptive statistics and engineering performance indices. The sample mean and standard deviation were used to summarize participant responses and measured performance, while the coefficient of variation (CV) was used to describe relative data variability. The sample standard deviation was calculated as:

$$SD = \sqrt{\frac{\sum_{i=0}^n X_i(X_i - \bar{X})}{n-1}} \quad (22)$$

Where X_i is the individual observation, $\bar{X}$ is the sample mean, and n is the number of observations.

The coefficient of variation was determined from:

$$CV = \frac{SD}{\bar{X}} \times 100 \quad (23)$$

Where CV is the coefficient of variation expressed as a percentage

For questionnaire responses, percentage frequency was calculated as:

$$P = \left(\frac{f}{n}\right) \times 100 \quad (24)$$

Where P is the percentage frequency, f is the frequency of a specific response category, and n is the total number of

respondents. Buoyancy, stability, and comfort ratings were reported separately because they represent subjective assessments, while head clearance, recovery time, and mass change represent measured physical quantities. Structural integrity was assessed qualitatively based on visual and manual inspection. The different performance variables were therefore not combined into a single numerical performance index.

RESULTS AND DISCUSSION

Analytical Design Results

The analytical calculations provide preliminary engineering estimates for the fabricated PFD and are not treated as experimental validation. The calculated 0.0223 m³ volume is the rectangular bounding volume obtained from the overall dimensions rather than a directly measured foam volume. Accordingly, the 218.76 N buoyancy value is an upper-bound geometric estimate. The adopted average design user mass was 77.5 kg, corresponding to a user weight of approximately 760.0 N, and the fastening-system design load was 2,280 N using a factor of safety of three. The simplified geometric stability analysis produced an estimated metacentric height of approximately 0.40 m under the stated idealized assumptions. This value is not an experimental measurement of human–PFD stability. Analytical and experimental results are therefore presented separately.

Table 5: Analytical Design Parameters of the Developed PFD

S/N	Parameter	Symbol	Value	Unit	Classification
1	Average design user mass	m_{avg}	77.5	Kg	Analytical
2	Average user weight	W	760.0	N	Analytical
3	PFD length	l	0.63	M	Measured/design
4	PFD width	w	0.59	M	Measured/design
5	Foam thickness	t	0.06	M	Measured/design
6	Bounding geometric volume	V_b	0.0223	m ³	Analytical
7	Upper-bound geometric theory buoyancy estimate	F_b	218.76	N	Analytical
8	Strap fastening design load	F_d	2280	N	Analytical
9	Second moment of area	I	0.0123	m ⁴	Analytical
10	Simplified metacentric height	GM	0.40	M	Analytical estimate

Note: The 0.0223 m³ value represents the rectangular bounding geometric volume rather than the directly measured volume of polyethylene foam. Consequently, the 218.76 N value is an upper-bound geometric buoyancy estimate and not an experimentally measured buoyant force of the fabricated PFD.

Fabricated Prototype Technical Specifications

Figure 2 presents the orthographic views and component identification of the fabricated vest-type PFD. The prototype consists of the red outer fabric, internal polyethylene flotation

panels, nylon webbing straps, plastic side-release buckles, plastic D-rings, and adjustable leg straps. The principal fabricated dimensions are 0.63 m in length, 0.59 m in width, and 0.06 m in thickness.



Figure 2: Orthographic Views and Component Identification of the Completed Vest-Type Personal Flotation Device

Experimental Buoyancy and Stability Performance

Ten adult participants within the intended design range participated in the calm-water flotation assessment. All ten participants maintained flotation during the 15-min evaluation period. Head clearance ranged from 9 to 11 cm, with a mean of 10.2 cm. The mean participant buoyancy rating was $4.60 \pm 0.52/5$. This rating represents a subjective assessment and should be distinguished from the analytical buoyancy estimate of 218.76 N. Stability testing involved a

controlled 90° rotational disturbance. The reported mean recovery time was 2.95 ± 0.16 s, while the mean stability rating was $4.40 \pm 0.52/5$. These measurements describe observed recovery behavior under the specified calm-water conditions. The calculated 0.40 m metacentric height remains a preliminary geometric estimate and was not used as experimental validation of human-PFD stability.

Table 5: Summary of Participant-Level Experimental Observations

Performance variable	Number of participants/observations	Minimum	Maximum	Mean	Standard deviation
Head clearance (cm)	10	9.0	11.0	10.2	Not reported in original record
Buoyancy rating (/5)	10	Not reported	Not reported	4.60	0.52
Stability rating (/5)	10	Not reported	Not reported	4.40	0.52
Comfort rating (/5)	10	Not reported	Not reported	4.30	0.48
Recovery time (s)	10 participant-level means	Not reported	Not reported	2.95	0.16

Recovery-Time Statistics were Calculated from the Ten Participant-Level Means, with Each Participant-Level Mean Based on ten Recovery Trials

Comfort and Water Absorption

The prototype achieved a mean comfort rating of $4.30 \pm 0.48/5$. The vest configuration, adjustable straps, polyethylene foam, and breathable fabric were associated with the reported user ratings; however, the present study does not permit causal attribution of comfort to any individual component. The complete PFD mass increased from 1.85 to 1.92 kg following immersion and controlled draining, corresponding to a 3.78% mass increase. This result describes mass uptake under the specified procedure and should not be interpreted as compliance with a standardized water-absorption requirement.

Structural Integrity

Structural integrity was assessed through visual and manual inspection of the nylon webbing, plastic buckles, reinforced stitching, polyester fabric, plastic D-rings, and polyethylene foam before and after the flotation tests. The assessment considered webbing tearing, broken or loosened stitching, buckle disengagement, fabric tearing, D-ring displacement, permanent deformation, and displacement of flotation components. Following the preliminary evaluation, no visible damage compromising the fastening or flotation function was observed. These findings provide preliminary evidence of

short-term structural integrity under the tested flotation conditions. Because calibrated tensile-load measurements were not obtained, the ultimate load-bearing capacity of the fastening assembly could not be established. The individual performance variables were retained as separate measures because they represent different physical and subjective characteristics. Buoyancy, stability, and comfort were assessed partly through participant ratings, while head clearance and recovery time were measured during human-PFD testing, mass change was determined gravimetrically, and structural integrity was assessed qualitatively.

Comparison with Published Evidence and Standards Benchmarks

The experimental findings can be discussed in relation to published evidence on PFD performance; however, direct comparison with commercial PFDs was not performed because no commercial comparator was evaluated under identical experimental conditions. The observed head clearance, participant ratings, recovery time, and short-term structural observations provide preliminary evidence of prototype performance under the tested calm-water conditions. These findings are consistent with the broader literature emphasizing buoyancy distribution, correct fitting,

retention, and user comfort as relevant characteristics of PFD performance (Barwood et al., 2014; Lincoln et al., 2012; Lunt et al., 2014). ISO 12402-5:2020 and ISO 12402-9:2020 are used here as standards benchmarks rather than evidence of certification. Because formal third-party conformity assessment was not conducted, the prototype should not be described as ISO-certified or as demonstrably equivalent to a certified commercial PFD.

Discussion

The experimental results demonstrate that the fabricated PFD provided flotation support for the ten participants under the controlled calm-water conditions investigated. All participants maintained flotation for 15 min, with head clearance ranging from 9 to 11 cm and a mean of 10.2 cm. Mean participant ratings were $4.60 \pm 0.52/5$ for buoyancy, $4.40 \pm 0.52/5$ for stability, and $4.30 \pm 0.48/5$ for comfort. The mean recovery time of 2.95 ± 0.16 s following the controlled 90° disturbance provides an experimental measure of recovery behaviour under the specified test conditions. The increase in complete-device mass from 1.85 to 1.92 kg corresponds to a 3.78% mass increase following immersion and controlled draining. Structural inspection revealed no visible damage compromising the fastening or flotation function during the preliminary test programme. These

findings should be interpreted as preliminary prototype-level evidence and not as certification or proof of full compliance with applicable PFD requirements. The experimental evaluation was limited to ten adult participants within the 75–80 kg design range and controlled swimming-pool conditions. The supplied experimental record contains aggregate participant results but not the complete participant-level head-clearance, rating, and recovery-time records; therefore, participant-level reconstruction was not attempted. The actual volume of polyethylene foam incorporated into the shaped PFD was not independently measured, so the 0.0223 m^3 value remains a bounding geometric volume and the corresponding 218.76 N buoyancy remains an analytical estimate. The 2,280 N fastening-system load is likewise an analytical design requirement, not measured strength. The 3.78% mass increase represents water uptake under the reported immersion and draining procedure rather than a standardized absorption-performance value. Future work should include independent measurement of foam volume and density, direct buoyancy testing, calibrated tensile testing of the complete fastening assembly, participant- and trial-level data collection, replicated immersion testing, broader water conditions, long-term durability assessment, and standards-based conformity testing.

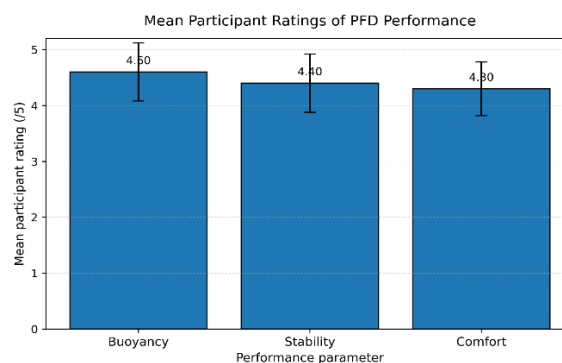


Figure 3: Mean Participant Ratings for Buoyancy, Stability and Comfort of the Developed PFD

CONCLUSION

This study successfully designed and fabricated a locally manufactured vest-type Personal Flotation Device (PFD) using closed-cell polyethylene foam, polyester fabric, nylon webbing, plastic fastening components, plastic D-rings, and reinforced stitching for adult users weighing 75–80 kg. The fabricated prototype measured $0.63 \text{ m} \times 0.59 \text{ m} \times 0.06 \text{ m}$ and was evaluated under controlled calm-water conditions at Alovera Hotel Swimming Pool, Minna, Nigeria. Analytical evaluation produced a rectangular bounding volume of 0.0223 m^3 and an upper-bound geometric buoyancy estimate of 218.76 N. The simplified geometric stability analysis produced an estimated metacentric height of approximately 0.40 m, while the fastening system had a calculated design load of approximately 2,280 N. These values represent analytical design estimates and were not treated as experimentally measured buoyancy, stability, or structural strength. The experimental evaluation involving 10 adult participants showed that all participants maintained flotation for 15 min, with head clearance ranging from 9 to 11 cm and a mean of 10.2 cm. Mean participant ratings were $4.60 \pm 0.52/5$ for buoyancy, $4.40 \pm 0.52/5$ for stability, and $4.30 \pm 0.48/5$ for comfort. Following the controlled 90° rotational disturbance, with participants permitted to assist their recovery using normal arm and body movements, the mean

recovery time was 2.95 ± 0.16 s. The complete PFD exhibited a 3.78% increase in mass following immersion and controlled draining, while visual and manual inspection revealed no visible structural damage capable of compromising the fastening or flotation function. Overall, the findings provide preliminary prototype-level evidence that locally available materials can be used to fabricate a functional PFD for calm-water applications. However, the study does not establish certification, full compliance with applicable PFD standards, passive self-righting performance, or quantitative structural strength. Further research should therefore include direct buoyancy measurements, calibrated tensile testing of the complete fastening assembly, replicated participant and immersion trials, participant-level data collection, testing under broader water conditions, long-term durability assessment, and formal standards-based conformity assessment before any certification or wider safety claim is made.

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