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The Experimental Study of Using Array of Wireless Accelerometer Sensors for Impact Loads on The Amphibious Float Model Test

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Abstract– **Maritime tourism in Indonesia holds substantial potential for future growth, contributing to the well-being of coastal communities. Amphibious aircraft, capable of taking off and landing on both water and land, provide an efficient means for tourists to explore the country's diverse regions. Accurately predicting hydrodynamic loads is therefore essential to ensuring the reliability of amphibious float structures. This study aims to validate the feasibility of replacing cable-based accelerometer sensors with wireless alternatives to measure impact loads on an amphibious aircraft float model. Accelerometers were mounted on the float model, and impact loads were tested using a launcher in a mechanical workshop prior to hydrodynamic tests in a water tank. The data revealed that the sensors effectively captured impact loads, with measurements averaging a 3.7% deviation from theoretical values. The maximum impact force recorded was 1.98 g, and the minimum was 0.61 g. These findings support the use of wireless systems for hydrodynamic impact load testing in water tank environments.**

Keywords–accelerometer sensors, wireless system, amphibious float model, impact load, sensor calibration, g-force

I. INTRODUCTION[1]

Indonesia, with its vast archipelago and stunning natural landscapes, is a premier destination for both domestic and international tourists. The potential for maritime tourism in Indonesia represents a promising avenue for future development, as it has been shown to significantly enhance the well-being of coastal communities. However, current inter-island travel predominantly relies on maritime transportation modes, such as wooden boats, which are limited by long travel times. The construction of airports for conventional airplanes on many islands faces significant challenges, including limited runway space and high costs. In this context, amphibious aircraft offer a viable alternative, providing tourists with rapid access to islands and enabling more extensive exploration of Indonesia's diverse regions. Beyond their application in the tourism industry, amphibious aircraft are also utilized for a range of other purposes, including the transportation of goods and logistical support for remote islands, thereby contributing to regional development and economic growth. Moreover, these aircraft play a crucial role in emergency situations at sea, offering rapid response capabilities in cases of technical malfunctions, accidents, or other unforeseen circumstances, thereby enhancing maritime safety.

Amphibious aircraft are seaplanes designed with the capability to take off and land on both water and land surfaces. This capability makes them particularly suitable for use on small islands in Indonesia, where building extensive airport infrastructure may not be feasible. This transportation system is highly flexible, as it can operate on land, lakes, large rivers, bays, and seas [1]. When landing on water, the floats of amphibious aircraft must withstand hydrodynamic loads, including the pressure exerted on the float surfaces. Numerous researchers have contributed to the understanding of these dynamics. Von Kármán was the first to propose a theoretical framework for analyzing the landing of amphibious aircraft [2]. [3] conducted numerical simulations of seaplane landings on wave surfaces, focusing primarily on the interaction between the aircraft and the water surface during landing. [4] addressed the structural strength challenges associated with amphibious aircraft landing on water, analyzing pressure distribution on the hull and simulating landings under various initial horizontal and vertical velocities. [5] conducted simulation studies to determine the effects on the float during water landings.

During operations such as takeoff, landing, and taxiing on the water surface, seaplanes are often subjected to continuous wave action and turbulence. Understanding the dynamic characteristics of these aircraft is crucial to

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prevent structural resonance damage and vibrational fatigue. As a key structural component, the float is vital for evaluating the dynamic performance of the seaplane. [6] assessed the bending natural frequency of seaplane floats using the finite element method, examining three conditions: dry, wet at zero speed, and wet at forward speed. [7] compared the pressure distribution on the nose of amphibious aircraft, considering it as both rigid and elastomeric, and analyzed the stress and pressure when the nose was treated as an elastomer. [8] numerically predicted the pressure on the float of an amphibious plane, conducting simulations with various angles of attack and heel conditions, including 0, 5, and 10 degrees for trim by bow and stern, and 0, 5, 10, and 18 degrees for heeling. To validate these numerical simulations, experimental work is essential. [9] performed analysis and testing to evaluate the feasibility of a small UAV capable of landing on water and being recovered for continued use. The tested UAV features a flying wing design constructed from expanded polypropylene foam, with a hollowed-out center section designated for housing the avionics. Acceleration data was collected using LIS331 3-axis accelerometers strategically placed at five locations, including the wingtips. [10] reviewed various impact safety challenges related to lightweight and small UAVs, including UAV weight threshold estimation tests, UAV impact tests on aircraft windshields, and horizontal stabilizer impact tests, comparing these results to bird collision data. Another study by [11] predicted impact loads using free-fall bodies in a water tank. This load prediction was achieved through a combination of numerical analysis and hydro-elastic model testing. [12] further conducted experiments to predict the fatigue life of composite seaplane floats based on proposed model test data. These studies also explored the application of wireless technology to facilitate more convenient measurement. [13] compared Wireless Sensor Networks with traditional laboratory-based and in-situ monitoring methods, highlighting the advantages of wireless systems, such as superior response speed, cost-effectiveness, ease of deployment, and reliable measurements. Their study also provided an overview of wireless sensor node architecture, discussing key aspects such as subsystems, Quality of Service (QoS) requirements, and the importance of low power consumption in microcontroller units. [14] presented an experimental study to monitor the health of submarine hull structures using strain sensors and wireless communication technology. The monitored submarine hull was constructed on a 1:30 hydro-elastic model scale, incorporating a steel bar backbone, and was tested in a water tank at the Indonesian Hydrodynamic Laboratory (IHL). [15] also conducted experimental work to monitor data acquisition of weather buoys, utilizing measurement sensors and wireless communication technology. [16] studied the design of a control system aimed at regulating levels of ethylene, oxygen, carbon dioxide, and temperature using an Arduino Uno microcontroller integrated with an Internet of Things (IoT) system. Their experimental results demonstrated that the control system was capable of conditioning the air within a container and integrating with IoT concepts. [17] developed a monitoring system that employed accelerometer sensors to detect vertical sea level changes over time. This device was equipped with an internet connection, allowing data collected from the sensors to be processed on-site using an Arduino microcontroller and subsequently transmitted to an online platform for remote monitoring.

Based on the literature review, it is evident that accurately predicting hydrodynamic loads is crucial to ensuring the reliability of the designed structure. Accurate load prediction is essential for conducting further analyses, such as stress analysis on the aircraft float. Failure to accurately predict these loads could result in catastrophic outcomes, such as tearing (rupture) of the float or damage to the aircraft’s landing gear, potentially leading to the sinking of the amphibious aircraft. The phenomenon of impact loads is studied both numerically and experimentally.

In recent years, data acquisition in model testing has increasingly relied on numerous cables to connect sensors to data recording and processing systems. While this traditional approach can be effective in certain scenarios, it poses significant challenges when applied to measuring impact loads in seaplane model tests. The primary issue arises from the requirement to install the measurement system and associated data storage within the confines of the seaplane model, which is typically designed to be lightweight and structurally delicate. The addition of numerous cables not only complicates the setup but also introduces potential risks, such as added weight, interference with the model’s aero-hydrodynamics, and physical damage to the model's structure. These complications can lead to inaccurate data collection and compromised integrity of the experimental setup.

To address these challenges, this research proposes the implementation of wireless impact sensors as a viable solution. By adopting wireless technology, the need for extensive cabling is eliminated, thereby reducing the complexity and potential drawbacks associated with traditional wired systems. With this approach, only the array of wireless impact sensors needs to be mounted on the seaplane model, which significantly simplifies the installation process. This not only helps preserve the model's structural integrity and aero-hydrodynamic properties but also enhances the accuracy and reliability of the data collected. The use of wireless sensors enables the real-time transmission of impact data to remote data acquisition systems, ensuring efficient, precise, and unobtrusive measurement of impact loads during seaplane model tests. Thus, the proposed wireless impact sensor system offers a streamlined and innovative solution to the challenges faced in current data acquisition practices in seaplane model testing.

This experimental study aims to validate the effectiveness of wireless accelerometer sensors in accurately measuring impact loads during hydrodynamic tests conducted on an amphibious aircraft float model. To achieve this objective, a sensor array comprising multiple wireless accelerometers was carefully mounted onto the float model to capture precise impact data. Prior to the main hydrodynamic impact tests, which were performed in a controlled water tank environment to simulate realistic operational conditions, the wireless accelerometer sensors underwent a series of preliminary tests. These preliminary tests were designed to confirm the sensors' capability to reliably measure impact loads in a wireless setup, ensuring data integrity and sensor performance before the actual experimental trials. The validation process thus ensures that the wireless accelerometer sensors provide accurate and reliable measurements, paving the way for their application in future impact load assessments of amphibious aircraft and similar maritime structures. The impact testing procedure involved the use of a launcher within a mechanical workshop, designed to propel the float model towards a net positioned strategically in front of the launcher to simulate landing scenarios. To ensure the accuracy and reliability of the measurements, each accelerometer sensor was calibrated before being installed on the float model. This calibration process was essential to verify the proper functionality of each sensor, thereby ensuring the integrity of the data collected during the impact tests.

II. METHOD

In this section, the experimental methodology is described. Initially, a flowchart outlining the study's procedure is presented in Figure 1 below.

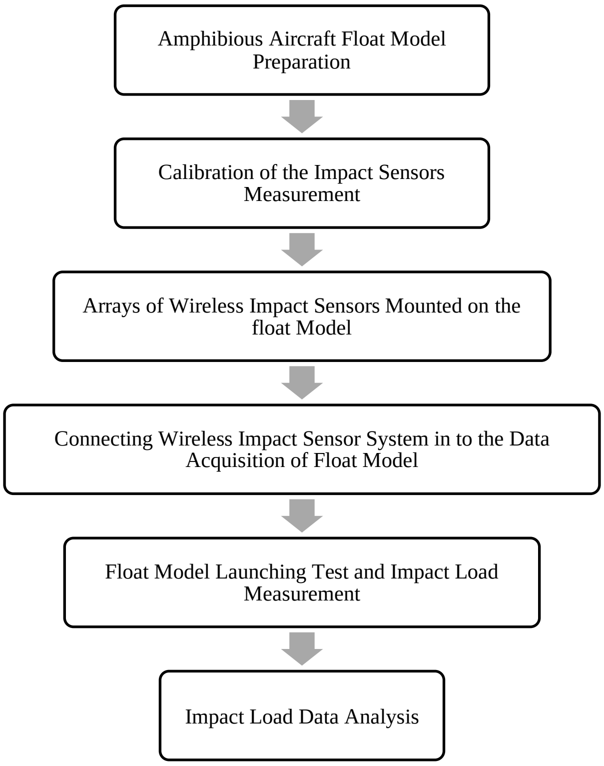

Figure 1. The flowchart of experimental study

TABLE 1.
FLOAT DIMENSION

Item	Value	Unit
Length Over All (LOA)	1.980	m
Length Water Line (LWL)	1.891	m
Length Between Perpendicular (LPP)	1.980	m
Beam (Beam)	0.262	m
Depth (H)	0.263	m
Draft (T)	0.148	m

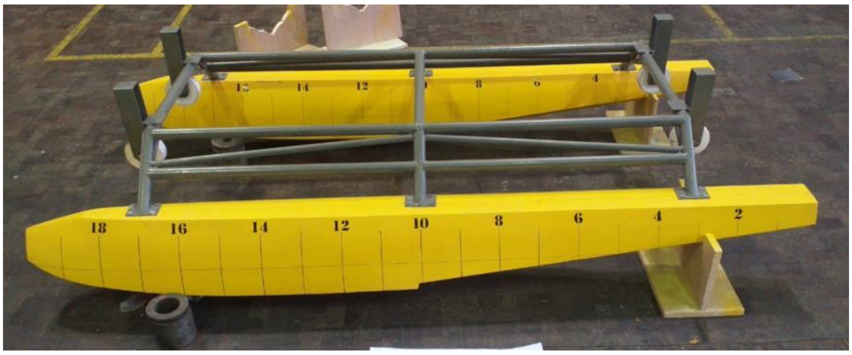

Figure 2. Model of the amphibious aircraft float

As shown in Figure 1, this experimental study investigates the use of an array of wireless accelerometer sensors to measure impact loads on an amphibious float model. The study is carried out in six steps. First, the amphibious aircraft float model is prepared. The float model is scaled at 1:5, with the dimensions presented in Table 1 [18]. This model is constructed from resin-laminated wood, as shown in Figure 2.

Second, prior to conducting impact tests, it is crucial to verify that the accelerometer sensors accurately record data and to calibrate the software code to address any inaccuracies. This is achieved by conducting multiple laboratory tests in which the sensors are dropped directly onto the lab floor. These tests facilitate a comparison between the actual data and the expected data under these conditions for the Z-axis acceleration.

Figure 3. Weighting the sensor on scales

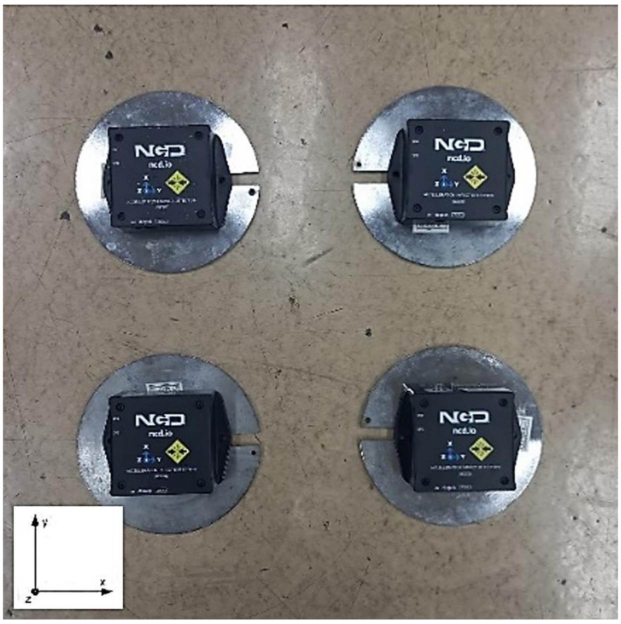

Figure 4. Dropped sensors on the lab floor

The impact sensor in this experiment has the main following features [19]:

- Industrial-grade with a 3-axis accelerometer for detecting impacts.
- Adjustable acceleration range from ±2g to ±16g.
- Configurable interrupt threshold from ±16mg to ±15.3g.
- Data rate adjustable between 1Hz and 5.37kHz.
- Temperature range of -40°C to +85°C.
- Line-of-sight (LOS) range up to 28 miles using 900MHz high-gain antennas.
- Compatible with Raspberry Pi, Microsoft Azure, Arduino, and other platforms.
- Supports wireless mesh networking via Digi Mesh® technology.
- Can integrate up to 256 sensor nodes in a single network.
- Uses an open communication protocol for custom applications.
- Capable of up to 500,000 transmissions with two AA batteries.

Sensor calibration began by measuring the weight of the sensor itself and the small weight attached to it, totaling 0.582 kg, as presented in Figure 3. The sensor and weight were then dropped from a height of 0.5 meters above the lab floor, as depicted in Figure 4.

The equation for impact velocity, v, can be estimated as:

$$v = \sqrt{2g * 0.5} = 3.132 m/s \qquad (1)$$

Momentum:

$$p = mv = 0.582 * 3.132 = 1.823\ kg\ m/s \qquad (2)$$

Assuming force is constant and time to decelerate to be approximately 0.1 - 0.25 seconds

$$F = \frac{1.823}{0.1} = 18.23 = 1.86\text{g} \qquad (3)$$

$$F = \frac{1.823}{0.25} = 7.29 = 0.74\text{g} \qquad (4)$$

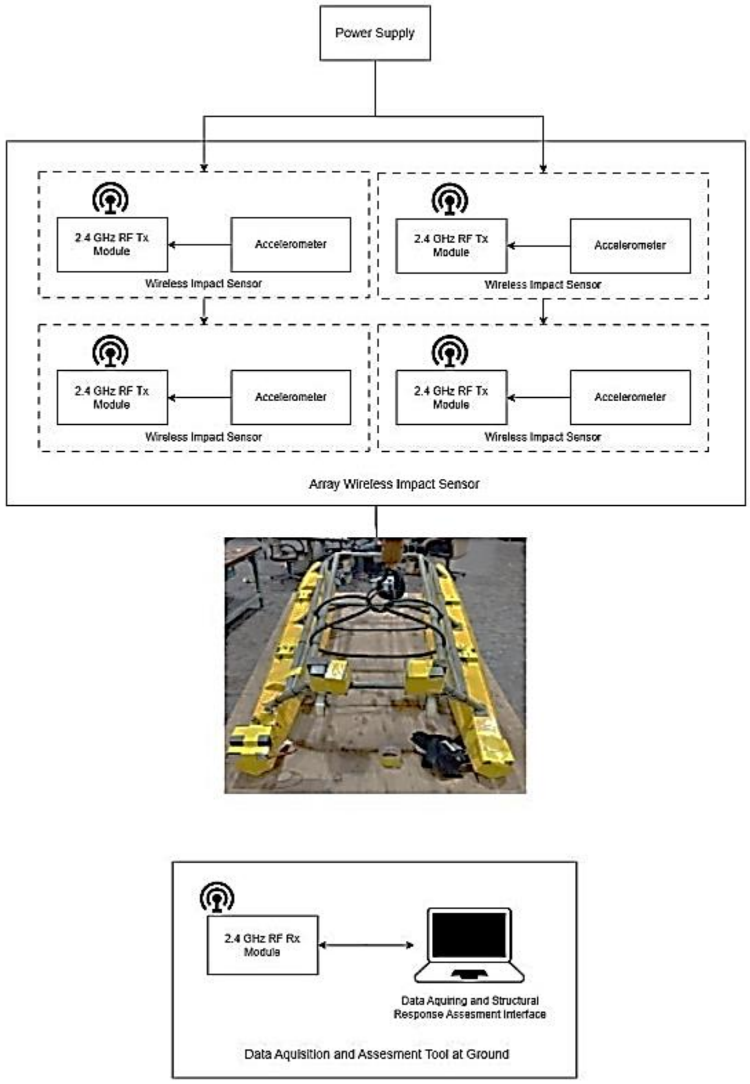

Figure 5. Schematic of wireless impact measurement system on the seaplane float model scale

Figure 5 illustrates the schematic of the wireless impact measurement system designed for the scaled seaplane float model. This system employs an advanced approach to capture and transmit impact data and is composed of two main components. The first component is the wireless impact sensor, which detects impact forces experienced by the seaplane float. This sensor is highly sensitive and precise, capturing even minor impact forces to ensure reliable and comprehensive data collection. The second component is the digital data acquisition system, which is integrated with wireless communication technology. This system records the impact data detected by the sensor and transmits it wirelessly to a remote monitoring station. The use of wireless technology eliminates the need for physical connections, making the system more versatile and easier to deploy, particularly in complex environments involving scaled-down seaplane float models. Combined, these components form a sophisticated wireless impact measurement system that enables real-time monitoring and analysis of impact forces on seaplane float models. The integration of wireless technology not only enhances the system's flexibility and ease of use but also ensures quick and secure data transmission for efficient processing and analysis.

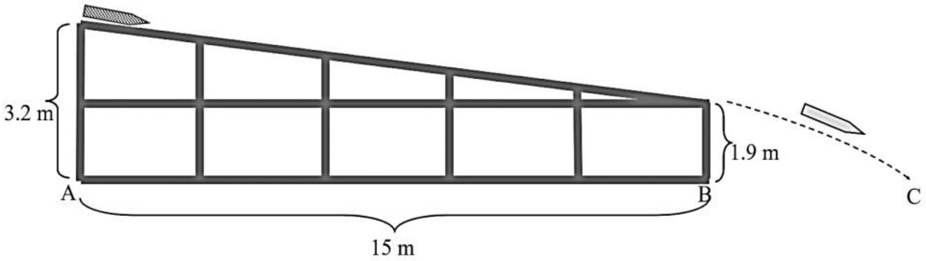

Figure 6. Method of the dry impact test for the N219A floater model using a launcher device

After completing the experimental setup of the scale model seaplane, the launching test can proceed. The schematic for this test is presented in Figure 6. This launching test examines the readings from the array of impact sensors installed on the seaplane float model. The process involves launching the N219A float model from a launcher device (see Figure 6) with a maximum height of 3.2 meters at point A at an elevation angle of 5 degrees [20]. The float model then glides freely for a horizontal distance of 15 meters, experiencing free fall from a height of 1.9 meters at point B before reaching position C. The distance between positions B and C can be influenced by the coefficient of friction between the launcher device rail and the wheels of the float model, as well as by the float model's weight.

Figure 7. Placement of mesh nets in front of the launcher for securing the N219A floater model upon landing.

Figure 8. Placement of impact sensors and placement of ballast weights.

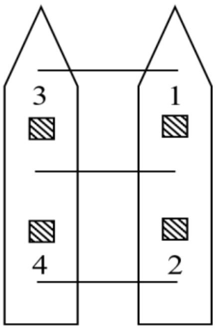

Figure 9. Sketch of impact sensor placement

Figure 10. Weighing the N219A floater model.

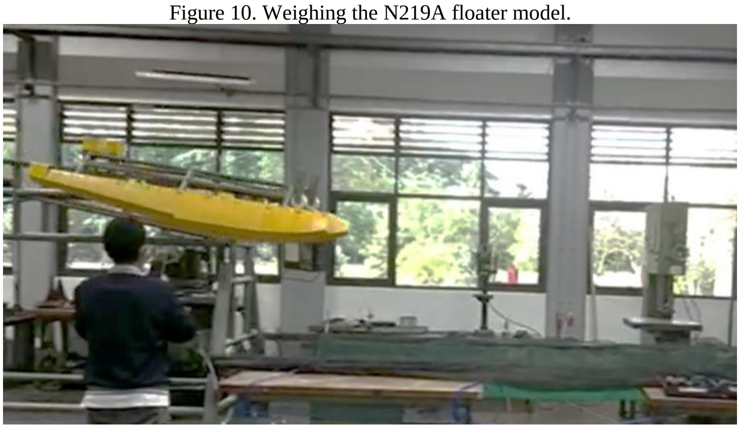

Figure 11. Time measurement of N219A floater model launching on the launcher until landing

To prevent damage to the float model upon touchdown, mesh nets are positioned where the float model is expected to land, as shown in Figure 7. Four impact sensors are mounted on the deck of the float model: Sensor 1 on the right front side, Sensor 2 on the right rear side, Sensor 3 on the left front side, and Sensor 4 on the left rear side. The placement of these sensors is shown in Figures 8 and 9. Figure 8 also shows the placement of ballast at the stern of the float model. Before conducting the test, the N219A float model is weighed, with the actual total weight during testing being 42.5 kg, as shown in Figure 10. Figure 11 illustrates the launch of the amphibious float model test. Acceleration measurement is conducted from point A to C (see Figure 7). The results of this experiment will be discussed in the following section of this paper

III. RESULTS AND DISCUSSION

This section presents and discusses the experimental results obtained from testing the N219A float model. The results are divided into two main parts: the first part covers the sensor calibration results, while the second part focuses on the impact measurement results.

TABLE 2.
Z ACCELERATIONS ON IMPACT WITH FLOOR

		Z – acceleration (g)
First Impact	Sensor 1	0.777
	Sensor 2	0.741
	Sensor 3	0.728
	Sensor 4	0.681
Second Impact	Sensor 1	0.631
	Sensor 2	0.689
	Sensor 3	0.505
	Sensor 4	0.539

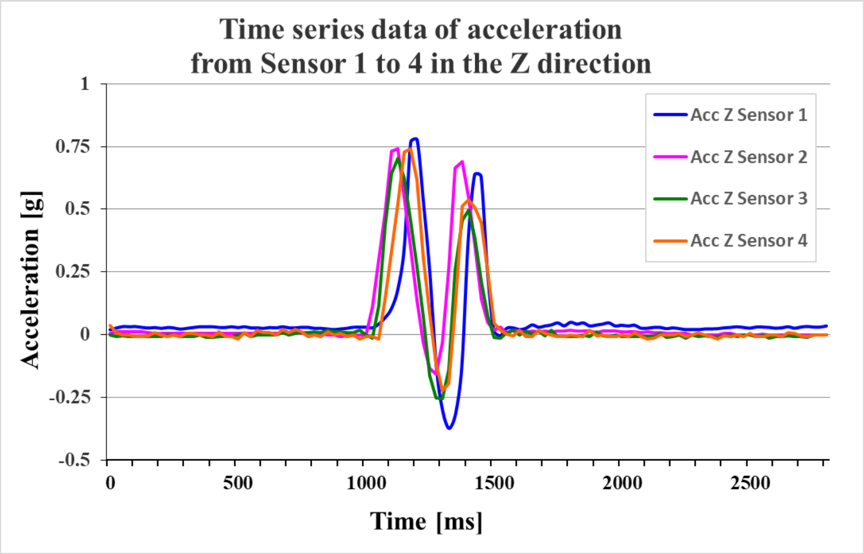

Figure 12. Result of Calibration of Wireless Impact Sensors

The results from each drop test conducted using the sensors are systematically tabulated in Table 2, and a corresponding plot illustrating these results is presented in Figure 12. Table 2 specifically displays the acceleration experienced in the Z-axis direction at the moment of impact with the floor. During these tests, the sensors were dropped from a height of 0.5 meters, ensuring that they landed at a flat angle, as specified in reference [21]. The recorded data indicate that the first impact force measured during these drop tests was, on average, approximately 3.7% in agreement with the theoretical value calculated using Equation (4). These calibration results provide strong evidence that the impact sensors are well-suited for application in the floater launching experiment, demonstrating their reliability and accuracy in measuring impact forces under controlled conditions.

TABLE 3.
THE MAXIMUM – MINIMUM LOAD FORCE (G)

		X	Y	Z
Maximum Load Force (g)	Sensor 1	1.24	0.79	1.98
	Sensor 2	0.67	0.95	1.17
	Sensor 3	0.00	0.00	0.00
	Sensor 4	0.71	0.34	1.22
Minimum Load Force (g)	Sensor 1	-1.22	- 0.95	-1.23
	Sensor 2	- 1.34	- 0.78	-1.44
	Sensor 3	0.00	0.00	0.00
	Sensor 4	- 0.79	- 0.76	- 0.61

The impact forces, measured in g, recorded by the sensors on the amphibious float model are comprehensively presented in Table 3 and depicted in Figures 13 through 16. Figure 13 illustrates the readings obtained from impact sensor 1 across the X, Y, and Z axes. The maximum load recorded in the X-axis direction is 1.24 g, while the minimum load is -1.22 g. For the Y-axis, the maximum value observed is 0.79 g, with a corresponding minimum of -0.95 g. In the Z-axis, the sensor recorded a maximum load of 1.98 g and a minimum load of -1.23 g.

Figure 14 displays the readings from impact sensor 2, also across the X, Y, and Z axes. The maximum load measured in the X-axis direction is 0.67 g, with a minimum value of -1.34 g. For the Y-axis, the highest recorded value is 0.95 g, while the lowest is -0.78 g. In the Z-axis, the maximum load recorded is 1.17 g, and the minimum load is -1.44 g.

Figure 15 provides data from impact sensor 3 for the X, Y, and Z axes. However, the data indicate that this sensor did not function correctly, potentially due to detachment from the float structure during the experiments, leading to unreliable readings.

Lastly, Figure 16 presents the readings from impact sensor 4 across the X, Y, and Z axes. The maximum load recorded in the X-axis direction is 0.71 g, with a minimum load of -0.79 g. In the Y-axis, the maximum value observed is 0.34 g, and the minimum value is -0.76 g. For the Z-axis, the maximum load recorded is 1.22 g, while the minimum load is -0.61 g.

These results suggest that the maximum loads recorded by the functioning sensors accurately correspond to the impact loads experienced by the float model. This correspondence underscores the reliability and effectiveness of the sensors in capturing the dynamic impact loads during the experiments.

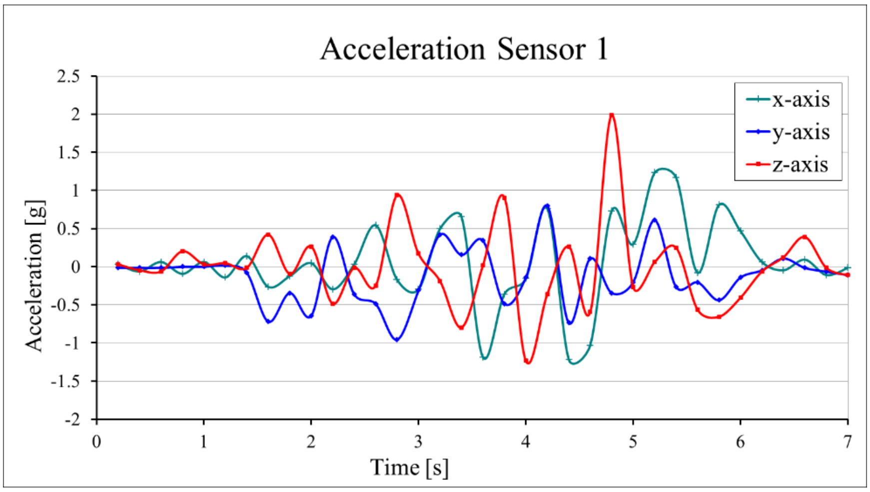

Figure 13. Acceleration graph along the X-axis, Y-axis, and Z-axis in sensor 1 readings of model floater N219A.

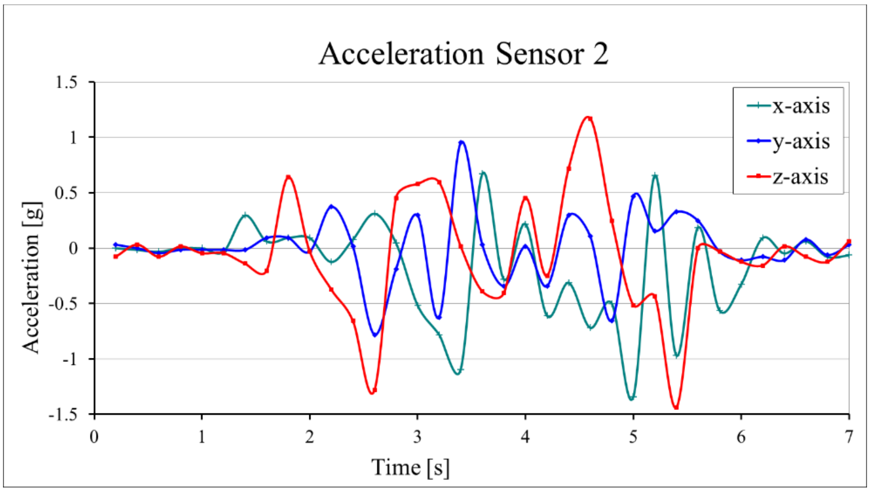

Figure 14. Acceleration graph along the X-axis, Y-axis, and Z-axis in sensor 2 readings of model floater N219A.

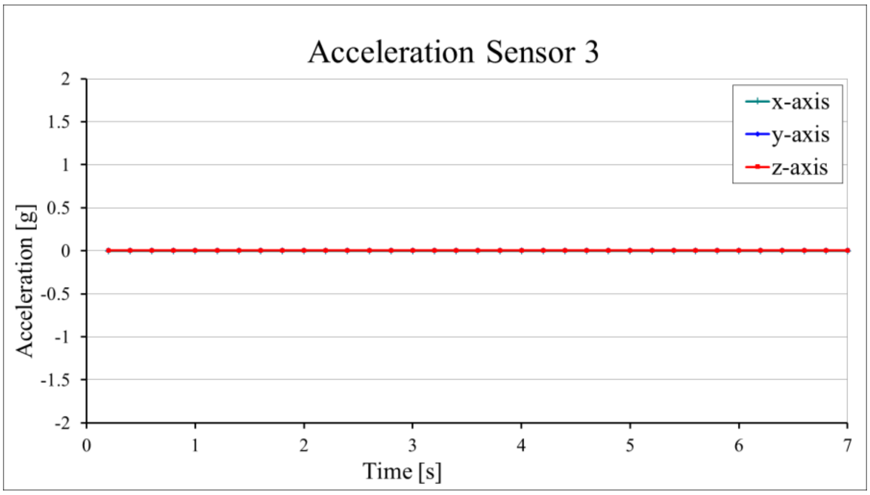

Figure 15. Acceleration graph along the X-axis, Y-axis, and Z-axis in sensor 3 readings of model floater N219A.

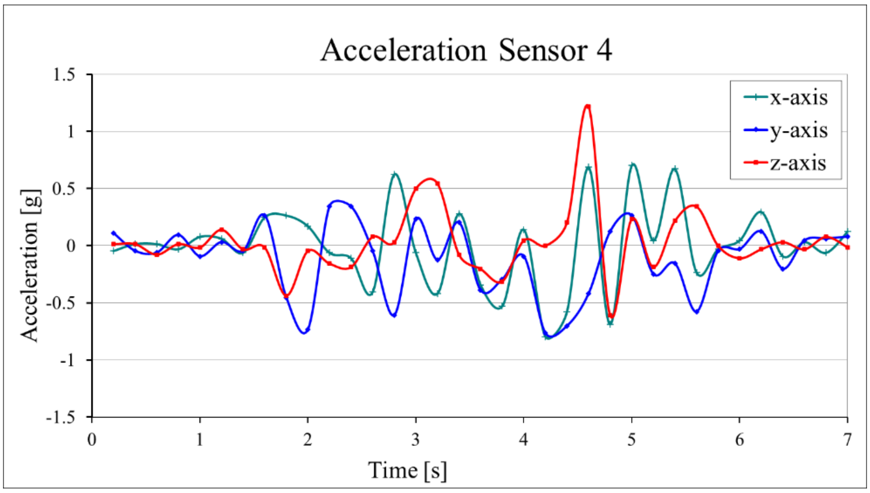

Figure 16. Acceleration graph along the X-axis, Y-axis, and Z-axis in sensor 4 readings of model floater N219A.

The accelerometer sensors utilized in this study are capable of monitoring both static and dynamic forces. Static forces, such as gravity and friction, do not alter the direction or position of an object and remain consistent over time. In contrast, dynamic forces, such as impact forces, cause changes in the direction or position of an object and are inherently less predictable. Accelerometers are highly valuable because they can detect changes in acceleration and convert these into measurable vibration data. In this study, the accelerometer sensors were employed to capture dynamic loads, specifically impact loads, by measuring the acceleration experienced by the float model. Data from the sensors were wirelessly transmitted to a remote notebook computer, where the sensor measurements were displayed in real-time and subsequently saved as data files for further analysis.

The sensor readings indicate that the maximum impact load occurs approximately 5 seconds after launch. Notably, sensors 2 and 4 recorded this peak impact load earlier than sensor 1, while sensor 3 did not function correctly during the tests. This pattern of readings suggests that the float made initial contact with the water at the aft section, followed by the bow. This landing sequence is the preferred condition, as the center of gravity (CG) was positioned toward the aft part prior to launch, leading to a more stable descent. The occurrence of readings in directions other than the Z-axis can be attributed to the forces exerted on the float by its motion along the launcher rail, which impacted the float in both the X and Y axes. Particularly, significant motion was observed in the X-axis after landing, which is likely due to the reduced restriction in front of the float compared to other directions. These observations provide valuable insights into the behavior of the float model under impact conditions and underscore the importance of accurate sensor placement and functionality for capturing relevant dynamic data.

The experimental results indicate that the implementation of wireless accelerometer sensors for measuring response impact forces on the seaplane float model was successful. The data demonstrate that these sensors effectively captured and transmitted impact force measurements with a high degree of accuracy, confirming their suitability for this application. Furthermore, the integration of wireless technology into the measurement system enhances the system's flexibility and ease of use, while also ensuring rapid and secure data transmission. This improvement is critical for efficient processing and analysis, particularly in real-time operational scenarios. The study highlights the potential of wireless sensor networks in advanced engineering applications, providing valuable insights for the development of more sophisticated monitoring and data acquisition systems in similar contexts.

IV. CONCLUSION

The impact load measurements conducted in the mechanical workshop provide clear evidence that the sensors used are capable of accurately capturing the impact loads experienced during testing. This conclusion is supported by the recorded data, which indicate that the impact force measured during the drop tests was, on average, approximately 3.7% in agreement with the theoretical value. In these experiments, the maximum impact force observed for the seaplane float model landing on the mesh was 1.98 g, while the minimum was 0.61 g. These experimental results establish a solid foundation for further investigations into hydrodynamic impact load testing using a wireless system within a controlled water tank environment.

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