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Comparison of Vibration Damping Characterization of Two Surfboards Using the Free-Decay Logarithmic Decrement Method

Lou Torregrosa[1,2], Tjokorda Gde Tirta Nindhia*[3], Hafda Setyawan[3], I Gusti Ngurah Nitya Santhiarsa[3]

Research Internship, Mechanical Engineering, Engineering Faculty, Udayana University[1]

ENSIACET, Département Génie Industriel, Toulouse, France[2]

Mechanical Engineering, Engineering Faculty, Udayana University[3]

*Correspondent Author: tirta.nindhia@me.unud.ac.id

Abstract This study reports the vibration damping of two polyurethane (PU) surfboards of different sizes and shapes . The method used for this study is the free-decay logarithmic decrement method. An inertial measurement unit (IMU) accelerometer was fixed at the midpoint of each board. An impulse excitation was applied at the same location using a hammer, and the resulting acceleration signal was recorded along the board's out-of-plane axis (Z-axis). The logarithmic decrement δ was computed from consecutive peak amplitudes, and the damping ratio ζ was given. Three trials were conducted per board. Trials with negative ζ values were rejected. The retained damping ratios are ζ = 0.1979 for Board A (Brain Yuki Just Foam, shortboard) and ζ_mean = 0.178 for Board B (Island R, funboard). The approximate 10% difference between the two boards is discussed in the context of board geometry, mass distribution, and the test setup limitations. These results constitute a preliminary mechanical baseline that can support future surfboard selection and optimization tools.

Keywords: surfboard; vibration damping; logarithmic decrement; damping ratio, free-decay, accelerometer; composite materials; polyurethane foam.

I. INTRODUCTION

Surfboards are subjected to complex dynamic loads when they are being used, such as hydrodynamic pressure from wave impact, periodic bending forces induced by the surfer's weight, and impulsive forces from wave breaking [1]. The structural response of a surfboard to these loads depends on both its geometry and the mechanical properties of the constituent materials [2].

The vibration damping ratio ζ is a key performance parameter. A board with a high damping ratio will dissipate vibrational energy rapidly after an impulse, resulting in a subjectively "smooth" or "muted" feel underfoot. On the other hand, a low damping ratio corresponds to a board that transmits more vibration to the surfer. These vibrations tend to be appreciated by experienced suffers but generally uncomfortable for beginners [3].

Despite the practical relevance of damping in surfboard design, the published literature on this topic remains low. Indeed, most mechanical studies of surfboards focus on static flexural stiffness [2] and systematic damping measurements using standardised methods are largely absent from the open literature [3]. The present study applies the free-decay logarithmic decrement method to two surfboards of different sizes.

The broader context of this work is an industrial engineering internship focused on the optimisation of surfboard selection based on surfer morphology (height and weight) [4, 5, 6, 7]. The damping characterisation reported here provides a quantitative mechanical baseline that can be integrated into a future product configurator linking surfer anthropometric data to board mechanical behaviour [4, 6].

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II. MATERIALS AND METHOD

2.1. Test Specimens

Two surfboards were selected for this study based on availability at the Udayana University laboratory, Bali, Indonesia. Their principal characteristics, as determined from visual inspection and markings inscribed on the boards, are summarized in Table 1.

The biggest difference between these two boards besides their weight and length is their tail shape and fin configuration as shown below on Figure 1 and Figure 2.

TABLE 1: PHYSICAL CHARACTERISTICS OF THE TWO TEST BOARDS.

Parameter	Board A - Brain Yuki Just Foam	Board B - Island R
Designation	Board A (yellow)	Board B (green)
Brand / Model	Brain Yuki Just Foam	Island Surfboards, Model R
Shape type	Shortboard	Mid-length
Length	6'3"	6'10"
Width	19½"	18½"
Thickness	2½"	2½"
Estimated volume	~34L	~32-36L
Mass	1.42 kg	3.48 kg
Core material	PU foam (polyurethane)	PU foam (polyurethane)
Shell	Fibre-glass / polyester resin	Fibre-glass / polyester resin
Stringer	Single-central wood stringer	Single-central wood stringer
Condition	Used - surface wear visible	Used - wax and surface wear
Fin configuration	Quad (4 fins)	Thruster (3 fins)
Tail shape	Fish tale	Pin tail

Figure 1. Botton view of board A, showing the quad fin setup

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Figure 2. Tail region of board B, showing the thruster fin setup

2.2. Instrumentation

Vibration data were acquired using an inertial measurement unit (IMU) connected via a serial interface to a laptop computer running a custom data acquisition application (Vibration Analyzer V1.0). The board was suspended by a string to a fixed metallic stand. The sensor was fixed to the deck surface at the midpoint of each board using adhesive tape as shown on Figure 3. The acquisition duration was set to 10 seconds per trial. Raw acceleration data (X, Y, Z axes, in m/s²) were recorded and exported to Excel format (.xlsx) for post-processing.

Figure 3. Board A suspended with the IMU sensor attached at the midpoint.

2.3. Excitation and Test Protocol

Impulse excitation was applied manually at the midpoint of each board using a small instrumented hammer on Figure 4. A free-free boundary condition was approximated by suspending the board from a metallic stand and minimizing contact between the board and the support structure. The IMU sensor was attached at the midpoint of the deck surface prior to suspension. Three independent trials were conducted for each board, with the acquisition system re-initialized between each trials. For each trial, the operator struck the board surface once with a short, sharp impact and the free-decay vibration was recorded for the subsequent 10 seconds.

Figure 4: Small instrumented hammer

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2.4. Theoretical Background

The free vibration of a damped single-degree-of-freedom system following an impulse excitation is described by :

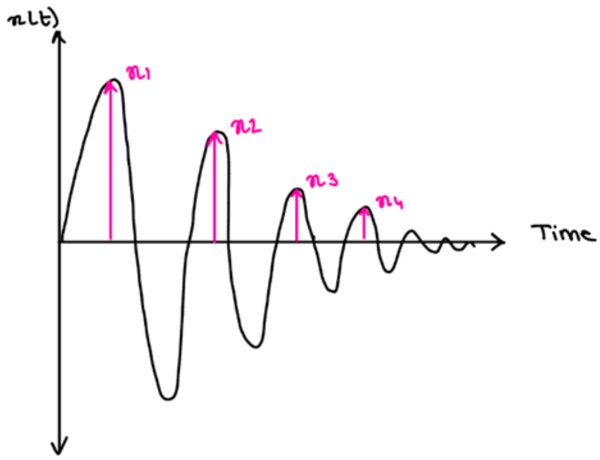
$$x(t) = A^0 . e^{-\zeta\omega_n t} . \cos(\omega d \cdot t) \quad (1)$$

where A_0 is the initial amplitude, $\omega_n = \sqrt{(\frac{k}{m})}$ is the undamped natural angular frequency (rad/s), $\omega d = \omega_n\sqrt{(1-\zeta^2)}$ is the damped natural frequency, and ζ represents the damping ratio. The signal is a sinusoid of frequency $f = \frac{1}{T} = \frac{\omega d}{2\pi}$ whose amplitude decays exponentially with time constant $\tau = \frac{1}{\zeta\omega_n}$.

The detection of two successive peaks at times t_1 and $t_2 = t_1 + T$, as shown on Figure 5, allows:

- (i) the measurement of the damped period T, which gives ωd and an indication of the board stiffness;
- (ii) the measurement of damping by comparison of the two amplitudes. The quantity $\ln(A_n/A_{n+1})$ is the logarithmic decrement δ, from which ζ is derived as :

$$\zeta = \frac{T}{\delta \cdot \ln(A_n/A_{n+1})} \quad (2)$$



2.5. Data Analysis - Logarithmic Decrement Method

In this study, the damping ratio ζ was directly given by the software. It can nevertheless be determined using the classical logarithmic decrement method, which is applicable to lightly damped linear systems exhibiting exponentially decaying sinusoidal free vibration. The logarithmic decrement δ is defined as:

$$\delta = \frac{1}{n} \cdot \ln |x_1 / x\_\{n+1\}| \quad (3)$$

Where x_1 is the amplitude of the first peak, x_{n+1} is the amplitude of the (n+1)-th peak, and n is the number of complete cycles separating them. In the present study, n = 1 (consecutive peaks) was used, as the signal decayed rapidly within the first two seconds. The damping ratio is then computed as:

$$\zeta = \frac{\delta}{\sqrt{(4\pi^2 + \delta^2)}} \quad (4)$$

Peak detection was performed automatically by the acquisition software which outputs Peak 1 Amplitude, Peak 2 Amplitude, δ, and ζ directly for each trial (six trials in total).

2.6. Validity Criteria and Data Rejection

In order to be retained, the damping ratio ζ must be strictly positive for a physically stable system (a negative ζ would imply energy amplification, which is physically impossible). All trials with ζ < 0 were therefore rejected and excluded from the analysis. This criterion was applied systematically prior to any statistical treatment. The cause of negative ζ values in rejected trials is attributed to erroneous peak detection, most likely resulting from insufficient impact energy or sensor noise dominating the late-time signal.

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3. RESULTS

3.1. Raw Data and Peak Detection

The peaks and given results are shown below in figures 6 to 11.

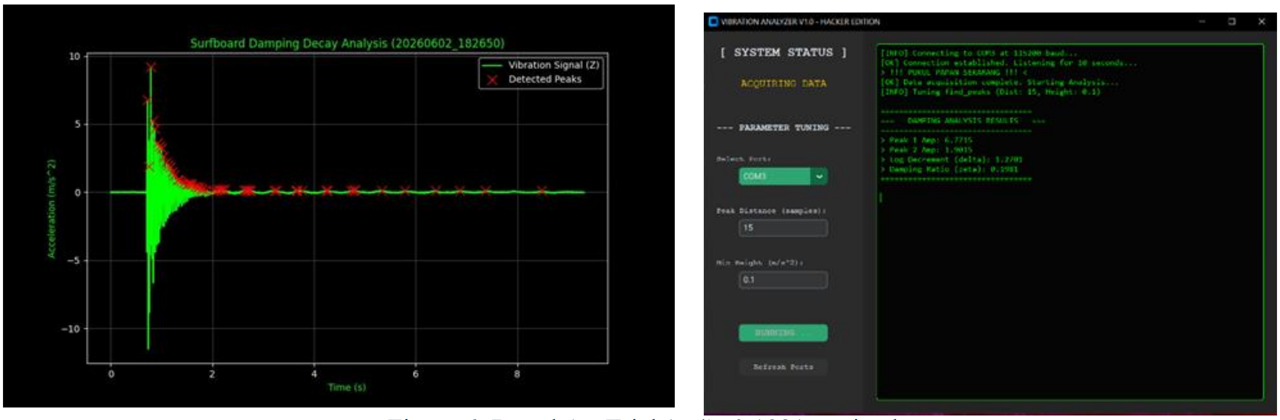

Figure 6: Board A - Trial 1 - ζ= 0.1981 retained

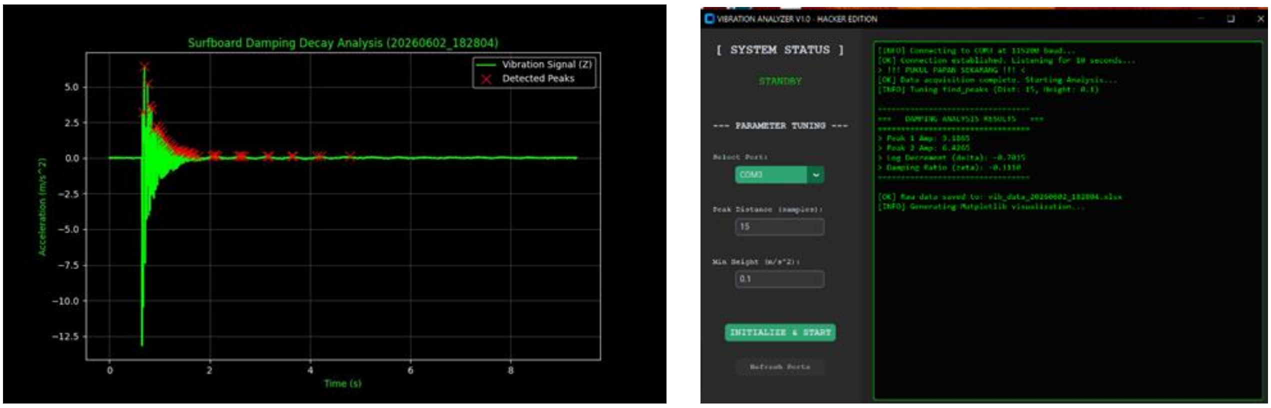

Figure 7: Board A - Trial 2 - ζ= -0.1110 rejected

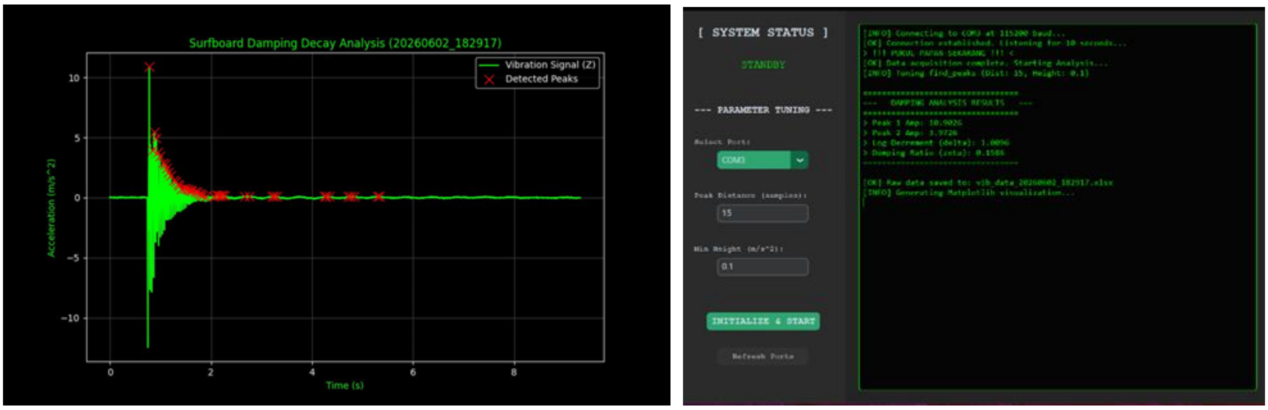

Figure 8: Board A - Trial 3 - ζ= 0.1586 retained

Regarding board A, two out of the three trials were retained. The first peak amplitude varies from around 6.7 to 10.9. This inconsistency is probably due to the fact that the impact is a manual impact.

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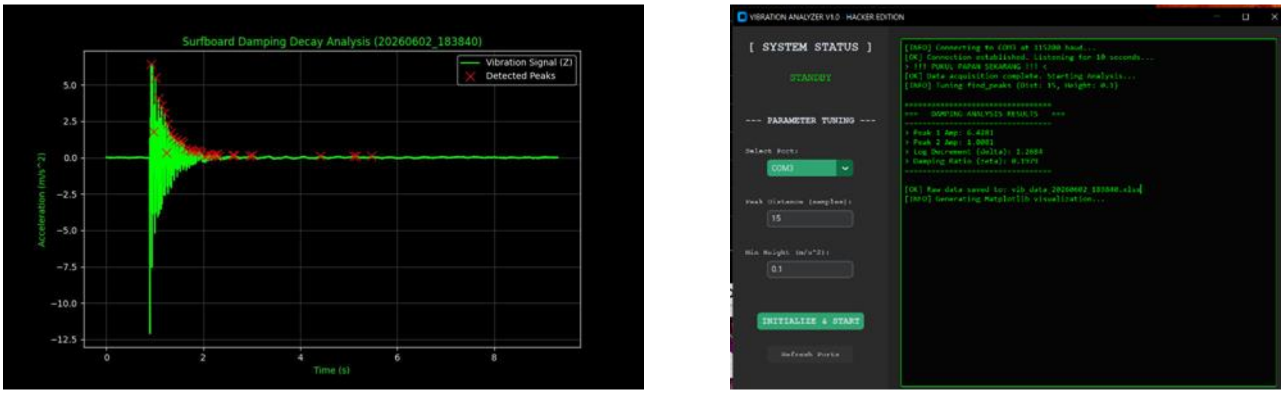

Figure 9: Board B - Trial 1 - ζ= 0.1979 retained

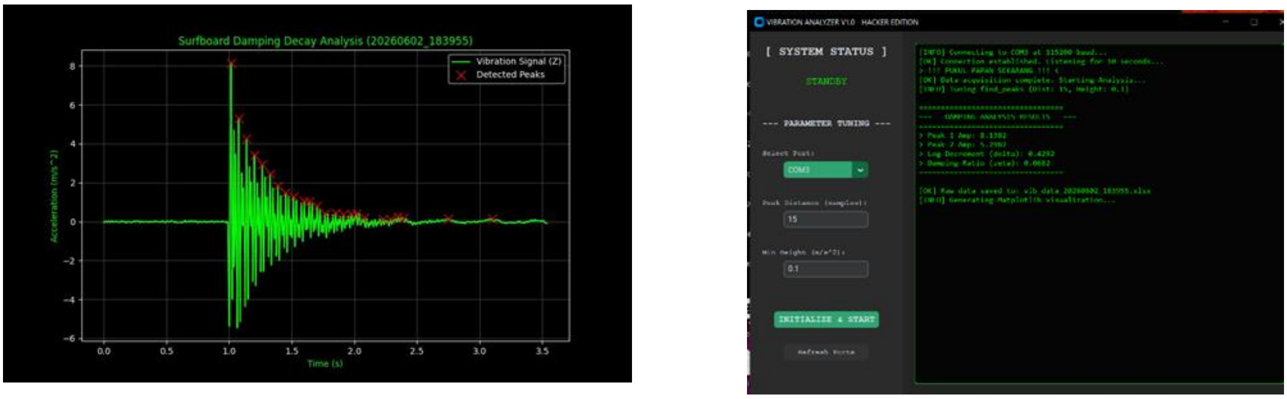

Figure 10: Board B - Trial 2 - ζ= 0.0682 rejected

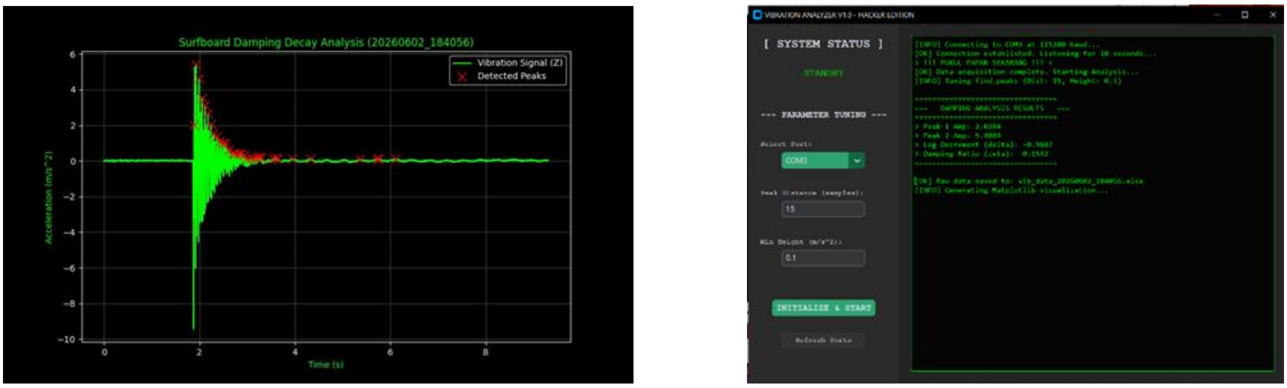

Figure 11: Board B - Trial 3 - ζ=-0.1542 rejected

Figures 9 to 11 show Board B's results. Unlike Board A only one trial was retained.

On each trial, there is a clear impulsive onset due to the hammer's blow, followed by a rapid exponential decay. The signal then eventually returns to the noise floor within approximately two seconds, indicating a relatively rapid energy dissipation.

3.2. Trial-by-Trial Results

The results of all six trials are summarized in Table 2. Rejected trials are indicated with a strikethrough.

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TABLE 2: TRIAL-BY-TRIAL DAMPING RESULTS

Board	Trial	Peak 1 Amp. (m/s^2)	Peak 2 Amp. (m/s^2)	δ	ζ -Status
A (Yellow)	1	6.7715	1.9015	1.2701	0.1981 — ✓ RETAINED
A (Yellow)	2	3.1865	6.4265	-0.7015	-0.111 — ✗ REJECTED
A (Yellow)	3	10.9026	3.9726	1.0096	0.1586 — ✓ RETAINED
B (Green)	1	6.4281	1.8081	1.2684	0.1979 — ✓ RETAINED
B (Green)	2	8.1382	5.2982	0.4292	0.0682 — ✗ REJECTED (inconsistent)
B (Green)	3	2.0284	5.4084	-0.9807	-0.1542 — ✗ REJECTED

Out of six trials conducted, three were retained on the basis of the validity criterion defined in Section 2.6. Three trials were rejected: two produced negative ζ values (physically inadmissible) and one produced an anomalously low but positive value (ζ = 0.0682) inconsistent with the other measurements of Board B. Table 3 shows the overall retained damping ration values.

TABLE 3. shows the overall retained damping ration values.

Board	n retained	ζ values retained	Mean ζ	Notes
A - Brain Yuki (Yellow)	1	0.1981; 0.1586	0.1784	The mean retained damping ratio for Board B
B - Island R (Green)	2	0.1979	0.1979	Single valid trial

IV. DISCUSSIONS

4.1. Comparison between the Two Boards

Board A (Brain Yuki, shortboard, 6'3", 1.42 kg) yielded a mean retained damping ratio of $\zeta_A=0.1784$ (mean of two valid trials). Board B (Island R, funboard, 6'10", 3.48 kg) yielded a single retained damping ratio of $\zeta_B=0.1979$. Therefore, it exhibits a slightly higher damping than board A, with an approximate difference of 10%.

From a structural dynamics perspective, this result can be partially explained by the significant mass difference between these two boards. Indeed, Board B is 2.45 times heavier than Board A (3.48 kg vs 1.42 kg), despite having similar thickness (both 2½"). A higher mass, combined with similar stiffness, lowers the natural frequency of the system and modifies the energy dissipation rate. Moreover, the thruster fin configuration (3 fins) of Board B versus the quad setup (4 fins) of Board A represents a different mass distribution at the tail, which influences the board's dynamic response.

Furthermore, the tail shape also differs between the two boards. Board A features a fish tail , which is wider and distributes mass more broadly at the rear, while Board B has a pin tail, which concentrates mass at a single point. This geometric difference affects the modal behaviour of each board under impulse excitation. It should however be noted that the dataset is very limited in this study. Board A has two valid trials while Board B has only one. The 10% difference between ζ_A and ζ_B is therefore indicative rather than statistically established.

4.2. Limitations of the Study

Several limitations must be acknowledged. First, the number of valid trials per board is very low (n = 2 for Board A, n = 1 for Board B). A minimum of five to ten valid trials per board would be required for reliable statistical characterization.

The high rejection rate (50%) is attributed to the manual nature of the impact excitation. Indeed, inconsistent hammer strikes leads to erroneous peak detection. Second, the boundary conditions, although approximating a free-free suspension, were not rigorously controlled. The metallic stand used introduced a fixed contact point, which may add stiffness or damping at the support location and partially contaminate the measured structural damping of the board itself.

Finally, the fins were absent from Board A during testing (fin boxes visible but empty), while Board B was tested with its thruster fins installed. This inconsistency in test conditions means the two boards were not tested in strictly equivalent configurations. The mass contribution of the fins and their effect on damping should be controlled in future experiments [8].

4.3. Industrial Engineering Perspective - Link to Surfboard Optimizations

In the context of this internship, the damping ratio provides a quantitative mechanical descriptor that can be integrated into a product configuration tool. The objective of the broader project is to develop a decision-support matrix linking surfer anthropometric parameters (height, weight, experience level) to board specifications (length, volume, shape type) [3] . The damping ratio adds a dynamic dimension to this matrix. The boards can be distinguished not only by hydrostatic properties such as volume or buoyancy but also by their dynamic mechanical behaviour.

Future work should extend the damping characterisation to a larger panel of boards, ideally covering at least three size categories (shortboard, funboard, longboard) and two construction types (PU and EPS/epoxy), in order to complete the configuration matrix with reliable mechanical data.

V. CONCLUSION

The free-decay vibration of two PU surfboards, Board A (Brain Yuki Just Foam, shortboard, 6'3" × 19½" × 2½", 1.42 kg, quad fin, fish tail) and Board B (Island R, funboard, 6'10" × 18½" × 2½", 3.48 kg, thruster, pin tail), was measured using an IMU accelerometer and analysed using the logarithmic decrement method. Out of six trials (three per board), three were rejected due to physically inadmissible negative damping ratios or anomalously low values resulting from erroneous peak detection. The retained results are $\zeta_A = 0.1784$ (mean of two trials) for Board A and $\zeta_B = 0.1979$ (single trial) for Board B, representing a difference of approximately 10% in favour of Board B. Despite these limitations, the study demonstrates the feasibility of low-cost vibration damping measurement on surfboards using accessible laboratory equipment and open-source signal processing tools. The methodology is reproducible and scalable to a larger sample.

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