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Characterizing Wave-Impact Response Motions for High-Speed Planing Hulls

High Speed Boat Operations Forum

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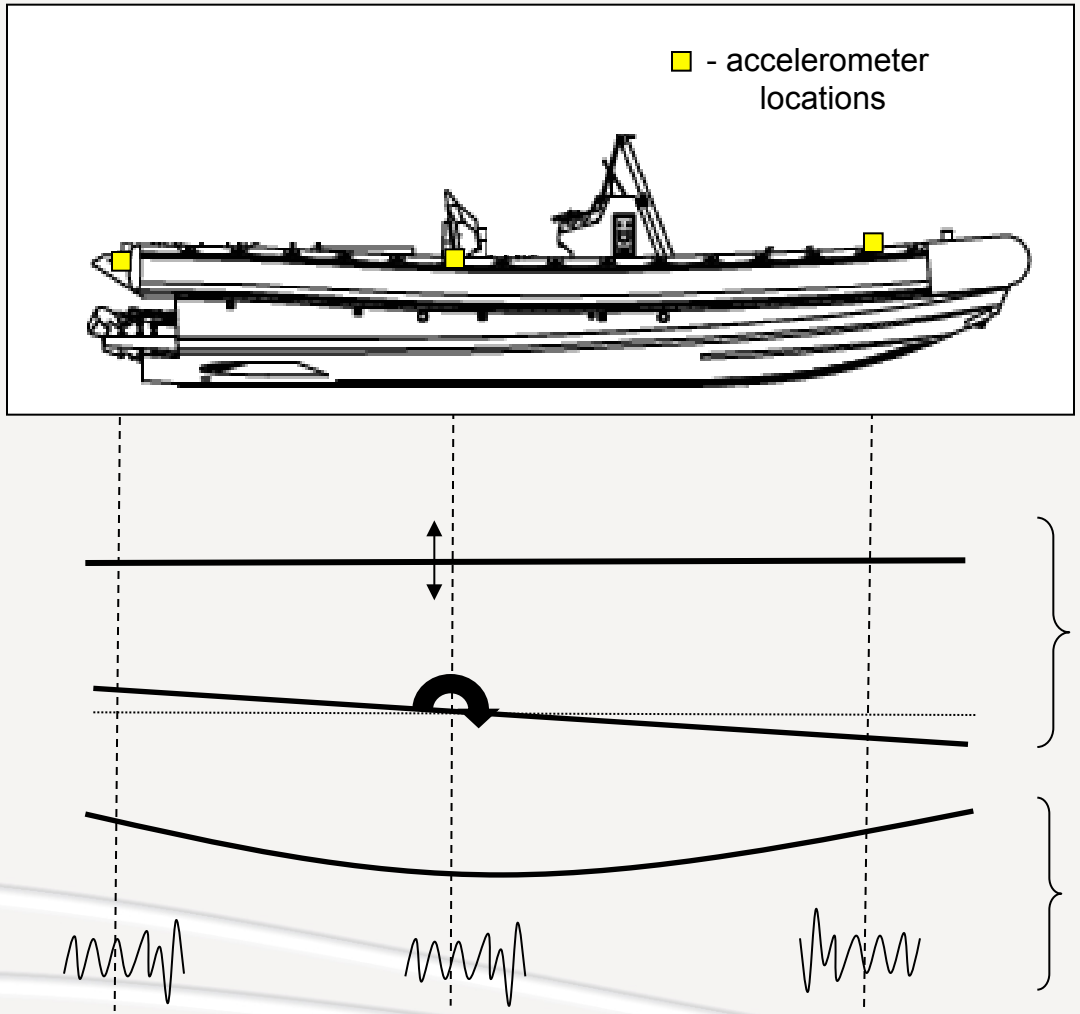
Outline

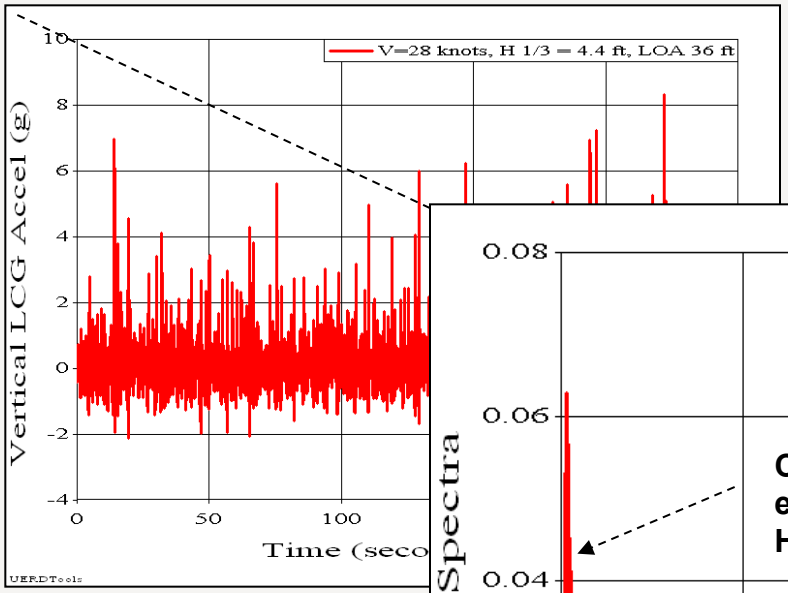
- What is a wave slam and a wave slam phenomenology?
- How can I represent the slam event mathematically?
- What does this mean to the user community and technology developers?

Accelerometers Record Rigid Body and Flexural Motions

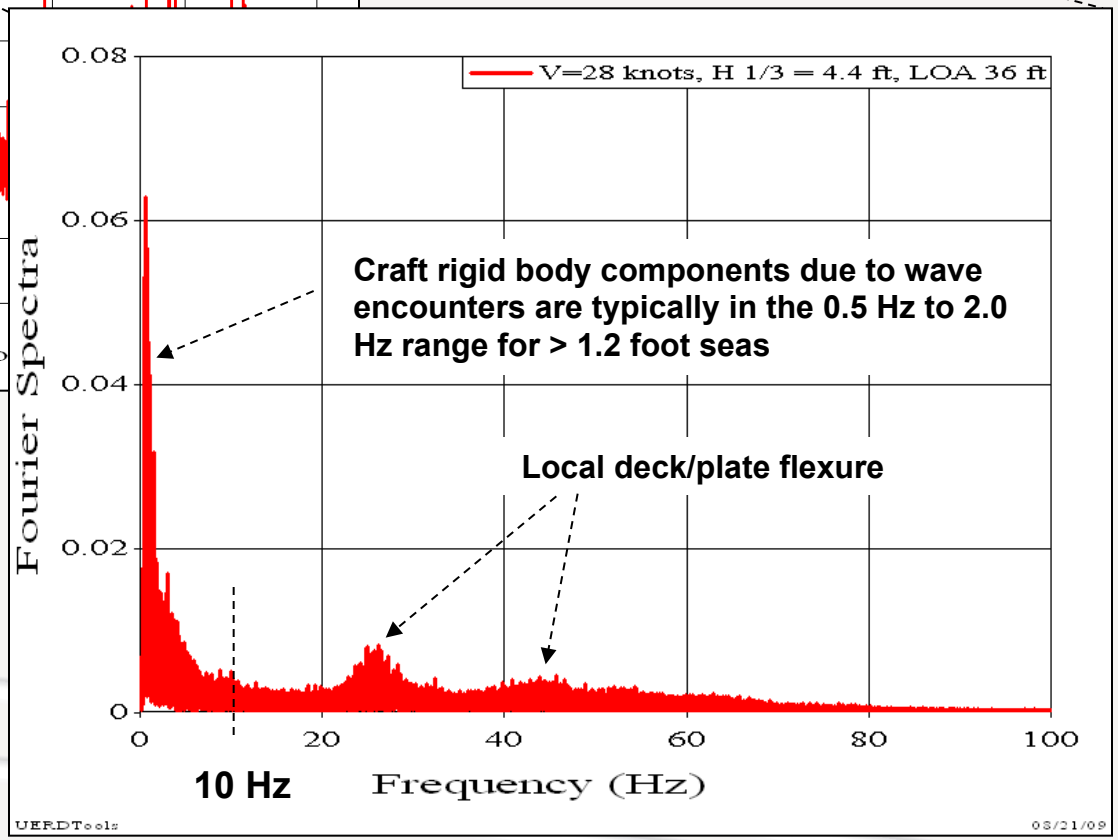


Data Processing

Frequency Content Assessment and Extraction of Rigid Body Acceleration



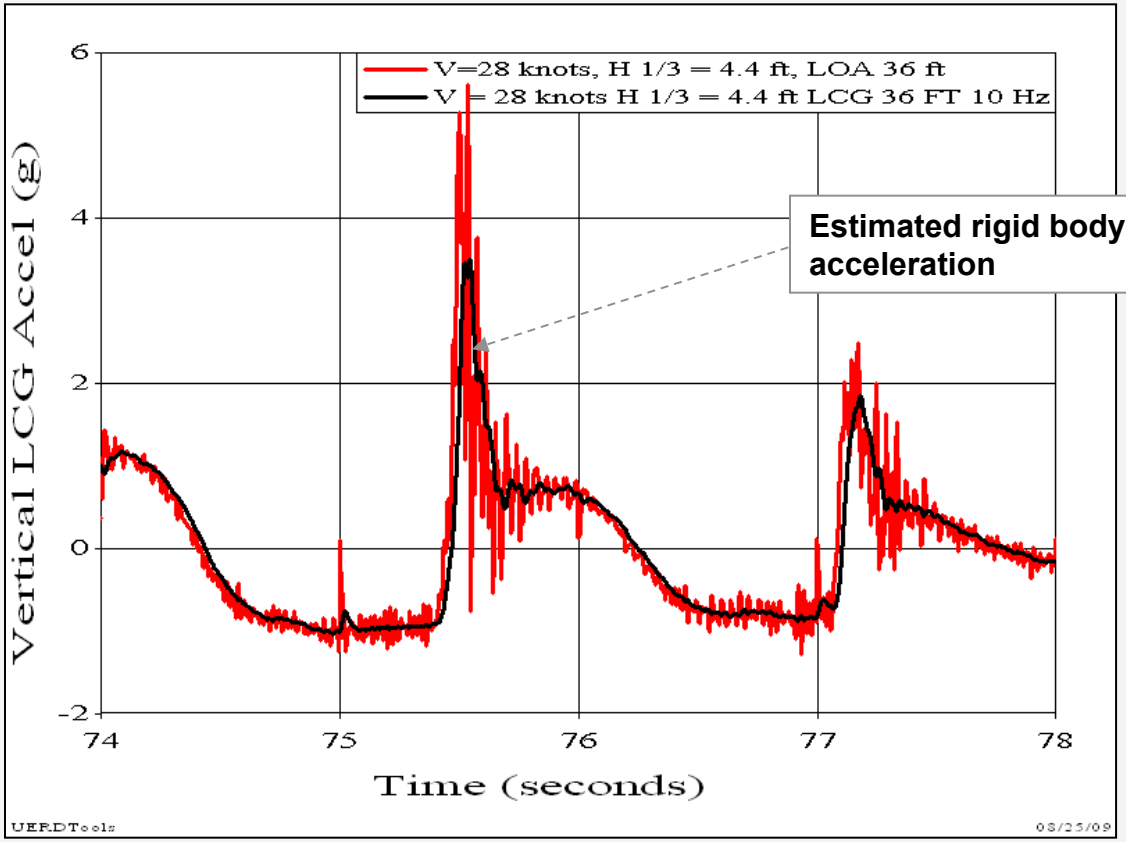
Fast Fourier Transform



Craft rigid body components due to wave encounters are typically in the 0.5 Hz to 2.0 Hz range for > 1.2 foot seas

Local deck/plate flexure

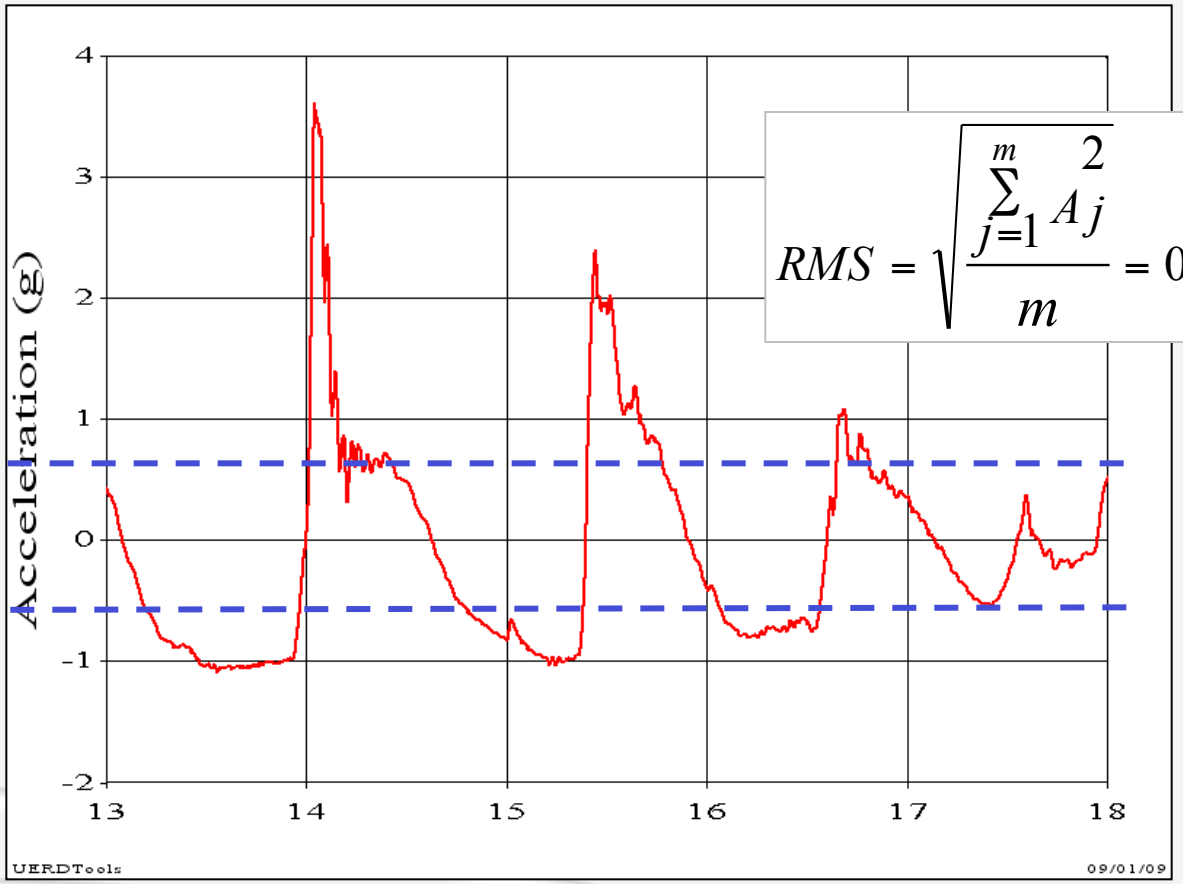
Filtered vs Unfiltered Wave Encounters



It is therefore recommended that a 10 Hz low pass filter be considered for post-trial data processing to estimate craft rigid body accelerations.

RMS Acceleration

In high speed craft acceleration records (Vk/ (L1/2) > 4.0, the RMS value correlates well with the lower amplitude values associated with positive and negative hydrodynamic forces (wave interaction), not peak values associated with wave impact (shock) events.**



$$RMS = \sqrt{\frac{\sum_{j=1}^{m} A_j^2}{m}} = 0.62g$$

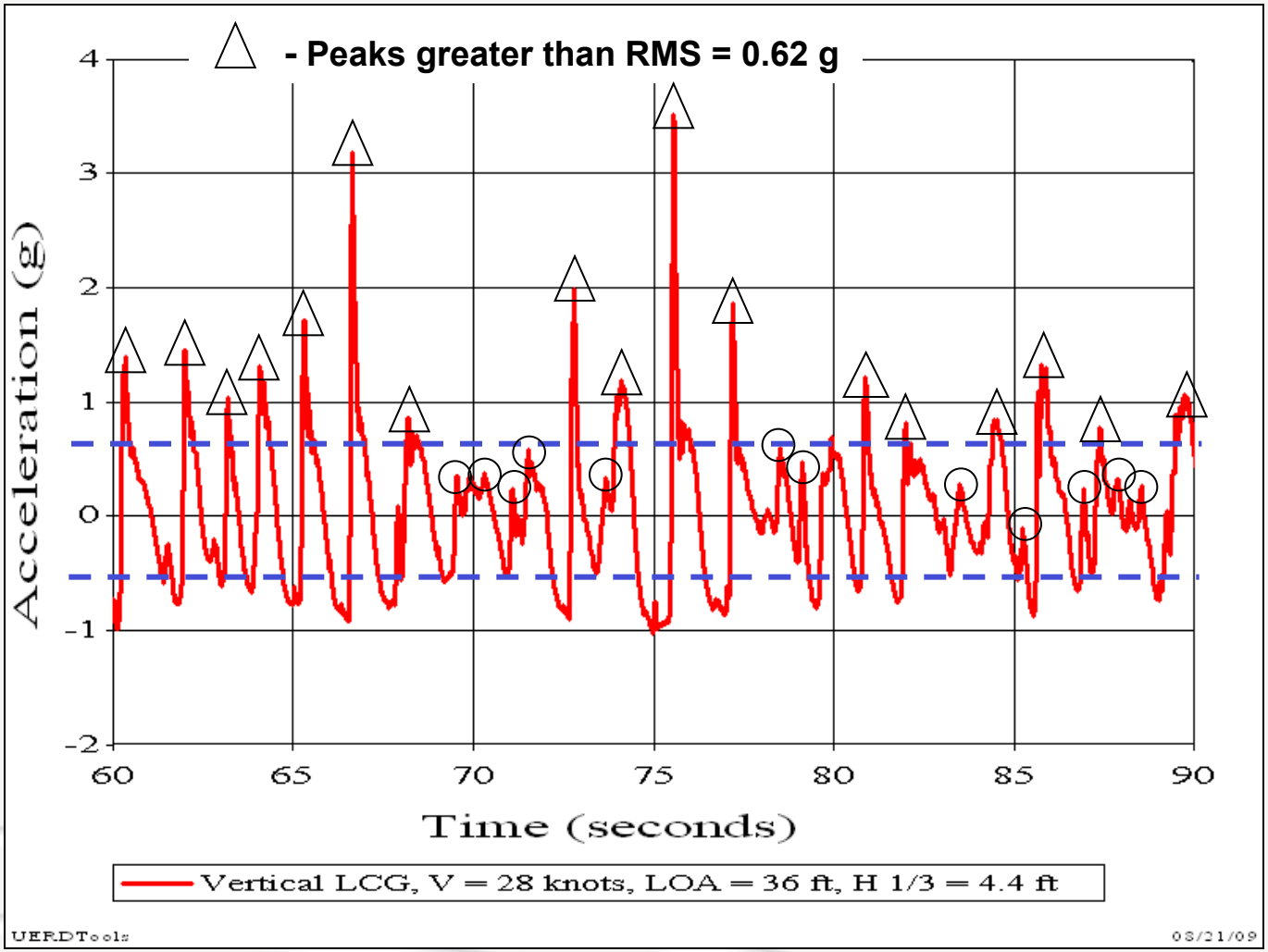
+ 0.62 g

- 0.62 g

V = 28 knots
H 1/3 = 4.4 ft

It is therefore recommended that a vertical threshold equal to the RMS acceleration be used

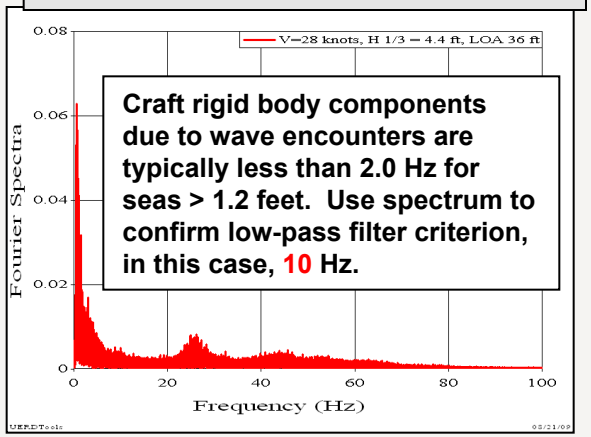
Example Peak Count



○ - Peaks less than RMS value not counted

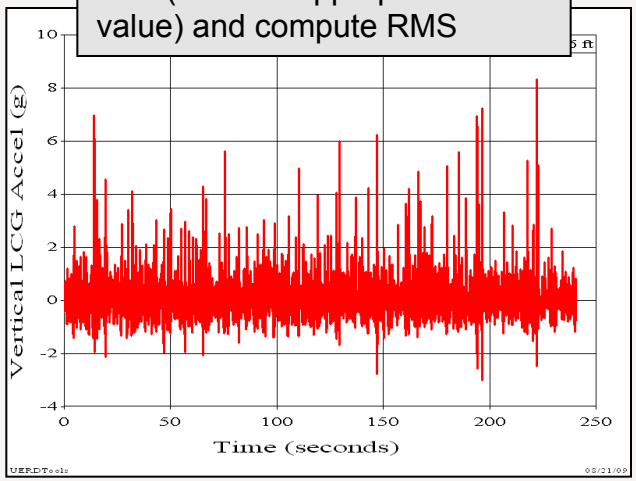
$A_{1/n}$ Generalized Calculation Approach
Unambiguous statistical calculations

Step 1 Demean data and compute spectrum of unfiltered record



Craft rigid body components due to wave encounters are typically less than 2.0 Hz for seas > 1.2 feet. Use spectrum to confirm low-pass filter criterion, in this case, 10 Hz.

Step 2 Apply 10 Hz low pass filter (or other appropriate value) and compute RMS



$$RMS = \sqrt{\frac{\sum_{j=1}^{m} A_j^2}{m}} = 0.62g$$

In high speed craft acceleration records (Vk/ (L1/2) > 4.0, the RMS value correlates well with the lower amplitude values associated with positive and negative hydrodynamic forces (wave interaction), not peak values associated with wave impact (shock) events. Therefore, an acceleration threshold is recommended equal to the RMS to identify data specifically associated with a slam event.**

Step 4 Compute average values

$A_{1/100} = 5.31\ g$

$A_{1/10} = 3.48\ g$

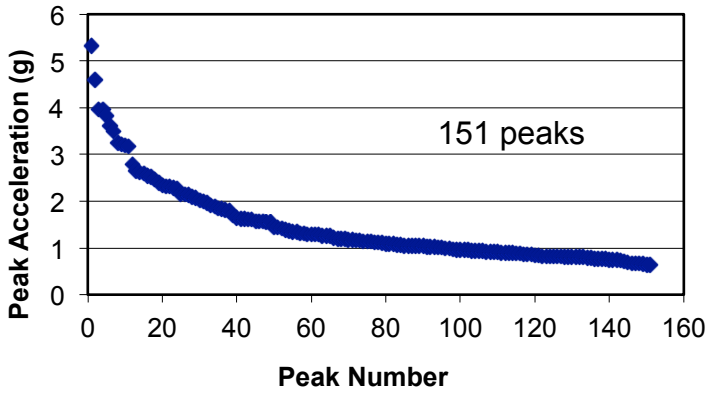
$A_{1/3} = 2.41\ g$

For sea states greater than 2 feet and craft speeds up to 60 knots the rigid body wave encounter period will be greater than ½ second.

Calculate the average of the 1/nth highest accelerations

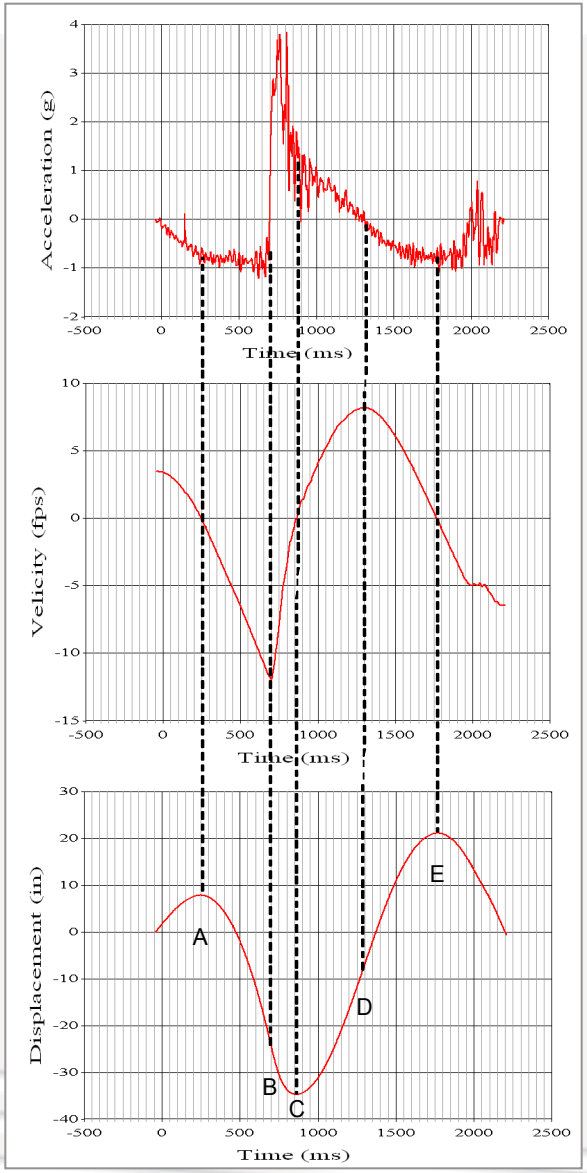
- ***Select the peaks***
- ***Define N as number of peaks counted***
- ***Tabulate peaks from highest to lowest***
- ***Divide N by nth value, and round to an integer (M)***
- ***Compute the average of the top M peaks***

Step 3 Extract peaks using vertical (RMS) and time thresholds based on encounter frequency (1/2 sec)



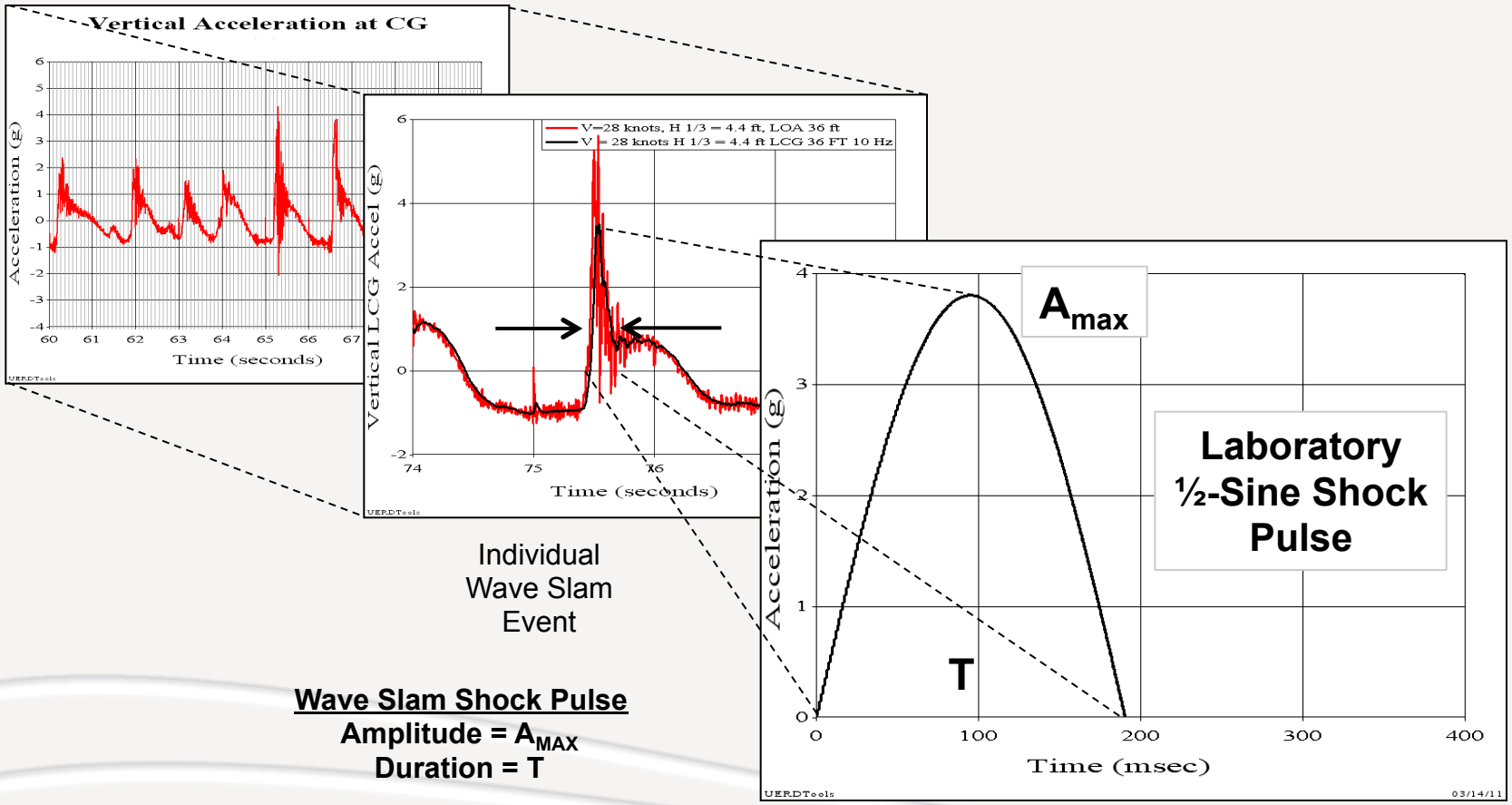
Wave Slam Sequence of Events

Time	Deck Motion at LCG
A to B	• Close to gravity free-fall (- 0.9 g)
B	• Maximum downward velocity • Time of initial water impact
B to C	• Craft moving down in water • Maximum loading phase • Wave slam period
C	• Time of maximum downward motion • Instantaneous velocity = 0
C to D	• Craft pushed upward by hydrodynamic lift, buoyancy, small thrust vector



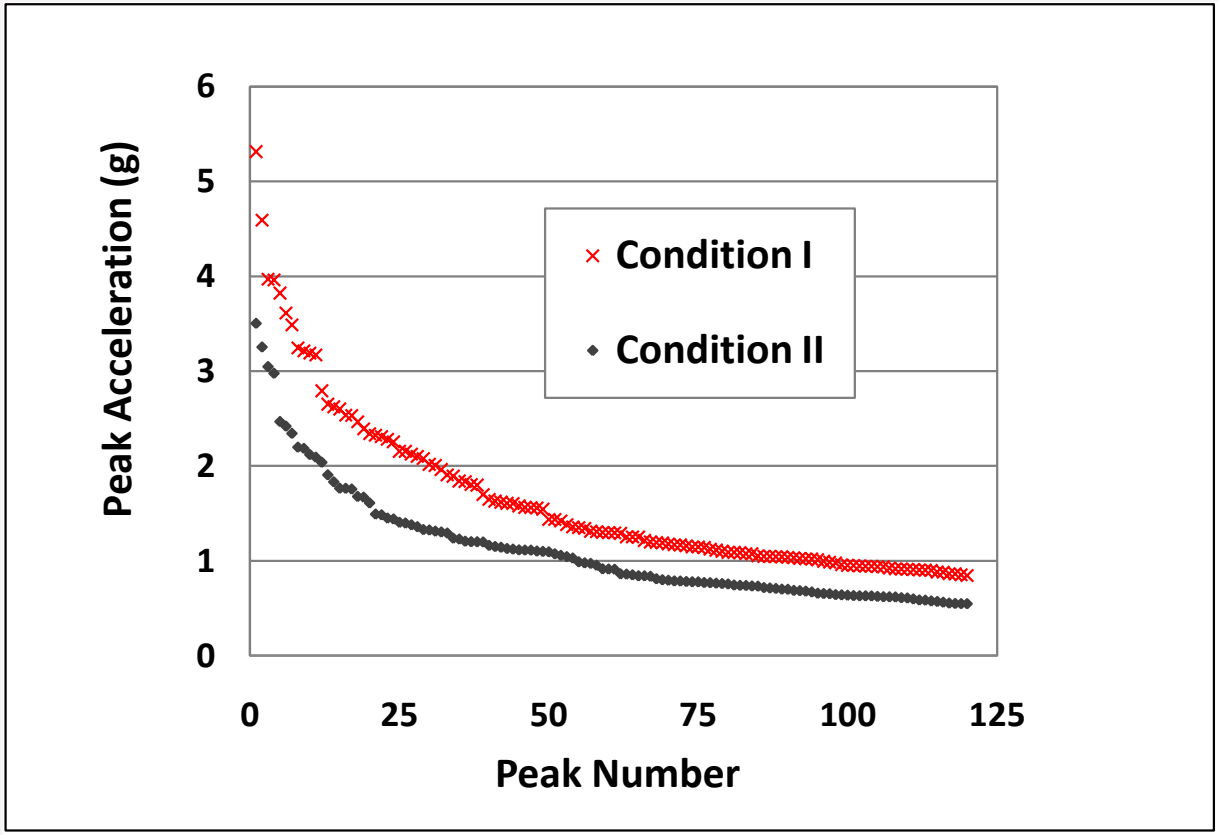
Single Severe Wave Slam

The wave slam shock pulse period (illustrated here by the half-sine pulse) is a small portion of the total wave encounter sequence of events.



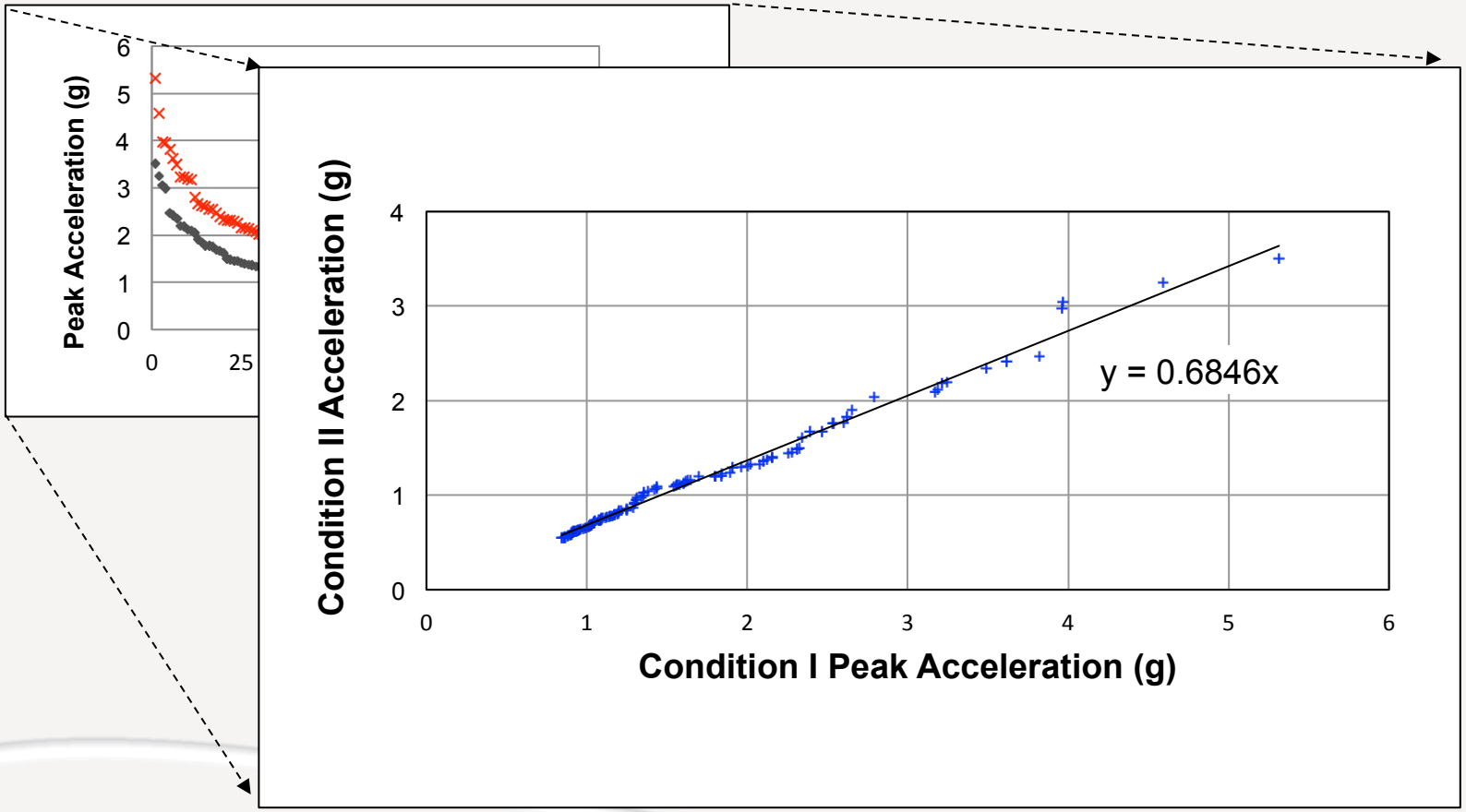
Wave Slam Shock Pulse
Amplitude = A_{MAX}
Duration = T

Peak Acceleration Comparison



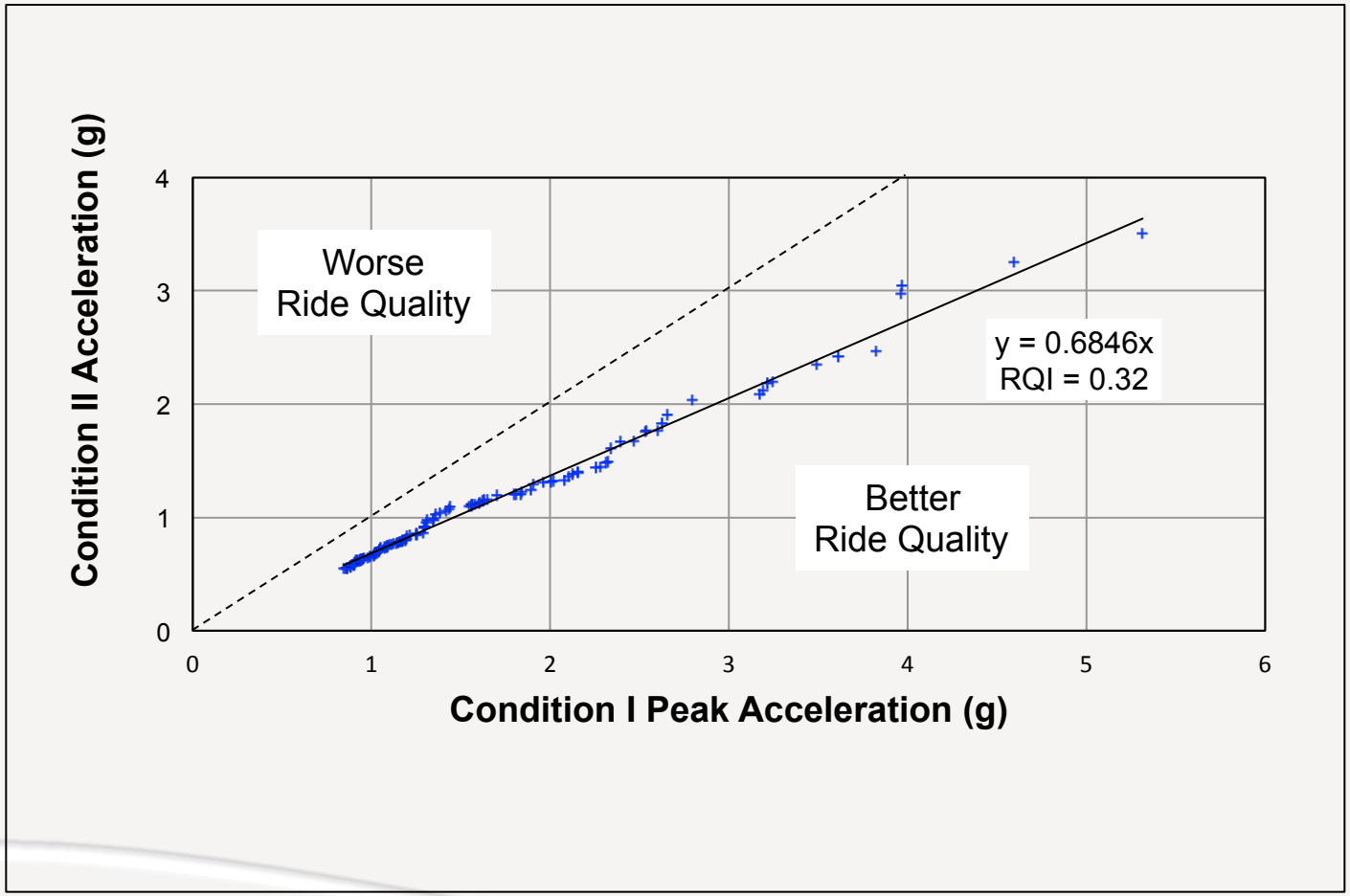
Test Condition Variables: different craft, speeds, wave heights, gage locations

New Comparison Format



The least squares linear fit has a zero intercept

Ride Quality Index

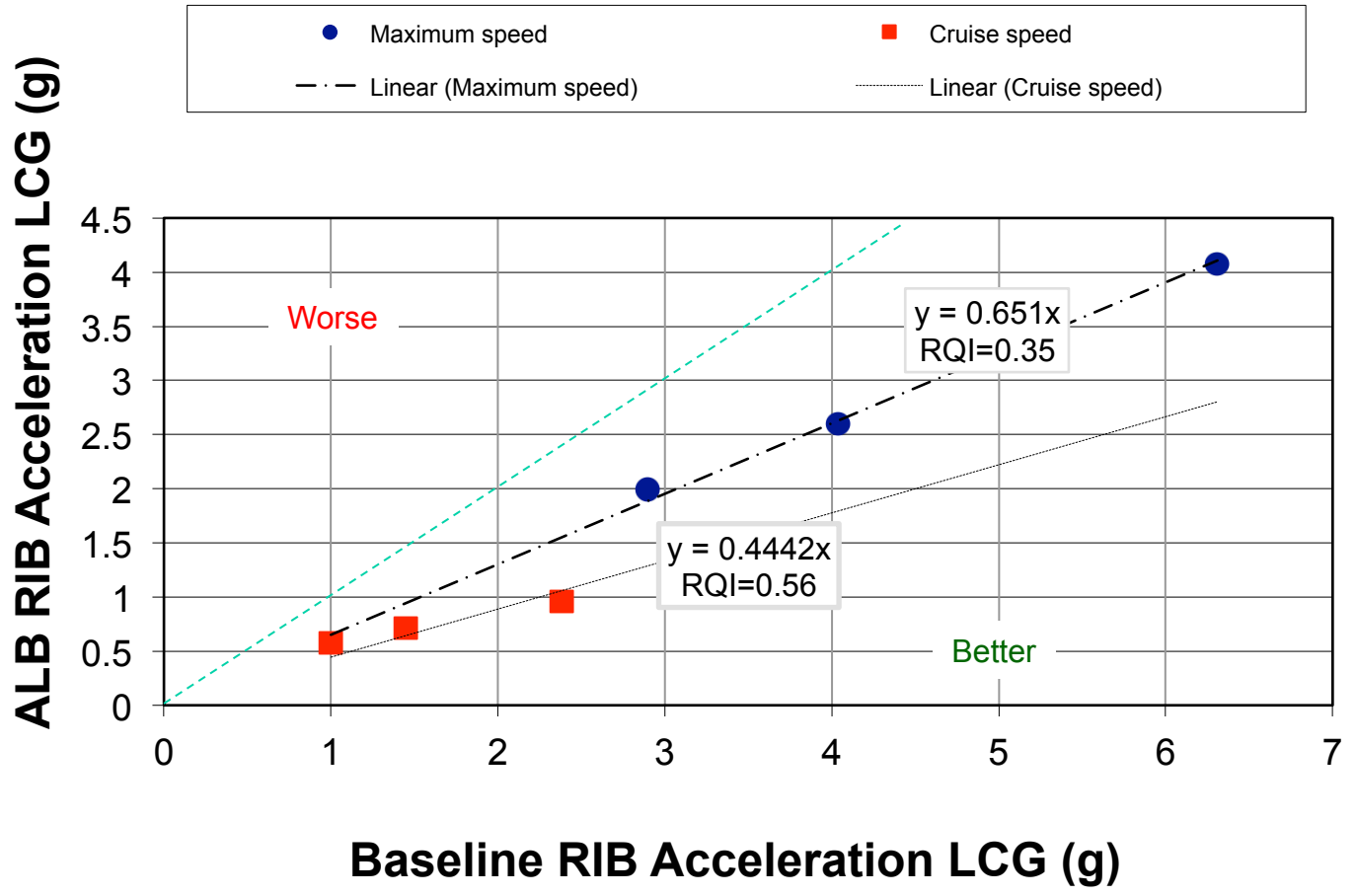


$$Ride\ Quality\ Index\ (RQI) = 1 - \frac{\Delta\ A_{Condition\ II}}{\Delta\ A_{Condition\ I}}$$

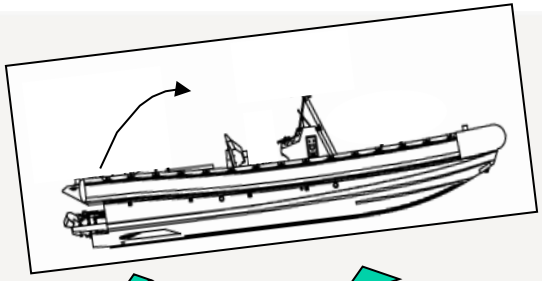
ALB Comparisons

2.9 ft seas ALB 32.7 knots Baseline 27.8 knots

4.0 ft seas ALB Cruise 21.1 knots Baseline 21.0 knots



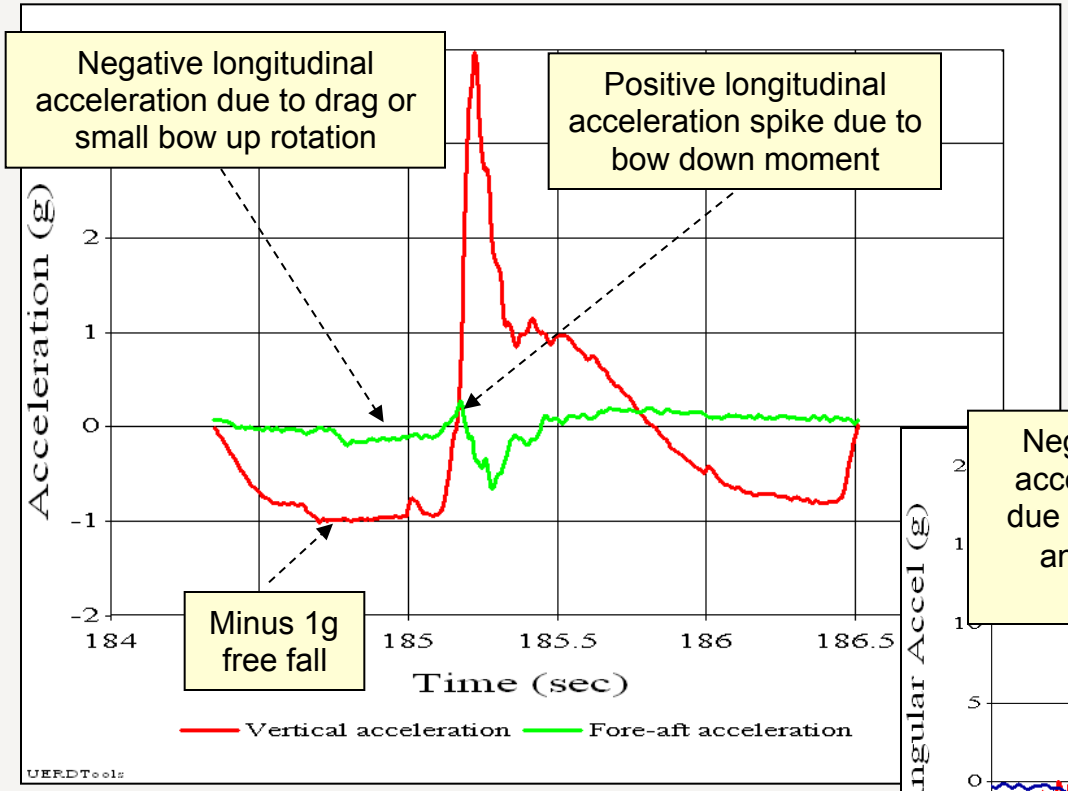
Type A Slam Pulse Shapes

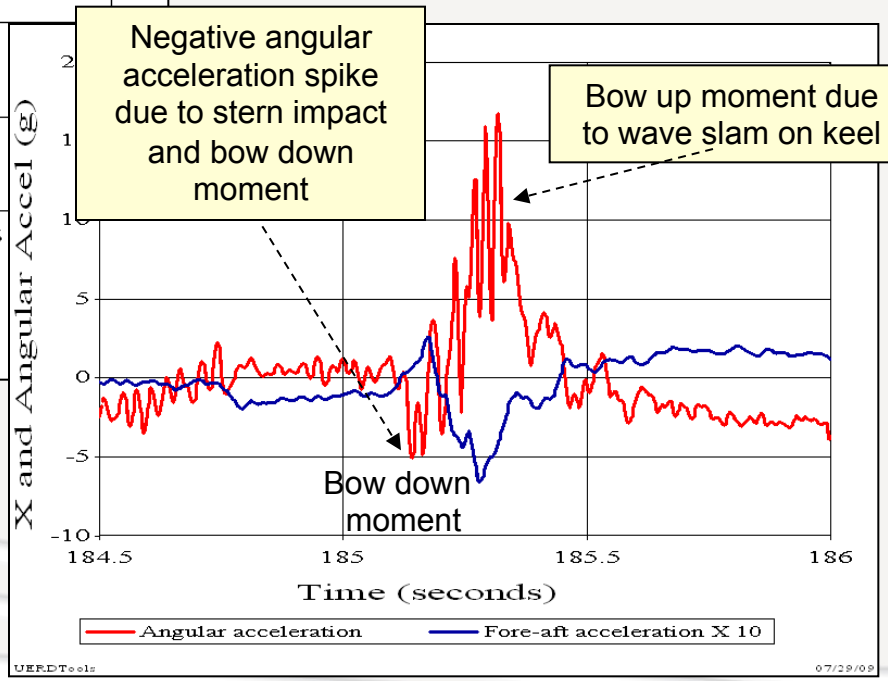


Negative moment 1/10th sec spike

Stern first

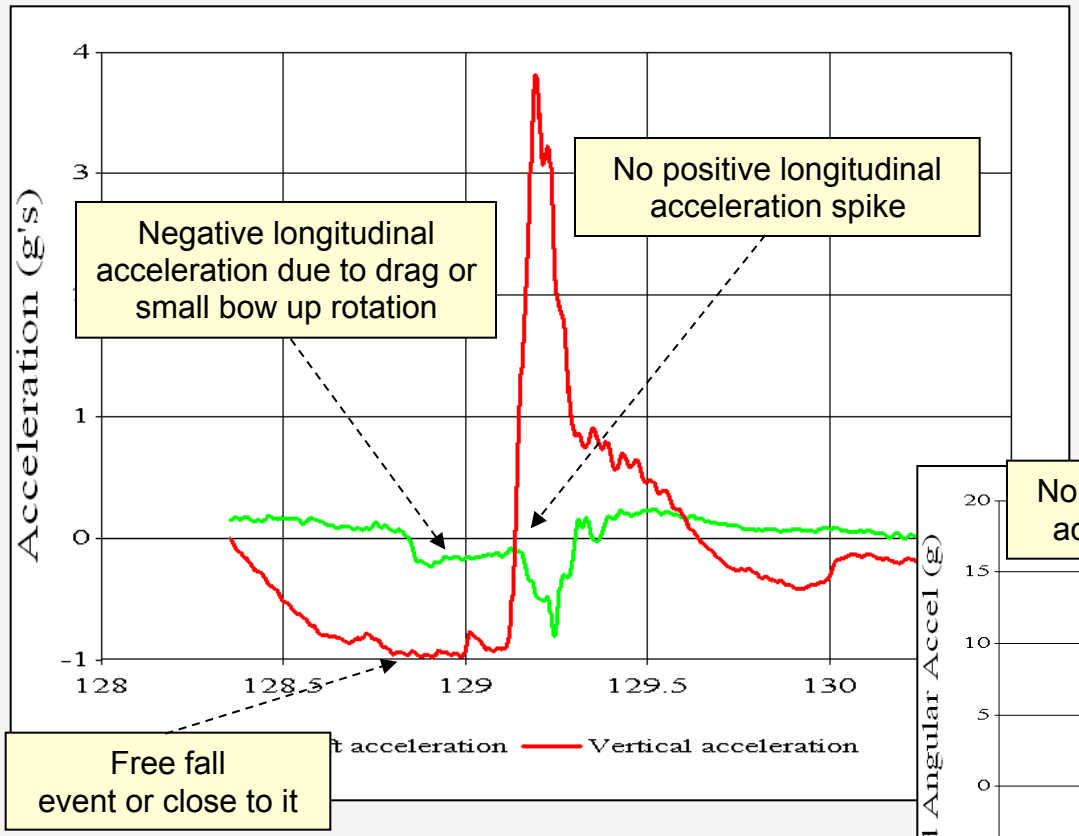
Then Slam event

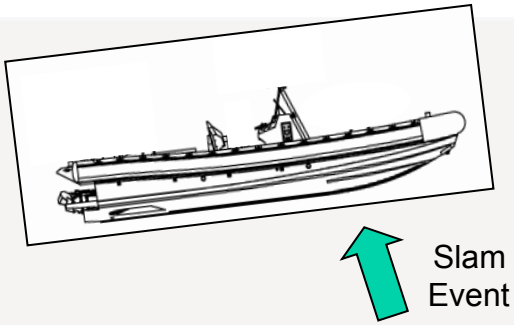


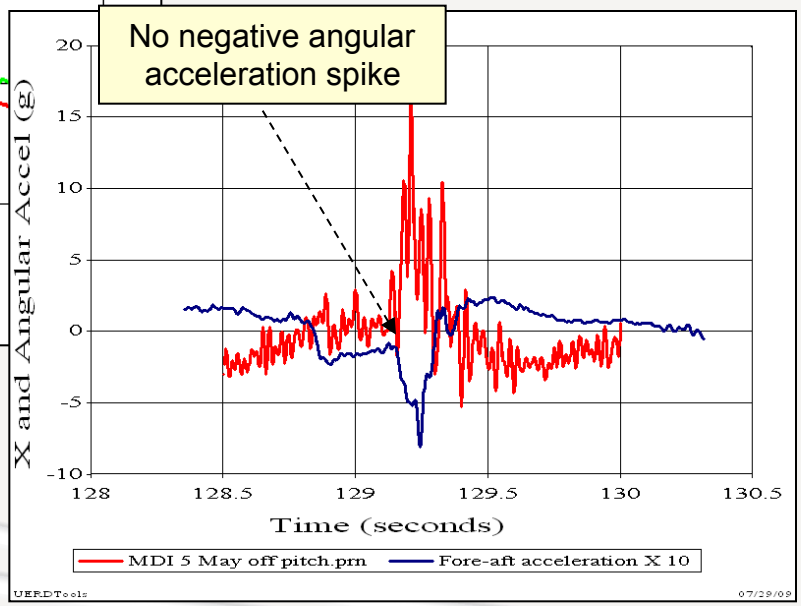


Plausible description:
Craft launched from wave
Free fall event
Stern water entry, brief bow down moment
Wave slam, bow up moment

Type B Slam Pulse Shapes

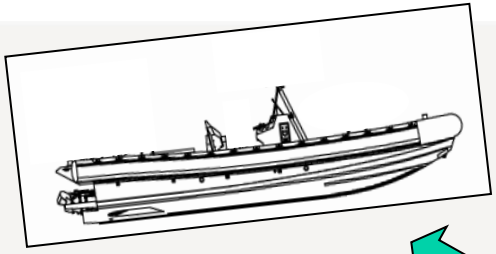






Plausible description: Free fall event with loss of forward acceleration before impact, keel water entry upon impact, followed by a bow up moment during the impact period

Type C Slam Pulse Shapes



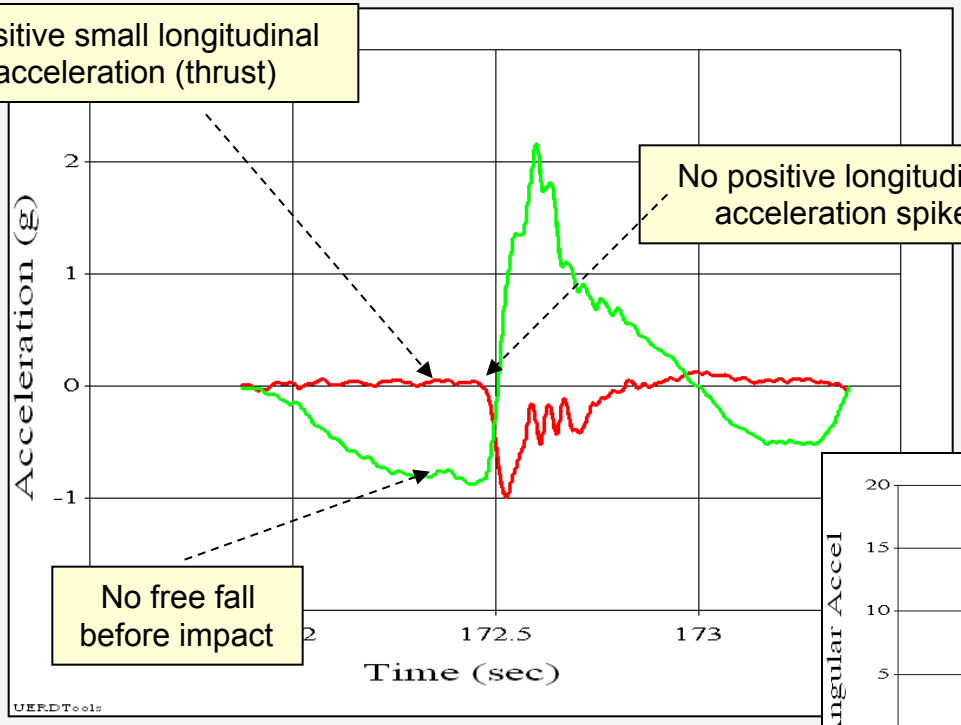
Thrust

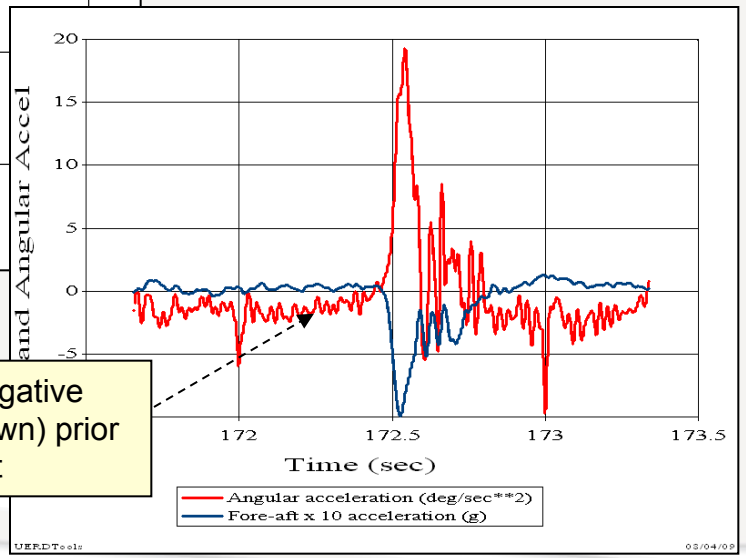
Slam Event

Positive small longitudinal acceleration (thrust)

No positive longitudinal acceleration spike

No free fall before impact

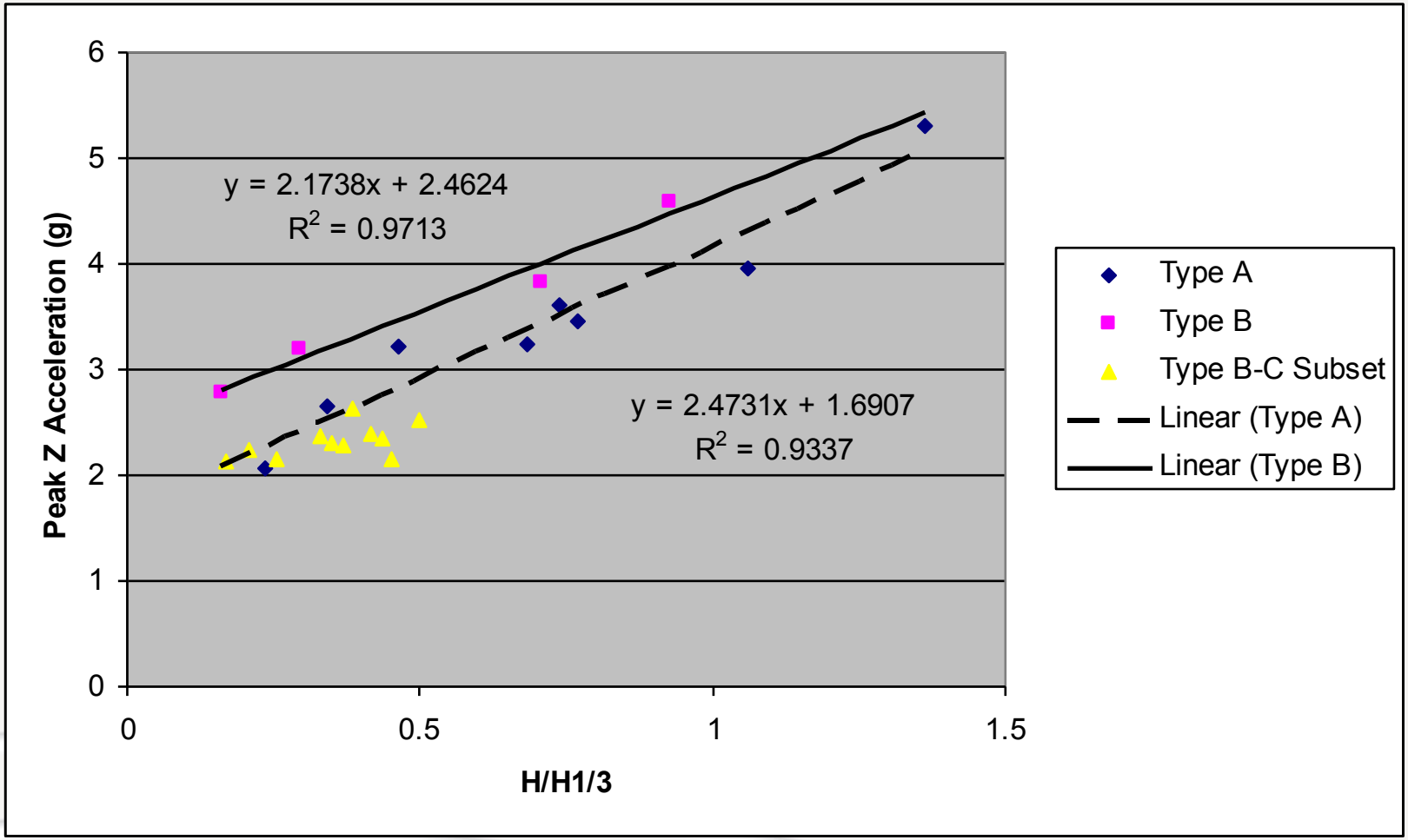




Continuous negative moment (bow down) prior to impact

Plausible description:
Forward acceleration with hull in water, no free fall, continuous bow rotation down Just before Impact

Type A and B Linear Data Fit



Summary

- *Introduced a 4-step computational process for improving repeatability when calculating $A_{1/n}$ peak accelerations*
  - *Analyze the data in the frequency domain (e.g. Fourier spectra) to confirm the use of a 10Hz low-pass filter to estimate rigid-body response acceleration.*
  - *Use the RMS value of the entire filtered record to establish a vertical threshold above which to count and tabulate peak rigid-body accelerations.*
  - *Use the horizontal time threshold based on wave-encounter frequency (½ second is acceptable for craft speed up to 60 knots) to count and tabulate peak rigid-body accelerations.*
  - *Compute $A_{1/n}$ average accelerations*

Summary

- *Introduced a simple Ride Quality Index*
  - *Proportional to wave slam (shock) damage potential*
  - *Cumulative damage or single-severe slam damage*
  - *Useful comparative tool for better/worse ride quality*
- *Use of each may foster future comparisons of ride quality of different craft or different test conditions regardless of the source of the data*

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