MACC Multi Agency Craft Conference 2003
Waves of the Future
Innovative Operations

Predicting Shock and Vibration Of Planing Craft Using Time-domain Simulation

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Topics

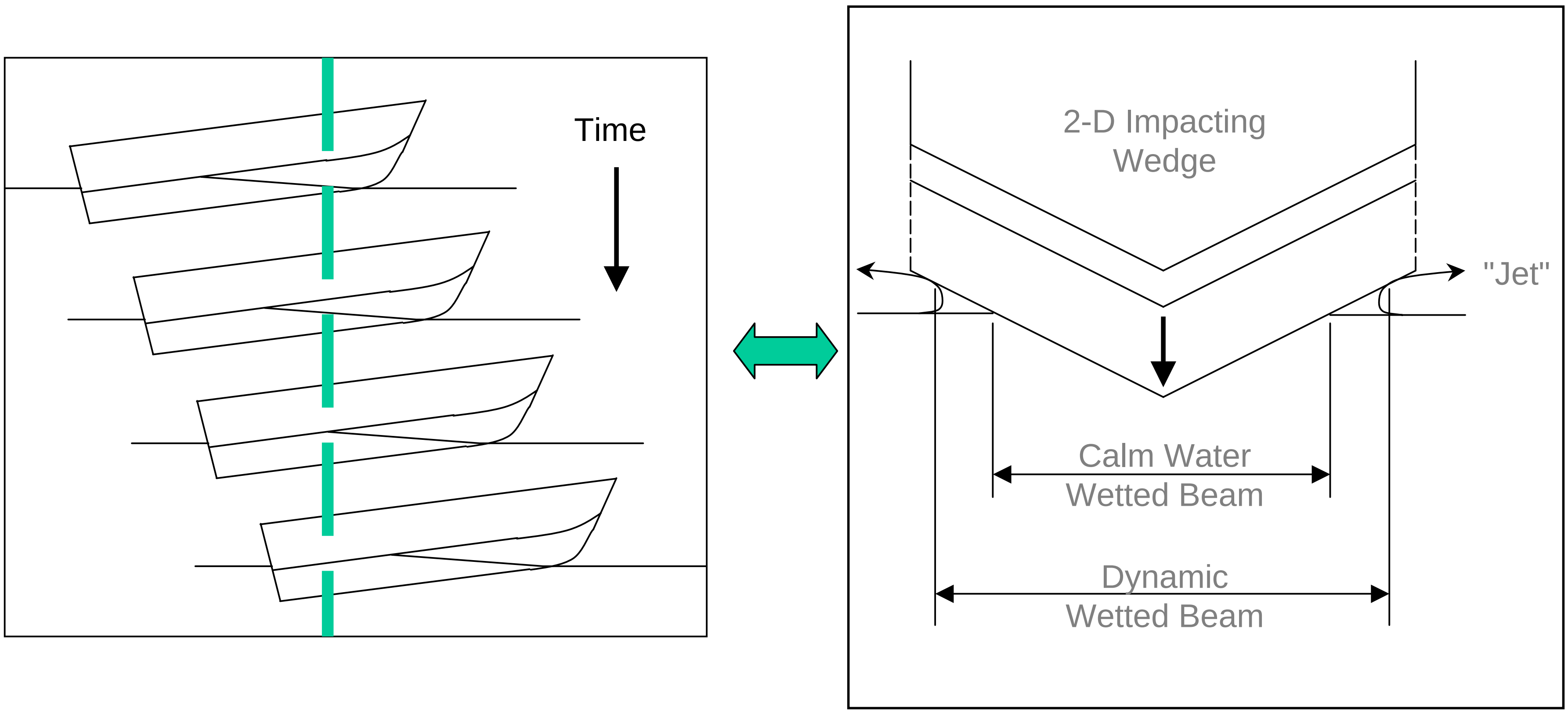
- Problem Definition
  - Injuries from shock, damaged or lost cargo, motion sickness
- Theoretical Analysis
  - Planing hull motion prediction (in the time-domain)
  - Validation of time-domain simulation
- Calculating Vibration/Shock/Motion Sickness Dosages from Time Data
  - ISO 2631-1:1997
- Case Study:
  - Predicting Shocks and Motions in Waves in Waves
- Summary and Conclusions

Theoretical Analysis: Planing Hulls

Planing hulls are *non-linear* systems

- High-speed boats can skip waves at certain wavelengths and heights
- Response to waves depends on starting conditions (speed, velocity) ← (chaotic system!)
  - Frequency analysis does not work, have to simulate in time-domain, not frequency-domain
- E. E. Zarnick at DTNRC (1978)
  - Combined theory to predict resistance, motions in waves, resultant pressures of planning craft
  - Technique: “Stripwise integration of forces on transverse sections modeled as wedges entering free surface vertically.”
    - In calm water and in head or following seas
    - (asymmetric problem is much harder)

Low Aspect Ratio Strip Theory: Impacting Wedge



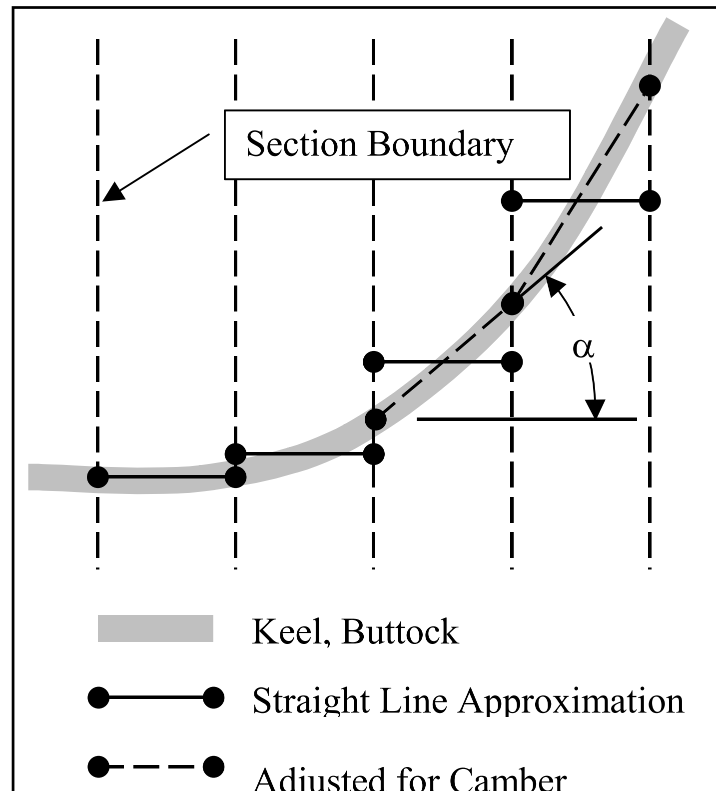
Low Aspect Ratio Strip Theory: Keel Camber and Chine Warp

- Wedge downward velocity

  $$V_Z = V_{FWD} * \sin(\text{trim angle})$$

  – (Only if hull is “prismatic”)
- If hull has keel camber or warp then effective downward velocity has to be modified:

  $$V_Z = V_{FWD} * \sin(\text{trim} + \alpha)$$



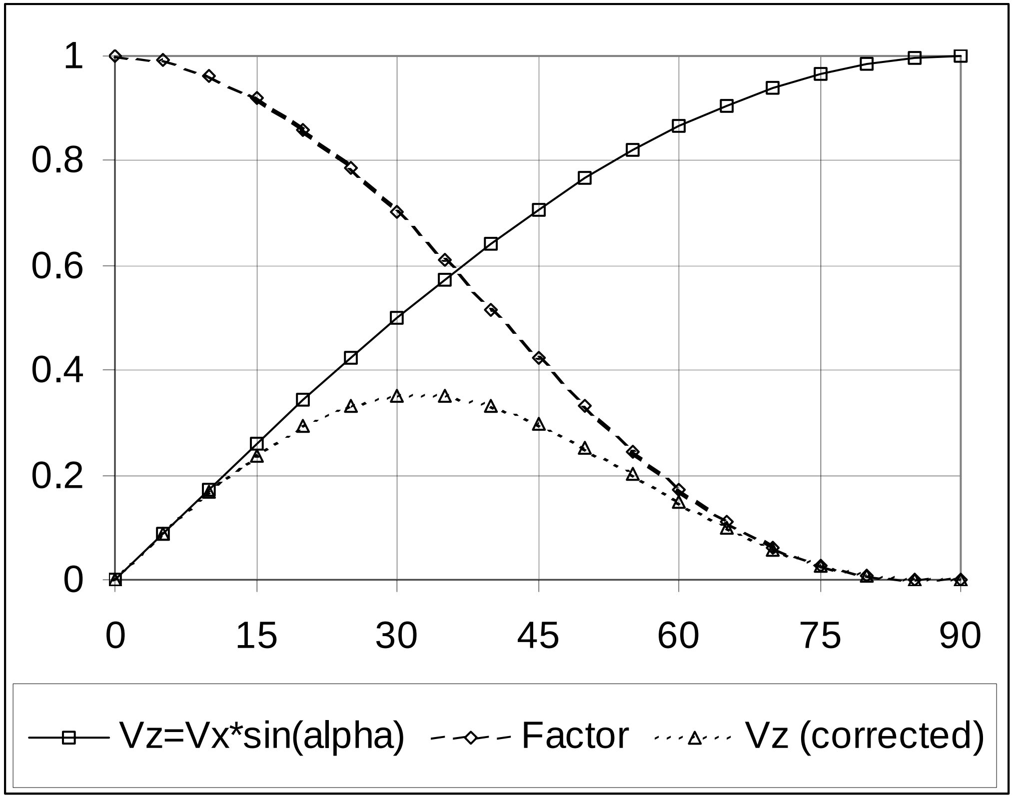
Low Aspect Ratio Strip Theory:
Keel Camber and Chine Warp

- V_{FWD} * sin(trim + α) over-predicts V_Z, lift force
  - Due to 3-D effects such as separation, turbulence
- Correction factor compensates for over-correction:

$$Factor = (C_P - C_P*(\alpha/90)^2))^3$$

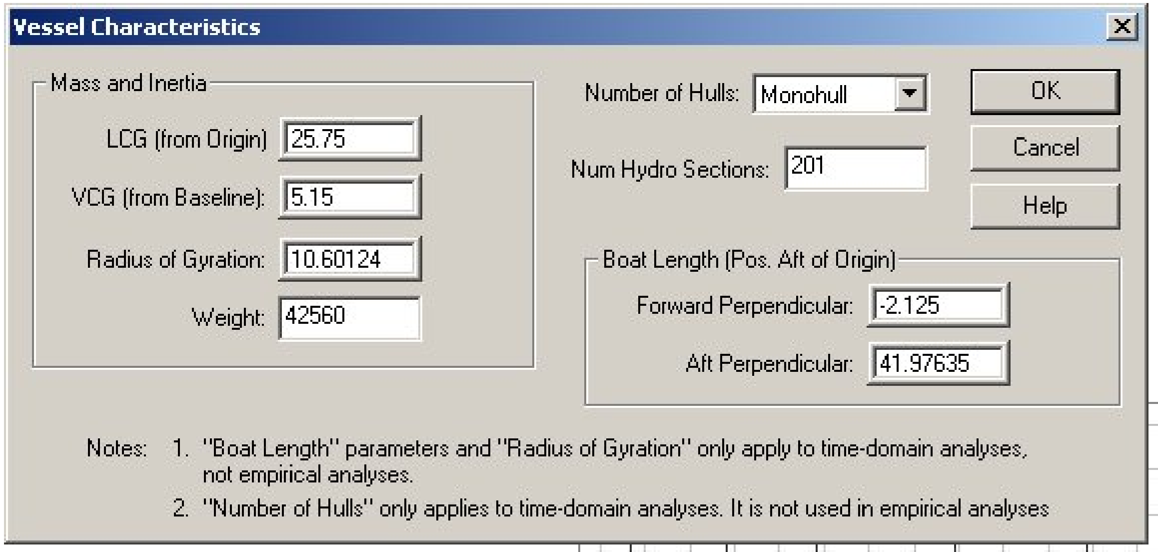
$$V_Z = V_{FWD} * \sin(\text{trim angle})$$

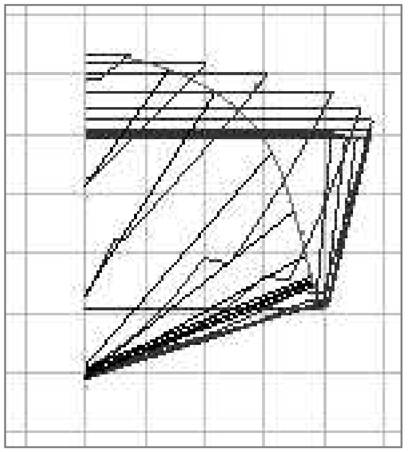
$$+ Factor * V_{FWD} * \sin(\alpha)$$

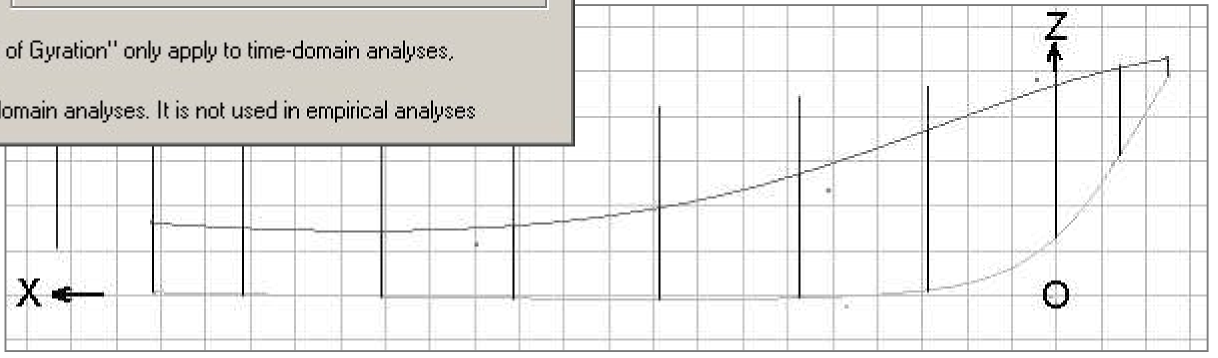


Low Aspect Ratio Strip Theory:

Geometry Parameters



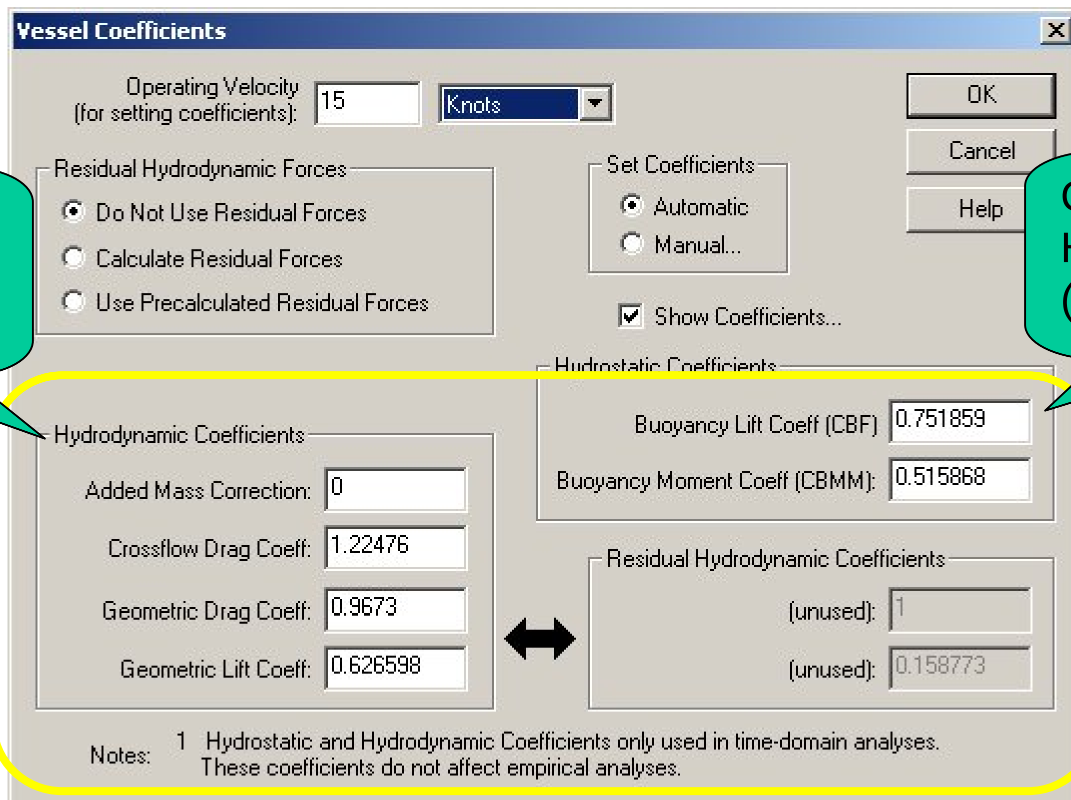




Low Aspect Ratio Strip Theory:

Empirical Coefficients

Corrections for Keel Camber and Chine Warp



Corrections for Hydrostatic Forces (Transom Effect)

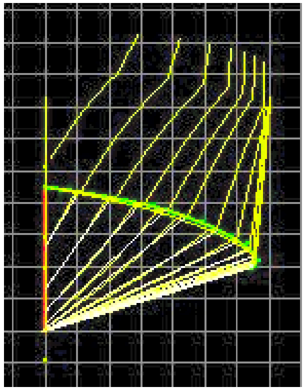
Parameters set automatically

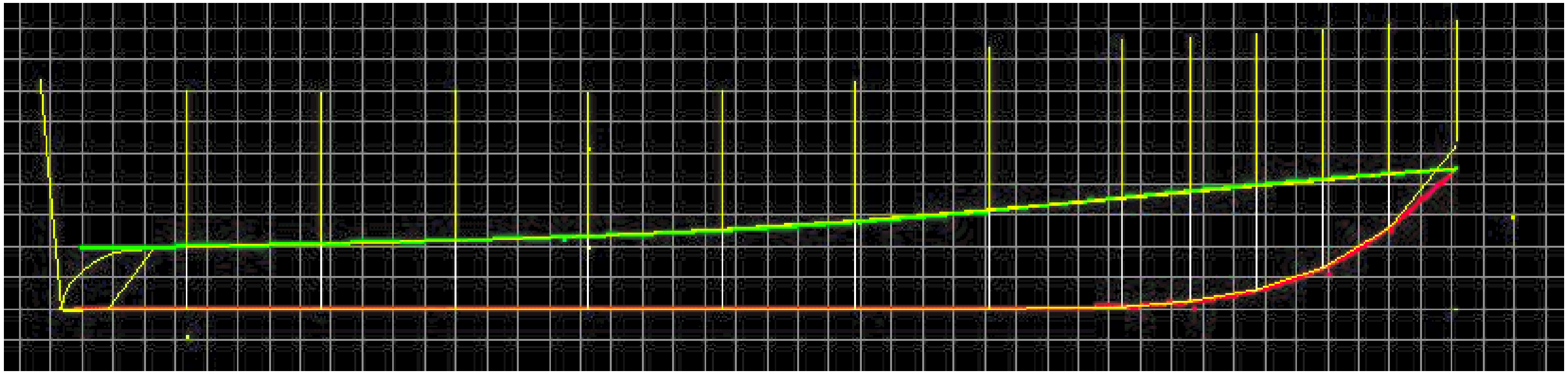
Theoretical Analysis:
Validation of Time-Domain Algorithm

- Four planing vessels were simulated using algorithm
  - USCG 47-ft Motor Life Boat (MLB)
  - 46-FT Army Corps of Engineers Survey Boat "Chernesky"
  - USCG 120-ft "Heritage" class patrol boat
  - 60-ft high-speed sportfishing boat designed by Band, Lavis and Associates
- Vessels chosen to represent wide range of sizes, speeds, and hullforms
  - (and for which test data were available)
- Analyses:
  - Calm water speed versus power
  - Seakeeping characteristics in irregular seas (SS 3, SS4-5)

Validation: USCG 47-foot Motor Life Boat

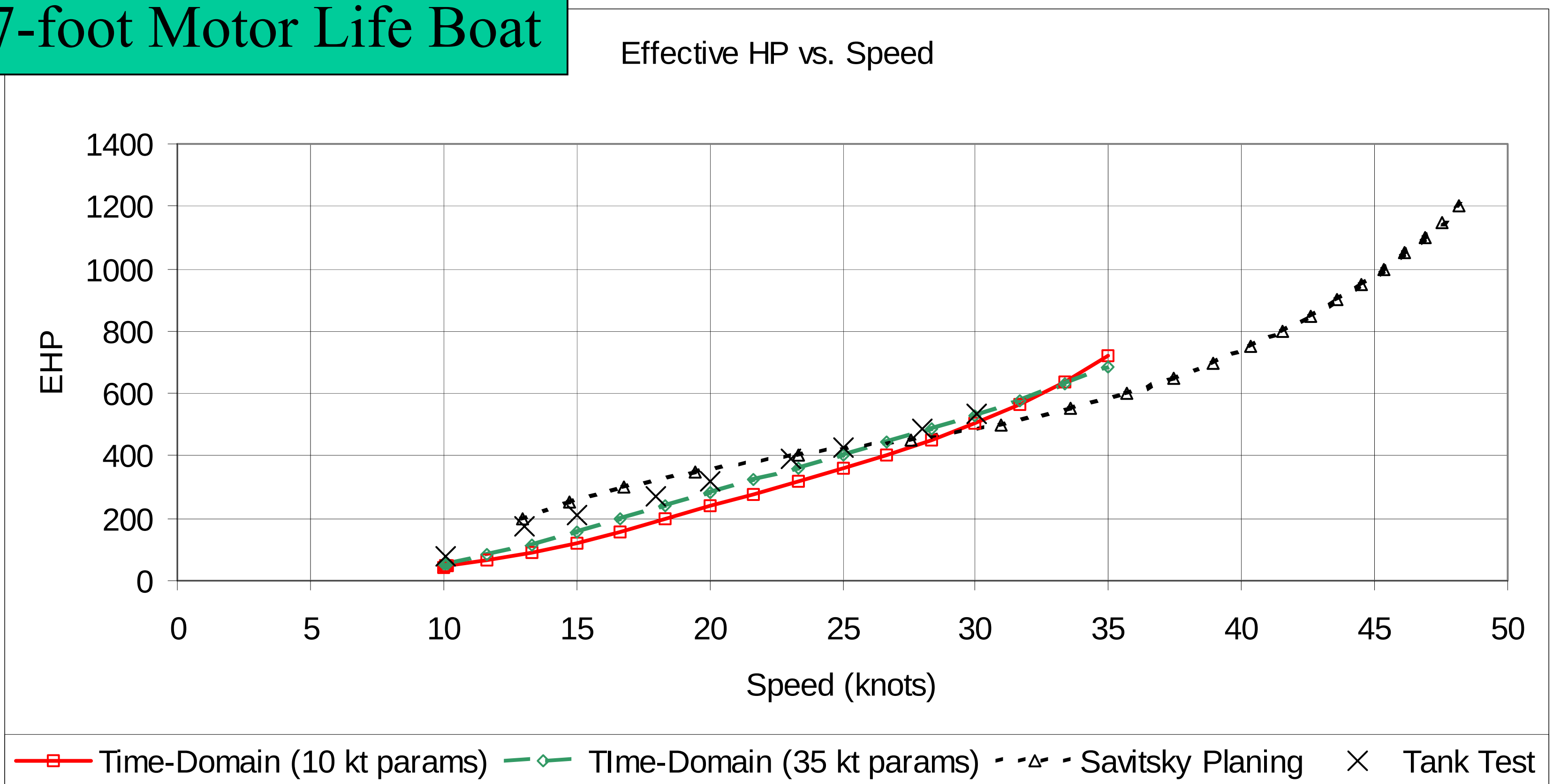
- Empirical model of transom wedge (3 degrees)
- Did not simulate air drag (tank data has unknown air drag scaling)
- Nominal loading (19 long tons), LCG (40% of LBP fwd of aft perpendicular)
- Curved transom modeled by averaging length
- Salt Water, 59 degrees F





Validation of Time-Domain Algorithm

47-foot Motor Life Boat



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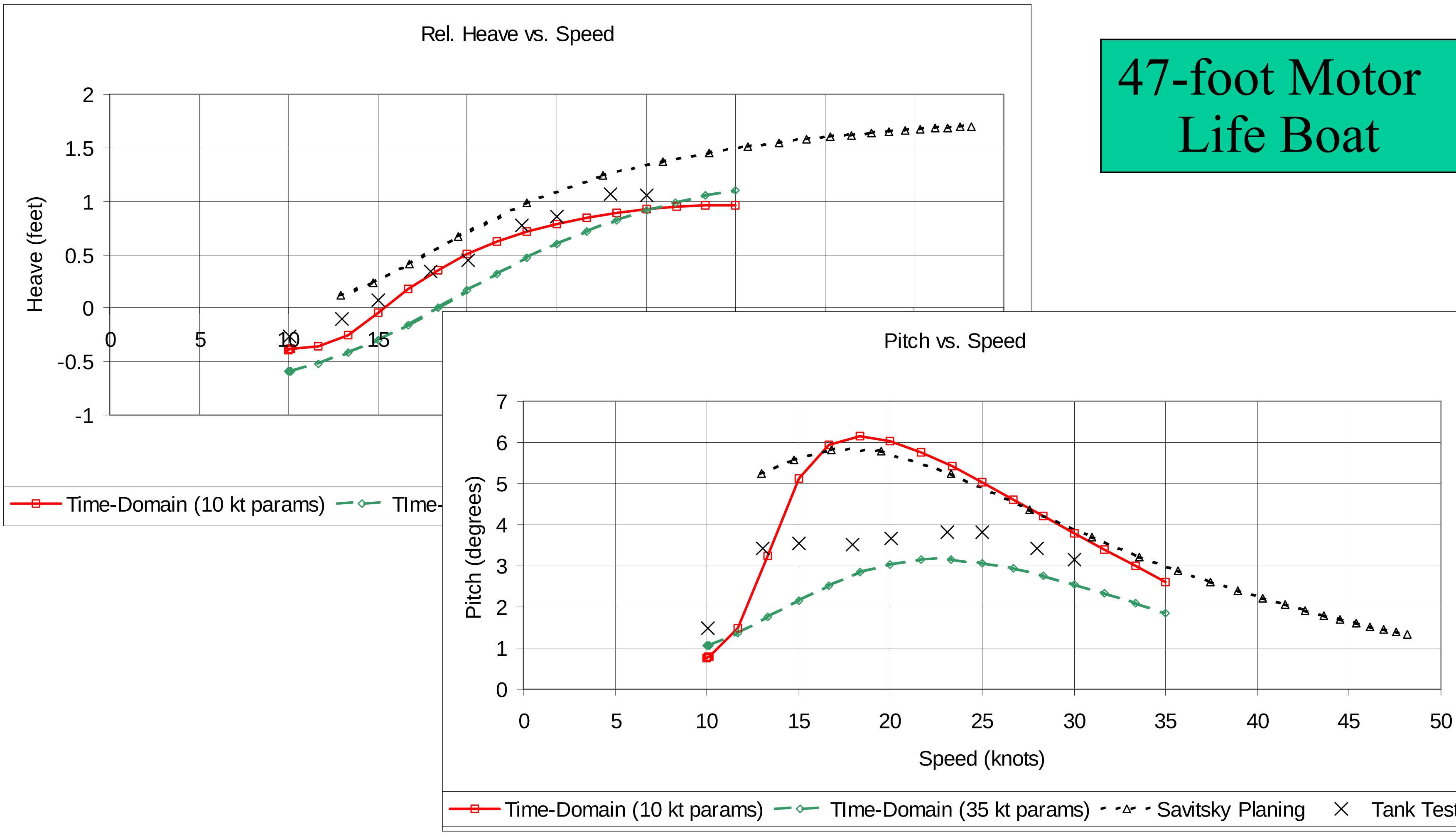
Validation of Time-Domain Algorithm

47-foot Motor Life Boat



Validation of Time-Domain Algorithm

- 47-foot Motor Life Boat: *Seakeeping*
  - 30 knots, SS 3 (Hsig = 2.89 feet, modal period = 7.5 seconds)

	Pitch (degr.)	Surge Velocity (knots)	Relative Heave (feet)	Wave Height (feet)	Eff. Power (British HP)	Heave Accel. (G's)	Vertical Accel., Sta. 0, Deck (G's)	Notes:
Min	-3.403	30.0	-1.680	-2.286	-123.4	-0.640	-0.827	
Mean	2.151	30.0	0.806	0.001	747.8	0.000	0.001	
Max	6.583	30.0	3.590	2.596	6065.9	0.740	2.232	
Std Dev	1.424	0.0	0.816	0.725	630.6	0.208	0.379	
Max Ht	9.985	0.0	5.046	4.492	6122.1	1.380	3.054	
H(1/3)	5.343	0.0	3.422	2.926	4531.9	0.800	1.913	
H(1/3)/2	2.672	0.0	1.711	1.463	2266.0	0.400	0.957	
Hs/2+Mn	4.823	30.0	2.517	1.464	3013.8	0.400	0.957	*Simulation*
	5.850		2.500			0.471	1.430	*USNA Report EW-7-88, Table II, Peaks*
4*stdev	5.694	0.0	3.265	2.899	2522.4	0.832	1.517	*Simulation*
	6.180		3.300			0.960	1.990	*USNA Report EW-7-88, Table III, 4*Std Dev*

Validation of Time-Domain Algorithm

- 47-foot Motor Life Boat: *Seakeeping*
  - 20 knots, SS 4-5 (Hsig = 9.12 feet, modal period = 9.0 seconds)

	Pitch (degr.)	Surge Velocity (knots)	Relative Heave (feet)	Wave Height (feet)	Eff. Power (British HP)	Heave Accel. (G's)	Vertical Accel., Sta. 0, Deck (G's)	Notes:
Min	-9.780	15.0	-8.648	-7.949	-1090.0	-0.941	-1.129	
Mean	1.873	15.0	-0.111	-0.001	205.3	0.000	0.003	
Max	14.439	15.0	9.485	7.140	2706.6	0.978	2.505	
Std Dev	3.722	0.0	2.581	2.261	353.9	0.301	0.499	
Max Ht	21.303	0.0	15.513	13.396	3252.8	1.848	3.445	
H(1/3)	14.899	0.0	10.607	9.091	2872.4	1.149	2.698	
H(1/3)/2	7.450	0.0	5.304	4.546	1436.2	0.575	1.349	
Hs/2+Mn	9.322	15.0	5.192	4.544	1641.5	0.575	1.353	*Simulation*
	11.200		4.780			0.637	2.080	*USNA Report EW-7-88, Table II, Peaks*
4*stdev	14.888	0.0	10.323	9.044	1415.5	1.202	1.996	*Simulation*
	14.800		8.940			1.360	2.500	*USNA Report EW-7-88, Table III, 4*Std Dev*

Theoretical Analysis:
Validation: Conclusions of USCG/BLA Study

- “…best suited for simulating single hard-chined planing hulls at speeds corresponding to a beam Froude number > 2.0.”
- “…tends to out-predict the Savitsky empirical method, coming within 5-10% of the towing tank resistance and EHP.”
- “…significant pitch and heave motions were typically predicted within 10-15% of model test results.
- “Significant accelerations were within 20% of towing tank results for the 47-ft MLB.”

Problem: Motion Sickness

- Multiple causes (usually conflicting signals)
  - When vestibular system (inner ear) gives conflicting signals to brain
  - When visual system (eyesight) conflicts with other systems
    - Also when visual images remind you of motion that has caused illness
  - When somatosensory system (for example, your diaphram) conflicts with other systems
- Motion sickness is influenced by:
  - Gender
  - Age (little kids on a car trip)
  - Alcohol / drugs
  - Temperature, environment

Problem: Shocks

- What is a shock?
  - "Jerk" is change in acceleration, results in a change in force:

    $$F = m\,A, \text{ so } \Delta F = m\,\Delta A$$
  - *Large* acceleration applied over *long* period
    - 10 G acceleration over 1 m-sec period isn't noticeable
    - 10 G acceleration over 1 second period causes blackouts
- Effects of shock depends on:
  - Orientation (shock in vertical or lateral direction)
  - Position (standing, sitting, prone)
  - Timing or phase of shock components
- Conclusion: Look at peaks (height and width) in time-history of accelerations

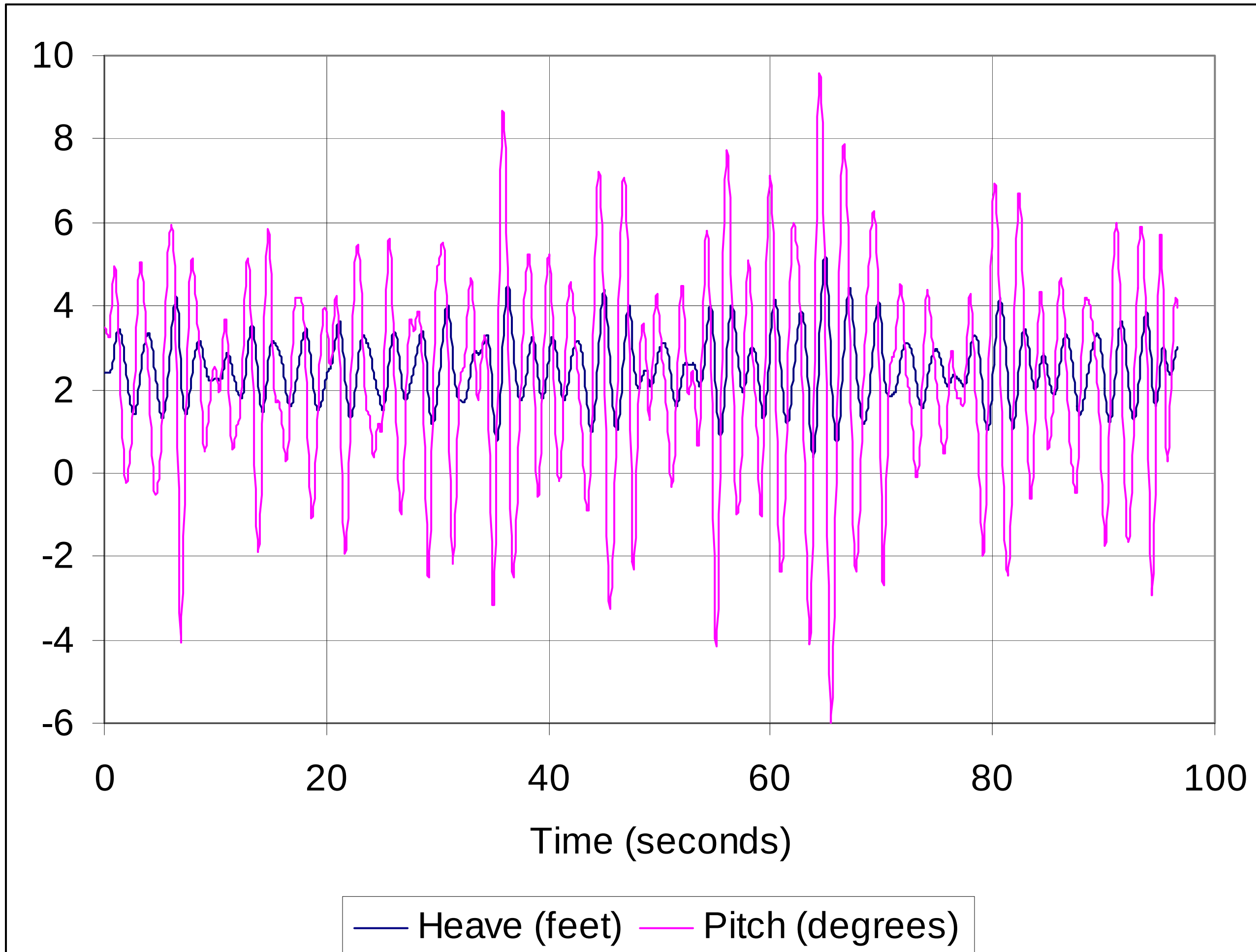
How Do We Use the Time History?

- Simulation Results

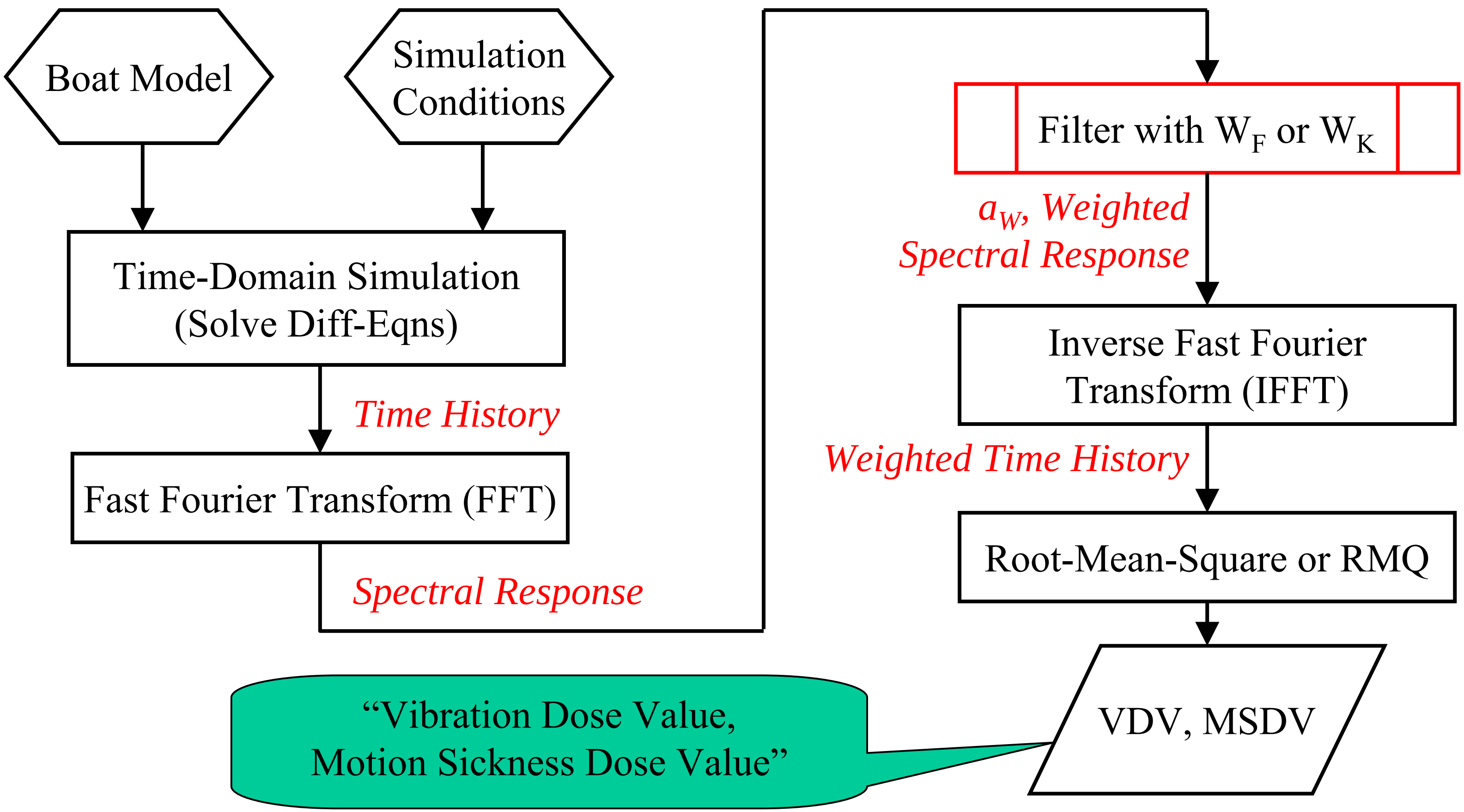
  Waves synthesized from measured sea spectrum

- Difficult to make design decisions based on so much data

  ∴ Convert to spectrum (frequency-domain) to interpret results



ISO 2631-1:1997
Calculating VDV/MSDV from Time-Data



Motion Sickness: "Severe Discomfort Boundaries"

1. Convert accel(t) to $a(\omega)$ using FFT
2. Apply weights to $a(\omega)$

   $a_W(\omega) = a(\omega) * w_F(\omega)$

where

   $a_W(\omega)$ = weighted accel. (freq)

   ω = frequency (rad/sec)

3. Convert $a_W(\omega)$ to $a_W(t)$ using IFFT
4. RMS value of $a_W(t)$

$$a_W = \sqrt{\frac{1}{T}\int_0^T a_W^2(t)\,dt}$$

where

   $a_W(t)$ = weighted accel. (time)

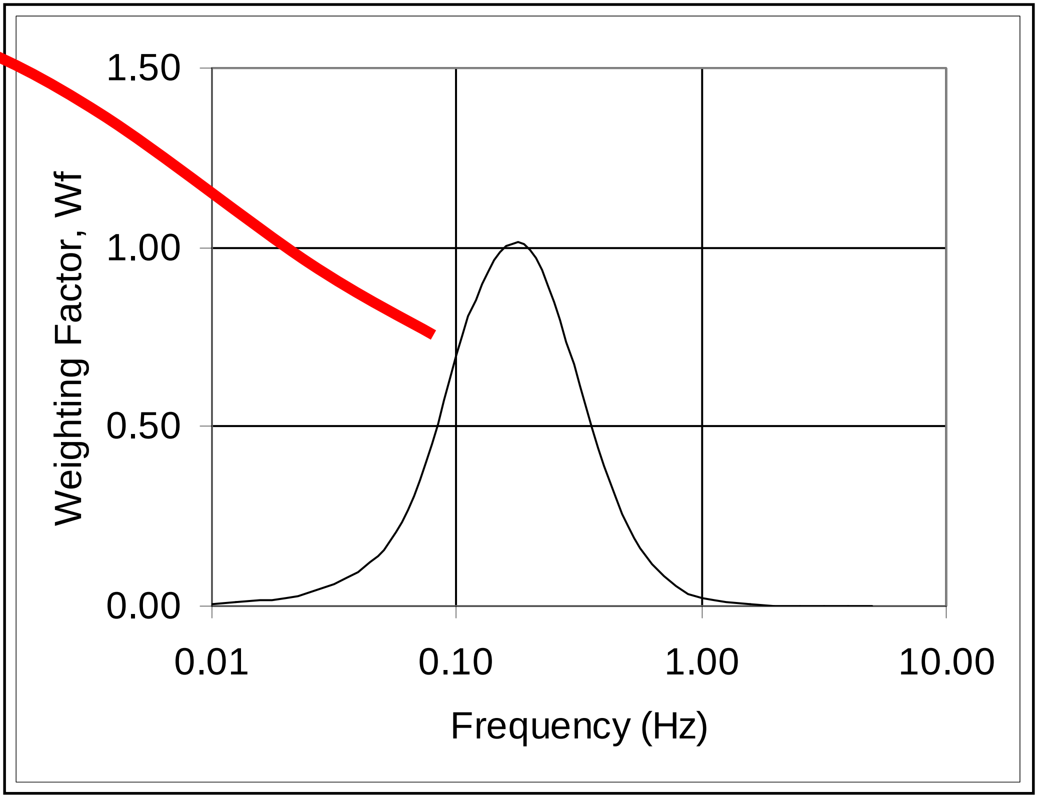
   T = length of measurement

5. Calculate $MSDV_Z$

   $MSDV_Z = a_W * T_0^{1/2}$

6. % Sick = $K_m * MSDV_Z = 1/3 * MSDV_Z$

ISO 2631-1:1997



ISO Standard 2631-1: Shocks

ISO 2631-1:1997

1. Convert accel(t) to $a(\omega)$ using FFT
2. Apply weights to $a(\omega)$

$$a_W(\omega) = a(\omega) * w_K(\omega)$$

where

$a_W(\omega)$ = weighted accel. (freq)

ω = frequency (rad/sec)

3. Convert $a_W(\omega)$ to $a_W(t)$ using IFFT
4. Root–Mean–Quad (RMQ) of $a_W(t)$

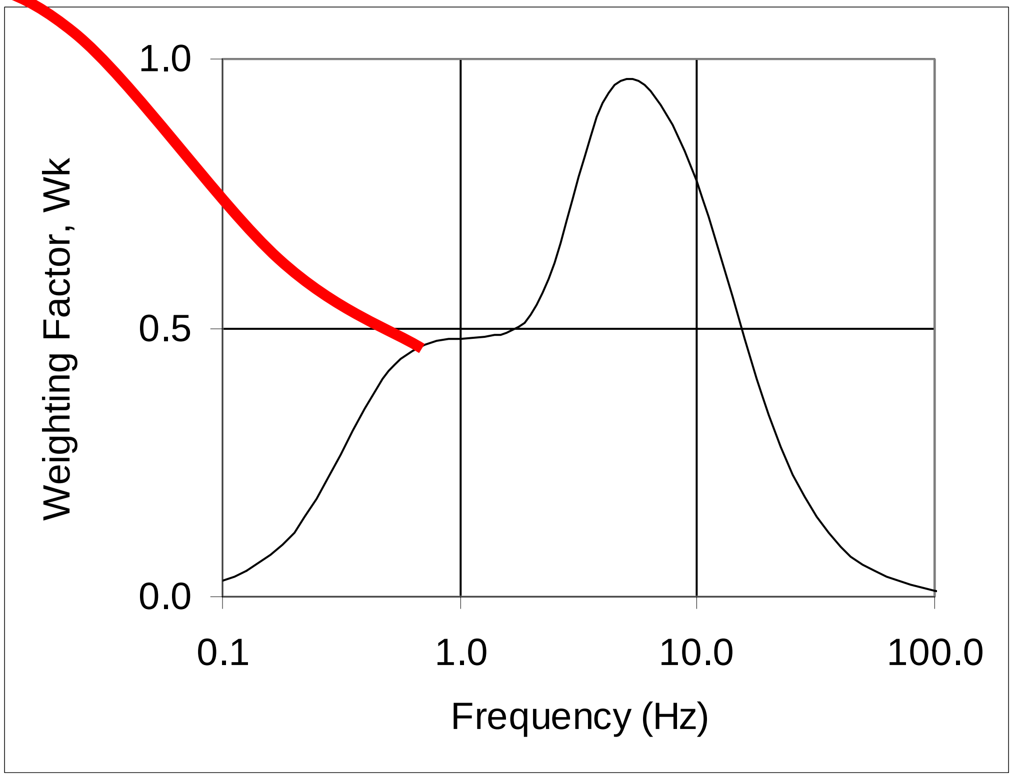
$$RMQ = \sqrt[4]{\frac{1}{T}\int_0^T a_W^4(t)dt}$$

where

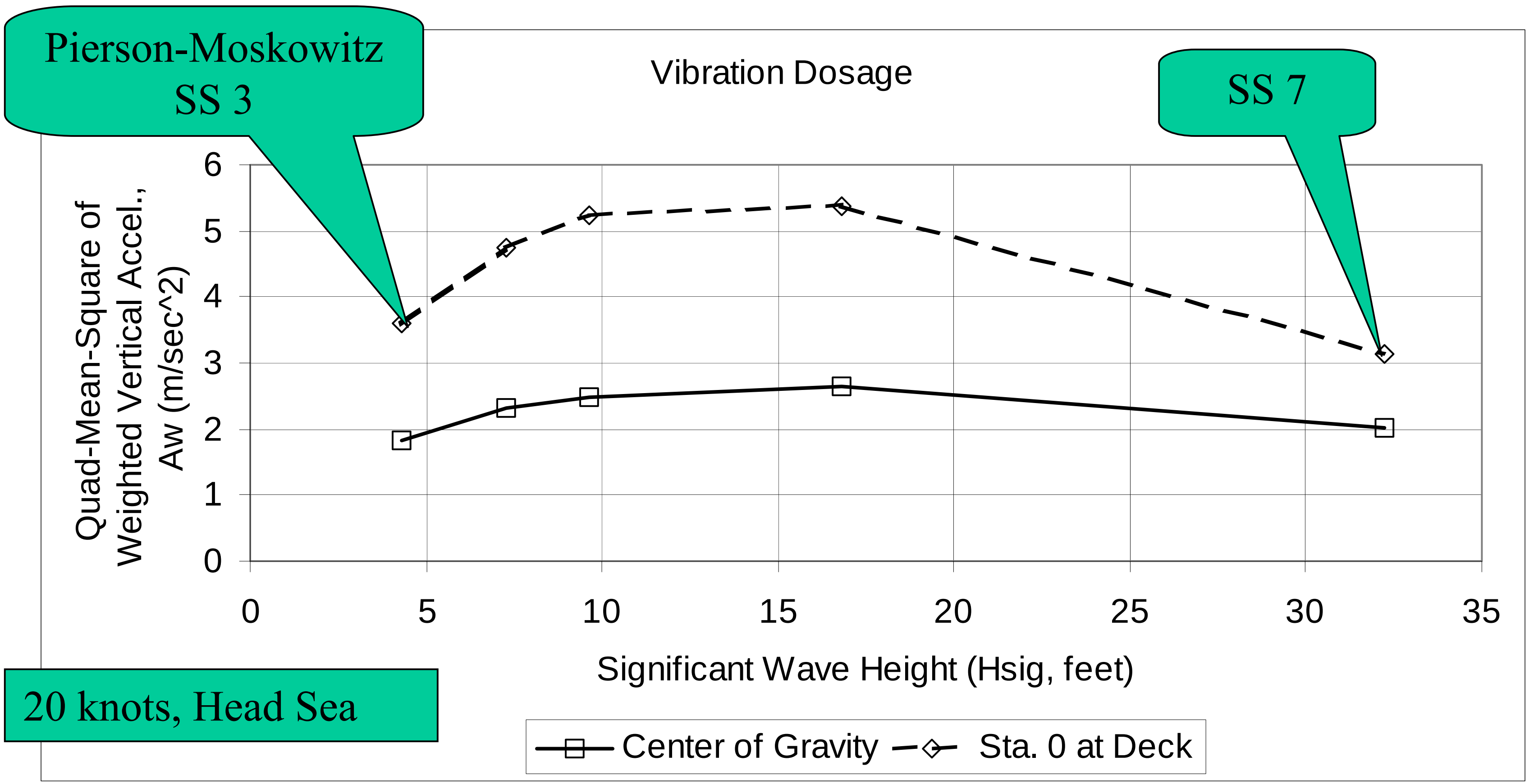
$a_W(t)$ = weighted accel. (time)

T = length of measurement

5. $VDV = RMQ * T^{1/4}$



Case Study: 47-Foot MLB Shock/Vibration Dosage



Case Study: 47-Foot MLB
Head vs. Following Sea

- 20 knots in SS 5 (Pierson-Moskowitz)
- Moving <u>with</u> waves results in *effective* frequencies below weighting curves
  - VDV and MSDV both attenuated
  - MSDV reduced *less* than VDV because MSDV sensitive to low frequencies in following sea

	Hsig (ft)		Center of Gravity		Sta 0 at Deck	
Sea State	Theoretical	PWRS	VDV	MSDV	VDV	MSDV
5 (head)	9.5	9.646	2.473	0.523	5.242	0.604
5 (following)	9.5	8.911	0.339	0.138	0.639	0.263

Case Study: Wave Data

- Station 42040 - MOBILE SOUTH
  - 64 nm South of Dauphin Island, AL
- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- 29.21 N 88.20 W (29°12'36"N 88°12'00"W)
- Water depth: 237.7 m

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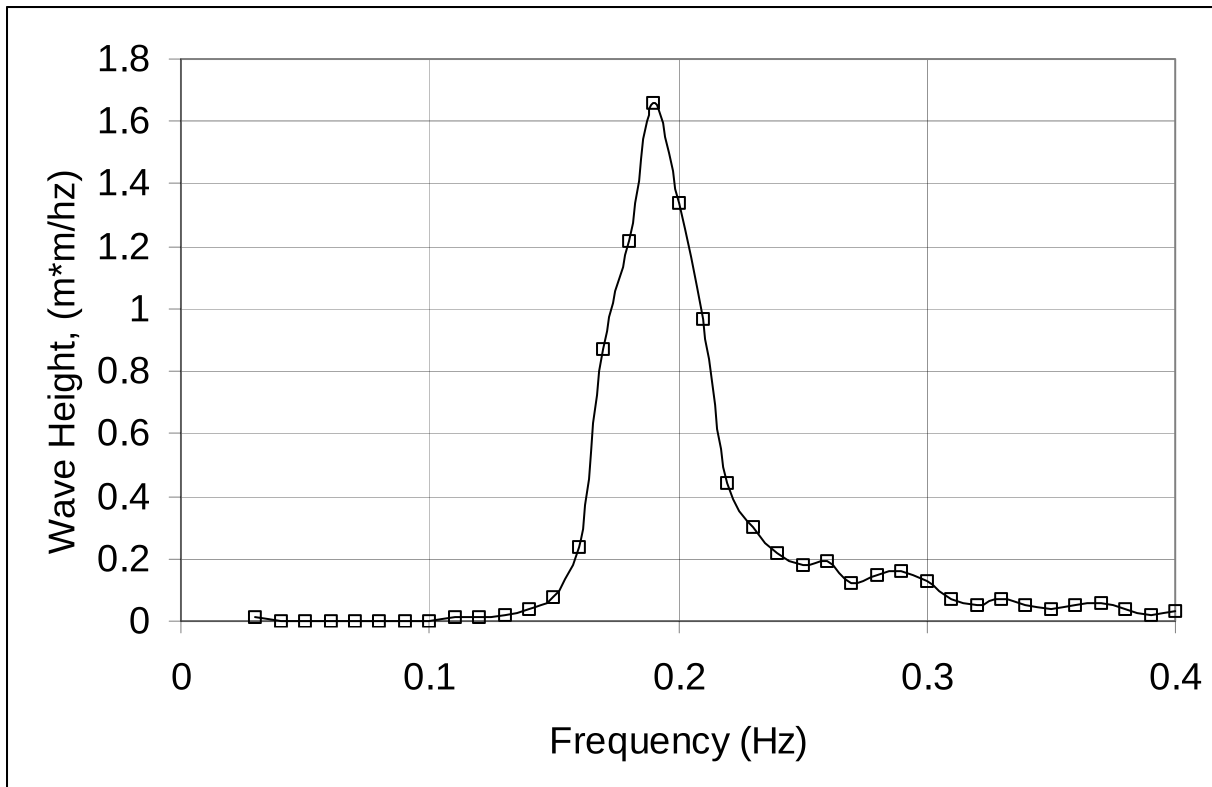
Case Study: Wave Data

- Spectral Density Function for Station 42040
  - July 14, 2002 07 at 10:00 PM GMT
  - HSIG=3.904 feet (1.19 m)



Case Study: Results from Gulf Buoy Data

- H_{SIG}=3.97 feet (NBDC reports 3.904)
  - Low SS 3 range
- 20 knots, head seas

Hsig (ft)		Center of Gravity		Sta 0 at Deck	
Theoretical	Simulated	VDV	MSDV	VDV	MSDV
3.904	3.97	1.929	0.184	3.596	0.272

- Heave / pitch motion would not cause motion sickness…
  - Large pitching motion (Significant pitching = 11.2°) is out of frequency range that causes motion sickness
- …but large Shock/Vibration value would require limited exposure time

Summary

- Simulation based on low aspect ratio strip theory can predict vertical-plane motion with engineering accuracy
  - Limited to surge, heave, pitch (not roll)
  - Reliably underpredicts peak accelerations by 20%
- Vibration Dosage Value (VDV) and Motion Sickness Dosage Value can be calculated using time-domain and frequency-domain methods

  Sea spectrum (F) → wave heights (T) → vessel motion (T)
  → response spectrum (F) → VDV/MSDV

- Conclusion: Useful technique for preliminary design of high-speed craft

Sources of Standards

ABYC Standards (also ISO Standards related to yachts and small craft)	American Boat & Yacht Council, Inc. 3069 Solomons Island Road Edgewater, MD 21037 Voice: 410-956-1050 Fax: 410-956-2737 Website: http://www.abycinc.org
ISO Standards (See ABYC)	International Organization for Standardization ISO copyright office Case postale 56 CH-1211 Geneva 20 Voice: +41 22 749 01 11 Fax: +41 22 749 09 47 Website: http:// www.iso.ch

Time Domain Simulation References

- Von Karman, W., “The Impact of Seaplane Floats During Landing,” National Advisory Committee for Aeronautics (NACA) Technical Memorandum, TN 321, 1929.
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