Marine Composites

Webb Institute
Senior Elective

Impact Damage

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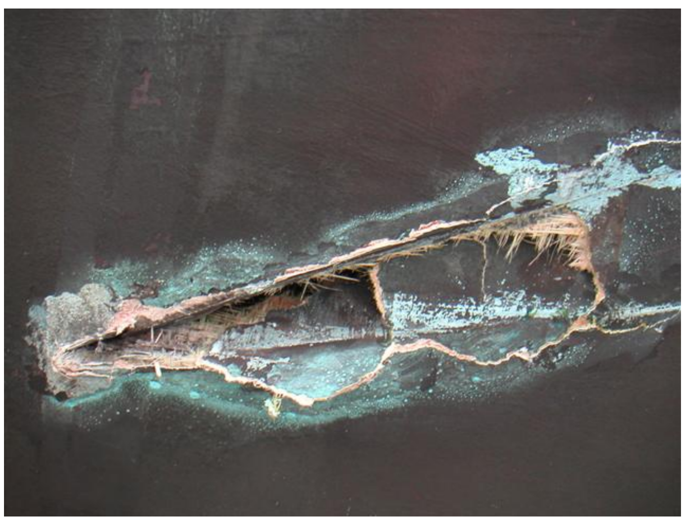
eric greene associates

Examples of Impact Damage

Just before 2 a.m., a 1992, 38-ft. Fountain power boat slammed into a fixed, channel marker, ripping a 17-ft. gash in the forward hull & becoming impaled on the steel piling holding the channel marker.

Roll stabilizer damaged after grounding (top) and resulting hull damage (below)



Sailboat hit by powerboat on autopilot in the open ocean

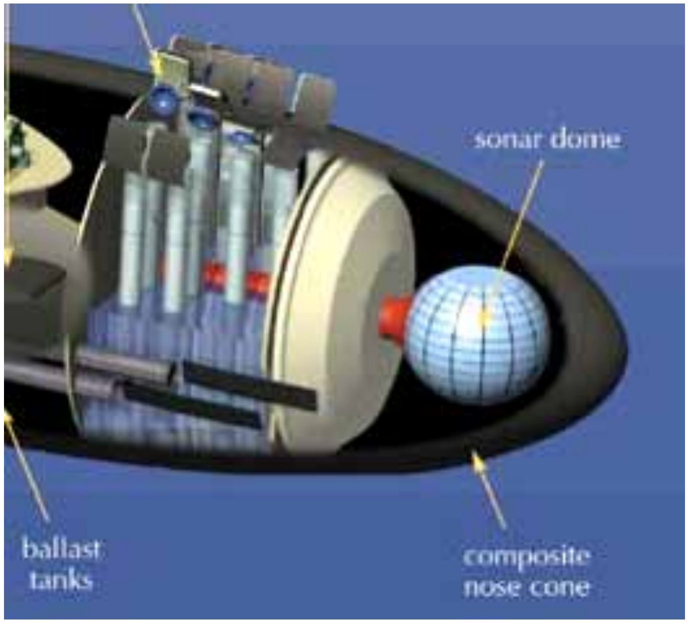
Impact Damaged Boats

www.yachtpals.com

Impact Damaged Boats

Submarine Impact Damage

SSN 711 *San Francisco* hit an uncharted seamount in Jan 2005



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Internal Damage

Crew repairs damage to ring frame sustained in 50 knot winds on Irish entry in the 2011-12 edition of the Volvo Ocean Race

Guo Chuan/Green Dragon Racing

Stringer damaged from grounding event

Examples of Slamming

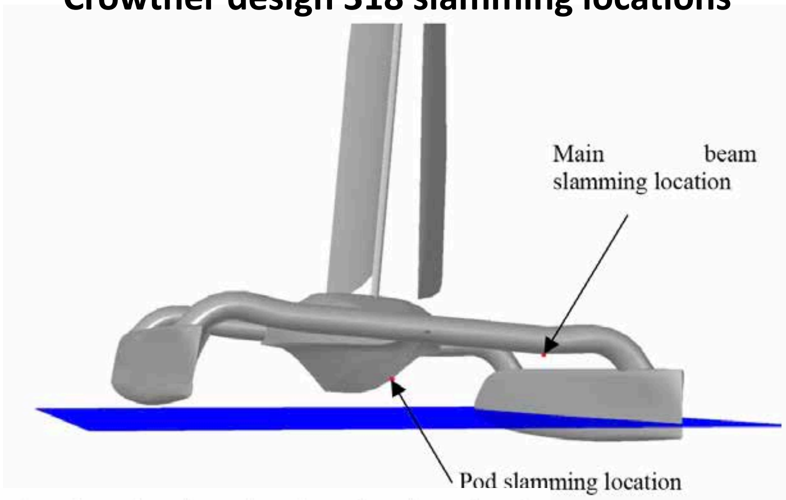
Sail

Power

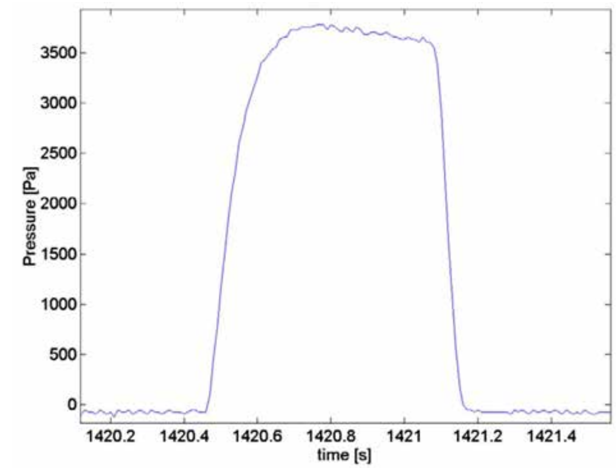
Illustrations of Sail, left [High Modulus] and Power, right [Structural Composites] High-Speed Vessel Slamming Events

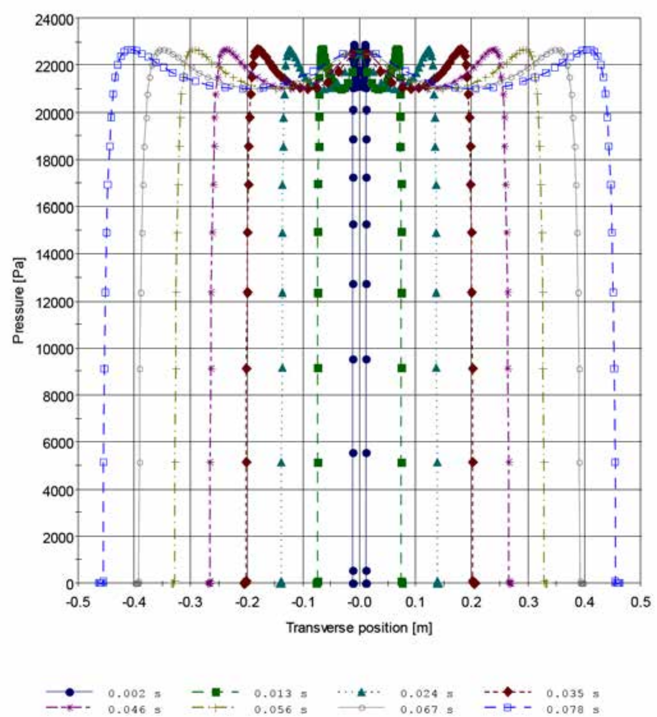
Catamaran Slamming

Crowther design 318 slamming locations

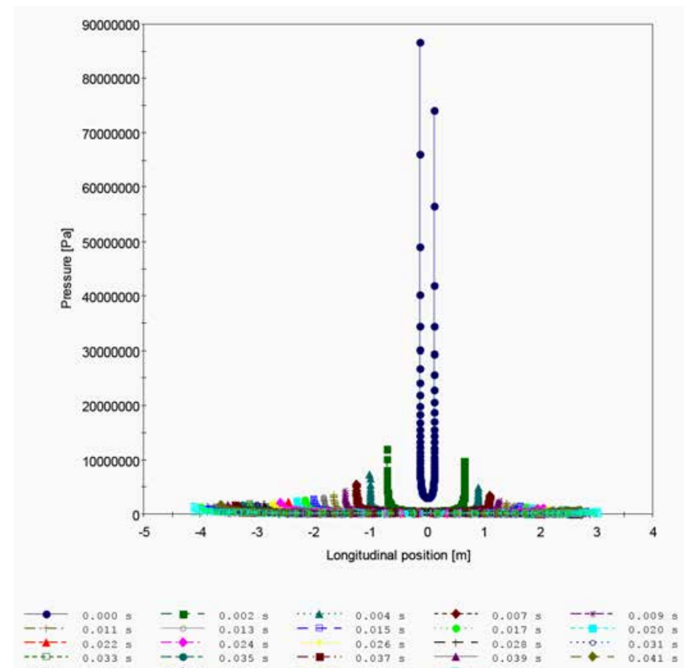


Typical Slam Impact Pressure





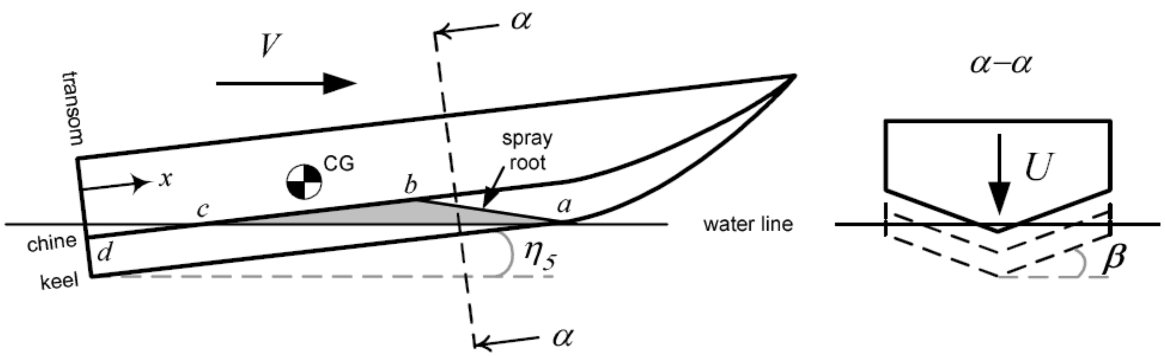
Transverse distribution of Crowther 318 pod slamming pressure for 4 m/s impact



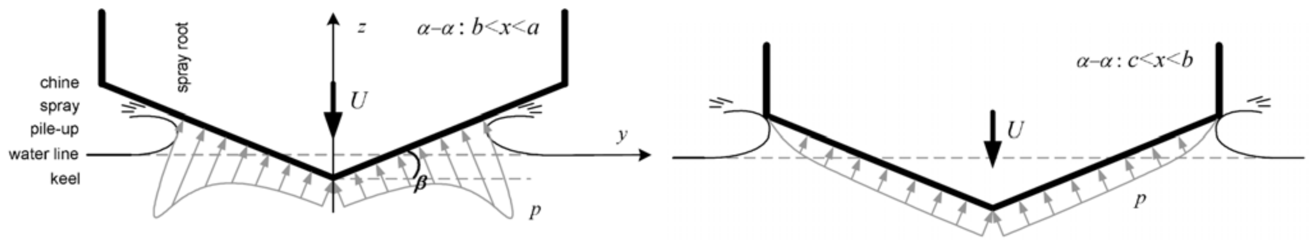
Longitudinal distribution of Austal H 63 slamming pressure for 4 m/s impact

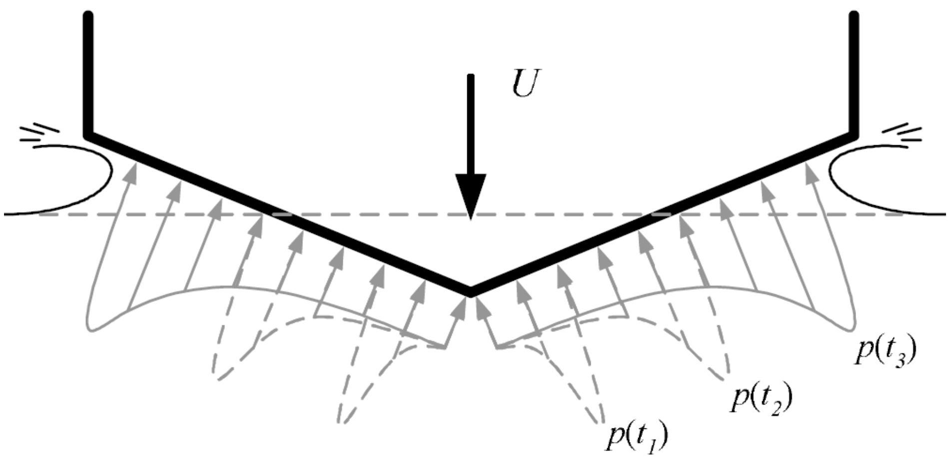
Kristoffer Grande, “Prediction of Slamming Occurrence of Catamarans,” Aug 2002.

Slamming Phenomenon



Planing Craft Wave Impact





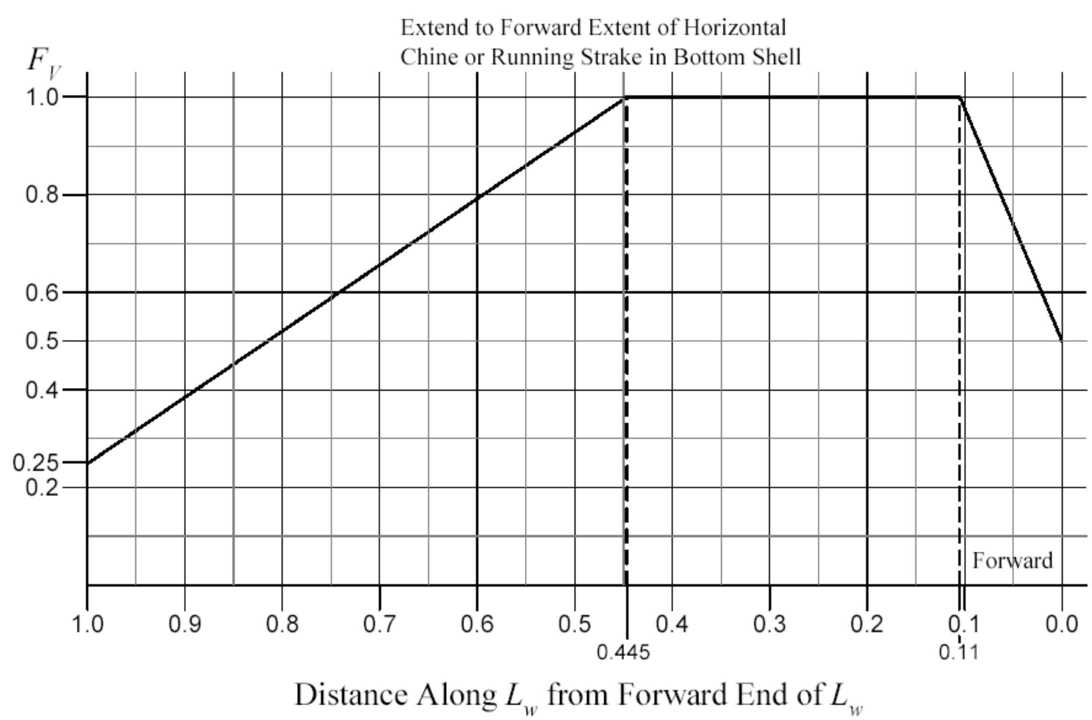
Pressure Distribution During Hull-Wave Impact

Slamming Pressure Distribution

$$p_{bxx} = \frac{N_1 \Delta}{L_w B_w}[1 + n_{cg}]F_D F_v$$

Δ = *Displacement*
L_w = *Length*
B_w = *Beam*

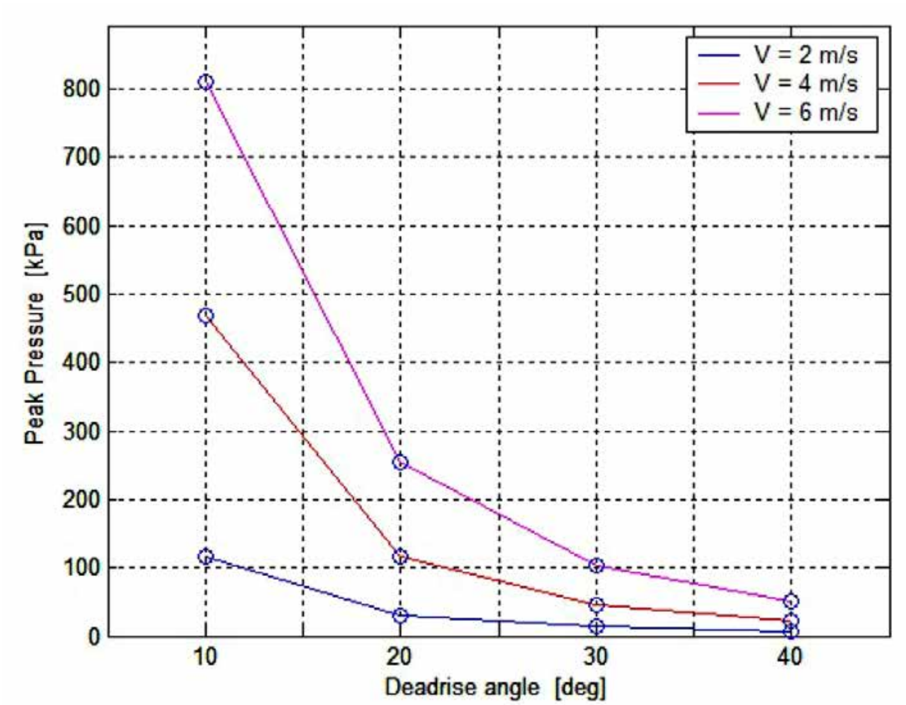
Vertical Acceleration Distribution Factor F_V



n_{cg} = the vertical acceleration of the craft as determined by a model test, theoretical computation, or service experience

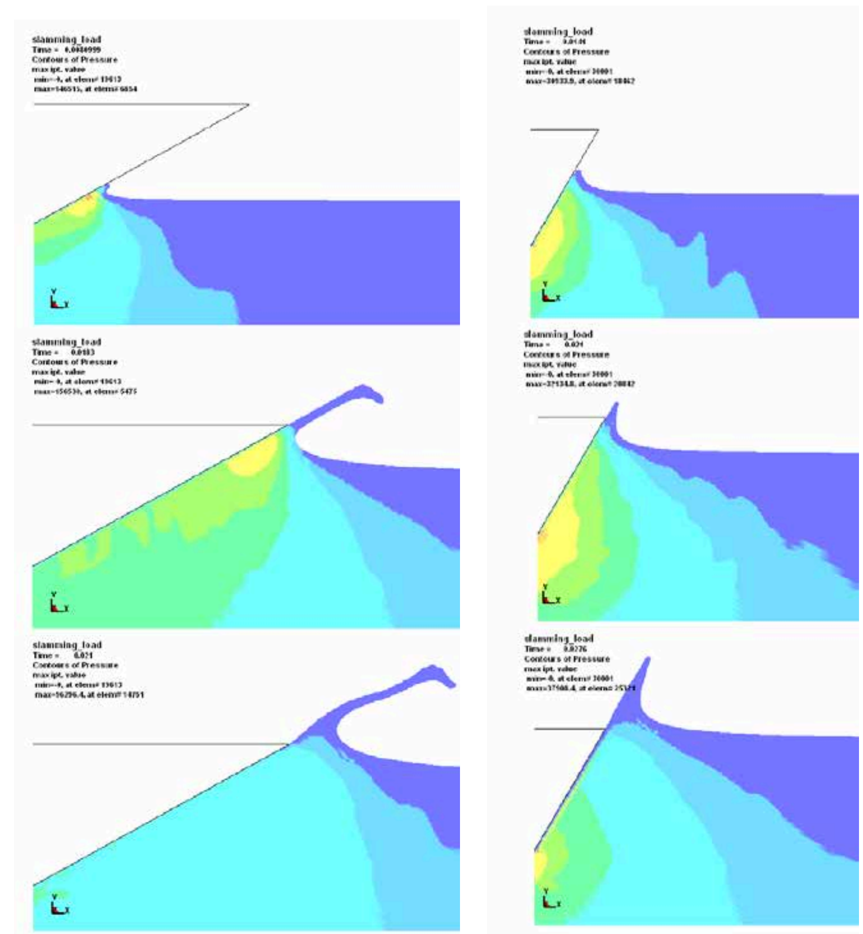
Deadrise Angle

Peak pressures plotted against deadrise angle for 3 different velocities.



Johan Breder, “Experimental Testing of Slamming Pressure on a Rigid Marine Panel,” Stockholm, Sweden 2005

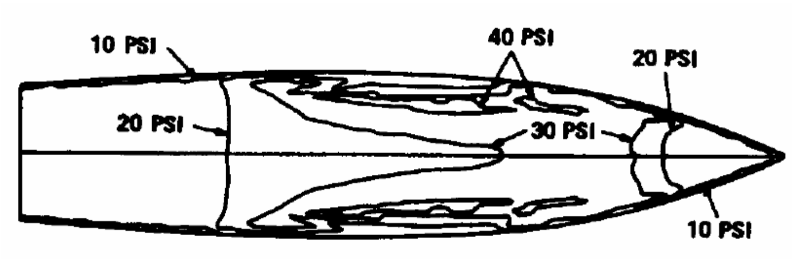
Predicted water jet flows and pressure contours in water by LS-DYNA for the wedge with 30° and 60° deadrise angle (scale is 5x for 30° deadrise)



Shan Wang, “Assessment of slam induced loads on two dimensional wedges and ship sections,” Dec 2011.

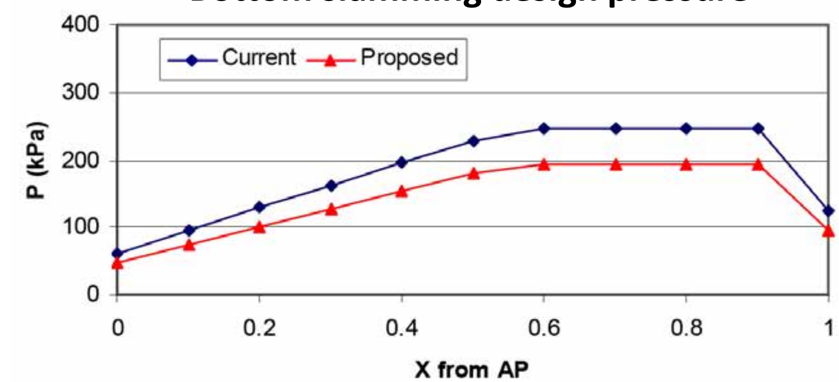
Slam Pressure Distribution

Example of momentary pressure distribution on a planing craft in head seas



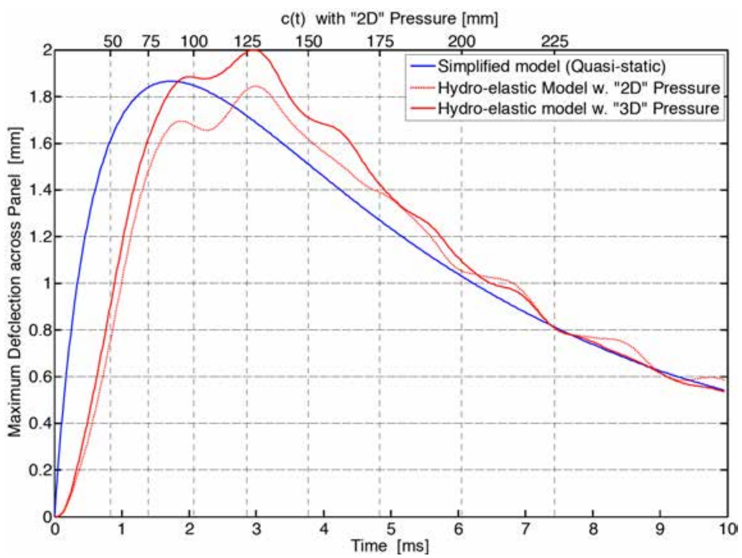
Allen & Jones 1978

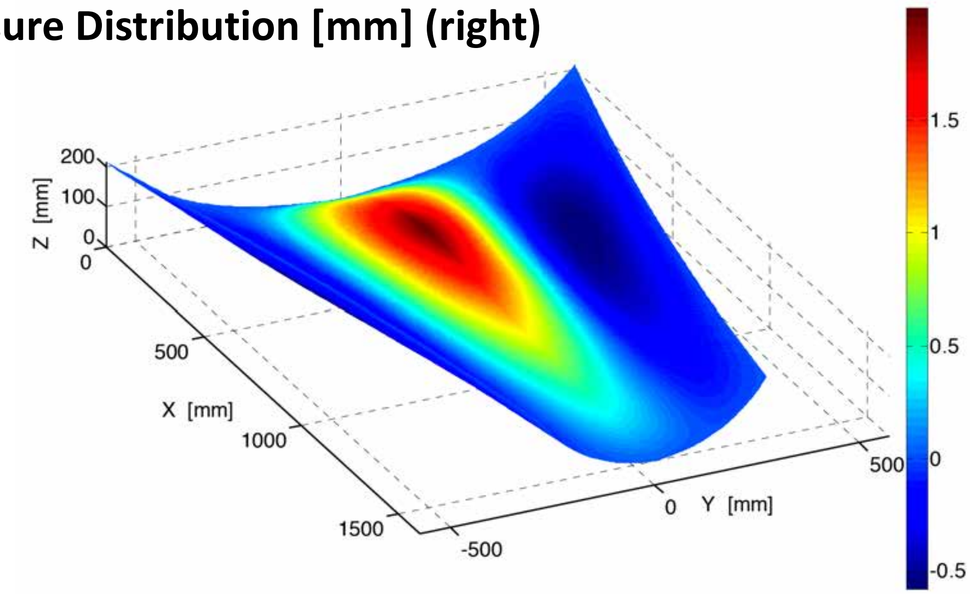
Bottom slamming design pressure



Peter Kim, Derek Novak, Kenneth Weems & Hamm-Ching Chen, "Slamming Impact Design Loads on Large High Speed Naval Craft," 2008

Time History of Panel Deflection (left) and Deflection at time of maximum deflection for "3D" Pressure Distribution [mm] (right)

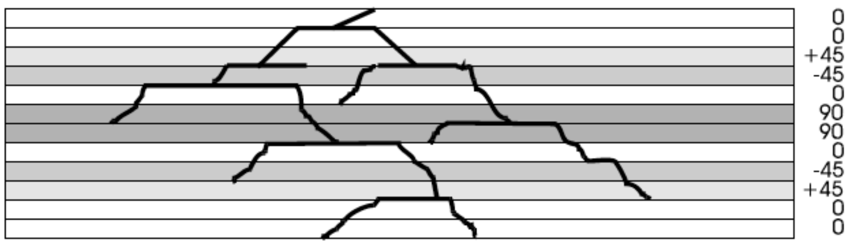




Frederic Louarn and Paolo Manganelli, "A simplified slamming analysis model for curved composite panels," 21st International HISWA Symposium, Dec 2010.

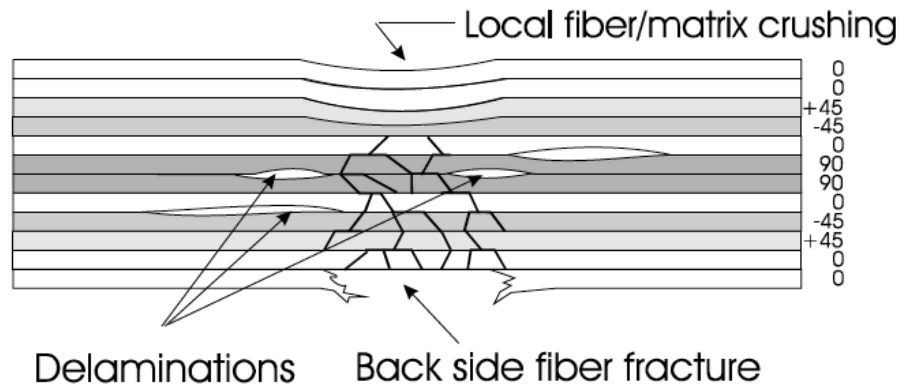
Impact Damage Types

Low-Energy Impact

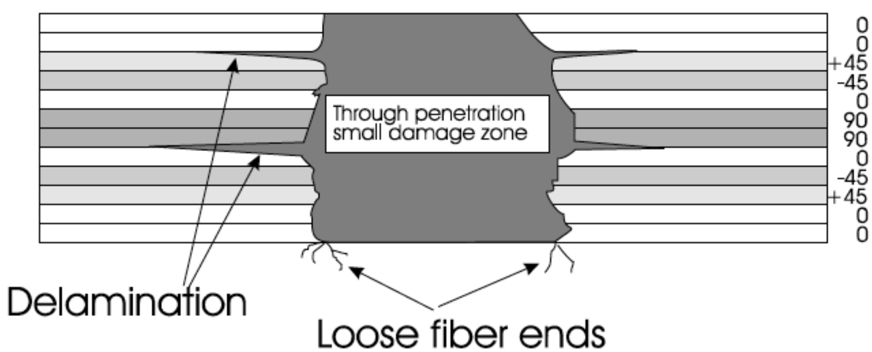


Pyramid Pattern Matrix Crack from impact.

Medium-Energy Impact



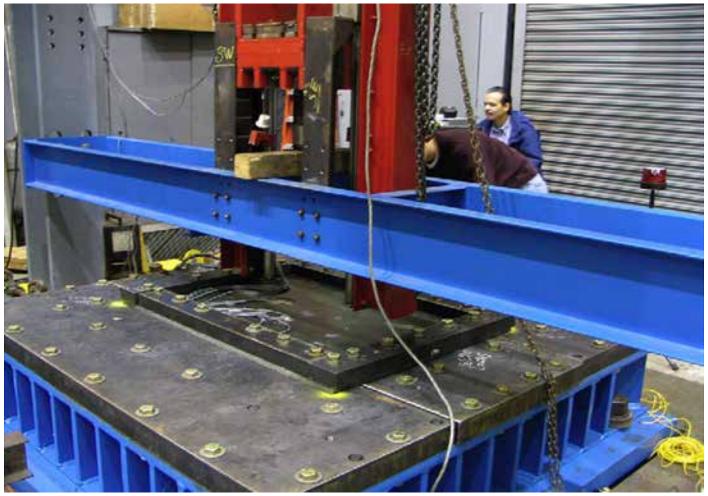
High-Energy Impact



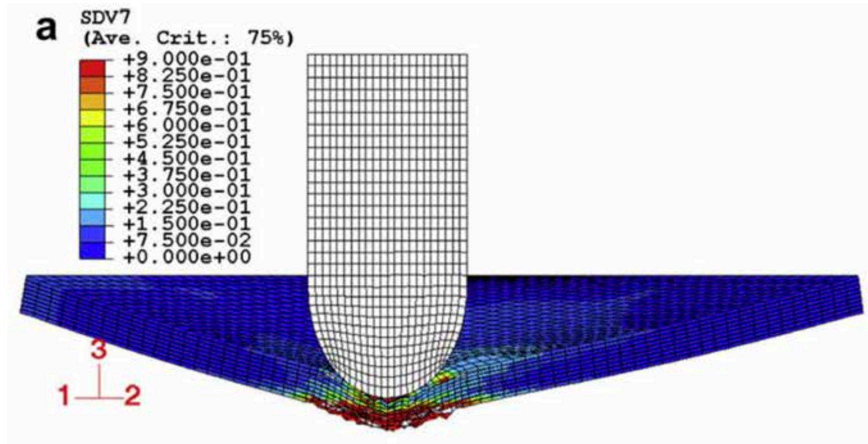
Abaris Training Resources Incorporated

Modeling Impact Damage

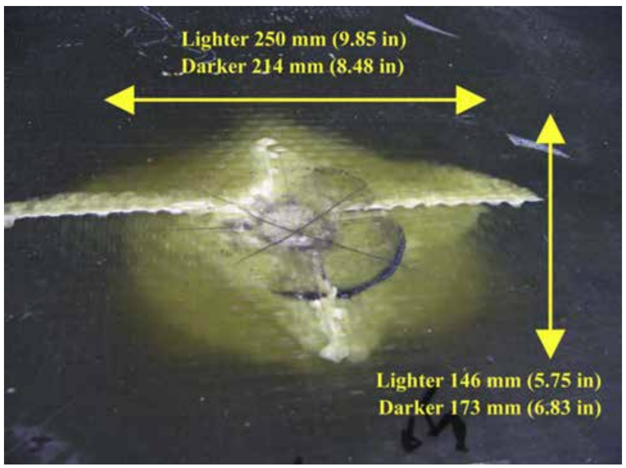
Impact rig for the large-scale plate tests

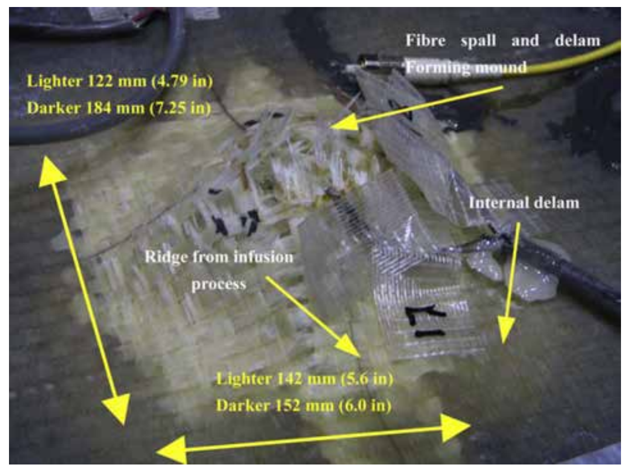


Damage predictions for test



Damage viewed from top (left) and bottom (right)





H.E. Johnson, L.A. Louca, S. Mouring, A.S. Fallah, "Modelling impact damage in marine composite panels," International Journal of Impact Engineering 36 (2009) 25–39

Free-Fall Lifeboats

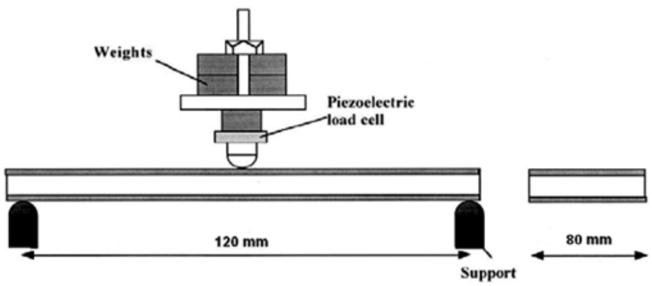
Schat-Harding freefall lifeboat

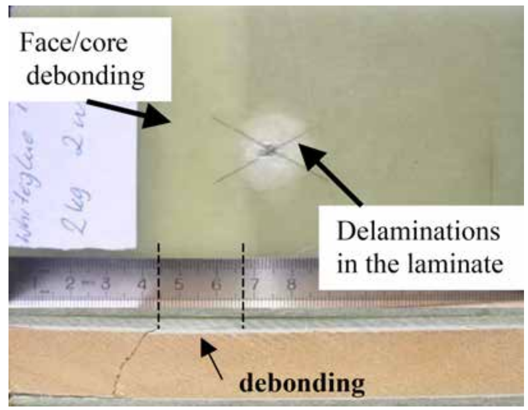
55 meter freefall test

Norsafe lifeboat structural grid

Skin-to-Core Bond Influence on Core Impact Damage

Schematic diagram of the instrumented impact test (left) and "high-density" sample following impact 39.3 J (right)





Impact damage area as a function of impact energy for sandwich structures: visual inspection and C-scan results

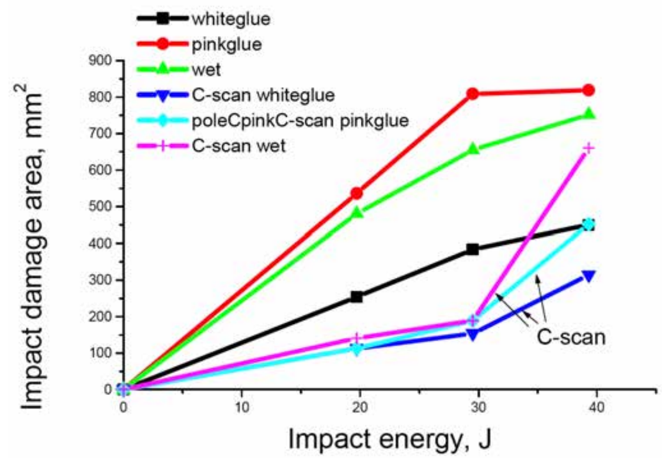
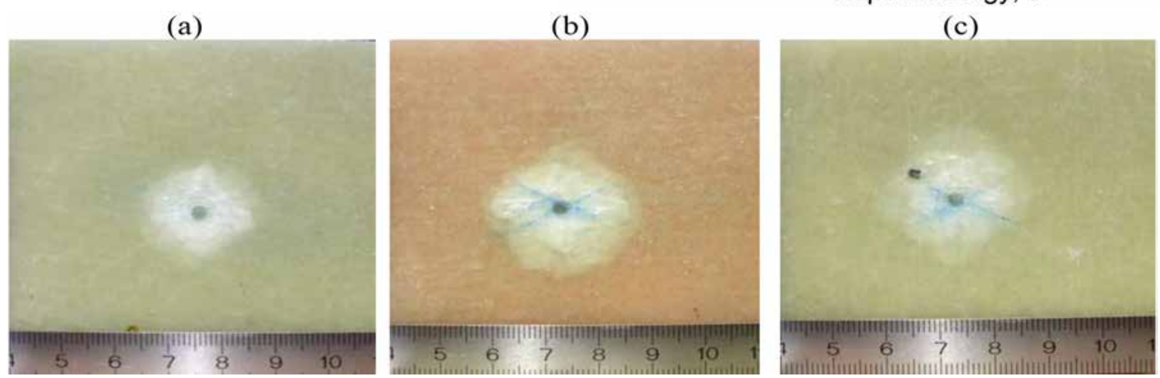


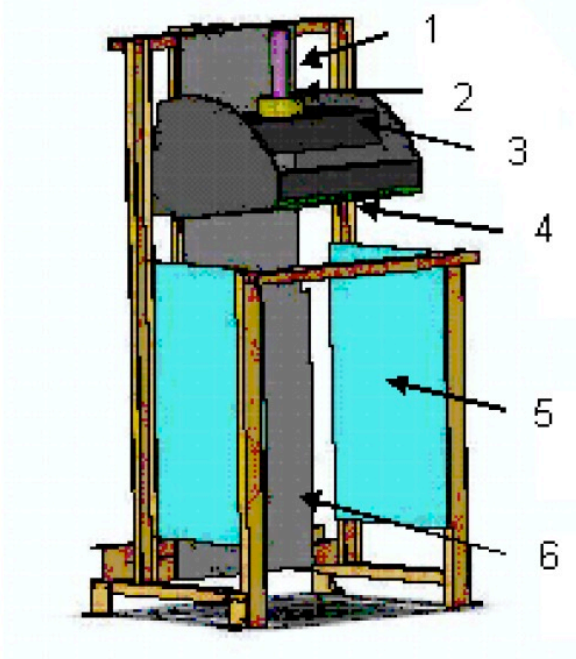
Illustration of damage observed visually on the surface of the samples subjected to impact 19,7J: (a) whiteglue", (b) "pinkglue", (c) "wet" sample.



In terms of impact damage size, in each case the size of C-scan damage area was significantly smaller than in visual inspection of the sample.

K. Imielińskaa, L. Guillaumatb, R. Wojtyrac, and M. Castaingsd, "Effects of manufacturing and face/core bonding on impact damage in glass/polyester–PVC foam core sandwich panels," *Composites Part B: Engineering*, September 2008

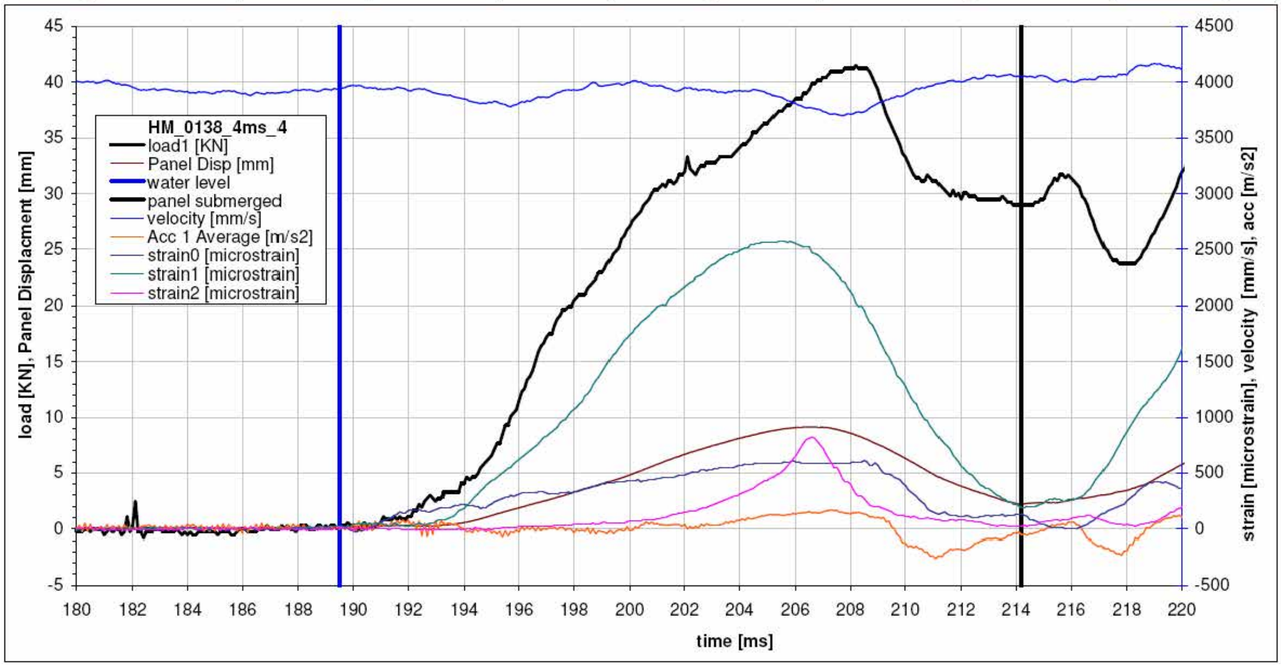
Servo-hydraulic Slam Testing System (SSTS)



Elements of the Servo-hydraulic Slam Testing System (SSTS) including Ram (1), Load Cell (2), Specimen Fixture (3), Test Panel (4), Side Plates (5), and Back Plate (6). Top left is Overall Equipment Setup with Computer Control and bottom Sequence is of Slam Test Event [Mark Battley, University of Auckland & Susan Lake, High Modulus]

Slam Testing Results

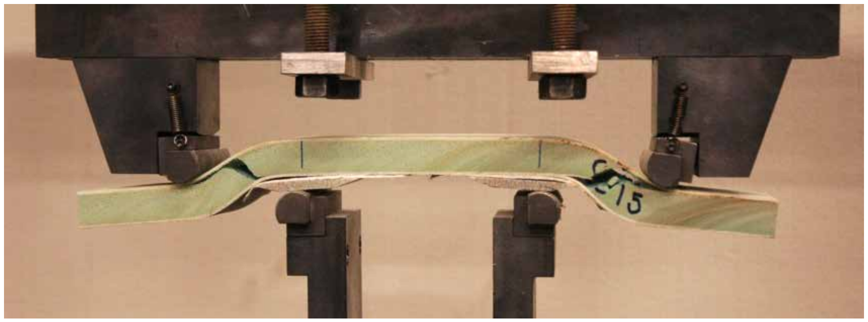
time [m/s]	load1 [KN]	acc1 [m/s2]	Panel Disp [mm]	velocity [m/s]	velocity [mm/s]	strain0 [microstrain]	strain1 [microstrain]	strain2 [microstrain]	acc	320
									dec	-22.9
min/max	min/max	min/max	min/max	min/max	min/max	min/max	min/max	min/max	scan rate	10000
0	-10.6	-534	-17.45	-0.6	-569	-80	-30	-29	panel depth	410
1000	41.5	516	9.14	4.2	4167	610	2572	821	end phase 2	826.1



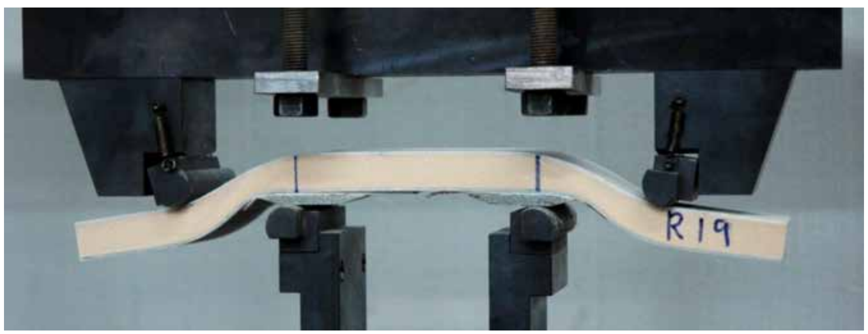
Typical Results from Slam Testing in the SSTS [High Modulus]

Servo-hydraulic Slam Testing System (SSTS)

Shear fracture of C70.130 core beam specimen

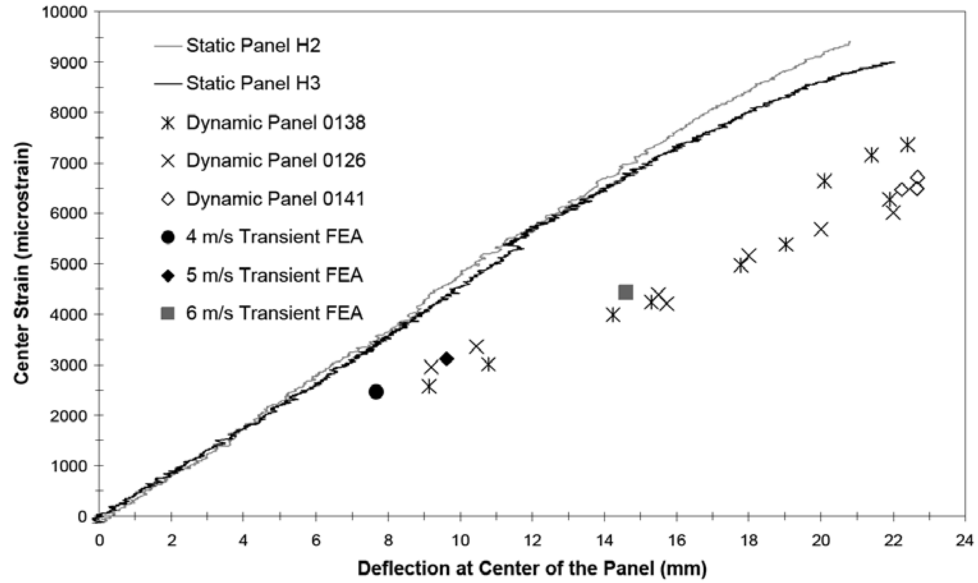


Shear deformation of R63.140 core beam specimen

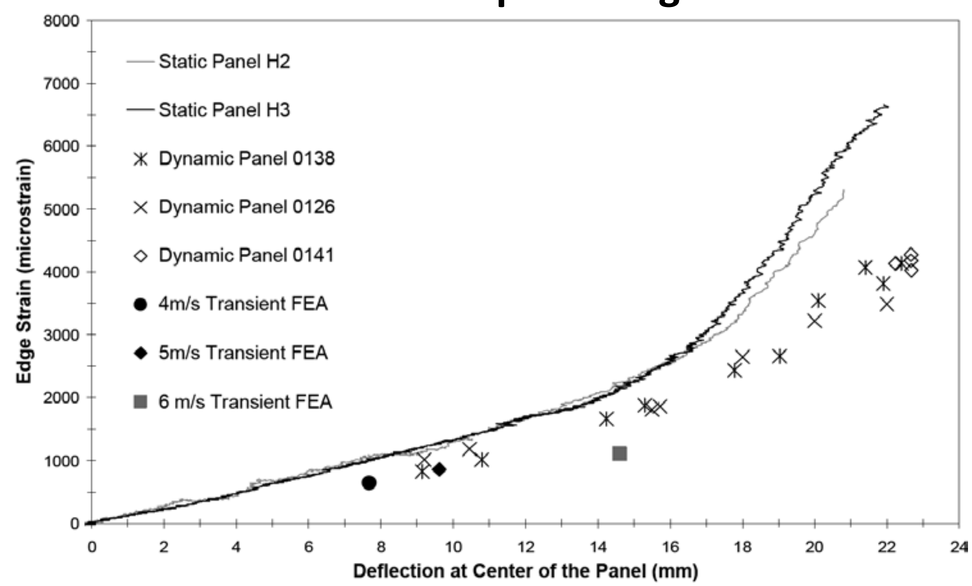


Mark Battley, Ivan Stenius, Johan Breder and Susan Edinger, "Dynamic Characterisation of Marine Sandwich Structures," 7th International Conference on Sandwich Structures, Aalborg, Denmark, August 2005

Deflection vs. panel center strain

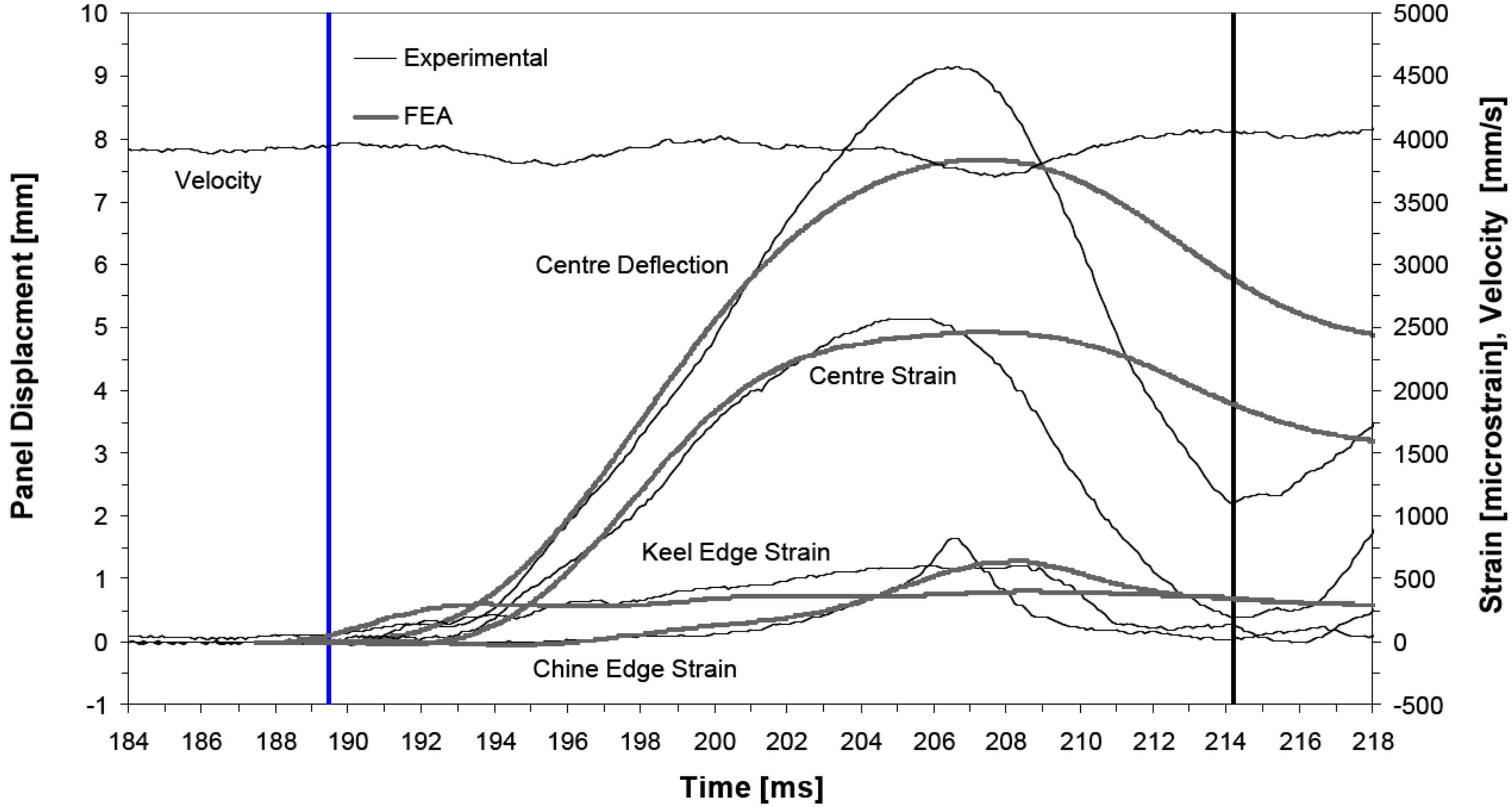


Deflection vs. panel edge strain



Servo-hydraulic Slam Testing System (SSTS)

Slam event of 10° panel at 4m/s with transient FEA predictions. The blue vertical line represents the water surface, and the black line full immersion of the panel



The dynamic panels have higher deflections relative to bending strains, confirming that the load distribution is not well represented by a uniformly distributed pressure. Under dynamic loading the transverse shear is more significant than bending compared to a uniformly loaded panel.

Mark Battley, Ivan Stenius, Johan Breder and Susan Edinger, "Dynamic Characterisation of Marine Sandwich Structures," 7th International Conference on Sandwich Structures, Aalborg, Denmark, August 2005

Slam Testing Takeaway Concepts

- The testing method used for characterization of core materials can have a significant effect on the shear strength obtained.
- The peak ratio of edge strain to center strain increases with velocity of impact
- Slam-loaded panels are subjected to higher shear loads relative to bending than is the case for uniform pressure-loaded panels.
- There are significant performance advantages for high-elongation foam cores in slam loaded hull panels (few scantling codes distinguish between rigid, low elongation cores; medium elongation foams; and high elongation linear cores).
- A Slam Tester larger than the SSTS is required to break panels of interest to the marine industry.

Design for Slamming
Safe Haven Marine's Interceptor 42




Photographs showing Pilot Boat operating conditions, including storm with 100-knot wind gust and 10 m waves [www.safehavenmarine.com]

The hulls scantlings are very closely spaced @ 500mm centers giving a 4300mm panel width, the frames themselves are a huge 150 x 150mm resulting in a massively strong structure

<u>Hull Bottom Laminate</u>

Isophthalic gel coat to minimum 10mm (300 & 2 x 900gm/m² layers) (white pigment used below water line to prevent osmosis)

300gm/m² using isophthalic resin. Composite as follows-

900gm/m² CSM. isophthalic resin

900gm/m² CSM. isophthalic resin

300gm/m² CSM stitched in combination to

600gm/m² Woven Roving

900gm/m² CSM

300gm/m² CSM stitched in combination to

600gm/m² Woven Roving

900gm/m² CSM

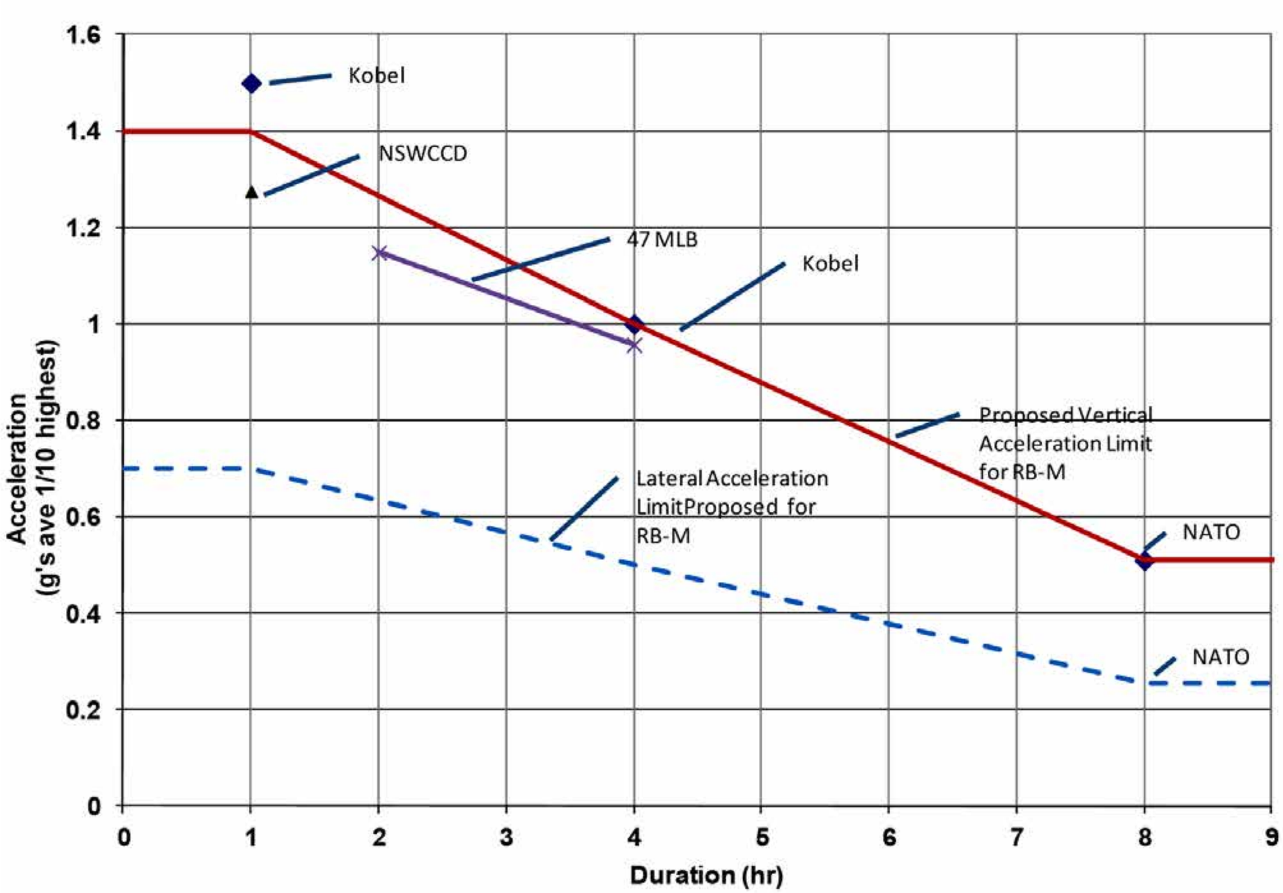
300gm/m² CSM stitched in combination to

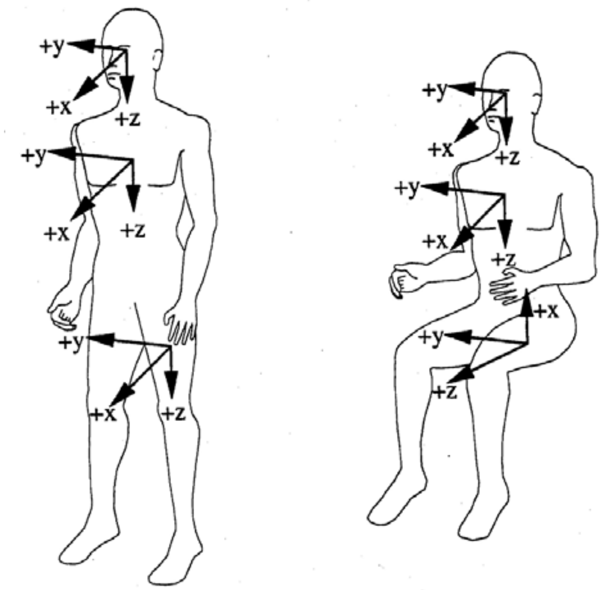
600gm/m² Woven Roving

900gm/m² CSM

Operator Tolerance

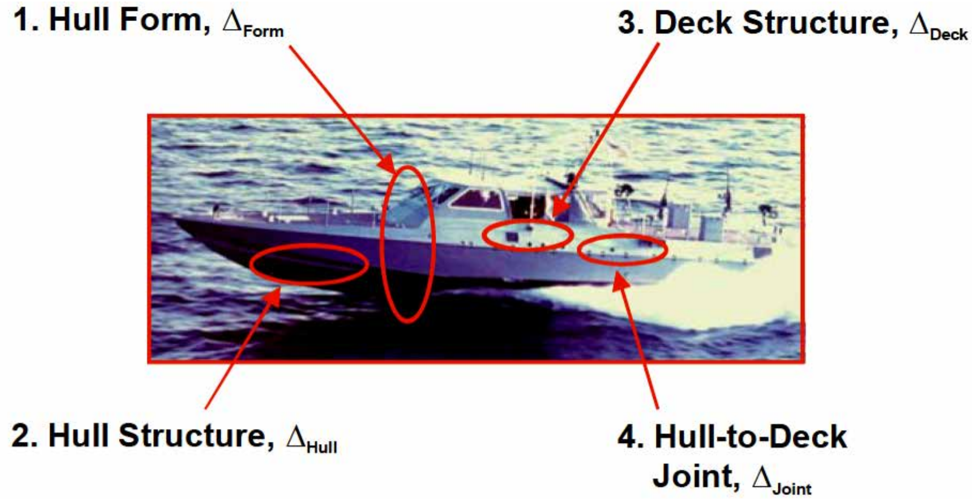
Acceleration limits for operator fatigue and injury





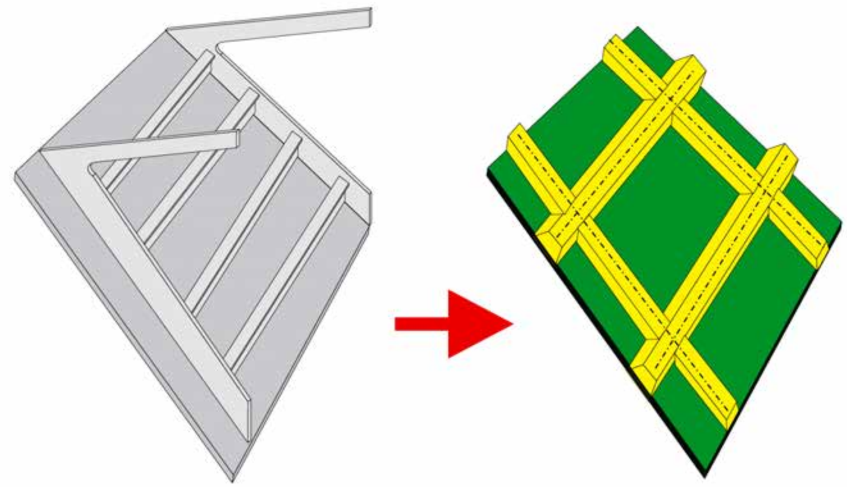
Frank DeBord, Karl Stambaugh, Chris Barry and Eric Schmid, "Evaluation of High-Speed Craft Designs for Operations in Survival Conditions," 3rd Chesapeake Bay Powerboat Symposium, June, 2012.

Hydro-Structural Shock Mitigation



Total Ride Improvement = $\Delta_{Form} + \Delta_{Hull} + \Delta_{Deck} + \Delta_{Joint}$

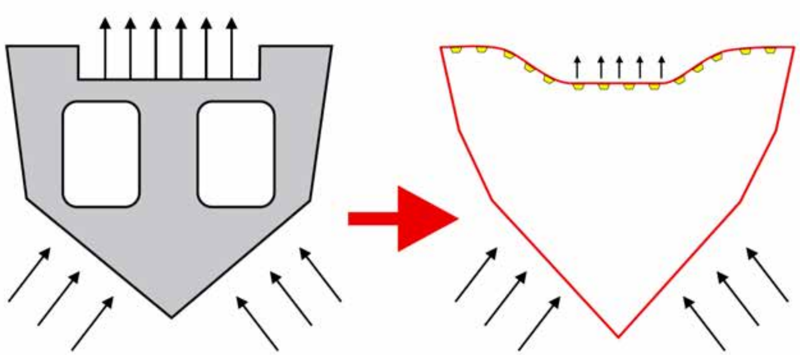
Hull Structure Improvement Methodology



Transverse-Framed Aluminum Grillage

Solid Composite Laminate with Low Profile Stiffeners

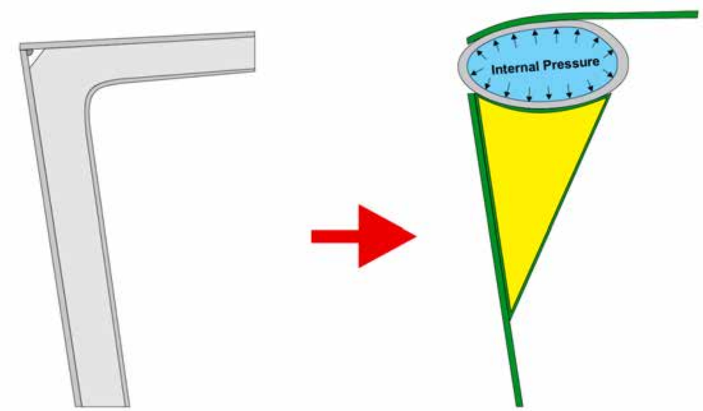
Deck Structure Improvement Methodology



Transverse Framing that Creates Hull & Deck Coupling

Longitudinally Stiffened Deck will Minimize Shock Transmission

Hull-to-Deck Joint Improvement Methodology



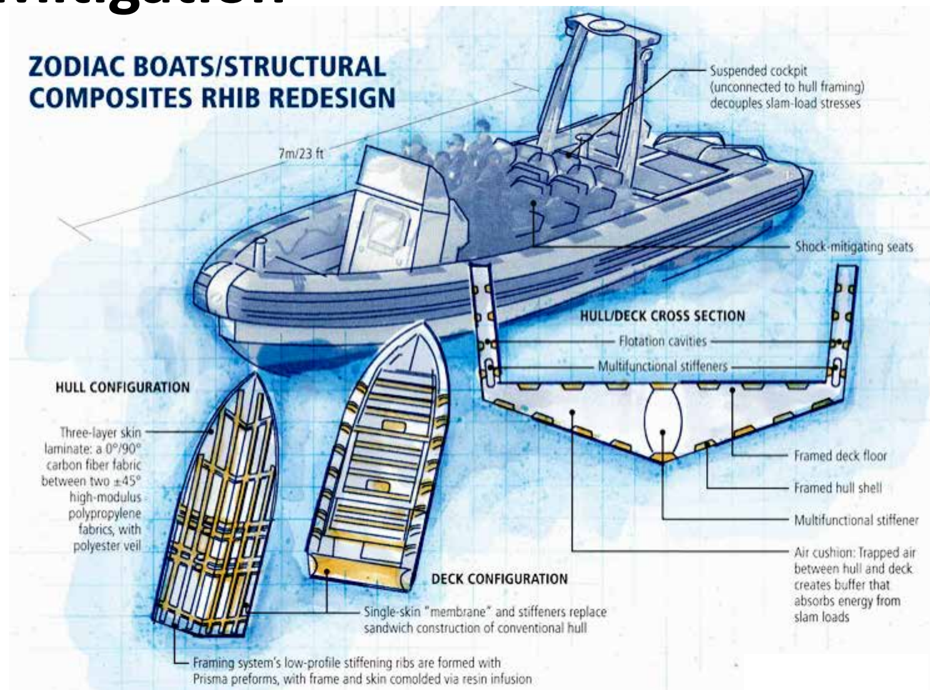
Transverse Knees at Deck Joint

Compliant Deck Joint Utilizing Tube with Variable Internal Pressure

RHIB Shock Mitigation

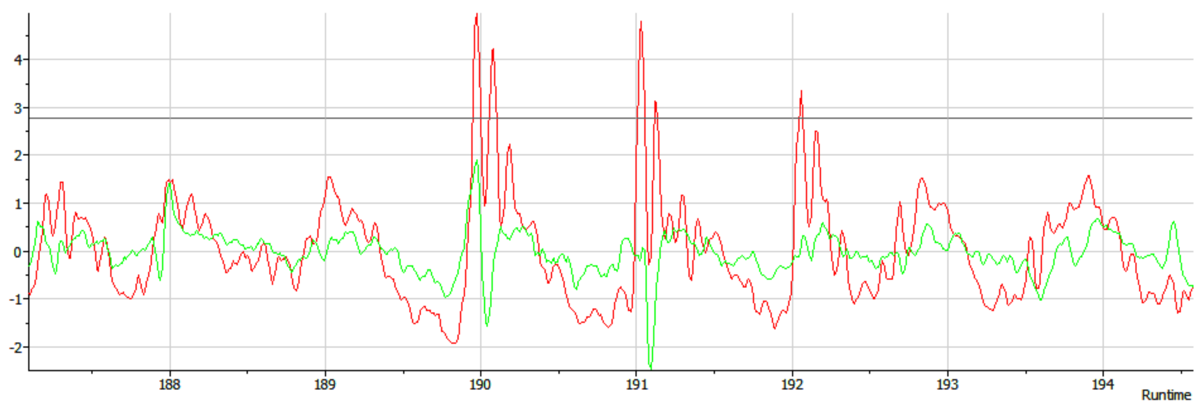
SBIR Program Objectives

- Low Section Framing
- Membrane Structure
- Suspended Cockpit Design
- SharkSkin™ Coatings
- Air Support
- VARTM/Infusion Manufacturing



Karl Reque, *Composites World*

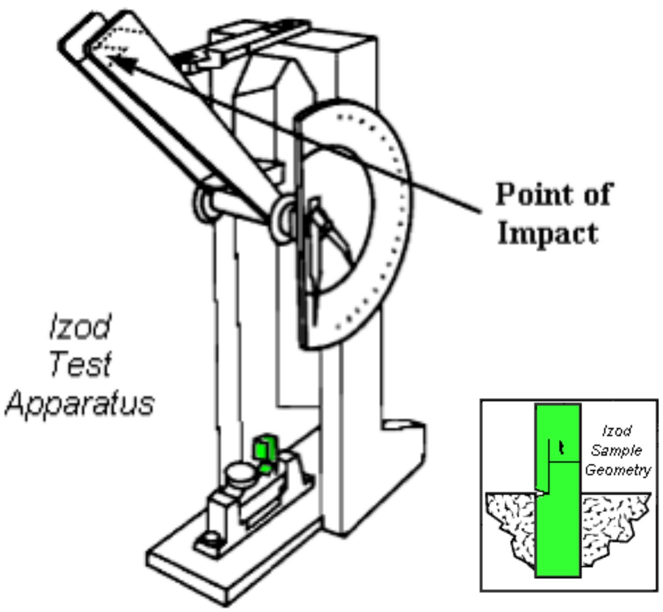
Helm Deck (green) and Hull (red) acceleration data seems to indicate peak g values are reduced by over 50% between the hull and the deck



Scott Lewit, Structural Composites, Inc.

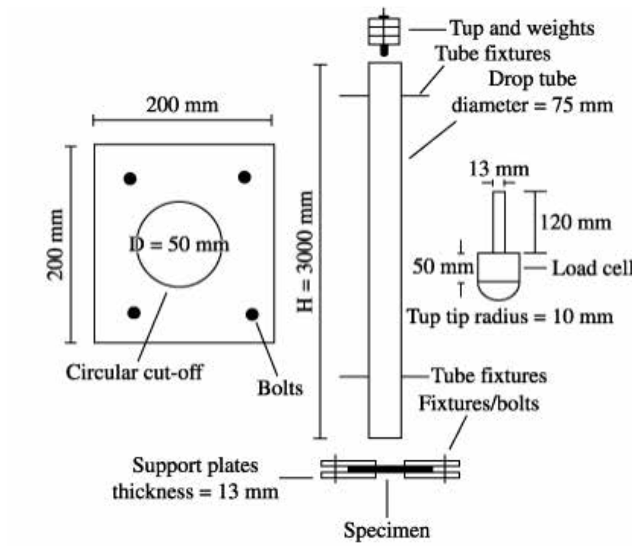
Impact Testing

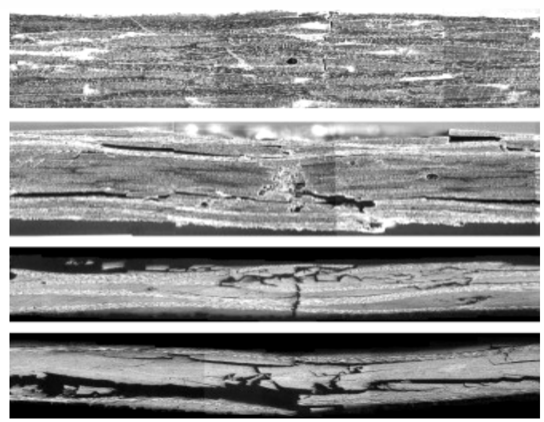
ASTM D256 - Izod Impact Strength Testing of Plastics



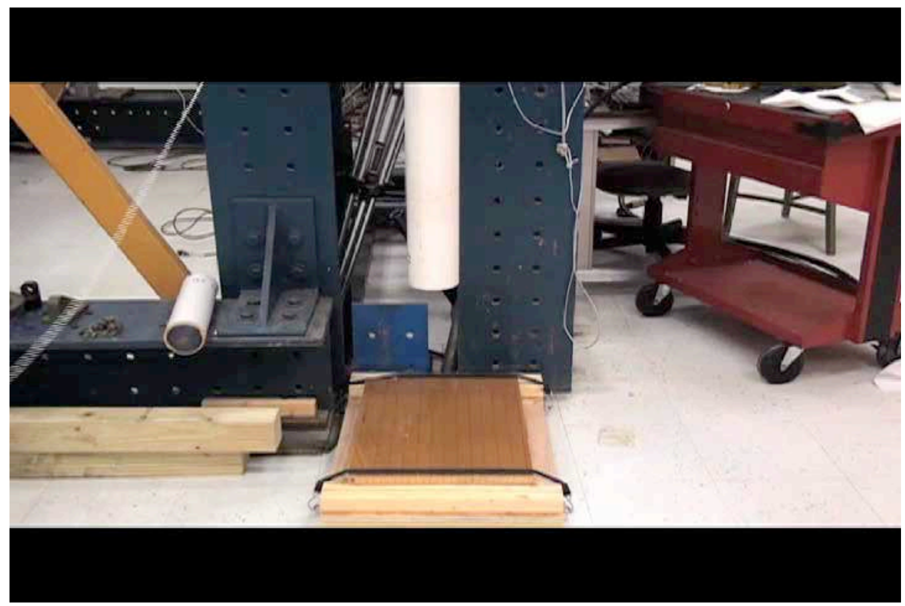
A pendulum swings on its track and strikes a notched, cantilevered plastic sample. The energy lost (required to break the sample) as the pedulum continues on its path is measured from the distance of its follow through.

ASTM D5628 - Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Falling Dart





Impact Testing



Foreign Object Impact

Types of Boating Accidents

	Vessels Involved	Fatalities
TOTALS	**8,591**	**865**
Grounding	390	14
Capsizing	545	289
Swamping/Flooding	252	60
Sinking	210	11
Fire/Explosion (fuel)	274	14
Fire/Explosion (other)	97	2
Collision with another vessel	**4,422**	**81**
Collision with fixed object	**864**	**76**
Collision with floating object	262	13
Falls overboard	451	239
Falls within boat	139	1
Struck by boat or propeller	191	7
Other	470	29
Unknown	24	29

U.S. Coast Guard Boating Safety Circular 72

The number of shipping containers lost overboard has been reported to be somewhere between 2,000 and 10,000 each year.

Tool Drop Impact Damage

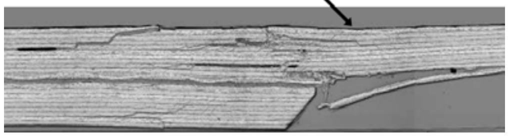
Aircraft Impact Damage Tolerance Criteria

Threat	Criteria	Requirement
Small Tool Drop	48 in-lbs normal to surface.	No visible damage No non-visible damage growth for 3 design service objectives (DSOs) Accounted for in Ultimate Design Allowables
Large Tool Drop (BVID)-general acreage	Up to 1200 in-lbs or a defined dent depth cut-off (considering relaxation) based on level of visibility as related to the inspection method.	Barely visible damage which may not be found during HMV No damage growth for 3 DSOs with life extension (LEF) Capable of Ultimate strength
Large Tool Drop (BVID)-repeat impact threat areas	Consider higher than 1200 in-lbs Consider multiple, superimposed impacts Consider clustered impacts	Barely visible damage which may not be found during HMV No damage growth for 3 DSOs with LEF Capable of Ultimate strength
Visible Impact Damage No energy cut-off (VID)	No energy cut-off	Visible Damage with a high probability to be found during HMV No damage growth for 2 times the planned inspection interval with LEF Capable of residual Limit strength

<u>Barely Visible Impact Damage (BVID)</u>

Small damages which may not be found during heavy maintenance general visual inspections using typical lighting conditions from a distance of five (5) feet

- Typical dent depth – 0.01 to 0.02 inches (OML)
- Dent depth relaxation must be accounted for

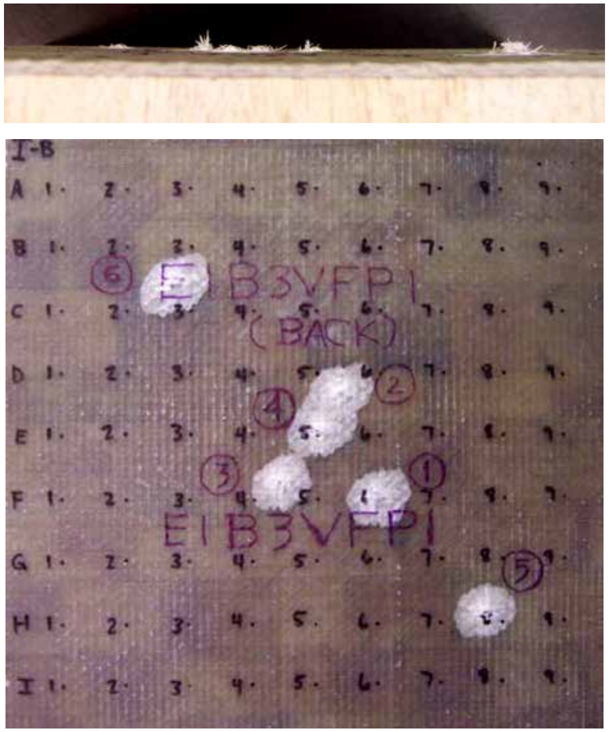


Allen J. Fawcett and Gary D. Oakes, "Boeing Composite Airframe Damage Tolerance and Service Experience," July, 2006.

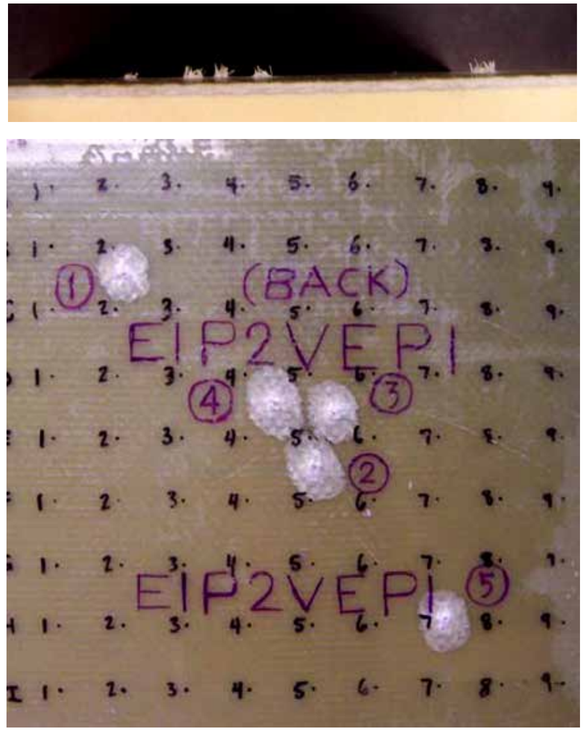
Ballistic Impact

Back face view of panels impacted with .30 caliber projectiles at approximately 880 m/s

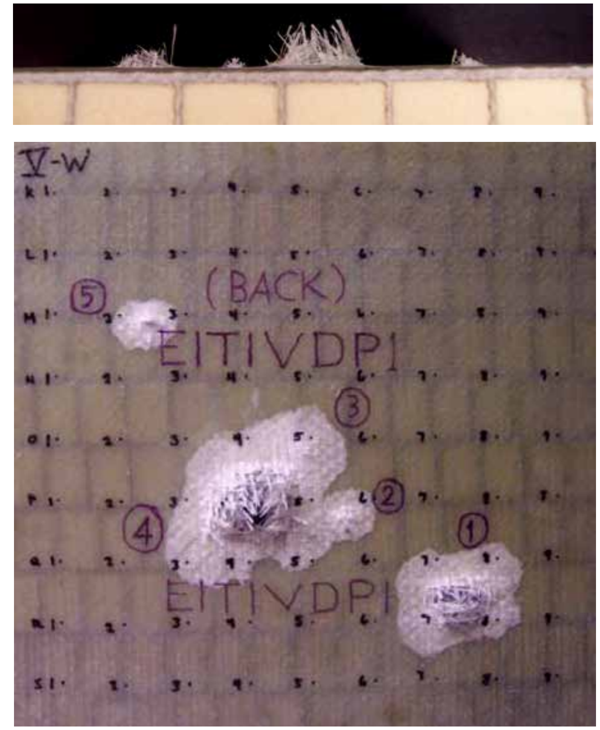
E-glass / Balsa vinyl ester

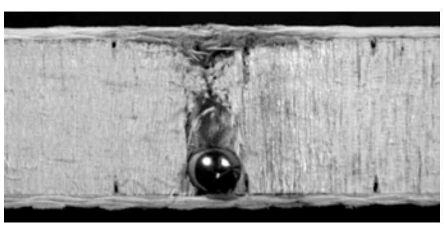


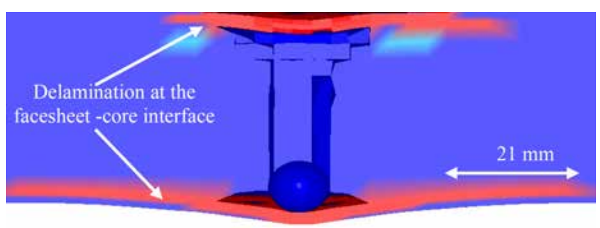
E-glass / PVC vinyl ester



E-glass/Tycor vinyl ester







Energy absorbed by the Tycor® core when impacted at the web intersection was 575% higher than that for balsa and PVC cores. The damage in balsa and PVC core was minimal, indicating lower energy absorption capacity.

U.K.Vaidya, S.Pillay, M.Magrini and P.R.Mantena, “Ballistic Impact Testing of Balsa, PVC Foam, Glass Reinforced Polyurethane Core Sandwich Structures,” July, 2009.

eric greene associates

Theme Park Boats

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