Composites 2004

ACMA

American Composites Manufacturing Association

Tampa Convention Center

October 7, 2004

presented by:
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Presentation Overview

Session 1 - Composite Materials & Design (2:00 - 3:00)
- Composite Materials
- Design Concepts
  - Structural Concepts
  - Design Methodology

Session 2 - Manufacturing Processes (3:00 - 3:45)
- Fabrication
- Joining Technologies
- Facilities

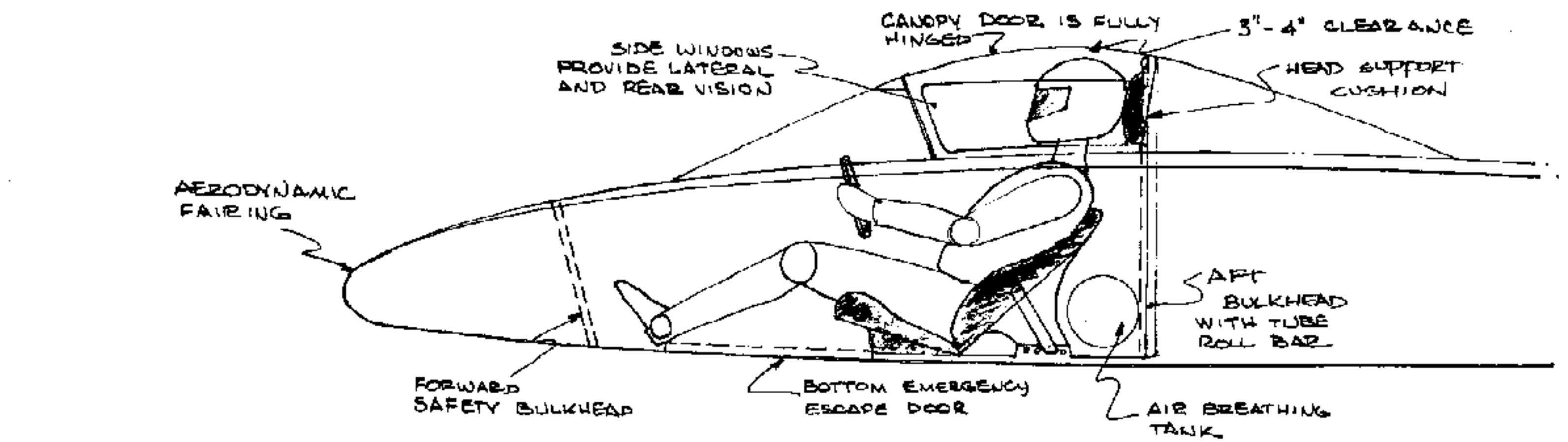
Break (3:45 - 4:00)

Session 3 - Military Applications of Composites (4:00 - 4:30)
- SOCOM Maritime Platforms
- Other US Navy Applications

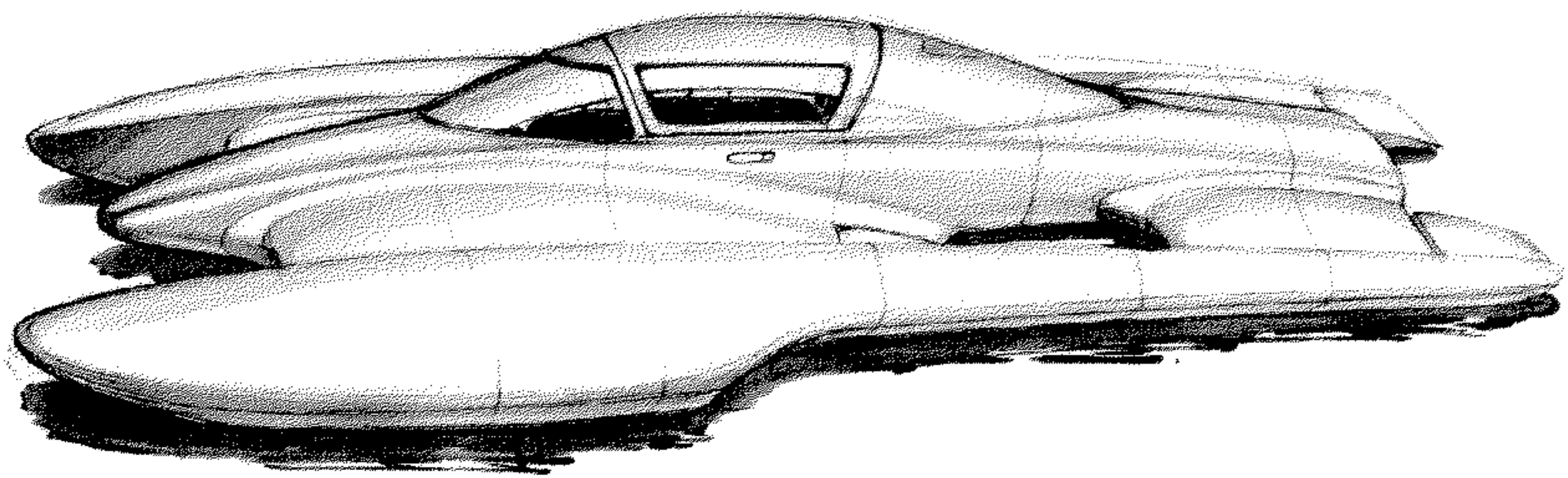
Session 4 - Performance of Composite Structures In-Service (4:30 - 5:00)
- Inspection & Repair
- Future Developments

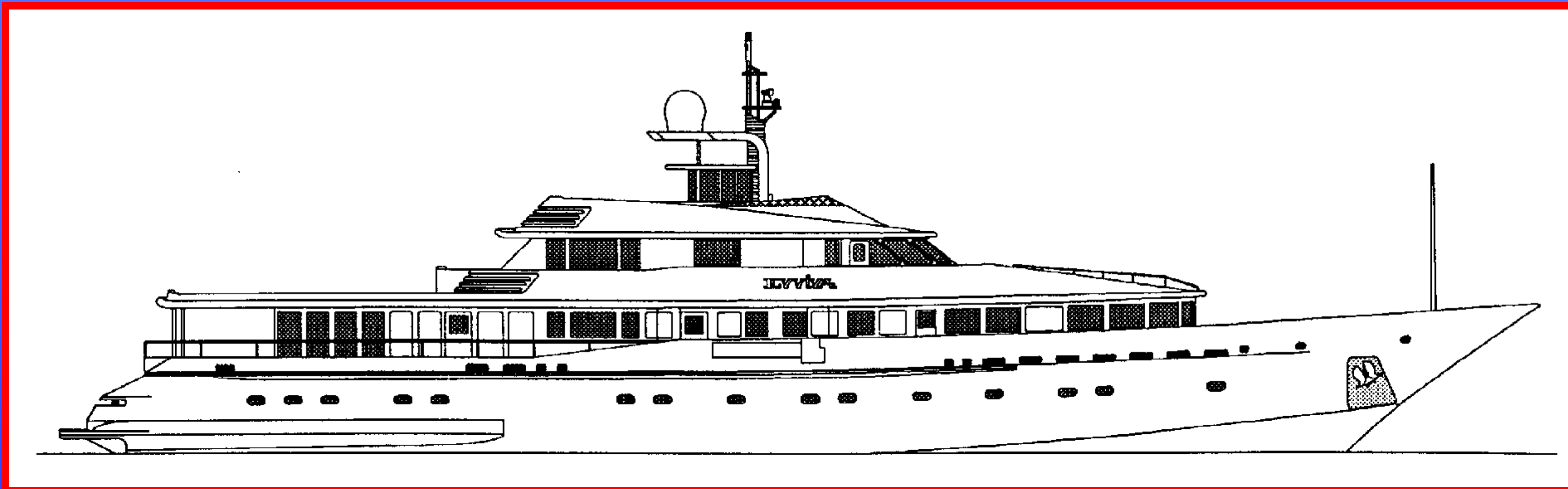
Session 1 - Composite Materials & Design (2:00 - 3:00)

- Applications of Marine Composites
- Composite Materials
- Design Concepts
  - Structural Concepts
  - Design Methodology



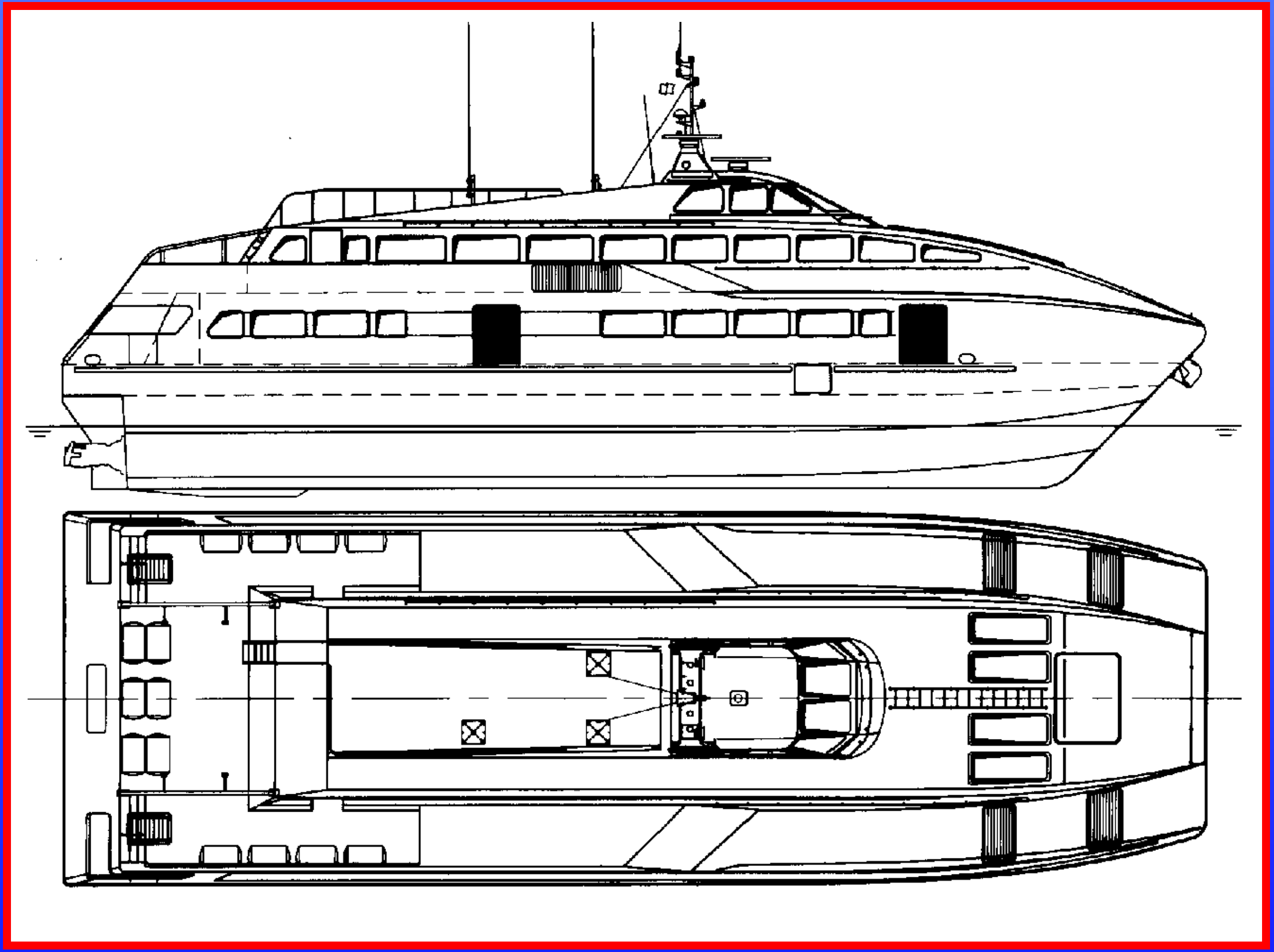
Safety Enclosed Driver Capsule from Ron Jones Marine and Rendering of High-Speed Hydroplane Built by with Prepreg Material [Ron Jones Marine]





161’ Motoryacht ***Evviva*** Built by Admiral Marine [Admiral]

150-foot Omohundro carbon Fiber/Epoxy Mast for 115' Ted Hood Designed Shallow Draft Sailing Yacht Built by Trident Shipworks [photo by the author]

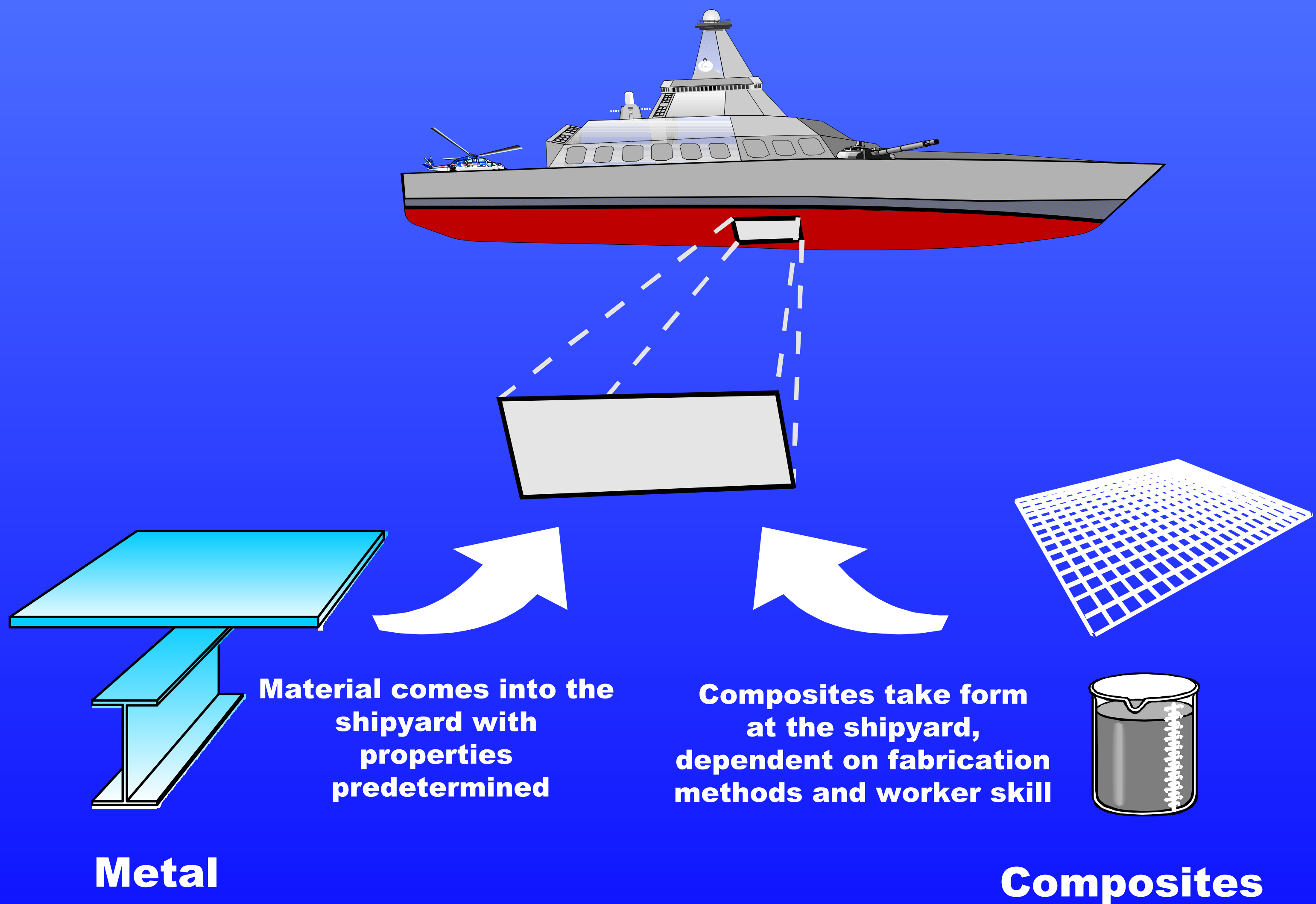


Samsung Built 37-meter SES Designed by Nigel Gee and Associates using a Kevlar® Hybrid Reinforcement for the Hull [DuPont, Oct 1993, Marine Link]

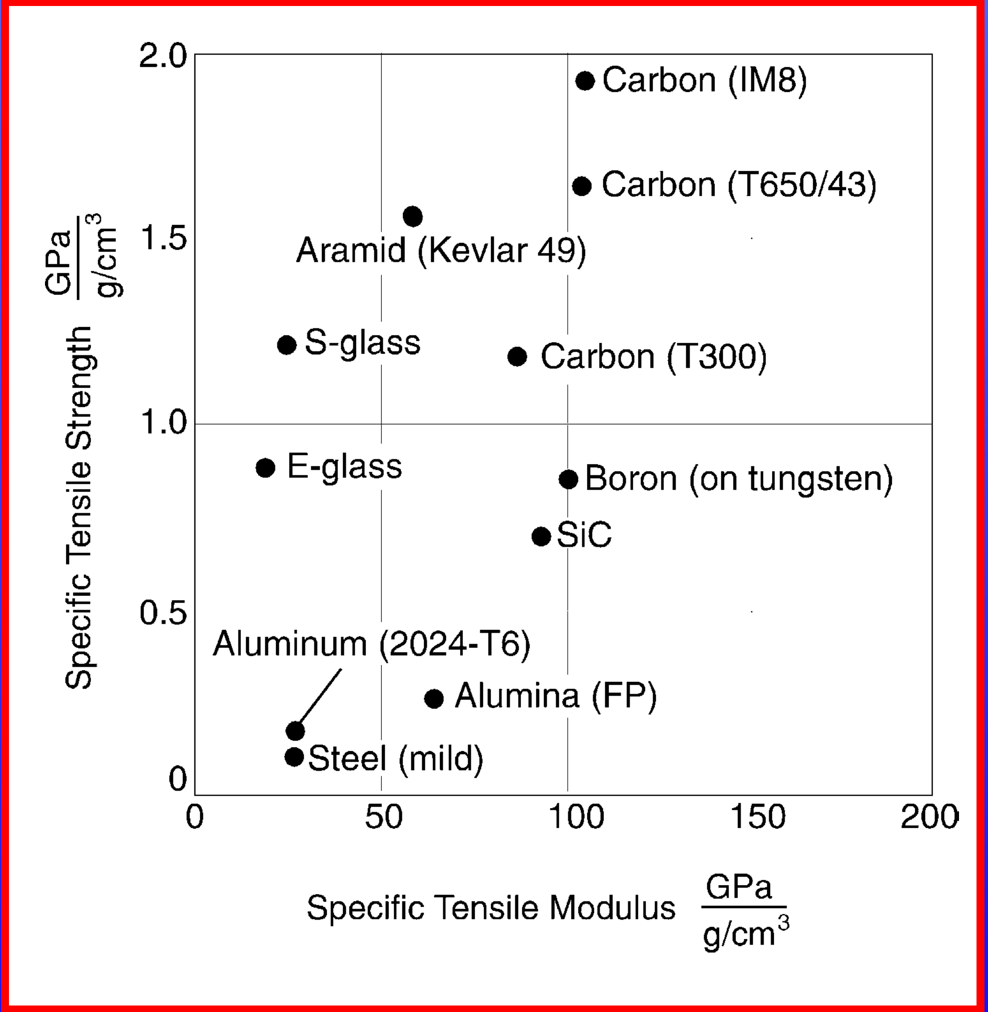
Manufacturing Technology Development

1966 Hand Lay-Up Mat and Woven Roving
1972 Sandwich Construction
1974 Alternative Resin Development
1981 Advanced Fabrication Techniques
1982 Alternative Reinforcement Materials
1990 Vacuum Bag Techniques
2000 Infusion Methods

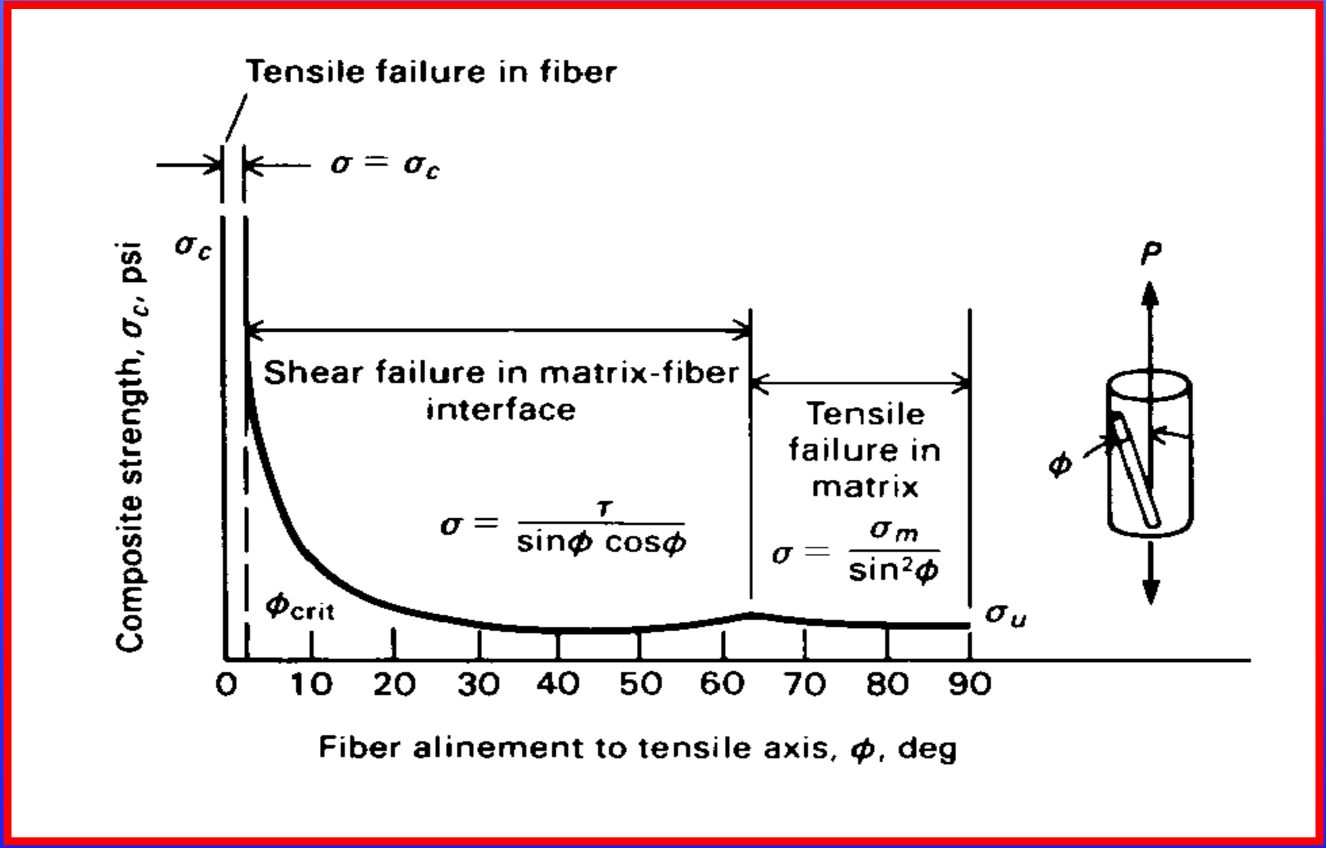
Metal & Composites



Specific Strength and Stiffness



Directional Properties of Composites



The strength of composite fibers are dramatically reduced as the angle to the applied load is increased

Rule of Mixtures

Volume fraction of the fiber component V_f is defined as:

$$V_f = \frac{v_f}{v_c}$$

where v_f is the volume of the fiber and v_c is the volume of the composite.

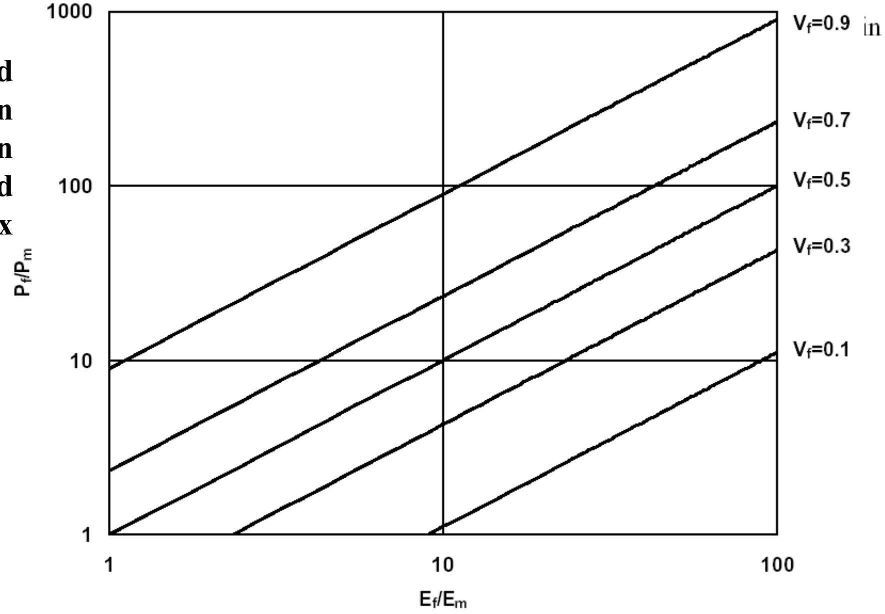
Volume fraction of the matrix component V_m is defined as:

$$V_m = \frac{v_m}{v_c}$$

where v_m is the volume of the matrix.

The sum of the volume fractions of all constituents in a composite must equal 1. In a two-component system consisting of one fiber and one matrix, then, the total volume of the composite is $v_c = v_f + v_m$, hence $V_m = (1 - V_f)$.

Load distribution between fiber and matrix



$$V_v = \frac{\rho_{theroetical} - \rho_{actual}}{\rho_{theoretical}}$$

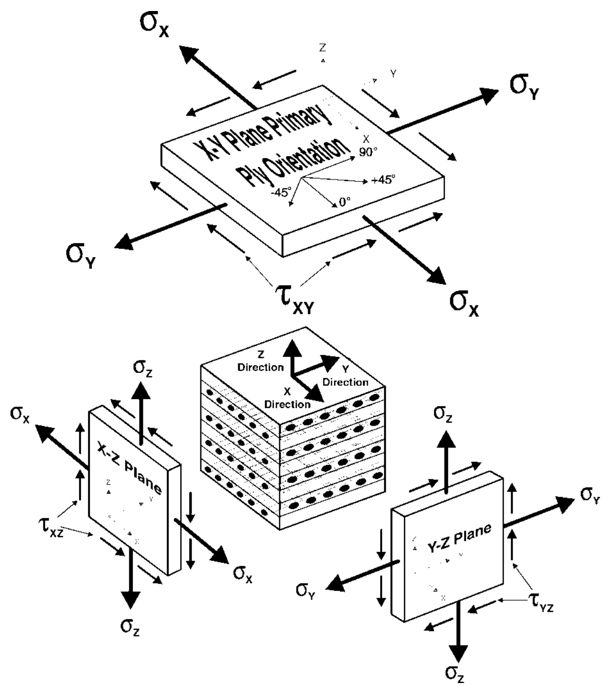
$$\sigma_c = \sigma_m V_m + \sigma_f V_f$$

$$E_c = E_m V_m + E_f V_f$$

$$\frac{E_f}{E_m} = \frac{\sigma_f}{\sigma_m}$$

$$\sigma_f = \frac{\sigma_c E_f}{E_f V_f + E_m V_m}$$

Laminate Properties



Stiffness	X	Longitudinal	Tensile Modulus	E_x^t	Compressive Modulus	E_x^c
Stiffness	Y	Transverse	Tensile Modulus	E_y^t	Compressive Modulus	E_y^c
Stiffness	Z	Thickness	Tensile Modulus	E_z^t	Compressive Modulus	E_z^c
Stiffness	XY	Longitudinal/ Transverse	Shear Modulus	G_{xy}		
Stiffness	XZ	Longitudinal/ Thickness	Shear Modulus	G_{xz}		
Stiffness	YZ	Transverse/ Thickness	Shear Modulus	G_{yz}		
Strength	X	Longitudinal	Tensile Strength	$\sigma_x^{t\,ult}$	Compressive Strength	$\sigma_x^{c\,ult}$
Strength	Y	Transverse	Tensile Strength	$\sigma_y^{t\,ult}$	Compressive Strength	$\sigma_y^{c\,ult}$
Strength	Z	Thickness	Tensile Strength	$\sigma_z^{t\,ult}$	Compressive Strength	$\sigma_z^{c\,ult}$
Strength	XY	Longitudinal/ Transverse	Shear Strength	τ_{xy}^{ult}		
Strength	XZ	Longitudinal/ Thickness	Shear Strength	τ_{xz}^{ult}		
Strength	YZ	Transverse/ Thickness	Shear Strength	τ_{yz}^{ult}		

Poisson's Ratio

Direction:	XY (Major)	YX (Minor)	ZX	YZ
Notation:	ν_{xy}^t, ν_{xy}^c	ν_{yx}^t, ν_{yx}^c	ν_{zx}^t, ν_{zx}^c	ν_{yz}^t, ν_{yz}^c

Fibers

Comparative Data for Some Reinforcement Fibers

Fiber	Density lb/in^3	Tensile Strength psi x 10^3	Tensile Modulus psi x 10^6	Ultimate Elongation	Bulk Cost 2003 $/lb
E-Glass	.094	500	10.5	4.8%	.36-.54
S-Glass	.090	665	12.6	5.7%	4.00
Aramid - Kevlar® 49	.052	525	18.0	2.9%	19.00
Spectra® 900	.035	375	17.0	3.5%	20.00
Polyester - COMPET®	.049	150	1.4	22.0%	1.75
Carbon - Aerospace	.062-.065	350-700	33-57	0.38-2.0%	15-100
Carbon - Recreational	.062-.065	550	35	1.5%	5-12

Resins

Comparative Data for Some Thermoset Resin Systems (castings)

Resin	Barcol Hardness	Tensile Strength psi x 10^3	Tensile Modulus psi x 10^5	Ultimate Elongation	Bulk Cost 2003 $/lb
Orthophthalic Polyester	42	7.0	5.9	0.91%	.75
Isophthalic Polyester	46	10.3	5.7	2.0%	.86
Dicyclopentadiene (DCPD)	54	11.2	9.1	0.86%	.77
Vinyl Ester	35	11.5	4.9	5.5%	1.10
Phenolic	45			1.8%	1.30
Epoxy	86D*	8	5.3	7.7%	4.00
* Hardness value for epoxies are typically given on the “Shore D” scale					

Cores

Core Material		Density		Tensile Strength		Compressive Strength		Shear Strength		Shear Modulus	
		lbs/ft³	g/cm³	psi	Mpa	psi	Mpa	psi	Mpa	psi x 10³	Mpa
End Grain Balsa		7	112	1320	9.12	1190	8.19	314	2.17	17.4	120
		9	145	1790	12.3	1720	11.9	418	2.81	21.8	151
Cross-Linked PVC Foam	Termanto, C70.75	4.7	75	320	2.21	204	1.41	161	1.11	1.61	11
	Klegecell II	4.7	75	175	1.21	160	1.10			1.64	11
	Divinycell H-80	5.0	80	260	1.79	170	1.17	145	1.00	4.35	30
	Termanto C70.90	5.7	91	320	2.21	258	1.78	168	1.16	2.01	13
	Divinycell H-100	6.0	96	360	2.48	260	1.79	217	1.50	6.52	45
Linear Structural Foam	Core-Cell	3-4	55	118	0.81	58	0.40	81	0.56	1.81	12
		5-5.5	80	201	1.39	115	0.79	142	0.98	2.83	20
		8-9	210	329	2.27	210	1.45	253	1.75	5.10	35
Airex Linear PVC Foam		5-6	80-96	200	1.38	125	0.86	170	1.17	2.9	29
PMI Foam	Rohacell 71	4.7	75	398	2.74	213	1.47	185	1.28	4.3	30
	Rohacell 100	6.9	111	493	3.40	427	2.94	341	2.35	7.1	49
Phenolic Resin Honeycomb		6	96	n/a	n/a	1125	7.76	200	1.38	6.0	41
Polypropylene Honeycomb		4.8	77	n/a	n/a	218	1.50	160	1.10	n/a	n/a

Structural Comparison Between Metal & Composites

	Material	Density	Tensile Strength		Tensile Modulus		Ultimate Elongation
		lbs/ft^3	$psi \times 10^3$	Mpa	$psi \times 10^6$	Gpa	%
Resins	Orthophthalic Polyester	76.7	7	48.3	.59	4.07	1
	Isophthalic Polyester	75.5	10.3	71.1	.57	3.90	2
	Vinyl Ester	69.9	11-12	76-83	.49	3.38	4-5
	Epoxy (Gougeon Proset)	74.9	7-11	48-76	.53	3.66	5-6
	Phenolic	71.8	5.1	35.2	.53	3.66	2
Fibers	E-Glass (24 oz WR)	162.4	500	3450	10.5	72.45	4.8
	S- Glass	155.5	665	4589	12.6	86.94	5.7
	Kevlar® 49	90	525	3623	18	124.2	2.9
	Carbon-PAN	109.7	350-700	2415-4830	33-57	227-393	0.38-2.0
Cores	End Grain Balsa	7	1.320	9.11	.370	2.55	n/a
	Linear PVC (Airex R62.80)	5-6	0.200	1.38	0.0092	0.06	30
	Cross-Linked PVC (Diab H-100)	6	0.450	3.11	0.0174	0.12	n/a
	Honeycomb (Nomex® HRH-78)	6	n/a	n/a	0.0600	0.41	n/a
	Honeycomb (Nidaplast H8PP)	4.8	n/a	n/a	n/a	n/a	n/a
Laminates	Solid Glass/Polyester hand lay-up	96	20	138	1.4	9.66	n/a
	Glass/Polyester Balsa Sand.	24	6	41	0.4	2.76	n/a
	Glass/VE PVC Sand, SCRIMP	18	6	41	0.4	2.76	n/a
	Solid Carbon/Epoxy fil wound	97	88	607	8.7	60	n/a
	Carbon/Epoxy Nomex prepreg	9	9	62	0.5	3.45	n/a
Metals	ABS Grd A (ASTM 131)	490.7	58	400	29.6	204	21
	ABS Grd AH (ASTM A242)	490.7	71	490	29.6	204	19
	Aluminum (6061-T6)	169.3	45	310	10.0	69	10
	Aluminum (5086-H34)	165.9	44	304	10.0	69	9
Wood	Douglas Fir	24.4	13.1	90	1.95	13.46	n/a
	White Oak	39.3	14.7	101	1.78	12.28	n/a
	Western Red Cedar	21.2	7.5	52	1.11	7.66	n/a
	Sitka Spruce	21.2	13.0	90	1.57	10.83	n/a

Note: The values used in this table are for illustration only and should not be used for design purposes. In general, strength is defined as yield strength and modulus will refer to the material's initial modulus. A core thickness of 1" with appropriate skins was assumed for the sandwich laminates listed.

Composite Materials Summary

- The physical properties of composite materials are a function of processed reinforcement and resin combinations
- Metals are isotropic with equal properties in all directions - composites have properties that vary with direction
- Carbon fibers have excellent in-plane properties when loads align with fibers - E-glass laminates are more damage tolerant
- Large marine structures have traditionally been built with E-glass - long-term experience with carbon fiber is limited

Mechanical Strength

Basic

- Live Loads
- Dead Loads
- Liquid/Tank and Cargo

Sea Environment

- Hull Girder Bending
- Passing Waves
- Heel, Pitch and Other Ship Motions
- Green Seas

Operational & Extreme

- One-Time Extreme Conditions (such as flooding)

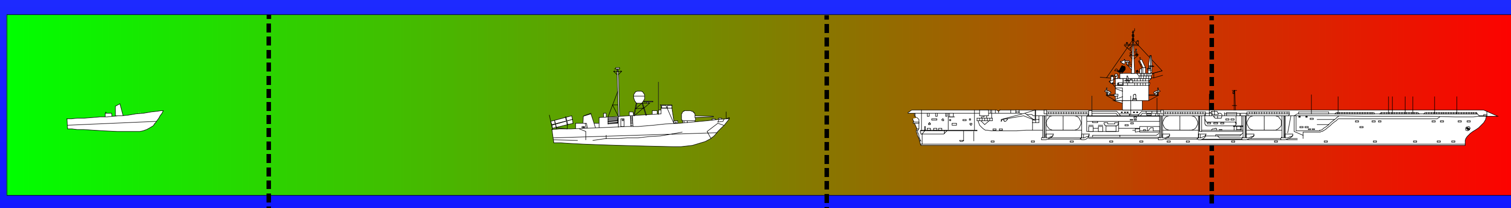
Combat (for Military Vessels)

- Shock
- Airblast
- Small Caliber Weapons
- Explosive Detonation

"Structural Design Manual For Naval Surface Ships", NAVSEA 0900-LP-097-4010, December 1976.

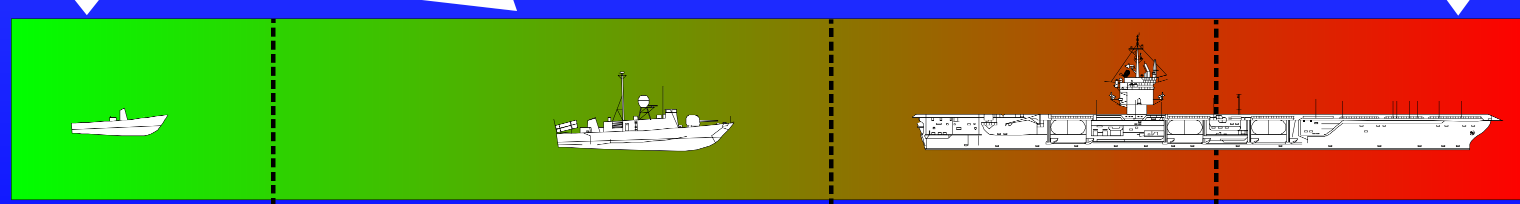
Design Tools

Design Tools	Metal Ships	Composite Ships
Isotropic versus Anisotropic Behavior	not applicable	Quasi-Isotropic Behavior Assumed for Large Structures
Upper Limit for Classification Society Rules	typically 400 meters	typically 60 meters
Status of Available FEA Programs	Programs Specific to Ship Structures Available	Dynamic, Out-of-Plane Loads not Yet Well Modeled for Ship Structures



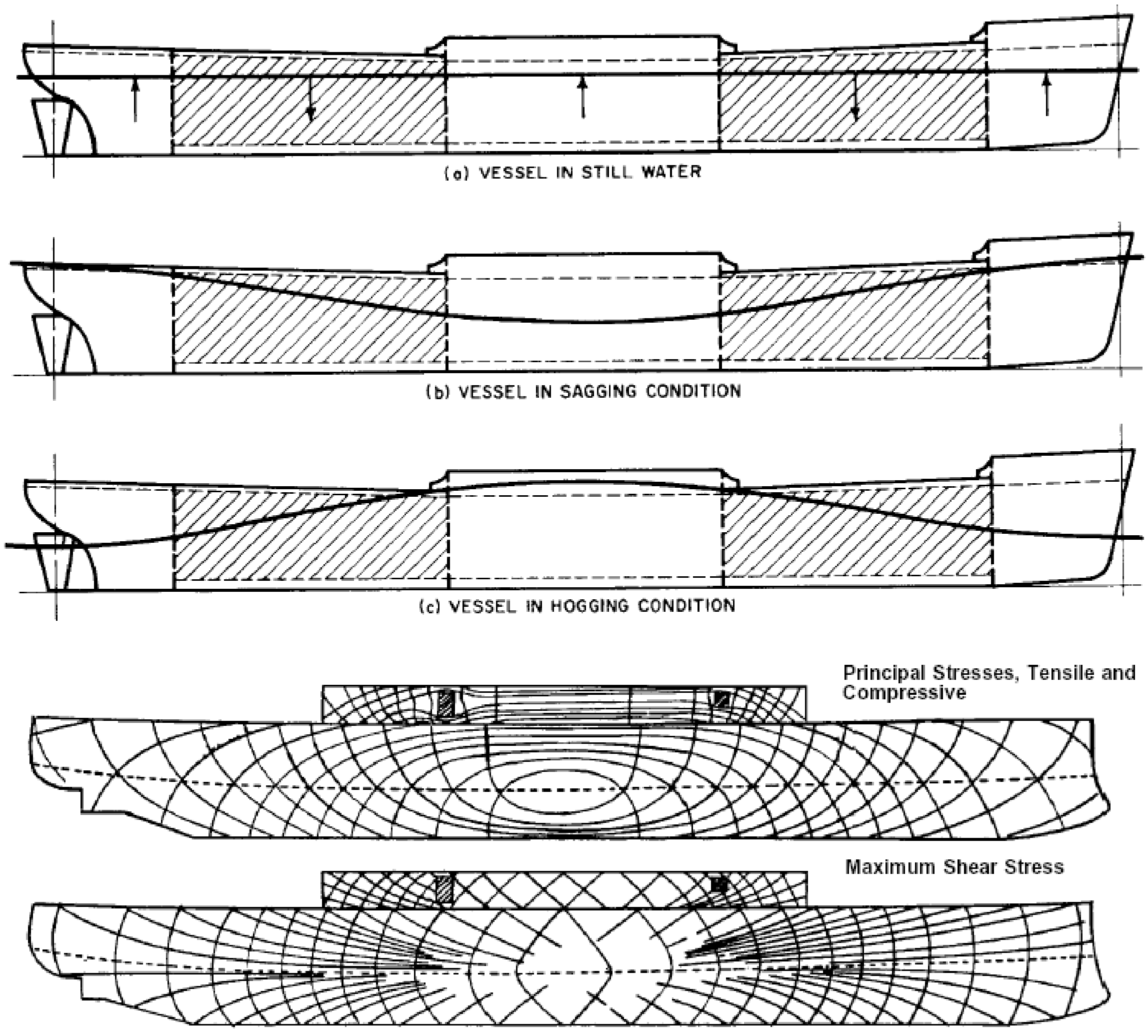
Design Methodology

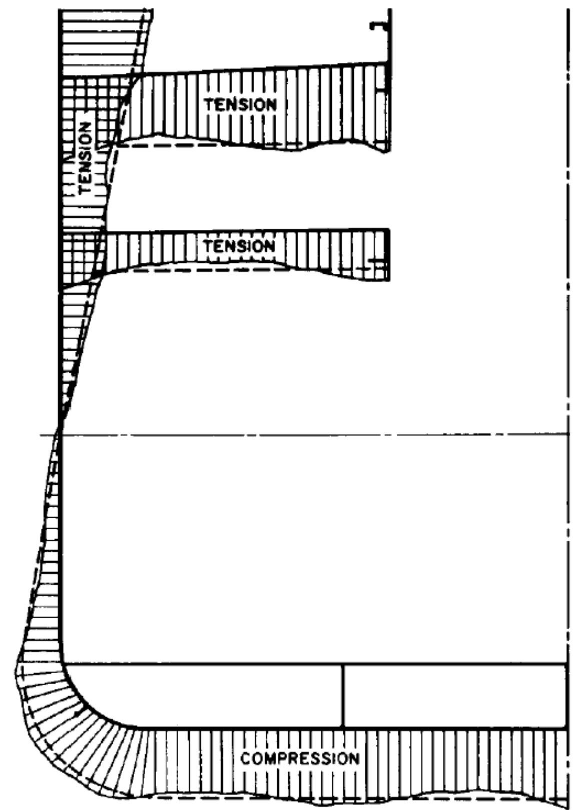
Design Methodology	Metal Ships	Composite Ships
Rule-Based Design Using Empirical Data	Good Experience Base for All Vessels	Good Experience Base for Small Vessels
Panel Design Based on Slamming Loads	Only Used for Smaller Vessels and Typicallly for Aluminum Only	Process Used for High Speed Craft
Midship Section Design Based on Stiffness and Strength	Traditional Method for Large Ships	Method not Generally Applied



10 meters 100 meters 300 meters

Hull as a Longitudinal Girder





Vessel in Hogging Condition

Slamming

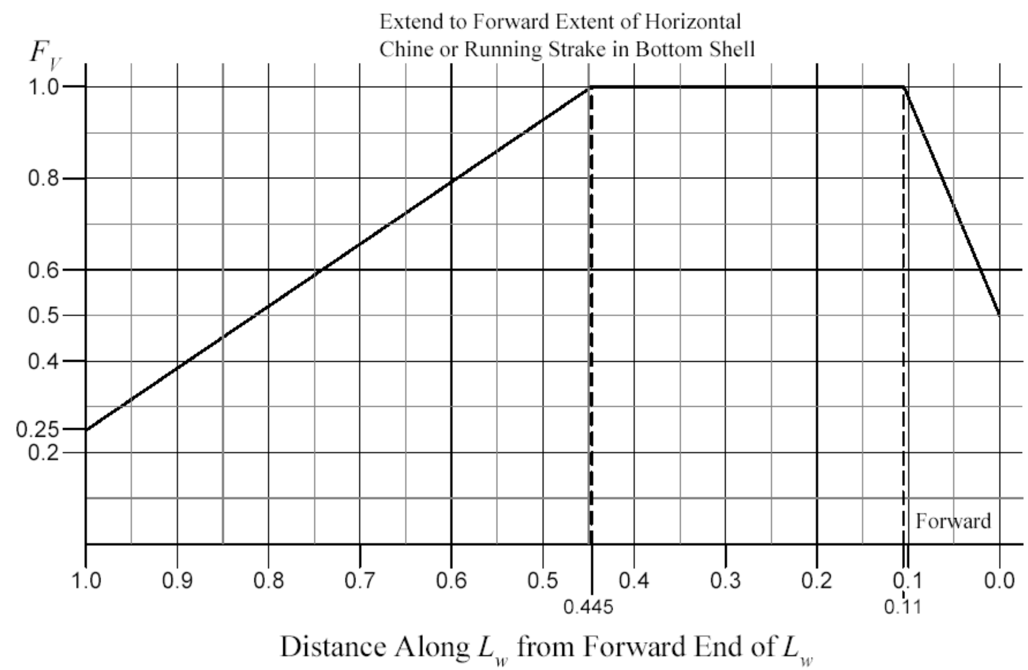
$$p_{bxx} = \frac{N_1 \Delta}{L_w B_w}[1 + n_{cg}]F_D F_v$$

) = Displacement

L_w = Length

B_w = Beam

Vertical Acceleration Distribution Factor F_V

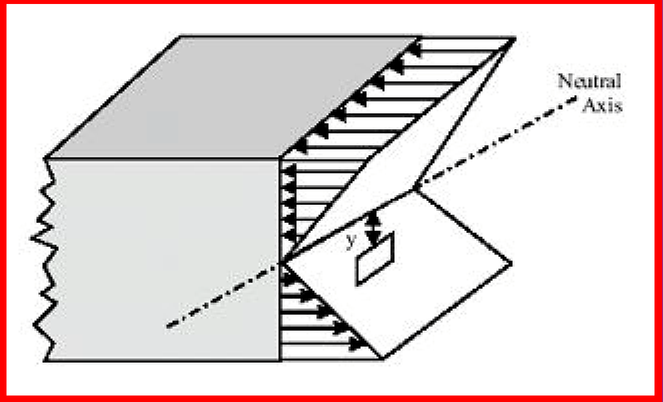


n_{cg} = the vertical acceleration of the craft as determined by a model test, theoretical computation, or service experience

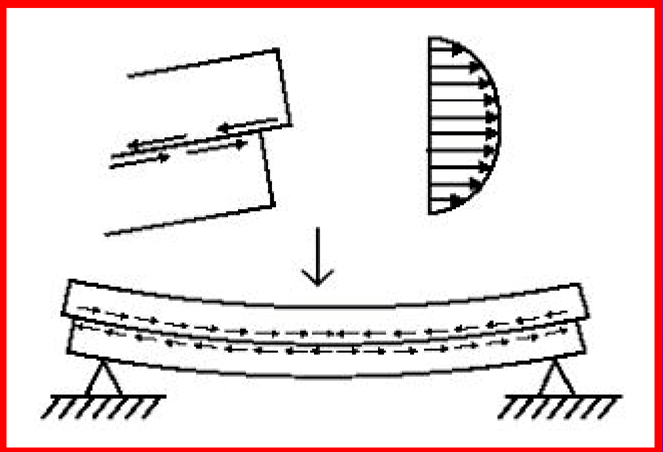
Design Tool Summary

- Design tools for large marine structures are more mature for metals than composites
- Composite laminates have 26 engineering parameters that need to be characterized with mechanical testing
- Composites do not have a “plastic” failure region - interlaminar failures and cracking precedes catastrophic failure
- There are numerous shear, tensile and compressive failure modes for composite structures

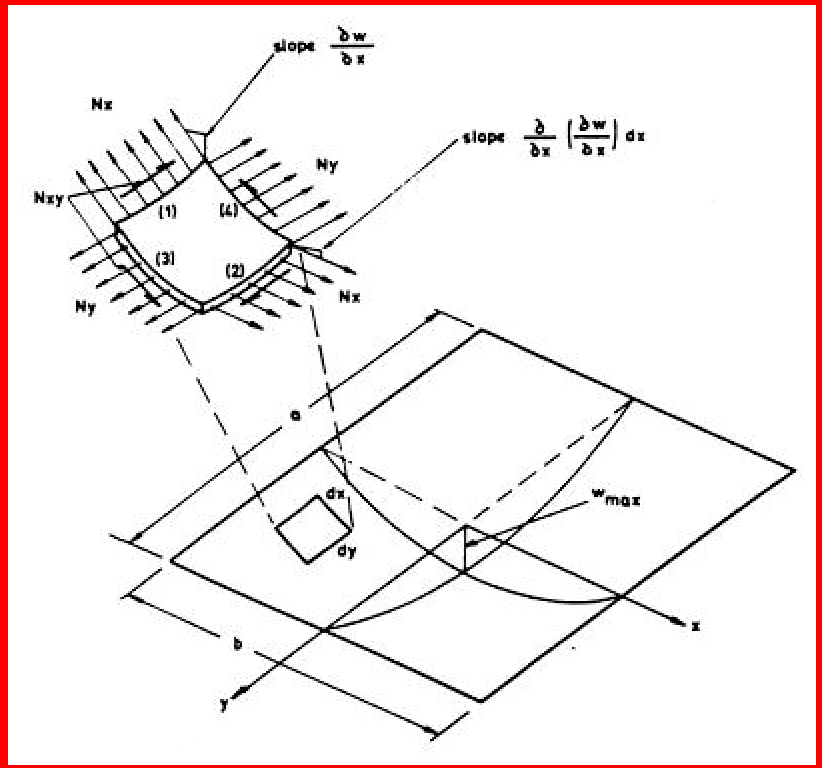
Bending Stresses in Panels



Maximum In-Plane Stress in Beams Subject to Bending



Maximum Shear Stress in Beams Subject to Bending

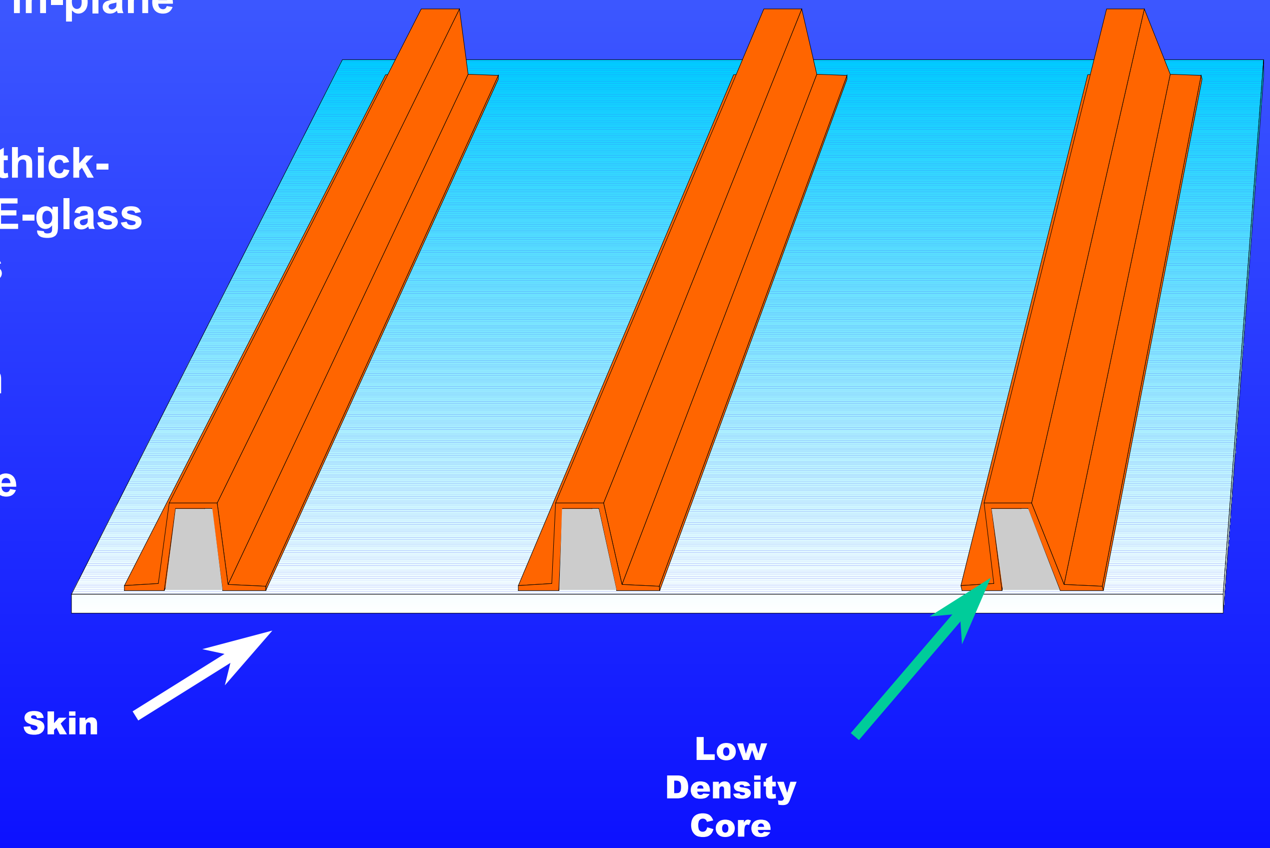


Stresses and Deflections due to Membrane Effects

Hat-Stiffened Solid Laminate

Best Suited for:

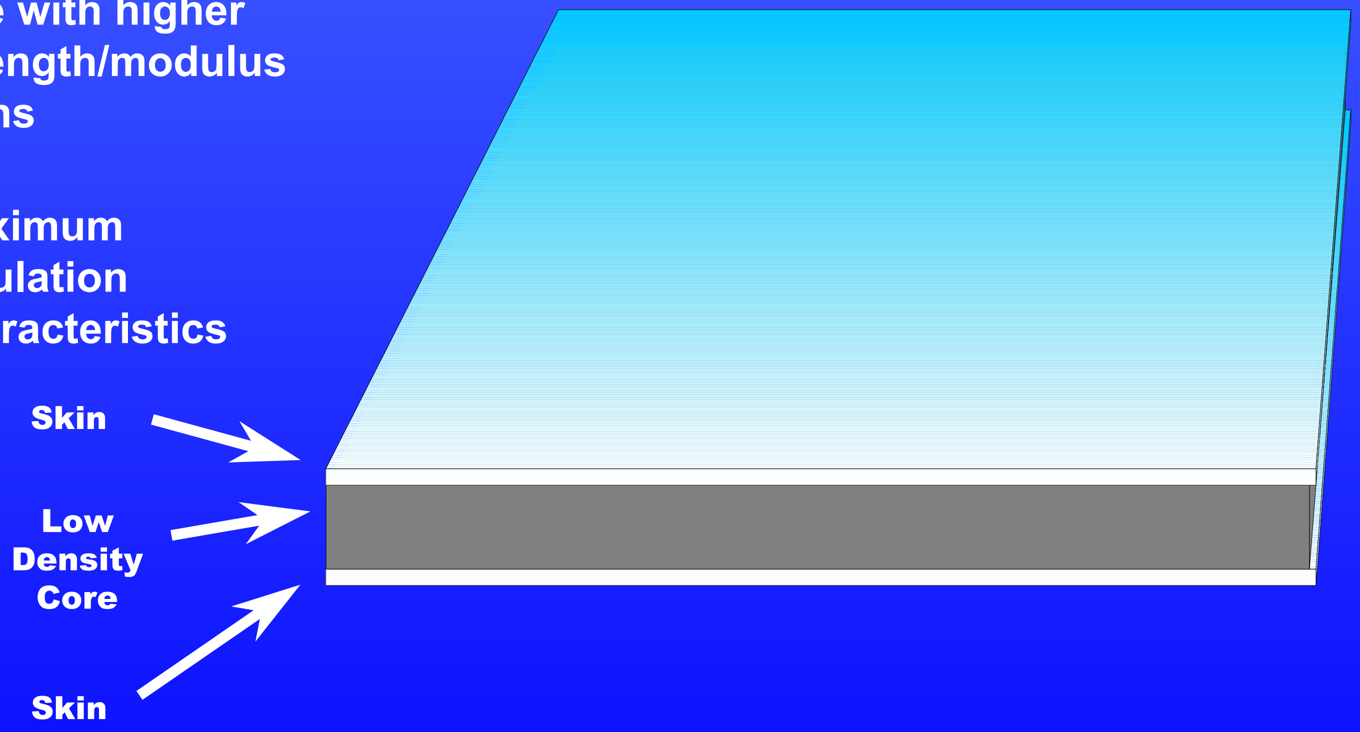
- Resisting in-plane loads
- Use with thick-skinned, E-glass laminates
- Maximum puncture resistance



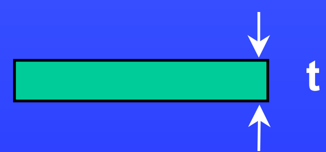
Sandwich Laminate

Best Suited for:

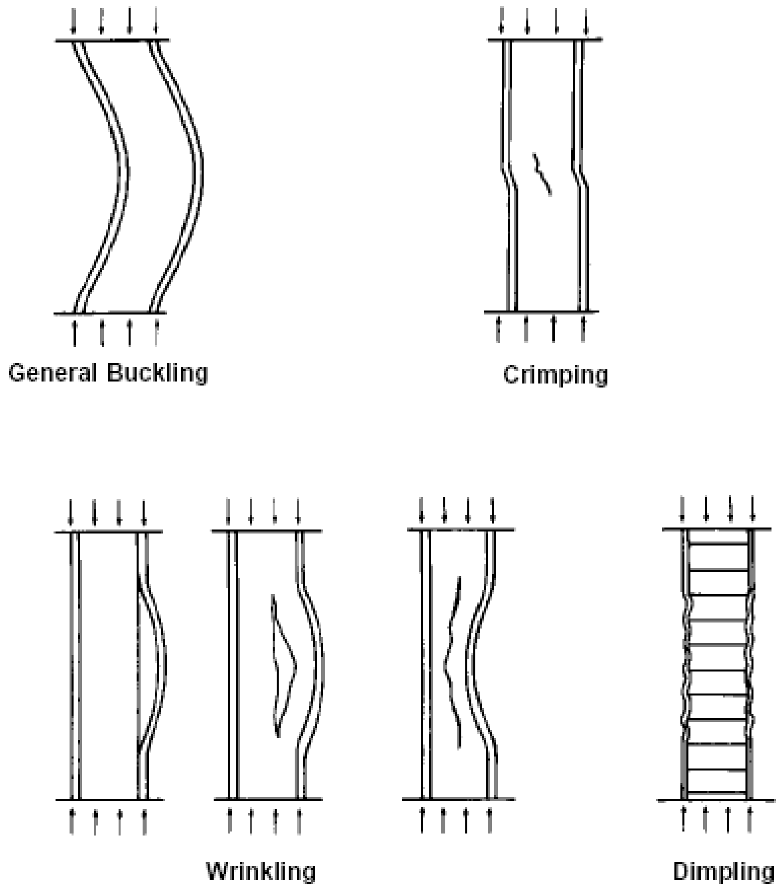
- Resisting out-of-plane loads
- Use with higher strength/modulus skins
- Maximum insulation characteristics

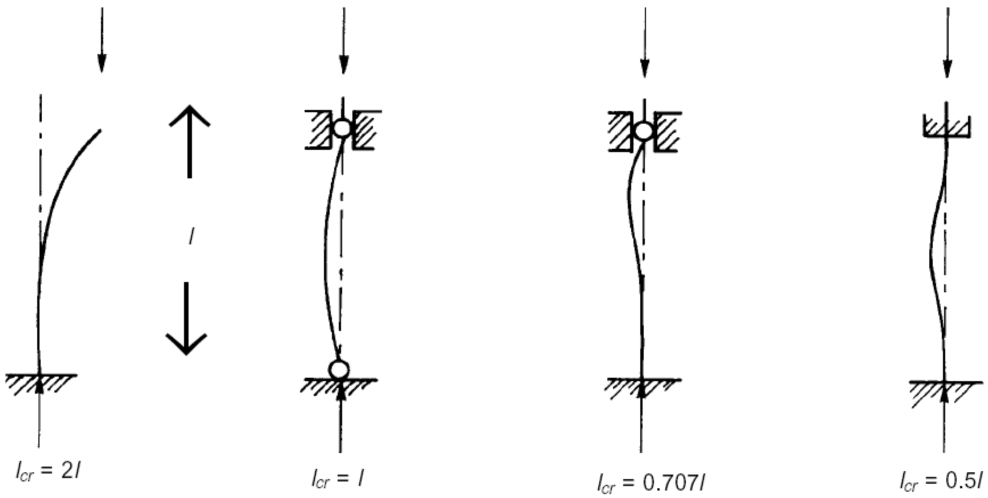


Comparison of Solid & Sandwich Laminates for Out-of-Plane Loads

			
Relative Stiffness	**100**	**700**	**3700**
Relative Strength	**100**	**350**	**925**
Relative Weight	**100**	**103**	**106**

Compressive Failure Modes

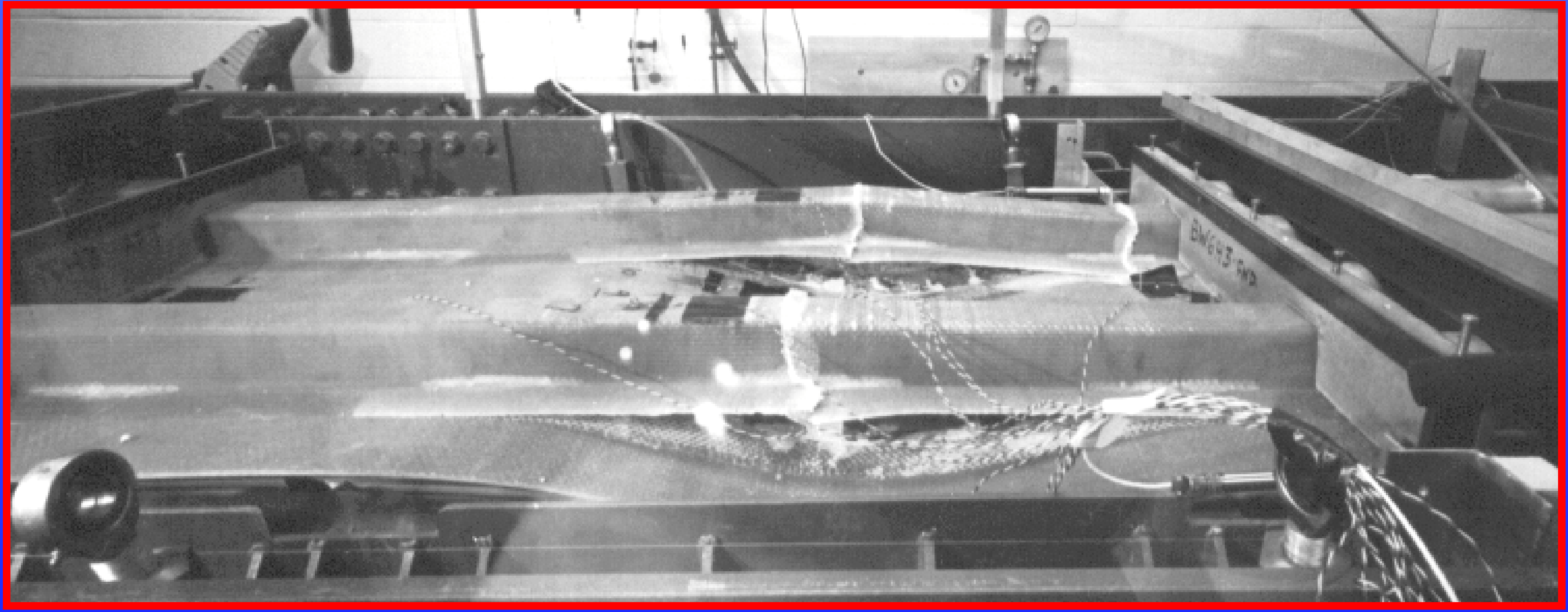




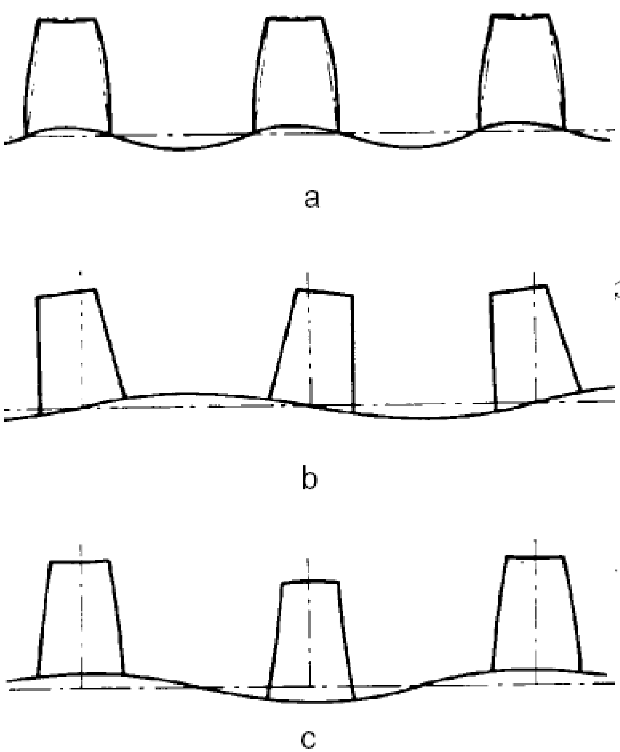
Critical Length for Euler Buckling Formula Based on End Condition (above)

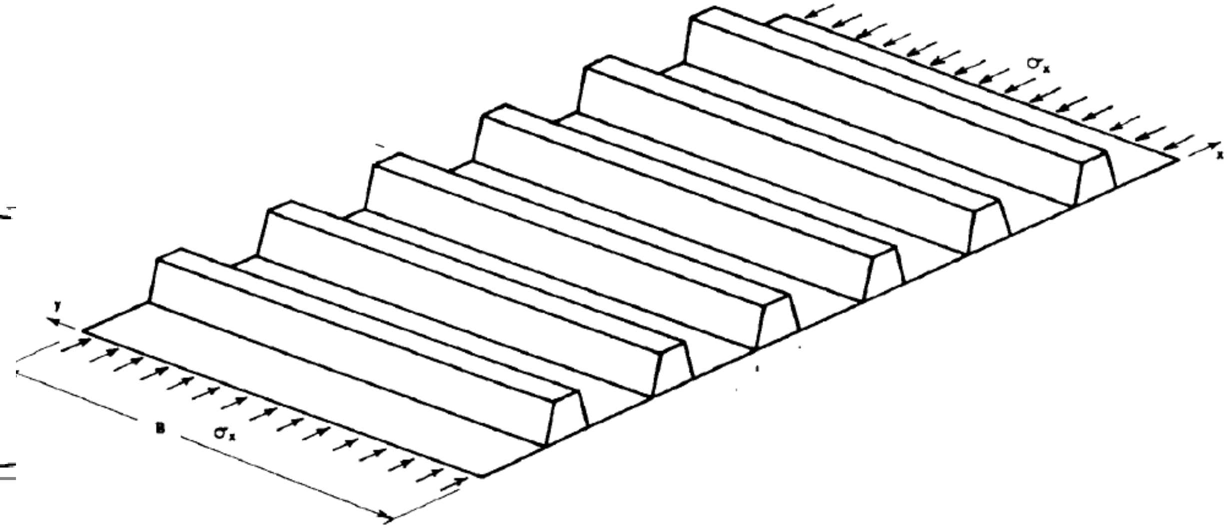
Compressive Failure Modes of Sandwich Laminates (left)

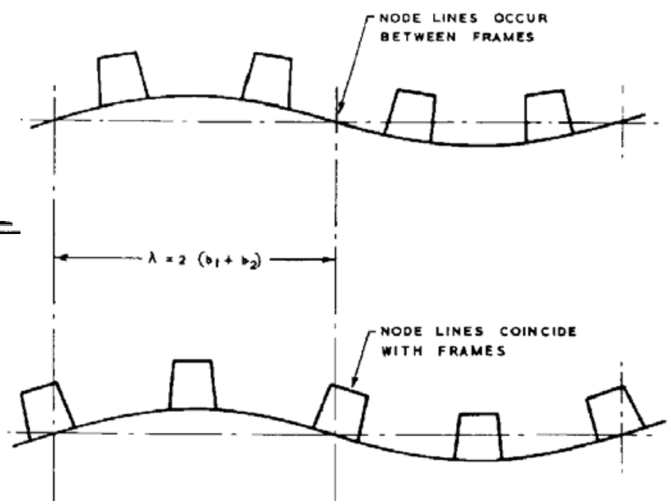
Longitudinally-Stiffened Panels in Compression



Transversely-Stiffened Panels in Compression

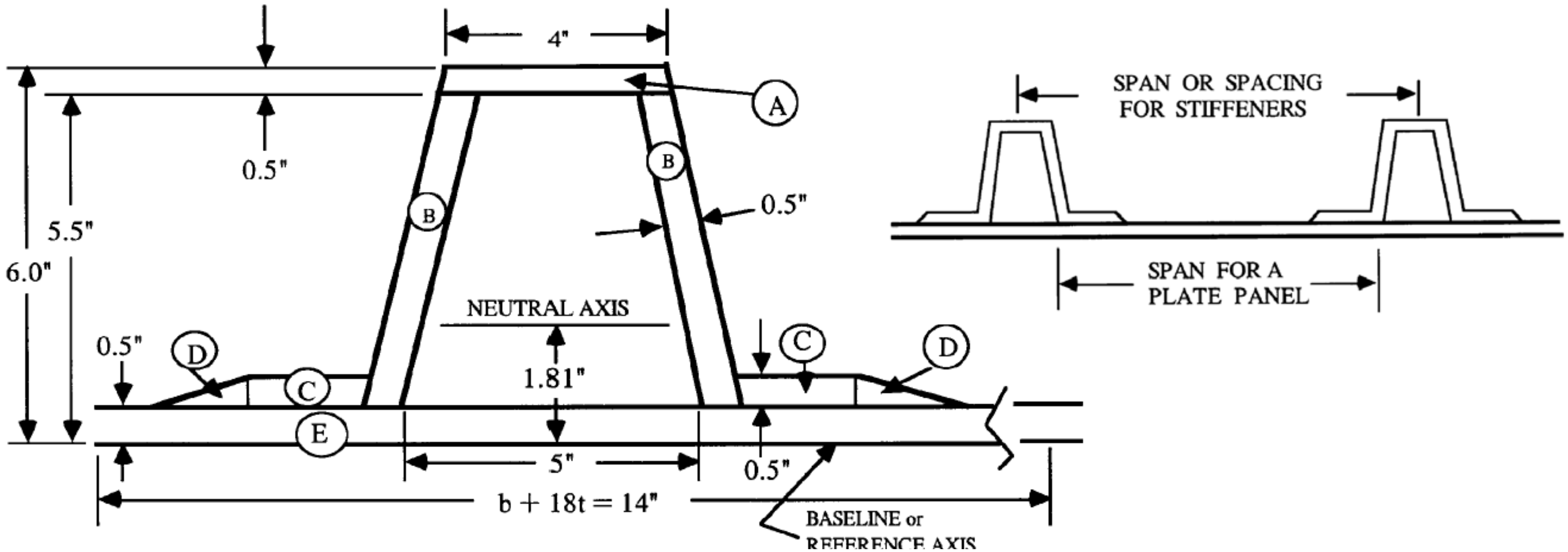






Transversely Stiffened Panel (above) and Buckling Modes (below) [Smith, *Buckling Problems in the Design of Fiberglass Reinforced Plastic Ships*]

Hat Stiffeners



$$d_{NA} = \frac{\sum Ad}{\sum A} = \frac{30.55}{16.85} = 1.81 \text{ inches}$$

$$I_{NA} = \sum i_o + \sum Ad^2 - [\ Ad^2\ ] = 10.86 + 115.92 - [16.85 \times (1.81)^2] = 71.58$$

$$SM_{top} = \frac{I}{d_{NA\ top}} = \frac{71.58}{4.19} = 17.08 \text{ in}^3$$

$$SM_{bottom} = \frac{I}{d_{NA\ bottom}} = \frac{71.58}{1.81} = 39.55 \text{ in}^3$$

Example of a single skin FRP stiffener to illustrate the design process taken from USCG NVIC No. 8-87

Structural Concept Summary

- Hat-stiffened, solid laminates built as monolithic structures offer the greatest amount of primary axis reinforcements to resist hull girder bending moments
- Solid laminates are easier to inspect for structural damage
- Sandwich laminates are the most efficient structures for resisting out-of-plane loads
- Sandwich laminates offer good insulation properties and a reserve inner skin to prevent flooding

Design Methodology

Consider life-cycle
requirements of the vessel
to determine expected
wave encounter in terms
of height and frequency

Determine In-Service Profile

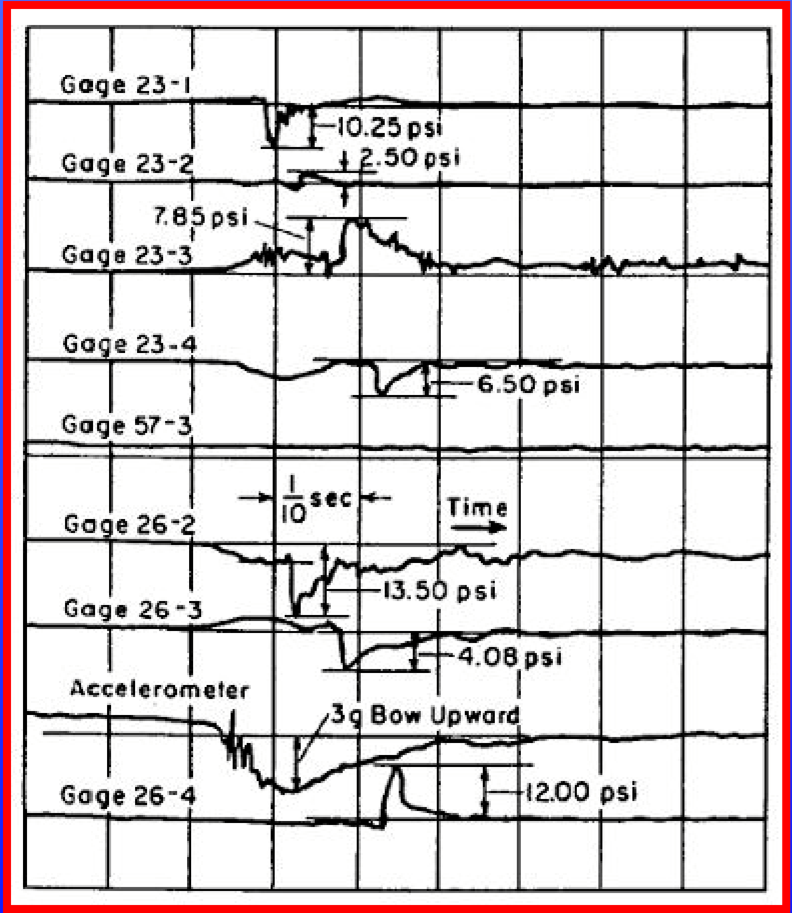
USCG 47-foot Motor Lifeboat

Larson 98 Model 226 LXI Advertised for Sale: “used very little”

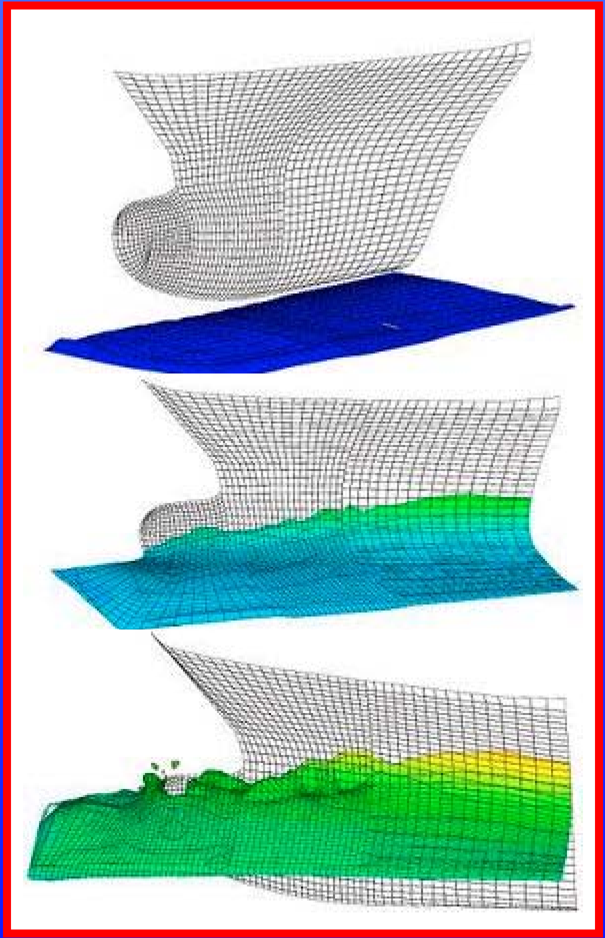
Consider life-cycle requirements of the vessel to determine expected wave encounter in terms of height and frequency

DEVELOP DESIGN PRESSURE
- Hull Geometry
- Vessel Speed
- In-Service Conditions
- Design Criteria

Develop Design Pressure



Pressures Recorded by Heller and Jasper on Patrol Craft at 28 Knots



Three-Dimensional Slamming Simulation by Germanischer Lloyd AG

Rule-Based Design Pressure

b *Planing Vessels* The thickness of the bottom shell plating in planing vessels is to be not less than either required by 7.1.2a or obtained from the following equations.

1 Where speed of vessel is less than or equal to 31 knots

$$t = 0.0384s\sqrt[3]{kV} \text{ mm or in.}$$

2 Where speed of vessel is greater than 31 knots

$$t = 0.0122s\sqrt[3]{kV^2} \text{ mm or in.}$$

t = thickness in mm or in.
s = span of shorter side of plating panel in mm or in.
k = coefficient that varies with bottom shell plating panel aspect ratio as shown in Table 7.1
V = sea speed of vessel in knots

From *ABS 1978 Rules for Reinforced Plastic Vessels*, Section 7

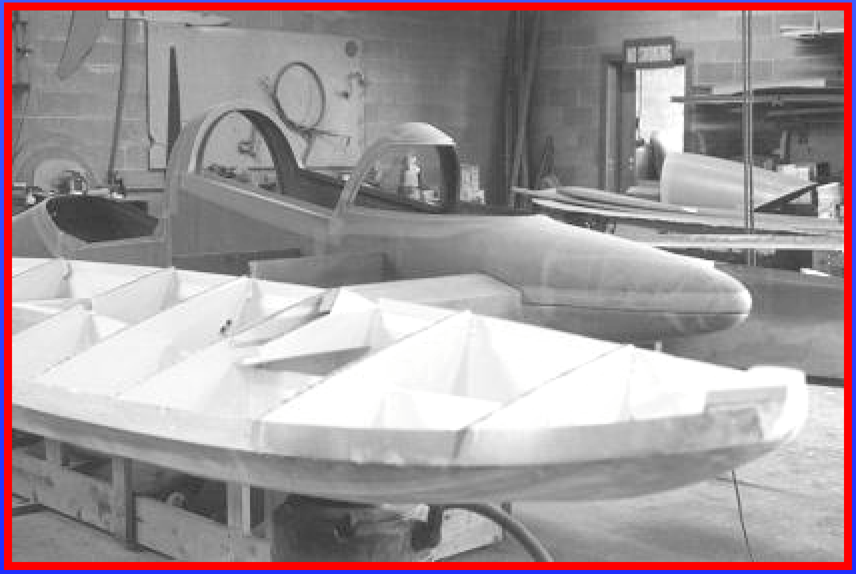
CONSTRUCTION
- Solid or Sandwich
- One-Off or Production

Consider life-cycle requirements of the vessel to determine expected wave encounter in terms of height and frequency

DEVELOP DESIGN PRESSURE
- Hull Geometry
- Vessel Speed
- In-Service Conditions
- Design Criteria

Construction Method

Hand Layup of Solid Laminate Hull
at Westport Marine



Prepreg/Nomex Honeycomb Core Construction
of Hydroplane at Ron Jones Marine

CONSTRUCTION
- Solid or Sandwich
- One-Off or Production

INITIAL MATERIAL SELECTION
- Reinforcement
- Resin
- Core

Consider life-cycle requirements of the vessel to determine expected wave encounter in terms of height and frequency

DEVELOP DESIGN PRESSURE
- Hull Geometry
- Vessel Speed
- In-Service Conditions
- Design Criteria

Initial Material Selection

Reinforcements

Parameter	E-Glass	Carbon	Kevlar®
Workability	Good	Fair	Fair
Cost	Excellent	Poor	Fair
Static Strength	Good	Excellent	Good
Dynamic Strength	Good	Good	Excellent
Elevated Temperature Performance	Good	Good	Fair

Resins

Parameter	Polyester	Vinyl ester	Epoxy
Workability	Excellent	Excellent	Good
Cost	Excellent	Good	Fair
Static Strength	Fair	Good	Excellent
Dynamic Strength	Fair	Good	Good
Elevated Temperature Performance	Fair	Good	Good

Cores

Parameter	Balsa	PVC Foam
Workability	Good	Good
Cost	Excellent	Good
Static Strength	Good	Fair
Dynamic Strength	Fair	Good
Elevated Temperature Performance	Good	Poor

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BULKHEAD SPACING

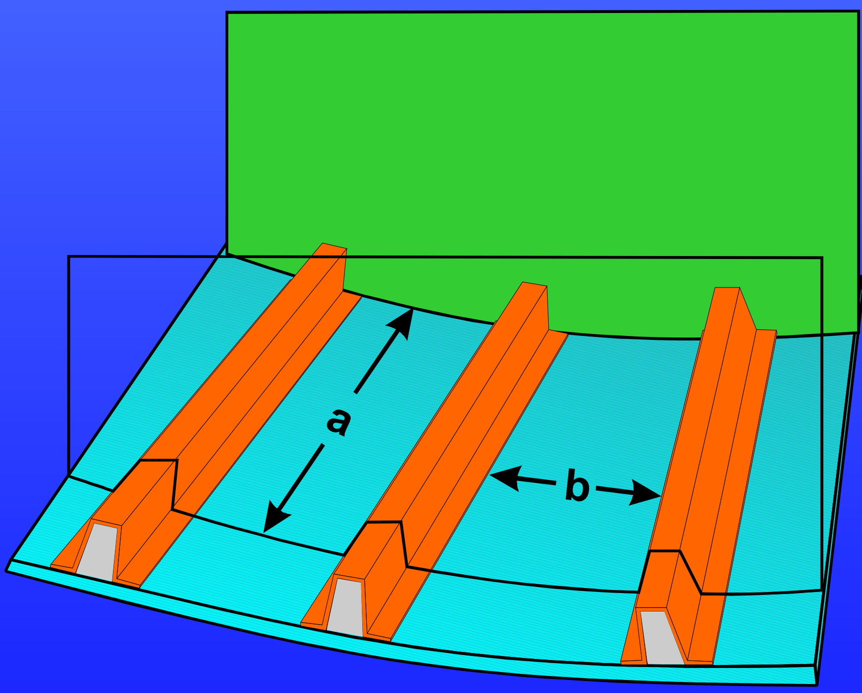
Optimize transverse and longitudinal spacing based on strength and layout requirements

LONGITUDINAL SPACING

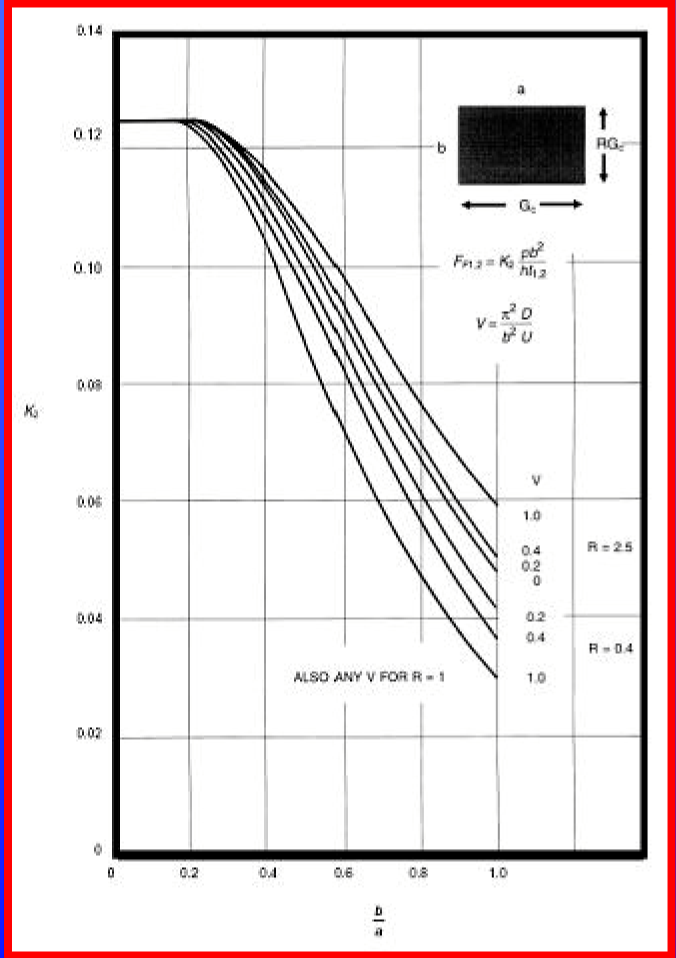
DETERMINE PANEL SIZE
- Aspect Ratios
- Dimensions

Consider end conditions of panel at bulkhead and stiffener attachment points

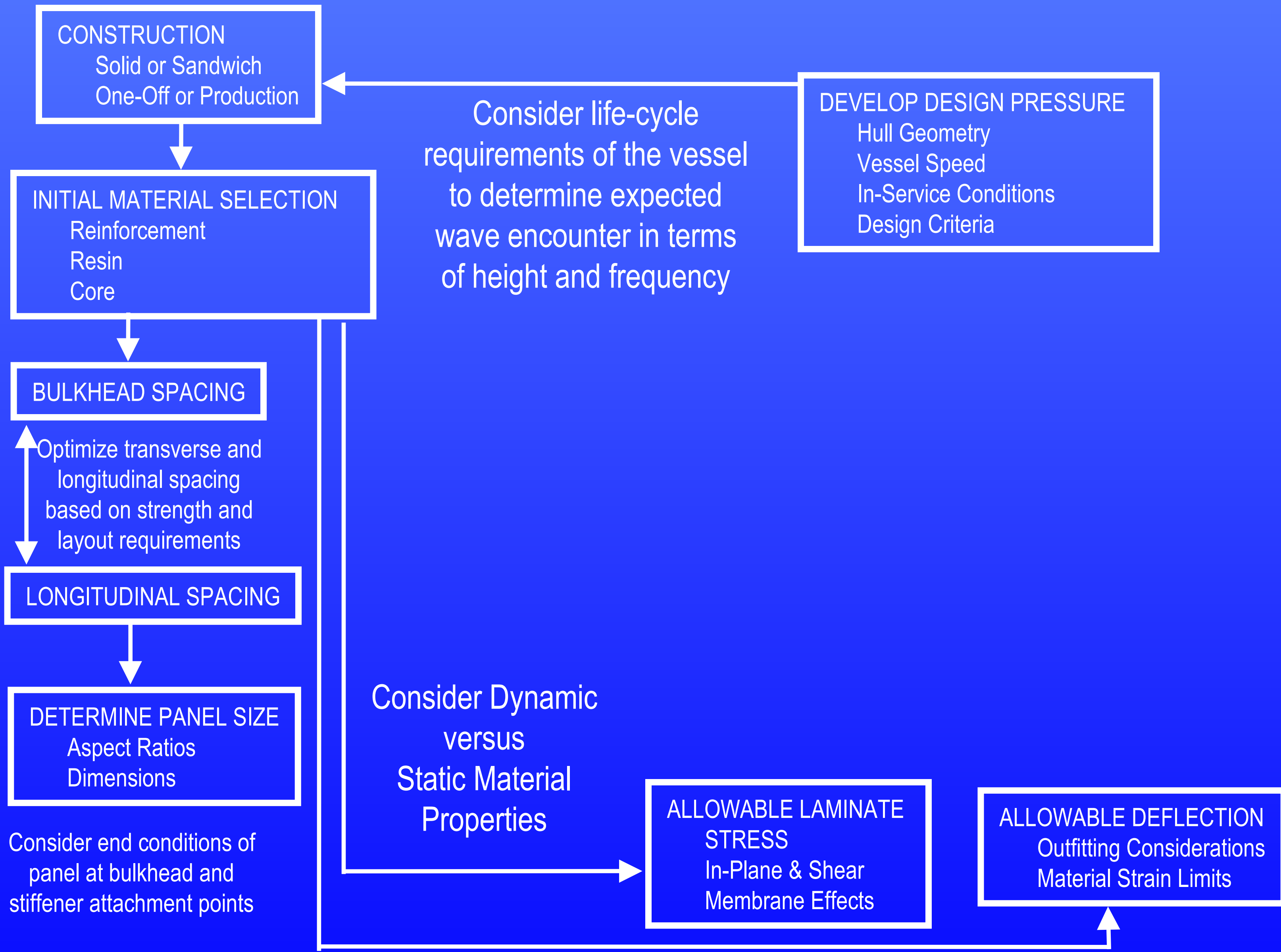
Determine Panel Size



Bottom Panel Geometry Showing
Aspect Ratio and End Conditions



Stress Coefficient as a Function of Panel
Aspect Ratio from MARINE COMPOSITES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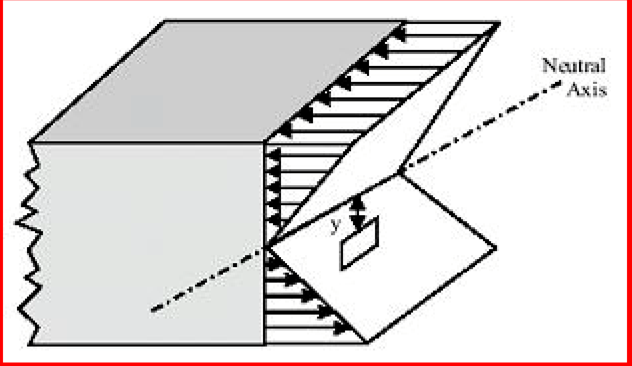
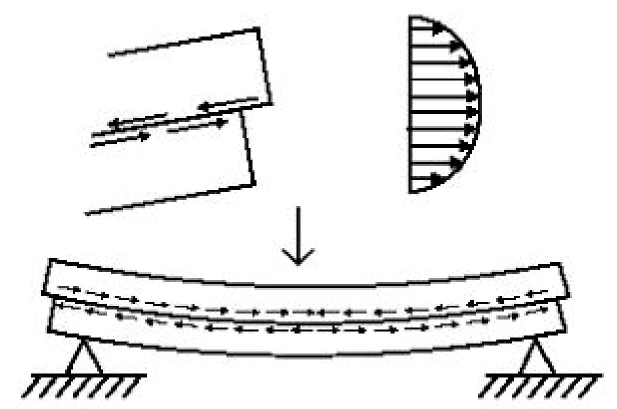
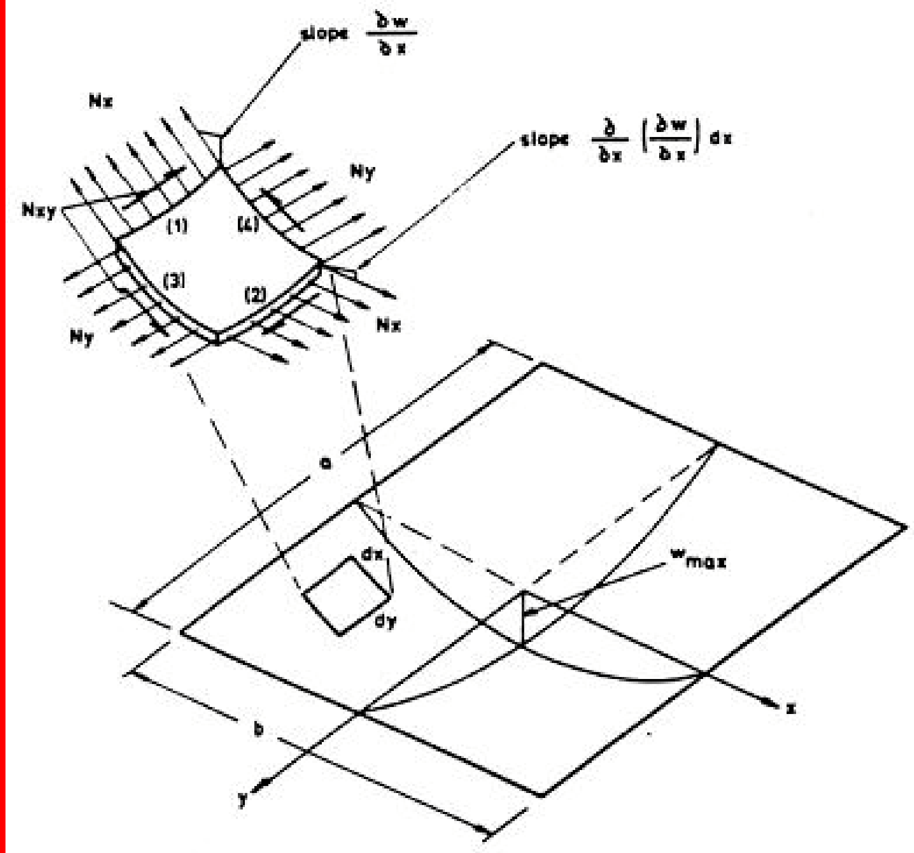
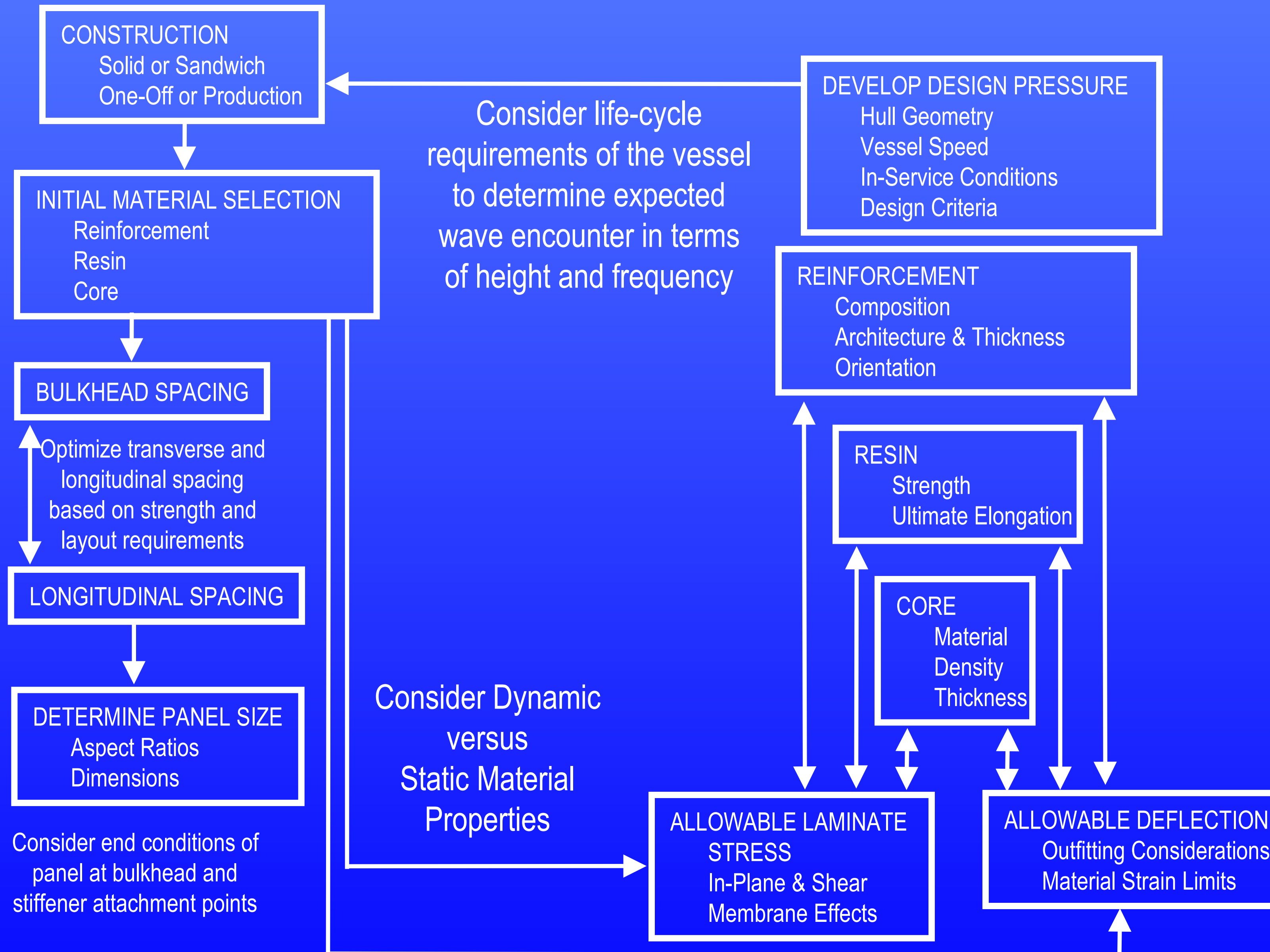
Consider end conditions of panel at bulkhead and stiffener attachment points
Consider Dynamic versus Static Material Properties
ALLOWABLE LAMINATE STRESS
In-Plane & Shear
Membrane Effects
ALLOWABLE DEFLECTION
Outfitting Considerations
Material Strain Limits

Stresses and Deflections in Panels





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Consider end conditions of panel at bulkhead and stiffener attachment points

Refine Material Selection based on Strain Limits

$$\varepsilon_{crit} = \frac{\sigma_{ai}}{E_{ai}\left[\,|\bar{y} - y_i| + \tfrac{1}{2}\, t_i\,\right]}$$

where:

σ_{ai} = strength of ply under consideration
= σ_t for a ply in the outer skin
= σ_c for a ply in the inner skin

E_{ai} = modulus of ply under consideration
= E_t for a ply in the outer skin
= E_c for a ply in the inner skin

$\bar{y}$ = distance from the bottom of the panel to the neutral axis

y_i = distance from the bottom of the panel to the ply under consideration

t_i = thickness of ply under consideration

σ_t = tensile strength of the ply being considered

σ_c = compressive strength of the ply being considered

E_t = tensile stiffness of the ply being considered

E_c = compressive stiffness of the ply being considered

First Ply Failure Based on First Play Critical Strain Limits from the *ABS Guide for Building and Classing High-Speed Craft*

Refine Material Selection based on Stress Limits

$$SM_o = \frac{\sum_{i=1}^{n} FM_i}{\sigma_{to}}$$

$$SM_i = \frac{\sum_{i=1}^{n} FM_i}{\sigma_{ci}}$$

where:

SM_o = section modulus of outer skin

SM_i = section modulus of inner skin

n = total number of plies in the skin laminate

σ_{to} = tensile strength of outer skin determined from mechanical testing or via calculation of tensile strength using a weighted average of individual plies for preliminary estimations

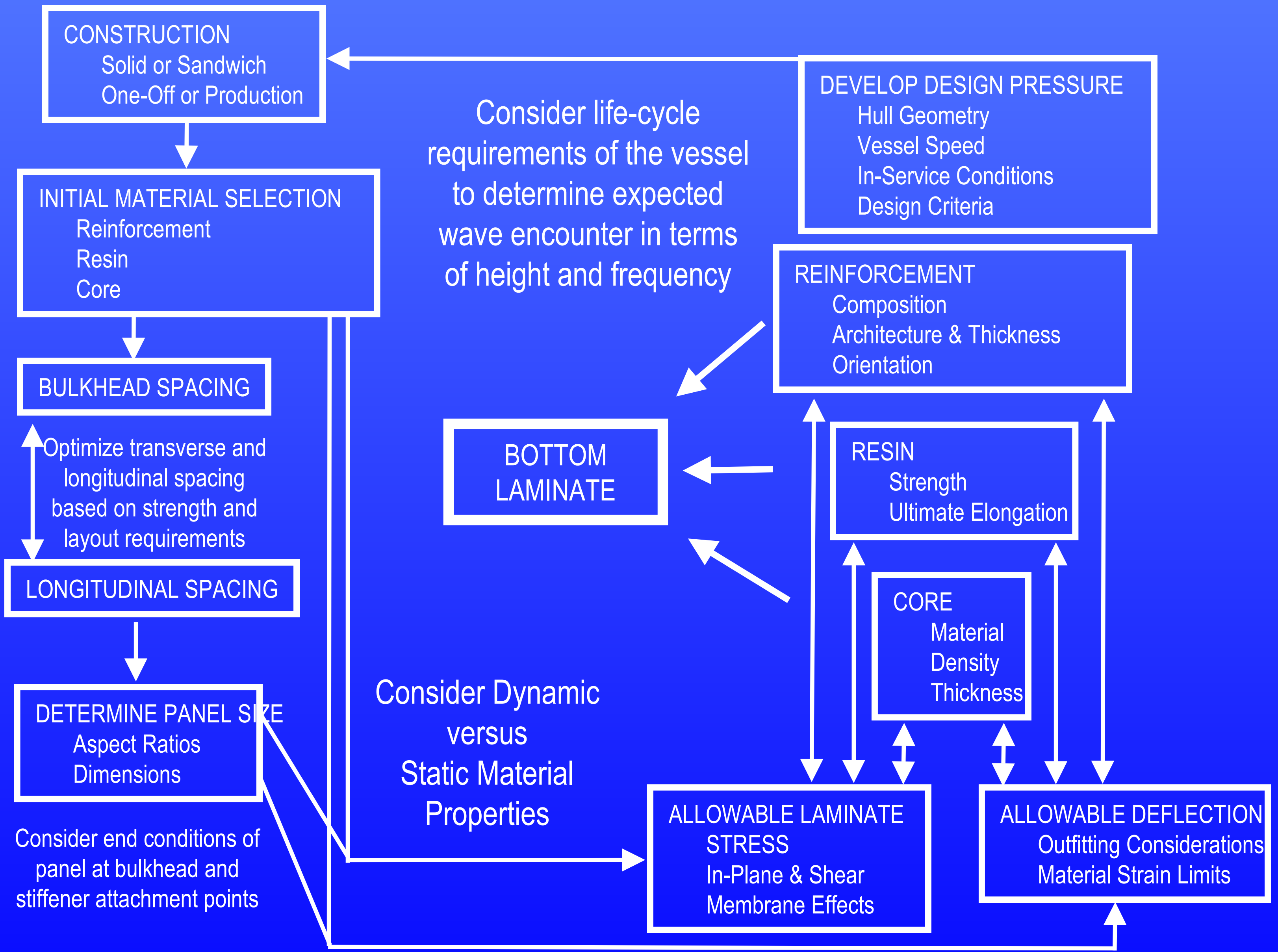
σ_{ci} = compressive strength of inner skin determined from mechanical testing or via calculation of compressive strength using a weighted average of individual plies for preliminary estimations

$$FM_i = \varepsilon_{min} \, E_{xi} \, t_i \left(\left|\bar{y} - y_i\right|\right)^2$$

where:

ε_{min} = the smallest critical strain that is acting on an individual ply

Skin Section Modulus Based on Applied Failure Moment
from the *ABS Guide for Building and Classing High-Speed Craft*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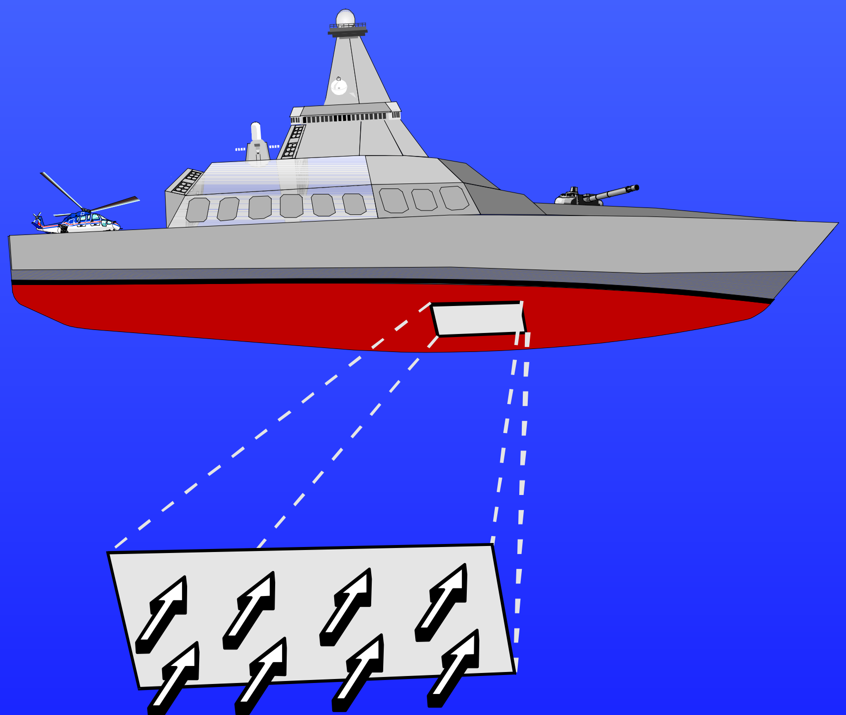
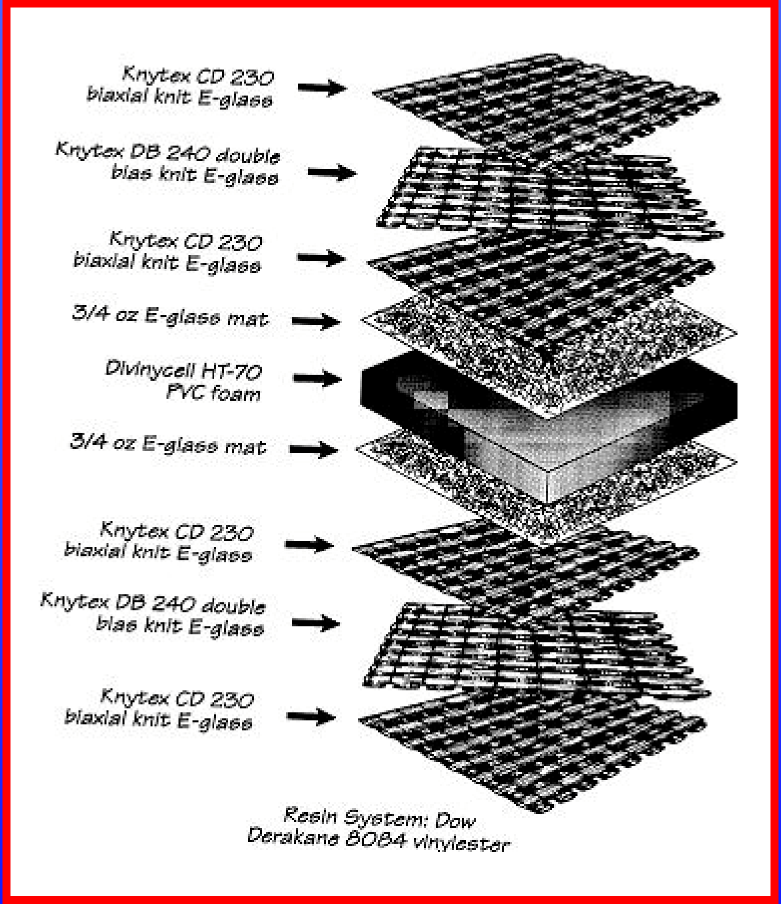
Develop Laminate Schedule





Typical Laminate Designation

Design Summary

- Composites offer the potential to "highly engineer" a structure when load paths are well defined
- Long-term experience with large, composite marine structures is limited to E-glass laminates
- In-plane loads dominate for ships - out-of-plane loads drive the design of boats
- Sophisticated design tools for composite structures have been developed for the aerospace industry but are immature for large, marine structures

Session 2 - Manufacturing Processes (3:00 - 3:45)

- Manufacturing Concepts
- Process Descriptions
- Joining Technologies
- Facilities

US Navy Processing Goals

Naval Surface Warfare Center, Carderock Division
Marine Composites Branch, Code 655

NSWCCD Approach for Building Superstructures

Fabrication

- Non-autoclave, inexpensive tooling, low voids, high fiber content, scaleable
- Vacuum Assisted Resin Transfer Molding (VARTM)
- SCRIMP
- Recirculation Molding
- Low Temp Prepreg
- UV Cure Resins

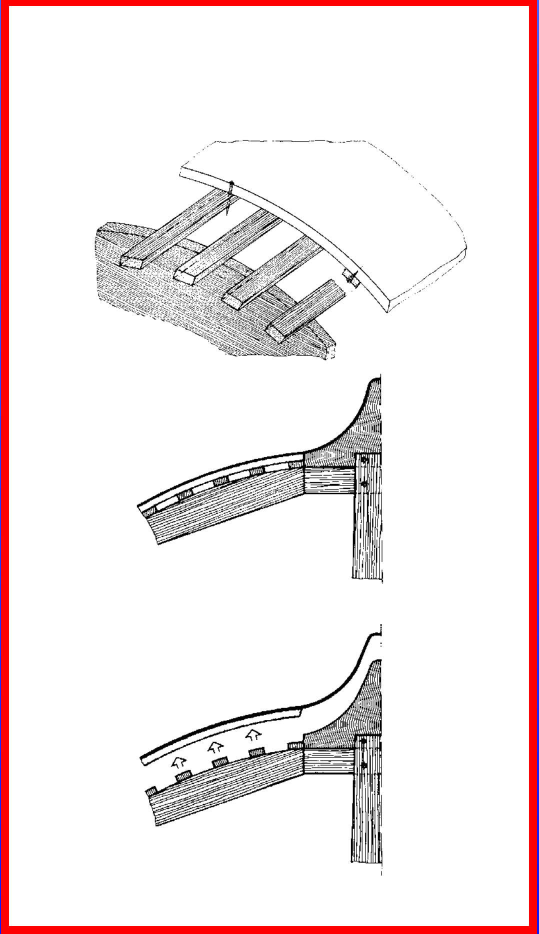
Sandwich Panel Being Fabricated by Northrop Grumman Ship Systems Using the SCRIMP Method

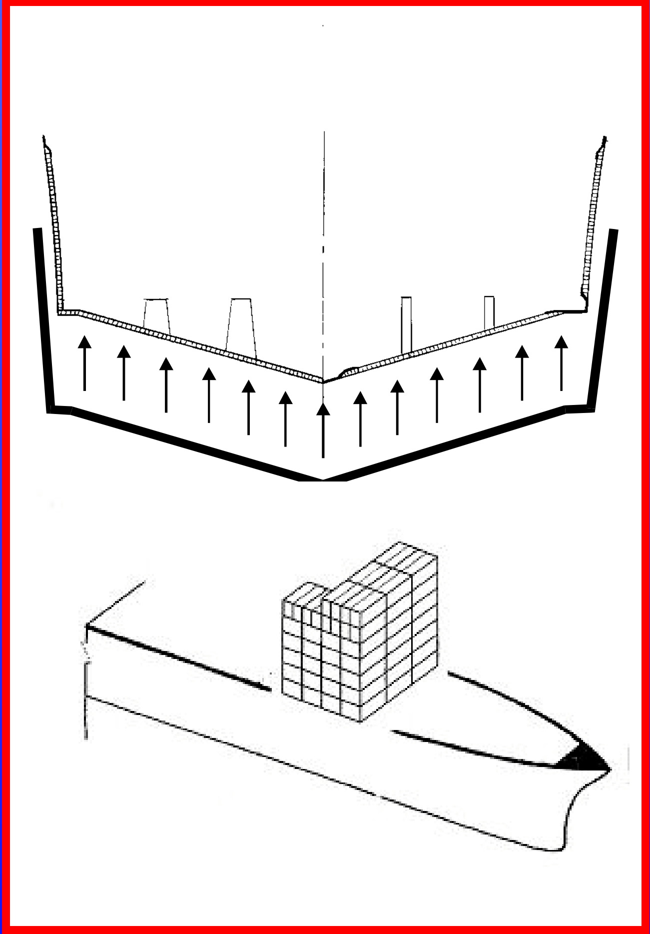
Materials

- E-glass, S2-glass, carbon
- Vinyl-ester, polyester, phenolic
- Woven roving, heavy fabrics, stitched uni, mat
- Balsa, foam

Manufacturing Concepts

One-Off Construction with Wood Batten Frame





Production Construction from Female Molds

Panel Construction with Secondary Bonds

Production Female Molds

The process of creating a three-dimensional hull shape generated by a designer on paper into a full-scale solid form that can be reproduced is called "Mold Making"

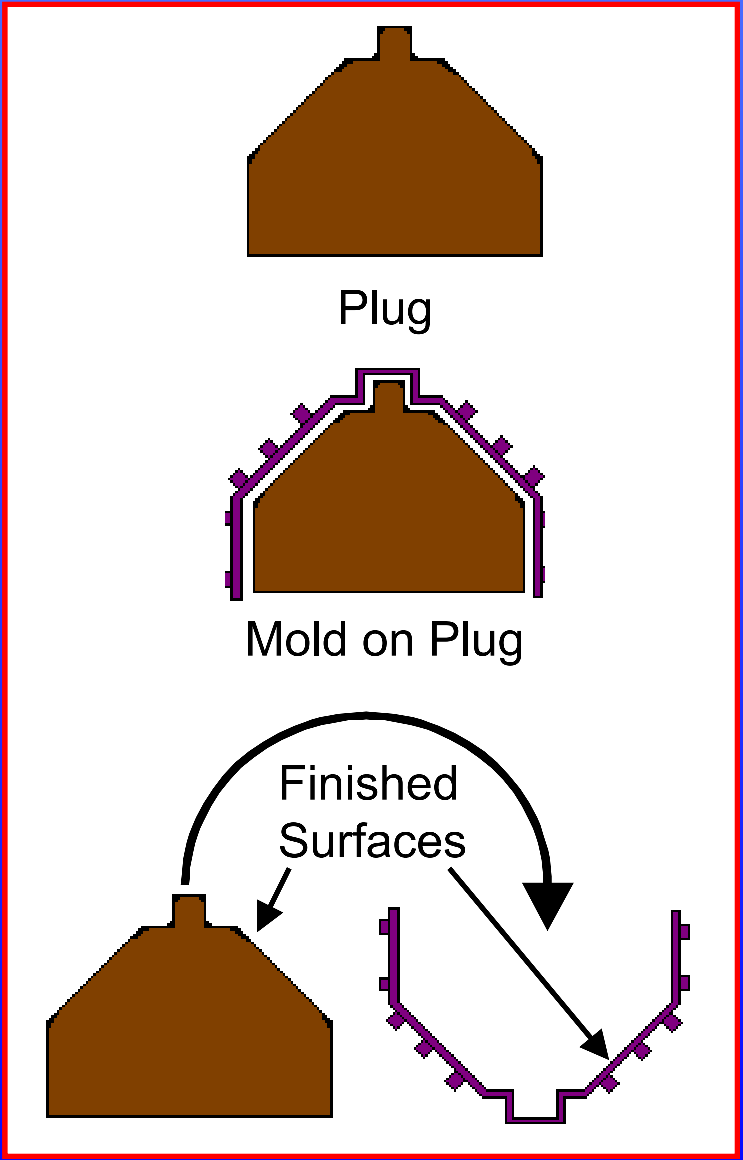
Mold - Tool used to reproduce parts

Plug - Copy of part used to produce mold

Female Mold - Concave form used to produce convex shape

Male Mold - Mold that resembles final part.

Release Agent - A compound applied to the mold that allows a cured part to be removed

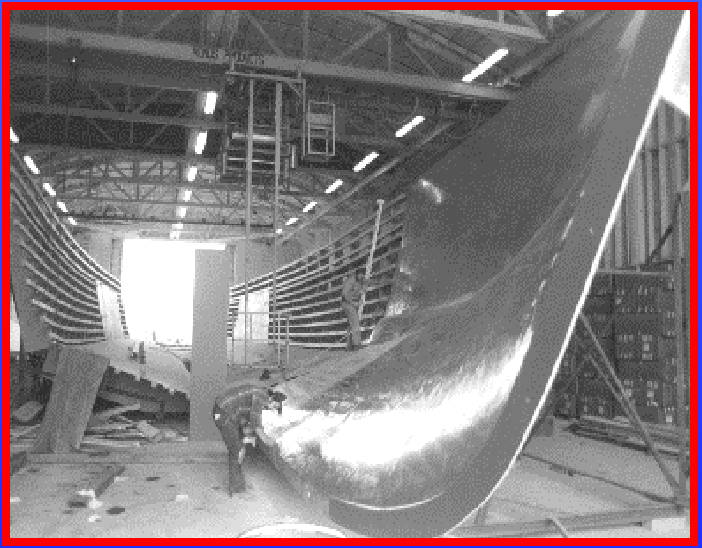


CNC Cut Plugs Improve Plug Fabrication

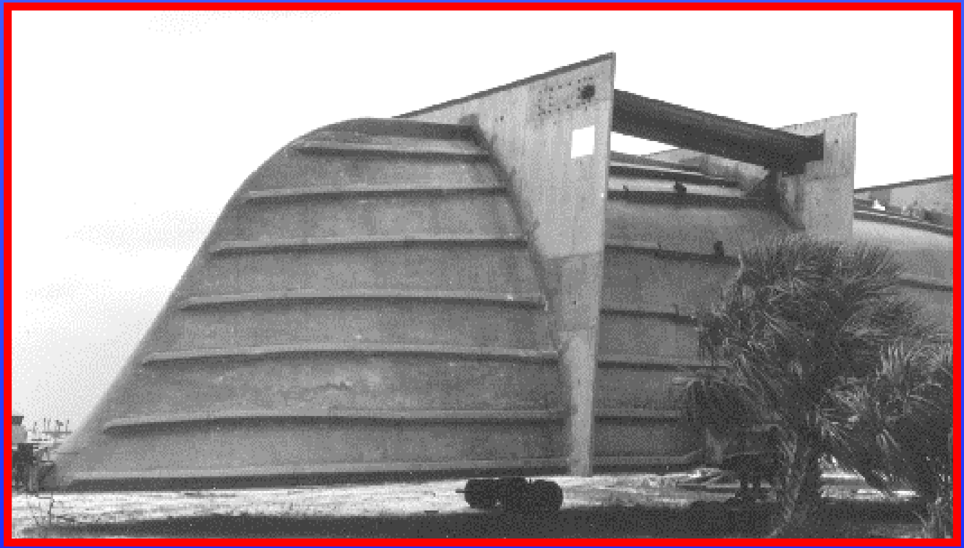
Vectorworks CNC Milling Machine

CAD to CNC opens new possibilities in boat design and engineering

Large Female Molds

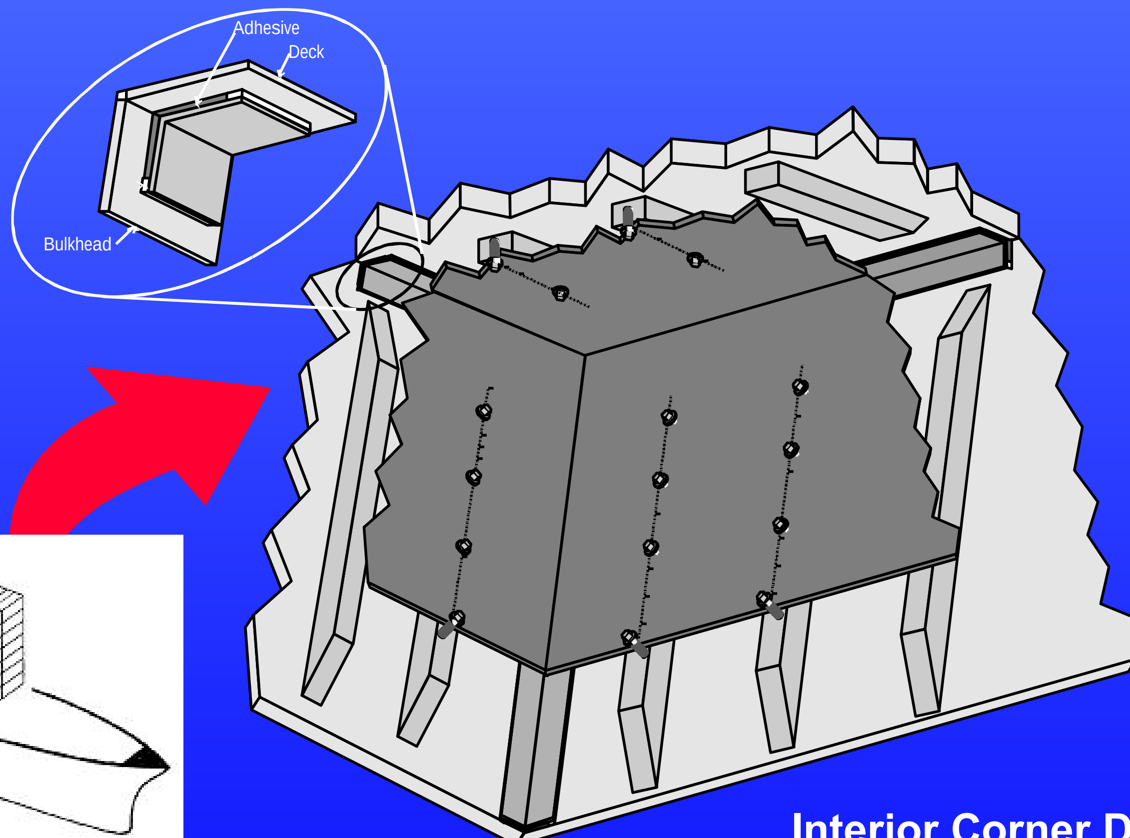


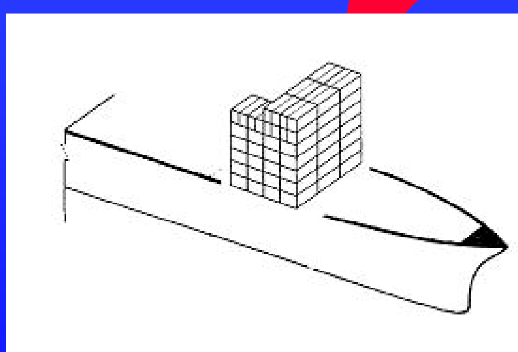
Two Part Female Mold



Large Female Mold with Stiffeners

Modular Topside Construction

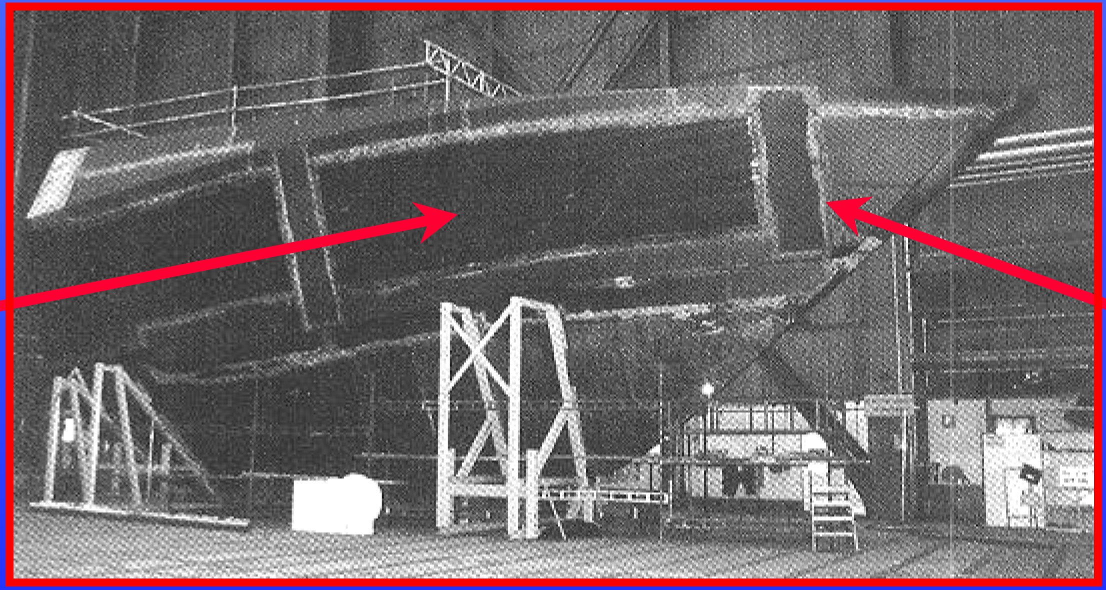




Interior Corner Detail

Process developed under MARITECH BAA 94-44

Hull Construction using Modular Panels



Modular Panel

Secondary Bond

Modular hull construction with panels results in greater control over panel quality

Overall hull girder strength is dependent upon the quality of secondary bonds

Visby Class Corvette , Captain Thomas Engevall, US Naval Institute *Proceedings*, March 1999

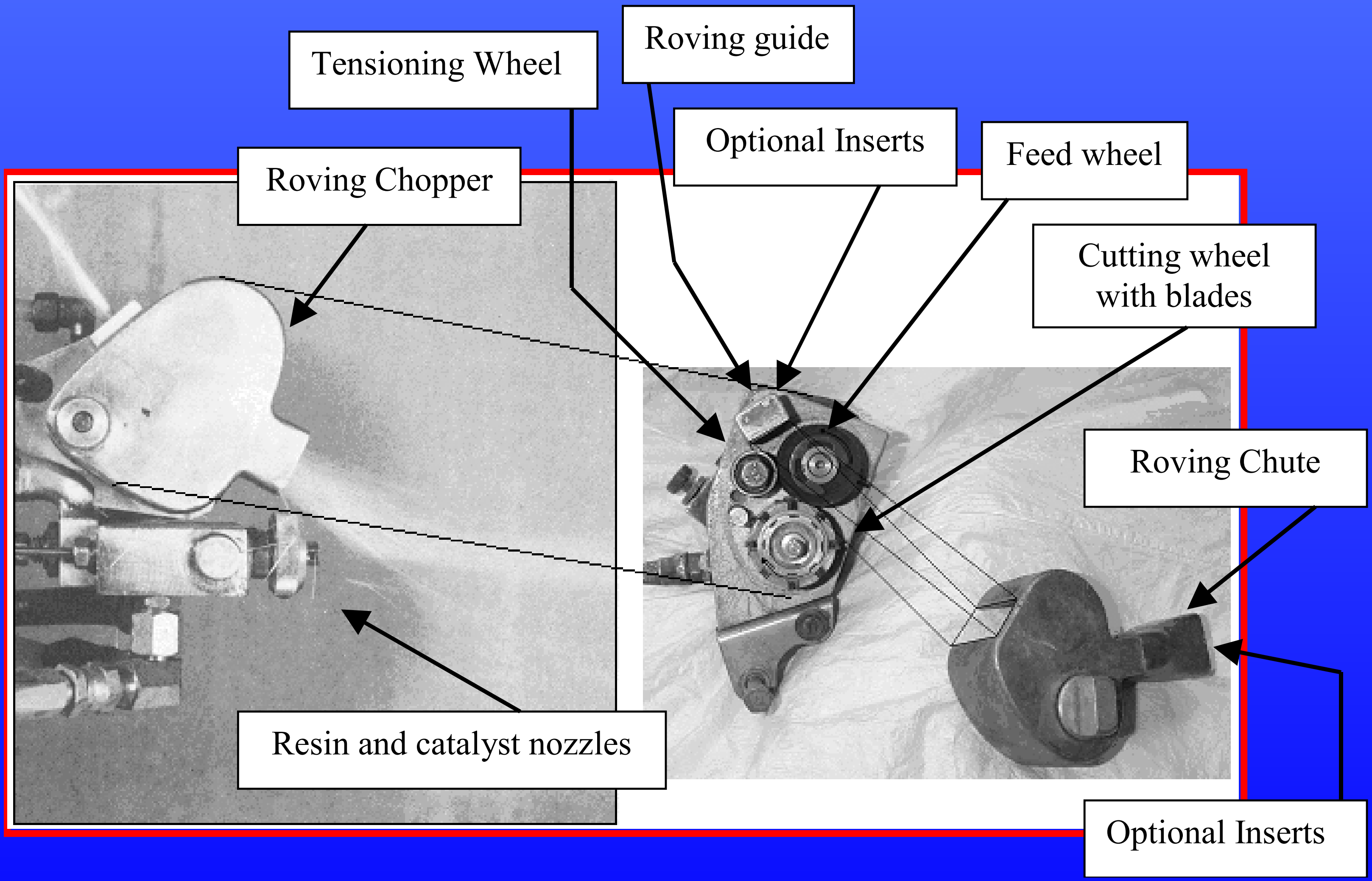
Manufacturing Concept Summary

- Monolithic hull construction from a large mold currently has practical limits around 65 meters
- Monolithic construction results in the strongest hull girder strength resulting from continuous reinforcement along the length of the vessel
- Modular construction with panels affords greater QA/QC potential at the component level but places a premium on assembly and joining technology
- Modular construction is attractive for topside structure that requires very flat surfaces and is not subject to “global” loads

Manufacturing Processes

- Chopper Gun Technology
- Hand Layup of Rolled Goods
- Sandwich Construction
- Vacuum Bagging Techniques
- Closed Molding
  - Infusion Methods
  - RTM
- Prepreg Construction
- Preform Technology

Chopper Gun Technology

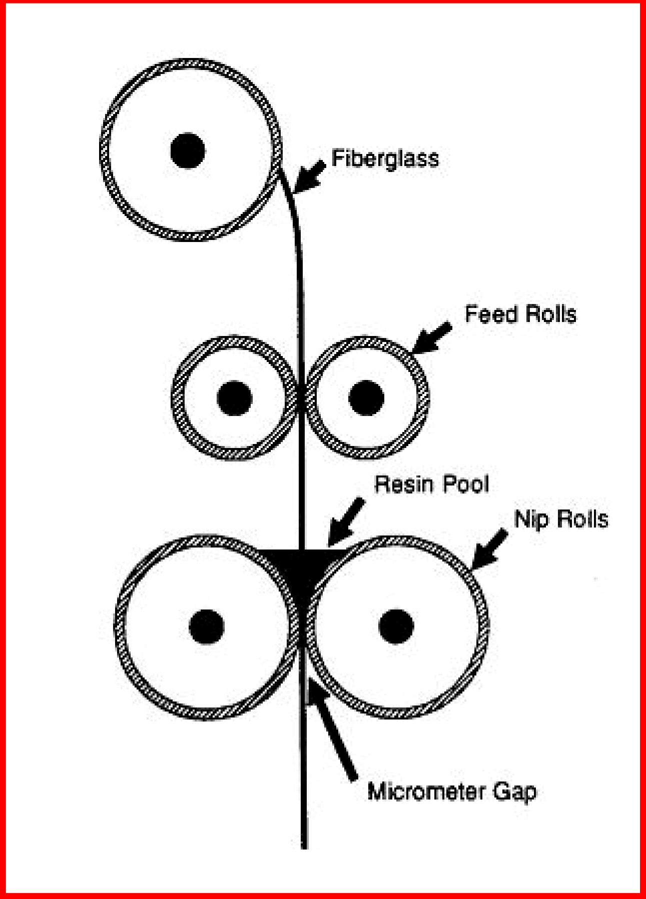


Hand Lay-Up

Workers Laminate Side of Large Hull

Workers Consolidate Reinforcements from Impregnator

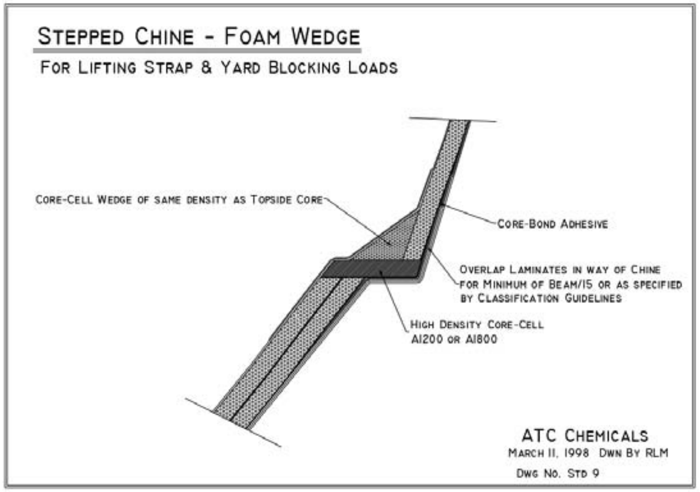
Impregnator-Assisted Open Molding

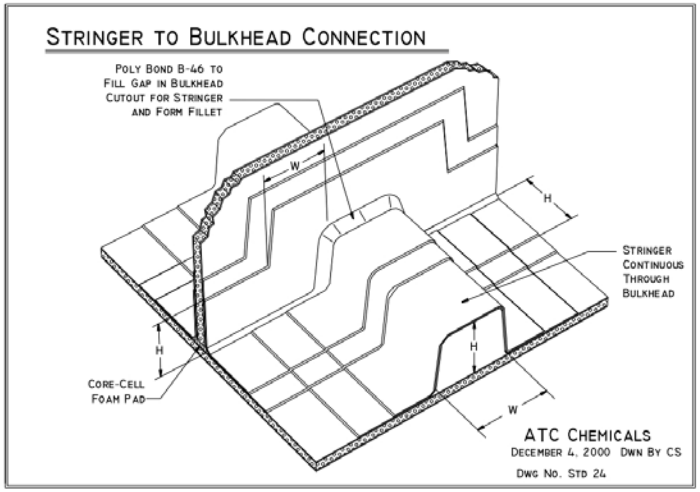


Schematic of Impregnator

Impregnator on Overhead Gantry for Open Molding of Large Hulls at Westport Shipyard

Sandwich Construction





Typical Sandwich Construction Details

Sandwich construction requires added attention to areas of stress concentration

Sandwich Construction Installation Goals

- Establish a consistent bondline (thickness of bedding compound or resin-rich chopped strand mat between core and skins),
- Eliminate voids in the bondline and the core,
- Ensure that bedding material co-cures with resin used to prime the core,
- Use plain sheets with bleeder holes instead of kerfed sheets where possible,
- Build a test panel to ensure that proper materials and process variables are being used, and
- Limit the exposure time of the core to wet resin and bedding compound.

Vacuum Bagging

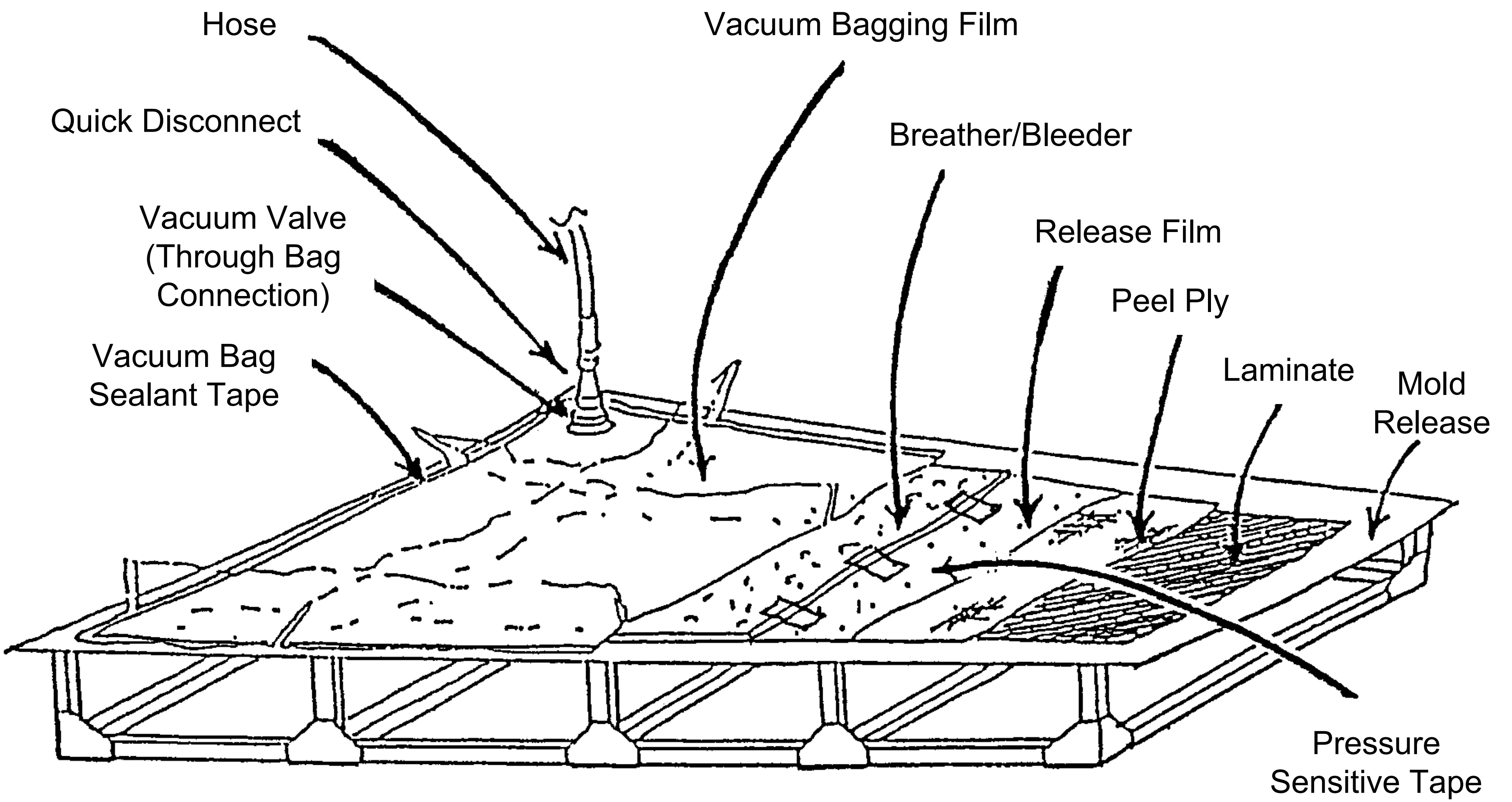


Illustration courtesy of AIRTECH

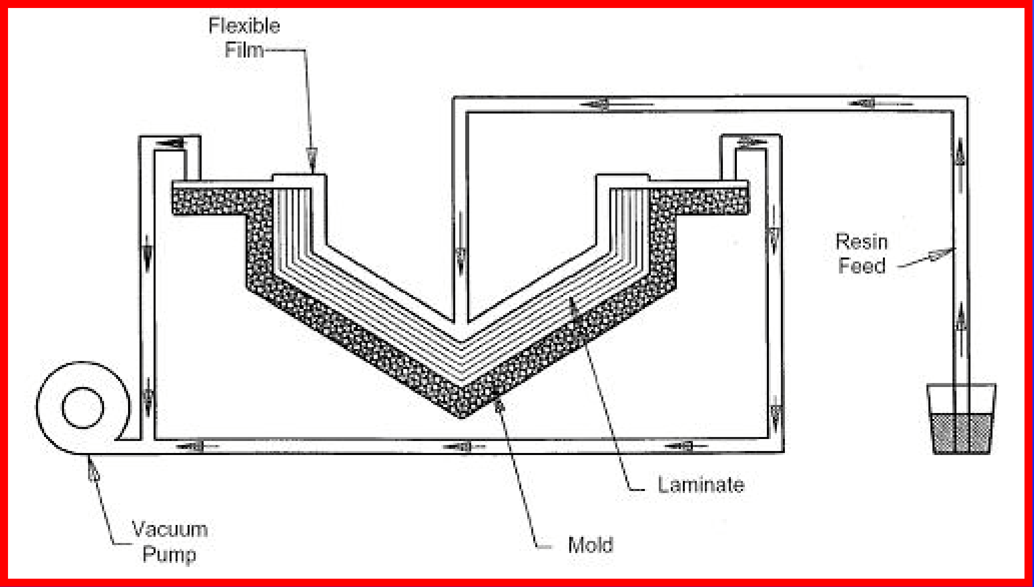
Infusion Methods

Manufacturing composite parts by "Infusion" methods implies that resin is transported by vacuum to dry reinforcement in a closed-mold process. Configuration of molds and methods for transporting resin distinguish each individual process. Some advantages that all infusion methods have over open mold hand lay-up are:

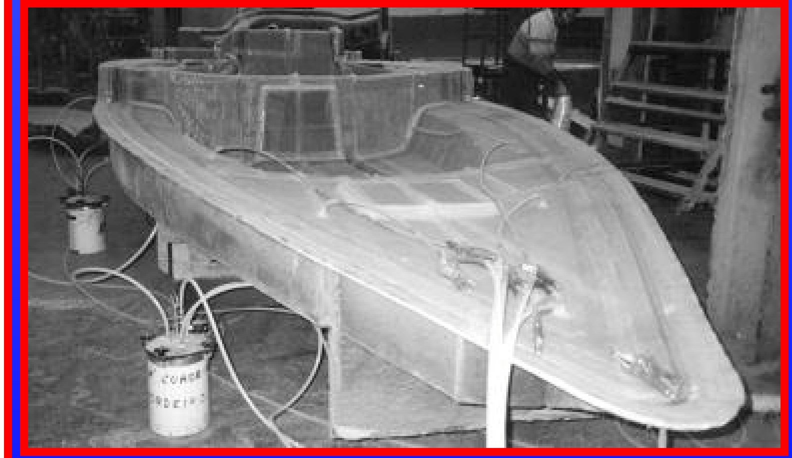
- Improved part consistency as wet-out is not dependent on the skill of the laminator,
- Better work environment because resin isn't being handled directly
- Reduced hazardous air pollutants (HAPs) in the form of styrene
- Ability to achieve higher fiber content laminates

Surface Infusion

SCRIMP™ is a patented surface infusion process that uses a vacuum bag that is placed over the dry lay-up and sealed to the tool. The part is then placed under vacuum and resin is introduced into the part via a resin inlet port and distributed through the laminate via a flow medium and series of channels, saturating the part.



Schematic of the Patented SCRIMP™ Surface Infusion Method



A Deck being Infused by the SCRIMP™ Method

Interlaminar Infusion

Interlaminar infusion introduces the resin at the center of the laminate stack, instead of the surface. As a result, the infusion media becomes part of the finished product.

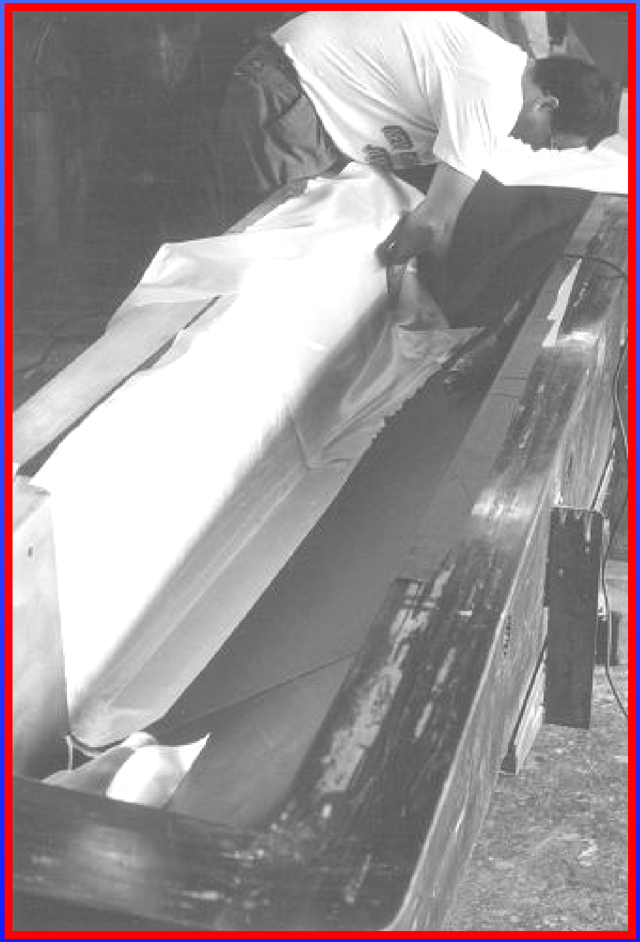
Boat Hull Being Fabricated Using the Interlaminar Infusion Method

Resin Transfer Molding (RTM)

Resin Transfer Molding (RTM) uses high pressure to introduce resin into two-sided molds. The RTM process can be highly automated for quick cycle times and to handle the bulky tooling associated with the process.

RTM molds are typically bulky in nature to handle the relatively high pressures associated with this process. Steel or aluminum materials are usually used to produce molds that are designed for multiple cycles without maintenance. The molds usually incorporate alignment pins or some sort of location method to assure the tools self locate in the proper position every time. The molds are typically clamped together using hydraulic presses or bars and clamps. Due to the high costs associated with the tooling, this process is typically reserved for high volume parts.

Prepreg Construction

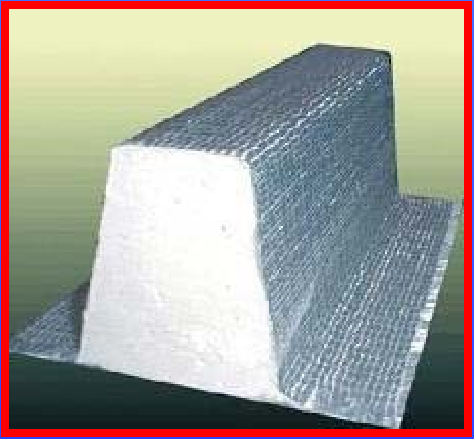


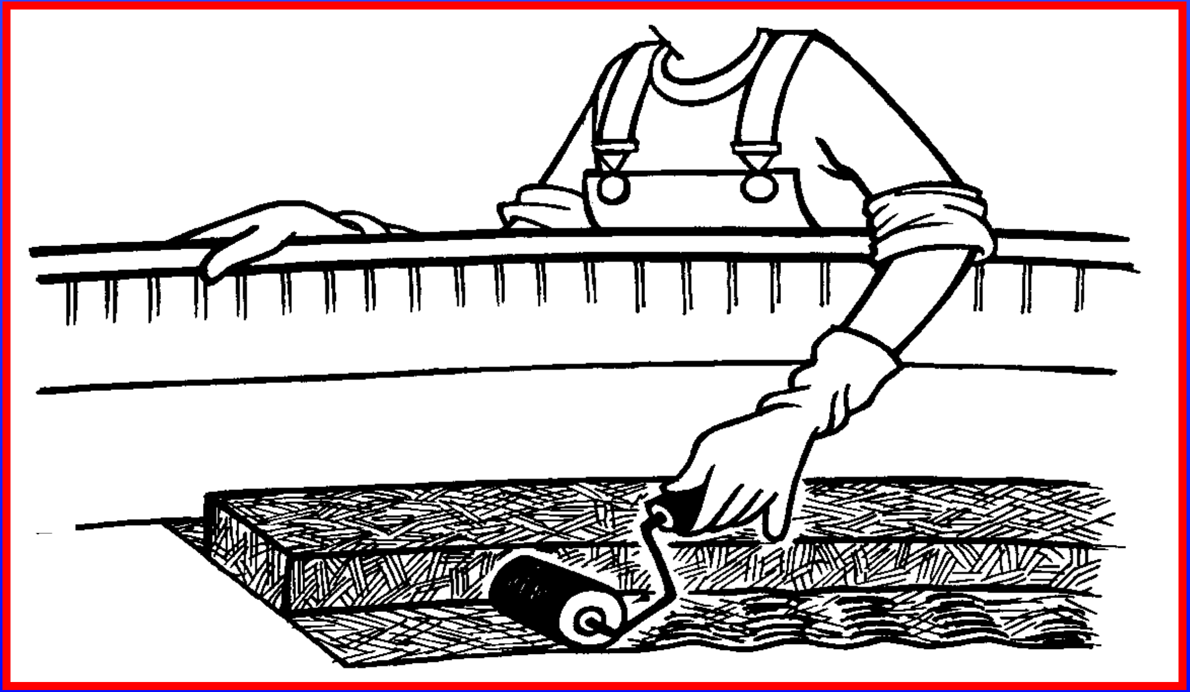
Prepreg Material Placed in Mold

Prepreg Material Consolidated Prior to Cure

Preform Technology

A preform is an assembly of dry reinforcement held together some way in a form that closely resembles the final geometry. In the case of preforms used for boat stiffeners, the fiber is held in place by an expanded foam core.

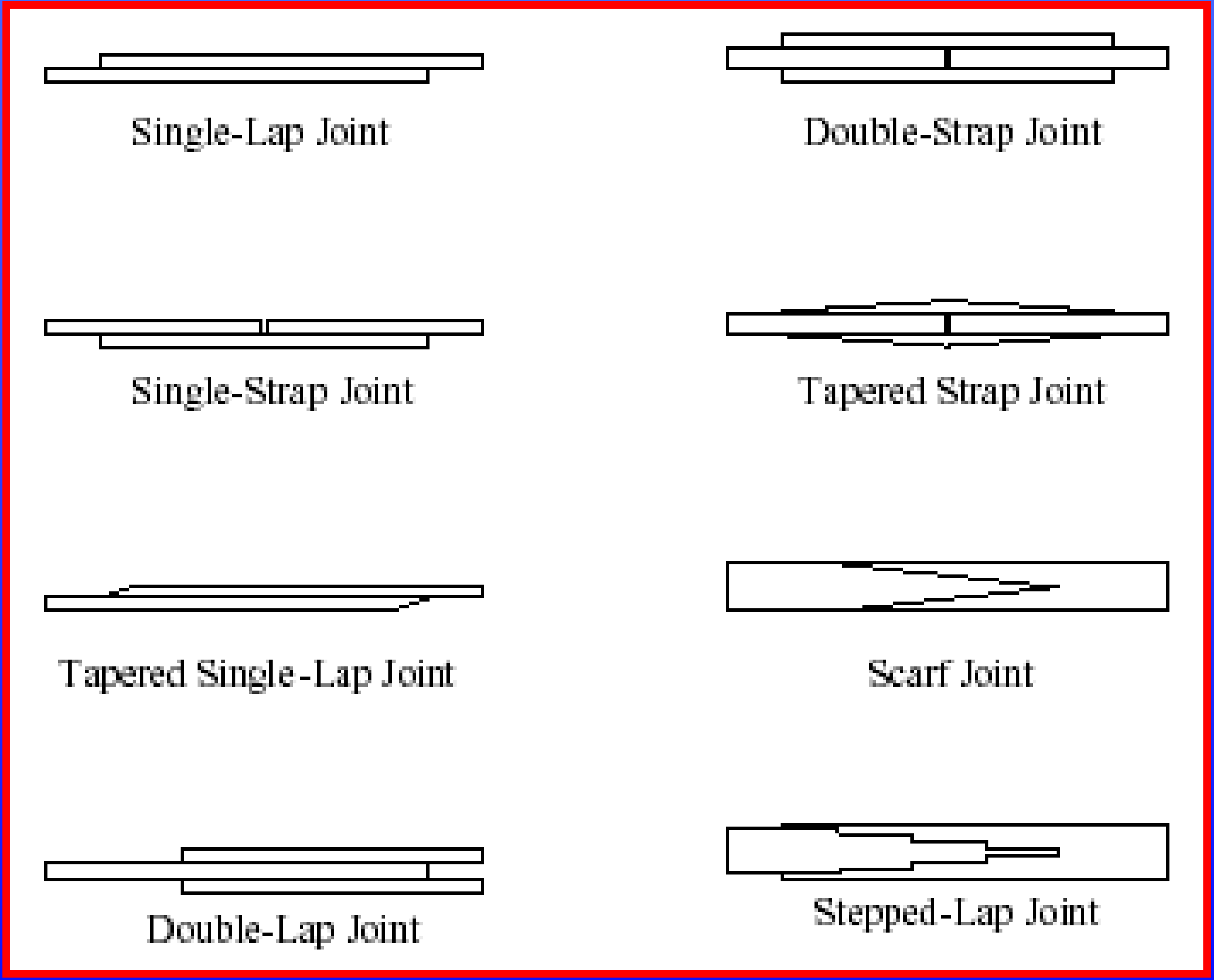




Manufacturing Methods Summary

- Long-term experience with composite hull structures in the 20 - 50 meter size range is based on hand lay-up construction methods
- Infusion methods have demonstrated the ability to produce low cost, high quality composite naval structures
- Aerospace manufacturing methods, such as prepreg technology, are not suitable for large marine structures because of material processing requirements
- <u>All</u> composite processing methods are highly dependent upon skill of the worker

Joining of Composite Panels



Adhesively Bonded Joints

Structural adhesives, such as methacrylate and epoxy are gaining wider acceptance in the boat building industry for the following reasons:

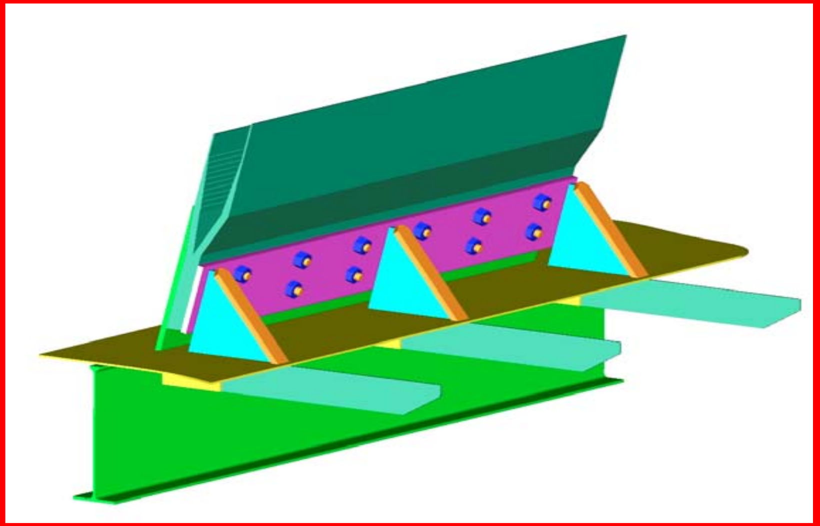
- Little or no surface preparation required beyond clean surface
- Bonds are more durable than structural putties.
- Product dispensing equipment makes handling easier
- Labor savings can offset higher material cost (as compared to structural putties mixed in the shop)

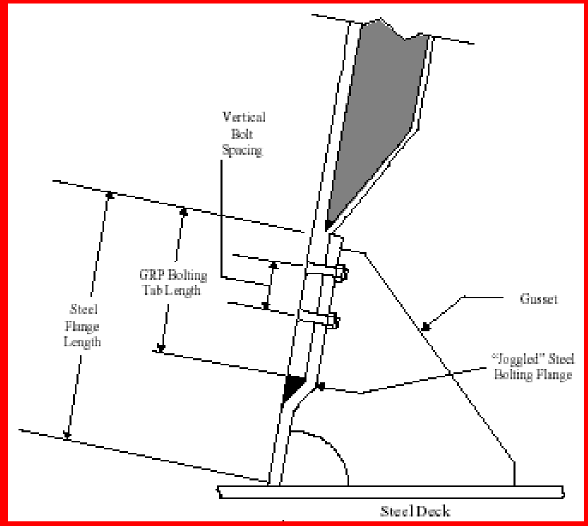
Hull-to-Deck Joints

There are about as many specific ways to create an effective hull-to-deck joint as there are builders. Whether adhesive or fiberglass is used to create the watertight joint, some basic principles should be kept in mind:

- The effectiveness of the joint will be proportional to the width of the mating surface area so care should be exercised when trimming hull and deck flanges
- Adhere to prescribed flange and tabbing laminate schedule
- Building good joints in tight corners is difficult - use structural putties
- Flat mating surfaces will create a consistent bondline
- Some adhesives do not require sanding of mating surfaces. However, mating surface should always be clean regardless of bonding method

Joining Composites to Metals



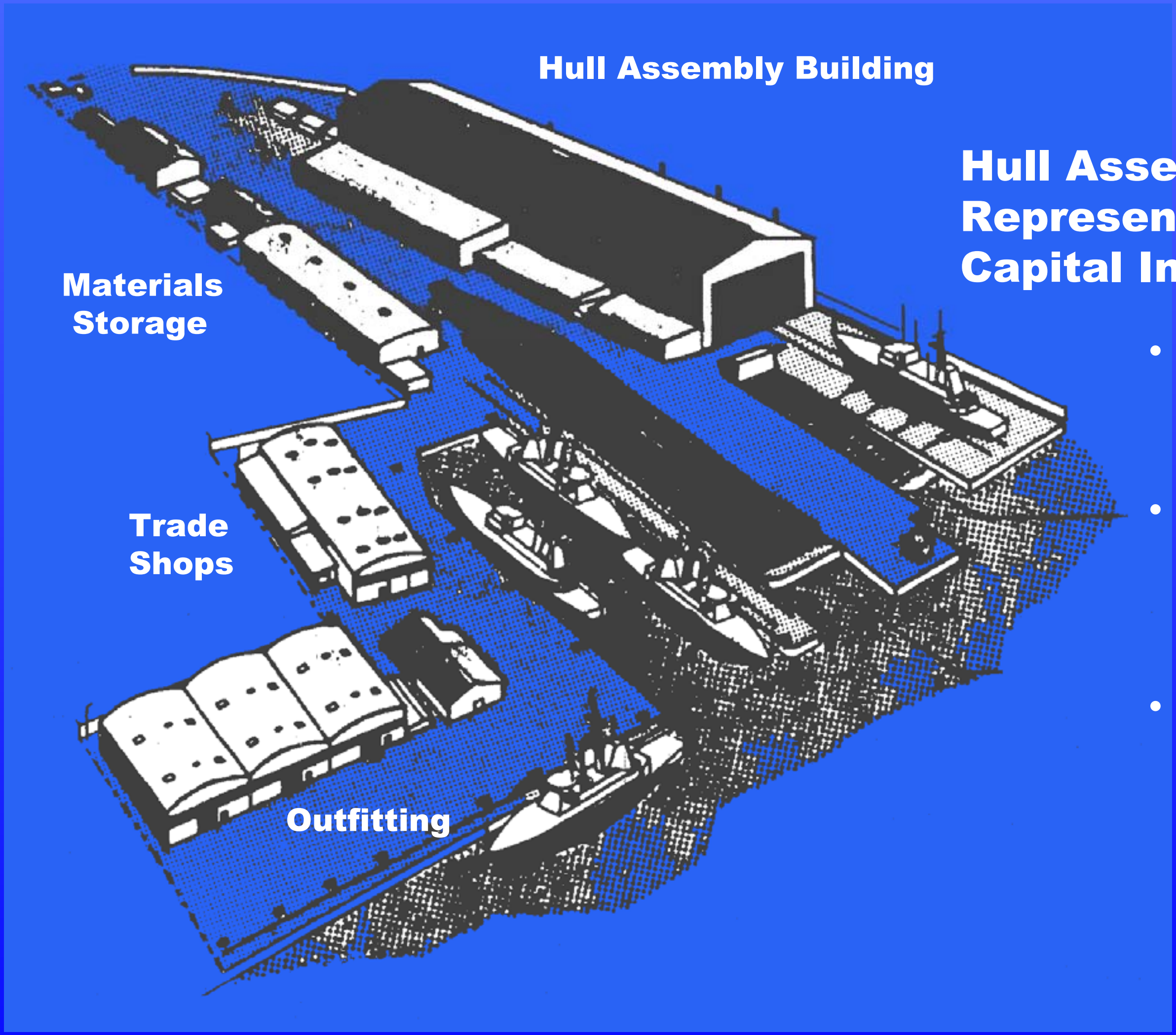


Parameter	Typical value
Bolt spacing (vertical)	3 inches
Bolt spacing (horizontal)	3 to 4 inches
Steel flange length	9 inches
Steel flange thickness	0.5 inches
GRP bolting tab length	6 inches
Nominal weight (9" x ½steel flange, ½bolts spaced every 3 inches, ½gussets spaced at 24")	22.40 lbs. per linear foot

Joining Technology Summary

- In-plane strength of secondary bonds can never match the primary laminate
- Automation techniques not as mature as metal construction
- Surface preparation, laminating environmental conditions and worker skill significantly influence the strength of composite material structural joints

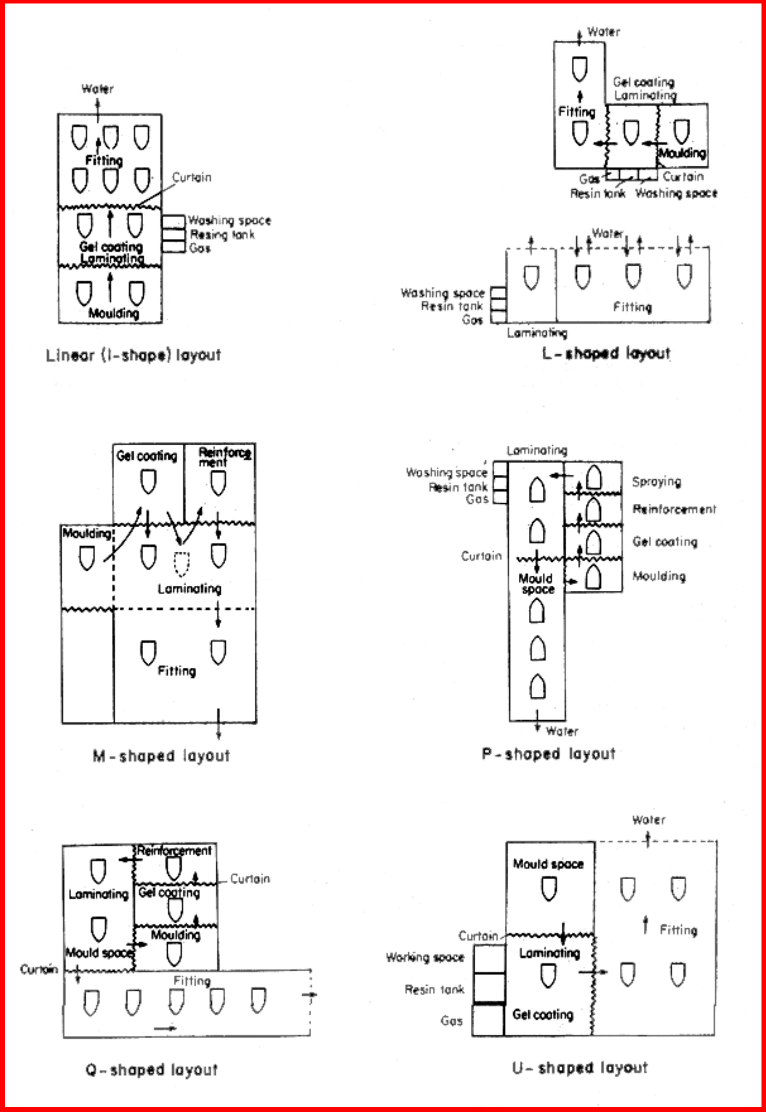
Typical Composite Ship Construction Facility



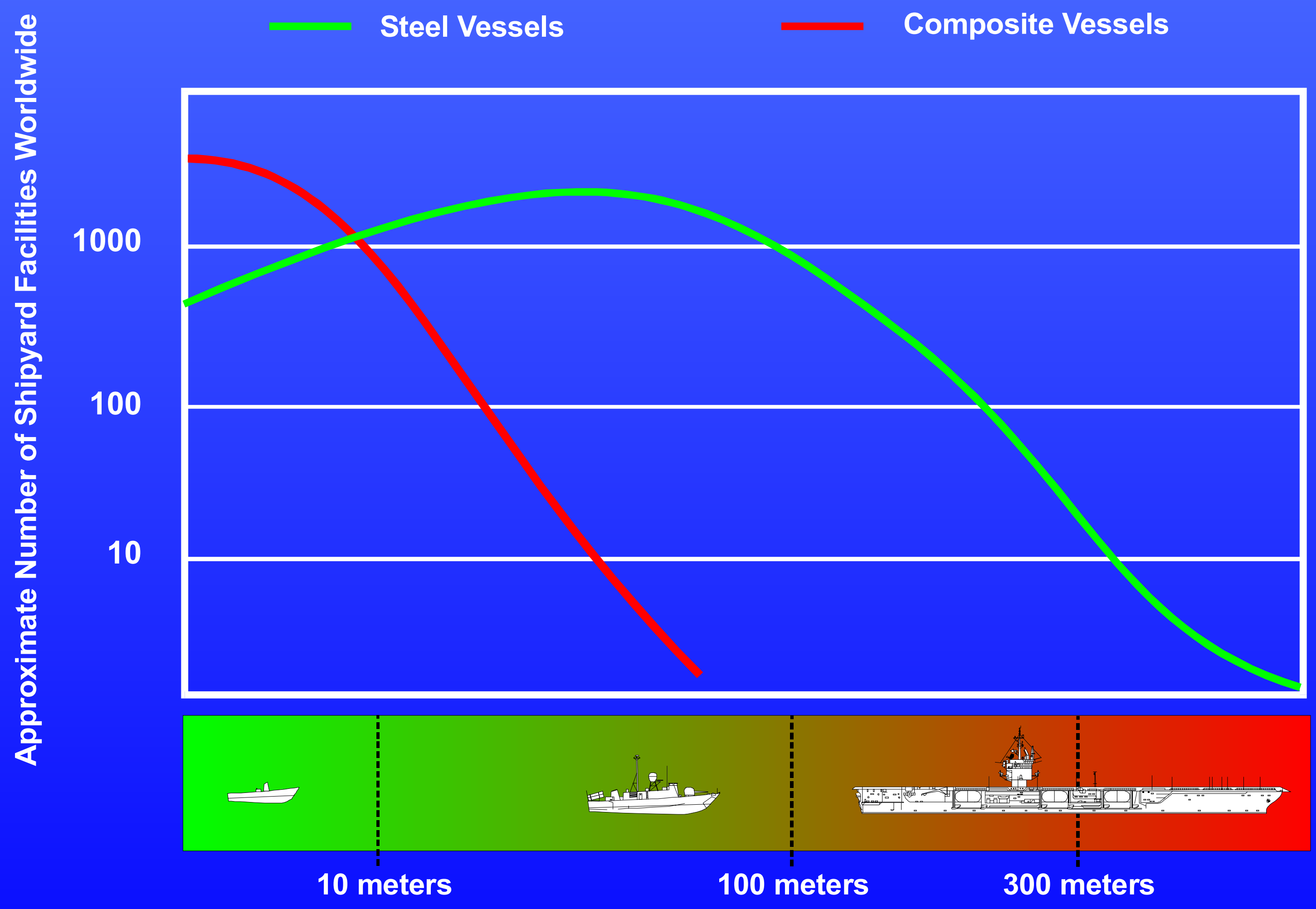
Hull Assembly Building Represents Major Shipyard Capital Investment:

- Facility must support multiple hulls - 10,000 m^2 minimum
- Atmospheric emissions control to meet local standards required
- Environmentally controlled facility required, including HVAC, central vacuum and fire suppression

Typical Composite Boat Construction Facility



Notional Worldwide Naval Composite Construction Capability



Facilities Summary

- Laminating must be done in an environmentally controlled facility, including HVAC, central vacuum and fire suppression
- Infrastructure shipyard improvements may also include:

  Raw material storage area
  HAZMAT containment area
  Acetone reclamation area
  QA/Test Facility

- Composite construction facilities must be segregated from steel shipbuilding operations due to contamination and fire hazards

Break: (3:45 - 4:00)

Military Applications of Composites (4:00 - 4:30)

- Primary Hull Structure
  - SOCOM Maritime Platforms
  - Boats & Minehunters
- Superstructure
- Foils and Appendages
  - Surface Ships
  - Submarines
- Shipboard Components

SOCOM Platforms

11- Meter RIB

Length:	36 feet
Speed:	45 knots+
Displacement:	18,500 pounds (full load)
Number in Inventory:	72
Builder:	United States Marine, New Orleans, LA
Years Manufactured:	1998 - present
Resin System:	Vinyl Ester
Fiber System:	E-glass & Kevlar
Core:	Linear & Cross-Linked PVC
Manufacturing Process:	Hand Layup, vacuum assist

Light Patrol Boat (PBL)

Length:	25 feet
Speed:	30 knots+
Displacement:	6,500 pounds
Builder:	Boston Whaler
Resin System:	polyester
Fiber System:	E-glass
Core (if used):	urethane
Manufacturing Process:	Hand layup, injected core

SOCOM Platforms

River Patrol Boat (PBR)

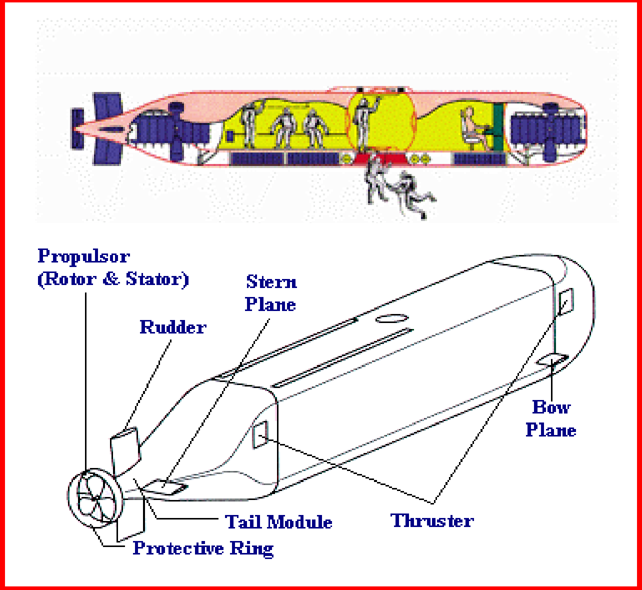
Length:	32 feet
Speed:	30 knots +
Displacement:	17,500 pounds
Number in Inventory:	24
Builder:	United Boatbuilders, Bellingham, WA
Years Manufactured:	500 built starting in 1966
Resin System:	polyester
Fiber System:	E-glass
Core (if used):	none
Manufacturing Process:	Hand layup

Swimmer Delivery Vehicle

Length:	22 feet
Speed:	6 knots
Builder:	Composites by Columbia Research Corporation, Panama City, FL
Resin System:	Vinyl ester
Fiber System:	E-glass
Core (if used):	PVC
Manufacturing Process:	Hand layup with vacuum assist for cores

SOCOM Platforms

Advanced Swimmer Delivery System



Northrop Grumman's 65-foot Advanced SEAL Delivery System

Length: 65 feet
Speed: 8 knots+
Displacement: 110,000 pounds
Number in Inventory: 1
Builder: Composites by Goodrich, Jacksonville, FL
Years Manufactured: 2001
Resin System: Vinyl ester, rubber toughened for nose
Fiber System: E-glass with some carbon (carbon being phased out)
Manufacturing Process: VARTM and prepreg for nose

Primary Structure

Boats

At sea Aboard ***USS Blue Ridge*** (LCC 19) Sailors Practice Deployment of Ship's Small Boats

Members of Inshore Boat Unit Seventeen (IBU 17) Patrol the Waters of Apra Harbor, Guam

OSPREY Class Minehunter

Length:	57.2 meters (187 feet, 10 inches)
Beam:	11.0 meters (35 feet, 11 inches)
Draft:	2.9 meters (9 feet, 4 inches)
Displacement:	895 metric tons
Propulsion:	two 800 hp amagnetic diesel engines with variable fluid drives turning two cycloidal propellers
Accommodations:	5 officers; 4 CPO; 42 enlisted

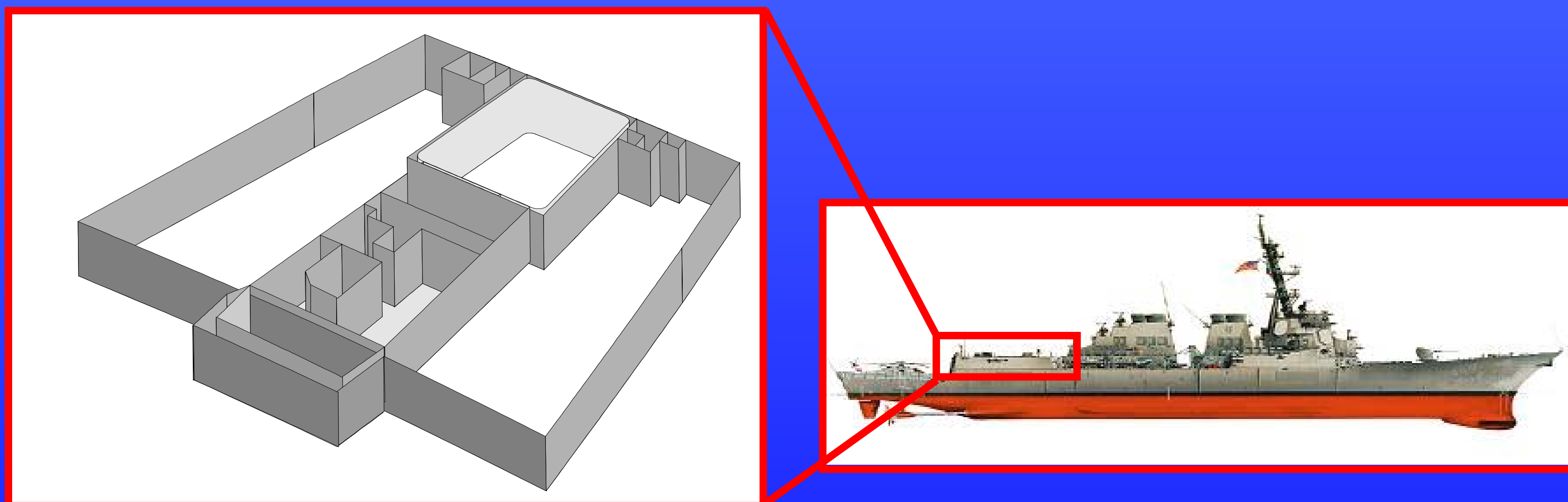
Construction Particulars

All glass reinforcement for primary structure is E glass. Spun woven roving of 1400 grams per square meter is used for the hull, transverse bulkheads, and decks. The spun woven roving is a fabric with the weft direction reinforcement consisting of rovings that have been "tufted." This treatment, which gives the fabric a fuzzy appearance, improves the interlaminar shear strength over traditional woven rovings. The superstructure is constructed of a "Rovimat" material consisting of a chopped strand mat stitched to a woven roving. Stitching of the two fabrics was chosen to improve performance with the semi-automated resin impregnator (which is used during the lamination process). The total weight of the Rovimat is 1200 grams per square meter (400 g/m^2 mat + 800 g/m^2 woven roving).

The resin is a high grade toughened isophthalic marine polyester resin. It is specially formulated for toughness under shock loads and to meet the necessary fabrication requirements. The resin does not have brittle fracture characteristics of normal polyester resins, which gives it excellent performance under underwater explosive loads. Combined with spun woven roving, the laminate provides superior shock and impact resistance. The resin formulation has been optimized for improved producibility. Significant is the long gel time (up to four hours) with low exotherm and a long extended delay time to produce a primary bond. [1-32]

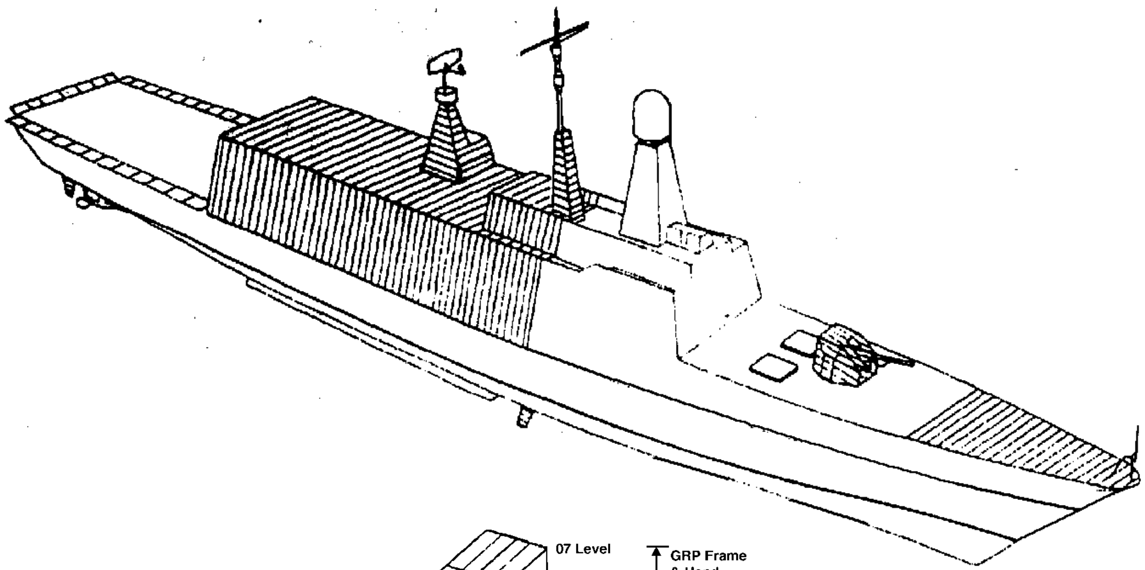
Superstructure

Helicopter Hanger for DDG 51 Flt IIA

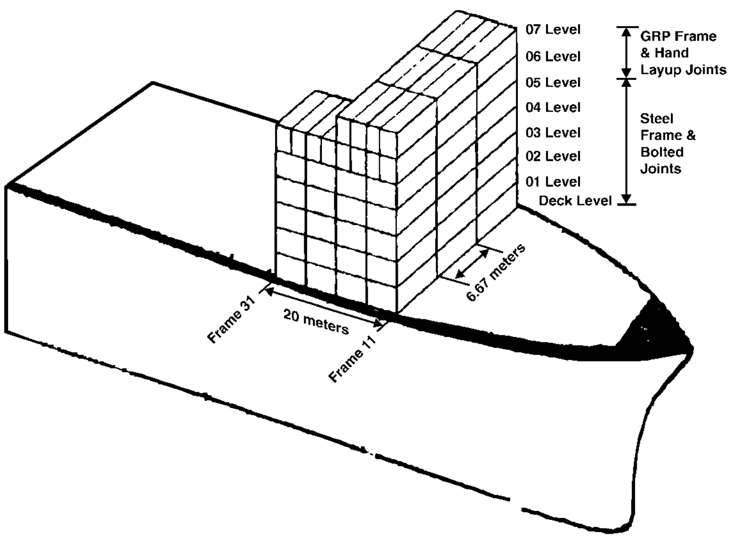


Composite Helicopter Hanger for DDG 51 Flight IIA Destroyer Built
at Northrop Grumman Ship Systems' Gulfport Facility
Scheduled to be Installed on DDG 100

Superstructure



French *LA FAYETTE* Class Frigate Showing Area Built with Balsa-Cored Composites [DCN Lorient, France]



Arrangement of GRP Deckhouse Proposed for the SSTDP Sealift Ship [Scott Bartlett, NSWC]

Superstructure

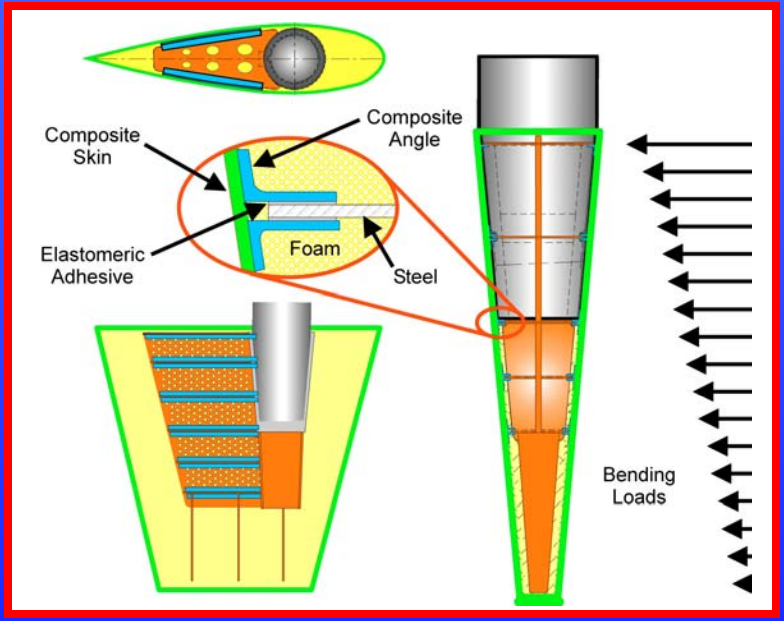
DDG 51 Forward Director Room

Forward Director Room Built by Northrop Grumman's El Segundo Facility as Technology Demonstrator for DDG 51 under ManTech Funding

Foils & Appendages

Surface Ships

Composite MCM Rudder Built by Structural Composites Shown During Shock Trials



Composite Rudder under Development for Naval Surface Combatants

Foils & Appendages

Submarines

Advanced Composite Sail Envisioned for Virginia Class Submarines (top left) and 1/4-Scale Prototype Built by Seemann Composites (bottom left)

Composite Submarine Bow Dome Produced by Goodrich Composites

Proposed Shipboard Applications for Composites

Structural
Topside Superstructure
Masts
Stacks
Foundations
Doors
Hatches
Liferails
Stanchions
Fairings
Bulkheads
Propellers
Control Surfaces
Tanks
Ladders
Gratings

Machinery
Piping
Pumps
Valves
Heat Exchangers
Strainers
Ventilation Ducts
Fans, Blowers
Weather Intakes
Propulsion Shafts
Tanks
Gear Cases
Diesel Engines
Electrical Enclosures
Motor Housings
Condenser Shells

Functional
Shafting Overwraps
Life Rails/Lines
Handrails
Bunks/Lockers
Tables/Worktops
Insulation
Partitions
Seachest Strainers
Deck Grating
Stair Treads
Grid Guards
Showers/Urinals
Wash Basins
Water Closets
Mast Stays/Lines

Bulkheads, Nonstructural

Priority	Medium
Opportunity	Opportunity to reduce cost and weight while improving fire resistance
Technical Issues	Fire, cost, supportability
Previous Work	Currently use Nomex/phenolic sandwich
Return on Investment	Medium

Webcore Hybrid Fabric-Web/Strut-Web Core with Pre-Attached Fabric Proposed for Navy SBIR Door Project

CHT Systems

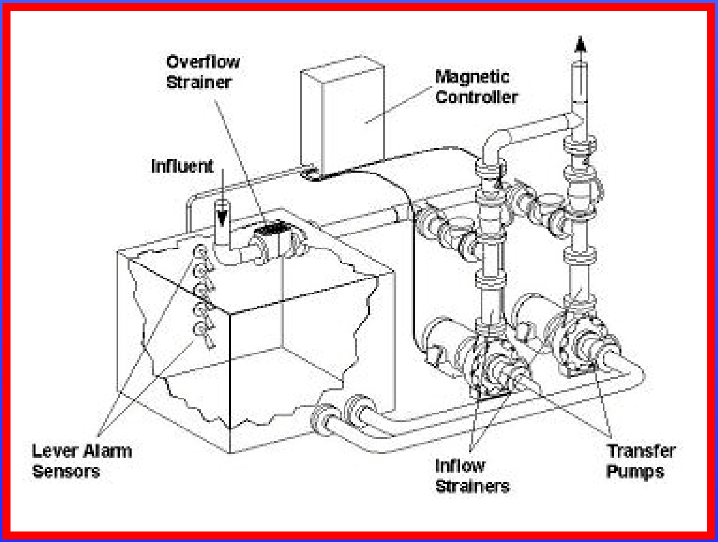
Priority High

Opportunity Eliminate severe corrosion and make maintenance easier

Technical Issues Fire; integrate with existing system elements

Previous Work Navy has fielded prototype composite systems. The U.S. Navy is now specifying GRP (fiberglass) piping and ladders for use inside the CHT tank, as this material holds up extremely well in the sewage environment.

Return on Investment Medium



U.S. Navy Type III Marine Sanitation Device [US Navy Shipboard Environmental Information Clearinghouse]

Deck Grating

Priority High

Opportunity Eliminate corrosion and related maintenance and safety issues

Technical Issues Fire and strength

Previous Work ERM-7 has fielded composite grating on 4 ships; numerous unauthorized replacements in the fleet.

NAVSEA Drwg 803-6983499, GRP Deck Grating specifies MODAR resin – parts expected to be in supply system late FY 03

Return on Investment High

Composite Deck Grating on FFG-58 ***USS Samuel B. Roberts***

Electrical Enclosures

Priority High

Opportunity Reduce corrosion and related maintenance

Technical Issues Fire and impact resistance

Previous Work ERM-7 is in the process of certifying ULTEM 2300 electrical enclosures

Return on Investment High

Typical Corrosion-Related Failure (above) and ULTEM 2300 Box Molded by Glenair (below)

Fairings

Priority High

Opportunity Metal rope guards difficult to replace underwater

Technical Issues Fastener interface

Previous Work Composite propulsion shaft rope guards installed on Aircraft Carriers showing:

- Less than ½ the cost and weight of original Cu-Ni
- Bolt-on vs. weld-on
- Easy waterborne removal/install gives full access to stave bearings & zincs

Return on Investment High

Installed Composite Fairwaters (NAVSEA 05M3)

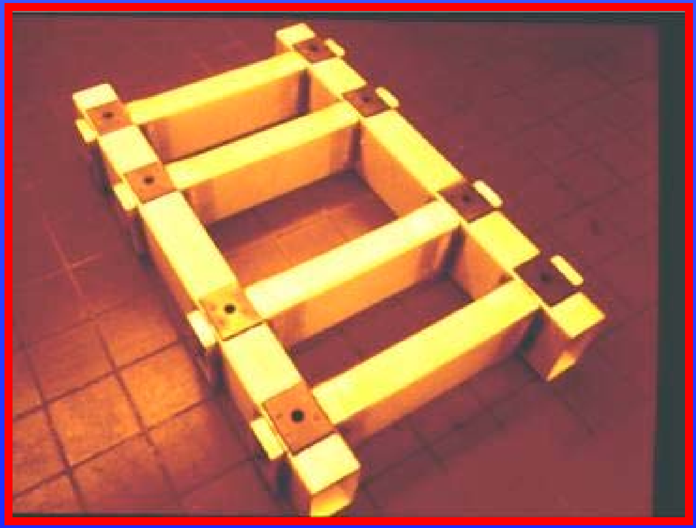
Fans & Blowers

Priority	High
Opportunity	Reduced corrosion, easier to maintain & quieter
Technical Issues	Fire, operability and strength
Previous Work	NAVSEA PMS 400D32 is pursuing composite fans via SBIR & ManTech programs
Return on Investment	High

Typical Axial Fan

Foundations

Priority	High
Opportunity	Severe corrosion on saltwater pump foundations is major maintenance issue and contributes to machinery vibration; potential to make machinery "quieter"
Technical Issues	Fire and shock
Previous Work	Brunswick Defense built a filament-wound foundation that was tested at NSWCCD
Return on Investment	Medium



Filament Wound Machinery Foundation by Brunswick Defense

Helicopter Hanger Doors

Priority High

Opportunity Reduced corrosion maintenance and machinery maintenance from less weight

Technical Issues Strength and fire resistance

Previous Work Seemann Composites and BIW have developed a composite helicopter door for DDG 51 Flt IIA. A composite helicopter hanger is scheduled to be installed on DDG-100.

Return on Investment Medium

Composite Helicopter Hanger First Article Door (above) and Operational Test Jig (below) [Seemann Composites]

Louvers

Priority High

Opportunity Reduce maintenance and improve stealth

Technical Issues Cost, certification and durability

Previous Work Composite louvers developed for the DDG 51 class destroyers

Return on Investment High

Radar Absorbing Composite Louver Developed for the DDG 51 Class Destroyers

Masts

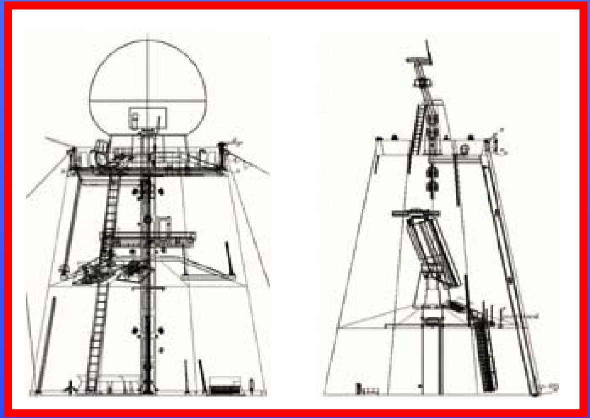
Priority Medium

Opportunity Improve equipment supportability

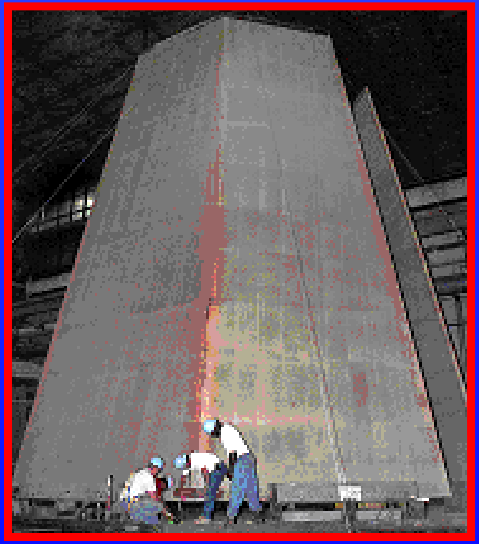
Technical Issues Cost

Previous Work AEM/S on ***USS Radford*** and LPD-17

Return on Investment Low



Advanced Enclosed Mast System for LPD 17 Class Ships



Piping

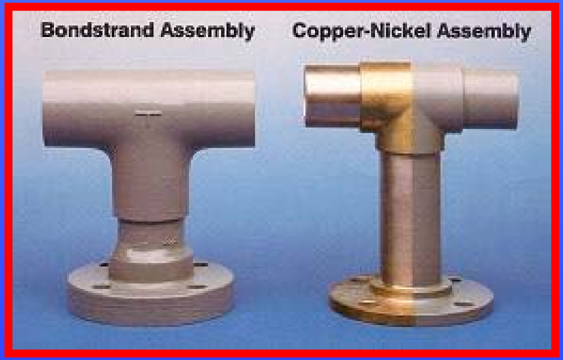
Priority High

Opportunity Eliminate corrosion related maintenance: reduce weight & vibration

Technical Issues Cost and fire

Previous Work Numerous offshore installations and Navy prototypes waiting congressional plus-up

Return on Investment High



Ameron's Bondstrand® 2000USN MIL-P-24608 Pipe Assembly Weighs 3.6 pounds Compared to 6.8 pounds for CuNi

FIBERBOND® Pipe Shown to Withstand 2000ºF Fires [EDO Specialty Plastics]

Plenums

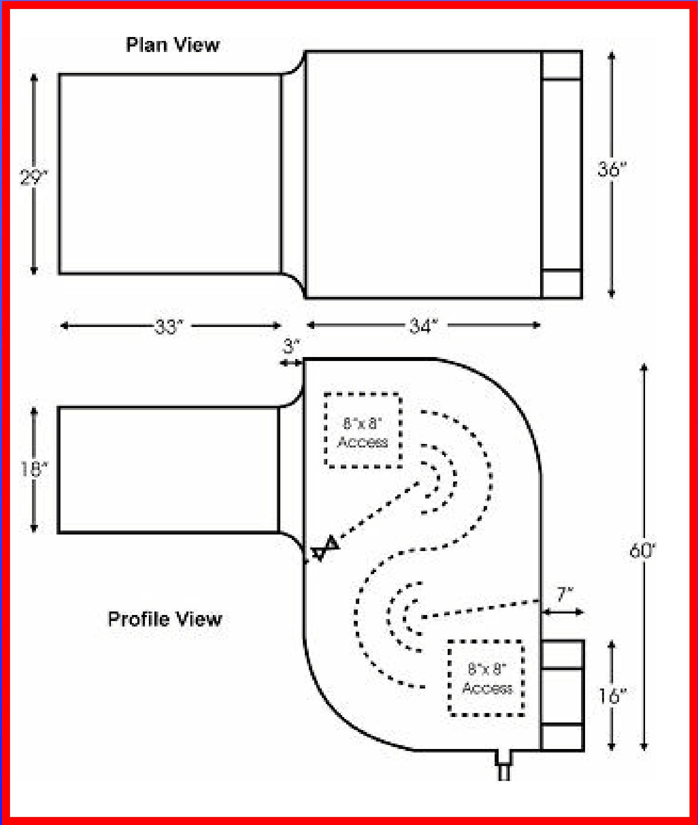
Priority High

Opportunity Eliminate severe corrosion and associated maintenance

Technical Issues Cost and fire

Previous Work Plastic turning vanes have been fielded on a limited basis

Return on Investment High



Proposed FFG Composite Plenum for 1180 CFM Nat Supply Aux Mchry Rm # 3, Helo Hgr #2, 1-278-2-Q

Propellers

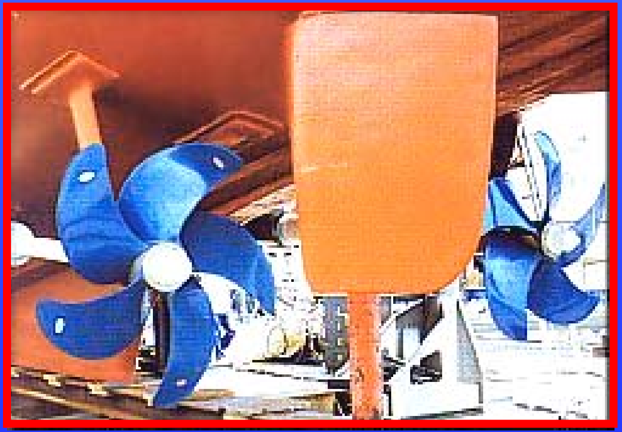
Priority Low

Opportunity Potential to make propellers quieter

Technical Issues Strength and cost

Previous Work Existing systems for large yachts and R&D work on underwater propulsors

Return on Investment Low



The Contur® Propeller with Exchangeable Composite Blades Offered by AIR Fertigung-Technologie GmbH, Germany

Propulsion Shafting

Priority Medium

Opportunity Reduce vibration, weight and corrosion maintenance

Technical Issues Interface to metal couplings and cost

Previous Work Commercially available for high speed craft, NSWC Annapolis prototype work on AOE & subs

Return on Investment Medium

33 inch Diameter Filament Wound Section of Propulsion Shafting Developed by DTRC, Annapolis for Testing to Meet AOE-Class Performance Requirements [George Wilhelmi]

Pump Internals

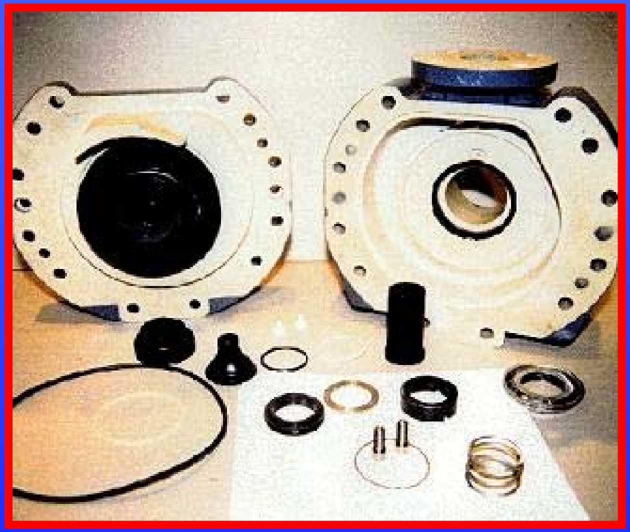
Priority High

Opportunity Increase mean time between failure and reduce time to repair

Technical Issues Standardization of U.S. Navy pump population

Previous Work ERM-7 has fielded composite pump internals on 19 ships

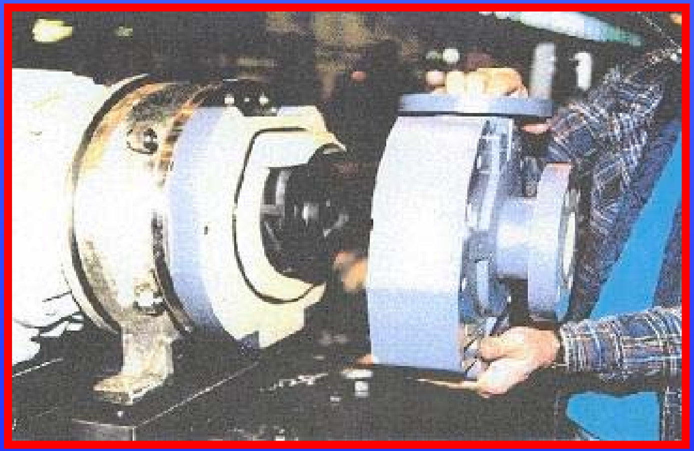
Return on Investment High



Navy Shock-Qualified Composite Pump Internals Built by Flowserve

Pumps

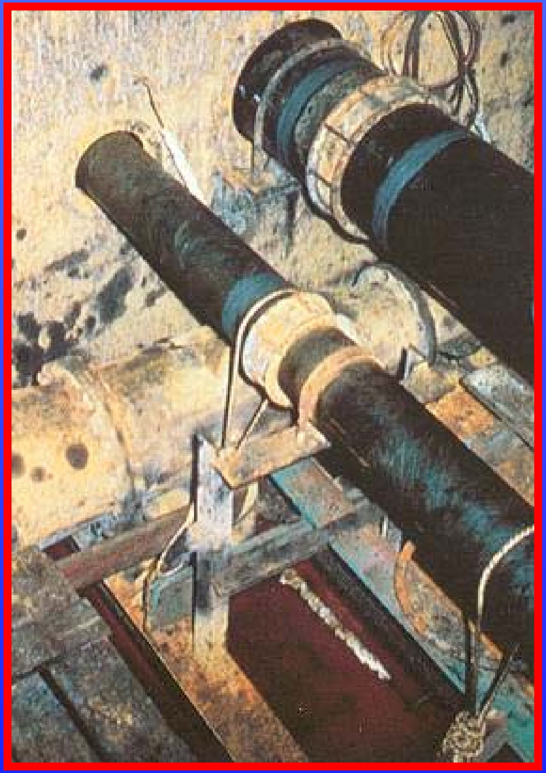
Priority	High
Opportunity	Reduce corrosion, much quicker to repair and quieter
Technical Issues	Cost and standardization of U.S. Navy pump population
Previous Work	ERM-7 has funded production of 1 size pump, ManTech effort pending
Return on Investment	High



Navy Shock-Qualified Composite Pump Built by Flowserve and Installed as Part of the Navy's SMARTSHIP Program

Saltwater Piping

Priority	High
Opportunity	Potential to reduce corrosion, fouling and vibration problems
Technical Issues	Fire & certification
Previous Work	Many offshore installations and proposed U.S. Navy use pending congressional plus-up
Return on Investment	High



Composite Pipe Installed in Severe Saltwater Ship Environment (Ameron®)

Seachest Strainers

Priority High

Opportunity Reduce corrosion and integrate antifouling agent

Technical Issues Integrate effective, environmentally-friendly antifouling

Previous Work PMS 400F funding pilot program

Return on Investment High

Fouled Seachest Strainer (top) Cutout (middle) and Prototype Composite Strainer (bottom)

Topside Superstructure

Priority Medium

Opportunity Potential for in-situ repair of chronic aluminum deckhouse corrosion areas

Technical Issues Fire and bond to aluminum

Previous Work Numerous prototype systems developed including MARITECH, Helo Hanger and ManTech projects

Return on Investment Low

MARITECH Composite Superstructure Project Built by Structural Composites and Ingalls using Adhesive Technology

Valves

Priority High

Opportunity Potential to extend service life, and significantly reduce maintenance and adverse mission impacts of corrosion-prone metal components by using composite materials. Potential to eliminate hydroblast cleaning of CHT system valves

Technical Issues Shock qualification and fire

Previous Work Composite valves have passed shock test (NAVSEA drwg 803-6983491) and installed on 6 ships. The Capital Investment for Labor program plans on a major carrier CHT system installation.

Return on Investment High

Composite Ball-Valve Family Developed by NSWCCD

Vent Screens

Priority High

Opportunity Eliminate corrosion related maintenance and improve operability

Technical Issues Fire

Previous Work ERM-7 has fielded composite vent screens on 13 ships. NAVSEA drwg 803-6983500, Vent Screen, GRP Installation and Details will lead to MODAR screens in the supply system by the end of FY 03.

Return on Investment High

Example of Vent Screen Fielded by ERM-7

Ventilation Ducting

Priority High

Opportunity Eliminate corrosion related maintenance; improve ship air quality and improve ship availability

Technical Issues Cost

Previous Work NSWCCD and ManTech have fielded prototype systems

Return on Investment High

Prototype Composite Ventilation Duct System Built by Boeing and Structural Composites Installed on the ***USS Samuel B. Roberts***, FFG-58

Naval Composites Application Summary

- U.S. Navy Focused on Vacuum Assisted Resin Transfer Molding (VARTM) and other Closed Mold Methods to Ensure Environmentally-Compliant, High-Quality Parts
- Major Drivers Towards the use of Composites on Navy Ships are: Corrosion Avoidance, Reduced Weight; Sensor Integration; and Increased Stealth
- Fire Performance Remains the Largest Obstacle, Although Cost is Increasingly Being Considered
- Procurement Process and Retrofit Opportunities Remain Difficult to Navigate - Supplier Partnerships Necessary

Session 4

Performance of Marine Composite Structures In-Service (4:30 - 5:00)

- Inspection Methods
- Sources & Types of Damage
- Repair Methods
- Future Developments
  - Manufacturing
  - Shock Mitigation

Inspection of Marine Composite Structures

- Visual Inspection is Still the Primary Method for Detecting Failures
- Failures in Cored Construction can be Detected by “Tap Testing” or “Weight Gain”
- Minor Surface Damage may not Necessarily Affect Performance of the Platform
- Boat Units Should Develop an Inspection Regimen that is Platform Specific

Typical Failures Found in Composite Boats

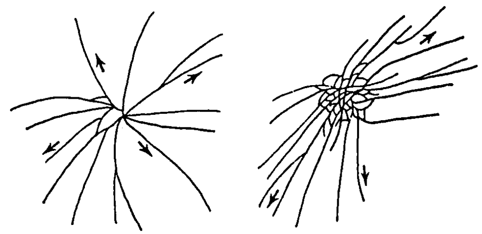
Most failures are from:

- Inadequate design
- Improper selection of materials
- Poor workmanship

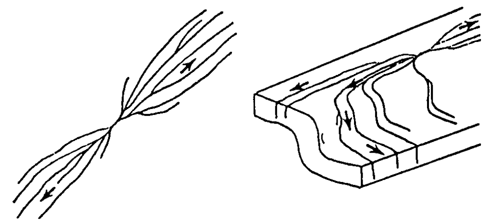
Most common failures:

- Gel coat cracking
- Core separation from skin in sandwich construction
- Blisters on underwater portion of hull

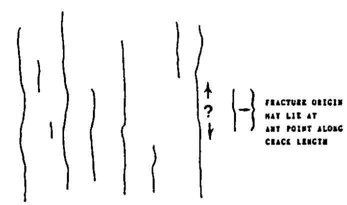
Examples of Gel Coat Cracking



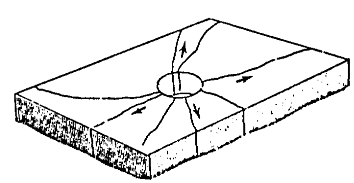
Cracks influenced by surrounding laminate



Radial Crack Pattern

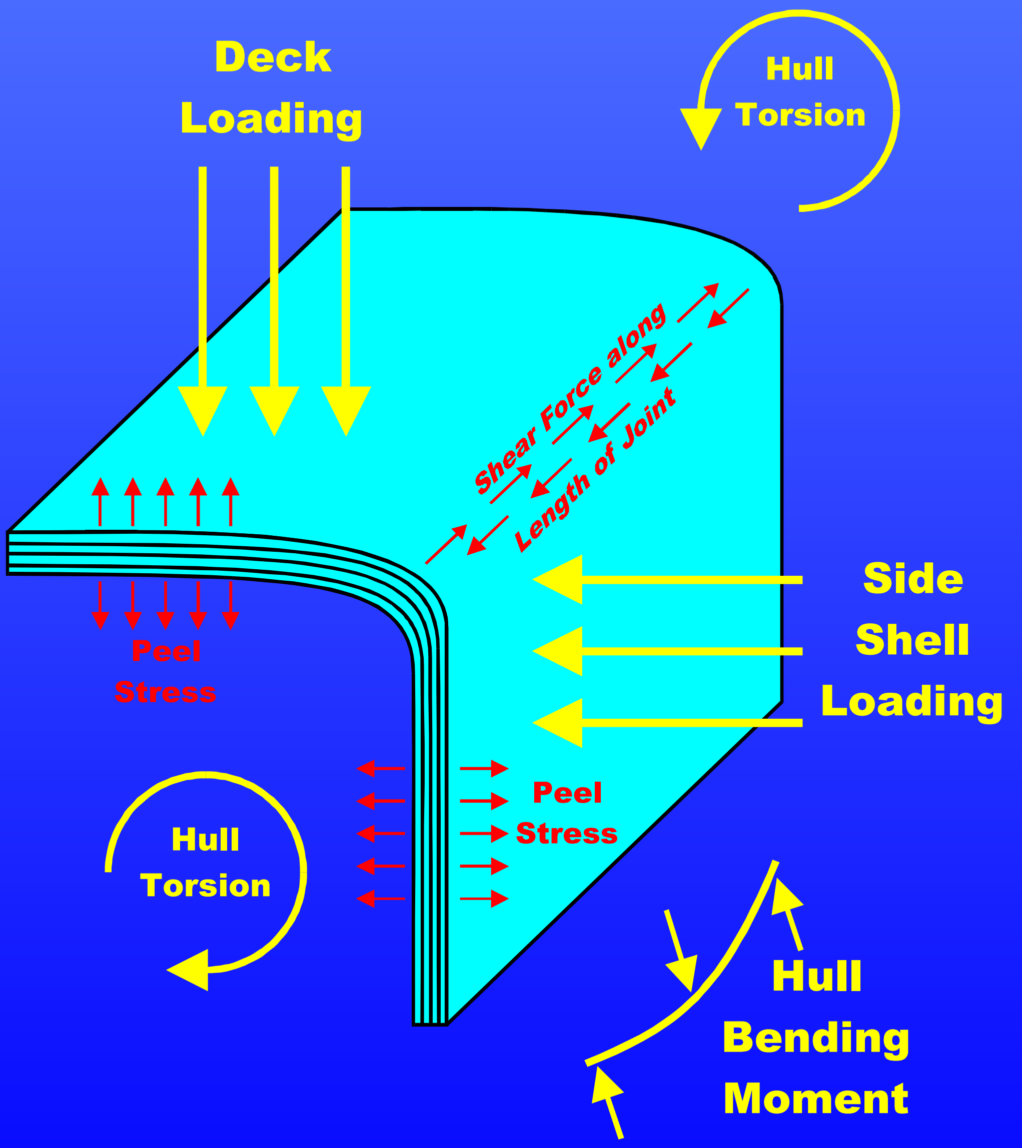


Parallel Crack Pattern

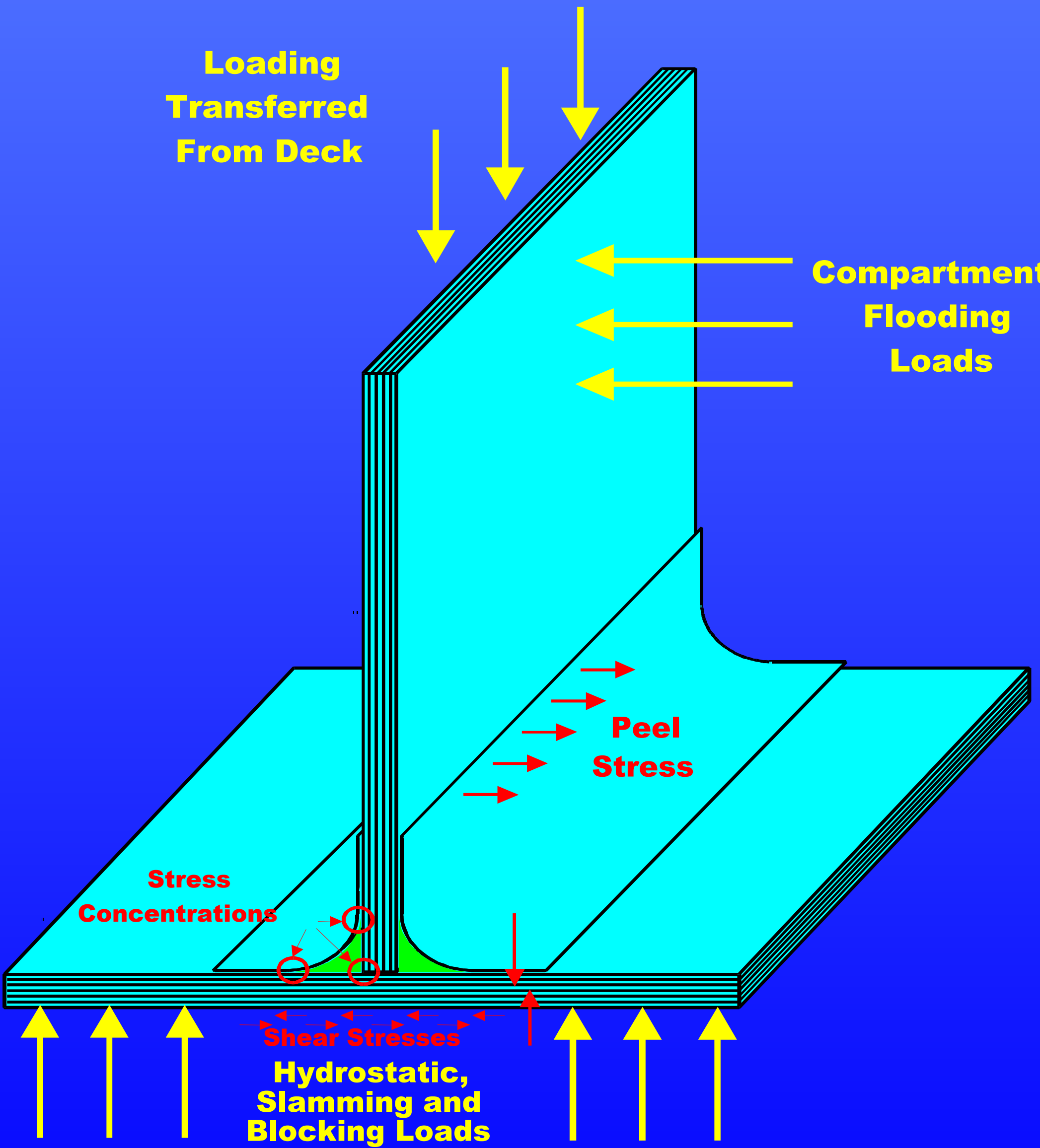


Crack caused by hole or other stress concentration

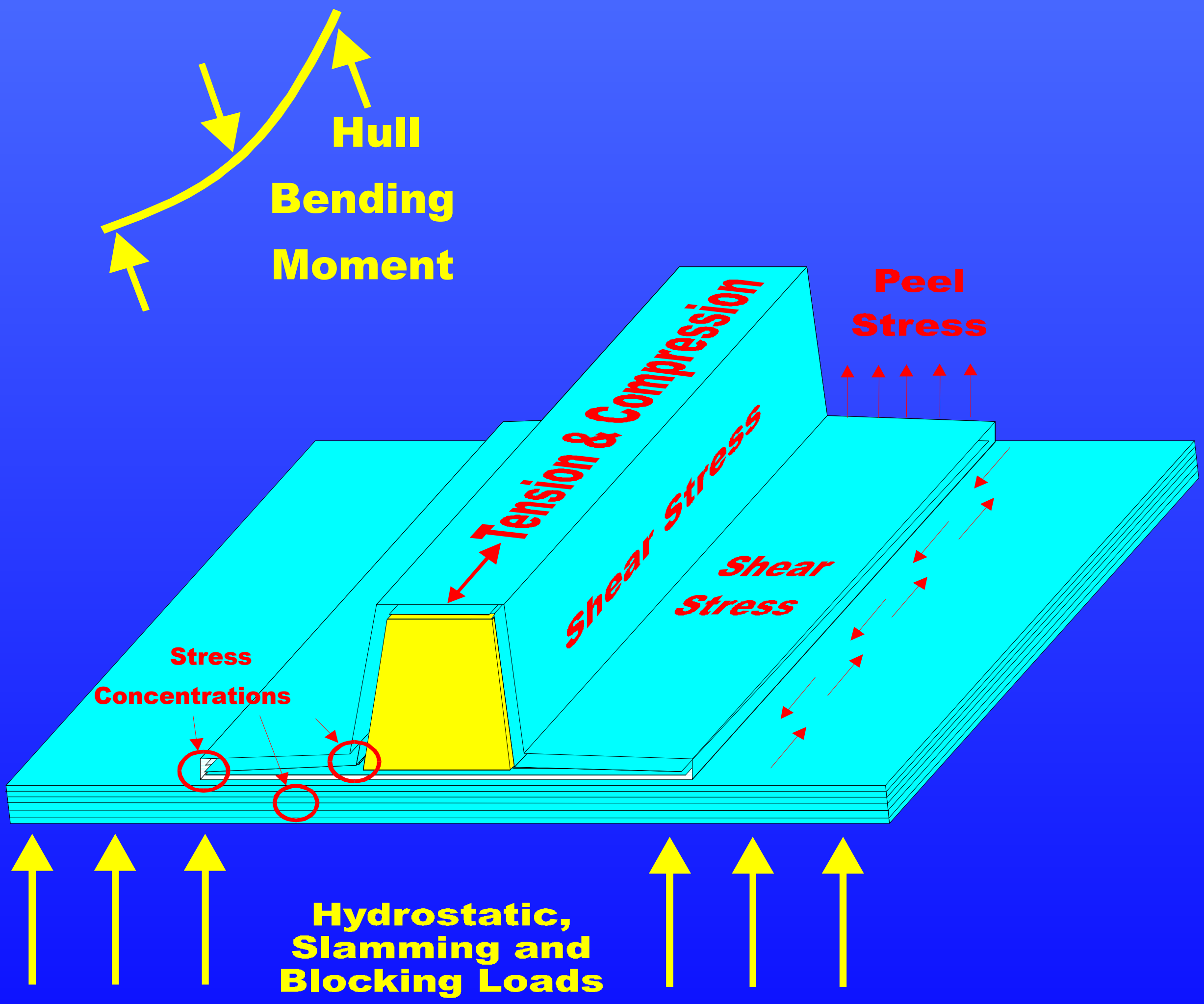
Hull-to-Deck Joint Stresses



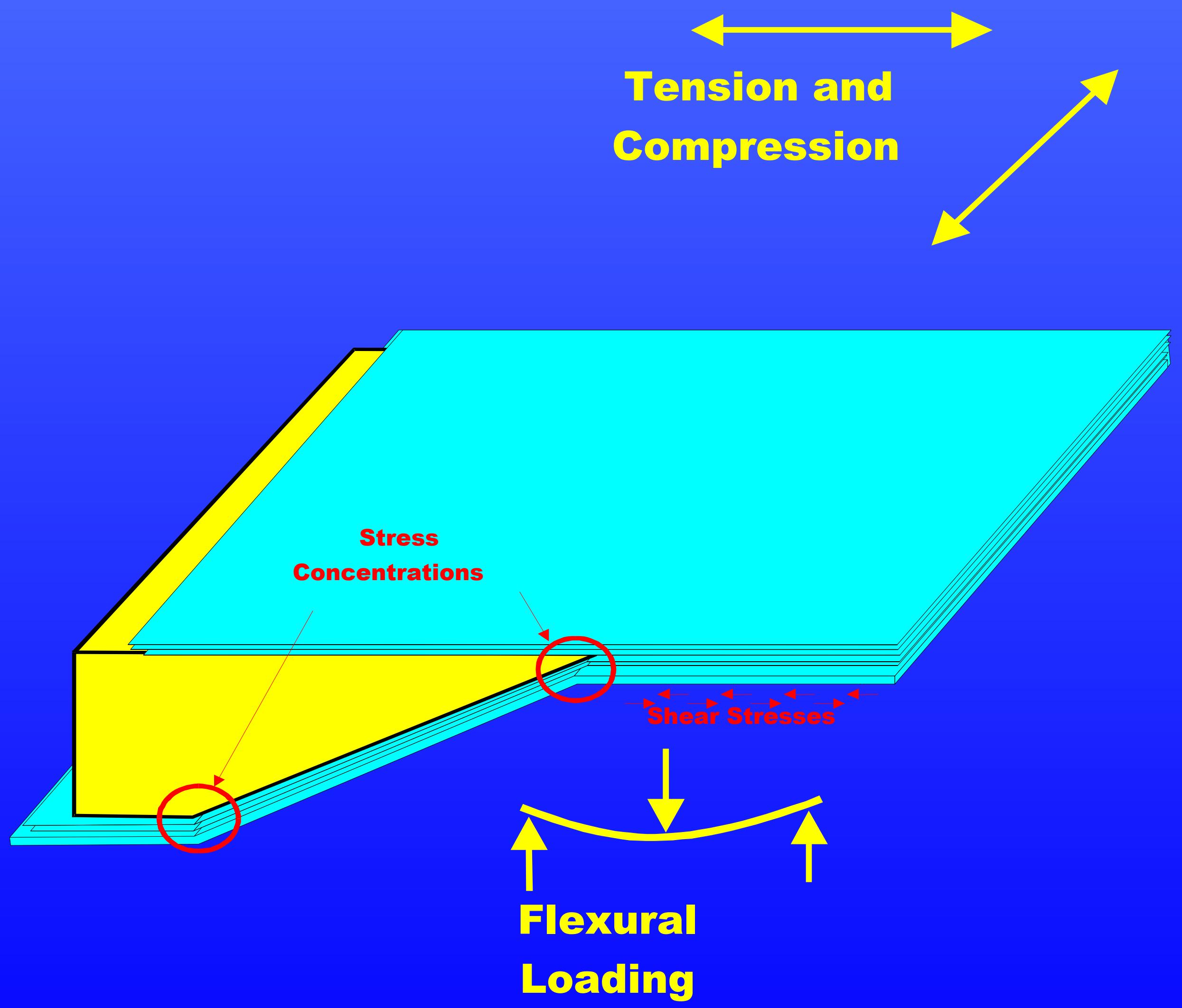
Bulkhead Attachment Stresses



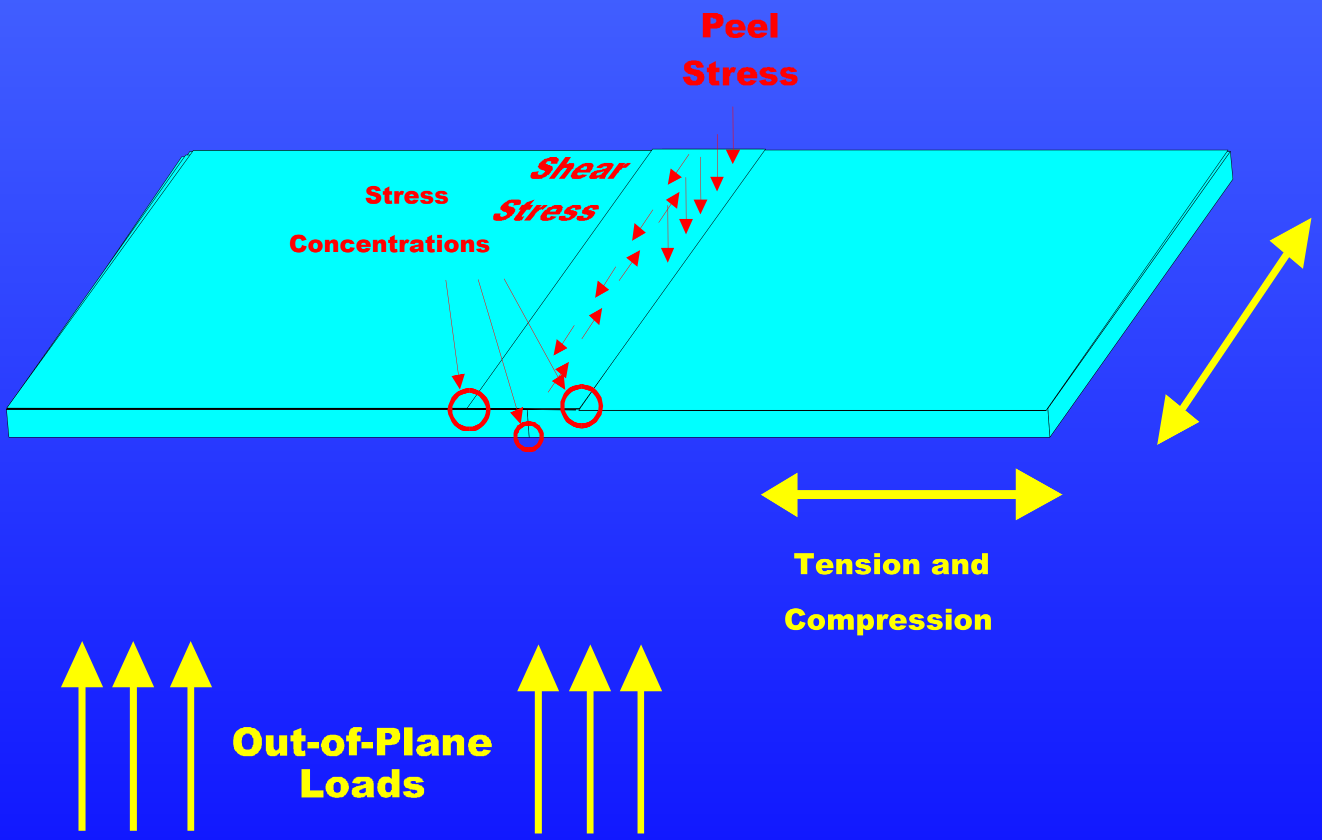
Stiffener Stresses



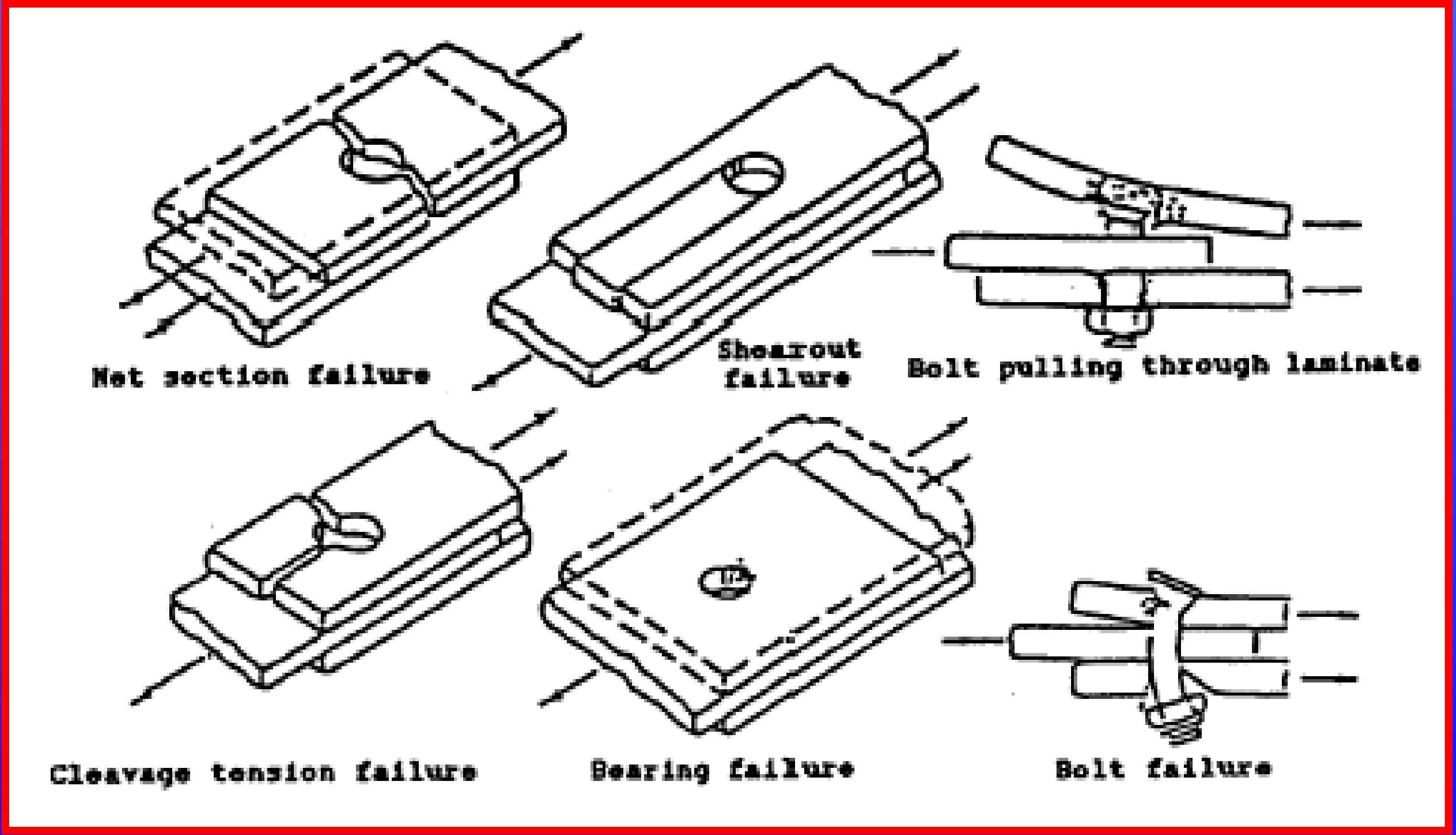
Sandwich-to-Solid Transition Stresses



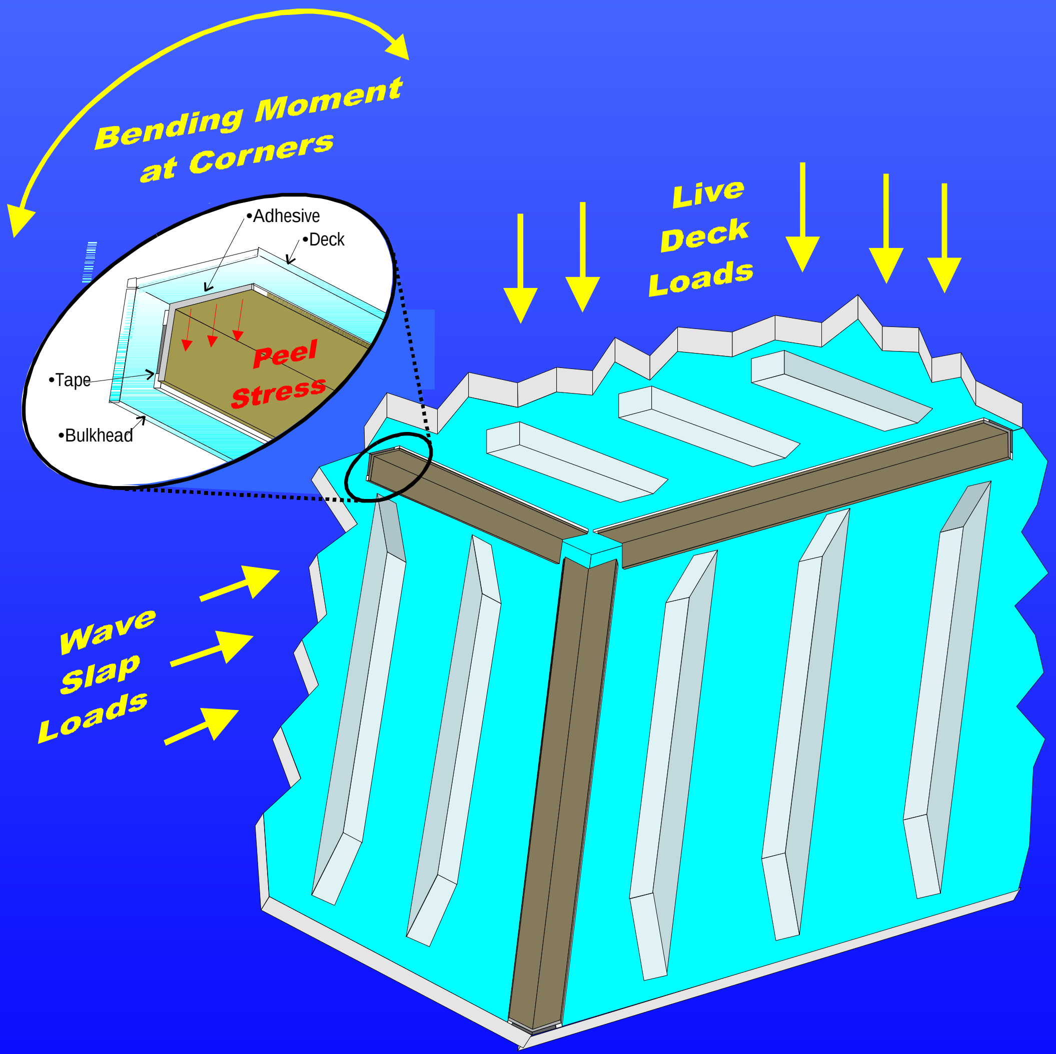
Secondary Bonded Joint Stress



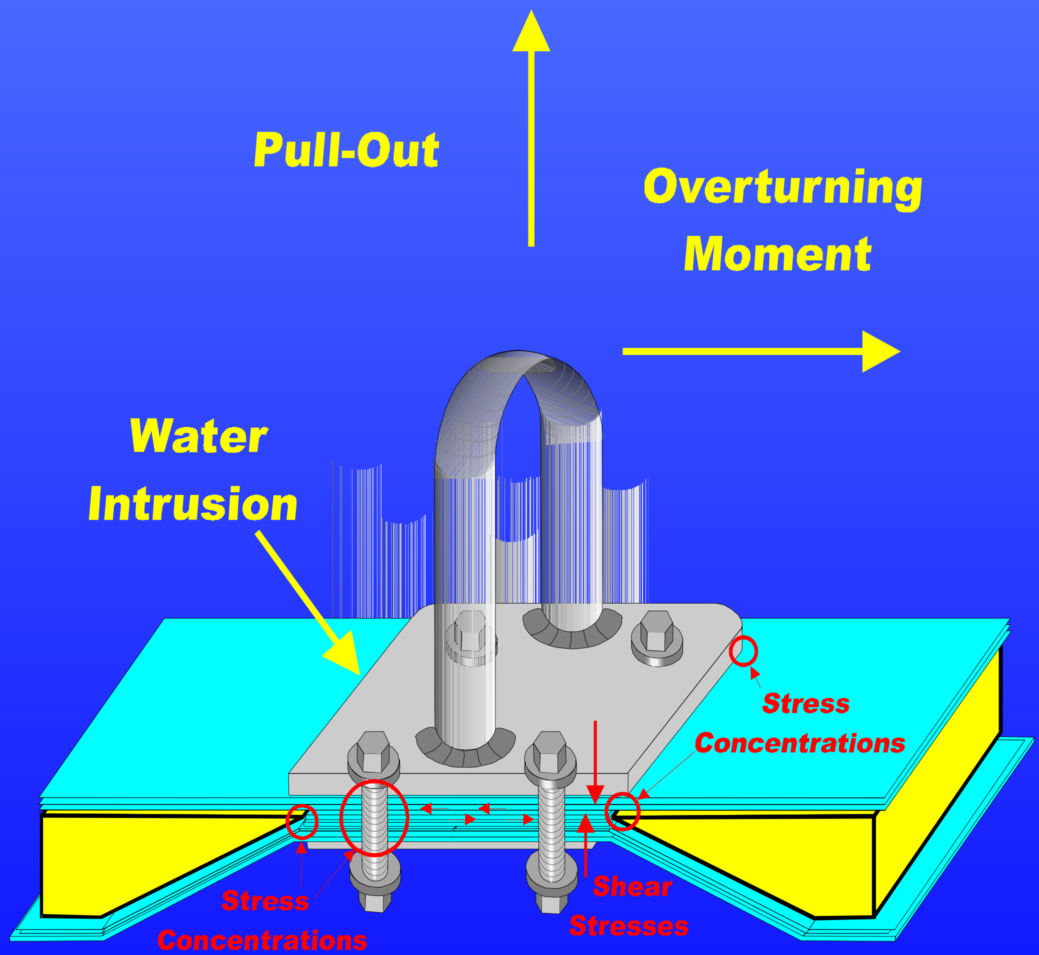
Types of Failures in Bolted Joints



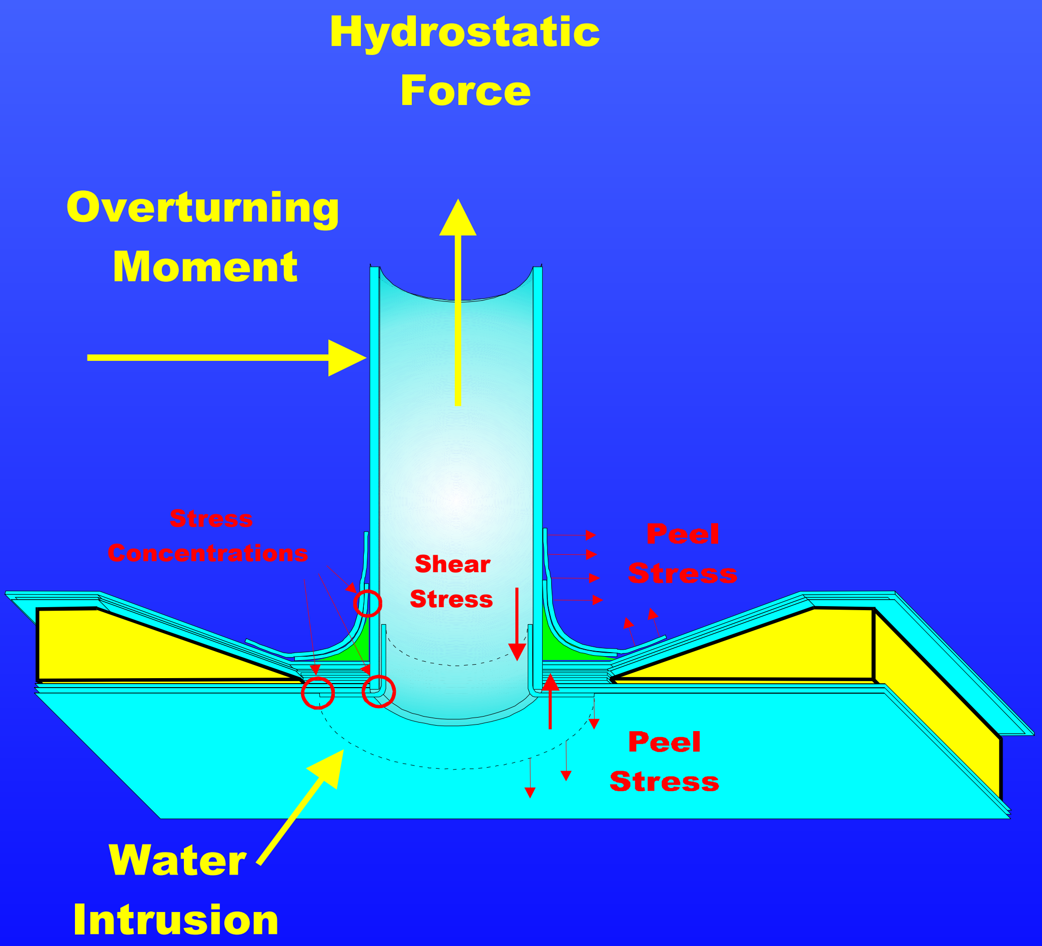
Adhesively Bonded Joint Stress



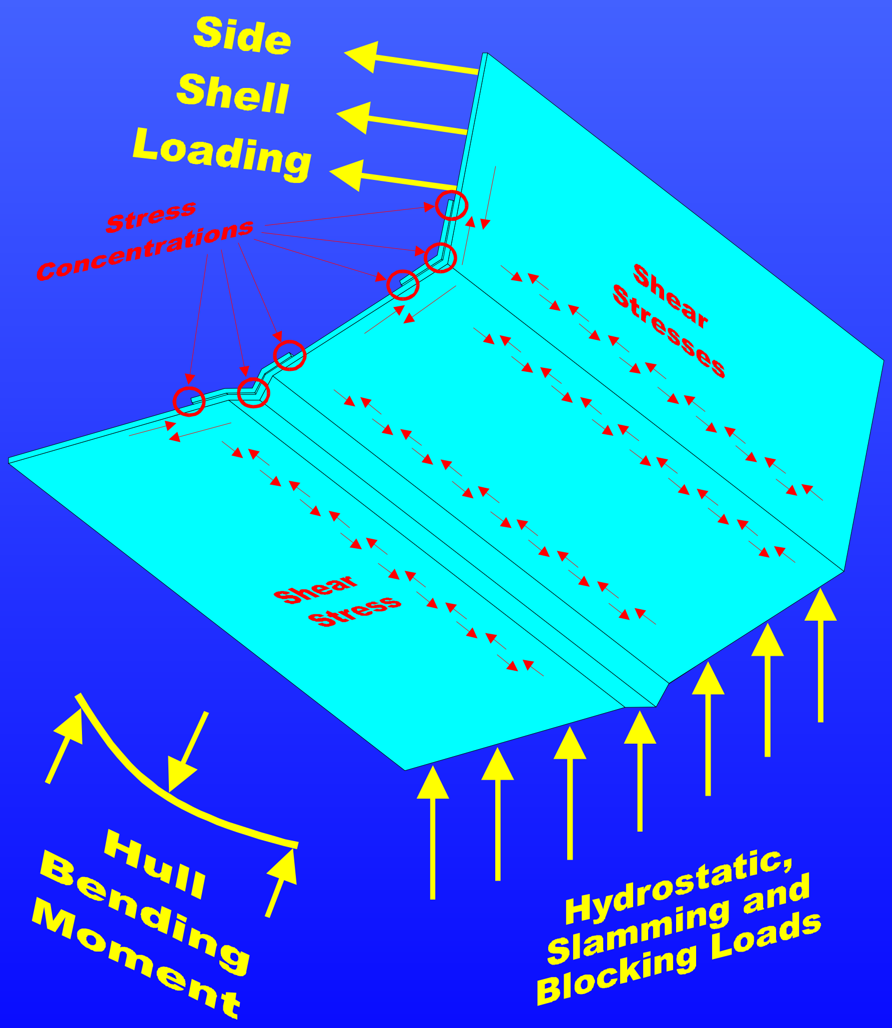
Deck Hardware Stresses



Through-Hull Penetration Stress

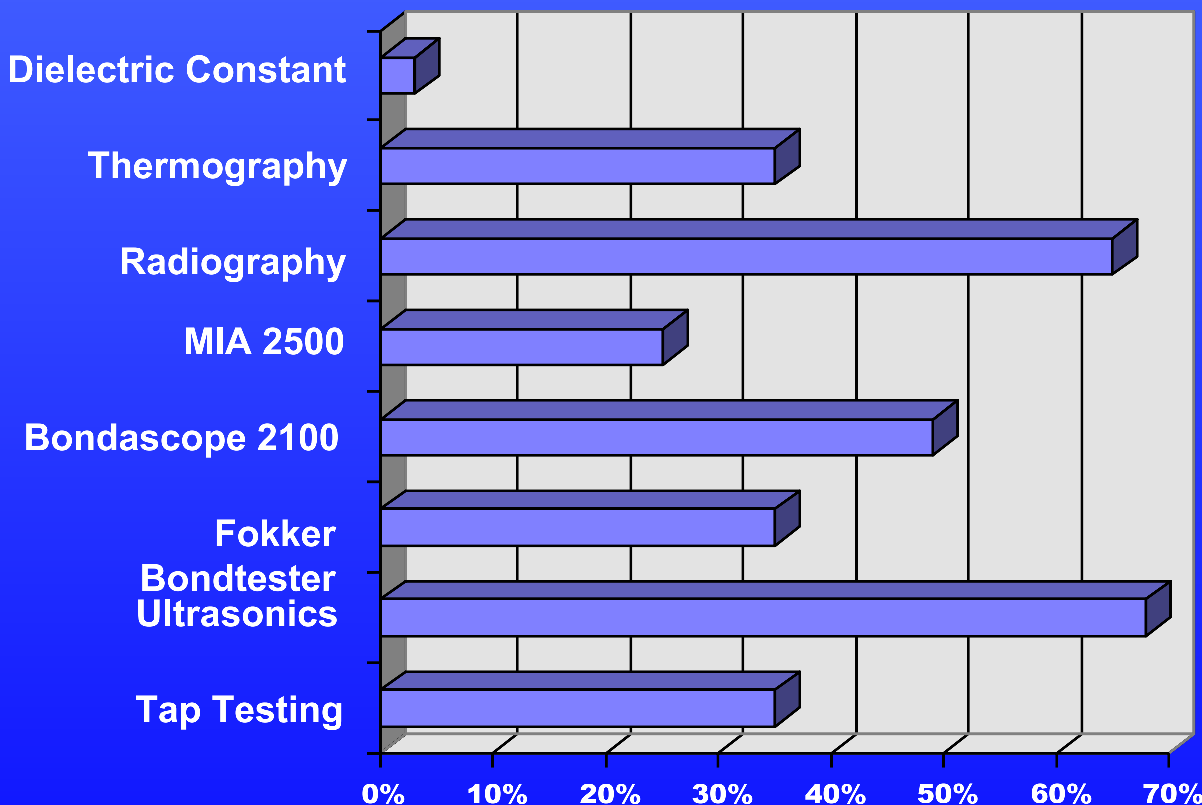


Chine & Spray Strake Stress



Nondestructive Evaluation of Composite Ship Structures

Effectiveness of Various Potential NDE Methods



Defects Considered:

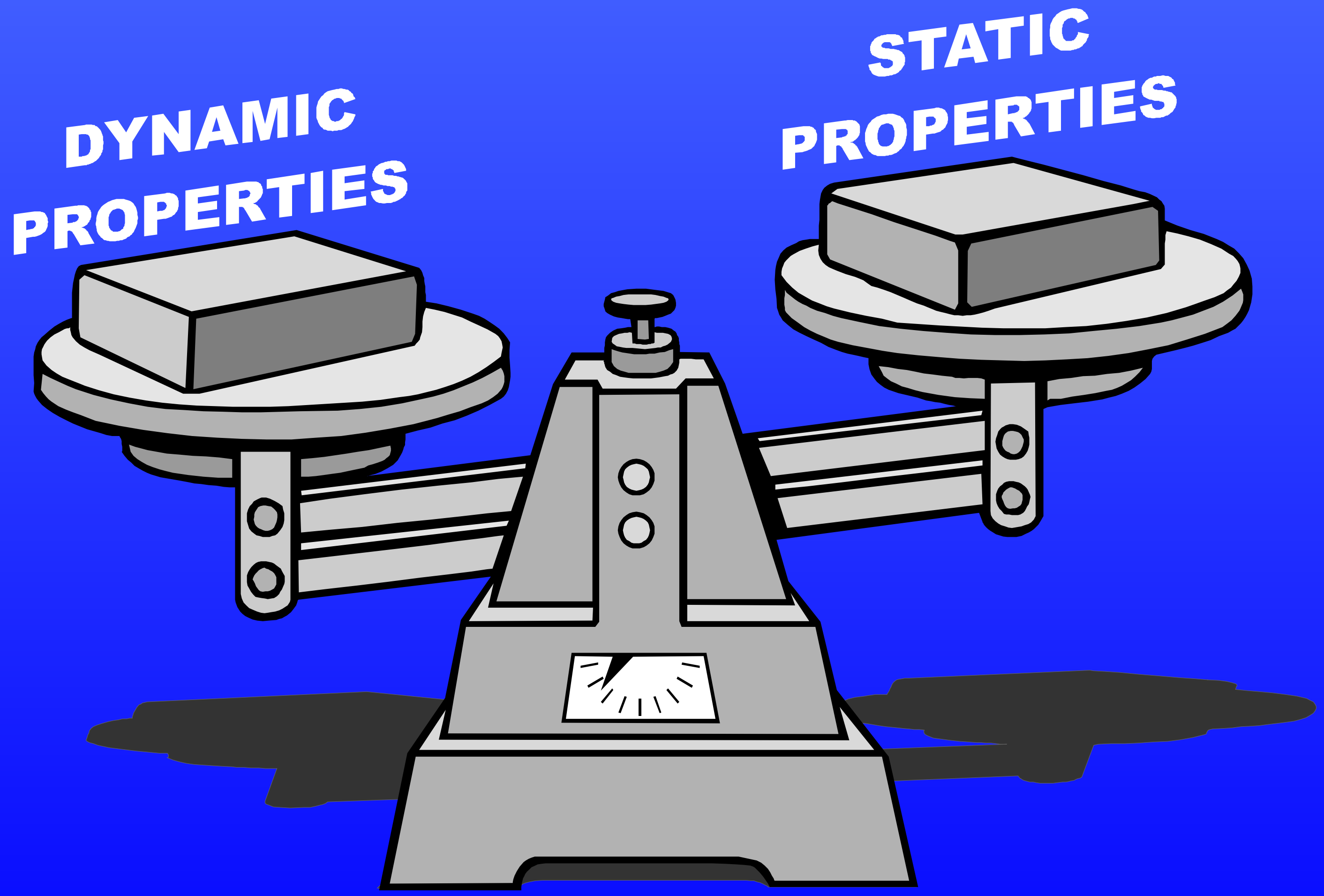
- Impact Damage
- Voids
- Dry Fibers
- Through Cracks
- Delamination
- Uncured Resin
- Excessive Core Filling
- Gap Between Stiffener and Web
- Sheared Stiffener

Bar-Cohen, *Nondestructive Evaluation (NDE) of Fiberglass Marine Structures*, US Coast Guard report CG-D-02-91

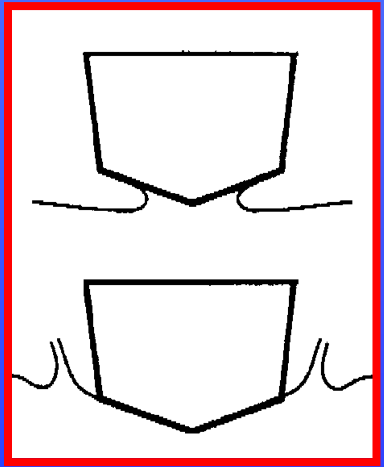
Sources of Marine Composite Damage

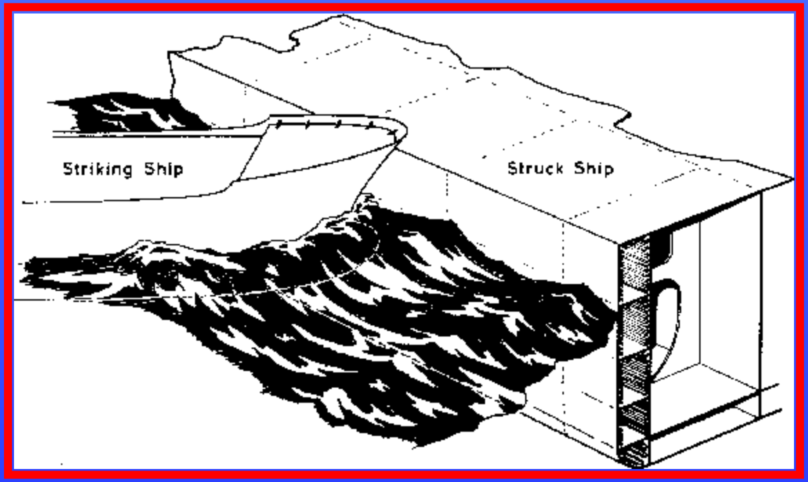
- Damage from In-Service Loads
    - In-Water Operational Loads
    - Trailering, Hauling and Blocking Loads
- Fatigue Loads
    - Wave Encounter
    - Machinery Induced
- Impact with Foreign Objects
- Fire
- Environmental Effects
    - Water Absorption
    - UV and Temperature Degradation

Static vs. Dynamic Damage Tolerance



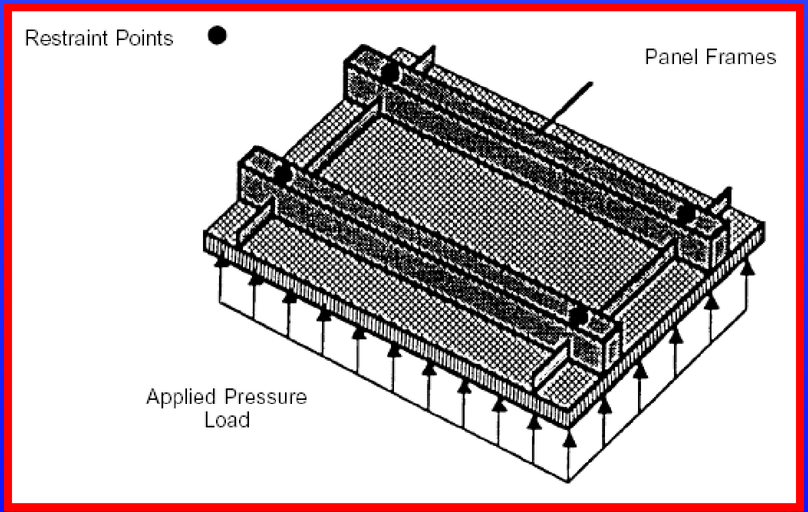
Impact Scenarios & Structural Evaluation





Wave Impact (left) and Ship Impact (right)

Instron's Dynatup® 8100 Series Drop Weight Impact Test System Can Handle Impact Energies up to 20,500 ft-lbs and Impact Velocities up to 22 ft/s



Schematic Diagram of Dynamic Panel Testing Pressure Table [Reichard]

Fire Performance Issues

Flame Spread

The rate that flame travels along the surface

Fire Resistance

The ability of a boundary to contain a fire

Time-to-Ignition

Time required before a combustible material ignites

Heat Release Rate

The heat release of a material is measures the amount of fuel that a combustible material contributes to a fire

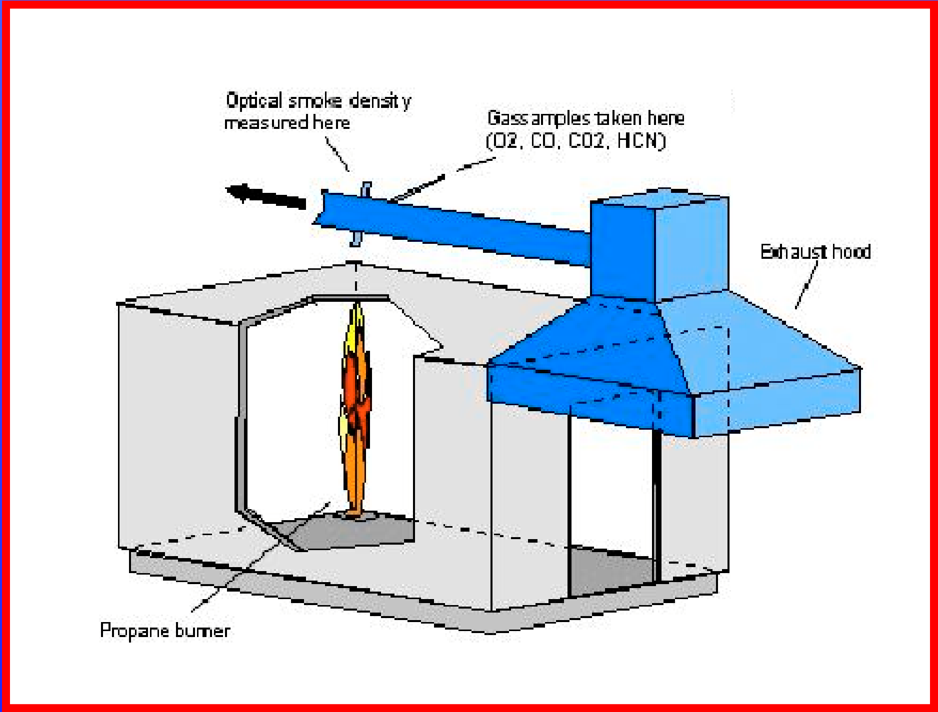
Structural Integrity

Hull, deck and bulkheads must support design loads during and after a fire

Composite Panels being Tested to ISO 9705 as per the International Maritime Organization

Intermediate-Scale Fire Testing

Lighting of Burner to Start Modified
ISO 9705 Room Corner Test
at VTEC Laboratories



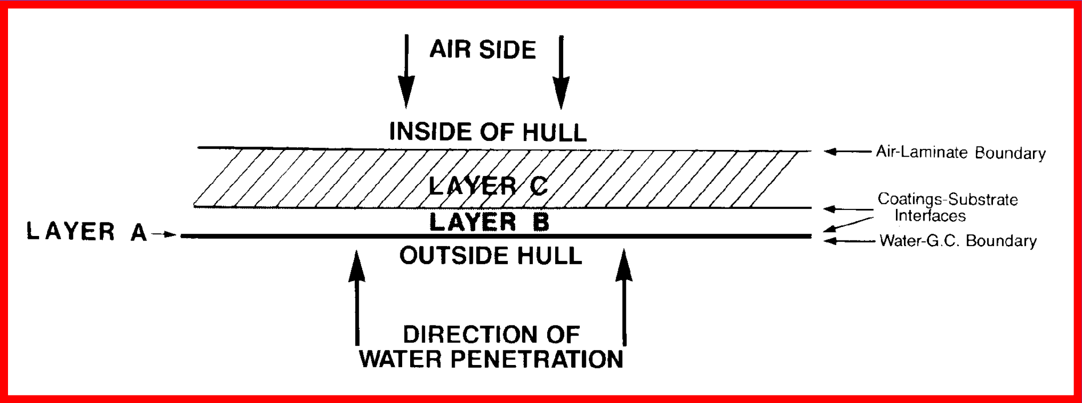
Schematic of ISO 9705 Room Corner
Test to Determine Flame Spread and
Smoke Generation

Full-Scale Fire Testing

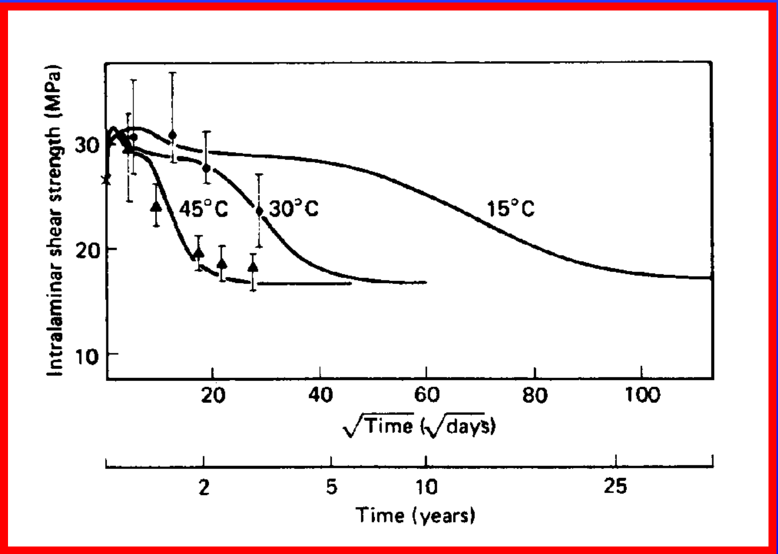
Test Arrangement for Burn Through Resistance of 10 x 10 - foot Panel

Full-Scale Fire Test for Helicopter Hanger Project with Fire Protection Around Door for Fire Test Only

Blistering and Water Absorption

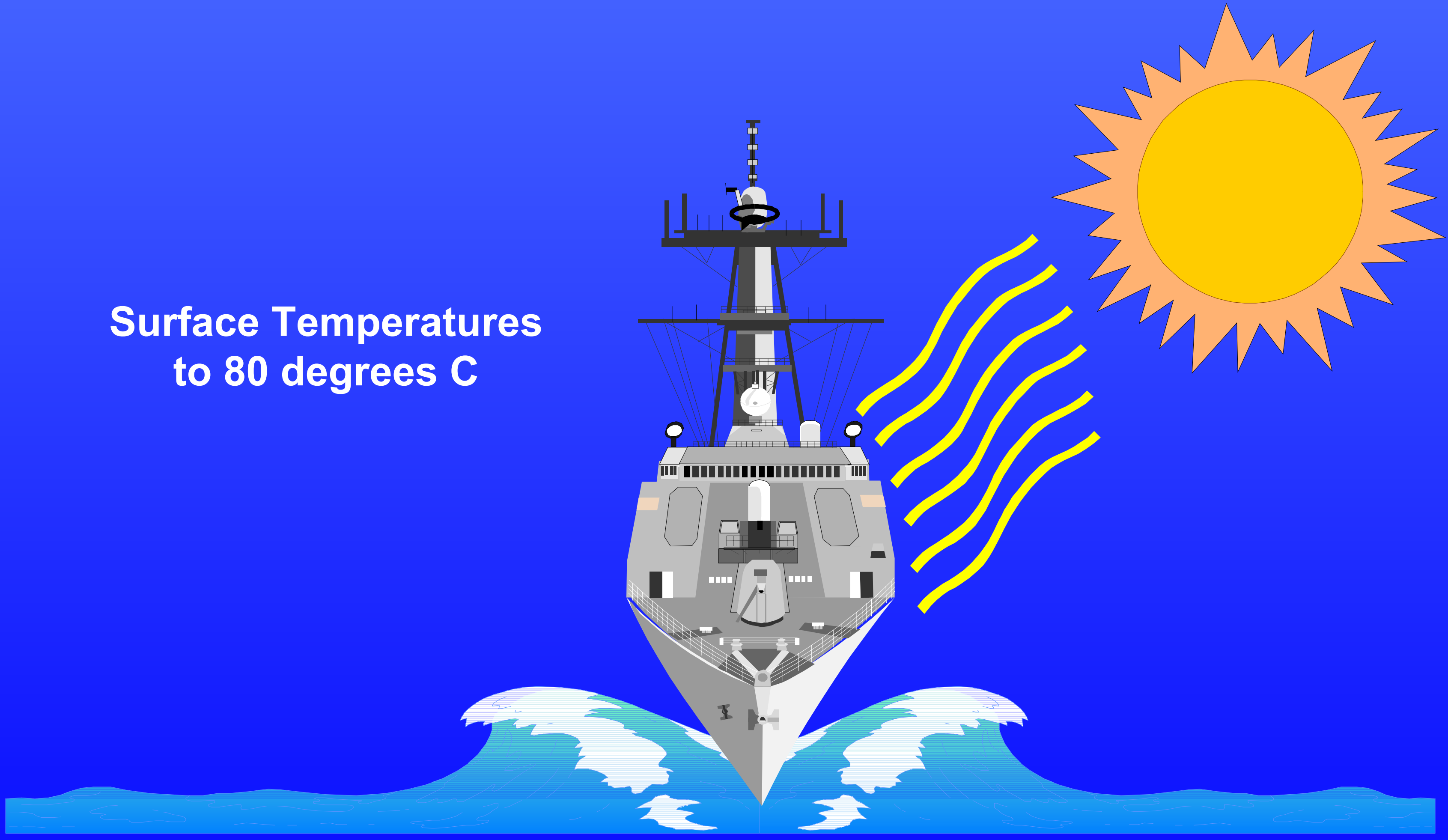


Layer A = Paint or gel coat
Layer B = interlayer
Layer C = laminate



Measured/Predicted Material "Knockdown" Strength based on Moisture Uptake (Springer)

Elevated In-Service Temperature



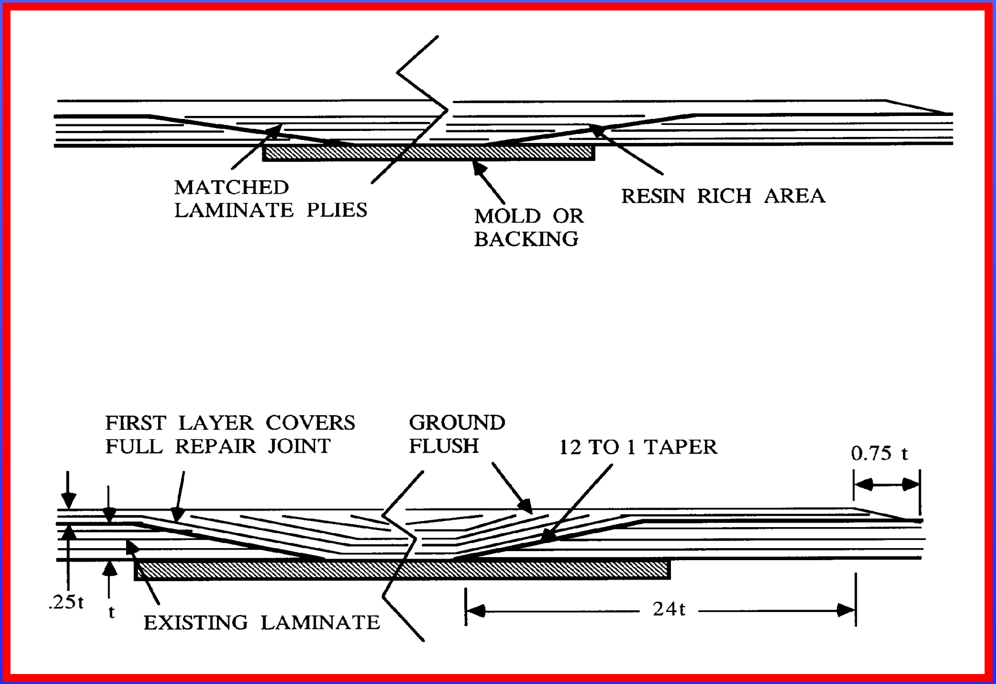
Surface Temperatures
to 80 degrees C

Damage Assessment

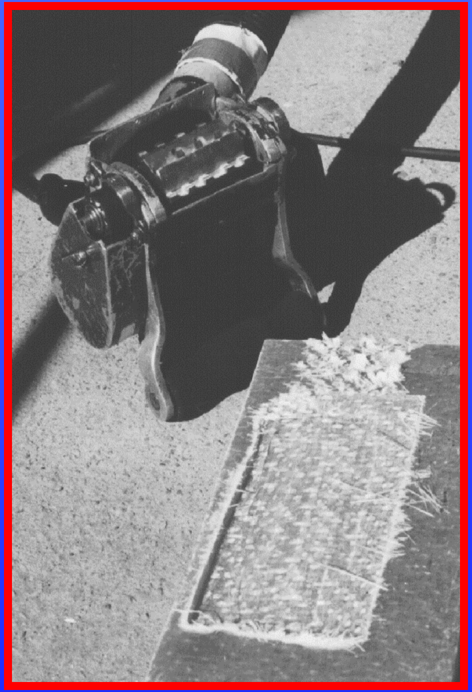
Damages can be found either by visual inspection, probing, or hammer sounding of the structure. Damage can be found from indicators such as the following:

- Cracked or chipped paint of abrasion of the surface.
- Distortion of a structure or support member.
- Unusual build-up or presence of moisture, oil, or rust.
- Structure that appears blistered or bubbled and feels soft to the touch.
- Surface and penetrating cracks, open fractures, and exposed fibers.
- Gouges.
- Debonding of joints.

Damage Repair



Typical Composite Material Repair Techniques



Laminate Peeler used to Repair Severe Blister Damage

Marine Composite Repair Summary

- In-plane properties are always degraded for repaired composite structures
- 20:1 scarf repairs are more effective than repairs made involving less area
- Special skills, materials and environmental controls required for effective repairs
- Aerospace level repair methods not envisioned for marine structures
- Single-skin, E-glass laminates are easier to repair than carbon fiber and sandwich constructions

Future Manufacturing Methods

Advanced Interlaminar Infusion

- **Thicker Laminates**
- **Center Out Process Advantage**
- **Embedded LO/EMI**
- **Damping Layers**
  - **Noise**
  - **Vibration**
  - **Shock**
- **Damage Tolerance**

Future Manufacturing Methods

Infusion Challenges

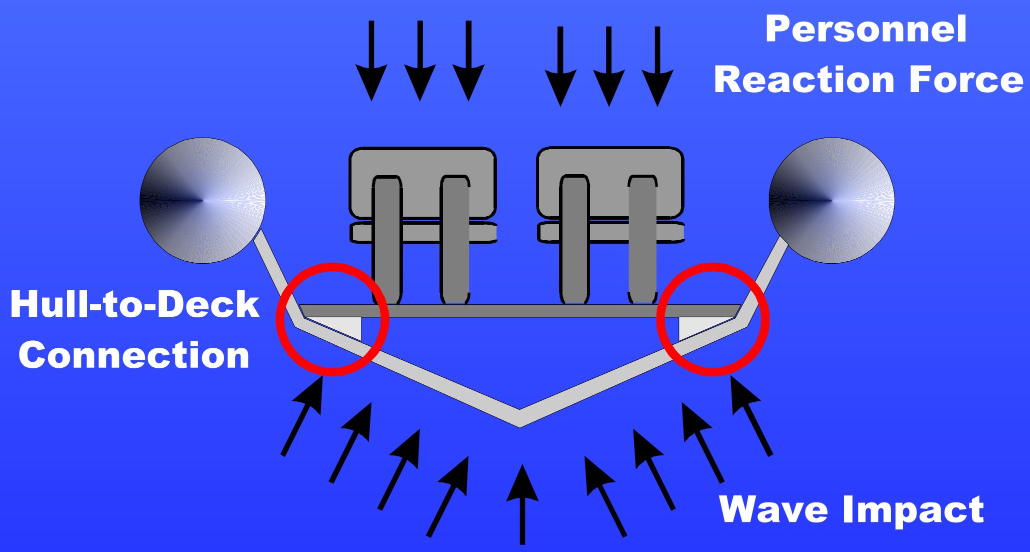
- Tool Loading
- Resin Technology
  - Cure on Demand (COD)
- Inclusion of Framing
  - Preforms
- Preform Laminates
- Kit Cut Laminates
- Bag System

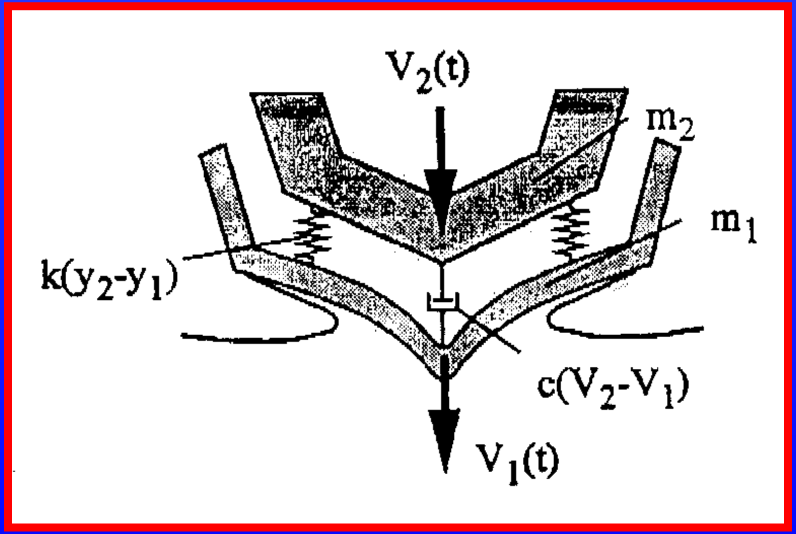
Future Manufacturing Methods

Spray-Bag Process

- Infusion Bag is Sprayed in Place
- Inclusion of Preform Frames and Resin Feeder System
- Bag Becomes Interior Surface
- ADVANTAGES
  - Reduced Cost
  - Elimination of Interior Gel Coat
  - Process Risk Reduction
  - Reduction in Expendables
  - Ship Applications Would use Bag as Fire Protection System

Composite Structure for Shock Mitigation





Schematic of Coupled Hydroelastic Impact Model with Variable Impact Velocity by Vorus et al

Summary and Conclusions

- Composite structures can be highly "engineered"
- Structural integrity is dependent upon worker skill
- The US continues to lead the world in the development of marine composite fabrication technologies
- Emerging manufacturing technologies will permit "environmentally compliant" fabrication of platforms
- Future maritime platforms can improve shock mitigation and durability using a combination of composite structural design and process development

Acknowledgments

This Composites Workshop was geared specifically to the needs of the US Marine Manufacturer. The Workshop was developed by Eric Greene Associates, Inc. with support from the US Navy and the American Composites Manufacturers Association (ACMA). Special thanks go to Mary Richman, CCT of the ACMA.