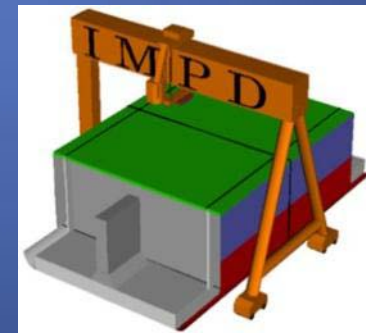


ALUMINUM BENEFITS & ADVANCEMENTS FOR NAVAL SHIPS

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Overview

- Introduction
- Benefits of Aluminum for Naval Ships
- Advances in Technology (for ship design and manufacturing)
- The Equivalent Naval Ship Trade Study
- Impact on Cost (Acquisition and TOC)
- Conclusions

Aluminum: Experience and Revival

Aluminum is a proven structural material that is helping the US Navy achieve its modern fleet needs:

Legacy

- CG
- FFG
- LHA/LHD
- LCAC
- CVN



All U.S. surface combatants from 1947 until DDG-51 had aluminum in their deckhouses

New

Littoral Combat Ship (LCS)

- LCS1
- LCS2
- HSVs
- SSC
- LHA
- X-Craft
- T-Craft
- CVN



Joint High Speed Vessel (JHSV)



Ship-to-Shore Connector (SSC)



Future (X) Programs



Future Topsides & Masts



Benefits of Aluminum for Naval Applications

Properties of Aluminum

High strength-weight-ratio

Density one-third that of steel

Excellent corrosion resistance

Weldable

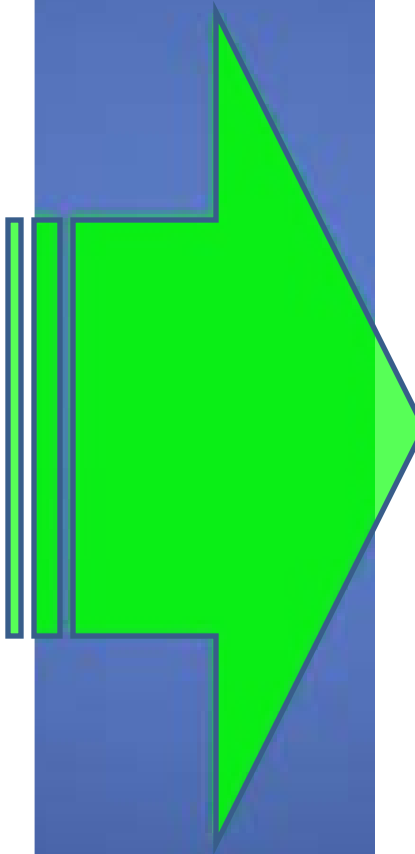
Ease of forming, bending and machining

Availability and diversity of functional semi-finished products

High thermal and electrical conductivity

Recyclable

Non-magnetic



Ship Result

Fuel Savings

Increased Range

Increased Payload

Higher Speeds

Maneuverability

Stability

Less maintenance

Lower total ownership cost

Advances in Technology

- Advancements in Technology:
 - Materials (new aluminum products, fire barriers, etc.)
 - Design Tools & Methods
 - Manufacturing Technologies
- Improved:
 - Cost (acquisition and TOC)
 - Quality (increased reliability & availability)
 - Manufacturing Throughput



Aluminum Advancements for Ships

- Materials:

- Today, all marine plate with greater than 3% Mg content must meet ASTM B928. This would include 5086, 5083 and 5456.
- More use of 5083 which has 0.5% less Mg than 5456.
- Avoid the use of marine alloys with greater than 3% Mg content in ship areas where the service temperature exceeds 65 C (150°F). Instead use 5454.
- Extruded integrally stiffened panels.
- Improved fire barriers.

- Design:

- Today's designer can use finite element analysis. A coarse mesh FEA can be developed for the entire ship structure and fine mesh for details.
- Fatigue is considered in the design of today's ships. A Spectrum Fatigue Analysis for 30 years (SFA-30) can be performed.

Aluminum Advancements for Ships

- Manufacturing:
 - Aluminum welding and fabrication is similar to steel, but different
 - Fabrication requirements and methods unique to aluminum were overlooked in the past
 - Shipbuilders have largely recognized this now
 - Many improvements and investments are being made
 - Has resulted in improved productivity, quality and throughput
 - Investments are being made in welder training, processes and equipment
 - Friction Stir Welding (FSW), higher deposition fusion and laser welding
 - Adhesive bonding and mechanical fastening

Repairman Milling Aluminum Aboard CVN



Steel Welding



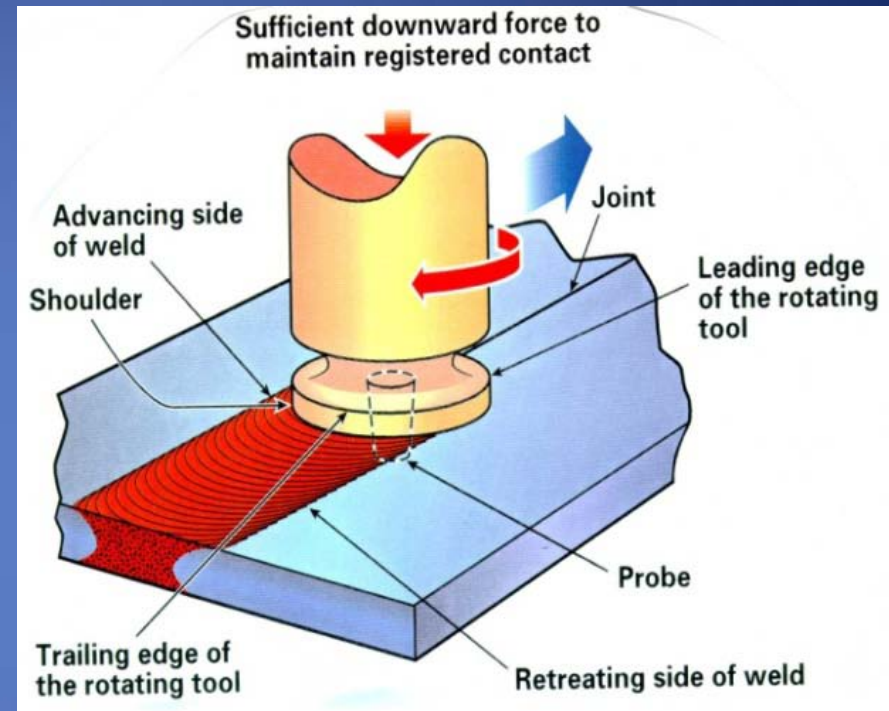
Aluminum Welding



Advances in Technology

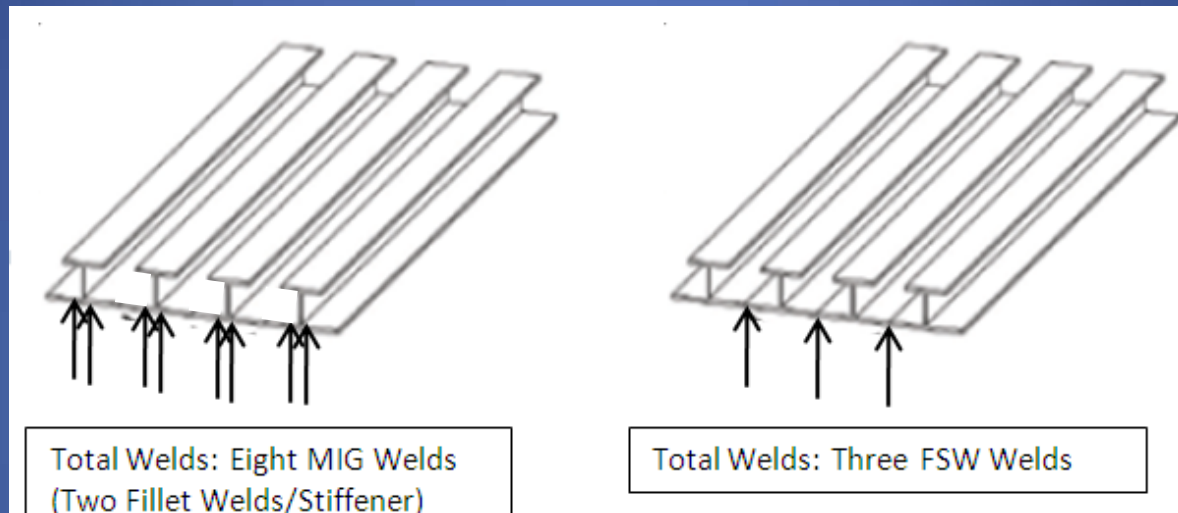
Friction Stir Welding (FSW)

- Usually only one weld pass
- Panels have less distortion
- No welding filler wire
- Fewer primary welding parameters
- Fully automated process
- FSW systems are simple to set up and maintain in production
- Extremely repeatable weld quality
- Results in reduced repair and reject rates

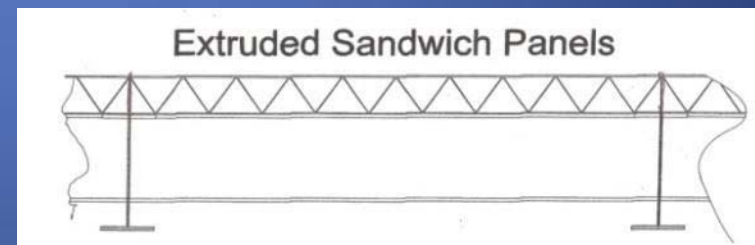
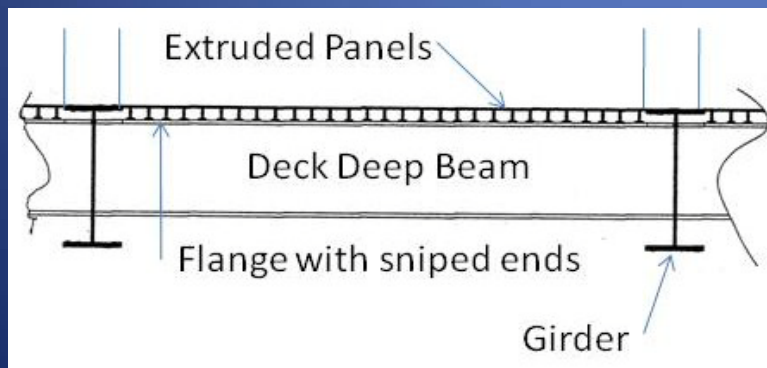


Advances in Technology

Sketch of MIG Built-Up Stiffened Panel vs. FSW Extruded Panel



Aluminum Extruded Panels in Decks



Advances in Technology

- Coupling the advantages of FSW with Aluminum Extruded Panels.
- Advantages include:
 - less weld preparation
 - less welds
 - less rework and distortion
 - panels offer better dimensional tolerance
 - can be pre-fabricated
 - reduced fixturing and fit-up time
 - reduced manufacturing labor

Technology Advancements Summary

Legacy	New
Alloy: Primarily 5456	Alloys: 5456, 5083, some 6xxx. (these are not really new alloys). Use of 5454 in elevated service temperature areas
Product forms: Plate, extruded stiffeners	Product forms: Plate, specialty extrusions including multi-hollows
Construction: manual labor intensive “stick building”	Panelization through the use of automated linear welding
Joining technology: GMAW or GTAW welding. Predominately manual	Joining technology: GMAW, GTAW, FSW, HDGMAW, etc
Marine plate specification: AMS-QQ-250 or ASTM B209	Marine plate specification: ASTM B928
Design tools: hand calculations, empiricism, global stress analysis	Design tools: all the legacy tools plus FEA (more localized stress analysis), Spectra Fatigue Analysis



Alcoa Advanced Technology

■ Advanced Alloys & Product Forms

- ✓ New corrosion resistant alloys with improved strength, durability & damage tolerance
- ✓ Low density, high toughness, fatigue resistant Al-Li alloys
- ✓ New weldable alloys
- ✓ High performance thick products
- ✓ Integrally stiffened product forms
- ✓ Fiber metal laminates (e.g., GLARE)
- ✓ Layered and/or Gradient Composition Sheet and Plate Products

■ Innovative Design Concepts

- ✓ Monolithic and semi-monolithic structure
- ✓ Selective reinforcement to improve damage tolerance
- ✓ Tailoring of stiffeners & damage containment features
- ✓ Reinforced hybrid panels
- ✓ Structural health monitoring / "smart structure" concepts
- ✓ Design for "Care-Free" Structure

■ Novel Manufacturing & Assembly Techniques

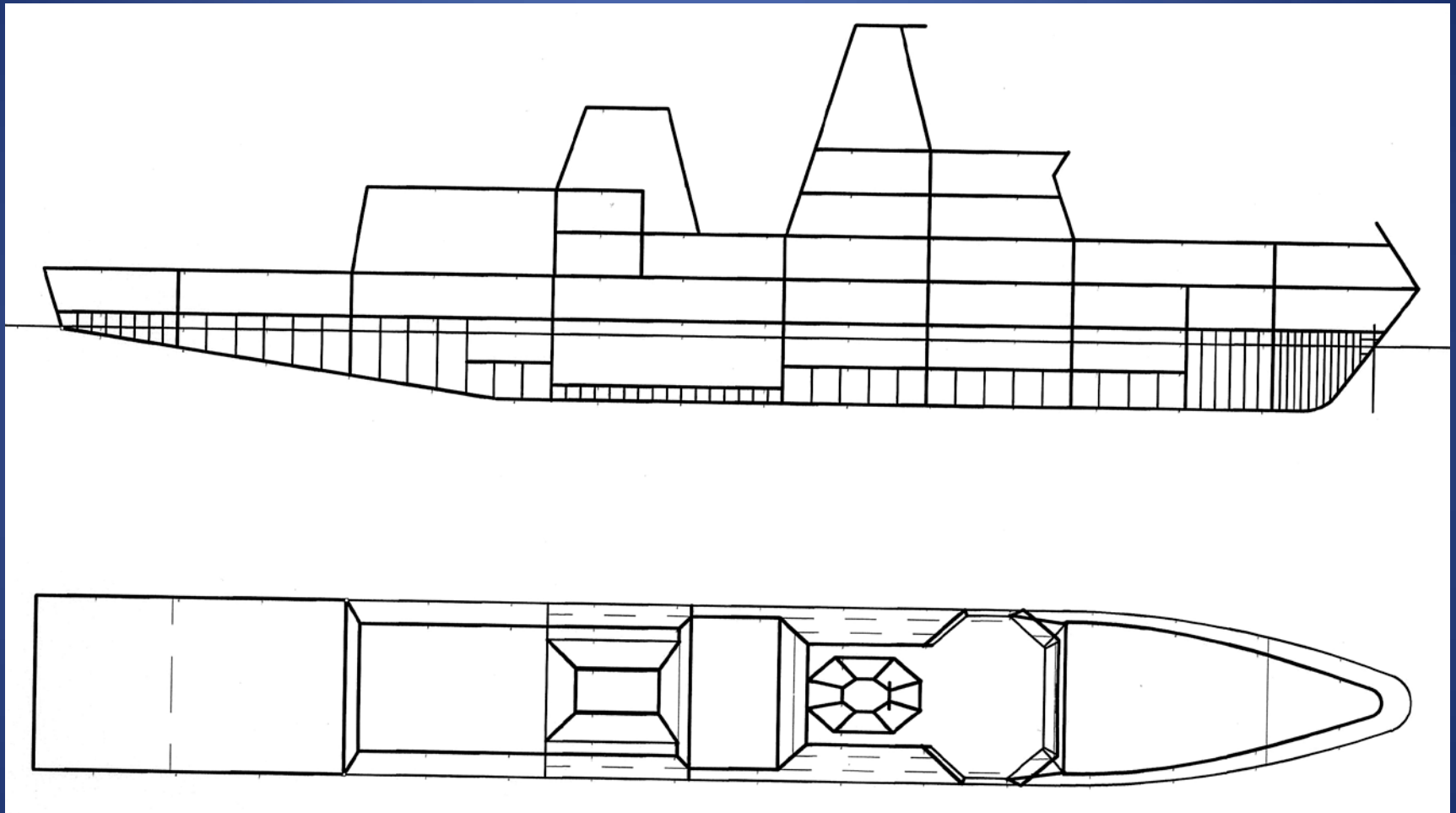
- ✓ Bonded metallic & hybrid structures capable of complex curvatures
- ✓ Advanced joining methods – FSW, Laser Beam Welding, Adhesive Bonding
- ✓ Advanced forming
- ✓ Age/creep forming
- ✓ Automatable manufacturing and assembly processes

The Equivalent Naval Ship Trade Study

Motivation for study was to develop primary data on and highlight:

- ✓ Validate weights of structure and fire insulation estimates used in SNAME paper.
- ✓ Cascading Benefits of Aluminum vs. Steel
- ✓ Relative Close Acquisition Cost between Aluminum and Steel
- ✓ Total Ownership Cost Advantages of Aluminum
- ✓ Impacts of Aluminum Technology Advancements
- ✓ Design, Manufacturing and Operational Advantages

AN Application Example



A Small Frigate

The Equivalent Aluminum Naval Ship

- Developed equivalent concept designs.
- Same performance requirements.
- Payload, speed, endurance, stability, fire protection, weapons integration, etc. are the same for both ships.

Equivalent Ship Design Particulars

	Baseline Steel	Aluminum Reduced Draft	Aluminum Reduced Block Coefficient
LBP	91 m	91 m	91 m
Beam at DWL	12 m	12 m	12 m
Depth	8.5 m	8.5 m	8.5 m
Draft	4.5 m	3.66 m	4.5 m
Block Coefficient	0.52	0.52	0.42
Midship Coefficient	0.85	0.85	0.76
Prismatic Coefficient	0.61	0.61	0.55
Propulsion Power	34,800 kW	28,800 kW	29,400 kW
Light Ship Weight	2095 t	1630 t	1641 t
Displacement	2627 t	2122 t	2140 t
Fuel Weight	413 t	342 t	349 t
Transverse GM	0.5 m	0.79 m	0.76 m

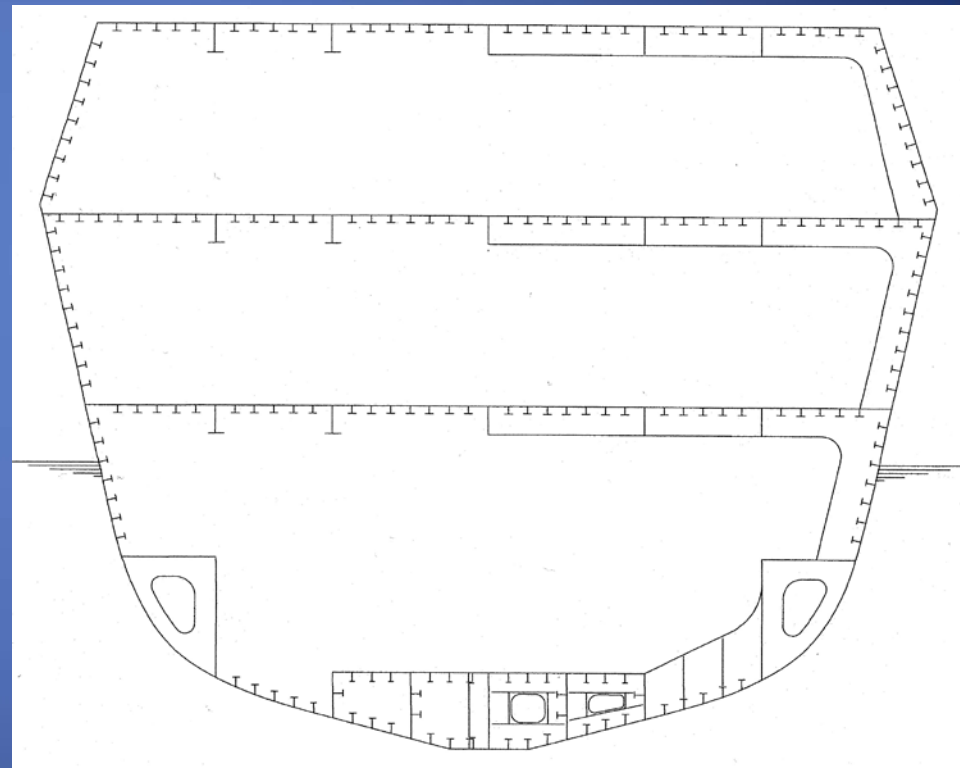
Weight Breakdowns

	Baseline Steel		Aluminum Reduced Draft		Aluminum Reduced Power	
Hull	919 t	43.9%	425 t	26.4%	436 t	27.0%
Machinery	518 t	24.7%	476 t	29.6%	476 t	29.4%
Electrical	94 t	4.5%	94 t	5.9%	94 t	5.7%
C & Co	61 t	2.9%	61 t	3.8%	61 t	3.8%
Auxiliary	279 t	13.3%	279 t	17.4%	279 t	17.3%
Outfit	197 t	9.4%	189 t	11.8%	189 t	11.7%
Add. Insulation			79 t	23.4%	79 t	3.4%
Weapons	27 t	1.3%	27 t	1.7%	27 t	1.7%
Light Ship	2095t	100%	1630t	100%	1641t	100%

Validation of Structural Weight

- Derived scantlings for a 10 m length of hull & superstructure.
- The scantlings were derived using the *ABS High Speed Naval Craft Rules*.

Built-up Stiffened Panel Hull & Superstructure



Scantlings

	STEEL	ALUMINUM	ALUMINUM PANELIZED
Bottom Shell Plate	12	13	13
Side Shell Plate	7	9	9
Superstructure Side Plate	7	9	
Superstructure Deck Plate	7	9	Shell 4mm with
Strength Deck Plate	7	9	40x4/30x15
2nd Deck Plate	7	9	on 75mm centers
Bulkhead Plate between Decks	7	9	9
Bulkhead Plate below Subdivision Deck	10	11	11
Bottom Longitudinals	T 200x10/100x20	T 240x10/140x25	T 240x10/140x26
Side Logitudinals	T 70x7/50x10	T 100x10/60x10	
Strength Deck Longitudinals	T 60x7/40x10	T 90x10/60x10	
2nd Deck Longitudinals	T 50x7/30x10	T 70x10/50x10	
Bulkhead Stiffener Above 2nd Deck	T 50x7/30x10	T 70x10/50x10	T 70x10/50x11
Bulkhead Stiffener Below 2nd Deck	T 120x7/60x15	T 180x10/80x15	T 180x10/80x16
Bottom Web Frame	T 700x7/160x20	T 800x10/180x20	T 800x10/180x21
SideWeb Frame above 2nd Deck	T 150x7/60x15	T 200x10/100x20	T 150x10/80x15
Side Web Frame below 2nd Deck	T 420x7/130x15	T 580x10/200x20	T 580x10/200x21
Superstructure Web Frame	T 150x7/60x15	T 200x10/100x20	T 150x10/80x15
Strength Deck Deep Beam	T 150x7/50x10	T 200x10/50x15	T 150x10/80x15
2nd Deck Deep Beam	T 120x7/50x10	T 160x10/50x10	T 160x10/50x11

Shade cells are those components affected by extrusions

Geometric Properties & Stresses

		Steel	Aluminum
Bending Moment Hogging	t m	146250	146250
Bending Moment Sagging	t m	109399	109399
Section Modulus deck	cm ² m	96091	111006
Section Modulus Keel	cm ² m	56856	63884
Stress Deck Hogging	t/cm ²	1.52	1.32
Stress Keel Hogging	t/cm ²	2.57	2.29
Stress Deck Sagging	t/cm ²	1.14	0.99
Stress Keel Sagging	t/cm ²	1.92	1.71

Structural Weights

STRUCTURAL COMPONENT	STEEL t	ALUMINUM t
Shell Plating	21.4	8.7
Deck Plating	27.2	11.7
Bulkhead Plating	7.2	3.5
Girder Plating	2.4	0.9
Shell Longitudinals	10.9	5.0
Deck Longitudinals	6.5	3.4
Bulkhead Stiffeners	2.1	0.9
Web Frames	6.1	3.2
Deck Deep Beams	3.7	2.2
Deck Girders	3.4	1.2
Structure Weight in t	91.0	40.7

Acquisition Cost

Fully Burdened Labor and Material Price Breakdowns (\$1,000)

	Steel		Aluminum Reduced Draft	
	Labor ¹	Material ²	Labor ¹	Material ²
Hull	\$42,778	\$6,610	\$64,043	\$6,969
Machinery	\$25,430	\$104,867	\$26,150	\$97,895
Electrical	\$6,638	\$36,142	\$6,638	\$36,723
Command & Communication	\$4,983	\$17,816	\$4,983	\$18,103
Auxiliary	\$22,239	\$18,860	\$24,277	\$19,164
Outfit	\$46,811	\$22,163	\$53,265	\$24,221
Weapons	\$243	\$783	\$242	\$796
SUB-TOTALS	\$149,122	\$207,241	\$179,598	\$203,794
SHIP TOTALS		\$356,363		\$383,392

1. Includes Labor Cost to install the Weapons and their Control Systems

2. Does NOT include Cost of Weapons and their Control Systems.

Acquisition Cost

Hull Man Hour and Material Breakdowns

	Steel		Aluminum Draft Reduced	
Labor	\$42.8 Million	87%	\$64.0 Million	89%
Material	\$6.6.Million	13%	\$7.0 Million	11%

- 20% improvement in material = cost benefit of \$1.4M.
- 20% improvement in labor = cost benefit of \$12.8M.
- Focus should be on improving labor productivity.

COMPARISON OF STEEL AND ALUMINUM STRUCTURE COST PER TON AND FOR EQUIVALENT SMALL FRIGATE

STEEL	\$49.4 M/901 Tons	= 54,823	Say \$55,000
ALUMINUM	\$71 M/436 Tons	= 162,844	Say \$160,000

ALMOST 3:1

HOWEVER THAT IS NOT CORRECT WAY TO COMPARE THE ALTERNATIVES

THE REAL RELATIVE COST OF STRUCTURE FOR AN EQUIVALENT ALUMINUM COMPARED TO STEEL SMALL FRIGATE IS:

Labor and Material	\$71 M/\$49.4 M	= 1.42 OR +42%
Labor	\$64 M/\$42.8M	= 1.47 OR +47%
Material	\$7 M/\$6.6 M	= 1.12 OR +12%

Total Ownership Cost (TOC)

- Fuel Example:
 - 71 t per voyage fuel savings is estimated.
 - Assuming the ships conduct 40 voyages per year, this would yield an annual fuel saving of 2840 t.
 - At today's price of around \$450/t, this is an annual cost saving of \$1.3M.
 - For a 25 year life-cycle, fuel cost savings would be \$32M.

Total Ownership Cost (TOC)

- Paint Example:
 - Cost to paint would be ~ \$500K (labor & material).
 - Assuming re-painting every five years.
 - Over life of ship, \$2.5M savings is estimated.



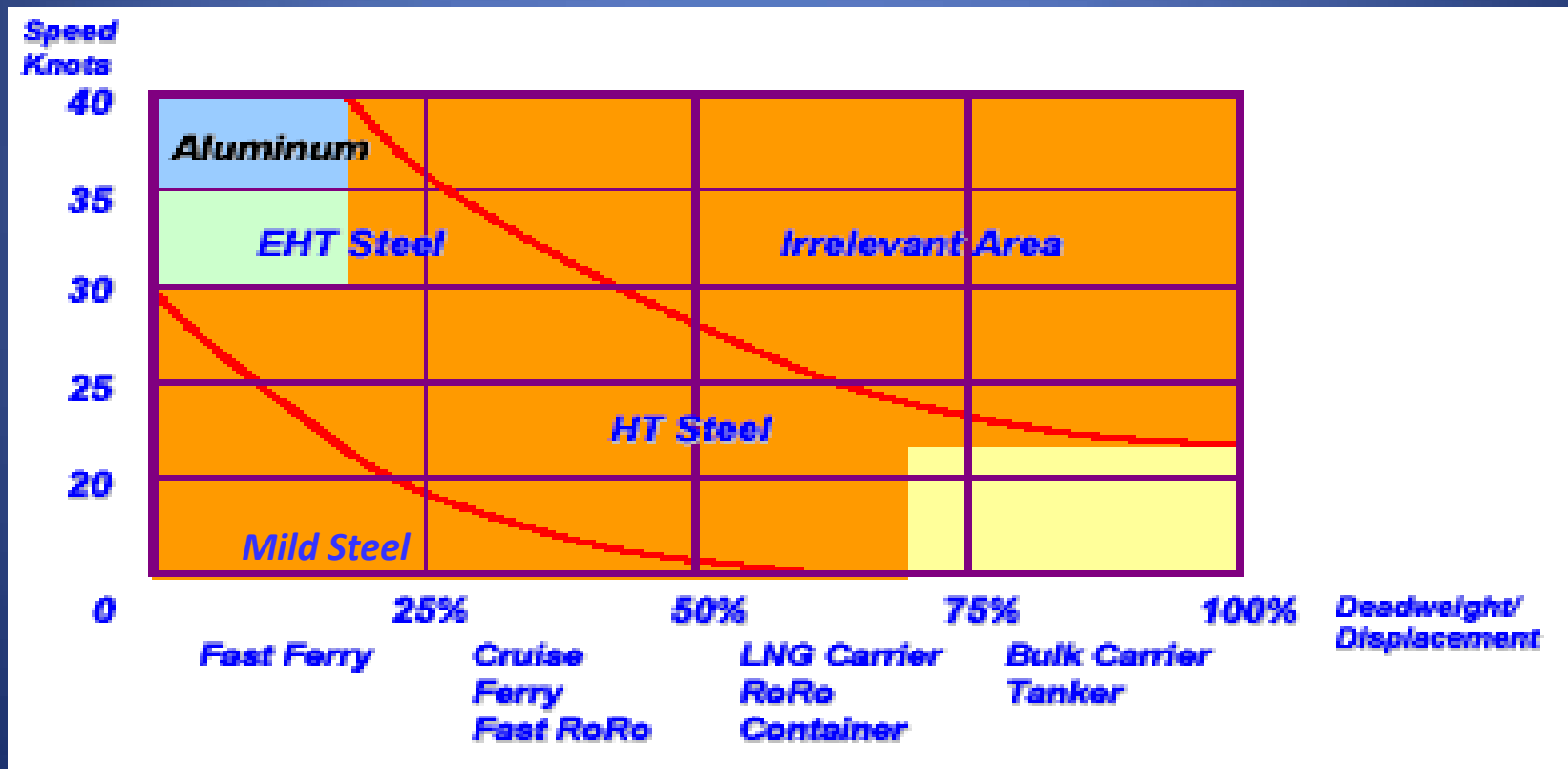
Total Ownership Cost (TOC)

- Aluminum ships have a TOC advantage, because they:
 - are lighter and thus require less power propulsion
 - can use less fuel than an equivalent steel ship
 - do not require painting
 - have a higher salvage value at end of life

Have a Lower Carbon Footprint

THE RIGHT APPLICATION

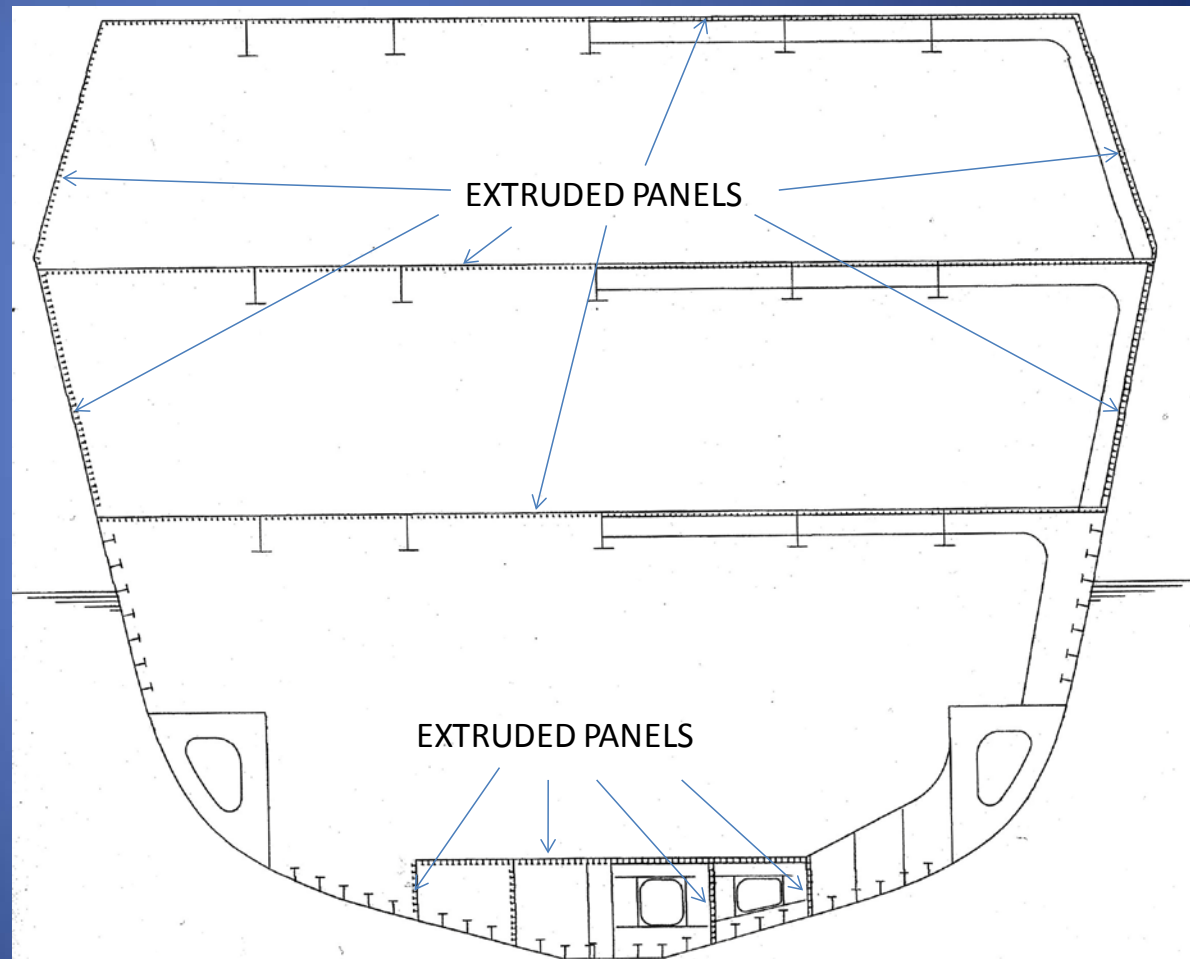
- Recent studies have shown that aluminum is the best solution for ships that have Deadweights (payloads) less than 20% of the Full Displacement even for moderate speeds (down to 15 knots). Plot from paper by Moan shows similar findings.



Advances in Technology

- Aluminum Extruded Panels Coupled with Friction Stir Welding (FSW)

Extruded Panelized Midship Section



Aluminum Built-up vs. Extruded Panel Ship Weights

STRUCTURAL COMPONENT	ALUMINUM BUILT-UP t	ALUMINUM EXTRUSIONS t
Shell Plating	8.7	8.2
Deck Plating	11.7	10.5
Bulkhead Plating	3.5	3.5
Girder Plating	0.9	0.9
Shell Longitudinals	5.0	3.5
Deck Longitudinals	3.4	0
Bulkhead Stiffeners	0.9	0.9
Web Frames	3.2	3.2
Deck Deep Beams	2.2	2.2
Deck Girders	1.2	1.2
Structure Weight in t	40.7	34.1

NOTE: The shaded items are those impacted by Extrusions.

JWL for Built-up vs. Extruded Panel Aluminum Ships (10 m Hull Length)

	Built-up Structure m	Extruded Structure m
Plating Seams	820	800
Friction Stir Welding of Extruded Panels ¹	0	1780
Longitudinals	3820	940
Built up Girders	300	600
Web Frames	2660	2880
Total Shipyard Welding	7600	5220

1. Note that total shipyard welding does NOT include friction stir welding of extruded panels

SMALL CRAFT CONSTRUCTION JIG



LARGE CRAFT/SMALL SHIP CONSTRUCTION JIG



Presented at NSRP PDMT Panel Meeting; June 15th, Pittsburgh, PA

Conclusions

- Aluminum structure is ~ 50% lighter than equivalent steel structure.
- This provides cascading weight and cost benefits.
- Makes aluminum ships acquisition cost competitive with steel.
- Structural materials account for only ~2% of surface combatant cost.
- Majority of structure cost is in manufacturing labor.

Conclusions

- Advancements in technology are improving the cost of aluminum ships further.
- Aluminum ships have a clear TOC advantage.
- Aluminum ships offer design and operational flexibility:
 - Reduced draft
 - Higher speed
 - Longer endurance (medium speed)
 - Increased payload
 - Greater stability

Conclusions

Aluminum is a proven structural material that can help navies meet their modern fleet needs.



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