

Metal-Forming Techniques

Chris Barry

IBEX 2004

Session 505

8:30 AM Wednesday, October 27, 2004.

“The Time Has Come, the Walrus Said, To Talk of Many Things”

- Bending Plate
- Bending Issues
- Definition Of Curved Plate
- Developed Surfaces
- Line Heating
- “English” Wheeling
- Designer’s Responsibility
- Resources

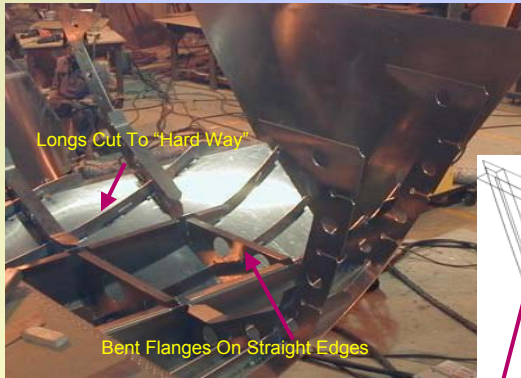


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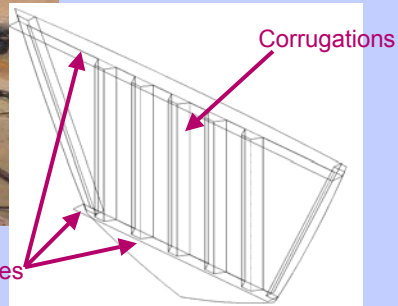
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Use Flanges, Corrugations Cut Instead Of Bending - With CNC



Bulkhead With
Minimized Welding:

Allows Use Of Lighter
Plate With Less
Distortion



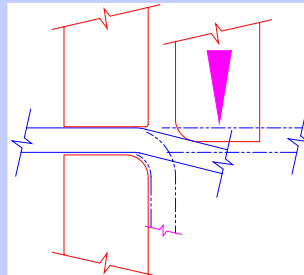
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Bending Plate

- Flanging, Corrugating And Rolling
 - Reduced Costs
 - Reduced Welding Distortion
- Forming Forces
- Bend Allowance & Springback
- Tool / Equipment Types
 - Press Brake
 - Flanging Machine
 - Rolls - Pyramid, Multi-Roll
- Tool / Equipment Limitations



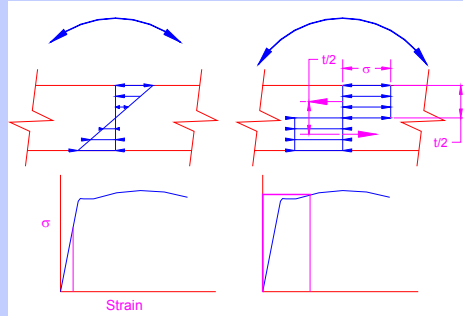
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Bending Forces

- Moment Increased Until Metal Reaches Yield Strength
- Stress Distribution Changes
- **Approximately** Uniform Through Thickness
- Curvature Proportional To Moment
- Moment Required = Area ($t/2$) * Arm ($t/2$) * σ
- Use Standard Formulas To Find Moment - But:
 - Double It For Friction, Actual vs. Handbook Values of Material Yield (Handbook Values Are *Minimums!*)



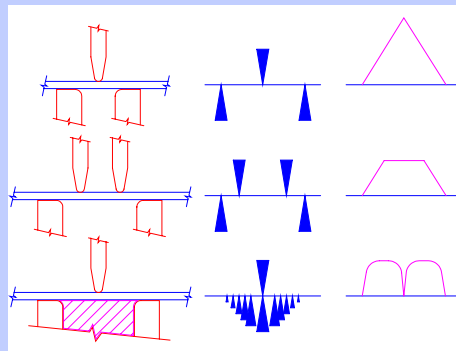
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Pressure & Load Form Effects

- 3 Point Bend:
Moment / Curvature
Decreases At Edges
- 4 Point Bend:
Moment / Curvature
Constant To Edges
But More Force Req'd,
Special Dies, Punches
- Elastomeric Die:
Punch Force Counteracted By Elastomer
Die Back Force Bends Plate
Die Back Force Reduces Toward Edges -
Constant Moment - Constant Curvature



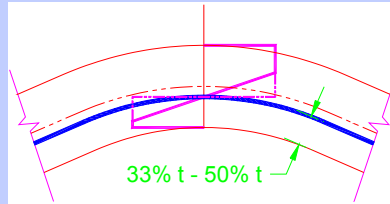
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Bend Allowance & Springback

- Neutral Neither Stretches Nor Shrinks
- Bend Will Be As Long As Neutral Axis
- Neutral Axis Not On Plate Center - Depends On Material - 33% Typical Increases With Harder Materials - Handbook
- $BA = \alpha / 360 * 2 \pi 33\% t$
- Springback - Material Isn't Really All Yielded - Residual Forces Cause Springback
- Overbend $\sim 3^\circ$
- Coin: Bottom Out Punch In Die To Compress Outside



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Tool Limits

- Some Bends Require Special Punches, Special Dies, Extra Hits - Increased Cost
 - U-Bends > 1.5 Height Apart
 - Long Flanges Require High Dies, Or Wipe Type Flanging Machine
- There Will Always Be A Straight Section At The End Of A Roll
 - Less With Four Point Rolls - If Yard Has One
 - Will Require Rework To Cut Off Flat
- Watch Out For Cones - Small End Radius
- Know The Specific Equipment Capabilities
- Be Sure Pressman Has Good Data



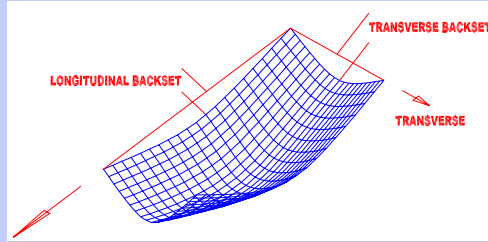
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Curved Plates

- Mathematical Curvature:
= $1 / \text{Radius}$
- Shipyard: “Backset”
= Depth / Width
- Also Interested In Twist
- Gaussian Curvature:
 - Maximum X Minimum
 - Zero = Single Curvature = *Developable* = No Stretch
Expanded Plates
 - Positive = “Double Curved” = Middle > Edges
 - Negative = “Warped” = Edges > Middle
 - Stretch By Force, Shrink By Line Heating (Not Aluminum)
 - Cut Surface Into Smaller Pieces (“Restrake”)



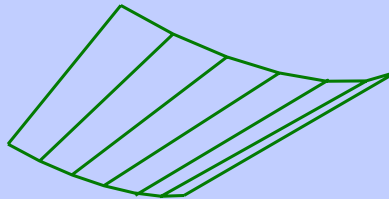
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What Are Developable Surfaces?

- Can Be *Developed* Onto Flat Surface Without Stretching
- “Zero Guassian Curvature”
- Single Curved
- Rulings - Straight Lines
- Running Between Two Curves (Chines)
 - However, All Ruled Surfaces Aren’t Developable
 - Warped Surfaces Have Rulings, But Don’t Develop
- Each Adjacent Pair of Rulings Is Coplanar
 - A Surface Made With Many Small Folds



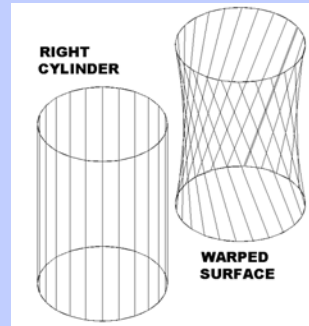
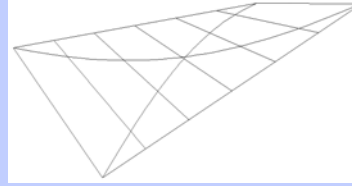
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Ruled Surface Is Not Sufficient !

- Developable Surface **Must Have Rulings**
- Warped Plate - **Not Developable**
 - Rulings Straight In Two Directions - **But**
 - Rulings Are **NOT** The Min & Max (Principal) Curvature
- Infinite Number Of Ruled Surfaces
- One (At Most) Is Developable



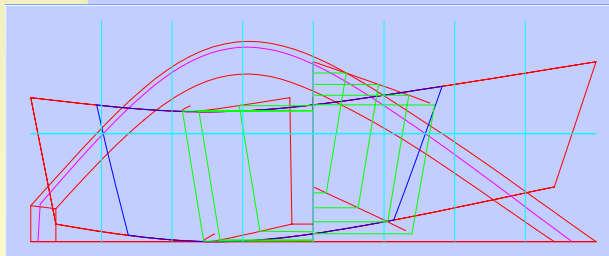
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Coplanar Rulings

- The Tangents On The Chines Are Also Coplanar
- Rulings Are Parallel
 - Cylinders - Dory Type Hulls
- Rulings Intersect
 - Cones (All Rulings Intersect at One Point)
 - Other Surfaces (Only Adjacent Pairs Intersect)



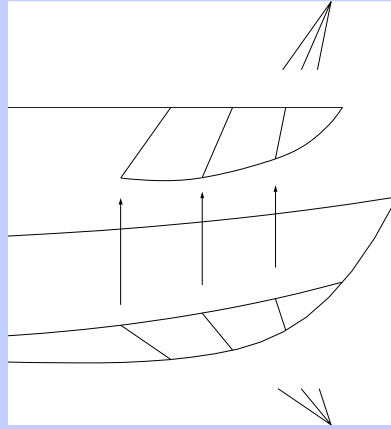
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How to Make Developable Surfaces

- Find Rulings For Given Chines
- Force Chines With Coplanar Rulings - Rabl's Method
 - Define Chines, Leave One Plane Free On One Curve Typically Keel, Chine (In Plan View) Are Fixed
 - Pick An Intersection, Draw Rulings Through Chines
 - Find Missing Curve View From The Intersections



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Find Rulings For Arbitrary Chines

- Kilgore's Method
- Calculation (Computer Based)
- But - Finding Rulings Gives Approximate Rulings
 - Up To About 6 Degrees OK For Metal
 - Very Limited For Plywood - Shear Stress Limits
 - There Is At Most One True Developable Between Given Chines
 - Infinite Number Of Approximate Developables
 - Many Of Them Won't Be Fair
 - Common Problem With Computer Lofting
 - Requires User Understanding Of Program

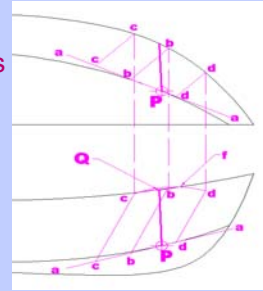
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Kilgore's Method (By Hand)

- Draw Tangent **aa** At **P** On One Chine, Both Views
- Draw **bb** Intersecting Other Chine In Both Views
- Draw **cc**, **dd** || To **bb** In Both Views
- Transfer Intersections **b**, **c**, **d** To The Other View
- Pass Curve **f** Through The Points In That View
- The Tangent To **P** is Midpoint Of The Curve Between Intersections - **Q**
- **Line PQ Is A Ruling (Approximately) Of The Developable At P**
- Why?
 - 3 Parallel Lines Are Tangent Plane To 1st Chine, & Cut 2nd
 - The Curve Was Trace Of A Cylinder Of 2nd Chine On The Plane
 - Midpoint Is Where Cylinder Passes Through Plane & Is Tangent



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Simple With 3D CAD

- Guess A Ruling
- Make A Coordinate System (UCS) On The Ruling
 - X Axis Origin At One End,
 - X Axis Along The Ruling
 - Select An Adjacent Point On The Chine As A Point In The Positive Y Plane
- Flip The Coordinate System 90° Around Y
- Change View To "Plane" In New Coordinate System
 - Looking Down The Ruling & Can See The Tangent
 - Now Put The Right Ruling In - Draw A Line From The Origin To the Obvious Tangent



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Computation

- Vector Is Three Numbers Times Unit Vectors In X, Y, Z (3 miles North, 2 West, 1 Up), Called i, j, & k

- The Vector Cross Product of **1 x 2** Is (Cramer's Rule):

$$\text{Det} \begin{vmatrix} i & j & k \\ x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \end{vmatrix} = +i*y_1*z_2 + j*z_1*x_2 + k*x_1*y_2 - k*y_1*x_2 - i*y_2*z_1 - j*z_2*x_1$$

- If The Cross Product Is 0, The Vectors Are Parallel
- Find Cross Product Of Ruling & One Tangent
- Find Cross Product Of Ruling & Other Tangent
- Find Cross Product Of The Two Cross Products
- Warp Angle = Arcsine (| **1 x 2** | / |**1**| * |**2**|)

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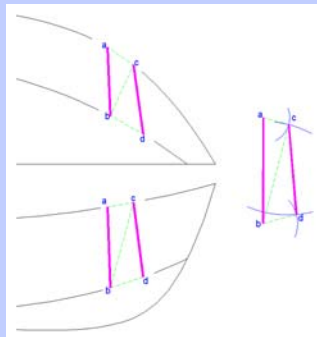
Plate Development

- Given Rulings, Development Easy
- Most Methods Use Triangulation
- Find Length Of One Ruling **ab**

$$ab = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2 + (z_a - z_b)^2}$$

Or Projection Techniques (By Hand)

- Find Distance Along Chine **ac**
- Find Distance **bc**
- Lay Out Triangle **acb**
- Repeat for Triangle **bcd**, Etc., Etc. (Easy For Computer)
- In CAD - Lay Plate Flat & Unroll On Rulings



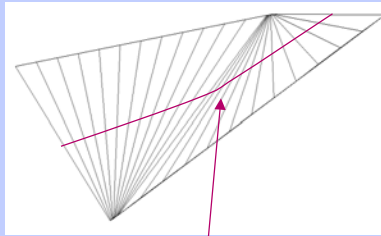
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Implementation

- Export Chine Data From CAD
- Use A Spreadsheet
- Get A Program That Does It
 - *ShipConstructor, Develop*
 - Control The Resulting Surface
 - Set Maximum Warp & “Fanning”
 - Trap - “Bad Fans” - Developable But Unfair
 - Tricks:
 - Extend The Chines Off The Real Hull, Plate & Trim
 - Transverse Curve With Correct Rulings On Chine
 - Break Chine Curves At Rulings, Plate Separately



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Using Distortion - Line Heating

- We Can Use Heat To Form (Steel Only)
 - Very Good For Forming Double Plates
- Gradual Process, Very Accurate
 - Very Good For Accuracy Control (Joining Modules)
- Simple Equipment
 - Concentrated Heat - Cutting Torch Tip (Cutting OFF!)
 - Water Hose or Compressed Air With Water Aspirator
- Apply Restraint To Counter Initial Expansion
- Speed of Travel Controls Bending or Shrinkage
- Use Sight Templates To Control Shape
 - CAD/CAM Software Provides Templates Automatically

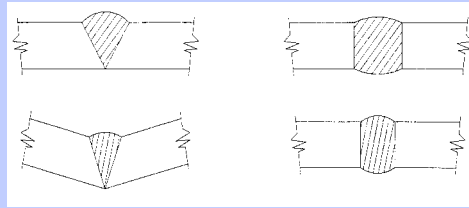
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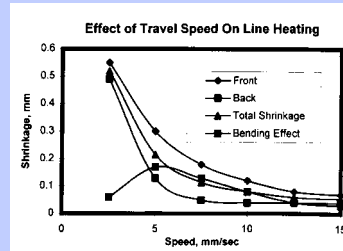
Line Heating

- Heat Expands Metal
- Metal Softens
- Is Restrained By Adjacent Cold Material
- Increases In Thickness
- Cools, Solidifies, Shrinks
- Metal Pulls In To Make Up Lost Volume
- Fast Travel, More Bending
- Slow Travel, More Shrinkage (Use For Double Curving)



Fast Travel

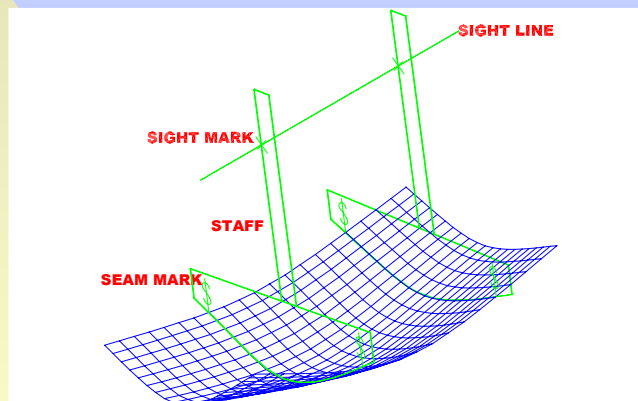
Slow Travel



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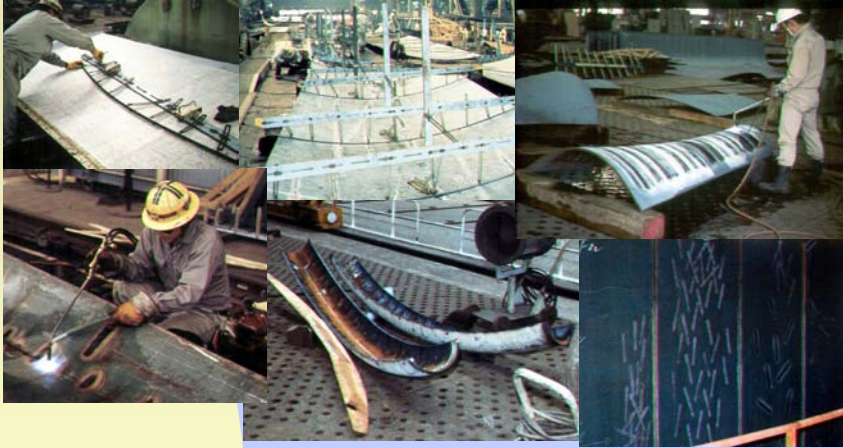
Sight Templates: To Measure Curvature



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Line Heating In Action



Photos Courtesy Lou Chirillo, IHI (Japan),
National Shipbuilding Research Program
NSNet, (<http://www.nsnet.com>)

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“English” Wheel

- Can't Use Line Heating On Aluminum
 - Heat Reduces Strength Properties, Low Melting Point
- Do The Opposite - Stretch The Metal By Pushing In
- Spherical Pressure Point - Very Small Contact Zone
- Easy To Get Enough Pressure - Push On Small Area
- Double Curved Wheel On One Side
- Cylindrical Wheel As Support
- Roll Metal Between Wheels - Lines Of Expansion
- Use Sight Templates - Just Like Steel
- CAD/CAM Software Can Account For Shrinkage Or Expansion & Direction Of Distortion Field

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Wheeling Aluminum



- Doesn't Require Much Force
- Wheels Can Be Yard Made

Photos Courtesy
Graham Radford Yacht Design
PO Box 1155
Brookvale NSW 2100 Australia



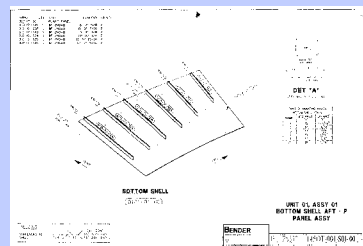
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Design Data For Forming

- Workshop Sketches
- Sight Templates (Pin Jig)
 - Needed Dimensional Data
 - Only The Part You Need
 - From Some Software
- Add Surface Data To Lines
 - Show, Tabulate Surfaces
 - Tabulate Rulings (On A Table Of Offsets)
 - Tabulate Plate Edges ("Sight Edges") - Traditional
 - Show Bow Cone Data- Axis Of Cone, Radii
- Understand Shipyard Requirements, Capabilities
 - Neat Cut Plates - If You Know Distortion Used



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Resources

- www.sname.org
 - Marine Technology
 - Journal Of Ship Production
 - Ship Production Symposium
 - T&R Panels
- Ship Structure Committee: www.ssc.org
- NSRP: www.USAShipbuilding.com, www.nsnet.com
- Why Not Recreational Boat Production Program?
- FMA: www.thefabricator.com, www.fmanet.org
- PMA: www.metalfformingmagazine.com
- AISC: www.modernsteel.com
- Yahoo Group: Tinboats (tinboats@groups.yahoo.com)

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