



National Shipbuilding Research Program All-Panel Meeting 2011

Design Space Navigator for Beam-Stiffened Ship Structures

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Applied Thermal Sciences, Inc.

Outline

- **Programmatic Overview**
- **Historical Perspective**
- **Technical Approach**
 - **“Optimal Design”**
 - **“Clean sheet of paper” - no prior design**
 - **“Substitutional Design”**
 - **Replacement of existing T-beams in existing design**
- **Design Tool Development Overview**
 - **“Design Space Navigator”**
 - **Beta Trials**
- **Recommended Future Work**

The Choice:

The ship you get with the shape “they” got

Or

The shape you need for the ship you want

Pick ***ONE!***

NSRP Ship Design & Material Technologies Panel Project
“Design Manual for Fabricated Shapes”

Awarded February, 2011

Project Team:

Applied Thermal Sciences, Inc.

HII - Ingalls

Concurrent Technologies Corp.

Fincanteri - Marinette Marine

Scheduled Completion: 1/31/2012

Programmatic Update

- Project Team: ATS – NGSB-GC – Marinette Marine - CTC
- Contracts / Subcontracts in Place: February 2011
- Conference Call with Marinette Marine 2/22/11 & 5/19/11
- “Optimal” Approach;
- “Look and Feel” of “Manual of Combined Properties...”
- “Alpha” Design Tool Development Completed April 2011
 - Inputs / Outputs / Constraints / User Interface
- Beta-Level Review Started 6/13/2011
- Developing User’s Manual
- Determination of Next Steps
- Project Status - ~ 80% Complete
- Funding Status - ~ 20% Remaining
- Completion well before 1/31/2012

Problems with Hot Rolled Shapes

Availability:

- Split or Stripped from I and W Shapes
- Mill Catalog & Schedule Limited

Weight:

- Avg. 5% Over Nominal,
- Not Optimized for Weight

Accuracy:

- Sweep, Twist and Camber to 5/8" in 50',
- Dims typically to +/- 3/16"

Variability:

- Major Cause of Rework,
- Prevents Simple Automation

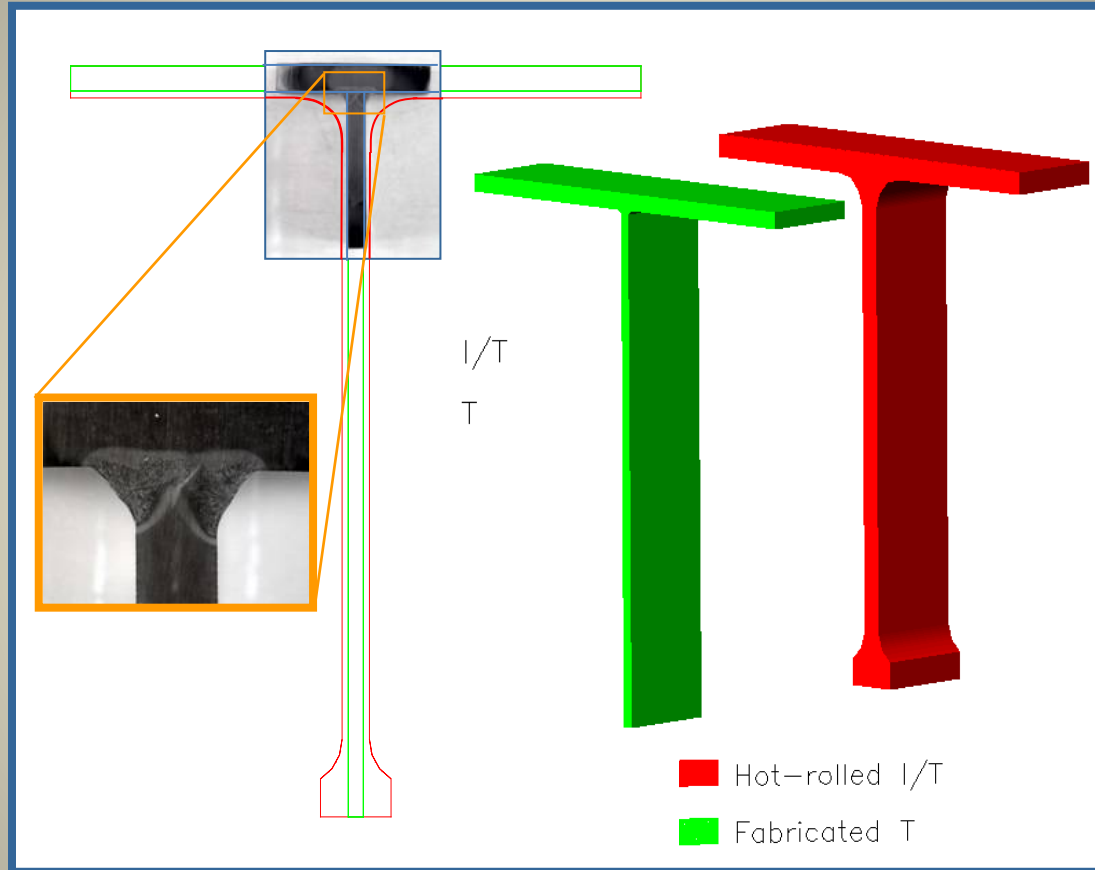
Cost:

- Raw Material Increasing
- Down Stream Assembly Costs: Extensive Fabrication & Rework

Benefits of Precision Beams

- **Weight Reduction**
 - Up to 20% through optimization
 - Up to 50% through optimization and high-yield materials
- **Accuracy Improvement**
 - Beam $\frac{1}{4}$ - $\frac{1}{10}$ the tolerance of hot rolled beams (ASTM-A6)
 - All features, holes, end cuts and markings to ± 0.005
- **Cost Reduction**
 - Procurement Cost-
 - Small increase in 1st costs over hot rolled beams
 - Very competitive with conventionally welded beams
 - Total Costs
 - Reduced in structural fab & assembly costs
 - Reduced inventory and cataloging costs

Benefits of Fabricate Shapes



9.0# AH-36 I/T Replaced by 6.3# DH-36 Fabricated Tee (33% wt. savings)

(Source: NSRP 7-91-4)

Historical Perspective

- Legacy Stiffeners
 - I/T's, W/T's, Angles, Bulb Flats, Flats
- First NSRP-Funded Analysis
 - N7-91-4 Tee-Beam Manufacturing Analysis (I/T's)
- Extended Analysis
 - DDG-51 Shapes – included W/T's as well as I/T'S
- Implementation on CVN-78
 - Shift to HSLA-65; Saves >450 Tons; Saves Assembly Costs
- ATS Completes Sandwich Panel Design Tool
 - Fast Iteration of Potential Designs
 - Less Than One Minute 30 Combinations of 16 design attributes
- Implementation on DDG-1000
 - Shift to HSLA-80
- Inquiry Regarding LCS
 - Issues with Mill Schedules, Interested in Potential

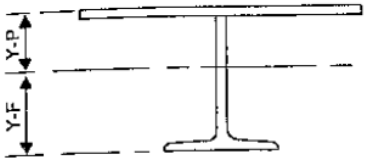
Referential Guidelines

MANUAL OF PROPERTIES OF COMBINED BEAM AND PLATE

PART I **TEES AND ANGLES**

Coordinated by the Society of Naval Architects and Marine Engineers for the Maritime Administration, U. S. Department of Commerce, and the Bureau of Ships, Department of the Navy

Referential Guidelines



STEEL

**PROPERTIES OF
COMBINED BEAM AND PLATE
I-T AND T**

60t

5.1# PLATE WEIGHT

NOMINAL SIZE IN. x IN. x LBS./FT.	WEIGHT PER FOOT LBS.	SECTION MODULUS		I IN. ⁴	r IN.	YF IN.	YP IN.	BEAM DIMENSIONS				
		LESSER IN. ³	GREATER IN. ³					AREA IN. ²	DEPTH IN.	FLANGE		SHEAR AREA IN. ²
										WIDTH IN.	THICK IN.	
18 x 11 3/4 x 105 I-T	71.22	70.6	161.4	905.8	6.43	5.6	12.8	20.95	18.32	11.79	0.911	10.14
96 I-T	65.10	65.2	148.0	827.6	6.42	5.6	12.7	19.15	18.16	11.75	0.831	9.29
18 x 8 3/4 x 85 I-T	60.34	66.1	128.7	805.3	6.56	6.3	12.2	17.75	18.32	8.84	0.911	9.63
77 I-T	54.46	60.4	117.4	728.9	6.56	6.2	12.1	16.02	18.16	8.79	0.831	8.62
70 I-T	49.48	55.6	106.9	663.0	6.54	6.2	11.9	14.55	18.00	8.75	0.751	7.88
64 T-T	45.19	51.7	98.3	609.4	6.54	6.2	11.8	13.29	17.86	8.71	0.686	7.20

Tool Development Overview

- Design and develop:
 - BEAM-stiffened plate optimization tool
 - MS Excel / Visual Basic
 - Run as a macro within MS Excel
- User Manual:
 - Guide for the using the tool
 - Section on fundamental theory

Input Parameters

- Load Case
 - Simply supported with uniform pressure distribution
- Span or Frame Spacing
 - Input parameters (Substitutional)
 - Output values (Optimal design)
- Safety Factor
- Deflection Criteria

rt Page

Load Input

Uniform Pressure (lb/ft²)

Span (ft)

Global Deflection Criteria ▾

Local Deflection Criteria

Minimum Plating Thickness Criteria

Case 1 Case 2 Case 3

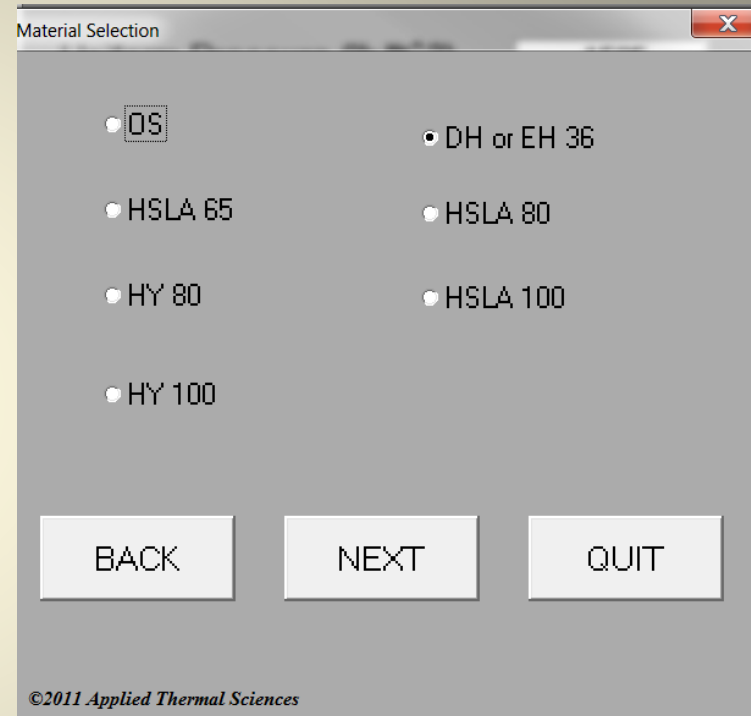
Plating Location	Loading Scenario	
Shell below a line 2 ft below the full load waterline and Tank boundaries, Floodable Voids and Bulkheads separating adjacent compensated fuel tanks	Wave Impact, Hydrostatic Head, Compensated fuel tank pressures, Tank pressure to top of overflow, Hydrostatic pressure to tank top or to overflow	<input type="radio"/> Case 1
		<input type="radio"/> Case 2
		<input checked="" type="radio"/> Case 3

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Input Parameters (continued)

Material Selection Dialog box:

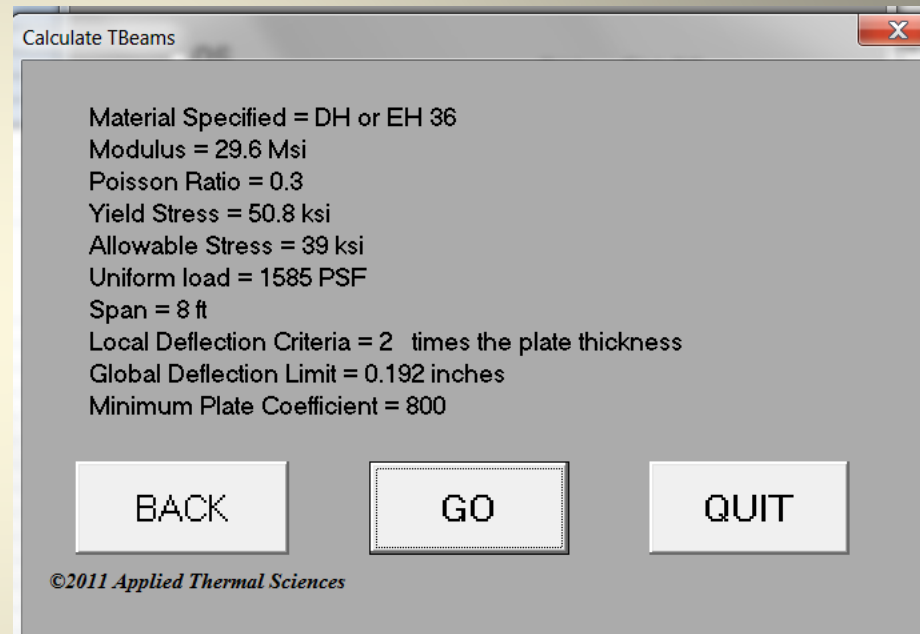
- All steel alloys currently in NVR:
 - OS
 - DH 36 /EH 36
 - HSLA 65
 - HSLA 80
 - HSLA 100
 - HY80
 - HY100
- Program selects & computes:
 - Standard thicknesses
 - 1/8" - 3/4" in 1/16" increments
 - Easily converted to metric units
 - Can be converted to gauge units



Input Parameters (continued)

Final Dialog box:

- Summarizes input values
- Options as shown



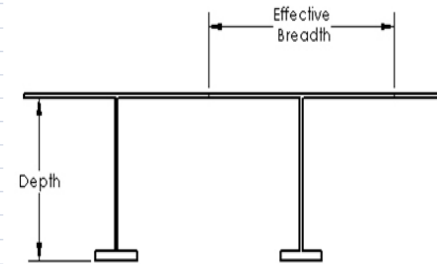
Input Parameters (continued)

Portion of Input Screen

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Date	6/13/2011													
2	Material Description	DH or EH 36													
3	Modulus of Elasticity (psi)	29600000													
4	Yield Stress (psi)	50800													
5	Allowable Stress (psi)	39843													
6	Poisson Ratio	0.300													
7	Weight Density (lbs/cu. in.)	0.284													
8	Safety Factor	1.3													
9	Required Span (ft)	8.0													
10	Maximum Global Deflection (in.)	0.192													
11	Uniform Pressure (psi)	11.01													
12															
13															
14															
15	Spacing	6													
16	Option	Weight Per Sq. Ft.	Center Deflection Ratio	Local Deflection UF	Local Stress UF	Web Shear Stress UF	Normal Stress UF	Limiting Element	Effective Breadth (in)	Stiffener Spacing (in)	Plate Thickness (in)	Lesser Section Modulus (in ³)	Greater Section Modulus (in ³)	Effective I (in ⁴)	r (in)
17	1	12.6	522	12%	46%	19%	63%	Flange	6.0	6.0	0.125	3.0	5.2	13.4	2.70
18	2	13.8	516	12%	46%	22%	48%	Flange	6.0	6.0	0.125	4.0	4.8	13.3	2.56
19	3	16.2	502	12%	46%	25%	43%	Plate	6.0	6.0	0.125	4.4	5.3	12.9	2.33
20	4	19.8	546	12%	46%	26%	44%	Plate	6.0	6.0	0.125	4.3	7.2	14.0	2.20
21	5	24.1	500	12%	46%	29%	48%	Plate	6.0	6.0	0.125	3.9	8.6	12.9	1.91
22	6	29.6	553	12%	46%	29%	47%	Plate	6.0	6.0	0.125	4.0	11.0	14.2	1.81
23	7	35.8	530	12%	46%	31%	50%	Plate	6.0	6.0	0.125	3.8	12.6	13.6	1.61
24	8	39.2	542	12%	46%	31%	50%	Plate	6.0	6.0	0.125	3.9	13.8	13.9	1.56
25	9	46.6	506	12%	46%	33%	52%	Plate	6.0	6.0	0.125	3.7	14.8	13.0	1.38
26	10	55.2	532	12%	46%	33%	51%	Plate	6.0	6.0	0.125	3.7	16.7	13.7	1.30
27	11	64.5	557	12%	46%	33%	50%	Plate	6.0	6.0	0.125	3.8	18.3	14.3	1.23
28	12	74.6	511	12%	46%	36%	53%	Plate	6.0	6.0	0.125	3.6	19.9	13.1	1.16

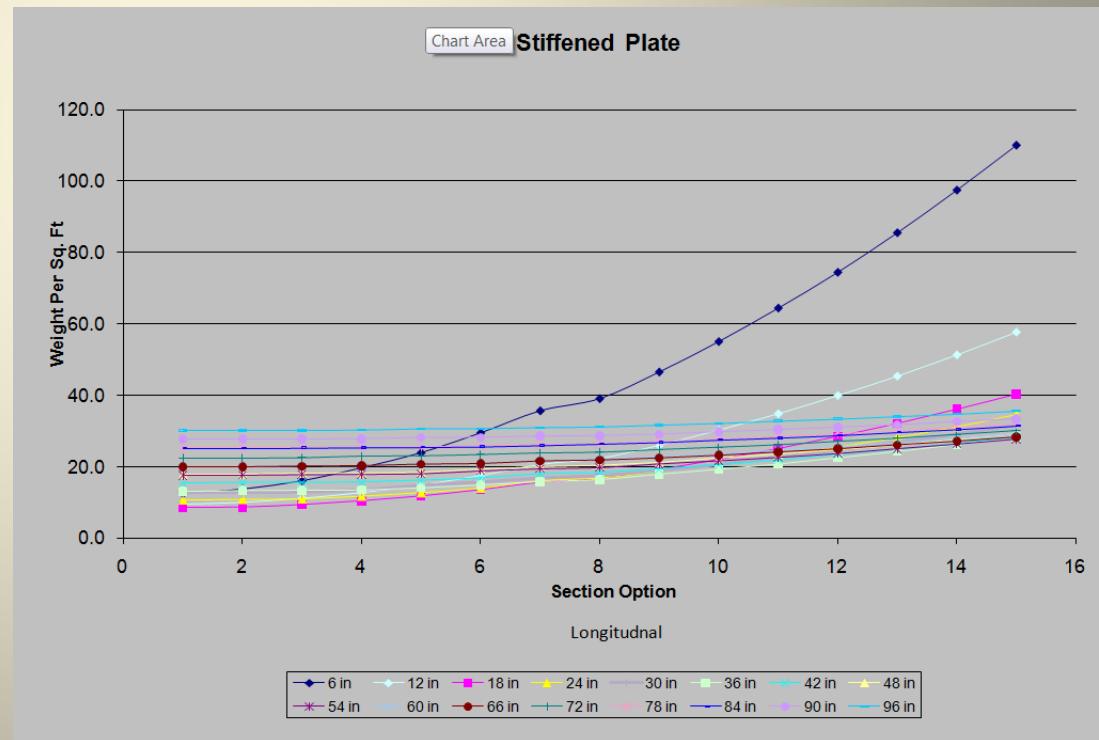
**Start Steel Tbeam Design
Space Navigator**

**Copy Data to Summary
Sheet**



Output Parameters

- Table of output parameters
 - T-Beam
 - Elastic properties: I_{xx} , I_{yy} , S_x , S_y , r_x , and r_y
 - Area
 - Web details
 - Flange details
 - Stiffener Spacing



Summary: Input & Output Parameters

Input Parameters				
Load	Span	Dfl Crit -Global	Dfl Crit-Local	Min Pltg Crit
Mat'l (Catlg)	Mat'l Usr-Def	Modulus	Poisson's Ratio	Yield Stress
Density	Safety Factor	Min Pltg "C" Fctr		

Output Values				
"Option"	Weight/Sq Ft	Ctr Defl Ratio	Local Defl UF	Local Strs UF
Web Shr Strs UF	Norml Strs UF	Lmtg Elmnt P? F?	Pl Thk Min	Lsr Sect Mod
Grtr Sect Mod	Effective I	R Gyr – Eff Sect	YF –ctrd to Flg	YP-Ctrd to Pl
Area – Full Sect	Sect Depth	Flg Width	Flg Thickness	Shear Area
Sect Wgt/ft	Web Thickns	I –Major Axis	Sect Md Mjr A	R Gyr Major
I Minor Axis	S Minor Axis	R Gyr - Minor	K- dst flg -ctrd	Name
Eff. Breadth	Int. Lat. Suppt			

Plate Calculation Validation

Reference:

Theory of Plates and Shells, 2nd Edition, S. Timoshenko, McGraw-Hill, 1959. pgs 4-12

Assumption:

Cylindrical Bending of Uniformly Loaded Rectangular Plates with Simply Supported Edges.

Example problem presented on pg 11 and 12

Plate Calculation Validation (cont.)

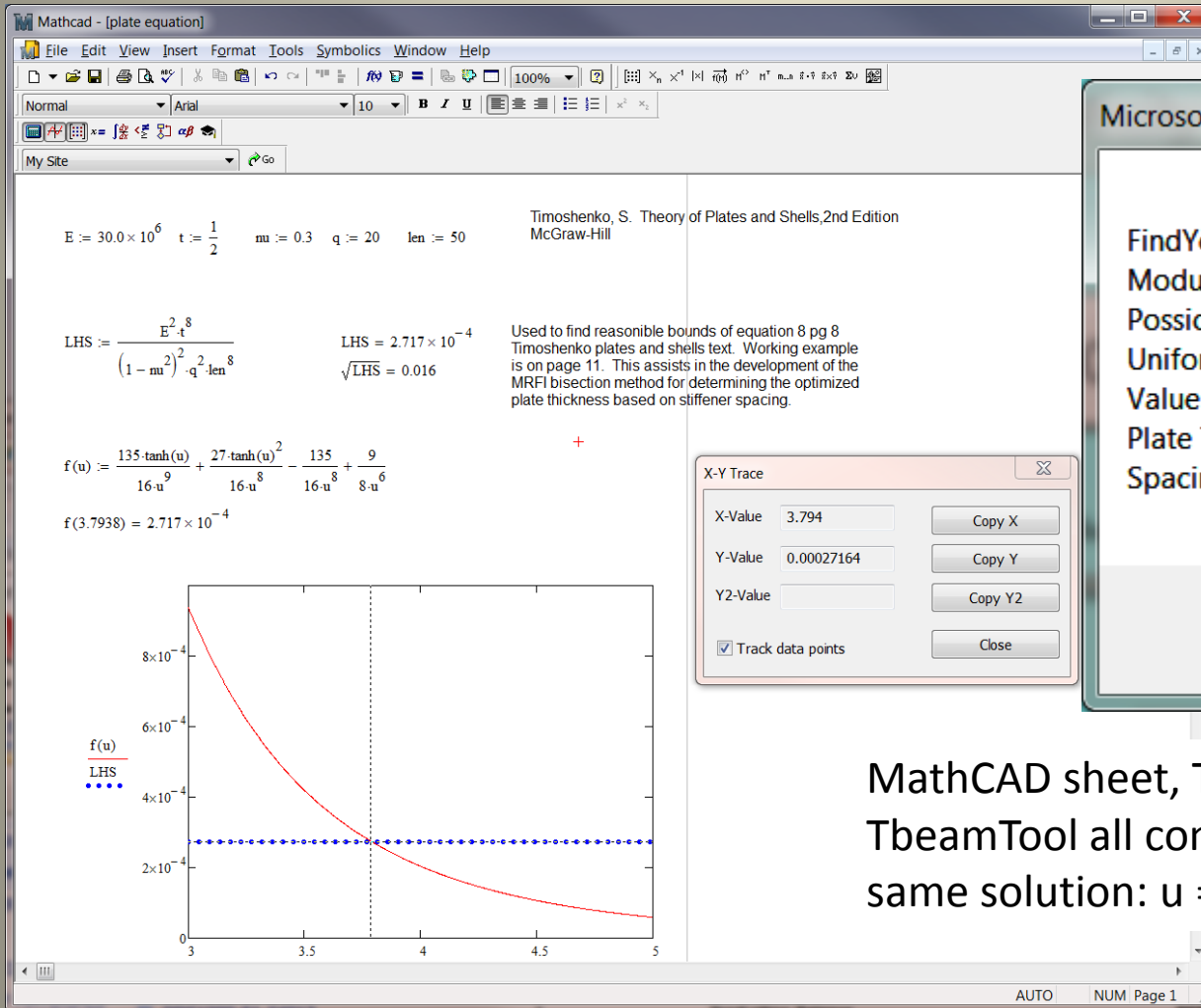
Solution to the differential Equation

$$\frac{E \cdot t^3}{(1 - \nu^2)^2 \cdot q \cdot \text{len}^3} = \frac{135 \cdot \tanh(u)}{16 \cdot u^9} + \frac{27 \cdot \tanh(u)^2}{16 \cdot u^8} - \frac{135}{16 \cdot u^8} + \frac{9}{8 \cdot u^6}$$

The variable u cannot be solved explicitly therefore, a numerical bisection techniques is employed to solve for u .

The technique chosen was the Modified Regula Falsi Method

Plate Calculation Validation (cont.)



Microsoft Excel

FindYou Function - Under Development

Modulus (psi) = 30000000

Possion Ratio = 0.3

Uniform Pressure (psi) = 20

Value of U = 3.79383054076032

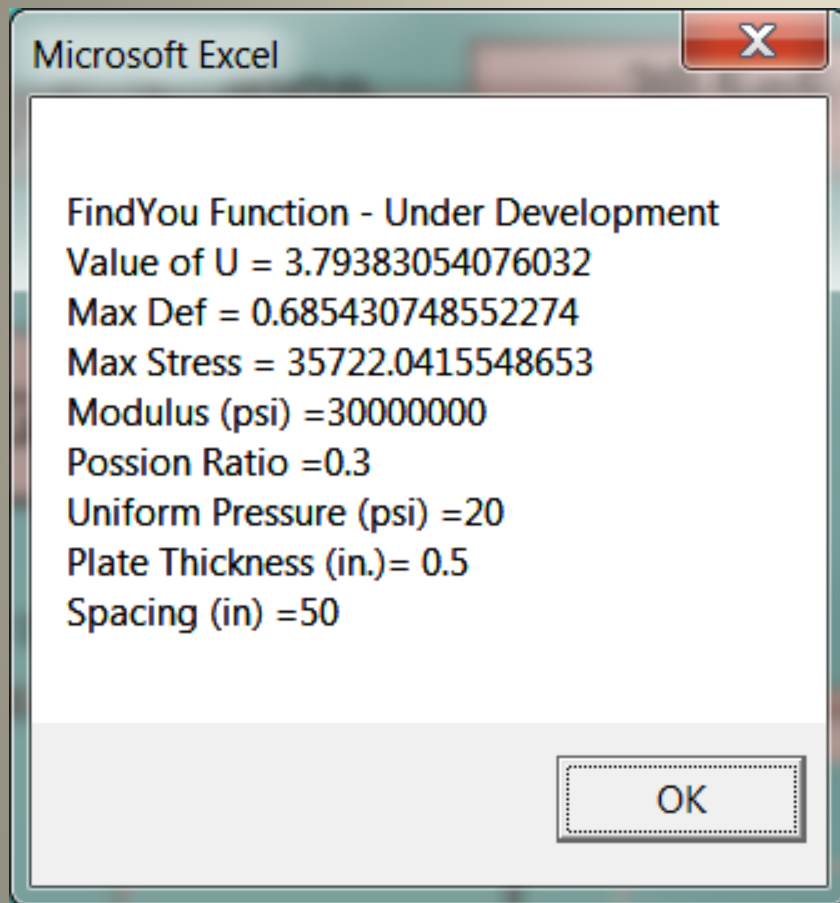
Plate Thickness (in.) = 0.5

Spacing (in) = 50

OK

MathCAD sheet, Text and TbeamTool all converge on the same solution: $u = 3.7938$

Plate Calculation Validation (cont.)



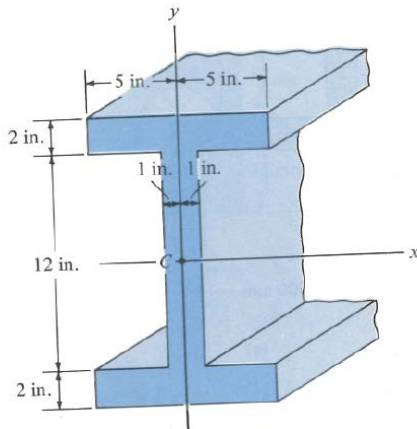
The Text presents a maximum deflection of 0.688 inches and a maximum stress of 35,760 psi.

The difference are due to the rounding errors in the text

Effective I-Beam Validation

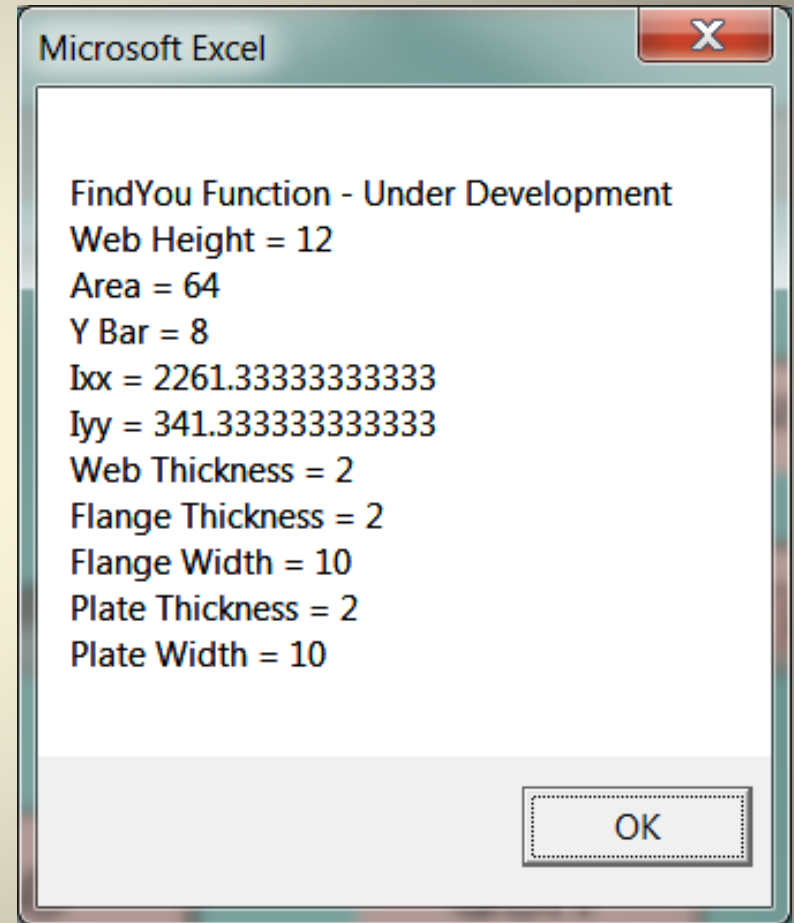
Problem Taken from a Statics Text solution provided as:
 $I_{xx}=2260$, $I_{yy}=341$ inches⁴

10–22. Determine the moment of inertia of the beam's cross-sectional area about the x axis.



Probs. 10–22/10–23

10–23. Determine the moment of inertia of the beam's cross-sectional area about the y axis.



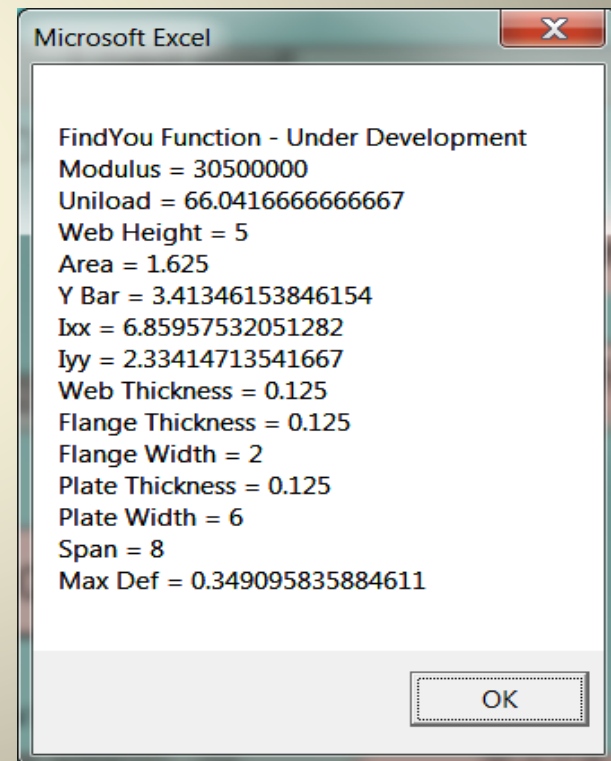
Effective I-Beam Validation (cont)

**Peak deflection for a
uniformly loaded simply
supported beam**

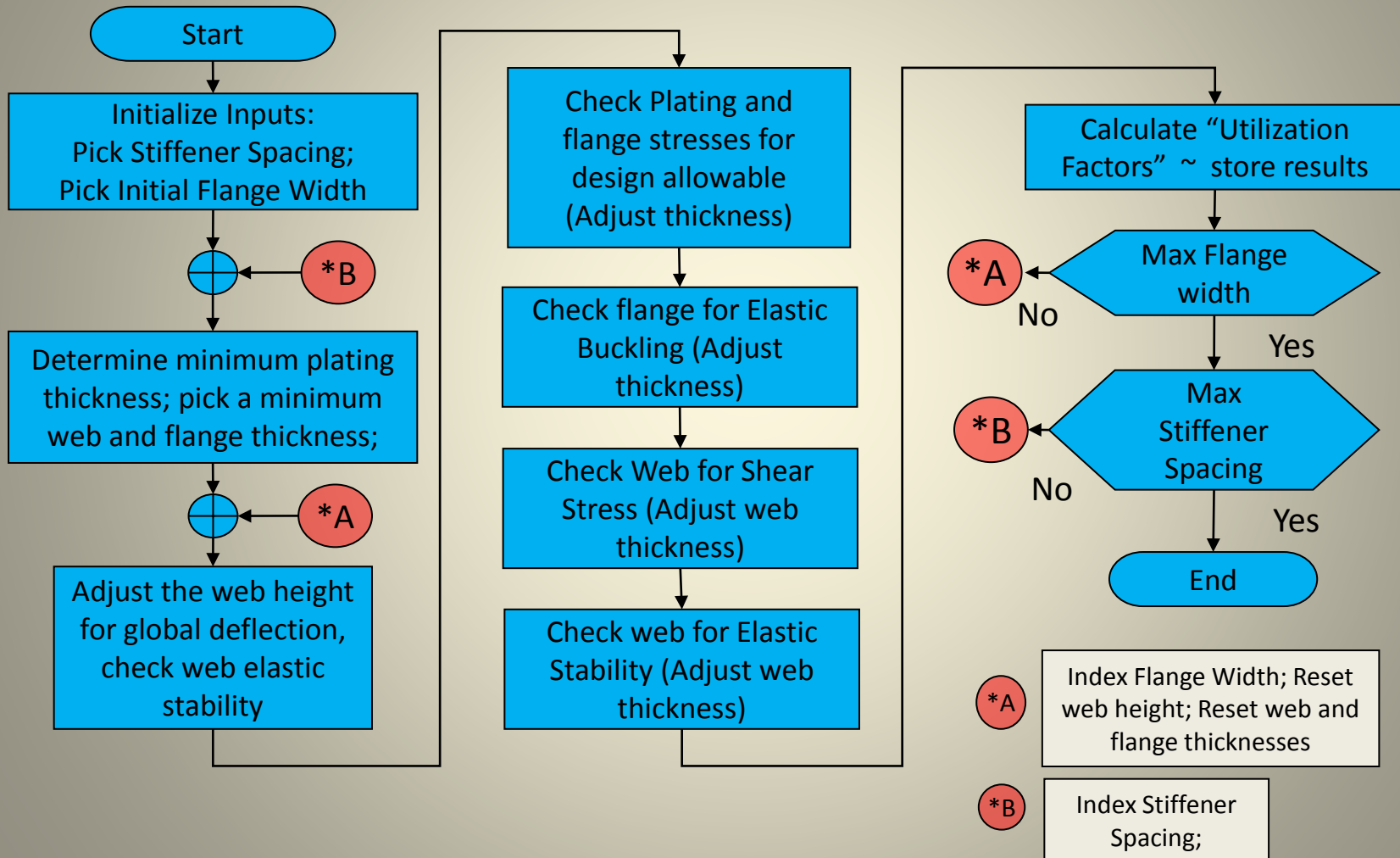
$$y_{\max} = \frac{5wL^4}{384EI}$$

$$y_{\max} = \frac{5 * 66.042 * 96^4}{384 * 30.5e^6 * 6.8596}$$

$$y_{\max} = 0.34909$$



Program Flow Diagram



Summary: Input & Output Parameters

Input Parameters				
Load	Span	Dfl Crit -Global	Dfl Crit-Local	Min Pltg Crit
Mat'l (Catlg)	Mat'l Usr-Def	Modulus	Poisson's Ratio	Yield Stress
Density	Safety Factor	Min Pltg "C" Fctr		

Output Values				
"Option"	Weight/Sq Ft	Ctr Defl Ratio	Local Defl UF	Local Strs UF
Web Shr Strs UF	Norml Strs UF	Lmtg Elmnt P? F?	Pl Thk Min	Lsr Sect Mod
Grtr Sect Mod	Effective I	R Gyr – Eff Sect	YF –ctrd to Flg	YP-Ctrd to Pl
Area – Full Sect	Sect Depth	Flg Width	Flg Thickness	Shear Area
Sect Wgt/ft	Web Thickns	I –Major Axis	Sect Md Mjr A	R Gyr Major
I Minor Axis	S Minor Axis	R Gyr - Minor	K- dst flg -ctrd	Name
Eff. Breadth				

Future Work

- Complete Beta Testing
 - Secure comments from shipyard
 - Update and complete
 - Finish “User Manual”
- Depending on Resources
 - “Publish” - Release to NSRP Community
 - Hold a Workshop for Potential Users
- Potential future project
 - Evaluate “In-Plane” Loading Scenarios
 - Evaluate other materials (e.g., Aluminum)

Questions?



Applied Thermal Sciences, Inc.

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