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VAASEL-ANSYS COMPARISION FOR A THERMALLY LOADED BEAM

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FORWARD

This report was prepared by Ms Estelle R. Anselmo, Aerospace Engineer in the Loads and Criteria Group, Structural Integrity Branch, Structures Division at Wright-Patterson AFB, Ohio. This effort was performed to verify the VAASEL computer code's thermal stress analysis capabilities.

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ABSTRACT

This report presents the results of calculating the deflection and stresses in a thermally loaded beam. Three different methods were used for the calculation: classical beam theory, ANSYS (Version 4.4) and VAASEL (Version 1.1). Comparisons between each of the methods are presented.

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1. INTRODUCTION

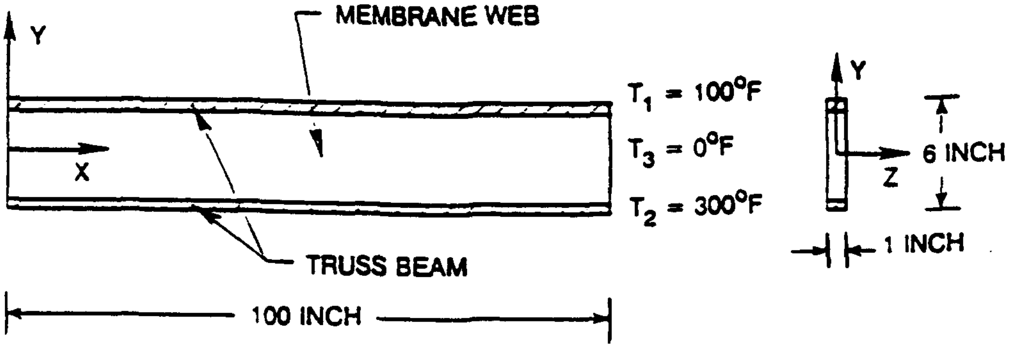
VAASEL (Vulnerability Analysis of Aerospace Structure Exposed to Lasers) is a finite element analysis computer code developed by the Northrop Corporation for the Air Force. VAASEL has a modular architecture that makes it a valuable tool for multi-disciplinary analysis. VAASEL is currently being used by SAIC (Science Applications International Corporation) for the SAVE (Structural Assessment and Vulnerability Evaluation) program.

The subject comparison came about when SAIC decided to run some test cases through VAASEL and repeat these cases through their current techniques for laser vulnerability analysis. SAIC uses the finite element program ANSYS to do the thermal and structural analysis. One of the problems chosen was a trapezoidal wingbox analysis that was used to benchmark the VAASEL code. This model contained CSHEAR elements to model the spar webs. Since the current version of ANSYS does not support shear panel elements, SAIC replaced the shear elements with membrane elements and ran VAASEL over. This resulted in a maximum tip deflection change from +11.0 inches to +3.3 inches for a combined thermal and flight load condition (pure thermal loading resulted in a maximum deflection of -0.05 inches.) This change in deflection was expected since the CQDMEM1 elements stiffened the model. ANSYS predicted -6.6 inches deflection. Although it was not independently verify that SAIC was running the same problem, it was recommended that additional modeling be done to check the validity of the thermal stress calculations in both VAASEL and ANSYS [1]. A comparison between the two codes for a problem with a classical solution was necessary.

2. ANALYSIS

2.1 Problem Statement

The selected problem was a pure bending problem with a beam theory solution. Figure 1 shows a schematic of the idealized composite beam. The beam is composed of one material but each section is at a different temperature. The reference temperature was taken to be 0°F. Under this loading, the top and bottom truss beams will try to expand while the web of the beam will restrain them causing the beam to bend.



$t_{mem} = 1$ in
$A_{Beam} = 1$ in^2
$E = 10$ Msi
$\alpha = 6\times10^{-6}$ in/in - °F
$\upsilon_{xy} = 0$

Figure 1: Idealized Beam for Thermal Load Check

2.2 Classical Solution

A strength-of-materials analogy is used to determine beam deflection [2]. This formulation ignores shear stress in the beam. The closed form solution is shown in Appendix A. The results are listed in Tables I-II.

2.3 Finite Element Solutions

2.3.1 VAASEL Model

To check VAASEL, two models were run: one containing CQUAD4 elements, and the other containing QDMEM1 elements. The QUAD4 element is an isoparametric quadrilateral plate element with both membrane and bending behavior. The QDMEM1 is an isoparametric

σ_{x1}	-6167.5 psi
σ_{x2}	4000 psi
σ_{x3}	-9832.5 psi

Table I: Stress Results

quadrilateral membrane element. Both elements were tested since SAIC used the QDMEM1 elements for the trapezoidal wing box problem, but, the element used for the ANSYS analysis is more closely related to the QUAD4 element. Both VAASEL models consisted of 1 row of CROD elements along the top and bottom edges to model the truss beam (Figure 1). The membrane web was modelled with two rows of quadrilateral elements. The current version of VAASEL doesn't support element temperature assignment (this problem was discovered while doing the analysis and will be corrected in the next version of VAASEL). To get around this problem all temperatures were assigned to the grid points and the membrane web was given a 0.0 coefficient of thermal expansion. This forced the solution to look like the classical problem (no thermal expansion in the membrane web).

2.3.2 ANSYS Model

The ANSYS model was run by Mr Chuck Heighland of SAIC [1]. His model used 2 rows of STIF63 (quadrilateral shell) elements to model the membrane web and a row of STIF8 (spar) elements along the top and bottom to model the truss beam. ANSYS supports element temperature assignment and this was used to analyze the beam.

x(in)	u_x (inch)	u_y (inch)
10	0.004	0.008
20	0.008	0.033
30	0.012	0.075
40	0.016	0.133
50	0.020	0.208
60	0.024	0.300
70	0.028	0.408
80	0.032	0.533
90	0.036	0.675
100	0.040	0.834

TABLE II: Displacement Results

3. RESULTS

The VAASEL and ANSYS results compare very well, all results are within 2% (Table III). The VAASEL's models were slightly stiffer particularly with the CQDMEM1 card. The additional stiffness using the CQDMEM1 card was predicted. The character of the finite element solutions were as expected. The axial stress in each component was nearly constant, except for end effects, in addition, the axial displacements were linear and the vertical displacements were quadratic (Figure 2 & 3). The comparison to beam theory appears to be good, since beam theory disregards shear stress, while both ANSYS and VAASEL include all stresses. Appendix B contains all the displacement results.

Description	Beam Theory	ANSYS	VAASEL (CQUAD)	VAASEL (CQDMEM1)
U_x(inch)	.040	.033	.033	.033
U_y(inch)	.834	.654	.645	.552
σ_1(psi)	-6167	-5844	-5736	-5288
σ_2(psi)	-9832	-11298	-11284	-11136
σ_3(psi)	4000	3429	3422	3423

TABLE III: Summary of Results

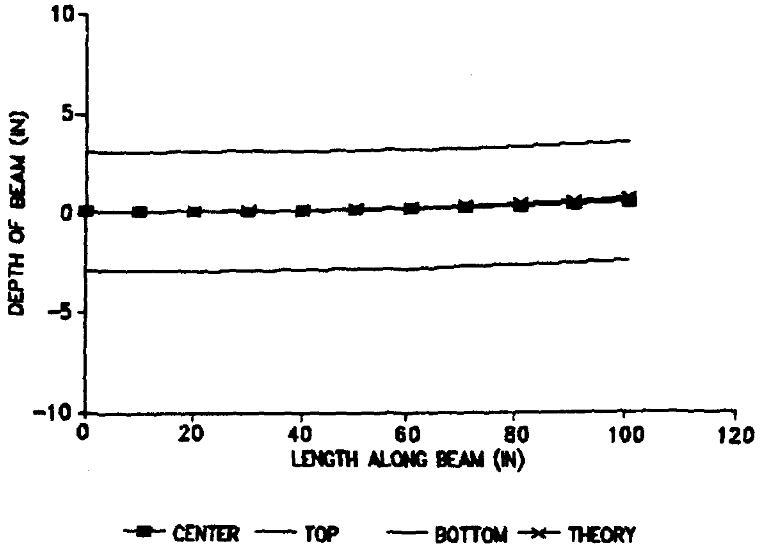


Figure 2: Beam Deflection CQUAD

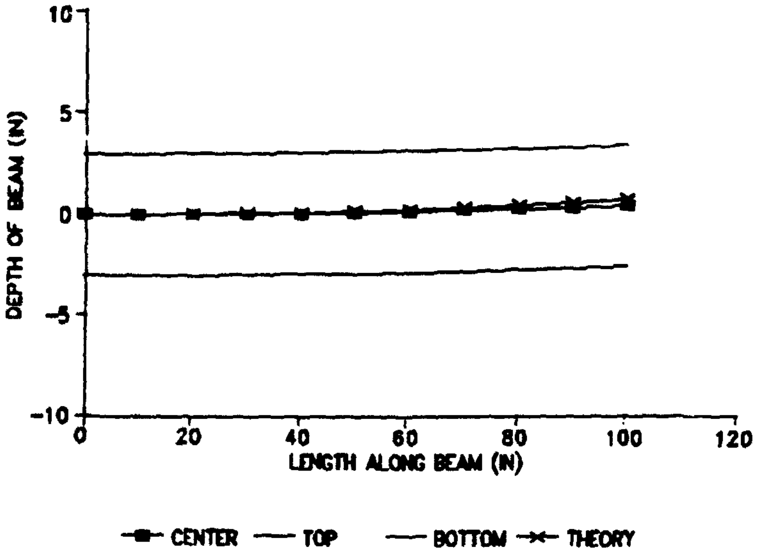


Figure 3: Beam Deflection CQDMEM

5. REFERENCES & BIBLIOGRAPHY

1. C. N. Heighland, SAIC, Santa Ana, CA; Memo on Structural Comparison and Evaluation of the VAASEL Code, Apr 91.

2. Boley and Weiner, Theory of Thermal Stresses, John Wiley & Sons, Inc., New York, 1960.

3. R. E. Blauvelt, et. al, "VAASEL - User's Manual," WRDC-TR-90-3070 Vol II, Apr 91.

4. R. E. Blauvelt, et. al, "VAASEL - Theoretical Manual," WRDC-TR-90-3070 Vol I, Apr 91.

APPENDIX A

BEAM THEORY SOLUTION

This section describes the classical solution to the thermally loaded beam problem. The primary equations used are listed.

$$M=\int\sigma_x z\,dA=b\int\sigma_x z\,dz \tag{1}$$

$$P=\int\sigma_x dA=b\int\sigma_x dz \tag{2}$$

$$\sigma_x=E_i(u_0'-zw''-\alpha\Delta T_i) \tag{3}$$

The analysis and results are shown below.

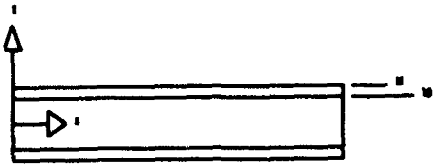


Figure A-1: Problem Setup

Calculate w:

$$M=\int\sigma_x z\,dA=b\int\sigma_x z\,dz=b\int E_i(u'-zw''-\alpha_i T_i)\,z\,dz$$

$$\frac{M}{b}=E_i\left[\int u' z\,dz-\int w'' z^2 dz-\int\alpha_i T_i z\,dz\right]$$

$$\frac{M}{b}=E_i\left[u'\left(\frac{z^2}{2}\right)\Big|-w'\left(\frac{z^3}{3}\right)\Big|-\alpha_i\Delta T_i\left(\frac{z^2}{2}\right)\Big|\right]$$

$$\begin{aligned}\frac{M}{b}=&E_1\left[u'\left(\frac{h_1^2}{2}-\frac{h_0^2}{2}\right)-w''\left(\frac{h_1^3}{3}-\frac{h_0^3}{3}\right)-\alpha_1\Delta T_1\left(\frac{h_1^2}{2}-\frac{h_0^2}{2}\right)\right]\\&+E_2\left[u'\left(\frac{h_0^2}{2}+\frac{h_0^2}{2}\right)-w''\left(\frac{h_0^3}{3}+\frac{h_0^3}{3}\right)-\alpha_2\Delta T_2\left(\frac{h_0^2}{2}-\frac{h_0^2}{2}\right)\right]\\&+E_3\left[u'\left(\frac{h_0^2}{2}-\frac{h_1^2}{2}\right)-w''\left(\frac{h_1^3}{3}-\frac{h_0^3}{3}\right)-\alpha_3\Delta T_3\left(\frac{h_0^2}{2}-\frac{h_1^2}{2}\right)\right]\end{aligned}$$

Let $\Delta T_2 = 0$ and $E_1 = E_2 = E_3 = E$:

$$\frac{M}{b}=\frac{E}{2}\left((\alpha_1\Delta T_1-\alpha_3\Delta T_3)\,(h_o^2-h_1^2)\right)-\frac{2}{3}Ew''h_1^3$$

Let M = 0 and $\alpha_1 = \alpha_3 = \alpha$:

$$w'' = \left(\frac{3}{4}\right)\left(\frac{\alpha}{h_1^3}\right)(\Delta T_1 - \Delta T_3)(h_0^2 - h_1^2) = B$$

Integrate:

$$\begin{aligned} w'' &= B \\ w' &= Bx + C_1 \\ w &= \frac{Bx^2}{2} + C_1 x + C_2 \end{aligned}$$

Apply end constraints:

$$\begin{aligned} w' &= 0 \quad @x=0 \Rightarrow C_1 = 0 \\ w &= 0 \quad @x=0 \Rightarrow C_2 = 0 \end{aligned}$$

$$\boxed{w = \left[\left(\frac{3}{8}\right)\left(\frac{\alpha}{h_1^3}\right)(\Delta T_1 - \Delta T_3)(h_o^2 - h_1^2)\right] x^2}$$

<u>Calculate u:</u>

$$P = \int \alpha_x dx = b \int \alpha_x dz$$

$$\begin{aligned} P &= Eb \int (u' - zw'' - \alpha_i \Delta T_i)\, dz \\ &= Eb\left[u' z - w'' \frac{z^2}{2} - \alpha_i \Delta T_i\right] \Big|_h \end{aligned}$$

$$P = Eb\left[2u' h_1 - (\alpha_1 \Delta T_1 + \alpha_3 \Delta T_3)(h_1 - h_0)\right]$$

Let P = 0 & $\alpha_1 = \alpha_3 = \alpha$:

Integrate:

$$U' = \frac{\alpha}{2}(\Delta T_1 + \Delta T_2)\left(1 - \frac{h_0}{h_1}\right) = A$$

$$u' = A$$
$$u = Ax + C$$

Apply end constraints:

$$u=0 \quad @x=0 \Rightarrow C=0$$

$$u=Ax$$

$$\boxed{u = \frac{\alpha}{2}(\Delta T_1 + \Delta T_3)\left(1 - \frac{h_0}{h_1}\right)x}$$

Calculate the deflections and stress using the following numbers:

E = 10 Msi	h_0 = 2.0	T_1 = 100°F
α = 6 E-6 in/in-°F	h_1 = 3.0	T_3 = 300°F

x (in)	u_x (in)	u_y (in)
10	0.004	0.008
20	0.008	0.033
30	0.012	0.075
40	0.016	0.133
50	0.020	0.208
60	0.024	0.300
70	0.028	0.408
80	0.032	0.533
90	0.036	0.675
100	0.040	0.834

Table A-1: Displacement Results

σ_1 (psi)	-6167.5
σ_2 (psi)	-9832.5
σ_3 (psi)	4000

Table A-2: Stress Results

APPENDIX B

DISPLACEMENT RESULTS

x (in)	u_x (in)	u_y (in)
0	0.000	0.000
10	0.003	0.006
20	0.007	0.026
30	0.010	0.058
40	0.014	0.103
50	0.017	0.161
60	0.020	0.232
70	0.024	0.316
80	0.027	0.413
90	0.031	0.522
100	0.033	0.645

Table B-1: QUAD4 Displacement Results

x (in)	u_x (in)	u_y (in)
0	0.000	0.000
10	0.003	0.005
20	0.007	0.022
30	0.010	0.050
40	0.014	0.088
50	0.017	0.138
60	0.020	0.198
70	0.024	0.27
80	0.027	0.353
90	0.031	0.447
100	0.033	0.552

Table B-2: CQDMEM Displacement Results

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