

Problem-Centered Approach in a Numerical Methods Course

Autar K. Kaw, Ph.D.¹
Ali Yalcin, Ph.D.²

Abstract: This paper is an illustration of using a problem-centered approach in an undergraduate course in Numerical Methods. The problem used in the course was first encountered in a research project that related to the assembly procedure of the fulcrum of bascule bridges. It involved the study of the fulcrum assembly procedure where a trunnion cooled in a dry-ice/alcohol mixture for shrink fitting got stuck halfway in the hub before full insertion could take place. The solution of the problem and its implementation involved numerical solutions of mathematical procedures taught in a typical Numerical Methods course. The effect of the problem-centered approach in the classroom was quantitatively and qualitatively surveyed over a two-semester period. The results indicate very high student satisfaction in helping them: acquire basic knowledge and skills; reinforce information presented in class, reading assignments and problem sets; learn to clearly formulate a specific problem and then work it through to completion; develop generic higher-order thinking and problem solving skills; and develop a sense of competence and confidence and see the relevance of the course material to their major.

Introduction

National scientific agencies such as National Science Foundation (NSF 2007) are continually encouraging integration of current research topics into undergraduate education. This is being mainly done to bring state-of-art research into the classroom to prepare and educate the future generation of engineers who also are increasingly facing global competition (Friedman 2005) for their skills and knowledge. Education and research are of equal value and should be viewed as complementary of any engineering and science education.

Incorporating a research problem into a graduate level course (Kaw et al. 2004) itself presents challenges, and to incorporate a problem into an undergraduate level course is even more challenging. Many a times, research problems may not be broad enough to encompass most of the course content to justify their introduction. In other instances, specific skills may be needed that either are too time consuming to teach or are out of scope for the education level of the students. However, we were able to meet such challenges and successfully integrate a research problem into the Numerical Methods course.

Description of Problem

Amongst movable bridges, bascule bridges are the most popular type as they are simple and speedy to operate. The pivot assembly (called the trunnion-hub-girder (THG) assembly) of a bascule bridge consists of a trunnion shaft attached to the leaf (girder) via a hub, and supported on bearings to permit rotation of the leaf (Figure 1).

The THG assembly is made by using interference fits (Shigley and Mischke 1986) between the trunnion and hub, and the hub and girder. The procedure (Besterfield et al. 2003a;

¹ Professor, Department of Mechanical Engineering, University of South Florida, 4202 E Fowler Ave ENB118, Tampa, FL 33620-5350

² Associate Professor, Department of Industrial Engineering and Engineering Management, University of South Florida, 4202 E Fowler Ave ENB118, Tampa, FL 33620-5350

Besterfield et al. 2003b) for assembling THG assemblies involves shrinking the trunnion onto the hub, and then shrinking the trunnion-hub onto the girder (Figure 2) as follows.

- Step 1: The trunnion is shrunk by immersing it in liquid nitrogen.
- Step 2: This shrunk trunnion is then inserted into the hub and allowed to warm up to ambient temperature to develop an interference fit on the trunnion-hub interface.
- Step 3: The trunnion-hub assembly is shrunk by immersing it in liquid nitrogen.
- Step 4: This shrunk trunnion-hub assembly is then inserted into the girder and allowed to warm up to ambient temperature to develop an interference fit on the hub-girder interface.

On May 3, 1995, during immersion of the trunnion-hub assembly in liquid nitrogen (Step 3 of the assembly procedure) for the Christa McAuliffe Bascule Bridge in Florida, a cracking sound was heard. On removing the trunnion-hub assembly out of liquid nitrogen, it was found that the hub had cracked near its inner radius. In a separate instance, during the fulcrum assembly of the Venetian Causeway Bascule Bridge in Florida, while inserting the trunnion into the hub (Step 2 of the assembly procedure), the trunnion got stuck halfway in the hub before complete insertion took place.

Each failure resulted in the loss of hundreds of thousands dollars in material, labor and delay. To prevent their recurrence, the Florida Department of Transportation (FDOT) decided to investigate the cause of these problems in the THG assemblies. For three years, (1998-2001), University of South Florida (USF) conducted a thermal stress analysis (Besterfield et al. 2003a; Besterfield et al. 2003b) of the fulcrum assembly procedure and used analytical (Denninger 2000), numerical (Ratnam 2000), and experimental techniques (Nichani 2001) to study the problem and recommended several solutions to the problems of the assembly procedure.

Problem Centered Assignments

Since 2003, the THG assembly procedure problem has been introduced on the first day of class in the Numerical Methods course. Background information about bascule bridges and the fulcrum assembly is explained via an audiovisual presentation. The problem presented to the students is limited to analyzing the Venetian Causeway Bridge where the trunnion got stuck in the hub.

The problem posed on the first day of class is as follows. A hollow trunnion of outer diameter 12.363" is to be fitted in a hub of inner diameter 12.358". The trunnion was put in dry ice/alcohol mixture at -108°F to contract the trunnion so that it can be slid through the hole of the hub. To slide the trunnion without sticking, a diametric clearance of at least 0.01" is specified between the trunnion and the hub.

Assignment 1. Assuming the room temperature is 80°F , is immersing the trunnion in dry-ice/alcohol mixture a correct decision?

The thermal expansion coefficient at room temperature is used to calculate the contraction in the outer diameter of the trunnion. The change, ΔD in the outer diameter of the trunnion is

$$\Delta D = D\alpha\Delta T \tag{1}$$

where

D = outer diameter of the trunnion,

α = coefficient of thermal expansion coefficient at room temperature, and

ΔT = change in temperature,

Given

$$\begin{aligned}
D &= 12.363'' \\
\alpha &= 6.817 \times 10^{-6} \text{ in/in/}^{\circ}\text{F at } 80^{\circ}\text{F} \\
\Delta T &= T_{fluid} - T_{room} \\
&= -108 - 80 \\
&= -188^{\circ}\text{F}
\end{aligned}$$

where

$$\begin{aligned}
T_{fluid} &= \text{temperature of dry-ice/alcohol mixture} \\
T_{room} &= \text{room temperature}
\end{aligned}$$

the change in the trunnion outer diameter is given by

$$\begin{aligned}
\Delta D &= (12.363)(6.47 \times 10^{-6})(-188) \\
&= -0.01504''
\end{aligned}$$

Is this enough contraction in the diameter of the trunnion? As per specifications, we need the trunnion to contract by a magnitude of

$$\begin{aligned}
&= \text{outer diameter of trunnion} - \text{inner diameter of hub} + \text{diametric clearance} \\
&= 12.363'' - 12.358'' + 0.01'' \\
&= 0.015''
\end{aligned}$$

According to the calculations, immersing the trunnion in dry-ice/alcohol mixture gives the desired contraction of 0.015'' as the predicted contraction is 0.01504''.

However, as shown in Table 1 and Figure 3, the coefficient of thermal expansion of steel decreases with decreasing temperature and is not a constant over the range of temperature the trunnion is subjected to. Hence, the formula in Equation (1) overestimates the thermal contraction.

To accurately find the change, ΔD in the outer diameter of the trunnion, instead of Equation (1) we need to estimate the integral

$$\Delta D = D \int_{T_{room}}^{T_{fluid}} \alpha dT \quad (2)$$

One may ironically question the authors' claim of accuracy of Equation (2) because the outer diameter of the trunnion also changes with temperature. But, Equation (2) assumes the diameter of the trunnion as a constant because when compared to the effect of the varying thermal expansion coefficient, the assumption of a constant diameter has a very small effect (<0.1% for practical purposes) in the calculation of the change in diameter. This is illustrated in Appendix A.

On the first day of class, the methods used by students to solve Equation (2) are limited to using average coefficient of thermal expansion with Equation (1) or graphical methods such as Riemann's sum (Thomas et al. 2002). These become the foundation of why we need to develop scientifically more rigorous numerical methods.

Later in the course, the students are asked to find the contraction in the diameter of the trunnion by several methods such as Trapezoidal rule for discrete and unequally spaced data, and integration of regression models or polynomial splines. These methods show that the change in the diameter (for example, $\Delta D = -0.01377''$ obtained using Equation (2) and a second order polynomial regression model for coefficient of thermal expansion vs. temperature) is well below the required magnitude of 0.015''. This leads to the next assignment.

Assignment 2. Using the aforementioned methods, the student has determined that the contraction is not enough to slide the trunnion through the hub. The next task is to establish the

temperature of the cooling medium that will produce the required clearance between the hub and the trunnion. In Equation (2), the minimum desired change in the diameter ($\Delta D = -0.015$ ") is known. When a second order polynomial regression curve

$$\alpha = -1.2278 \times 10^{-11} T^2 + 6.1946 \times 10^{-9} T + 6.0150 \times 10^{-6} \quad (3)$$

is used as an approximation for the thermal expansion coefficient, it follows that

$$-0.015 = 12.363 \int_{80}^{T_{fluid}} (-1.2278 \times 10^{-11} T^2 + 6.1946 \times 10^{-9} T + 6.015 \times 10^{-6}) dT$$

which results in a cubic equation

$$f(T_{fluid}) = -0.50598 \times 10^{-11} T_{fluid}^3 + 0.38291 \times 10^{-7} T_{fluid}^2 + 0.74363 \times 10^{-4} T_{fluid} - 0.021168 = 0 \quad (4)$$

Equation (4) is solved numerically. In addition, since Equation (4) is cubic, it has three roots, and the physics of the problem need to be discussed to find the acceptable root.

Again, we are assuming that the outer diameter of the trunnion is a constant function of temperature. When compared to the effect of the varying thermal expansion coefficient, the assumption of a constant diameter has a very small effect (<0.11%) in the calculation of the temperature of the cooling medium. This is illustrated in Appendix A.

Assignment 3. Discrete data of coefficient of thermal expansion vs. temperature for steel needs to be regressed to find the relationship between the two. Questions include choosing the optimum degree of polynomial regression by plotting the variance $S_r / (n - m - 1)$ vs. m , where S_r is the sum of the square of the residuals, n is the number of data points, and m is the order of the polynomial. The order of polynomial where $S_r / (n - m - 1)$ is a minimum or does not change appreciably is the optimum order of the polynomial.

Assignment 4. Regression models obtained using default Excel format do not properly account for significant digits, and hence create artificial large differences between the observed and predicted values. For example, if Excel is used to regress the coefficient of thermal expansion vs. temperature data to a second order polynomial, using default format the result is

$$\alpha = -1 \times 10^{-5} T^2 + 0.0062T + 6.015, \quad (5)$$

where

α = coefficient of thermal expansion ($\mu\text{in/in}^\circ\text{F}$), and
 T = temperature ($^\circ\text{F}$).

At $T = -300^\circ\text{F}$, the value of the thermal expansion coefficient calculated from the above formula is $3.26 \mu\text{in/in}^\circ\text{F}$, while the actual value of the data is $3.07 \mu\text{in/in}^\circ\text{F}$, a 6% difference. This is not evident, as the regression line visually agrees very well with the data (Figure 3).

This discrepancy is quite unsettling to students, and only when the format of the regressed line is changed from default to scientific, the resulting curve is found to be

$$\alpha = -1.2278 \times 10^{-5} T^2 + 6.1946 \times 10^{-3} T + 6.015, \quad (6)$$

At the same value of $T = -300^\circ\text{F}$, the value of the thermal expansion coefficient is calculated as $3.05 \mu\text{in/in}^\circ\text{F}$, while the actual value of the data is $3.07 \mu\text{in/in}^\circ\text{F}$, a difference 0.6%. This

clearly shows the effect of significant digits on the accuracy in a real-life problem. One can change the number of significant digits, change the format from general to scientific in Excel, and now quantitatively study the effect of number of significant digits on the difference between predicted and observed values.

Assignment 5. When one is solving to find the coefficients of the polynomial regression curve for the coefficient of thermal expansion vs. temperature data $(T_1, \alpha_1), (T_2, \alpha_2), \dots, (T_n, \alpha_n)$, for example a second order polynomial, it results in three simultaneous linear equations

$$\begin{aligned} na_0 + a_1 \sum_{i=1}^n T_i + a_2 \sum_{i=1}^n T_i^2 &= \sum_{i=1}^n \alpha_i \\ a_0 \sum_{i=1}^n T_i + a_1 \sum_{i=1}^n T_i^2 + a_2 \sum_{i=1}^n T_i^3 &= \sum_{i=1}^n \alpha_i T_i \\ a_0 \sum_{i=1}^n T_i^2 + a_1 \sum_{i=1}^n T_i^3 + a_2 \sum_{i=1}^n T_i^4 &= \sum_{i=1}^n \alpha_i T_i^2 \end{aligned} \quad (7)$$

These equations are then solved by numerical methods such as Gaussian elimination. In addition, solution of equations for higher order polynomial regression is used to illustrate the effect of relatively large differences in the order of coefficient matrix elements on the accuracy of the solution.

Assignment 6. To cool the trunnion for shrink fitting into the hub, time needs to be estimated to determine when the trunnion reaches steady state temperature in a cooling medium. The trunnion is approximated as a lumped system and the cooling process is modeled as a first order ordinary differential equation of temperature of the trunnion, θ as a function of time, t as

$$MC \frac{d\theta}{dt} = -hA(\theta - \theta_a), \quad (8)$$

where

- h = convective cooling coefficient,
- A = surface area of trunnion,
- θ_a = ambient temperature of cooling medium,
- M = mass of the trunnion,
- C = specific heat of the trunnion.

The above has an exact solution. However, when it is shown to the students that the large temperature changes make the convective cooling coefficient and the specific heat strong functions of temperature, the ordinary differential equation needs to be solved numerically.

Based on the above posed problems during the course, all major mathematical procedures, namely, nonlinear equations, simultaneous linear equations, interpolation, regression, integration, and ordinary differential equations that are taught in a typical Numerical Methods course are covered.

Assessment

To measure student satisfaction with the problem-centered approach, a survey was developed to gather information on students' perceptions of the problem-centered approach and how it affected their learning of the course material. The survey included both quantitative and qualitative questions, thus permitting exploration of the reasons behind student ratings. The

instrument consisted of six questions (see Table 2) using Likert (1932) scale from 1 (truly inadequate) to 7 (truly outstanding), and three open-ended questions as follows:

- What did you like most about the problem-centric approach? Please be specific.
- What did you like least about the problem-centric approach? Please be specific.
- What would you like to change about the problem-centered approach? Please be specific.

The survey was administered in Spring 2007 and Summer 2007 to two classes of 58 and 71 students, respectively.

Quantitative Analysis

The percentage of students responding to the survey was 90% for the spring and 85% for the summer terms. These response rates are well above the recommended 75% rate for classes of this size (Franklin 2001).

Using the two-sample *t*-test (Montgomery 2001), the student evaluations showed no significant difference (at the $\alpha=0.05$ level) for the six quantitative questions between the summer and the spring semesters. This was expected, as there were no changes to the course material between these semesters. Table 2 shows the mean, standard deviation and the 95% confidence intervals of the student evaluations for the quantitative questions.

Based on the responses to the quantitative questions, the students felt that the problem-centered approach was *very good* in helping them: 1) acquire basic knowledge and skills; 2) reinforce information presented in class, reading assignments and problem sets; 3) learn to clearly formulate a specific problem and then work it through to completion; 4) develop generic higher-order thinking and problem solving skills; and 5) develop a sense of competence and confidence. The students felt that the problem-centered approach was *very good/excellent* in helping them see the relevance of the course material to their major.

Qualitative Analysis

The responses to the three open-ended questions are reviewed and thematically analyzed.

Question 1. What did you like most about the problem-centric approach? Please be specific.

Of the 108 total number of responses to this question, two distinct themes emerge. 34 students indicated that *application of course material to real-life engineering problems* and 13 students indicated that *application of different solution approaches to the same problem and comparing the quality of the solutions* were what they liked most about the problem-centered approach.

Question 2. What did you like least about the problem-centric approach? Please be specific.

Of the 106 responses to this question, 25 students indicated that they had no dislikes associated with the problem-centered approach. With 27 responses, the topic of working on a single problem over the course of the semester being monotonous and needing more examples prevailed as the most disliked aspect of the problem-centered approach.

Question 3. What would you like to change about the problem-centered approach? Please be specific.

Of the 105 responses, 26 indicated that they would change nothing associated with the problem-centered approach. The most frequent change indicated in 35 responses was related to increasing the number of examples. This topic was also prevalent in the comments to the previous open-ended questions.

Studying the effect on student learning was not possible, as one would need to isolate the impact of the problem-centered approach. While integrating the problem-centered approach, we

had other synergistic improvements simultaneously implemented in the course. These improvements (Kaw et al. 2003) included 1) user controlled simulations in multiple computational systems such as MathCAD (2007), Maple (2007), MATLAB (2007), and MATHEMATICA (2007), 2) textbook notes and EBooks, 3) problem assignments and multiple choice tests based on Bloom's taxonomy, and 4) real world problems from multiple engineering majors.

Conclusions

A problem-centered approach in an undergraduate course in Numerical Methods has been successfully implemented by means of integrating a research problem. The breadth of topics covered includes all the mathematical procedures covered in the course. Coupled with other improvements, the effect of the problem-centered approach resulted in high student satisfaction. The most prevalent criticism associated with the problem-centered approach focused on the repetitiveness associated with using a single problem throughout the course.

Acknowledgments

This material is based upon work (<http://numericalmethods.eng.usf.edu>) supported by the National Science Foundation under Grant#0341468, and the Research for Undergraduates Program in the USF College of Engineering. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation. The research problem used in the course was funded by Florida Department of Transportation (FDOT) under contract#B-C008 (1998-2001). Mr. T. A. Cherukara was the Project Manager and Professor G.H. Besterfield of University of South Florida was the PI for the FDOT grant. Portions of this paper were presented at the 2007 ASEE Annual Conference and Exposition, Honolulu, HI, June 24-27, 2007. The authors thank all the anonymous reviewers for their comments in making this a better manuscript, especially Reviewer A, who pointed out the effect of assuming the outer diameter of the trunnion to be a constant.

References

Anonymous Reviewer, (2007) "Derivation of change in diameter when diameter is assumed to be varying," Reviewer of manuscript submitted to *Journal of Professional Issues in Engineering Education and Practice*.

Besterfield, G.H., Kaw, A.K., Nichani, S., Ratnam, B., Cherukara, T., Denninger, M. (2003a). "Assembly Procedures of a Trunnion-Hub-Girder for Bascule Bridges", *Theoretical and Applied Fracture Mechanics*, 40, 123-134.

Besterfield, G. H., Nichani, S., Kaw, A. K., and Eason, T. (2003b). "Full-scale testing of trunnion-hub-girder assemblies for bascule bridges," *ASCE Journal of Bridge Engineering*, 8, 204-211.

Bloom, B. S. (1956). *Taxonomy of educational objectives handbook I: cognitive domain*, David McKay Co.

Denninger, M. (2000). "Design tools for trunnion-hub assemblies for bascule bridges", M. S. Thesis, University of South Florida.

Franklin, J. (2001). "Interpreting the numbers: using a narrative to help others read student evaluations of your teaching accurately", *New Directions for Teaching and Learning*, 87, 85-100.

Friedman, T. L. (2005). *The world is flat: a brief history of the twenty-first century*. Farrar, Straus and Giroux, New York.

Kaw, A. K., Collier, N., Keteltas, M., Paul, J. and Besterfield, G. H. (2003). "Holistic but Customized Resources for a Course in Numerical Methods," *Computer Applications for Engineering Education*, 11, 203-210.

Kaw, A. K., Besterfield, G. H., and Nichani, S. (2004). "Integrating a research problem in a course in applied elasticity," *International Journal of Mechanical Engineering Education*, 32, 232-242.

Likert, R. (1932). "A technique for the measurement of attitudes," *Archives of Psychology*, 140, 55.

Maple 11, Advancing Mathematics. <<http://www.maplesoft.com/>>, accessed August 2007.

MATHCAD 14, The industry solution for applying mathematics. <<http://www.mathcad.com/>>, accessed August 2007.

MATHEMATICA 6, The way the world calculates. <<http://www.wolfram.com/>>, accessed August 2007.

Matlab 13: Increasing the scope and productivity of engineering science.
<<http://www.mathworks.com/>>, accessed August 2007.

Montgomery, D.C. (2001). *Design and analysis of experiments*, 5th Edition, John Wiley & Sons Inc., New York.

National Science Foundation, Where discoveries begin <<http://www.nsf.gov/>>, accessed August 2007.

Nichani, S., (2001) “Full scale testing of trunnion-hub-girder assembly of a bascule bridge,” M. S. Thesis, University of South Florida, FL.

Ratnam, B., (2000) “Parametric finite element modeling of trunnion hub girder assemblies for bascule bridges,” M. S. Thesis, University of South Florida, FL.

Shigley, J. E., and Mischke, C. R. (1986). *Chapter 19 - limits and fits, Standard handbook of machine design*, McGraw-Hill, New York.

Thomas, G. B., Finney, R. L., Weir, M. D., and Giordano, F. R. (2002). *Thomas' calculus*, 10th edition, Addison Wesley, New York.

Notation

a_i = coefficients of polynomial regression model

A = surface area of trunnion

C = specific heat of the trunnion

D = outer diameter of the trunnion

D_{room} = outer diameter of the trunnion at room temperature

D_{fluid} = outer diameter of the trunnion at fluid temperature

h = convective cooling coefficient

m = order of polynomial regression model

M = mass of the trunnion

n = number of data points

S_r = sum of the square of the residuals for a regression model

T_{fluid} = temperature of cooling medium

T_{room} = room temperature

α = coefficient of thermal expansion coefficient at room temperature, and

ΔD = reduction in the outer diameter of the trunnion is

ΔT = change in temperature

θ = temperature of trunnion

θ_a = ambient temperature of cooling medium

Appendix A. On the effect of varying diameter on calculating the change in diameter

Equation (2) assumes the outer diameter of the trunnion does not vary with temperature. When compared to the effect of the varying coefficient of thermal expansion on change in the outer diameter of the trunnion, the effect of assuming constant outer diameter is small. In this appendix, we show the derivation (Anonymous, 2007) for the change in diameter with varying outer diameter and its effect.

The coefficient of thermal expansion coefficient is defined as

$$\alpha(T) = \frac{1}{D(T)} \frac{dD(T)}{dT} \quad (\text{A.1})$$

where

$D(T)$ = Outer diameter of trunnion

T = Temperature

Rearranging Equation (A.1) for integration, we get

$$\frac{dD(T)}{D(T)} = \alpha(T)dT \quad (\text{A.2})$$

As the trunnion is cooled from room temperature, T_{room} to the temperature of the cooling medium, T_{fluid} and hence the diameter changing from the initial outer diameter, D_{room} to the final outer diameter, D_{fluid} integrating both sides of Equation (A.2)

$$\int_{D_{room}}^{D_{fluid}} \frac{dD(T)}{D(T)} = \int_{T_{room}}^{T_{fluid}} \alpha(T)dT$$

gives

$$\ln\left(\frac{D_{fluid}}{D_{room}}\right) = \int_{T_{room}}^{T_{fluid}} \alpha(T)dT \quad (\text{A.3})$$

Further simplification using $\Delta D = D_{fluid} - D_{room}$ gives the change in the diameter as

$$\Delta D = D_{room} \left(e^{\int_{T_{room}}^{T_{fluid}} \alpha(T)dT} - 1 \right) \quad (\text{A.4})$$

For all practical input values, the value of the $\left| \int_{T_{room}}^{T_{fluid}} \alpha(T)dT \right| \ll 1$ (for example,

$\int_{T_{room}}^{T_{fluid}} \alpha(T)dT = -0.00111$, using $\alpha(T)$ from Equation (3), $T_{room} = 80^{\circ}F$ and $T_{fluid} = -108^{\circ}F$).

Expanding the exponential term, $e^{\int_{T_{room}}^{T_{fluid}} \alpha(T)dT}$ in Equation (A.4) in terms of a Maclaurin series gives

$$\Delta D = D_{room} \int_{T_{room}}^{T_{fluid}} \alpha(T)dT + \frac{1}{2!} D_{room} \left(\int_{T_{room}}^{T_{fluid}} \alpha(T)dT \right)^2 + \frac{1}{3!} D_{room} \left(\int_{T_{room}}^{T_{fluid}} \alpha(T)dT \right)^3 + \dots \quad (\text{A.5})$$

The first term on the right hand side is identical to that of Equation (2), while the contribution from the rest of terms in Equation (A.5) is too small (0.06% of the first term of Equation (A.5))

for $\int_{T_{room}}^{T_{fluid}} \alpha(T) dT = -0.00111$ to be considered significant.

For Assignment#1, using $\alpha(T)$ from Equation (3), $T_{room} = 80^0 F$, $T_{fluid} = -108^0 F$, $D_{room} = 12.363''$, the change in diameter calculated by Equation (A.4) is $\Delta D = -0.01376''$, while the change in diameter calculated by Equation (2) is $\Delta D = -0.01377''$, resulting in a relative difference of less than 0.07%. Even in the case of the cooling medium being liquid nitrogen ($T_{fluid} = -321^0 F$), the difference in the calculated change in diameters with and without assuming the outer diameter is varying is less than 0.1%.

For Assignment#2, using $\alpha(T)$ from Equation (3), $T_{room} = 80^0 F$, $D_{room} = 12.363''$, $\Delta D = -0.015''$ in Equation (A.4), the cubic equation obtained for the required fluid temperature is

$$-0.40927 \times 10^{-11} T_{fluid}^3 + 0.30973 \times 10^{-8} T_{fluid}^2 + 0.60500 \times 10^{-5} T_{fluid} + 0.71231 \times 10^{-3} = 0 \quad (A.6)$$

giving the acceptable solution as $T_{fluid} = -127.45^0 F$. Assuming the outer diameter of trunnion to be constant, the acceptable solution from Equation (4) is $T_{fluid} = -127.31^0 F$, resulting in a relative difference of less than 0.11%.

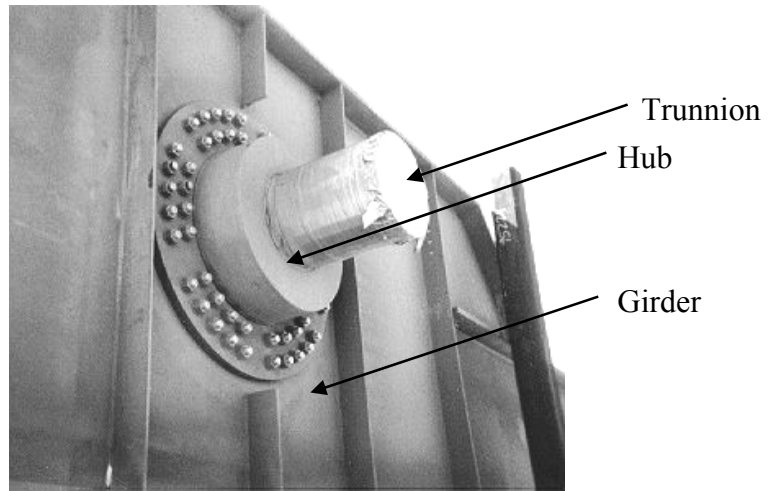


Figure 1 Trunnion-Hub-Girder (THG) Assembly

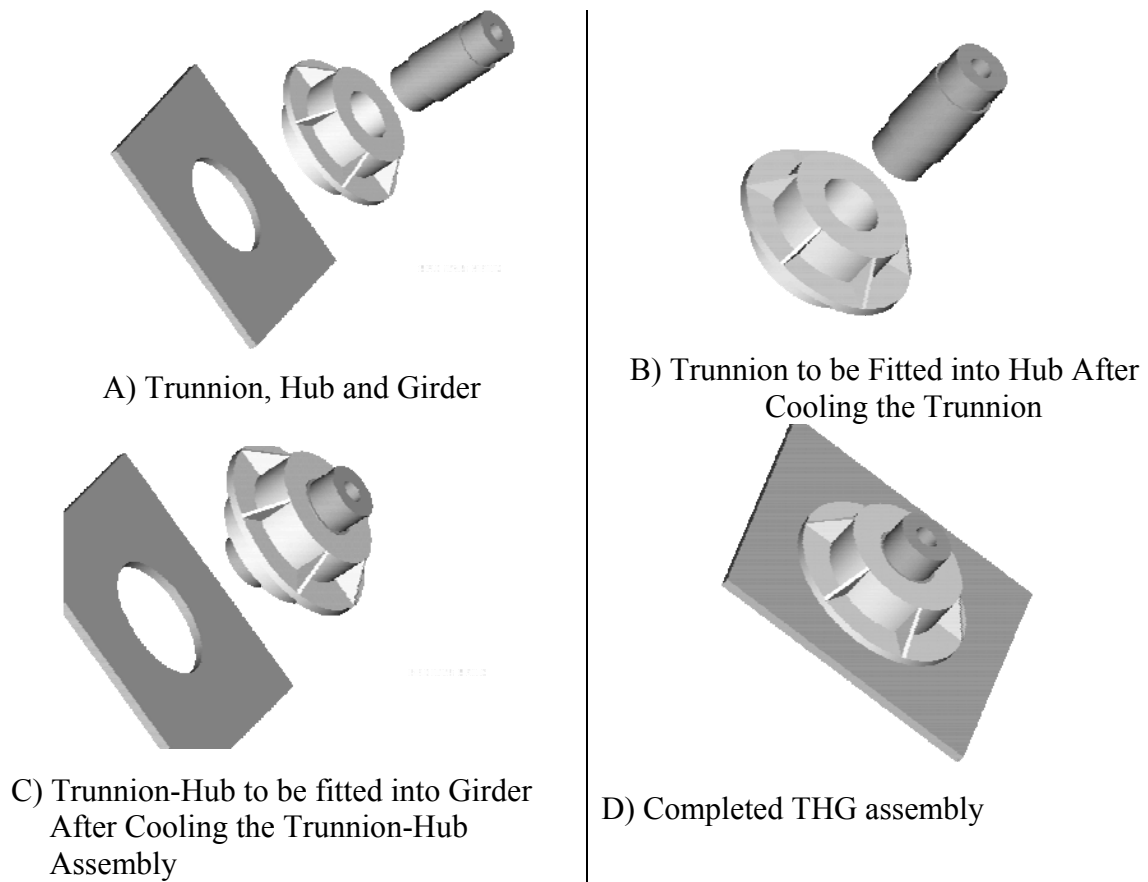


Figure 2. Procedure for THG assembly.

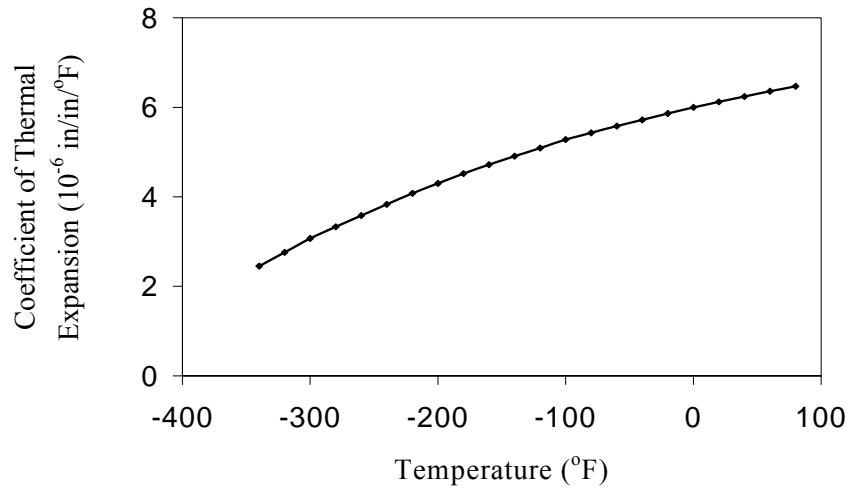


Figure 3. Coefficient of thermal expansion of steel as a function of temperature.

Table 1. Coefficient of thermal expansion of steel as a function of temperature

Temperature	Instantaneous Thermal Expansion
°F	($\mu\text{in}/\text{in}/^\circ\text{F}$)
80	6.47
60	6.36
40	6.24
20	6.12
0	6.00
-20	5.86
-40	5.72
-60	5.58
-80	5.43
-100	5.28
-120	5.09
-140	4.91
-160	4.72
-180	4.52
-200	4.30
-220	4.08
-240	3.83
-260	3.58
-280	3.33
-300	3.07
-320	2.76
-340	2.45

Table 2. Summary results of quantitative student survey questions

Questions	Mean* (Standard Deviation) [95% confidence interval]	
	Spring 2007 (n=52)	Summer 2007 (n=60)
In terms of the value of helping me acquire basic knowledge and skills, I'd say that using the problem-centered approach was	5.13 (1.03) [4.9-5.4]	5.25(1.23) [4.9-5.6]
In terms of their value in reinforcing information presented in class, reading assignments and problem sets, I'd say that the problem-centered approach was	5.13 (1.05) [4.8-5.4]	5.30(1.06) [5.0-5.6]
In terms of their value in helping me learn to clearly formulate a specific problem and then work it through to completion, I'd say that the problem-centered approach was	4.98 (1.16) [4.7-5.3]	5.27(1.23) [5.0-5.6]
In terms of the value of helping me develop generic higher-order thinking (e.g. analysis, synthesis and evaluation from Bloom's taxonomy (Bloom 1956) handout) and problem solving skills, I'd say that the problem-centered approach was	4.94(1.18) [4.6-5.3]	4.82(1.47) [4.4-5.2]
In terms of their value of helping me develop a sense of competence and confidence, I'd say that the problem-centered approach was	4.90 (1.12) [4.6-5.2]	4.85 (1.29) [4.5-5.2]
In terms of helping me see the relevance of the course material to my major, I'd say the problem-centered approach was	5.42 (1.29) [5.1-5.8]	5.33 (1.28) [5.0-5.7]

* 1=Truly inadequate 2=Poor 3=Adequate 4= Good 5=Very good 6=Excellent 7=Truly outstanding