

# Introduction to Scientific Computing

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Transforming Numerical Methods Education for STEM Undergraduates

1/8/2017

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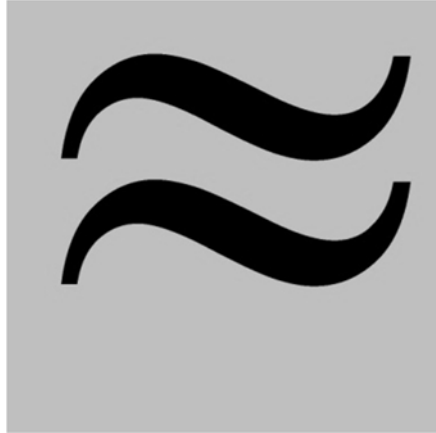
- **Welcome to EML3041: Computational Methods.**
- **My name is Dr. Kaw.**
- **Sign the attendance sheet as it gets passed around.**
- **Have you gotten your textbooks and TI 30Xa calculator!**
- **Introduce yourself to the person on your left and right. Say one thing (nothing personal) about yourself to them.**
- **At home, go thru the CANVAS modules.**
- **All is well that ends well; well-begun is half-done.**
- **No cell phones, laptops or other distractions. Daydreamers and sleepers will not be disturbed.**
- **First HW is due on next Monday.**



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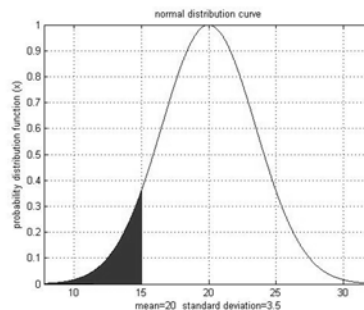
## Why use Numerical Methods?



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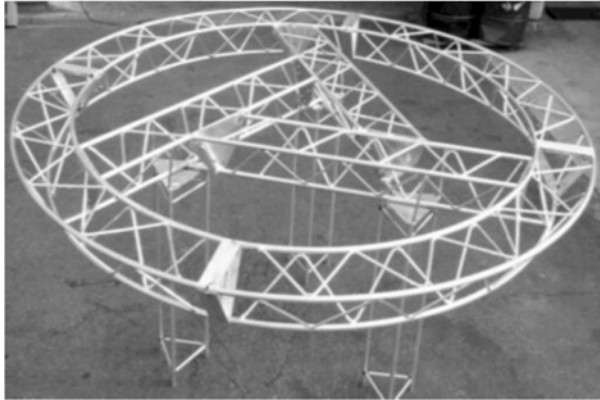
- To solve problems that cannot be solved exactly

$$\frac{1}{\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{u^2}{2}} du$$



## Why use Numerical Methods?

- To solve problems that are intractable to solve exactly!



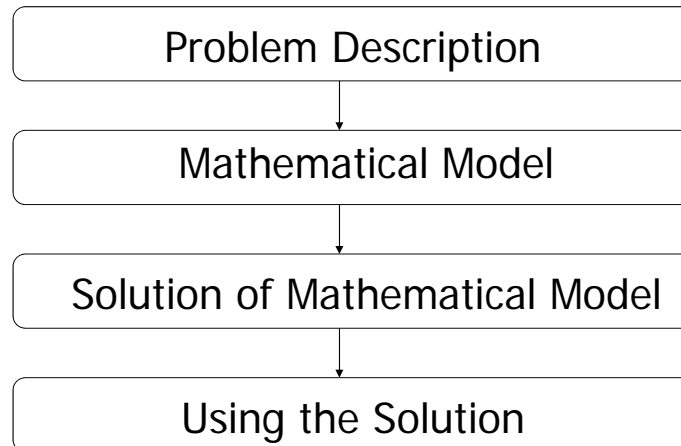
## Steps in Solving an Engineering Problem

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## How do we solve an engineering problem?



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## Example of Solving an Engineering Problem



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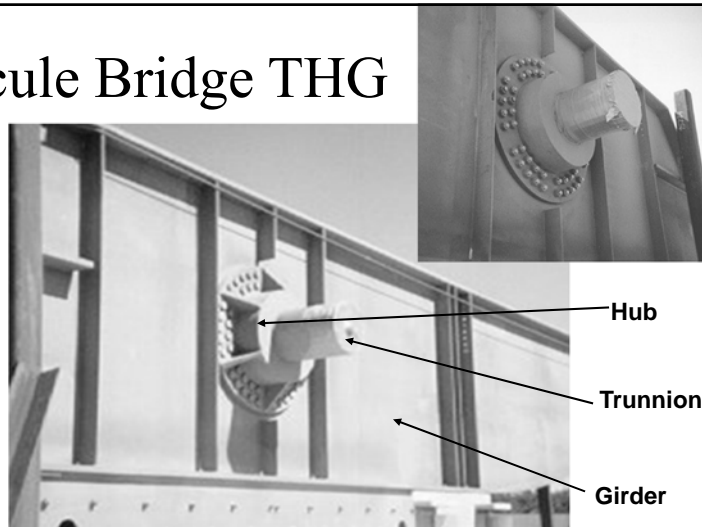
## Bascule Bridge THG



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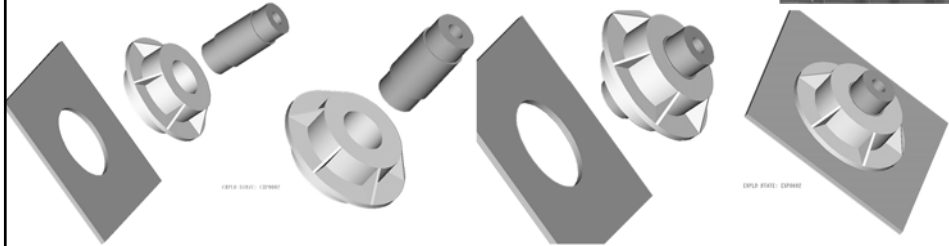
## Bascule Bridge THG



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## Trunnion-Hub-Girder Assembly Procedure

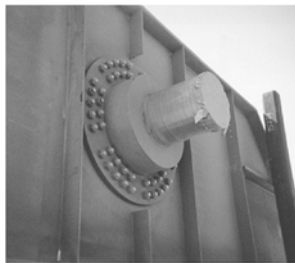


- Step1.** Trunnion immersed in dry-ice/alcohol
- Step2.** Trunnion warm-up in hub
- Step3.** Trunnion-Hub immersed in dry-ice/alcohol
- Step4.** Trunnion-Hub warm-up into girder

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## Problem



After Cooling, the Trunnion Got Stuck in Hub

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## Why did it get stuck?

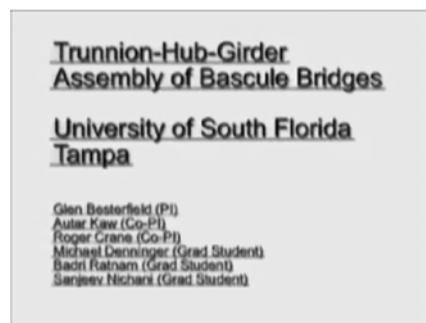
Magnitude of contraction needed in the trunnion was 0.015" or more. Did it contract enough?



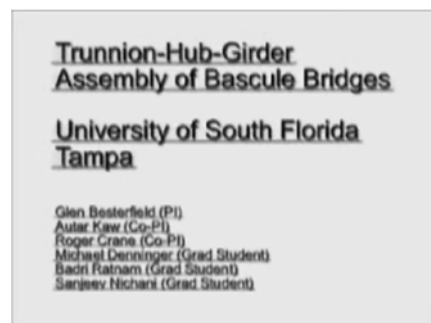
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## Video of Assembly Process



Unplugged Version



VH1 Version

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## Consultant calculations

$$\Delta D = D \times \alpha \times \Delta T$$



$$D = 12.363''$$

$$\alpha = 6.47 \times 10^{-6} \text{ in/in/}^{\circ}\text{F}$$

$$\Delta T = -108 - 80 = -188^{\circ}\text{F}$$

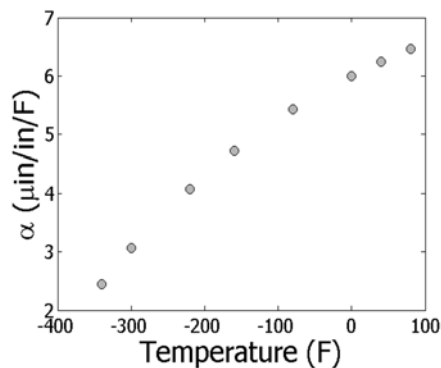
$$\begin{aligned}\Delta D &= (12.363)(6.47 \times 10^{-6})(-188) \\ &= -0.01504''\end{aligned}$$

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## Is the formula used correct?

$$\Delta D = D \times \alpha \times \Delta T$$



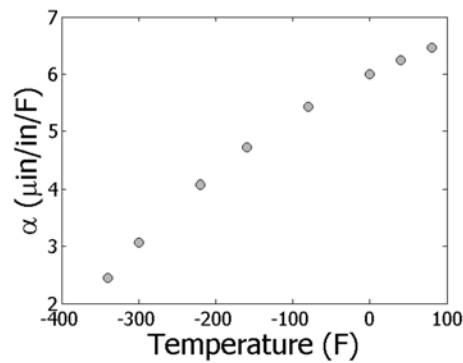
T(°F)	α (μin/in/°F)
-340	2.45
-300	3.07
-220	4.08
-160	4.72
-80	5.43
0	6.00
40	6.24
80	6.47

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## The Correct Model Would Account for Varying Thermal Expansion Coefficient



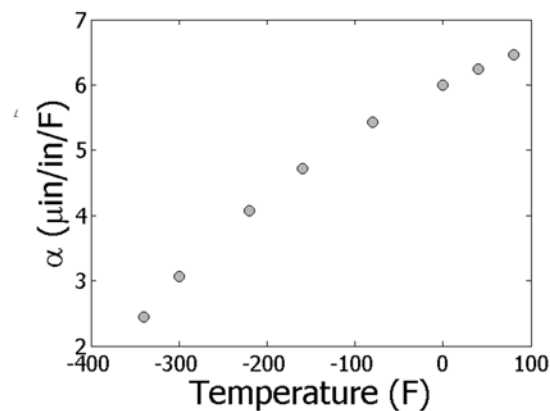
$$\Delta D = D \int_{T_a}^{T_c} \alpha(T) dT$$

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## Can You Roughly Estimate the Contraction?

$$\Delta D = D \int_{T_a}^{T_c} \alpha(T) dT \quad T_a = 80^\circ\text{F}; T_c = -108^\circ\text{F}; D = 12.363''$$



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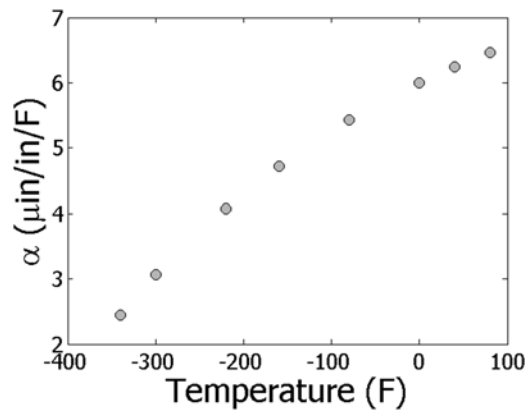
## Can You Find a Better Estimate for the Contraction?

$$\Delta D = D \int_{T_a}^{T_c} \alpha(T) dT$$

$$T_a = 80^\circ\text{F}$$

$$T_c = -108^\circ\text{F}$$

$$D = 12.363''$$



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## Estimating Contraction Accurately

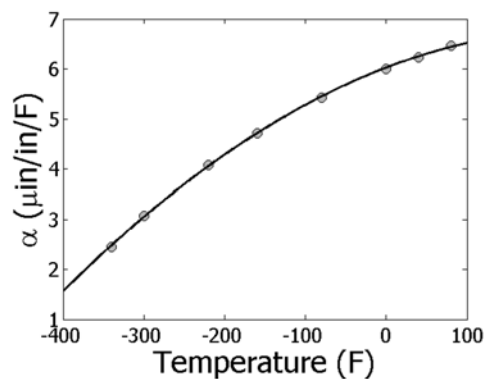
Change in diameter ( $\Delta D$ ) by cooling it in dry ice/alcohol is given by

$$\Delta D = D \int_{T_a}^{T_c} \alpha(T) dT$$

$$T_a = 80^\circ\text{F}$$

$$T_c = -108^\circ\text{F}$$

$$D = 12.363''$$



$$\alpha = -1.2278 \times 10^{-5} T^2 + 6.1946 \times 10^{-3} T + 6.0150$$

$$\Delta D = -0.0137''$$

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## So what is the solution to the problem?

One solution is to immerse the trunnion in liquid nitrogen which has a boiling point of  $-321^{\circ}\text{F}$  as opposed to the dry-ice/alcohol temperature of  $-108^{\circ}\text{F}$ .

$$\Delta D = -0.0244''$$

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## Revisiting steps to solve a problem

- 1) Problem Statement: Trunnion got stuck in the hub.
- 2) Modeling: Developed a new model

$$\Delta D = D \int_{T_a}^{T_c} \alpha(T) dT$$

- 3) Solution: 1) Used trapezoidal rule OR b) Used regression and integration.
- 4) Implementation: Cool the trunnion in liquid nitrogen.

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## Introduction to Numerical Methods

### Mathematical Procedures

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## Mathematical Procedures

- Nonlinear Equations
- Differentiation
- Simultaneous Linear Equations
- Curve Fitting
  - Interpolation
  - Regression
- Integration
- Ordinary Differential Equations
- Other Advanced Mathematical Procedures:
  - Partial Differential Equations
  - Optimization
  - Fast Fourier Transforms

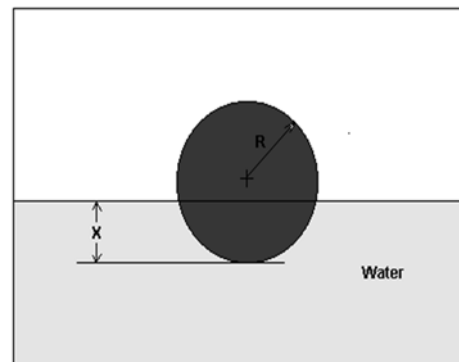
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## Nonlinear Equations

How much of the floating ball is under water?

Diameter=0.11m  
Specific Gravity=0.6



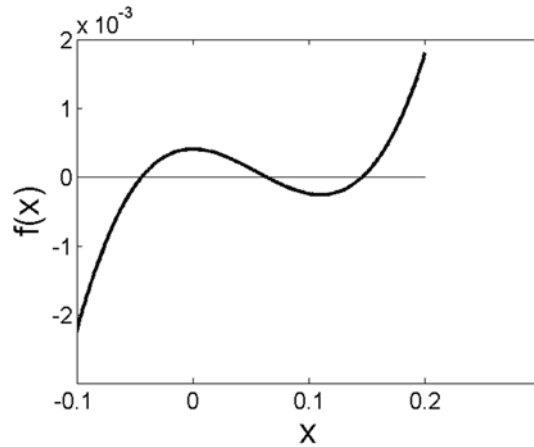
$$x^3 - 0.165x^2 + 3.993 \times 10^{-4} = 0$$

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## Nonlinear Equations

How much of the floating ball is under the water?



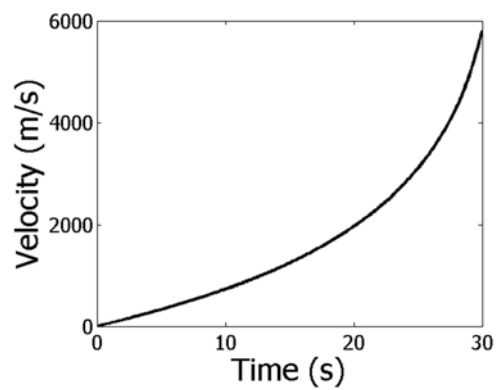
$$f(x) = x^3 - 0.165x^2 + 3.993 \times 10^{-4} = 0$$

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## Differentiation

What is the acceleration  
at  $t=7$  seconds?



$$v(t) = 2200 \ln\left(\frac{16 \times 10^4}{16 \times 10^4 - 5000t}\right) - 9.8t$$

$$a = \frac{dv}{dt}$$

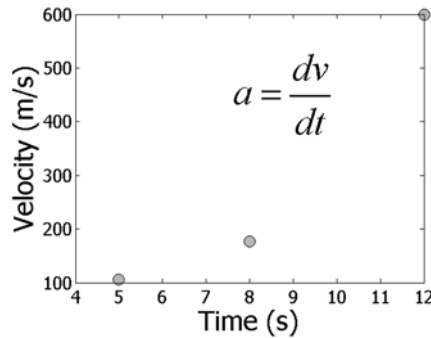
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## Differentiation

What is the acceleration at  $t=7$  seconds?

Time (s)	5	8	12
Vel (m/s)	106	177	600



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## Simultaneous Linear Equations

Find the velocity profile, given

Time (s)	5	8	12
Vel (m/s)	106	177	600



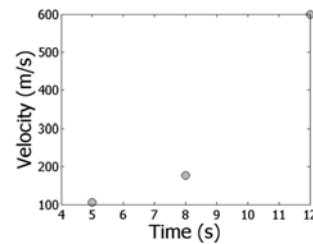
$$v(t) = at^2 + bt + c, 5 \leq t \leq 12$$

Three simultaneous linear equations

$$25a + 5b + c = 106$$

$$64a + 8b + c = 177$$

$$144a + 12b + c = 600$$



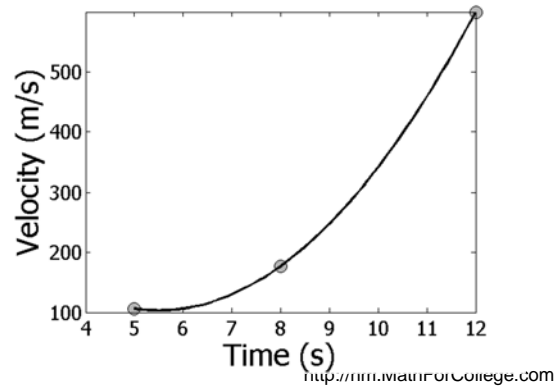
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## Interpolation

What is the velocity of the rocket at  $t=7$  seconds?

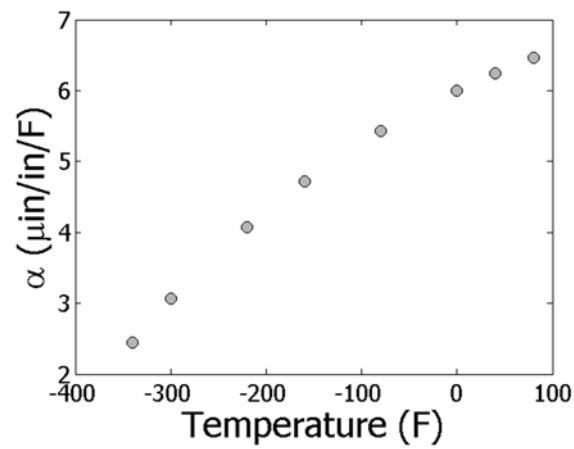
Time (s)	5	8	12
Vel (m/s)	106	177	600



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## Regression

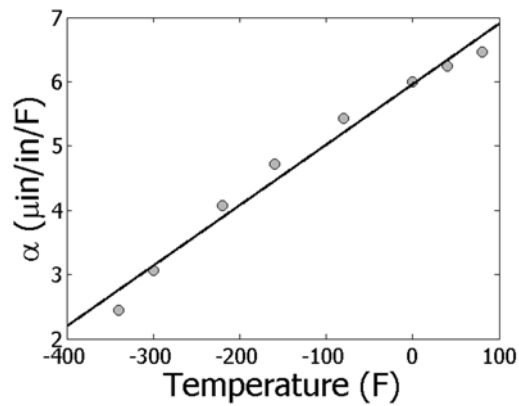
Thermal expansion coefficient data for cast steel



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## Regression (cont)



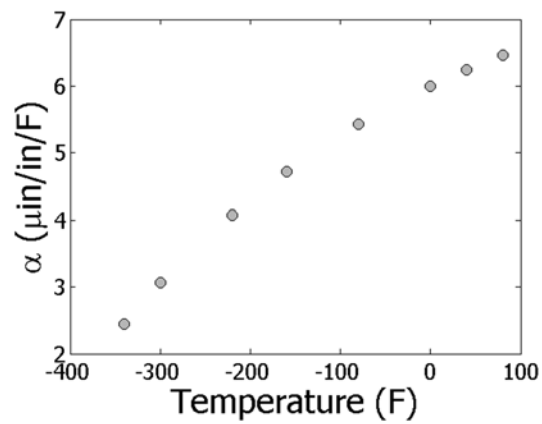
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## Integration

Finding the diametric contraction in a steel shaft when dipped in liquid nitrogen.

$$\Delta D = D \int_{T_{room}}^{T_{fluid}} \alpha \, dT$$

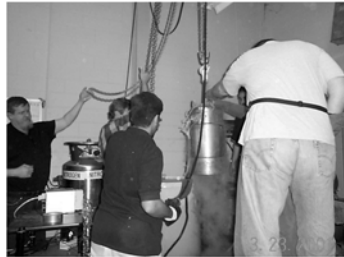


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# Ordinary Differential Equations

How long does it take a trunnion to cool down?



$$mc \frac{d\theta}{dt} = -hA(\theta - \theta_a), \quad \theta(0) = \theta_{room}$$

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