ME 355 – System Modeling and Numerical Methods
Fall 2023

Project 2

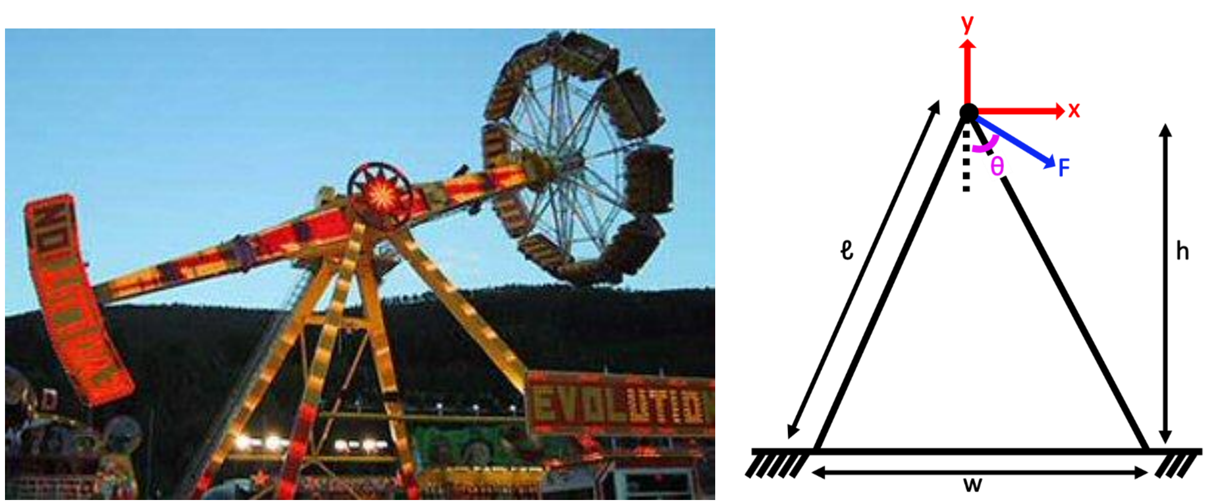
Due Friday, October 20 by 11:59 pm
Preliminary functions are due Wednesday, October 11 by 11:59 pm
This project must be turned in on Blackboard.

Honor Code: You are welcome to work together and talk about your code. However, it is an honor code violation if you send your code to your classmates or are typing your own code while looking at another student's computer screen. Similarly, telling another student what you did line-for-line is not appropriate. Instead, you want to describe the algorithm, or steps, you used to solve the problem; then your classmate would write the algorithm, or steps, in their own words.

You have been hired by FarFabbri, a thrill ride manufacturer based in Italy. One of the products your company has manufactured was the Fabbri evolution pictured in figure 1a. As you are working on a completely unrelated project to the Fabbri evolution, your project lead comes to your cubicle with an urgent request.

"This may be a bit of work, but one of the current companies that has purchased one of the old Fabbri evolutions is Six Flags. Some of the guests at Six Flags St. Louis have noticed a lot of movement with the ride and are concerned. They are saying most of the motion is at the point of the ride which connects the supports to the swinging arm. Can you take a look at this?"

You sigh and begin sketching out the system, creating a free-body diagram in figure 1b. For the entire system, you assume it is static and no dynamic forces will impact the energy of the system at any finite point in time. You then decide to look up the material properties and parameters for the ride. These are listed in Table 1.



(a) (b)

Figure 1. (a) A picture of the Fabbri evolution (https://en.wikipedia.org/wiki/Evolution_(ride)) and (b) a diagram of the model used to examine the Fabbri evolution.

Your job is to analyze the deflection of the center pin when a given force is applied to the system. During your analysis, you assume that it is approximately 5 tons (50,000 N). You plan to accomplish this analysis by:

1) Developing the model equation for potential energy based on the variables E, A, w, l, h, θ, and F.
2) Developing a model equation for the angle θ.
3) Optimizing the potential energy model to calculate the current (x, y) deflection.

Table 1. Material and geometric parameters for the Fabbri evolution.

Parameter	**Symbol**	**Value**	**Units**
Young's Modulus	E	2×10^{10}	Pa
Cross-sectional Area	A	0.01	m^2
width	w	10	m
length	l	12	m
height	h	10	m

The ride runs for 60 seconds starting at $t = 0$ seconds. Assume that the angle θ with respect to time t can be modeled as a cos/sin wave with 4 oscillations in 30 seconds. The motion starts at an angle of 0 radians and the cos/sin wave's magnitude increases linearly with time to a maximum amplitude wave of 3 radians at 30 seconds. At 30 seconds, the angle wave magnitude begins decreasing linearly with time back down to an amplitude of 0 at 60 seconds at the same frequency.

You plan on modeling the beams using the truss model from your ME 355 class back at Valpo.

Truss Method

In this method, the two beams will be modeled as truss elements. The truss elements can be modeled as springs with stiffness EA/l. Like the in-class example, you will need to develop the potential energy equation using this method.

1 Functions

To complete this task, you will need to develop 3 MATLAB functions. Preliminary versions of these functions are due on the date specified above. To get full credit for the preliminary functions you must have made a legitimate attempt. You may make changes to the functions after the preliminary function due date and prior to the final due date.

1. **PETruss.m**
   PE = PETruss(x, y, F, theta, E, A, w, l, h)
   This function calculates the potential energy of the Fabbri evolution by modeling the beams as truss elements.
2. **ThetaFunc.m**
   theta = ThetaFunc(t)
   This function calculates the value of θ from figure 1b where θ is in radians and t is the time in seconds.
3. **PEMax.m**
   [x, y] = PEMax(F, theta, E, A, w, l, h)
   This function calculates the (x, y) position which minimizes the potential energy from the PETruss function. To calculate the x and y displacement for a given set of parameters you will need to use the fminsearch function. For examples, see the example code from class.

2 Analysis Documentation

For your project, you want to provide documentation to show your project lead your analysis. To complete your documentation, your report should include the following sections.

1. Title Page

2. Model
   Explanation of the model using the truss method. This should include:
   a. A Figure of the system. This figure can be hand drawn on **unlined paper** and scanned into your report. You may use engineering paper.
   Note: you may not use the graphic from this document!
   b. A figure of the system modeled using spring elements. This figure can be hand drawn on **unlined paper** and scanned into your report. You may use engineering paper.
   c. Model assumptions
   d. Clear instructions on how you derived your model equation for potential energy for the truss method.
   e. Your model equation for potential energy for the truss method.
   f. Clear instructions on how you derived your theta equation.
   g. Your theta equation.

3. Analysis
   This section only needs to include the following captioned figures.
   You should make these figures in a file called **project2.m**.
   Note: plots are in the form of y-axis versus x-axis variable.
   Plot all length variables in millimeters.
   a. Plot of θ versus time for the length of the ride
   b. Plot of x displacement versus time for the length of the ride
   c. Plot of y displacement versus time for the length of the ride
   d. Plot of total displacement versus time for the length of the ride
   e. Plot of y displacement versus x displacement for the length of the ride

3 Deliverables

Be sure to submit all 5 files!

1. PETruss.m
2. ThetaFunc.m
3. PEMax.m
4. Project2.m
5. Analysis Documentation PDF

4 Rubric (Total 100 Points)

Function 1 – **10 Points**
Function 2 – **10 Points**
Function 3 – **10 Points**
Turned in preliminary functions on time **– 10 points**

Modeling Documentation – 5**0 Points**
Your modeling documentation is worth 50 points. It is important you spend significant time on this portion of the project. You will be graded on **clarity, conciseness, ease to follow steps, and completeness**. If you want to check if you are successful on this part of the project, send it to someone outside of the class and see if they can follow your thought process.

Model & Analysis – 5**0 Points**

Analysis Documentation format and Code Comments – **10 points**

5 Notes for Report

For any equations, please use the equation editor.
For Figures and Tables, please follow the guidelines outlined in the example report on Blackboard.
Include a title page.

6 Notes for Functions

These notes do not apply to the **project2.m** file.
All functions must be named EXACTLY as listed above. This includes capitalization.
Functional inputs and outputs must be EXACTLY as defined in the Functions section.

7 Test Data

If you run the following code below in the MATLAB command window, you should get the following output. Do note, this does NOT guarantee your code is correct.

```
a = PETruss(0.2, 0.4, 25, -0.4, 1E3, 0.001, 2, 3, 0.7)
b = ThetaFunc(0)
c = ThetaFunc(30)
d = ThetaFunc(60)
e = ThetaFunc(11.3)
f = ThetaFunc(44.4)
[g, h] = PEMax(25, -0.4, 1E3, 0.001, 2, 3, 0.7)
```

```
a =   11.2476
b =    0 (You may get a number really close to 0 like -2.9392e-15)
c =    0 (You may get a number really close to 0 like -2.9392e-15)
d =    0 (You may get a number really close to 0 like -2.9392e-15)
e =   -0.0473
f =   -0.7515
g =  -10.2021
h =  -21.4348
```