QIQI WANG: Welcome to 16.90. I'm Professor Qiqi Wang and this is Professor Wilcox. So we are going to be together teaching 16.90 this year. So 16.90 is Introduction to Computation Methods for Engineering Aerospace Engineering.

So what I'm going to do today is [INAUDIBLE]

But before that let's go over about what this class is about. [INAUDIBLE]

OK. So I'm first going to go over the syllabus. And then professor Willcox is going to show you something new this semester that is very exciting for you to-- actual a great way to guide yourself to learn the material yourself.

Because this lecture is really-- this class is really taking advantage of the [INAUDIBLE] classroom structure, we really want you to learn the material before you come to class. And in class we are going to be assuming you have read the material and we are going to be solving problems together. So this is really not a new style. This style has been practiced in this department for a while.

So lecture one. We are now using computers to do a lot of things. Every one of you are using computers checking email [INAUDIBLE].

The reason we have computers is because of things we are going to be talking about in this class. So the first real computer is designed not for checking emails but for computational simulation to help engineers solve problems in ballistics. And these are really aero problems. So we are going to see something very similar to the world's first computer applications in this subject.

OK. So let's fast forward in time and come to today.

Today's computer simulations are-- haven't become less important but increasingly important for studying, interpreting, and predicting many different processes. And we are in aerospace engineering so I'm just going to be talking about aerospace examples. But outside aerospace you can find even a lot of broad application for computational simulation.

So this is a class even though you not end up doing aerospace, it is going to be also [INAUDIBLE] --related to either science or engineering. This is going to be useful.

So two examples are simulation of spacecraft reentry. And this is a real thing. [INAUDIBLE] Another example is designing [INAUDIBLE] this is the simulation.

And we're going to be talking about how to perform this kind of simulations. And these are [? PD's ?] because you have multiple spacial dimensions where you have x, y, and z. And if you are unsteady you also have a fourth dimension which is time.

So, to solve problems using numerical methods some problems like that. It really involves two steps. So this subject we are going to be spending a lot of money talking about how to solve differential equations. But let's not forget the first step. That is how you would actually get this differential equation. OK, so the first really is to reduce a real system or process or [INAUDIBLE] into a mathematical model. And in a lot of times you are going to find out the mathematical model is going to be a differential equation.

So to figure out what kind of mathematical model is suitable for the system or process you are studying you have to first know what are the quantities of interest. [INAUDIBLE] What do you want to know? OK. And what are the key processes involved? What approximations can we reasonably make that is going to lead you to [INAUDIBLE]

And the model we are going to derive [INAUDIBLE] from the differential equation-- [INAUDIBLE] it can be linear or non-linear. Or you could look at the [? method outcomes, ?] distinguished between linear and non-linear equations-- [INAUDIBLE] It can be deterministic or probabilistic. At the end of this chapter we are going to be looking at [INAUDIBLE]. It can be static or dynamic, involve time or [INAUDIBLE]. It can be discrete or continuous, either based on [INAUDIBLE] principle [INAUDIBLE] of math, --of momentum, [INAUDIBLE] --or empirical. And once you have that you design a computation code and solve the mathematical model.

So let's take a look at an example of a computational model. The model is a thermal problem. So this is really-- this guy is a [INAUDIBLE] thermodynamics problem. Problems like this [INAUDIBLE] where you have something spinning up. Different parts are going to heat up at different rates and expand at different rates.

You want during the entire process of different parts expanding at different rates, nothing is going to heat another part. Right? You know on the spinning-- spinning [INAUDIBLE] or turbines which actually expands-- heats up faster than the outside of the turbine engine to actually keep the outside safe. So you need to really predict well how fast different parts heat up during the process.

So our model problem is this. This is aluminum. It's a 3.89 cm cube, initially at room temperature. It is going to be heated up by this [INAUDIBLE]. starting at time equals t0. We're going to be turning off our air at time equals t1. So here comes the quality [INAUDIBLE] the measured temperature. So you see here it's a thermocouple basically stuck inside [INAUDIBLE] how this thing heats up.

No, what I want you to do is form a team of either two or three. [INAUDIBLE] And answer this question. I've already given you what is the quantity of interest, the temperature in the middle of the cube. Now the question is what are the important [INAUDIBLE], and how to model the [INAUDIBLE] mathematically. OK. And last, I'm actually going to show you because this is what you are going to be learning in this class. How to use the mathematical model to make the prediction which means how to solve this equation [INAUDIBLE].

So, when we're here and start with these two questions, at the same time as you form a team I'm going to start [INAUDIBLE]. The last time we actually had more time for you to solve these so this time we are running out of time. I know a lot of you haven't gotten to the bottom yet. A lot of you I think given more time is going to derive the equation, especially some of you are looking up online and taking a lot of time to calculate.

So here I think I'm just going to wrap up by telling you how I would model. There is no single way of modeling this. But, my way is just a-- OK. All right.

So, what is the physical process that determines the quantity of interest which is the temperature of the cube? I'm saying the temperature of the cube because aluminum is very good conductor of heat. So If there is uneven heat in the temperature distribution inside the cube, it is going to even out very fast. Especially for a cube of this small size. All right?

So one can assume that the temperature distribution inside the aluminum is basically uniform throughout. When you look at the time history it heats up slowly over the course of many minutes. The temperature-- the conduction inside the aluminum is actually much faster than that. So we can say that the temperature-- [INAUDIBLE] OK the temperature of the aluminum is only a function of time. So this is the temperature of the cube. OK. Now we have the temperature of the cube. So what governs the temperature of the cube? What makes the temperature of the cube change? Heat convection. OK. So we have heat convection. OK? We have heat convection that makes the delta of the internal energy of the cube. Right? Equal to what?

So let's say that been two time points the change of the energy of the cube is equal to what-- what has contributed to the energy change? Yes, what I'm looking for is the change in the energy is really equal to the heat that goes into the cube plus what's done to the cube. Right? And nobody did any work to the cube. Right? I didn't, I don't know if you did.

So it is only equal to the heat convection into the cube. All right? So this is how you start putting the physical process into equations.

Now let's look at how do we relate both sides of the equation to the temperature of the cube. OK? How do you relate the delta in the internal energy to the temperature of the cube?

So the change in the energy relates to the change in temperature. Right? How does it relate to the change in temperature? Delta t times what? C? Cp? Times the mass. Right? OK and the mass we-- although we don't know exactly what it is, we can look up for the density of the aluminum and the size of the cube. Right?

So this is going to give us the changing energy. And what is the-- what determines how much heat has convected it into the cube?

[INAUDIBLE]

OK. So I think I should write it like this. What determines Q? What determines the heat that goes through the surface of the cube into the cube?

So that is Q from the gun minus Q-- so this is gun to cube right? So this is cube to air. So this is gun to cube minus cube to air.

Now how do you model-- how does the rate of heat transfer from the gun to the cube depends on the temperature. And how does the rate of-- how does the heat convect from the cube to the air?

[INAUDIBLE]

Yeah, they linearly depend on the difference in the temperature. So if you look back on unit five notes-- OK. So this is-- these are heat convection right? Heat convection. And the way you blow air from the gun to the cube is forced convection. OK. So this is C-- the rate of the forced convection, it is proportional to the temperature of the hot air minus the temperature of the cube times the coefficient. And the coefficient is the forced convection coefficient in the air times the area of the convection. And for example, [INAUDIBLE]

So maybe we can just say 2 times the square is the temperature of the heat. And maybe the cube to air is C free convection times now four [INAUDIBLE] now is T minus T air. All right? And this is the rate of heat conversion.

Now we time the delta of time. We are going to get the amount of heat that went into the cube during a small time unit.

Now this is going to give us a differential equation. Because if we let the delta T, the amount of time we are looking at goes to zero, we are going to get to the equation of Cp times rho d cubed dT/dt. So this is the rate of change in the temperature equal to C force times 2 d squared T H minus T minus C free, 4 d squared T minus T air. right

So this is the differential equation we get. Now what changes when we turn off the heat gun? C force is gone and the C free becomes [INAUDIBLE]. Right. So that's the difference. And let's go to Matlab, and I wrote a code for simulating this.

So here is the parameters. Ambient temperature we said today is a little bit colder than I thought. And the hot air temperature, if we look at this, I think is like 106 or something. Let's put 106. And the start time in seconds I actually don't know, so let's just put 0 here. And the T stopped in seconds. What time is it like 11 minutes? What is 11 minutes in-- so this is 11 minutes right? OK. tend I think I'll just do this. OK.

So these are what I looked up online. Some of the values for the free air convection and the forced air convection. And the [INAUDIBLE] of the aluminum cube the density of aluminum, and the specific heat capacitance. All right. And these you don't need to look at them because they are never used in the code because radiation exactly is not important.

So heating and we are using [INAUDIBLE] so solve the equation. I'm basically saying that the heating rate is proportional to two sides, and the cooling rate et. cetera, and we are also doing the cooling.

So let's do the simulation. We are getting a plot like this. And let's compare our temperatur.txt-- [INAUDIBLE]

Oh, OK. I need to get rid of this. Let me push the stop. Not responding. Error writing.

[INAUDIBLE]

OK.

Now we are plotting. So look at the difference between the simulation and the experiment. It's huge. Right? So what is causing this Difference It is because now here what I said is the force convection coefficient is 10 watt per meter square plus K. Right? Now let's go to the internet and search for force convection coefficient of air. Engineering toolbox.

Is it this one? Yes. Forced convection of air goes all the way from 10 to 200. OK. And here I am actually putting the lower bound. If I put something like 200 and do the simulation again, and do the experiment again, this is what I got. OK. I've got a much better match and I also have my free convection to be 5. If you look over the internet free convection goes from 5 to 25. OK.

And also if I go to 25 I think I am also going to be getting a much better match. OK. So the rate of decaying is much better now. And another thing I assume there are only two sides of the cube are being heated. [INAUDIBLE] But actually if you switch over to the next problem you will see more than two sides are being heated.

So that is actually another motivation for why we need to look at not only one simulation but several simulations. And that is leading into the fourth part of this subject, probabilistic simulations. Because when you look at a lot of physical phenomena there is a lot of uncertainty in it when you look at the range of coefficients you can possibly get in modeling physics. And convection is a primary example if this because there are so much uncertainty in what rate you can get.

All right. So this is our first lecture. I will see you next Monday. But remember, one thing is you need to read and do the homework, do the embedded questions before you come to class next Monday.