Kaelyn (00:14):

Dr. YJ Lin is currently serving as Professor and Director of the Mechatronics Engineering Program in the College of Engineering and Engineering Tech at Northern Illinois University, where he first joined in 2019. Dr. YJ Lin has received all of his degrees in mechanical engineering, including BSME from Tsinghua University, Taiwan, MSME and PhD from University of Illinois at Chicago. His academic professorship began with the University of Akron, where he taught and conducted research for 20 years. In his academic career for three decades, Professor Lin has built up a rich research and teaching experiences in mechanical and mechatronics design, structural mechanics, and control engineering that has grown into engineering application areas, leading to aircraft's health monitoring, deicing, and more recently, to the design of MEMS devices for energy harvesting.

He has been invited to serve on the editorial advisory board of three international journals in automation, sensors, and robotics in recent years. He's also served as a PI for a number of NASA-sponsored key projects in the development of aircraft mechatronics deicing technology that's of interest to the aerospace industry. He is authored and co-authored more than 100 reference papers published in journals and conference proceedings. Recently, professor Lin has also co-authored two engineering books in mechatronics and robotics fields, published by Elsevier and ASME press in 2018 and 2019. Today, Dr. YJ Lin will be speaking on a new look on aircraft deicing technology.

Dr. YJ Lin (01:56):

Thank you, Kaelyn, for the introduction. Hi, everybody. It's my great pleasure to be able to talk to you today regarding deicing technology for aircraft. This is closely related to space technology development and I will go through a few slides to tell you what we are aiming at and how we can really attack the problem with icing and try to remove ice using the mechatronic way instead of using the traditional way, and the pros and cons of our approach. First of all, as Kaelyn introduced, I'm currently with the new program called Mechatronic Engineering Program at NIU. If you are having any questions or interest in this program, you can send me an email or call me and we can discuss about your questions or queries regarding our new program. Currently, our program have a bachelor's degree, but we are developing our degrees in the near future. We have about a hundred students currently.

You might wonder what mechatronic engineering is all about. Mechatronic engineering, as you can see here on the chart, it's actually an integration. I use an integration sign here. I think all this students attending today's lecturer, you should be able to understand the symbol here. By integration, it means that we actually take the common part of all these disciplines together and mix together and called this mechatronic engineering. The disciplines that we hear traditionally would be a mechanical electrical control computer. But if you put them all together here by taking the common part, it becomes the mechatronic engineering. So in other words, mechatronic engineering actually make use of all this spirit, of all this different disciplines. Our students will have the good chance to actually learn all this different disciplines. Not necessary in depth, but at least you have the enough knowledge and skill to use them in your design, work, and your technology development work.

If you do have any interest of mechatronic engineering and wanted to attend our school in this program, please don't hesitate to contact me and let me know your questions, if any. And if you wanted to visit with us, you are welcome to do so. As I mentioned earlier, we do have a bachelor's degree program currently. We started about two years ago. Currently, we have about a hundred students in our program. The graduate programs in masters and PhD would be in development. As with our current enrollment growth, I believe that in very short period of time, maybe two, three years, we are going to have our graduate program ready to offer degrees too. Currently, our faculty are interested in these few areas related to mechatronics. As you can see robotics and automation, mechatronic-based applying energy. I have also a postdoc working on this topic too. And measurement and control, which is essential part of the mechatronic engineering. So these are something that if you are interested in, we can discuss more through different ways of communication.

For today's topic, I am looking at the proof account concept to see if we can really develop new technology with deicing for the aerospace structure mainly for aircraft. So the motivation for this research is aimed at the deficiencies of the current aircraft deicing system, which is usually overloaded. It's very heavy. If you look at the 747 aircraft, their deicing system, which usually is thermal system, it's weighing more than 500 kilograms. But as opposed to that if we use our technology here, we only need to have about five kilograms of the device weight. So if you compare, you can see that almost a hundred times of reduction in weight in terms of the aircraft deicing equipment on the aircraft.

All the aircraft currently in use, no matter it's on ground in the wintertime or it's in-flight, it needs a deicing system. And most of the current aircraft, their deicing system are thermal-based and we use electro-mechanical base some of deicing system so that makes the difference. And the fundamental techniques that we apply is by using piezoelectric material as our transducers, either doing sensing and actuating using this piezoelectric. That's why we can have a very lightweight deicing device instead of having a heavyweight like currently using in the aerospace industry or in aircraft industry.

So that's the motivation. Our team do have good experience, many years on doing a smart structure, especially for vibration suppression. I'm using PZT-based sensing system and actuating system. For doing the vibration suppression, we use a PZT-based structures and transducers to try to reduce the vibration of any device that have over-vibrating situations. So we will be able to control the vibration and reduce that vibration into a very stable system. So in use of that technology, we can do reverse side to try to generate some kind of vibration to be able to remove ice from the surface of aircraft structure.

As you can see, usually ice will be accumulated at leading edge of the aircraft. For example, wind structure over here which is usually in the arrow foil, the configuration here. Something here at the end or close to the end of the wind or in the engine housing, we would be able to see some configuration like this. This would be the area or the tail and nose also. Usually when the aircraft in flight or on ground in the winter or extreme weather situation in snowy days, it would be accumulated in this area and that's the danger of flying. So we try to remove them and that's why I mentioned earlier in the talk thing that most of aircraft going into use, they always have some kind of deicing system and current deicing system, they all use the heat to try to melt the ice. And the thermal system usually is heavyweight and it's very critical for carrying that heavyweight into air, but it's necessary to have that. That's why we thought of this using the mechatronic way to develop our deicer.

As I mentioned earlier, the negative effect of having ice accumulated on the aircraft would cause the aerodynamic performance degradation, stability problem that would lead to control issues. Because of that, we have some safety concern obviously would be generated due to having some ice accumulated on part of the air aircraft structure. So we would need to remove them. And how do we do that? Well, there's another adding benefit using our technology. If you compare to the current technology of deicing, which is on ground deicing for like say Chicago O'Hare Airport, if you see some aircraft parking there before flight in winter snowy day, usually we will see some truck coming over with some staff there and spray on the aircraft. And usually, pilot or the flight attendant will tell you that we are doing deicing before fly. So that's why it's very important to have ice removed from the surface of the aircraft.

However, if we use the traditional way, if you look at the spray onto the aircraft, those are chemicals. If we use those liquid chemicals spray, that will cause some environmental problem after all this going to the ground. And also, it's very costly to do that. So in statistic over the years, the data shows that each year, we almost spend $200 million US dollars in doing this in all over the world, in the airport that have the winter situation or snowy situation to do deicing using this chemicals. So if we can apply our technology there, we are able to do it, not only in-flight when the aircraft, but also on ground to do our deicing using mechatronic way. We don't have to use any chemicals at all. So in terms of the material itself and the staff or labor that costs for doing the job, that deicing job, we can save about 300 millions per year in the world or all the airports that you see chemicals to do deicing. So it's a big saving here, as you can see, even that would lead to some pros of using our technology.

Over here, as I mentioned earlier, we wanted to apply the experience that we have, the research experience that we have for using piezoelectric transducers to do vibration control, to do a lot of different actuation purpose for mechanical and electrical structures. Here, we use the reverse side to generate some vibration to be able to remove ice, but that has to be based on the features of the ice sticking to the surface of the aerospace structure. So that's why we did some evaluation-based on some papers that publish regarding the sticking strengths between the ice itself and the surface. Of course, the surface will be a different materials that people are looking at mainly like aluminum, copper, stainless steel, or polish standard steel. All these, you can see different values that we can dig from published journal papers to look at their strengths. That means the strength between the ice and the surface of the aircraft structure being the wind tail or nose of the aircraft or fuse lodge.

So wherever we see ice there, the sticking, actually sticking strength can be look at over here. And our job here is to be able to really break that and be able to remove it. Just imagine that in your home, when you go to kitchen in the refrigerator, if you make some ice using the traditional ice pack, those are small box, small two big box. And then if you try to remove the ice from the refrigerator by hand, it's very sticky. That's the job that we need to do over here. We are going to really generate some kind of shear stress to be able to remove the ice from the surface. And we did some analytical study using simulation, but based on the information and go into the lab and use some commercial subzero freezer here as you can see to do our testing using our technology. This is just for a proof of concept. We have used, we have obtained one piece of the material. This is a composite material from aerospace industry.

A company gave us the structure like this is a composite material and I would say in the future aircraft industry, most of the structure of the aircraft would turn into composite material to reduce the weight. If you really understand the material itself, this material in fact is very strong. Very strong compared to metallic material that used to be, used for making aircraft structure. But if we can really change to composite structure, it may be giving us advantage of saving the weight to be carrying into the air, but still maintaining the strengths of material of the structure of the aircraft. So that's why we obtain a sample, a piece here, which is actually a plate surface.

On here, we are going to have some ice made within this commercial freezer to make use of our technology. You can see that we have some piezoelectric transducers connected to our controller outside of this to do our testing. So this is a one type of structure, which is a rectangular plate that we obtained with some material, composite material obtained from aircraft industry. We also fabricate one piece of aluminum leading edge structure. This is based on FAA standard air foil configuration. There is some standard that you have to bear in mind when we do our coverage here for the leading edge structure. That's why we can call this aircraft leading edge. The material is aluminum. So this is a metallic material we wanted to also do our testing. And you can see that, again, we have attached our transducers at certain important locations to test our technology, to see how effective our deicer will work. So this is the testing structure or test rig developed in the lab.

Based on analytical study as I mentioned earlier, we actually look at the composite structure and measure the structure and develop into differential equations. As you can see, this represents the mathematical model or physical model of the structure. And our purpose here is to use the model to study as to how much we can do with our deicer added to the dynamic of the system to change the differential equation into some solutions that we would like to see without having ice or we can actually generate enough vibration to remove the ice from the surface. So this is the force order differential equation or partial differential equations that we generate for the structure. It's a rectangular plate, which is on the left hand side in the previous slide. And we use that model to do our analysis with the simulation. As you can see, the computer simulation will give us the vibration mode for this type of the structure.

So based on that force order partial differential equation, we can plug in our software to be able to study and find out the significant mode of vibration for the system and we are able to identify that and try to attack those significant modes to be able to generate some kind of shear stress to remove the ice from the surface. And this is the purpose of doing that using the simulation. As you can see here, we use the freezer to go overnight to be able to form rigid ice onto the composite rectangular plate. And these ice cubes are very sticky just like when you try to remove ice cube directly from the ice pack that you put in your refrigerator overnight. You would really have a hard time to get it out directly and a lot of time, people use just some kind of operation generated by your hand or hitting on the sink or so to try to get rid of the ice pack and try to get your ice.

And then over here, we are not able to really knock anything on the structure. But using our transducer, we'll be able to generate something that you are not able to see. However, it will be some shear stress generated so that you will be able to remove the ice from the surface. Same thing, we did another testing. You can see that with a long piece of the ice cube generated overnight in the subzero freezer here to be able to do our testing. So for the rectangular plate, we did have this testing. And as you can see over here, we also measure the time for once we trigger the icer, the transducer will generate vibration and be able to remove the ice and this is just the data for the average deicing time that you can see.

And we did that for also the leading edge structure, the aluminum structure, and be able to prove that our concept of removing ice using mechatronic way with a lot of reduction in the weight of the icer really work. Obviously giving like two minutes or so, we'll be able to remove the ice from the surface. However, these ice are actually sticking stronger than those that we see in the real aircraft because when aircraft is moving in-flight with very high speed, all the accumulated ice will be looser compared to those ice that we make in the refrigerator or in the freezer. So if we need to take two minutes to remove ice here in the freezer, it would probably only take 10 seconds or so to remove ice from aircraft.

So those are things that we found out that we did successful deicing within certain given time using our technology. So it shows our approval of concept and the total electric power that we use is only 600 watts, which per square meters. So it's very low compared to other type of the device. And also, we did the leading edge structure on this too so when we found out to be very successful. So that's all I wanted to talk to you about regarding our testing of the new deicing technology and see if you have any questions or suggestions. And also, don't forget if you do have any questions or interests of mechatronic engineering program at NIU, please contact me. Any questions?

Heidi (25:33):

I actually have a question, Dr. Lin. This is Heidi from the [inaudible 00:25:38]. What are the next steps? So you've done this basic testing, what's your next steps? Do you have industries interested in furthering your research and testing it out on the aircraft?

Dr. YJ Lin (25:55):

Yes. Our next step obviously will be going into icing wind tunnel to do our testing instead of in the lab, in the refrigerator to test it. Icing wind tunnel is more expensive and only NASA and a few industry that making the icer, having that icing wind tunnel. So I have contacted one companies around area to see their interest or letting us working on testing with their facilities. And since it's a kind of a contract deal, so we will have to see if they are interested in getting us over to do this testing. And to set that up, it would take a few months, I believe, to get mutual agreement on everything. Yeah. We do plan to do that with industry.

Heidi (27:02):

Thank you.

Dr. YJ Lin (27:02):

Thank you.

Heidi (27:04):

Well, before you leave, the mechatronics program.

Dr. YJ Lin (27:08):

Yes.

Heidi (27:10):

You said that it probably will be a couple years, but you'll get the graduate program and possibly PhD program going as well.

Dr. YJ Lin (27:17):

Yes.

Heidi (27:18):

What kind of backgrounds should students have if they're looking into transferring into your program? So I think we have a few students in their early years of school. What classes should they be taking to transfer or to apply for the master's program in a couple years?

Dr. YJ Lin (27:37):

In fact, we don't have any requirement other than the traditional engineering requirement to be able to transfer into our program. Maybe starting from the third year from junior and into the senior, student needs to have one preparation, which is computer programming to be able to get our degree. I think C++ is a requirement and usually, they can be taken anywhere from university. It can be from community college too. Once you have that, they are able to take our first course called programmings for mechatronics and that's the prerequisite for that. And once you have the programmings for mechatronic, then you can move on into taking another six courses required for the bachelor's degree of mechatronic engineering. Other than that, it would be taking some mechanical engineering courses, electrical engineering courses, and the [inaudible 00:28:49]. That's for the bachelor's degree.

Heidi (28:52):
Oh, thank you.

Dr. YJ Lin (28:54):
You're welcome.