Stability Analysis of Aeroelastic Systems

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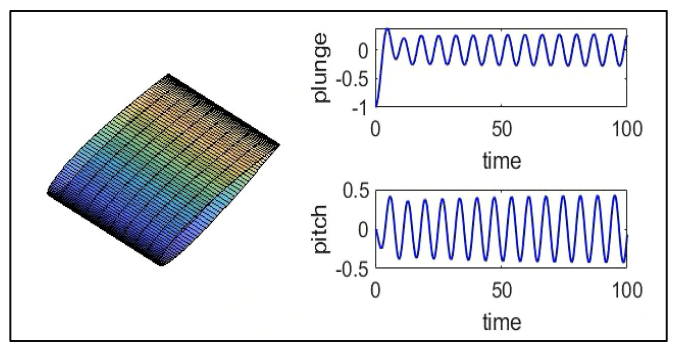
Introduction

In our lab we are studying flutter instability in systems. A place where you would encounter instability in real life would be in more places than you think. Flutter instability is prominent in air planes, bridges, biological systems. We studied these systems that involve instability and modeled them in MATLAB.

Animation Model of a Wing:

The wing maintains a constant amplitude, the graph is not decaying. Pitch and plunge are being monitored.



Objective & Impact of Professor's Research

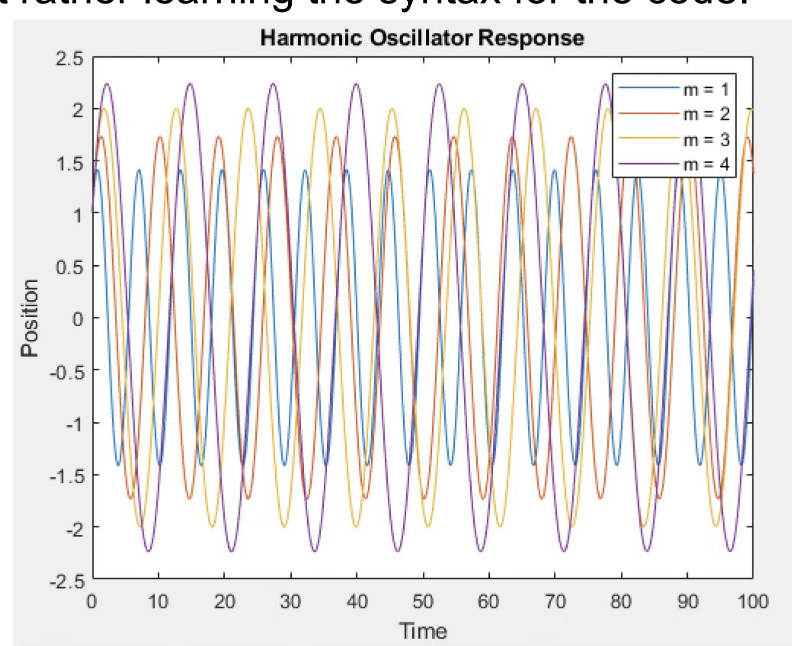
Dr. Ghadami's research area centers around the utilization of data-driven and artificial intelligence methods for forecasting, designing, and managing the dynamics of intricate systems. The primary objective is to enhance the systems' ability to withstand undesirable and unforeseen outcomes in their behavior. The scope of this work spans from predicting catastrophic events in the dynamics of both natural and engineered systems to analyzing and enhancing the resilience of multi-agent system dynamics when operating in uncertain settings.

Acknowledgements

I would like to thank Professor Ghadami for giving me the opportunity to perform this research. I would also like to thank my mentor Nami Mogharabin, for aiding me through this program and helping me through the research. I have learned so much from Professor Ghadami and Nami and I'm grateful for the research I've done and the research processes I practiced.

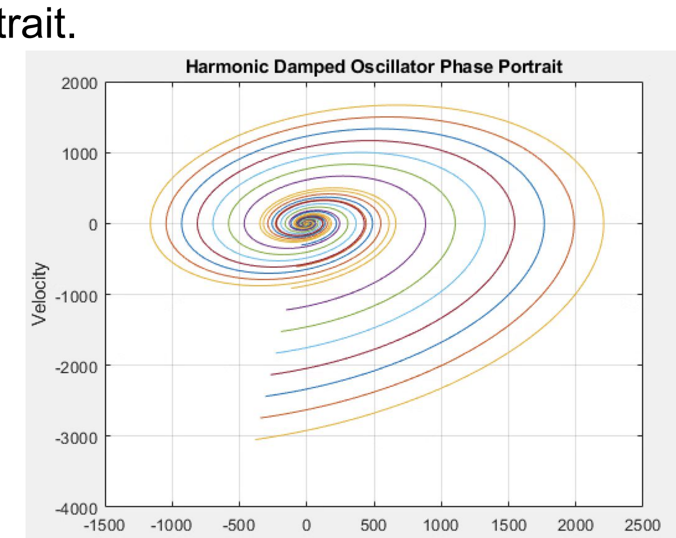
Research & Learning Process

Because this lab was mostly computational, we had to learn the basics of MATLAB in order to properly model data. We started off with learning the basics such as writing loops and graphing plots. One of the first few graphs we made modeled position versus time. Using ode45, I was able to find the values for t(time) and y(position and velocity). The coding part was not the hard part but rather learning the syntax for the code.



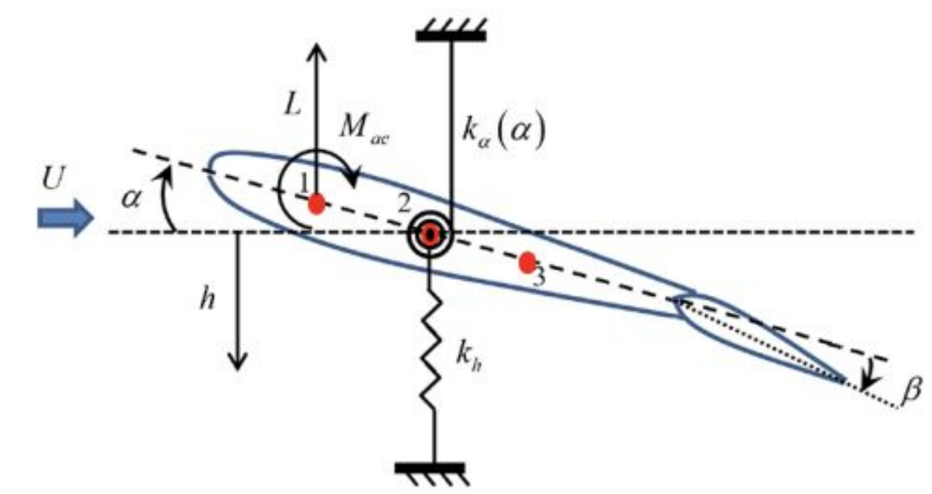
Then we learned a little bit about flutter instability in real life situations. One situation was the Tacoma Bridge that was erected one July 1st, 1940. Sadly due to engineering design flaws, the bridge broke due to a windstorm just 4 months later. Here is an image of the bridge that was fluttering due to unforeseen circumstances.

After, we started learning about a harmonic damped oscillator system. We were given an equation and using the equation we had to model a system where we could change the variables such as position, velocity, damping, angular velocity, ratio between force and natural frequency of the system, and the amplitude of the force. Here is a graph of the system I modeled, it is called a phase portrait.

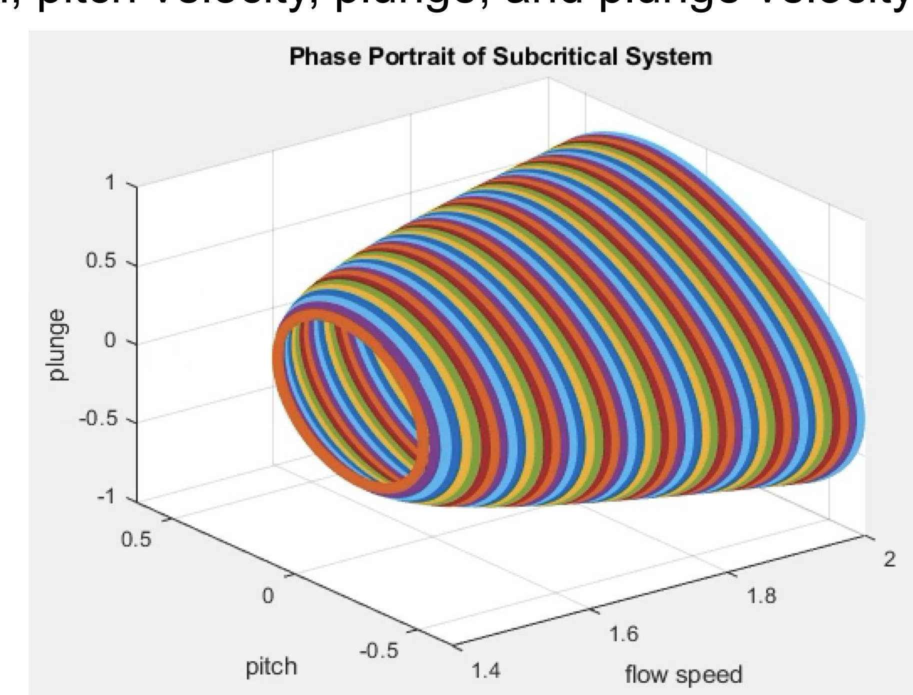


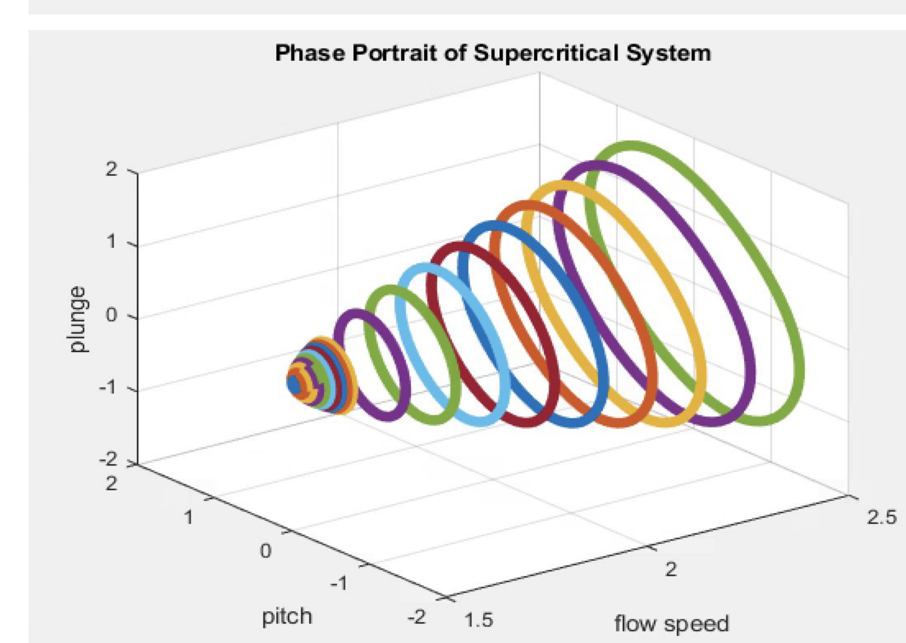
Methods & Results

Our goal was to understand the effect of different parameters on the stability and dynamics of an airfoil. A subcritical scenario is extremely dangerous because the system can experience oscillation below the flutter speed. A supercritical scenario is safe because there will be no oscillations below the flutter speed.



Both graphs models a nonlinear aeroelastic system. The general equation is $\dot{X} = f(X, U)$, this equation was provided in the research paper [1]. The function f in the original equation is a non linear vector function of system states. X is a vector containing pitch, pitch velocity, plunge, and plunge velocity.





Conclusion

I learned two major concepts during the SHINE program. I learned about supercritical and subcritical nonlinear aeroelastic systems. A supercritical system occurs if the system decays when the flow speed is below the flutter speed and oscillates when the flow speed is above the flutter speed. A subcritical system occurs when the system can still oscillate when the flow speed is lower and higher than the flutter speed. The way the supercritical and subcritical graphs are related are when you change the stiffness in the systems, you can change from sub to super critical. Both systems can be changed by the stiffness in the equations that model the scenarios.

Next Steps for You & Advice to Future SHINE participants

I want to continue studying and taking courses relating to the aerospace/mechanical field. I plan to be using machine learning and mathematical models to analyze aeroelastic systems. I will continue to use MATLAB to model systems where I can study changes due to perturbation or surrounding scenarios. I have been interested in aerospace engineering for a long time and this program answered a lot of questions about what I wanted to do in the future. For future SHINE participants, SHINE is a great program and make sure you make use of your time. You can only learn something if you put effort into studying and understanding it. SHINE is a program that will help you succeed so make the most of it.

Citations

1. Shukla, Himanshu, and Mayuresh J. Patil. "Controlling Limit Cycle Oscillation Amplitudes in Nonlinear Aeroelastic Systems." *American Institute of Aeronautics and Astronautics*, 2017, https://arc.aiaa.org/doi/pdf/10.2514/1.C034239. Accessed July 2023.