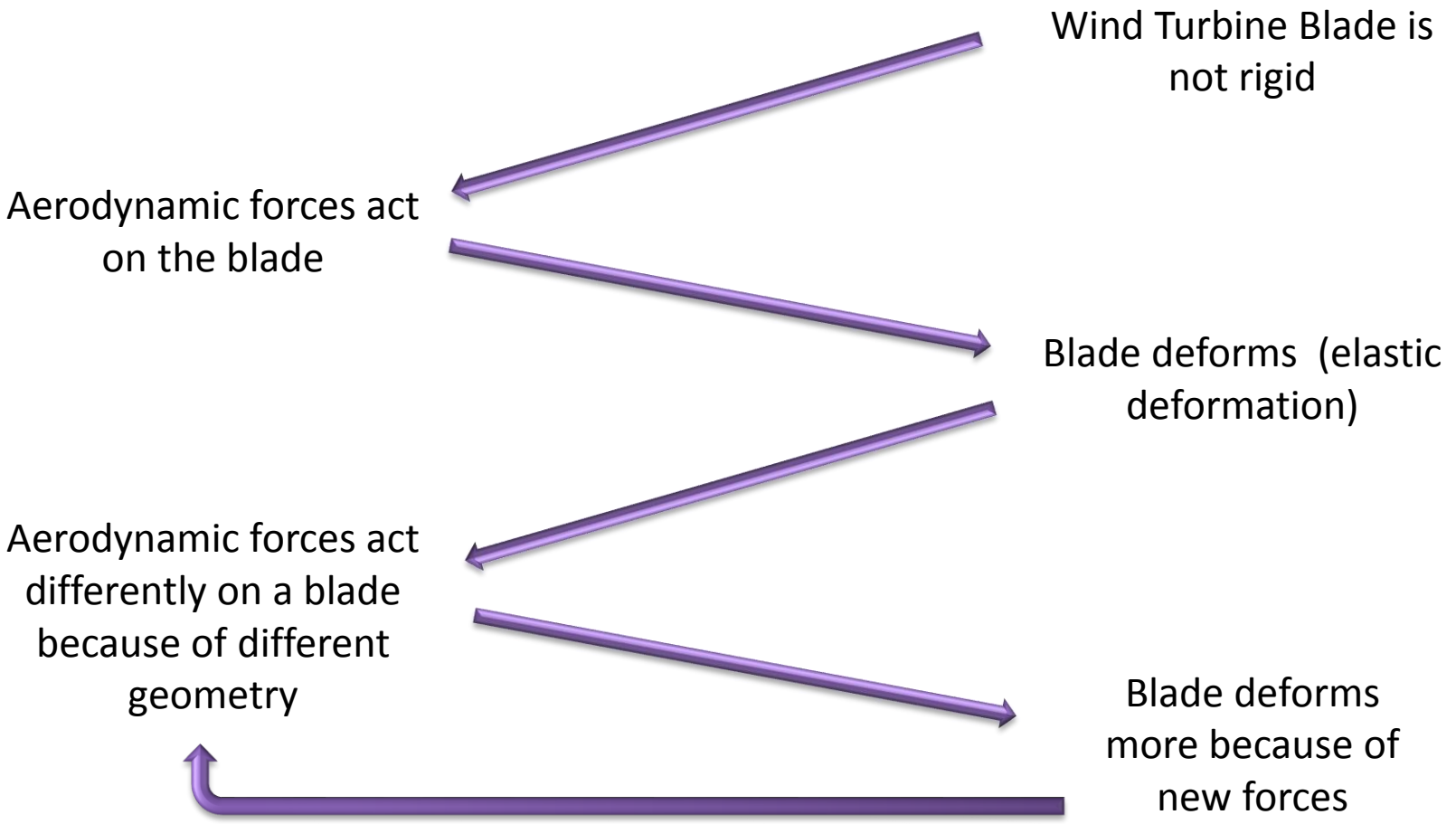
Aeroelastic Loads and Response of Wind Turbine Blades

The primary objective of this research is to develop a better understanding of the Aeroelastic loads and responses of healthy and damaged wind turbine blades in varying wind conditions, (i.e. smooth flow, turbulent flow, gusty winds, and yaw misalignment).

OBJECTIVE

AEROELASTICS



AEROELASTICS

The study of the effect of aerodynamic forces on elastic bodies

FLUTTER

Known as a self-excited response, flutter is characterized by the interplay between aerodynamic, elastic, and inertial forces. Flutter is sometimes known as dynamic aeroelastic instability. Particularly dangerous when small disturbances (essentially incidental) induce violent oscillations!

FLUTTER SPEED

Above a certain wind speed the kinetic energy of the structure will no longer be dissipated and it will become dynamically unstable. This wind speed is known as the flutter speed.

Are Wind Turbine Blades Susceptible to Flutter?

Short Answer: No

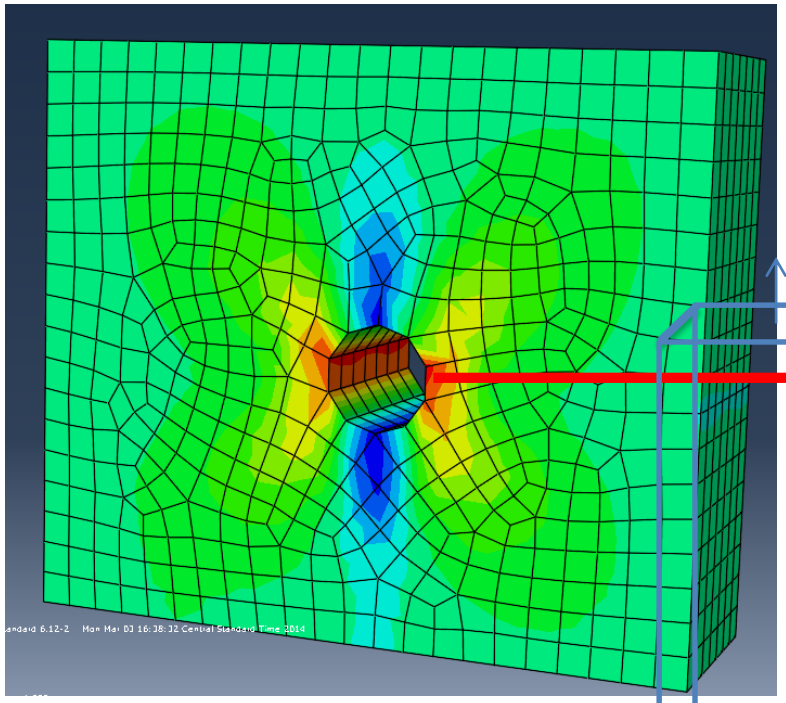
But...

The flutter speed of a typical (1.5 MW) wind turbine blade is about 2x the operating wind speed and the flutter speed decreases as the blade gets longer!

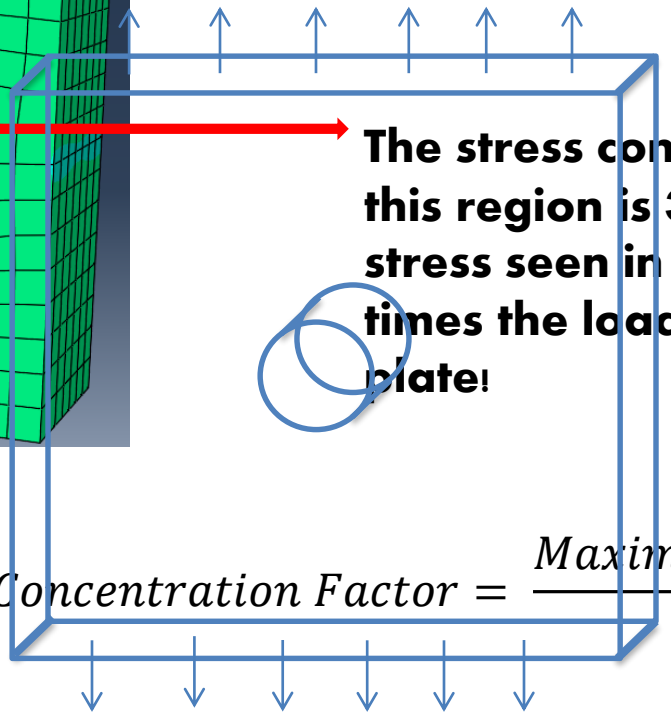
Then why is this research important?

Wind turbine blades deform when operating and when parked. The hope is to use these deformations as a means to identify damage in the blade. But, in order to use it we must first understand the loads and the inherent response of the blade when it is deforming. This should allow us to identify areas where the stress is higher than it should be, indicating damage.

But how?



Stress increases around a hole in a plate



The stress concentration factor in this region is 3. Meaning that the stress seen in this area is three times the load being applied to the plate!

$$Stress\ Concentration\ Factor = \frac{Maximum\ Stress\ in\ Region}{Load\ applied}$$

Stress around a hole in a plate

Flutter Derivatives

$$L_{se} = \frac{1}{2}\rho U^2 B\left[K H_1^*(K)\frac{\dot{h}}{U} + K H_2^*(K)\frac{B\dot{\alpha}}{U} + K^2 H_3^*(K)\alpha + K^2 H_4^*(K)\frac{h}{B}\right]$$

$$M_{se} = \frac{1}{2}\rho U^2 B^2\left[K A_1^*(K)\frac{\dot{h}}{U} + K A_2^*(K)\frac{B\dot{\alpha}}{U} + K^2 A_3^*(K)\alpha + K^2 A_4^*(K)\frac{h}{B}\right]$$

Each flutter derivative tells us something different about the response. For example, H_1^* is aerodynamic damping in the vertical and A_2^* is aerodynamic damping in torsion.

These are the equations for the 2 degrees of freedom case. When considering all 3 DOFs there are 18 flutter derivatives.

$$H_1^* = -\frac{1}{K}\left(\frac{dC_L}{d\alpha} + C_D\right)$$

$$A_1^* = \frac{1}{K}\frac{dC_M}{d\alpha}$$

$$H_3^* = -\frac{1}{K^2}\frac{dC_L}{d\alpha}$$

$$A_3^* = \frac{1}{K^2}\frac{dC_M}{d\alpha}$$

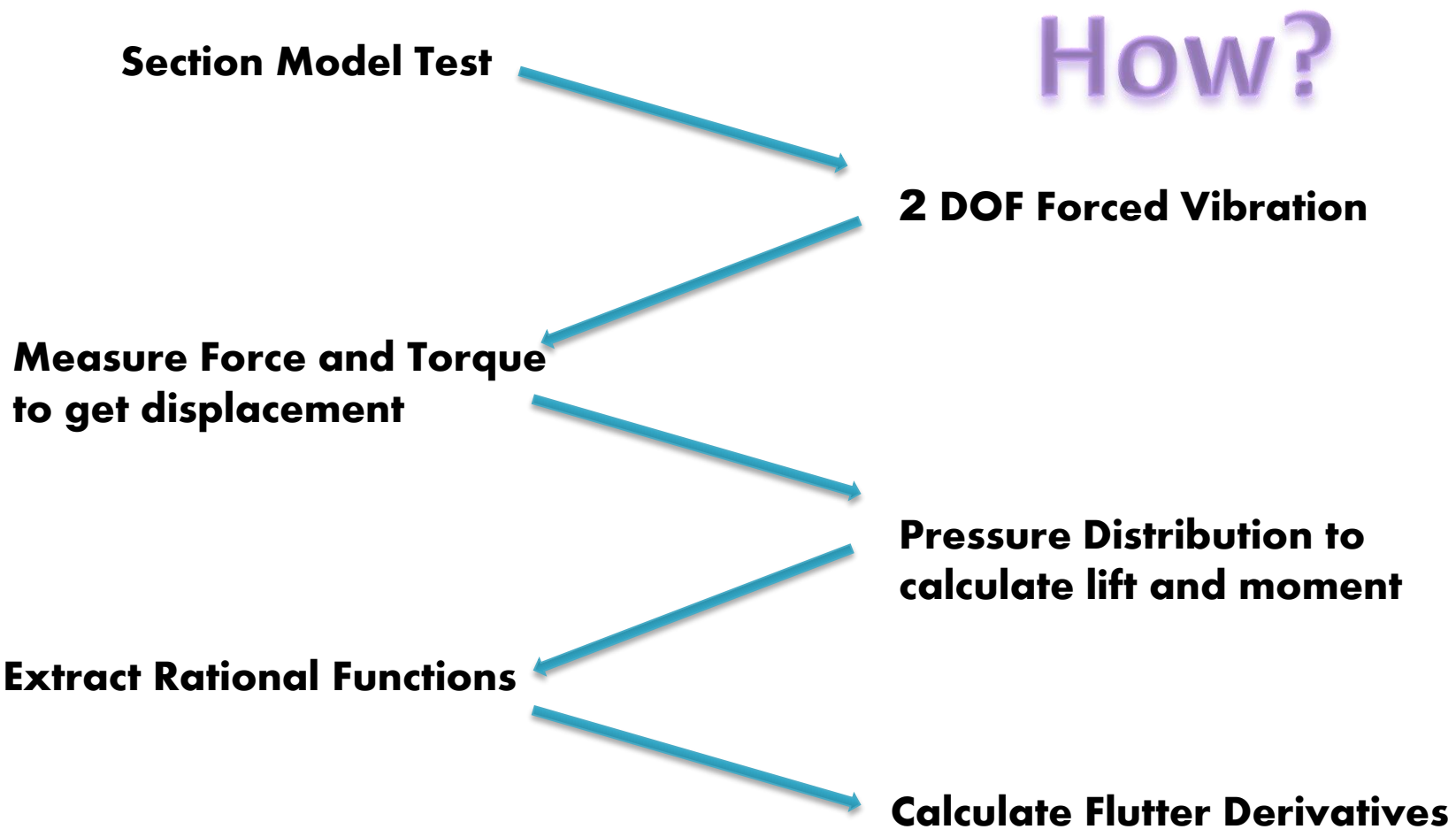
Reduced Frequency

$$K = \frac{2\pi}{RV}$$

Quasi-Steady Flutter Derivatives

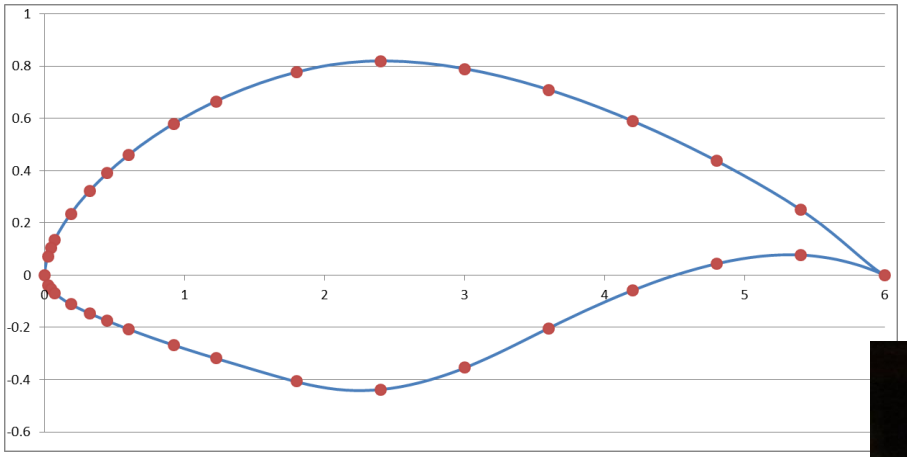
Reduced Velocity

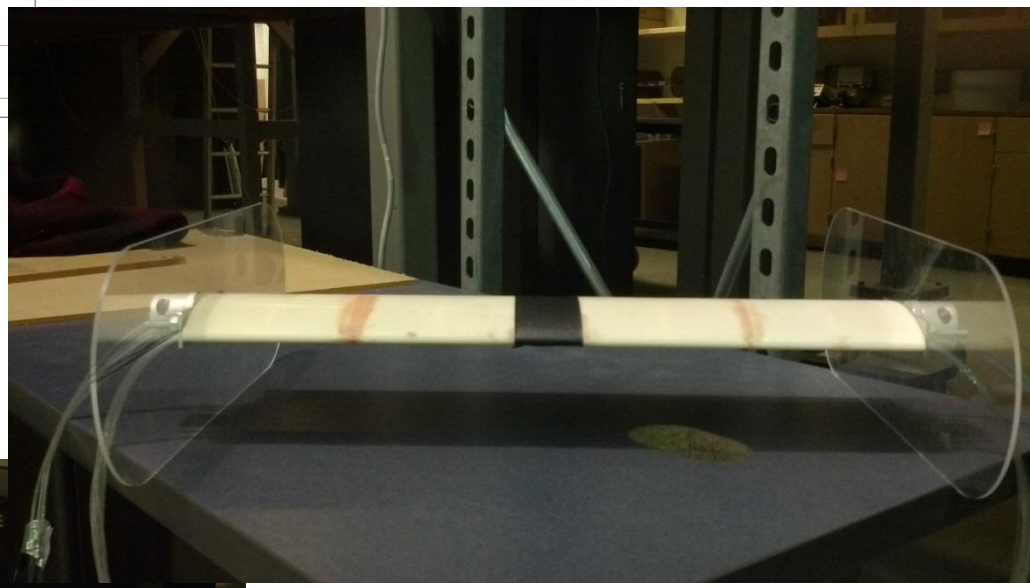
$$RV = \frac{U}{fB}$$

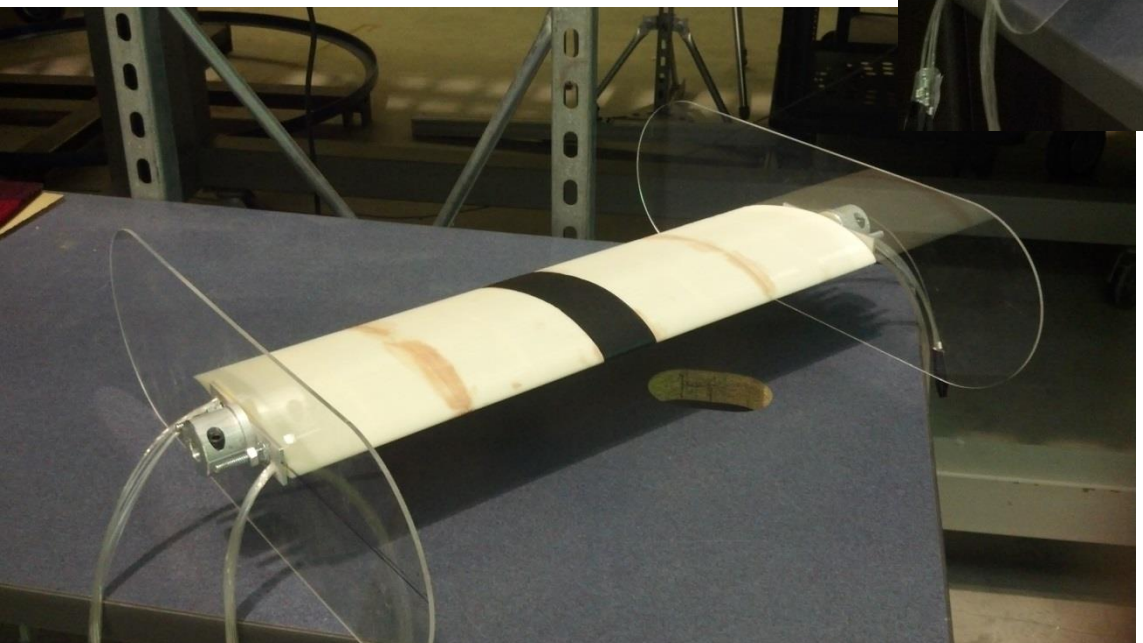


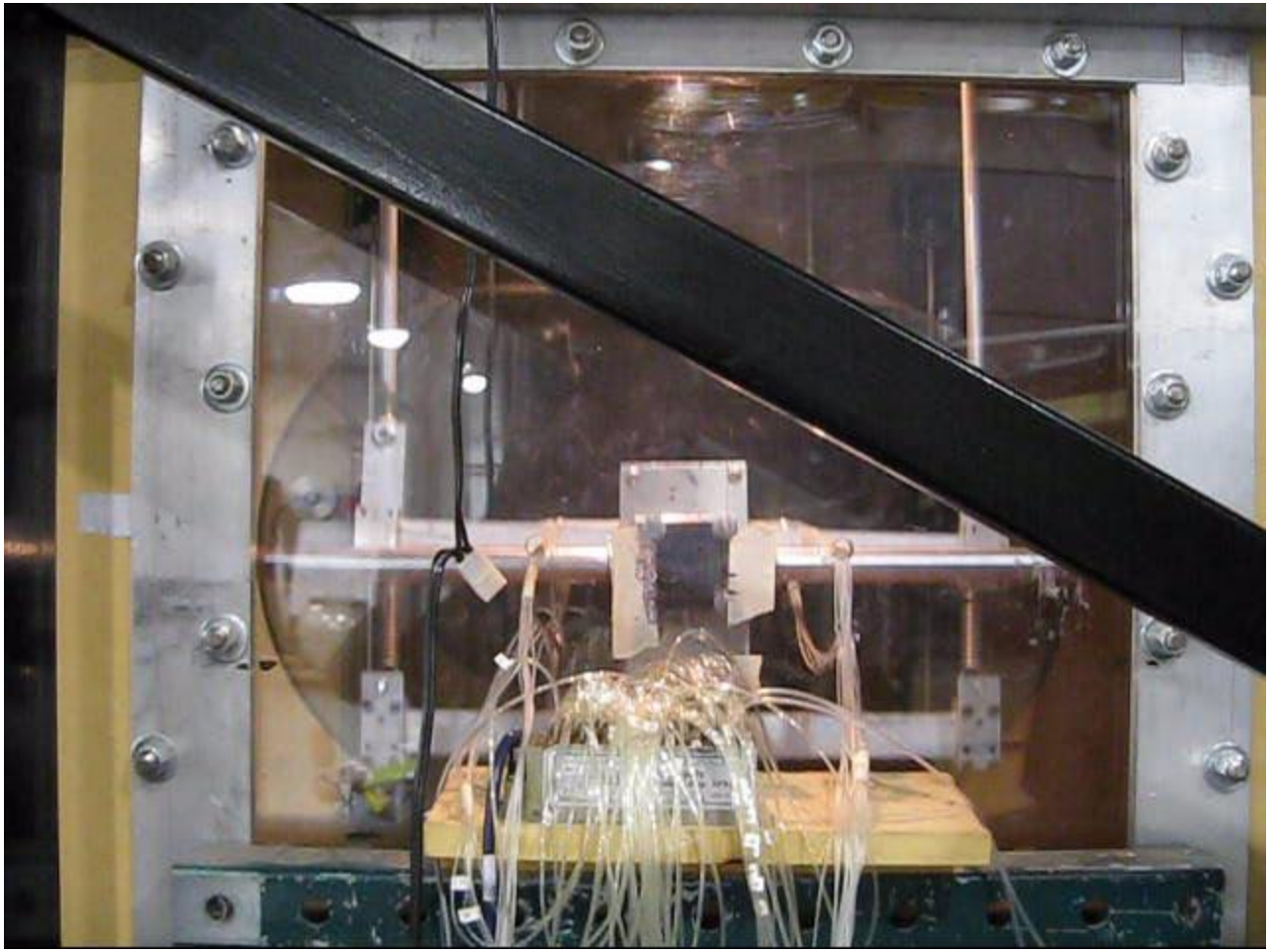
Task 1: Extracting Flutter Derivatives of the S830 Airfoil

Section Model

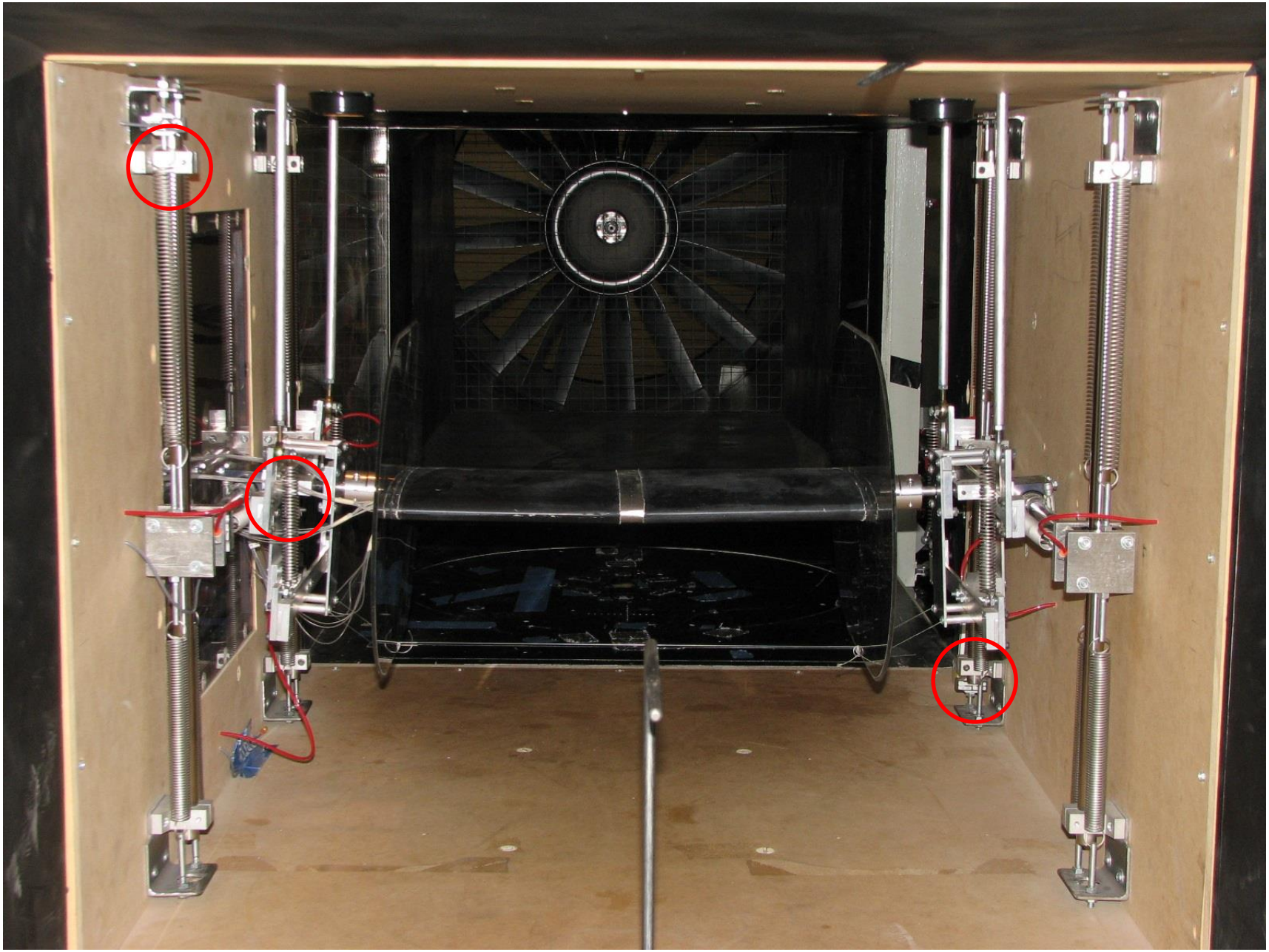




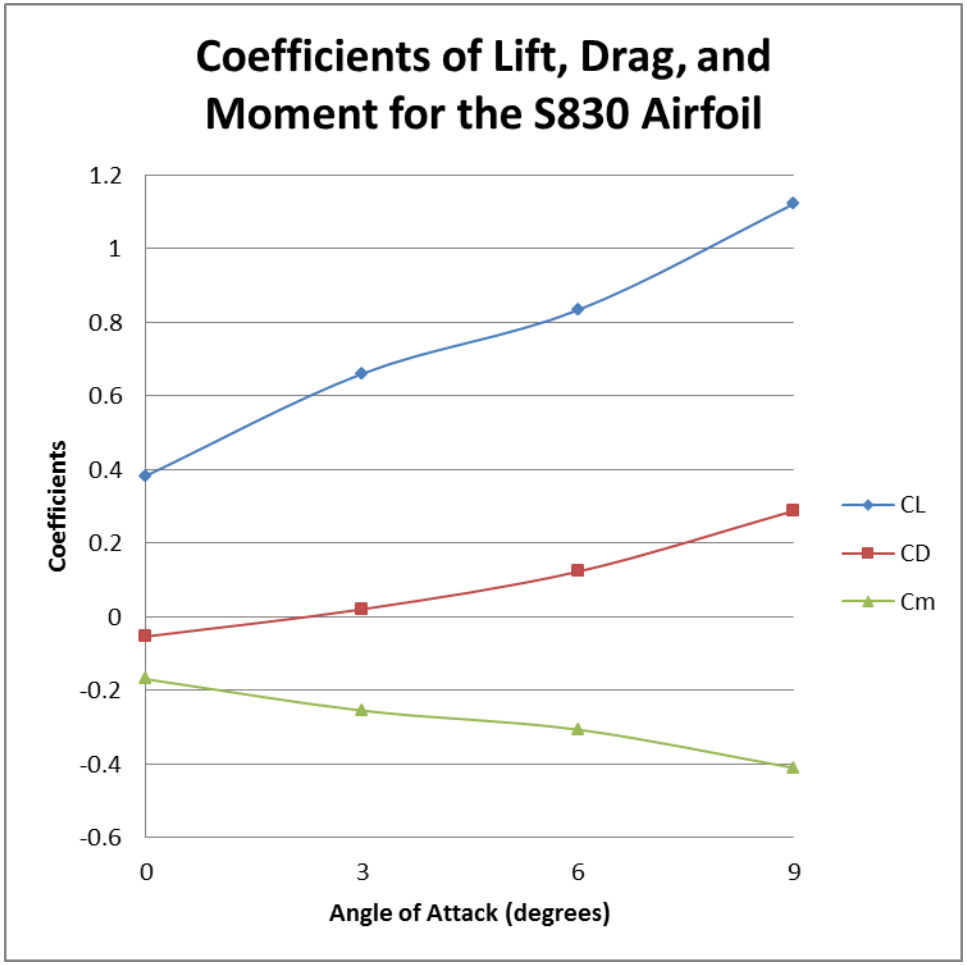




Forced Vibration

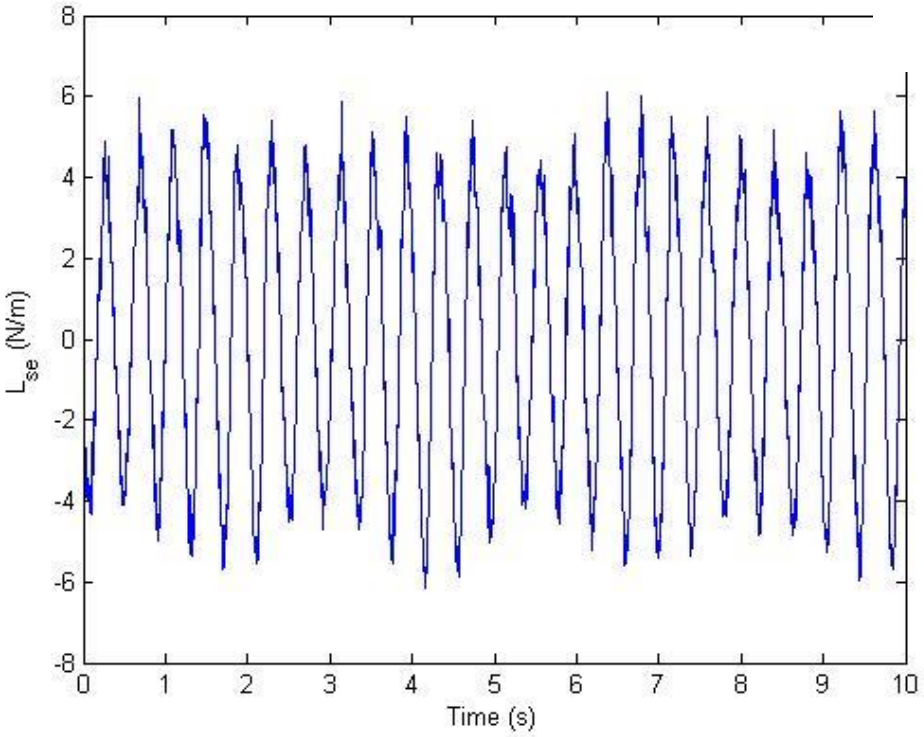


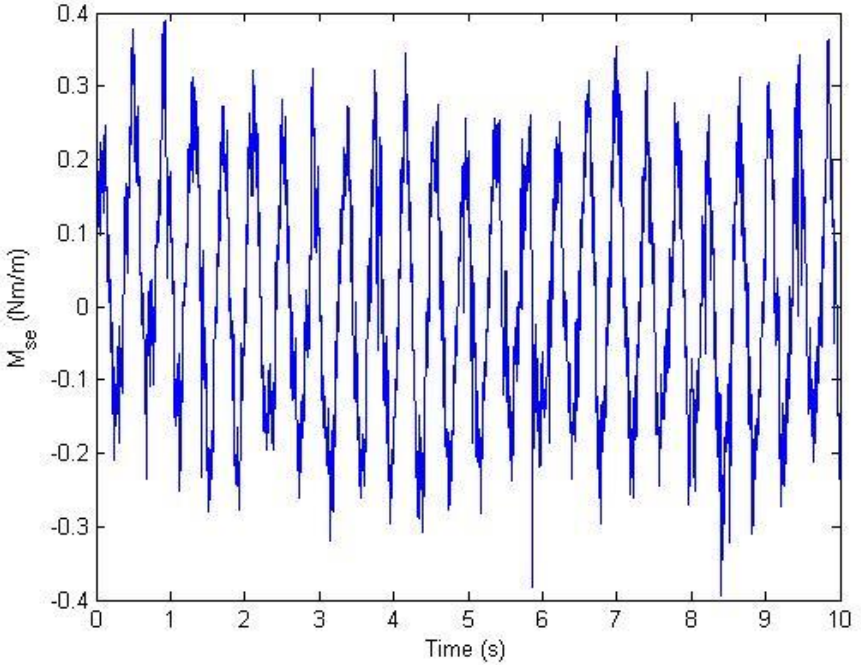
Some Preliminary Results



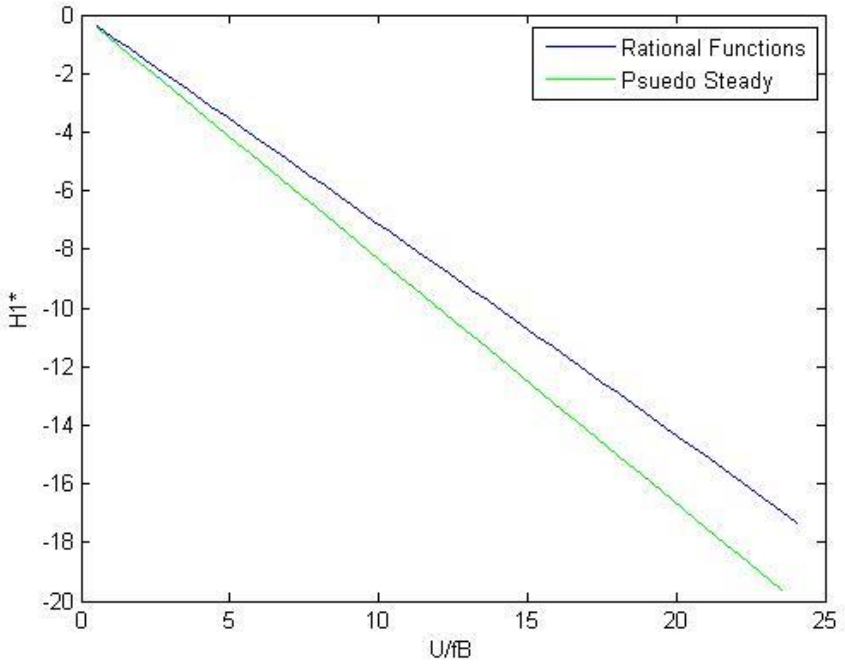
Stationary Results

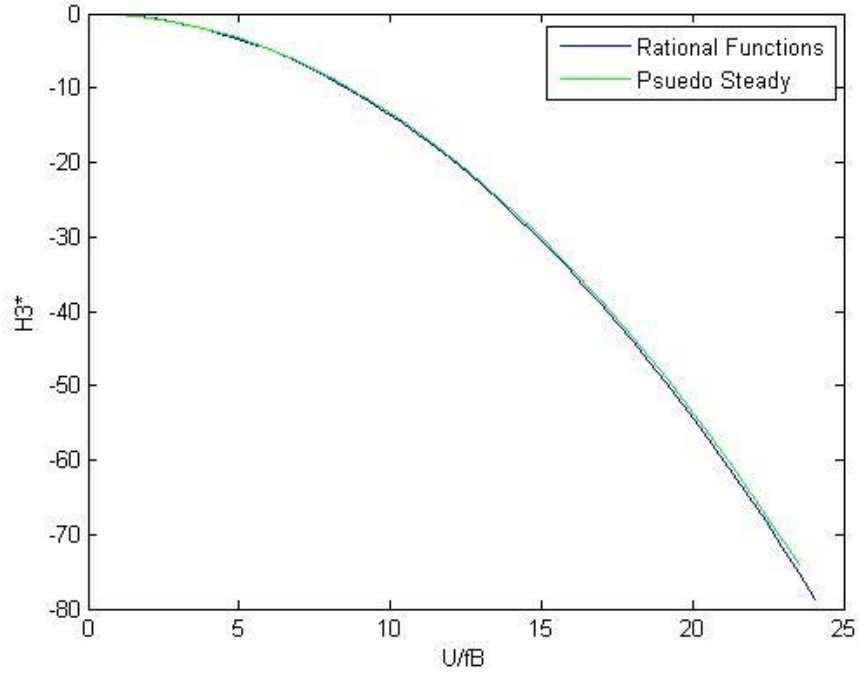
Dynamic Lift



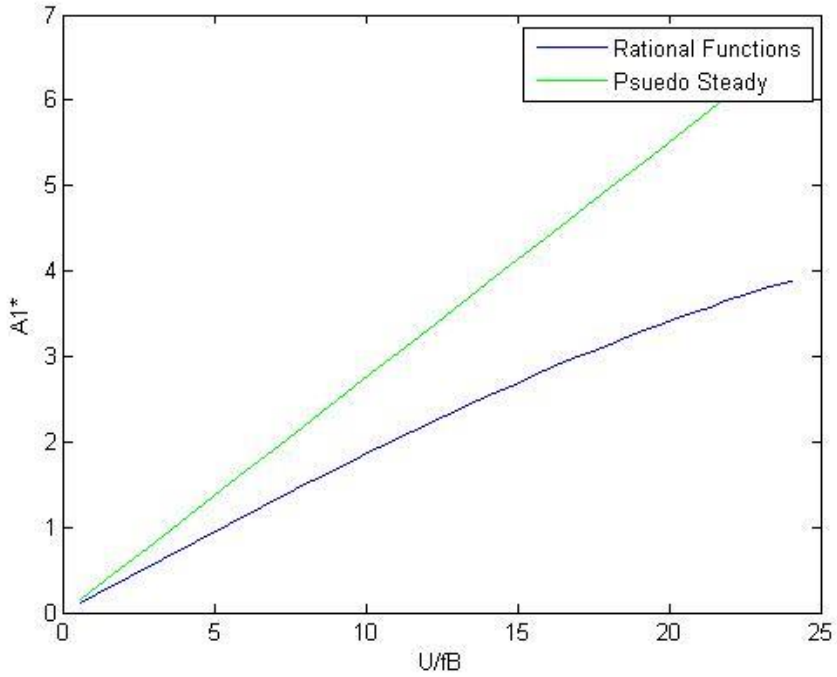


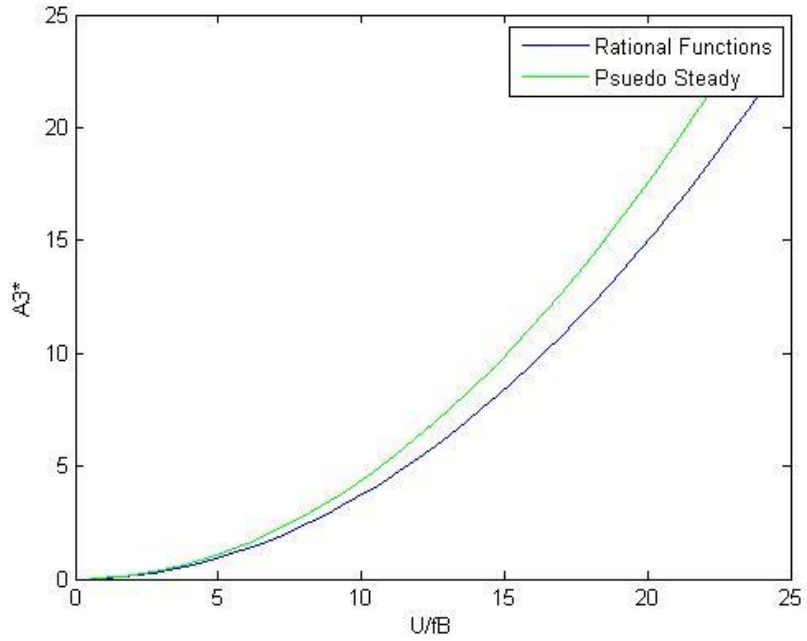
Dynamic Moment





Flutter Derivative Results



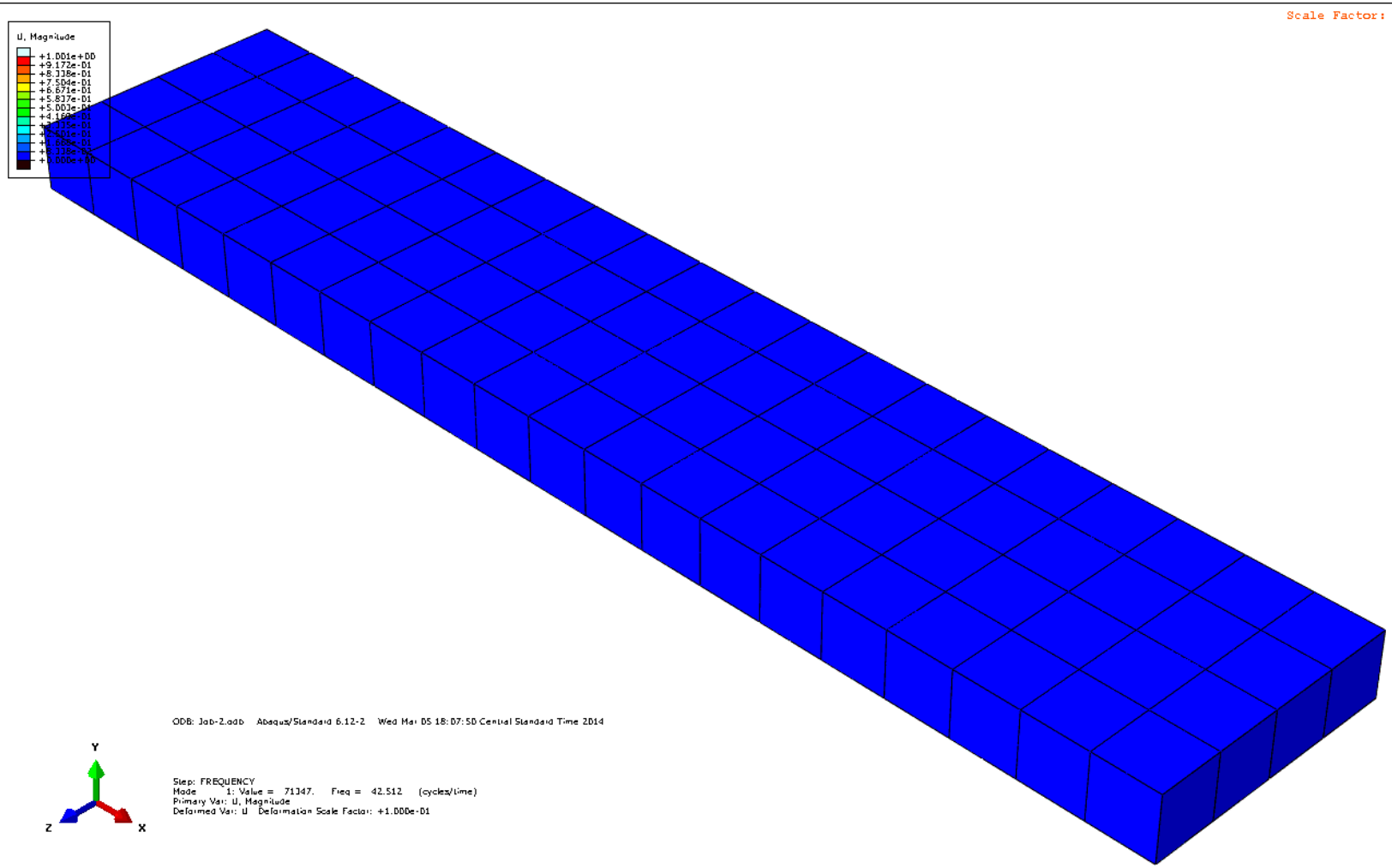


Flutter Derivative Results

Designing Prototype Blade

(Currently working on this)

Prototype Blade and Finite Element Analysis



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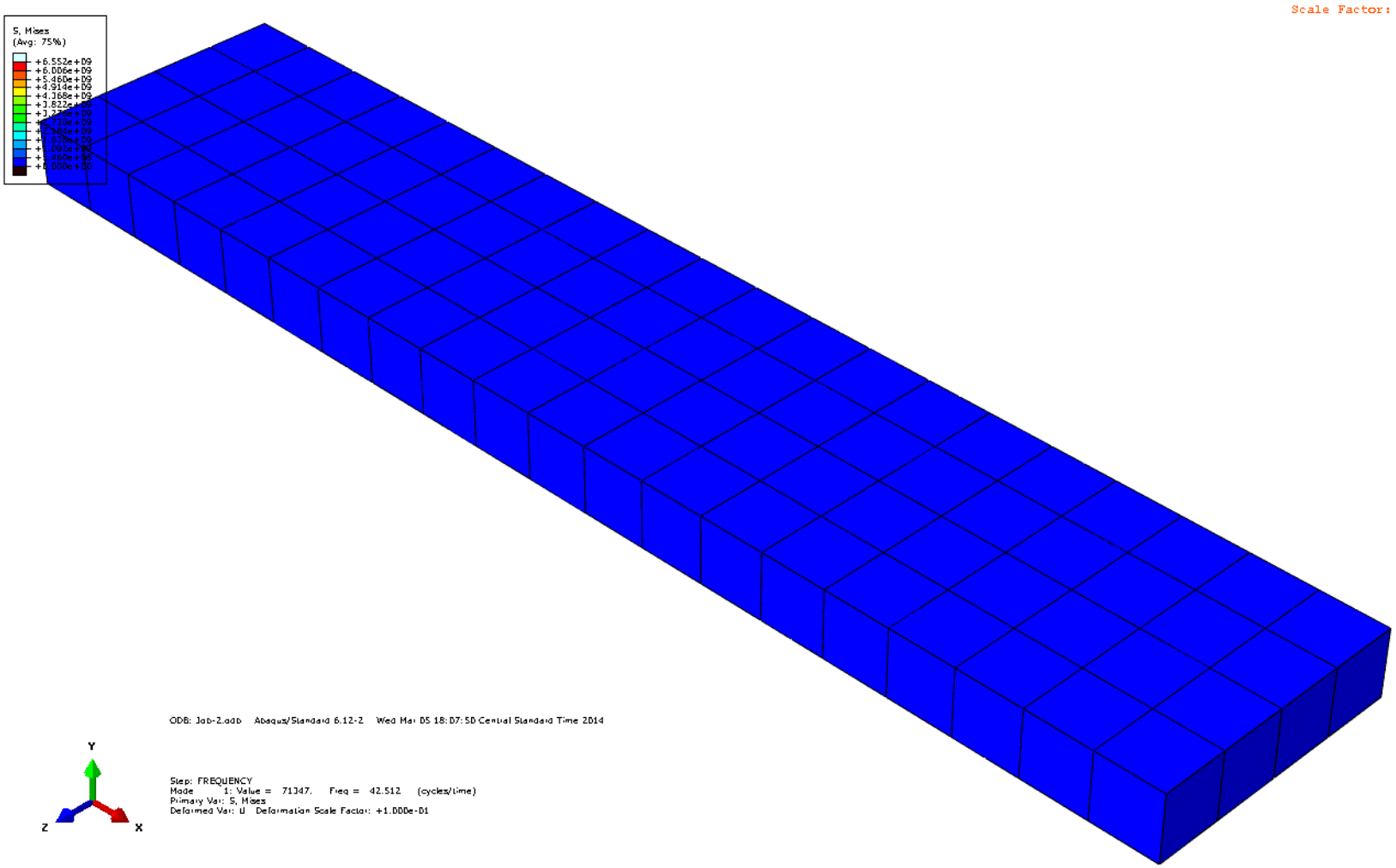

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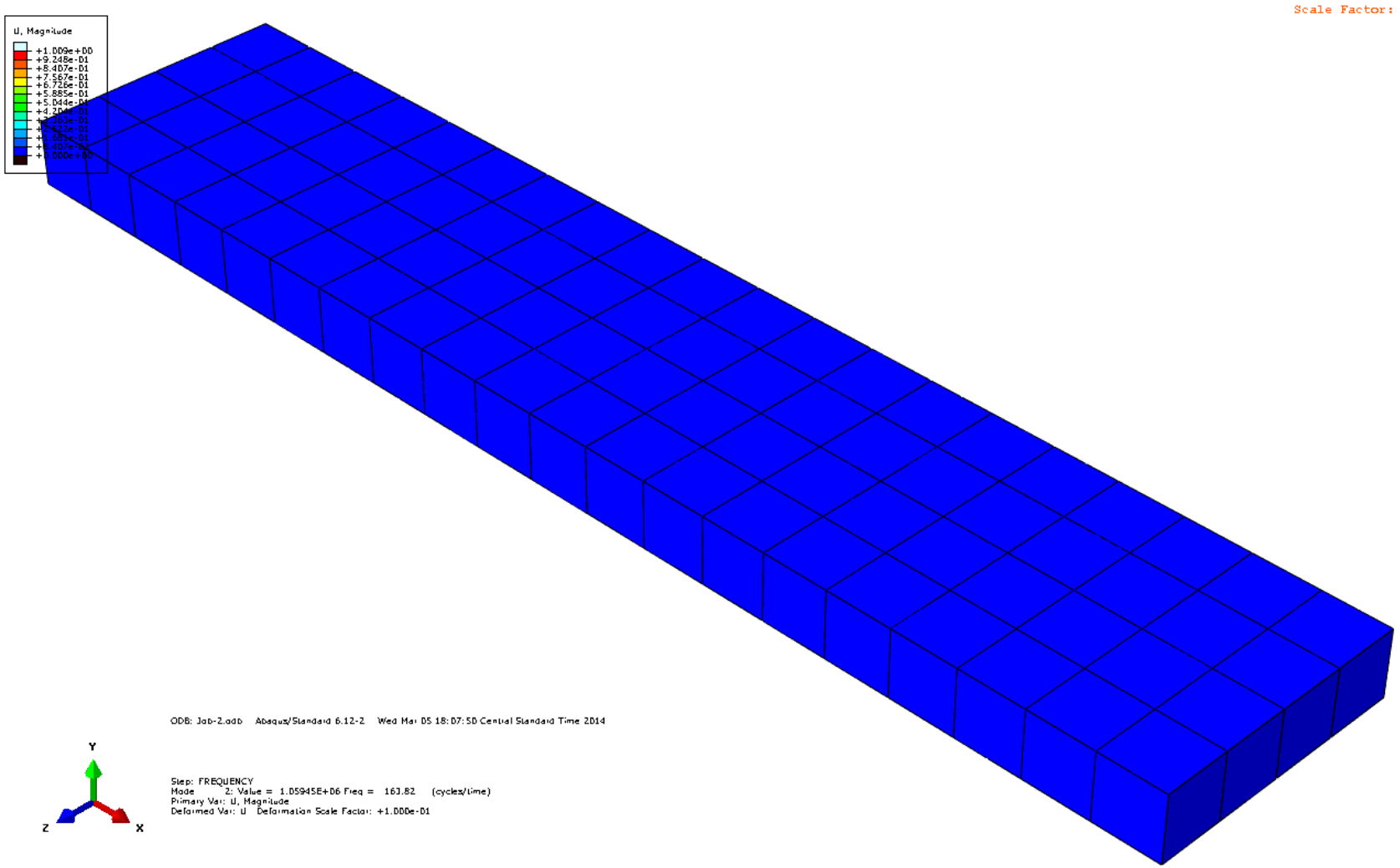

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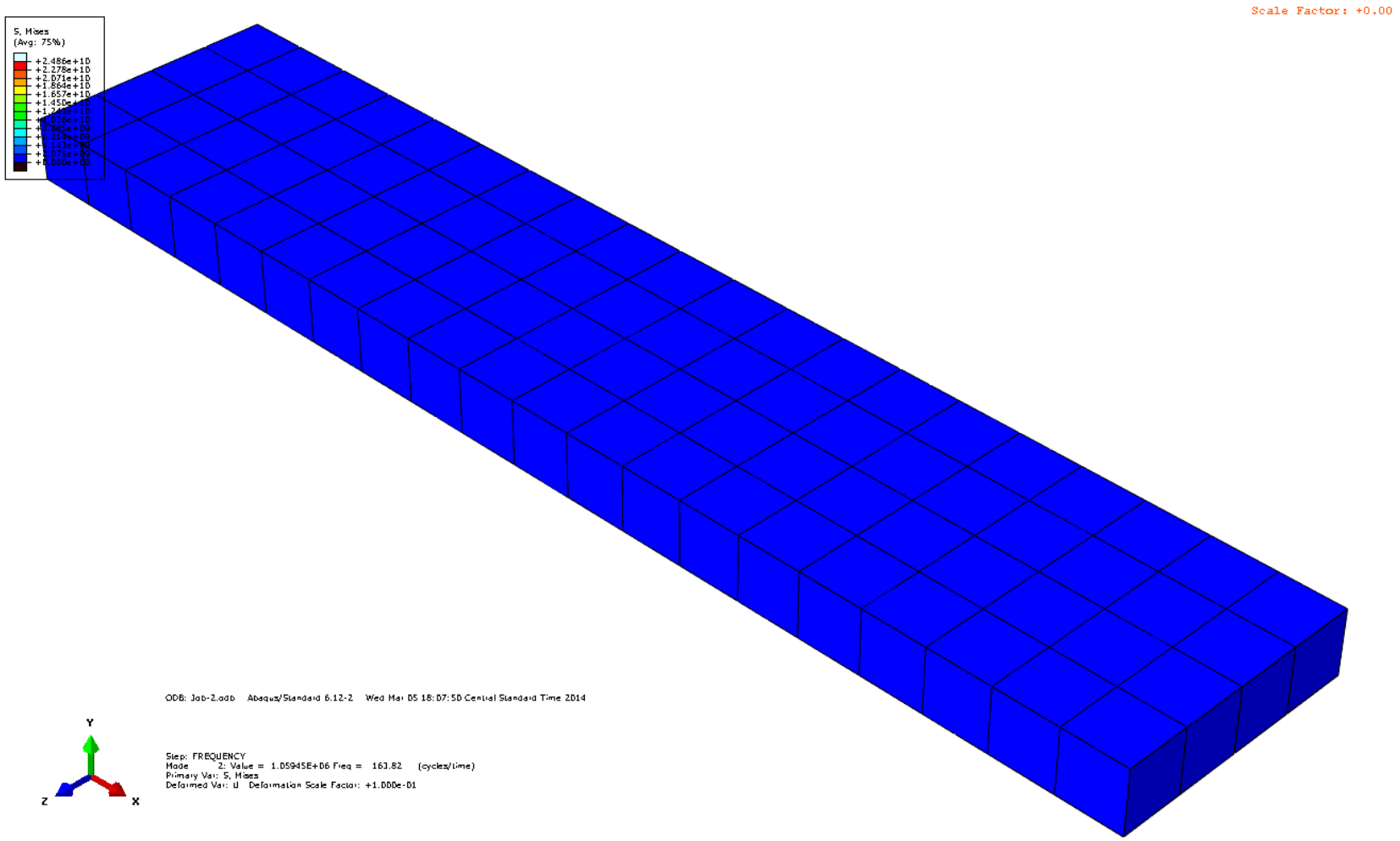

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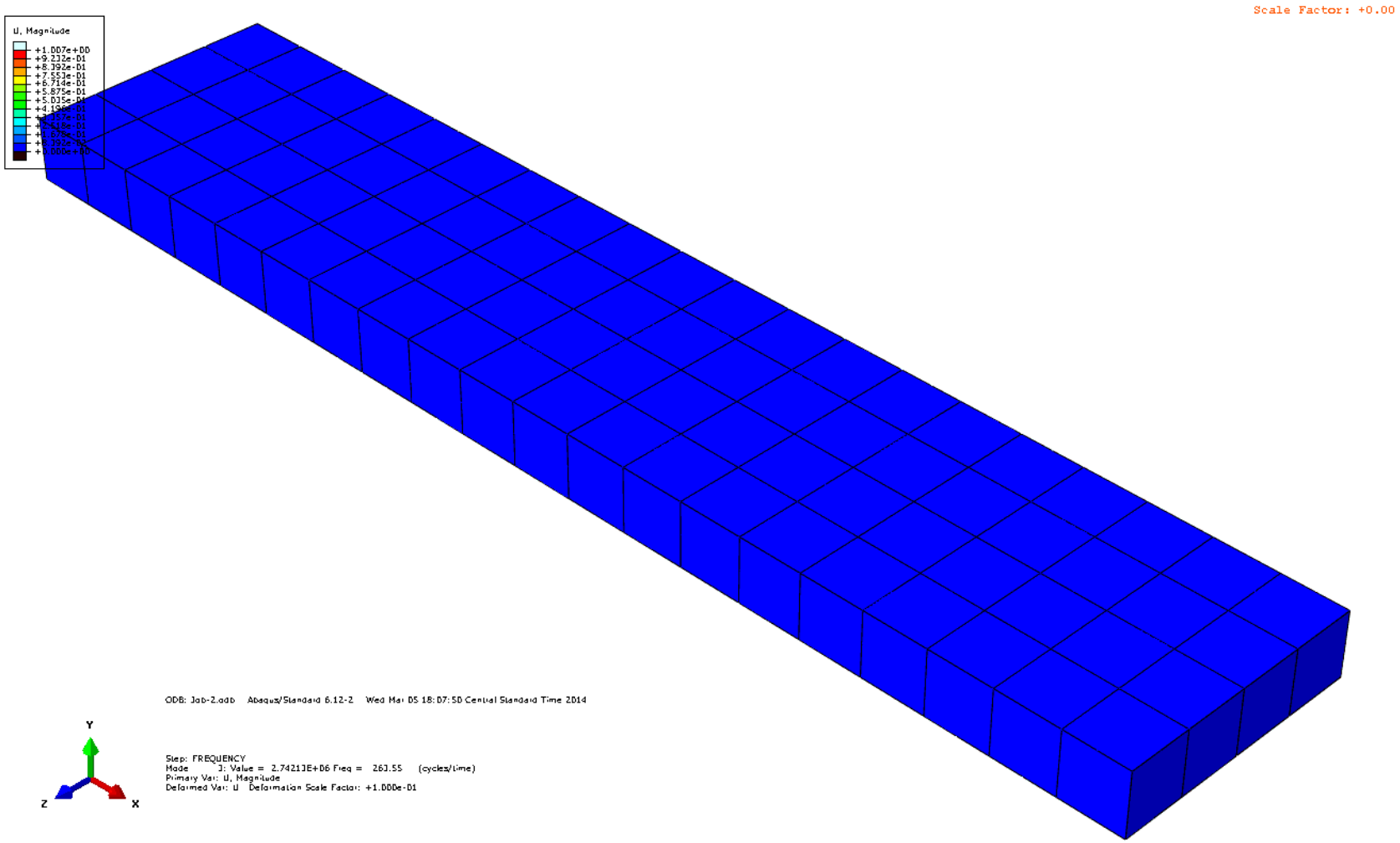

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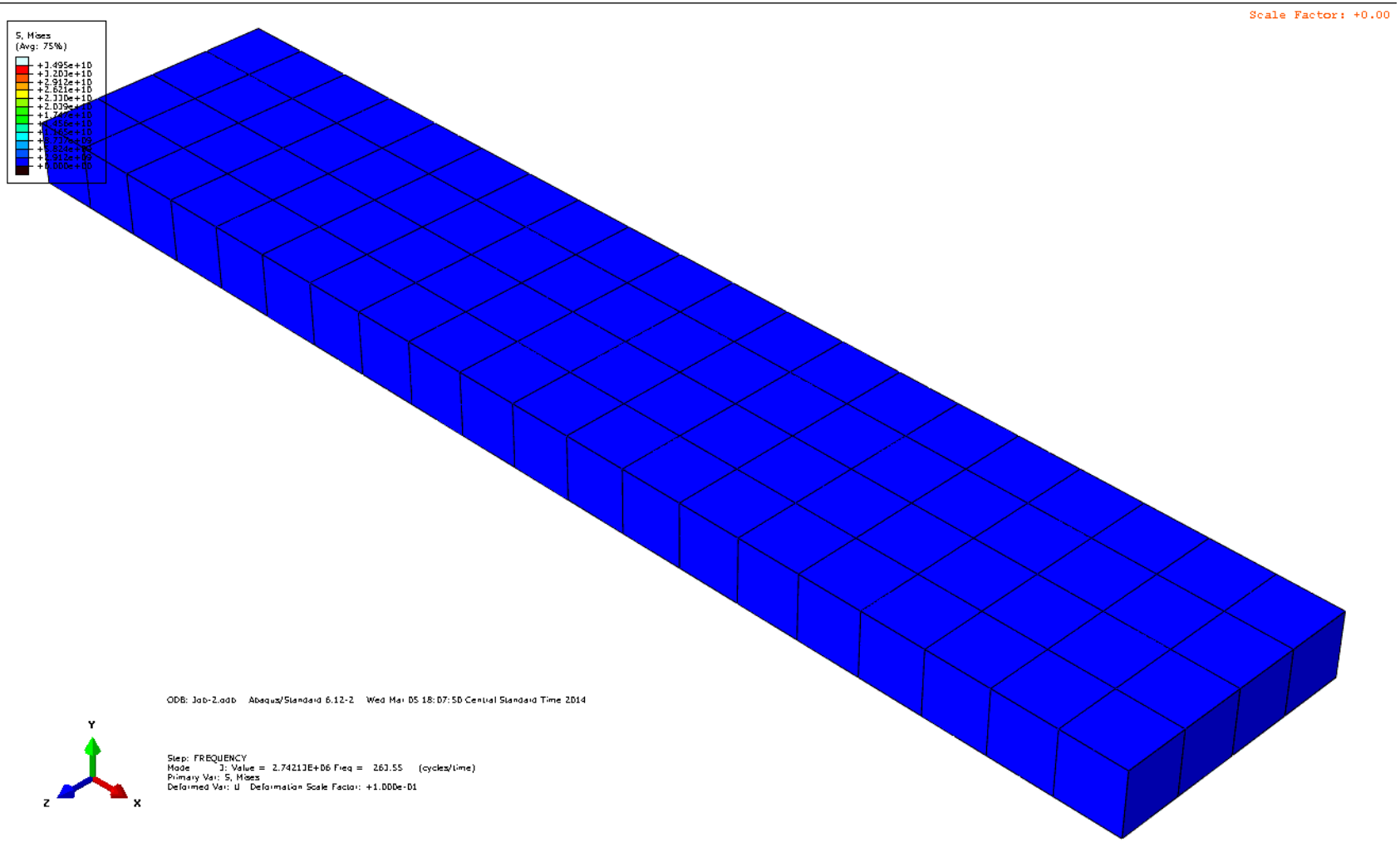

Next Steps:

Finite Element Model

- ANSYS
- Fluid Structure Interaction Problem
- Use to vary damage to decrease number of models

Prototype Blade Tests

- Testing scaled version of full blade
- Using skin sensors

Gust Effects?

Turbulence?

YAW MISALIGNMENT?

QUESTIONS?