Dyson Outreach Event 2025

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Project Title: Saving The Great London Plane of Ely

The project is focused on a mechanical vibrations analysis of a computer model of the Great London Plane of Ely, a historically significant specimen of a London Plane tree, aged at almost 400 years old.

The purpose of the outreach event was to introduce the school children to and expand on the concept of resonance and natural modes of vibration, within a mechanical systems perspective. The aim was to give the school children a physical, hands-on opportunity to visualise the effect of changing mass and stiffness on both the natural frequencies of a mechanical system, and the mode shapes that occur.

The first step was to introduce the oscillation of a single degree of freedom (SDOF) system via a simple mass on a spring. It can easily be shown by moving the mass – via the spring in hand – that at a low frequency, the mass moves with the hand; the whole system behaves as a rigid body. At higher frequency oscillation, it is clearly seen that the mass will remain at approximately the same position in space, even though the oscillations of the other end of the spring is large. This can intuitively be explained by the concept of inertia. At resonance, the mass will oscillate significantly, and is a very useful visualisation of these phenomenon.

The idea of resonance is extended to multiple degree of freedom systems (MDOFs) by considering the discretisation of larger systems into numerous smaller "masses on springs", as is done in typical finite element methods.

To do this more visually, whilst relating the outreach event to the project at hand, plywood 'trees' were laser-cut out of 4mm plywood sheets. These cut-outs incorporated small slots in key locations to introduce compliance into the system, thus reduced the natural frequency of mode shapes of interest. Then, the base of the 'tree' was clamped into a vice, and a stiff copper wire attached just above this base attachment point. The other end of this wire was attached to a vibration shaker, from which an input force could be applied at variable frequency (see Figure 1).

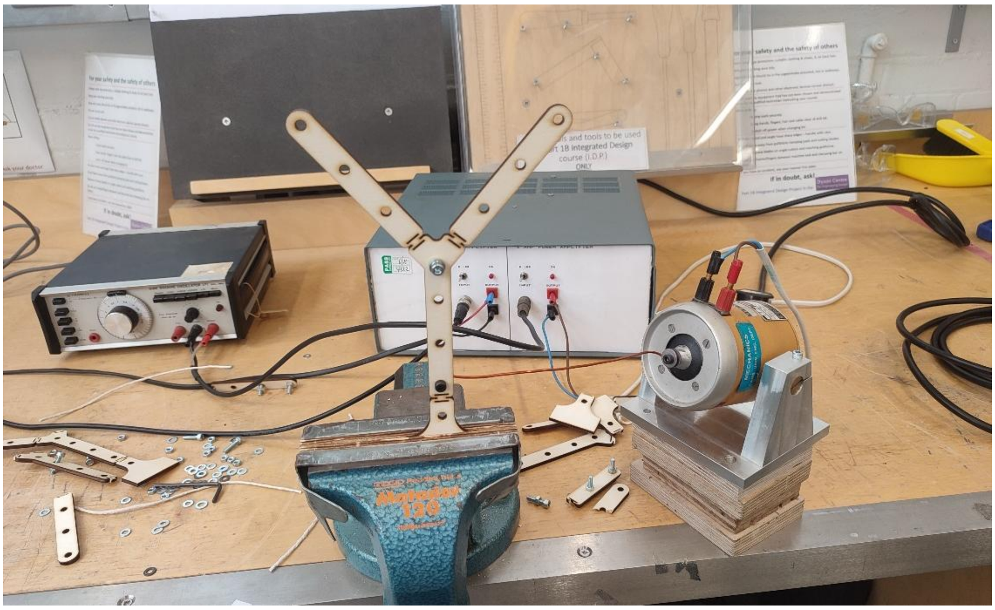
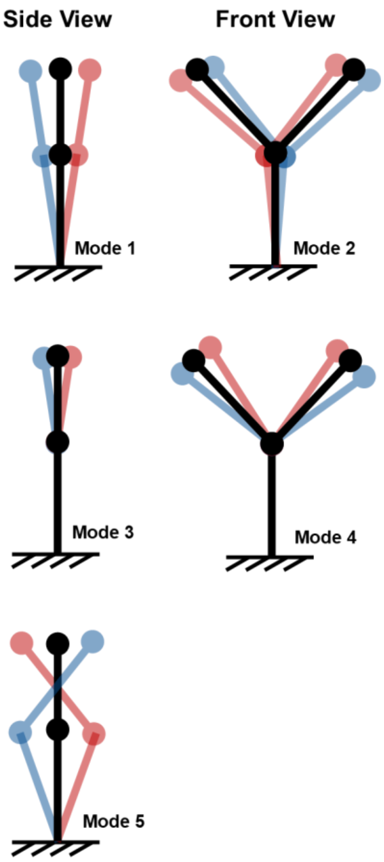


Figure 1: Experimental setup

The structure was then swept through a frequency range of 0.9-10 Hz, and natural modes of vibration could be visualised on a more complex structure.

Five clear modes of vibration were visualised, as shown in the diagram to the right.



Emphasis was placed on the fundamental relationship for natural frequencies of dynamical systems:

$$f_n \propto \sqrt{\frac{k}{m}}$$

Where *k* is the stiffness, and *m* is the mass. This implies that the natural frequency of a given mode of vibration will increase with increasing stiffness, and decrease with increasing mass.

To visualise this, the school children were given 10-15 minutes to try the demonstration for themselves (3 identical vibration shaker/plywood 'tree' demonstrations were set up). They were also provided with a series of nuts, bolts, washers, and string. By attaching these to the structure using the holes provided, they could add mass (using the bolts) and stiffness (by tying portions of the structure together) using the string. In this way, it is hoped that the school children will gain a more intuitive picture of how the vibration behaviour of structures changes as these parameters vary.

The school children came up with many interesting configurations, and often caused the 'tree' structures to break at resonance by adding lots of mass (and thus increasing the loading on the structure) – make sure each group has multiple spare 'trees!'. This is in itself is a useful demonstration of the effect of resonance; often it is undesirable as it causes unwanted wear on a structure/component, due to excessive motion and loading.

As a final point of explanation, it may be useful to ask the school children what might happen to the vibration modes if the mass is added in certain locations e.g. What happens to the vibration of a particular vibration mode when the mass is added to a node (point of zero amplitude)? What about an antinode (point of maximum amplitude)?

Finally, it is also possible to perform approximate back-of-an-envelope calculations to predict what the frequency of a particular mode will be once mass is added to the structure, based on the initial frequency, and the masses of the base structure, and the added nuts/bolts. It is important to ask why might this not agree perfectly with what is measured? Things to consider would be:

- Boundary condition
- Mass distribution
- Weight accuracy