Vibrations 2, Lecture 1
Introduction

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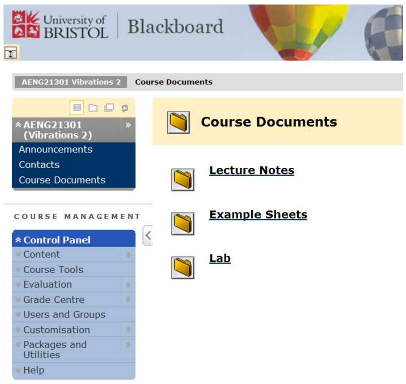
Lecture overview

- Unit organization
- Background
- Basic concepts
- Newton’s method

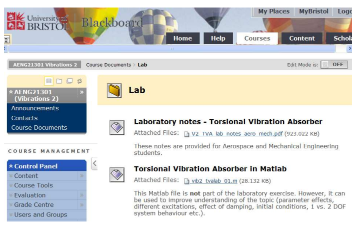
Blackboard

- www.ole.bris.ac.uk
  - Log in: UoB ID, Password
  - Vibrations 2
- Find:
  - Lecture notes
  - Example sheets
  - Lab information



Unit organization

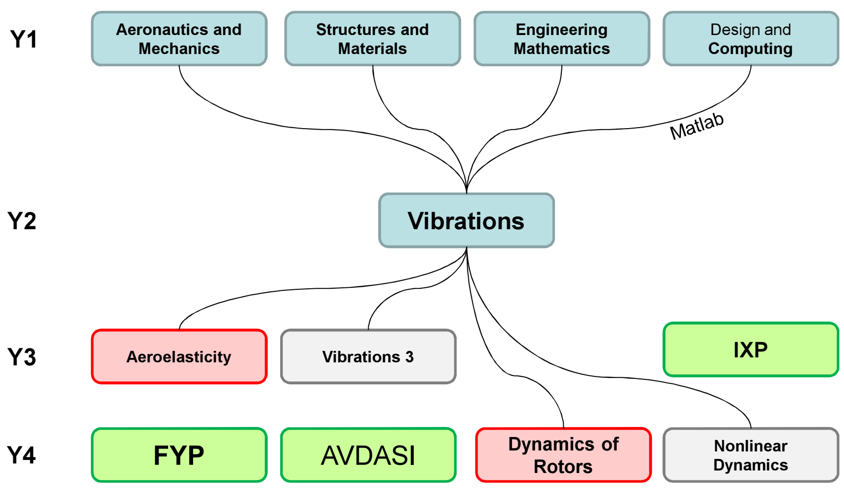
- Lectures
  - 2-3 lectures per week
  - ~23 lectures, **Dr Titurus** (unit director)
  - 1 DOF, 2 DOF, Aeroelasticity
  - 1 industrial lecture: tbc
- Laboratory classes
  - Tuned Mass Absorber, experimental lab
  - Matlab and Vibrations, computer lab
  - One assessed report = 20%
- Exam
  - 2 hours
  - 80%



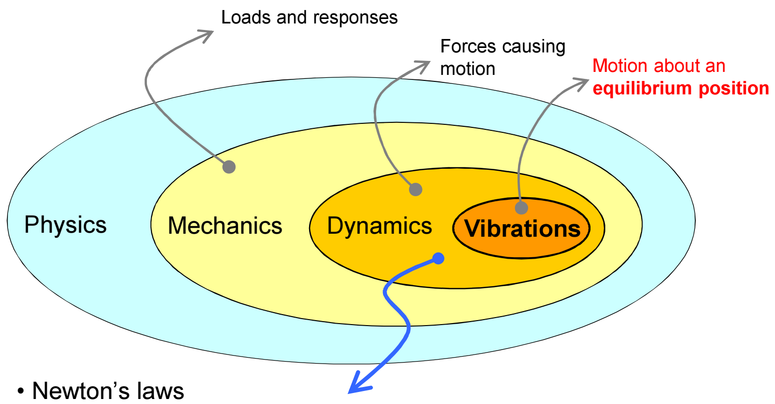
Unit organization

- Unit objectives:
  - understand **natural frequencies** and how these relate to free and forced vibration, vibration transmission,
  - understand **multi-degree of freedom systems** in free and forced vibration and how to apply numerical methods of solution,
  - understand the basic sources of **aeroelastic problems** in aerospace
- Learning resources:
  - Lecture notes (**online** or in print after each teaching block)
  - Example sheets (via Bb)
  - Past exam papers (see Engineering Faculty Bb)
  - Books:
    - Thomson, *The Theory of Vibration with Applications*, 1992
    - Meirovitch, *Fundamentals of Vibrations*, 2001
    - Hodges, Pierce, *Introduction to Structural Dynamics and Aeroelasticity*, 2002

Vibrations context



Vibrations context



- Newton's laws
- Energy conservation (kinetic, potential)
- Energy dissipation (damping)
- Equations of Motion, loads, displacements, etc.

Main concepts

- **Degree of Freedom (DOF)**: Minimum number of coordinates required to define completely the configuration of a mechanical system.

- **Equation of Motion (EOM)**: Ordinary Differential Equations that describes the behavior of a system (Newton's laws).

- Newton's laws are used to identify forces acting on *moving rigid bodies* = **Newton's method**

$$\mathbf{F} = \mathbf{0} \Rightarrow \mathbf{v} = const$$

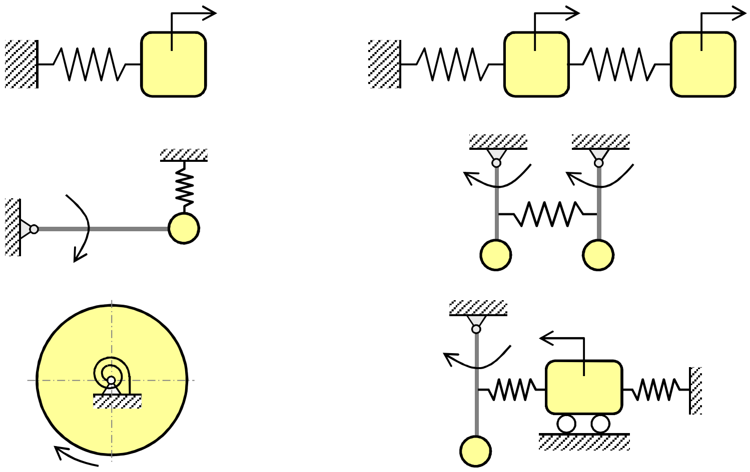
$$\mathbf{F} = m\mathbf{a}$$

$$\mathbf{F}_{AB} = -\mathbf{F}_{BA}$$

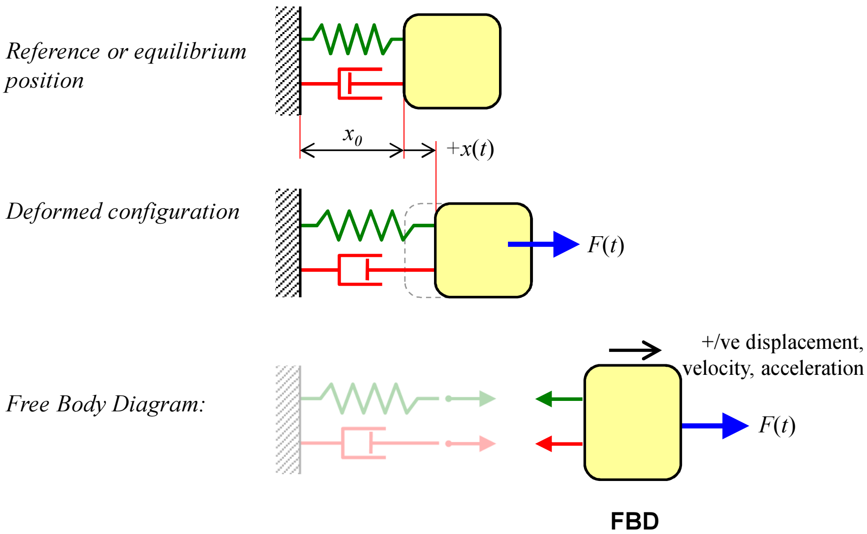
Simplified models

1 DOF examples

2 DOF examples



Introducing Newton's method

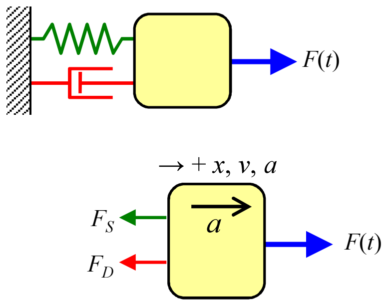


Newton's method – approach A

Accelerating forces

$$m\mathbf{a} = \sum_{(i)} \mathbf{F}_i$$

EOM?



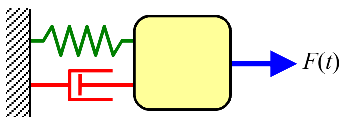
$$\boxed{ma = F(t) - F_S - F_D}$$

Newton's method – approach B

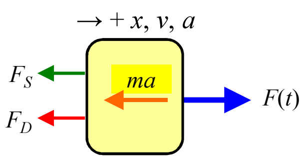
Dynamic equilibrium (d'Alembert)

$$\mathbf{F} = m\mathbf{a} \;\Rightarrow\; \mathbf{F} + m(-\mathbf{a}) = \mathbf{0}$$

EOM?



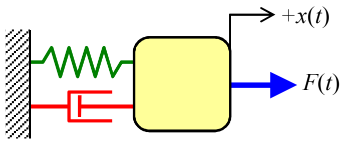
Free Body Diagram



STATICS?

$$\boxed{(F(t) - F_S - F_D) - ma = 0}$$

Mathematical models



$$\boxed{ma + F_D + F_S = F(t)}$$

We need equations (models) that can be solved.

This is the EOM of the above 1 DOF problem where:
- F_D … force in the damper or dashpot
- F_S … force in the spring

After finding F_D and F_S and defining F(t) (excitation), the EOM can be **solved**, or **studied further** (e.g. to find special properties of the system).

Forces produced by springs and dampers will be explained in the next lecture.

Newton's method summary

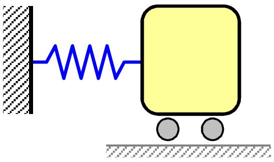
- identify all **DOFs**
- choose **positive directions** for these DOFs (define the coordinate system if required)
- **Move/displace/deform** the system from its equilibrium position (in the chosen *positive* direction)
- use **cuts**, identify **internal reactions** and create **free-body diagrams** *for each body* with nonzero mass
- use 2nd Newton's law to write EOMs
  - dynamic equilibrium approach (d'Alembert's approach)
  - accelerating forces approach (Newton's approach)

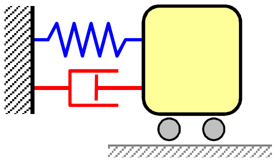
Vibrating structures

Vibration mechanical oscillations about an equilibrium point.

Vibration occurs due to exchanges between potential and kinetic energy in systems (e.g. springs and masses)

… real systems require also damping (ability to dissipate energy).





Free vibration: vibration after the removal of excitation or restraint.
Forced vibration: vibration of a system due to an external time-dependent force.
Periodic vibration: vibration where the values of the vibration parameter recur for certain equal increments of the independent time variable.
Harmonic vibration: periodic vibration where the values of the vibration parameters can be described as *sinusoidal* function

Vibration motion

Harmonic vibration: periodic vibration where the values of the vibration parameters can be described as sinusoidal function of time.

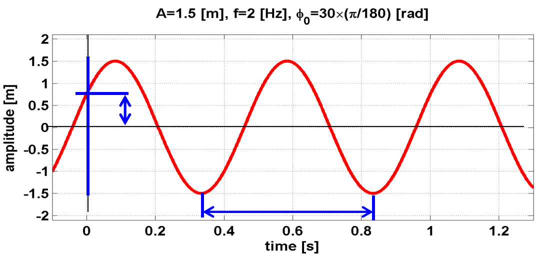
$$y = Y_0 \sin(\omega t + \phi_0)$$

$$\omega T = 2\pi,\ f = 1/T,\ \omega = 2\pi f$$

Y_0 … is the amplitude [m]
ω … is the angular frequency [rad/s]
ϕ … is the initial phase angle [rad]

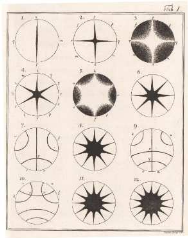
Period T [s] smallest increment of time for which a periodic function repeats itself. **Frequency f** [Hz] reciprocal of the period.

Try this Matlab:

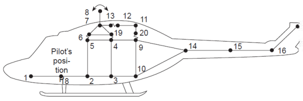


Vibrations – recent history

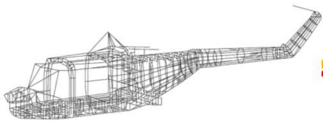
Ernst Florens Friedrich Chladni, Entdeckungen über die Theorie des Klanges (Discoveries in the Theory of Sound), 1787



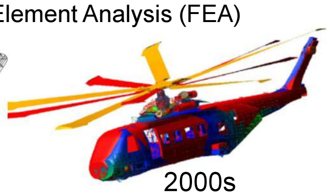
Problem: increasingly complex systems
Tools: Computer Aided Engineering (CAE) and Finite Element Analysis (FEA)
Example:



1970s

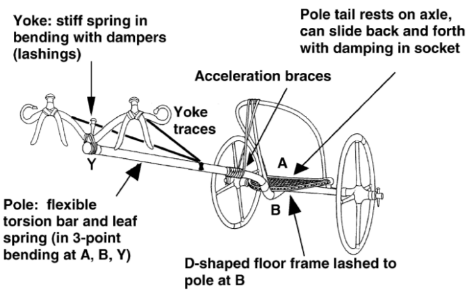


1990s



2000s

Vibration pre-history



"… The **complex suspension system of springs and shock absorbers** has advantages in structural dynamics, ride quality and safety. An example of the latter is a dual-purpose anti-roll device. The chariots' wheels have aircraftlike **damage tolerance**, and have fundamentally more perfect spokes and joints for carrying multi-axial loads than the wooden spokes of any classic car. …"

*Sandor, **The rise and decline of the Tutankhamun-class chariot**, Oxford Journal of Archaeology, 23(2), 2004*

Summary

- Newton's method
  - dynamic equilibrium
  - accelerating forces
- DOF, EOM, …
- Harmonic motion
  - amplitude, period, phase, angular frequency
- Always include physical units