FUN WITH SLOWING DOWN AND SPEEDING UP TIME

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ABSTRACT

In the course of this project, high-speed and low-speed imaging was used as a tool to analyse various fluid phenomena, and learnt about the applications of these experiments in the real world.

It is necessary to choose high speed or low speed imaging to capture a phenomenon while keeping in mind the time scale of the same, which governs the required frame rate. The mode of sampling- Spatial or Temporal must also be chosen based on the parameters to be analysed in the phenomenon.

The low-speed phenomenon observed was that of Oil Coalescence, wherein a drop of oil spread on a surface of water.

The high-speed phenomenon observed were the impact of a small droplet and large droplet on water, bursting of a soap film due to a jet of air, and the behaviour of various sprays.

The usage of dimensionless constants, as well as constants such as the Strouhal Number, Weber Number and Reynolds Number were also studied.

1. Why Do We Conduct Experiments?

Experiments play an important role in analysing phenomena.

Large scale phenomena can be studied and analysed by carrying out experiments at a smaller scale level. The observations of the same can be extrapolated to real life situations, and have a variety of benefits, including reducing cost, preventing damage and reducing errors in these real-life scenarios.

1.1. Vortex Shedding and the Strouhal Number

An experiment was observed to analyse the phenomenon of vortex shedding in an experimental setup.

On a large scale, vortex shedding happens when wind hits a structure, causing alternating vortices to form at a certain frequency. This in turn causes the system to excite and produce a vibrational load.

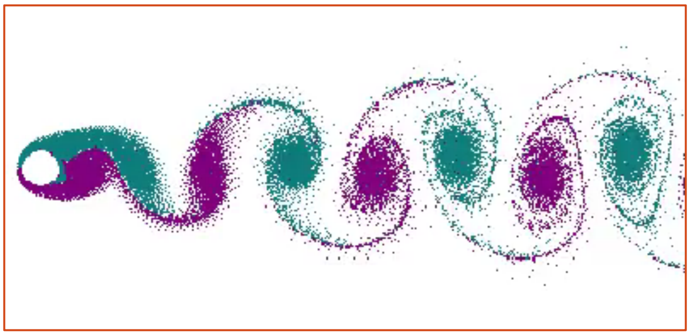


Figure 1: Vortices formed as fluid passes across a bluff body

1.1.1. Principle

The frequency of the vortices is dependent on the shape of the blunt body, and the velocity of the fluid flow or wind hitting this body. The vortices create low pressure zones on the downwind side of the object on alternate sides. As the fluid flows to fill the low-pressure zone, it produces a vibration at a specific calculable frequency.

This vibration is only a major concern if it happens to coincide with the natural frequency of the structure. For structures that are tall and uniform in size and shape, the vibrations can be damaging and ultimately lead to fatigue failure. Masts or towers are highly susceptible to vibrations induced by vortex shedding.

1.1.2. Strouhal Number

$$S = \frac{fl}{v}$$

f= frequency
l= length (or the characteristic dimension of the body)
v= velocity

The Strouhal number is affected by Reynolds number, but over a large range of Reynolds Number where the flow is laminar, the Strouhal Number is found to 0.2.

The frequency of the vortices can then be calculated from the same, and is then compared to the natural frequency of the body.

1.1.3. Applications

By completing a vortex shedding analysis of structures under realistic wind loading, engineers can evaluate whether more efficient structures can and should be developed, and the Strouhal Number is a tool for the same.

2. High Speed Imaging vs Low Speed Imaging

2.1. High Speed Imaging

High speed imaging is done to capture intricate events or processes that are too fast to be observed by the naked eye. It images events at a rate of 10000 to 50000 frames per second (fps), such that it can be reduced to about 30 to 40 fps to aid in visualization.

The time scale of the phenomena to observe which high speed imaging is used is around the order of microseconds.

Figure 2: A High-Speed Imaging Camera

2.2. Low Speed Imaging

Low Speed Imaging is done in order to analyse events that take place over a long period of time, across a time scale of the order of minutes or even hours.

The process generally shows changes at a longer time interval, allowing it to be sped up by increasing the frame rate, in order to view it in a manner that aids visualization.

Figure 3: A Low-Speed Imaging Camera

2.3. Prerequisites for Imaging

- Suitable lens must be chosen
- An apt light source
- Appropriate frame rate must be chosen according to the time scale of the process

3. Spatial Sampling vs Temporal Sampling

3.1. Spatial Sampling

It is a type of sampling in which properties are measured at a particular instant of time across a large sampling area by taking a snapshot. The time of sampling is fixed, whereas, the spatial location of the drop or molecule varies.

It is done by taking a freeze frame and measuring the properties of all molecules or drops in that frame.

3.2. Temporal Sampling

It is a type of sampling in which measurements are taken at a particular spatial location over a period of time. Here, time is the variable factor.

It is carried out by staying at one spatial location acquiring the properties (time statistics) of all molecules or drops passing through that point during a certain interval of time.

3.3.

Though spatial and temporal sampling are two different ways of sampling properties and generally do not give the same results, they can be made the same under certain conditions.

For example, if we want to measure the size of the drops of a spray, the spatial method would be to take a snapshot of a particular frame of length l. The temporal sampling would include fixing a particular spatial location and sampling all the drops passing through that particular location for a time t.

Here, spatial and temporal sampling become the same under two conditions,

1) All the drops must move with the same velocity (v)
2) $t = \frac{l}{v}$ (where l is length of the frame of spatial sampling and v is the velocity of the drops) has to be the time for which the temporal sampling is done so that the same number of drops are examined.

4. Oil Coalescence

4.1. Experiment

4.1.1. The spreading of a drop of

i) Coconut Oil

ii) Olive Oil

on water was analysed using Low Speed Imaging.

4.1.2. Graphs of radius (r/r_n, where r is the radius of the puddle of oil at a given instant and r_n is the radius of the nozzle) versus

i) A dimensionless constant ($\rho\sigma^2 t/ \mu^3$)

ii) Rayleigh Time ($\sqrt{\frac{\rho R^3}{\sigma}}$)

iii) Viscous Time ($\mu R/\sigma$)

4.2. Observation

When the oil droplet reaches the surface of water it starts spreading by breaking up into small fragments. The fragments then coalesce to form larger droplets and then reach a steady equilibrium state.

Because of the difference in the values of density, coefficient of viscosity and surface tension of coconut oil and olive oil, they show variation in the spreading pattern.

4.3. Principle

Although the force of gravity acts downwards, it causes a sidewise spreading motion of a floating oil film by creating an unbalanced pressure distribution in the pool of oil and the surrounding water. As the oil film spreads the force of gravity diminishes.

At the front edge, an imbalance exists between the surface tension at the water-air interface and the sum of surface tensions at the oil-air and oil-water interfaces. The net difference, called the **spreading coefficient**, is a force which acts at the edge of the film, pulling it outwards. The cessation of spread is caused by the evaporation of some oil fractions which reduces the spreading coefficient to zero.

The three plots of constants show which parameter- viscous time or capillary time is dominating, and the dimensionless constant helps in quantifying this variation.

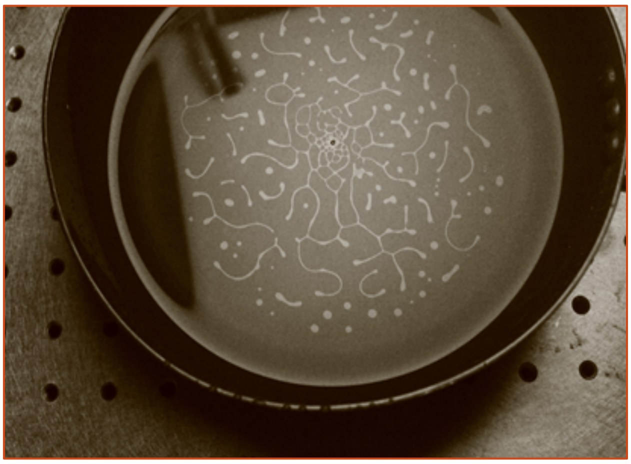
4.4. Applications

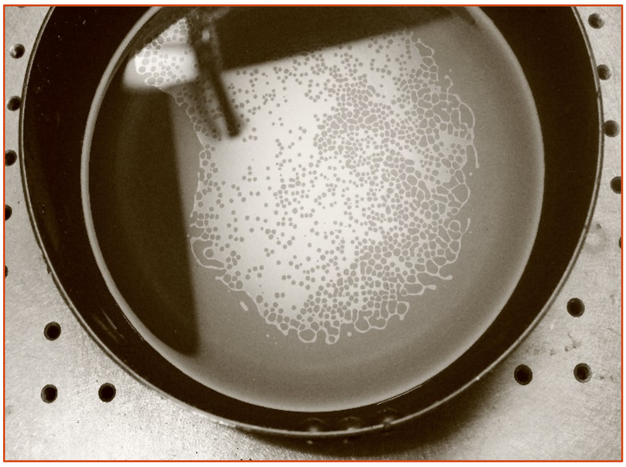
This experiment can be extended to larger real-life events such as oil spills.

The dimensionless constant functions as a parameter to quantify the properties of an oil, and can be extrapolated to estimate the rate of spread of oil and thus prevent and control the adverse effects of oil spills.

COCONUT OIL | OLIVE OIL

t=20s





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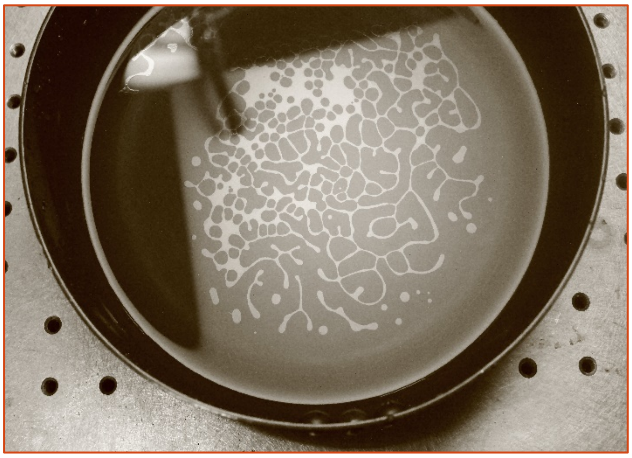

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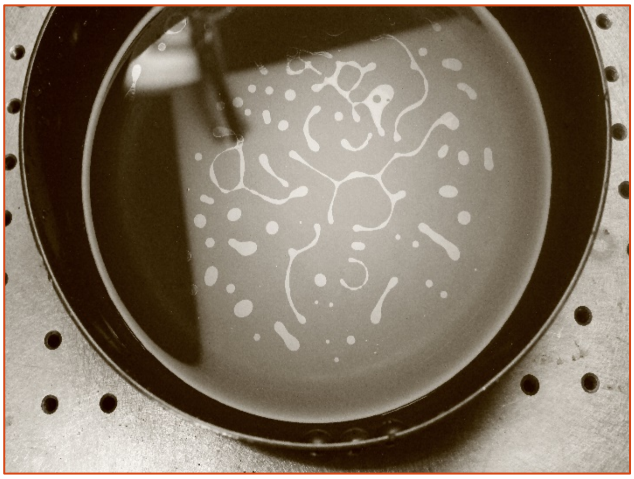


5. Small Drop Impact

5.1. Experiment

Small sized drops of water were dropped onto a water surface from the heights of 0 cm to 90 cm, and the process was captured and analysed with the help of Reynolds Number.

5.2. Observation

Three regimes were observed in the effect of the drop hitting the surface of water.

5.2.1. HEIGHT: 0 cm- 9 cm

Droplet falls on the surface, floats, and then sinks forming ripples.

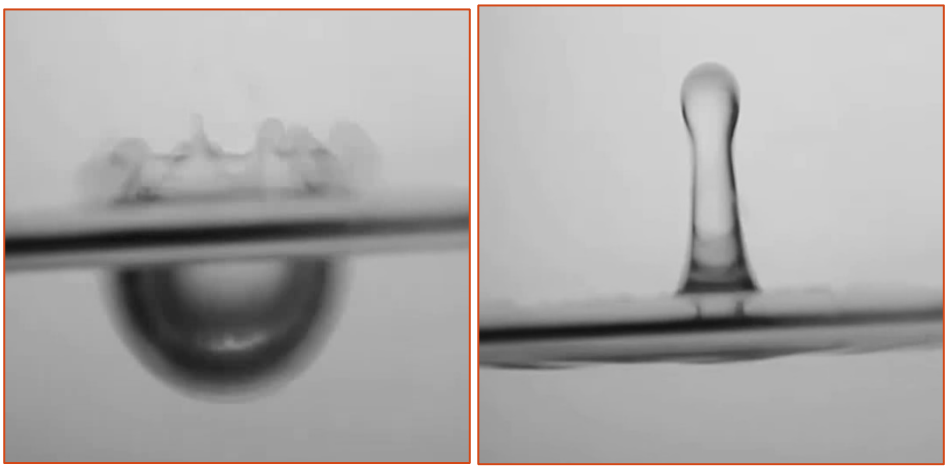
5.2.2. HEIGHT: 10 cm- 30 cm

Droplet falls on the surface, creating a jet of water.

5.2.3. HEIGHT: 30 cm- 90 cm

Droplet falls on the surface, creating a depression with a crown, and then a jet of water.

Regime 2- Jet of water



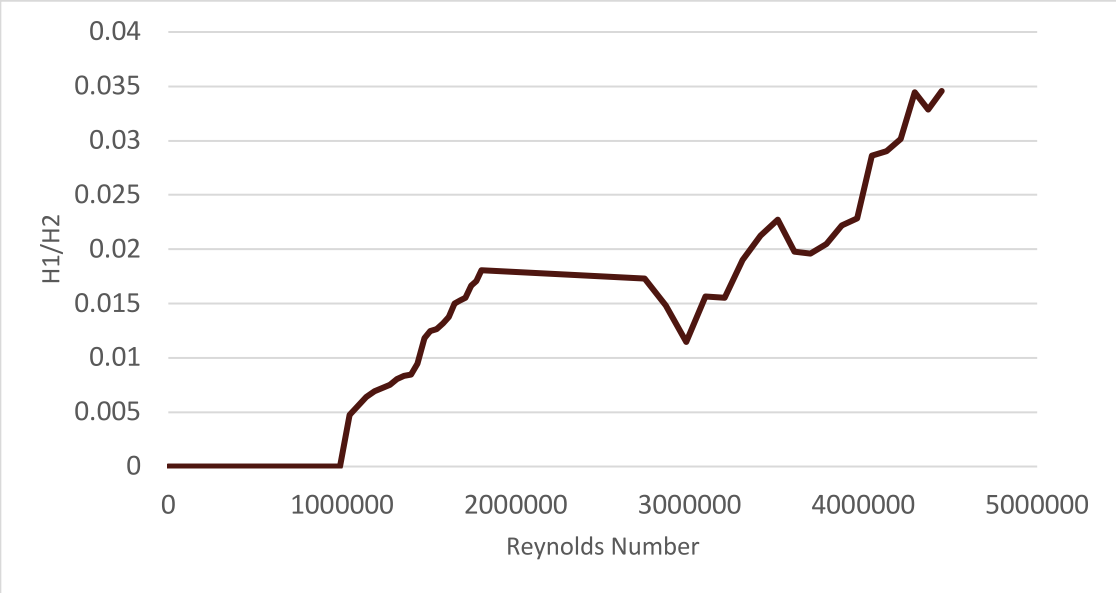
Regime 3- A crown is formed, followed by a jet of water

5.3. Principle

The increase in height leads to the droplet having an increased potential energy which is converted to kinetic energy as it hits the surface of the water, causing variations in the reactions.

It is seen that as the energy increases, the amount of water that bounces back also increases, and its orientation changes as well.

The plot of Reynolds Number vs the ratio of the height of bounce back and the height of dropping depicts the three regimes.



6. Large Drop Impact

6.1. Experiment

In order to simulate the falling of a large drop of water, a balloon as filled with water. In its absence, the drop wouldn't hold its shape and would fall as an irregular drop.

Three different radii were chosen and the drops were dropped form a constant height, and the difference in the splashes were observed and analysed with the help of the Weber Number.

6.2. Observation

Figure 4: Radius = 0.02948 m

Figure 5: Radius = 0.0326 m

Figure 4: Radius = 0.0396 m

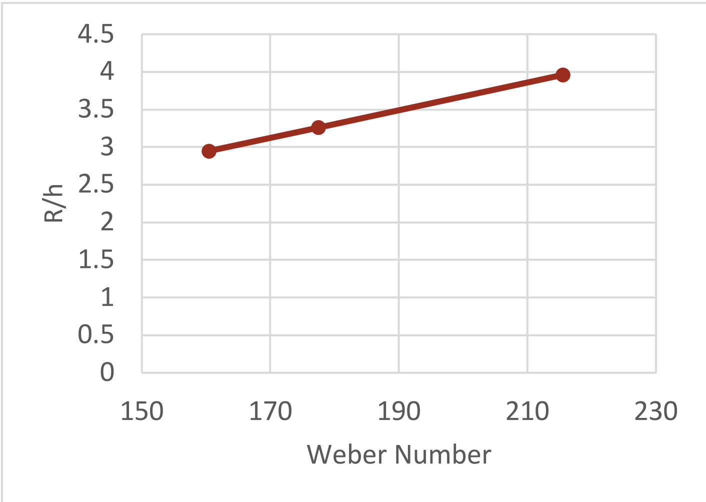
It can be seen that the splashes differ in the height of the sheet formed and its size as well.

6.3. Principle

The drops with a greater radius hit a greater surface area of the water, and as they possess a greater mass, a greater force is exerted as well. This results in a splash that reaches a greater height.

A graph was plotted of Weber Number vs the ratio of the radius of the drop and the height from which the drop was dropped.

Weber Number, which can be thought of as the ratio of the inertial forces to the surface forces can be seen to vary, and helps to quantify the variation in the splashes.



$$Weber\ Number = \frac{\rho v^2 l}{\sigma}$$

7. Soap Film Burst

7.1. Experiment

The phenomenon of the bursting of soap film due to a jet of air of constant velocity hitting it from underneath the film was captured using a high-speed imaging camera and the behaviour was analysed.

7.2. Observation

The jet of air causes the soap film to rise up, puncture and undergo multiple bursts.

The bursts take place at a particular range of height and ligaments are formed at the surface of the film during a burst.

Over 15 cases, the average

- Breakup height = 4.5 cm
- Number of bursts = 3
- Number of ligaments = 14

Figure 7: Ligament Formation

7.3. Principle

When the soap film pops, it collapses, folding in on itself trapping a ring of air in the shape of a donut.

But the donut shape is unstable, so the film breaks up into little droplets all around the donut shape as smaller droplets have a lower surface area and hence are stable.

The process can repeat in cycles, with the daughter bubbles popping to create a ring of even smaller granddaughter bubbles. It only stops when the bubbles themselves become almost the same size as the thin layer of film.

8. Sprays

8.1. Experiment

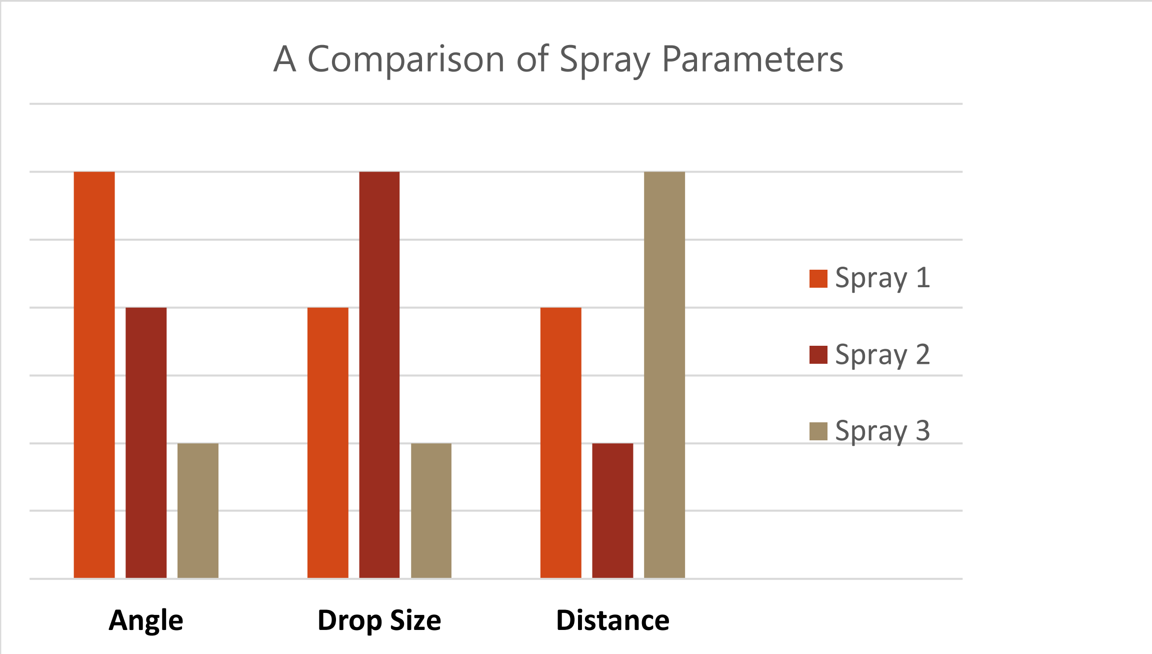
All of the above phenomena discussed have their application in sprays.

Three sprays and their parameters were analysed using high-speed imaging.

8.2. Observation

The three sprays were tabulated based on the following properties:

i) Spray angle
ii) Droplet Size
iii) Distance



8.3. Principle and Applications

The real-life applications of each spray are inherently related to these parameters.

For example, Spray 3 has the least angle and drop size, but the greatest distance. This shows that it is used for specific targets, which matches its application as an Insect Repellent Spray.

Similarly, Spray 1 is used as a deodorant, with a large angle, and Spray 2 as a Cleaning Fluid spray, with large drop size as a significant property.

9. What We Learnt

- The importance of thought experiments
- How experiments are performed in a lab, and how post processing takes place
- The various constants and numbers involved in fluid analysis
- Cameras and time scales of various events
- How experiments that are performed in labs are scaled and extrapolated to the real world.

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NPTEL Lectures

Mod-01 Lec-02 Spatial versus Temporal Sampling by Prof. Mahesh Panchagnula

Mod-01 Lec-03 Spatial Vs Temporal Sampling Example Problem, by Prof. Mahesh Panchagnula