6) Physical Modelling

SUMMARY: Introduction to advantages and disadvantages in physical modelling

REFERENCES: http://sems.auckland.ac.nz/Edu/423.310/bin/lectures_frameset.html?../lecture3/lecture3_text.html

Introduction

So-called physical or hardware models are widely used in environmental studies. They are simplified versions of the system using physical materials. Hardware modelling encourages visualising relationships and is useful in that it is often possible to get a high degree of control over the experimental conditions. The 2 most important types of hardware models are *static* and *dynamic models*, respectively. The former is designed to represent the physical characteristics of a phenomenon and the latter replicate certain processes of interest.

Advantages of hardware models:

- They are desirable because essential variables can be controlled at will
- Time and expense are greatly reduced from those required in full-scale studies
- Good for visualization

Limitations of hardware models:

- The main limitation of these models is one of reconciling the distortion of scale (see below).
- For correct modelling, certain *non-dimensional parameters* in the prototype must be duplicated in the model. Almost invariably, this is impractical or impossible. Hence, a decision must be made as to which parameters (i.e. processes) are dominant which often depends on the phenomenon of interest.
- These models are only intended to reproduce some aspects of the structure or a subset of the relationships in the system
- Often difficult to get quantitative information from physical models but they are generally good for getting ideas on processes.

1. Analogue Models

Involve a radical change in the media representing the system. Most widely used are maps: roads expressed as lines, relief by contours etc. Also satellite images of certain properties of the earth's surface.

2. Scale Models

Examples: Wind tunnels
Open air wave tanks
Scale models
Biosphere - physical reproductions of the real system)

The main problem associated with scale models is one of scaling and dimensional similarity. Changes in scale can affect the relationships between certain properties of the model and the real world.

For all models:

Similarity of geometric length scales such as length (L), height (H), width (W), etc. of prototype (p) and model (m). For example: $L/D_{(p)} = L/D_{(m)}$ or $H/W_{(p)} = H/W_{(m)}$

For dynamic models:

It is important to retain dimensional similarity when constructing scale models of fluid flows. The Reynolds number is a ratio expressing the relative importance of intertial forces in the fluid to the viscosity of the fluid. Viscosity is the stickiness of the fluid and is a consequence of molecular attraction between the molecules of the fluid. Honey is very viscous. The intertial forces tend to cause the flow to become turbulent, *i.e.* the greater the value of inertial forces the more likely the flow is turbulent. Counteracting this tendency for the flow to become turbulent is the viscous forces, decreasing turbulence activity and giving rise to laminar flow. The viscosity of most fluids is known and is a constant number. Whether a fluid flow is laminar or turbulent can be estimated from the Reynolds number (Re):

$$\mathrm{Re} = \frac{U\ L}{\nu} = \frac{\text{external forces}}{\text{internal forces}}$$

where U – characteristic (reference) velocity (m s^{-1}); L – characteristic (reference) length scale (m); and ν – kinematic viscosity (1.5 x 10^{-5} m^2 s^{-1} for air; 10^{-6} m^2 s^{-1} for water).

Re enables viscous effects to be accurately reproduced in a model, *i.e.* Re should be similar in both prototype and model. To reproduce “real” atmospheric flows in a wind tunnel it is important to keep Re large enough to ensure fully turbulent conditions. This is achieved for $\mathrm{Re} > 10^5$ in which case the flow is called Reynolds number independent (i.e. the flow is fully turbulent as long as Re is above the critical number).

As long as the Reynolds number of our scale model remains similar to that of the real system we can model the system with a range of combinations of U, L and ν.

For thermal models:

If thermal effects (*i.e.* stratification) are important in the system of study, the Froude Number (Fr) enables buoyancy effects to be accurately reproduced:

$$\mathrm{Fr} = \frac{U}{\sqrt{g\ L\ \delta\ \left(T_R / T_0\right)}}$$

where g – acceleration due to gravity (m s^{-2}); δ – height of thermal layer (m); T_R – reference temperature (º K); and T_0 – surface temperature (º K).

Exercises:

	Prototype	Model
	Atmosphere:	Wind tunnel:
5 cm high scale model of 10 m building in atmosphere	U = 5 m s^{-1}, L = 10 m Re_p = ?	U = 2 m s^{-1}, L = 5 cm Re_m = ? Comments?
Increase the height of the model until $Re_m = Re_p$		L = ? Comments?
	Ocean:	Water tank:
Oceanic flow around an isolated island with diameter L	$U = 10^{-1}$ m s^{-1}, L = 100 m Re_p = ?	$U = 10^{-1}$ m s^{-1}, L = 1 cm Re_m = ? Comments?
Change U to compensate for different L		U = ? Comments?

Examples of physical models in used in urban climatology:

(1) Urban albedo as a function of the urban roughness:
Models of an urban structure resembling buildings and canyons were constructed by using concrete blocks. By changing the urban morphology (through moving blocks), changes in the albedo could be observed.

(2) Radiation exchange within an urban canyon:
Measurement of long-wave fluxes taken within a scaled down urban canyon constructed from concrete building blocks are used to validate a numerical model.

(3) Simulation of radiative cooling for different park types:
A wood model consisting of houses and trees was constructed to determine the relative magnitudes of surface geometry, thermal properties and evapotranspiration on nucturnal cooling.

(5) Scale modelling of the nocturnal urban heat island:
A plywood scale model consisting of individual blocks was used to mimic the radiative nocturnal cooling.

(6) Urban heat island studies in stratified wind tunnels:
A “patch” in the surface of a wind (or water) tunnel floor which can be heated serves as a model for the urban heat island.

(7) Air flow over roughness:
Small cubes fixed to the floor of a wind tunnel serve as a representation of urban areas. The spacing of the cubes can be changed and their influence on the flow properties monitored.