1. MODELING and SYSTEMS

Basically, Engineering Science is about modeling!

However, it must always be remembered that any kind of model (whether it is plastic, wire, or mathematical) is, at best, an approximation of a real world object.

A model is considered 'good' if it represents the real object well. If it doesn't, it may be considered 'bad', but that also depends on what the model is used for. An example is the picture (model) of a male and female on toilet doors. They don't look much like real people at all, but they serve the purpose of making the distinction! In so far as that is all they are meant to do, they are adequate for the job.

Models of components or structures can be very useful. They can save a great deal of money, time and effort because we don't have to go to the expense of making and testing the real thing every time. We simply 'create' and 'test' a model instead, enabling us to predict what will happen in real life.

However, in order to get the design right we also need to be sure that our models are 'fit for purpose'. i.e. that they predict reasonably accurately how the real thing will behave. In other words they must also be 'adequate for the job'. If a model is not adequate then we have to amend it, refine it, or scrap it and start again.

A system is a collection of components put together for a specific purpose. We often define it by the purpose:
e.g. a braking system, steering system, control system etc.

Types of models:

1. Physical (scale or geometric) models

These represent the real object but are often smaller or larger than the real thing. e.g. a plastic model aircraft may be 1/8, 1/36 or 1/72 actual size.
A model of a molecule may be millions of times actual size.
Working models - move, and replicate the actual real action.

2. Analagous models

An analogous model is where one system is used to represent another because it works on the same principles. e.g. an electrical system can be used to represent a hydraulic system because the rules are the same.
Electric current and heat 'obey' the same rules so one can represent the other. It is sometimes cheaper and quicker to build an electrical system than a real system.
DTµQ (as in use of *Teledeltos* paper)

3. Mathematical models

A mathematical model is essentially one or more mathematical equations which describe the way in which a component or system responds to external events such as a force being applied, a temperature rise, or friction.
They typically come in two kinds - theoretical or empirical.
<u>Theoretical</u> means based on known laws of physics, chemistry or biology. e.g. Newton's laws.
<u>Empirica</u>l means an equation that fits the results of experimental data. i.e. it works!
Most of the models we are going to use are mathematical.
Computers can be of great help when using mathematical models.

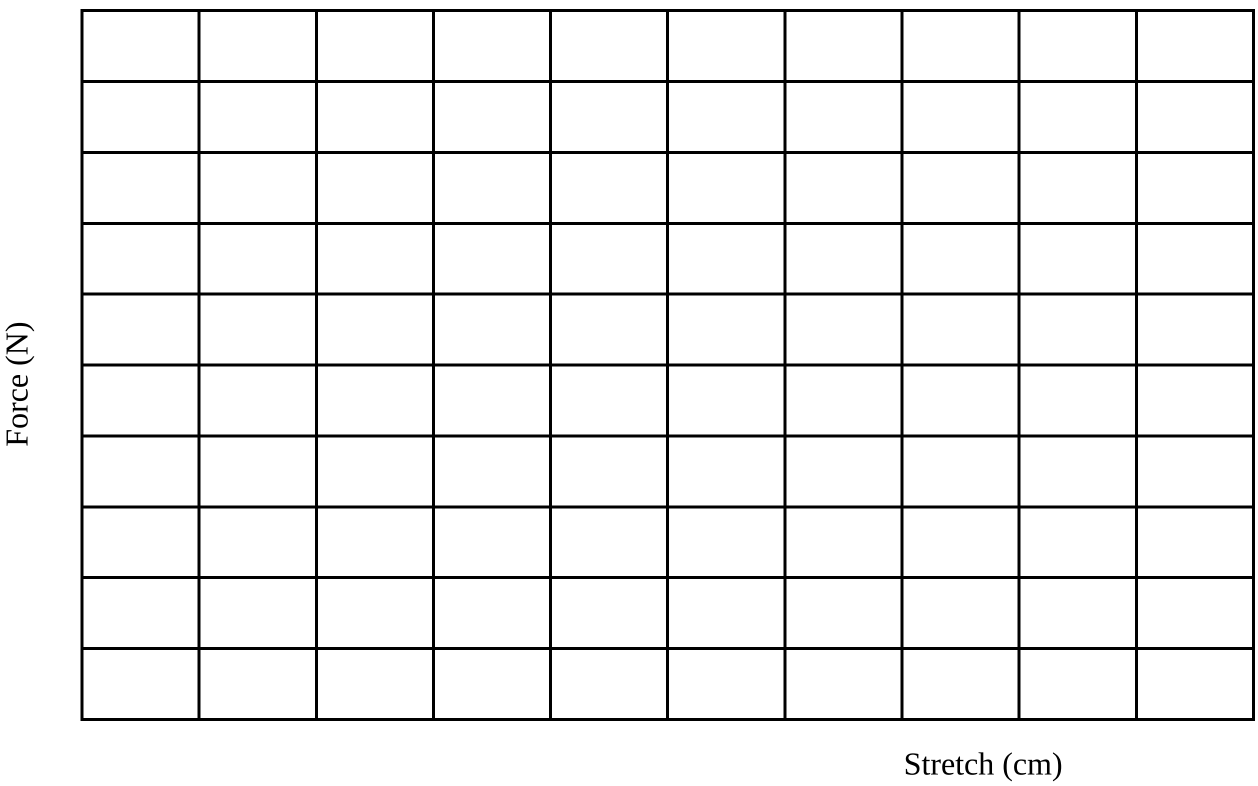
Example of a Mathematical model

An ordinary tension spring stretches when pulled. The amount of pull needed to stretch it by a certain amount is given by Hooke's law, which simply states: the pull force ***(F)*** needed is proportional to the stretch required ***(x)*** .
The constant of proportionality is known as the <u>stiffness</u> of the spring. This is a <u>property</u> of the spring also known as the spring constant. The greater the stiffness, the greater the pull force needed for a given stretch.
The model is written mathematically:

$$F = kx$$

F is the pull force (in Newtons)
x is the amount of stretch (in meters)
k is the stiffness (in N/m)

To check how good this model is we can test a real spring and plot our results:



When we draw the best straight line through the results, although we obtain a reasonably straight line, it doesn’t go through the origin. However, our model predicts that it should. So which is wrong? The model - because it doesn't properly predict the results we obtained from experiment, or the spring because it doesn't behave like the law says it should? (!)

In all cases where there is disagreement between a model and the results of testing the real thing, the problem is with the model. (Assuming our measurements are accurate.)

In this particular case the spring is wound with an inbuilt pre-load which the model fails to take into account.
We need to amend the model to take it into account.

$$F = F_0 + kx$$

According to the model, x can have any value we like.

Would it still predict the force correctly if x was very large?

What if x was negative?

We note that there are limits (or boundaries) within which the model works well, but beyond which the model is invalid. We always need to be aware of these real world limits, and not use models blindly. This is where our knowledge of the real world of engineering combines with our mathematical knowledge to ensure that we don't make silly mistakes.

Notes on models:

Models are usually simplifications of real life. They often take into account first order effects only. i.e. those that directly influence an outcome. They often ignore second order (or higher) effects, i.e. those that have a lesser or secondary effect on the outcome.
e.g. if our model assumes 'no friction' (a second order effect), the difference between our predictions and our measurements is because the model doesn't take friction into account rather than because friction always occurs in real life!

Mainly because of the above, models are accurate to within limits. A model's acceptability depends on how accurate we need its predictions to be:-

±1% may be needed when we can't afford to get it wrong,
±10% is good and generally acceptable,
±25% is useable but we need to allow for uncertainty,
±100% needs care, but is better than ±200%!

We allow for uncertainty by means of factors of safety, or margins of safety.

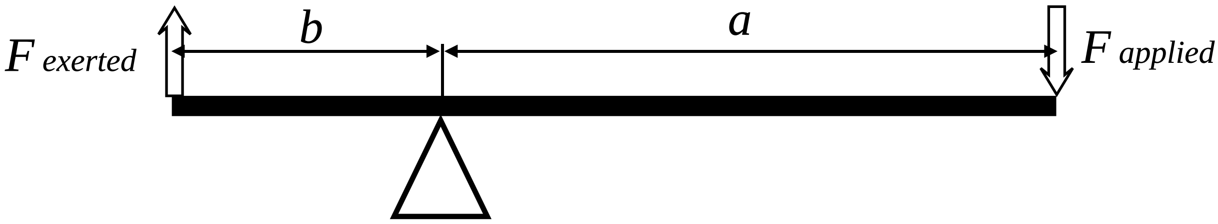
Typically, the more accurate and realistic a model, the more mathematically complex it will be.

In an experimental situation, if our predictions and measurements don't agree (assuming no mistakes in our calculations and reasonable measuring accuracy!) it is the model which is wrong.

(The laboratory demonstrations will further illustrate these points.)

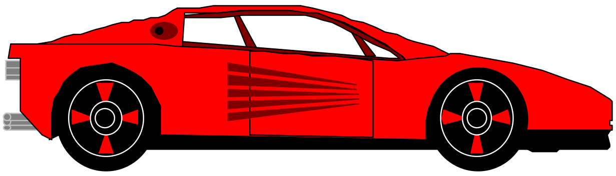
Examples of simple models:

Force exerted by a lever:



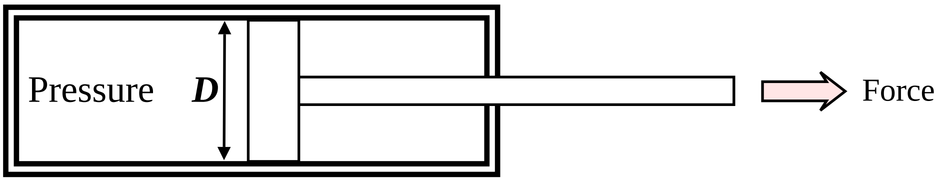
$$F_{exerted} = F_{applied} \times \frac{a}{b}$$

Acceleration of a car of a given mass and engine power:



Force* = *ma and
Power* = *Force* x *v therefore $\quad a = \dfrac{Power}{m \times v}$

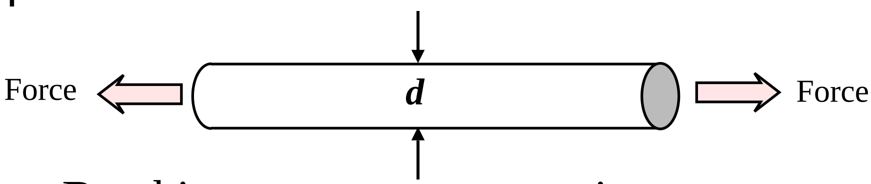
Force available from a hydraulic or pneumatic cylinder:



Force = Pressure x Piston face area

$$= \text{Pressure} \times \frac{p}{4} D^2$$

Force required to break a bar or wire in tension:



Force = Breaking stress x cross-section area

$$= \text{Breaking stress} \times \frac{p}{4} d^2$$