Delft University of Technology
Faculty of Aerospace Engineering

Aerospace Engineering
Experimental Research & Data Analysis
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# Assignment 1

**Group E01**

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| | Q1a | Q1b | Q1c | Q1d |
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| Lennert Luyckx | | | x | |
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| Mattijs Berendsen | | x | | |
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# 0.1 Question a

### 0.1.1 The role of mathematics in early aviation

Today mathematics is used in aviation heavily. However, the first experiments in man-made flight done by pioneers such as the Wright Brothers and George Cayley used very little maths and was mostly done by trial and error. However the majority of progress from then onwards was due to mathematics. For example fluid dynamics, which is the larger category of aerodynamics, is what brought the optimization of aviation. The most important achievement in fluid dynamics are the Navier Stokes equations, which are all mathematics, and it is these equations that made the optimization of the aerodynamics of aircraft possible.

In a similar fashion, stability and control of aircraft started experimentally, but soon was mathematically described to gain a better understanding of the underlying factors. The understanding of these factors, facilitated the process of designing better control systems. Comprehension of stability and control of aircraft is arguably what made modern aviation possible.

Another example is the Flight Management System used in modern aviation. This system continuously gets inputs of various parameters (pressure, temperature, etc.) and computes the best speed and altitudes to fly at. These systems save airlines millions of euros. Without these systems, flights would not be accessible for the masses as it would be too expensive. It is these systems that made aviation a useful method, the first prototypes built by the pioneers were too restrained and had little application possibilities.

We discussed three areas where mathematics is used in aviation, however there are many more areas. Nowadays aerial vehicles are designed with a systems engineering approach which is all mathematics based. In the early days of flight, mathematics was not used much to build the first aerial vehicle prototypes, these were built based on knowledge gained from experiments and trial and error. This experimentation allowed for the idea of the concept to flourish. However to make this concept useful and applicable to real life situations, mathematics bridged the gap, enabling optimization, and deeper understanding of important factors to make aviation possible.

### 0.1.2 The development of new control algorithms

The development of new control algorithms originates from both the mathematics and the application. Mathematics gives the ability to improve and optimize control algorithms, however, these new algorithms need to be tested (application) to see if they work well. During the application other points of improvements can be more obvious than they were during the mathematical designing.

The application will always be an important source of new developments in control algorithms since it might give the person designing them a thought to think about the system differently and giving them another type of insight.

Mathematics and the application can be seen as two different tools giving different insights and with different advantages. Using both of them in parallel allows us to increase the speed of development of new control algorithms.

### 0.1.3 Are control algorithms literally true?

In Aerospace Engineering, there is a strong need for control algorithms. When an aircraft is in cruise control, for example, control algorithms are used to keep the aircraft flying in the proper direction, at the proper speed, and at the proper altitude. Maintaining stable flight is very important as there could be turbulent air masses or other disturbances over a flight.

Bang-bang, fuzzy logic, and PID control are all different types of control algorithms that can be used to keep an aircraft flying as it should. However, it would be incorrect to say that any of them are literally true. All algorithms have some amount of error when measuring anything. Even though some algorithms like PID control are built to take into account any steady state error and correct for it, it can never be literally true. The best these algorithms can do is make the best approximations they possibly can.

### 0.1.4 How space flight has contributed to the development of new mathematical theories

The preparations that went into making the Apollo 11 moon landing a success led to developments in estimation theory. In trying to land on the moon, it was important to get an accurate estimate of the rocket's trajectory, speed, and position at any time. Since there was no mathematical solution, there needed to be a numerical solution that could also be computed by 1960s era computers. A Hungarian mathematician, Rudolf Kalman had developed an algorithm for linearly estimating the position and speed of a vehicle, although the problem with Apollo 11 was decidedly non-linear. An American aerospace engineer, Stanley Schmidt, who was working on the Apollo 11 mission discovered that the Kalman filter could be applied to a non-linear system as well, and developed the necessary equations to do so. This represented a major development in mathematics, and the Schmidt-Kalman filter is still used to this day.

# Question b: Parsimony principle

## Definition

The parsimony principle refers to the proposition that the simplest explanation of a phenomenon is the most accepted explanation. According to Hugh G. Gauch, this allows for a clearer insight on the phenomenon, which in term increases efficiency.

## Principle applied to fatigue tests

Consider the the test for which one is testing a specimen for the number of cycles until failure for 5 different stress levels. Using the parsimony principle one is trying to find a linear relationship between the stress and number of cycles to failure.

To begin, one should consider how the outputs of such test will vary resulting from an experimental test. Material tests are by nature imperfect due to small imperfections present in the material itself. Therefore the "true" relation between stress and the number of cycles will not correspond to the value obtained from the experimental test. Another error in the measurement could be as a result of the test setup. Measurement errors and effects of clamping can both contribute to deviations from the "true" value.

To achieve a more accurate prediction of this relation one can apply the parsimony principle by seeking to find a linear relationship that takes into account all data points as to "average out" the experimental errors mentioned above. As described in the figure bellow:

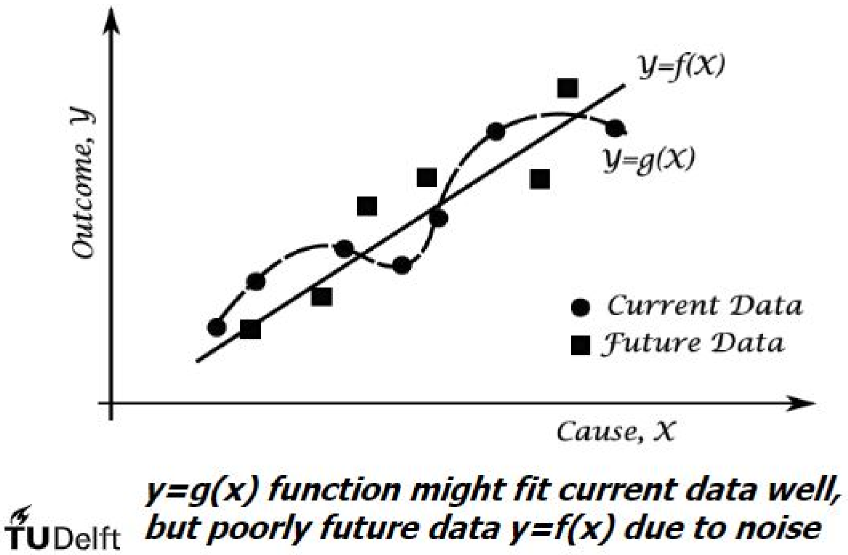


Figure 1: Parsimony principle [1]

With regard to the example this can be visualised in the following figure:

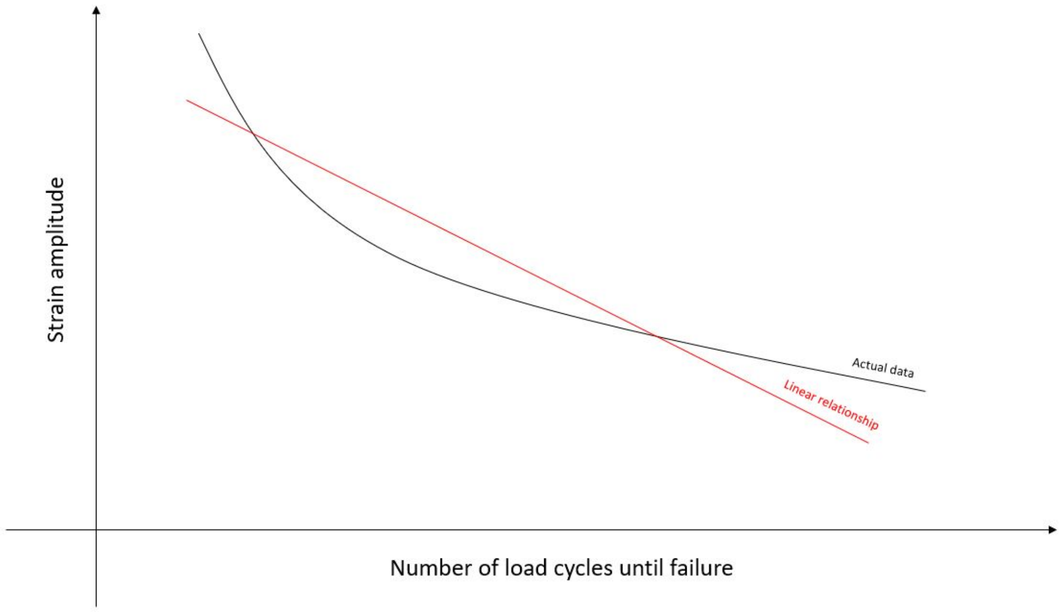


Figure 2: Example parsimony principle: linear relation for fatigue calculations

Obtaining such linear relation would allow for designers to obtain an rough estimation of how the material will behave after a number of load cycles. This is particularly useful for preliminary designs choices where one more looks at the order of magnitude.

## Simplification using Parsimony's principle

To take the example of a fatigue cycle further, the simplest relationship between stress and number of cycles will now be investigated. In order to do so the example shown in figure 2 will be examined. The amplitude of strain is dictated by the stress experienced. The curve is downward sloping. To simplify the real world data into something resembling a model the number of load cycles axis can be separated into sections. This achieves two things - the curve is more consistent within these boundaries, and the linear model becomes a more accurate representation of the real world. If, for example, this curve were split in to 5 sections and linear approximations of these 5 sections used, the overall model would be more true to reality without increasing the complexity of the process.

Therefore, as the parsimony principle advises the curve will be reduced into segments and a linear approximation of each made in the form

$$\sigma_{max} = A * Cycles + C \tag{1}$$

Using this method the model can be more or less accurate depending on the number of sections chosen, without increasing in complexity.

## How accurate is this representation?

Of course an approximation made using this model will never perfectly mimic reality and as such this is not literally true. Additionally, the experiments used to collect the data required to create the model diverge from pure theory as there are always slight deviations from the 'true' values, either due to experimental error or imperfections in the material.

The this linear approximation can approach a high level of accuracy if sufficient sections are made, it will never be a perfect match to the theoretical 'true' equation that perfectly describes the relationship between the strain and load cycles.

## 0.2 Q1c. Experimentation

### 0.2.1 Definitions

In this subsection, the terms observation, prospective and retrospective experiments will be defined for further use.

First of, observation is the act of using the senses to receive input from naturally occurring phenomena. Which is then analysed trough rational and irrational thought. During observation it is important to keep in mind who is observing, since this does impact the results. One must also be careful to not fill the gaps between what is observed with what one expects or hopes to observe. [2]

Secondly, prospective experiment looks for outcome during the study and tries to relate those outcomes to causal factors. In order to find statistically relevant factors, the outcome should be relatively common. [2]

Retrospective experiments on the other hand start from a pool that satisfies the sought after outcome and looks for possible causal factors that are common in the pool. [2]

### 0.2.2 Application of observation to aerodynamics

In this subsection, the application of the observation principle to aerodynamics experiments will be discussed.

Airflow visualisation around an object such as an airfoil, using the operation of a wind tunnel is a common aerodynamics experiment. This experiment usually involves the use of tracers such as smoke particles or coloured fog which illuminates the airflow, allowing observation of its movement.
Visualisation is the most suitable tool in fluid flow research as it provides a clear picture of the flow field behaviour. These observational experiments make it possible for flow phenomenons governed by viscosity like boundary layer flow, separation to be analysed and from there make quantitative measurements.

### 0.2.3 Application of retrospective experiments in aircraft manufacturing

This subsection deals with the application of retrospective experimentation to aircraft manufacturing in order to improve efficiency and reduce production costs.

Retrospective experimentation in aircraft manufacturing can start with reviewing traditional methods and manufacturing approaches utilised for aircraft production. From there, we identify bottlenecks in the processes and determine the key technical challenges as well as production methods that significantly impact system life-cycle costs.
For example, in aircraft manufacturing the fuselages represent the highest material costs. This is primarily due to the use of expensive titanium parts to construct such a highly-loaded assembly. The reliance on traditional titanium parts have caused reduced availability of such materials, further increasing its cost. This drove a surge in aerospace material research in most companies which led to the development of more cost-effective metal-product technologies. Examples include powder metallurgy superalloy billets as well as aluminium-beryllium products that can replace the usage of titanium. This development of aerospace materials can eventually bring an improvement to material efficiency and reduce production costs.

### 0.2.4 Principles applied to numerical modelling

In this subsection the application of the experimental principles to numerical modelling for composite structures will be discussed.

Prospective experimentation can be used in numerical modelling of composite structures by first designing a numerical model based on certain principles that are expected to have a positive impact and then compare the data acquired by the numerical model to see if the model fits the needs. If not, the model has to be further improved and tested again.

In order to use a retrospective study, a set of accurate numerical models has to exist first, so that it is possible to find the cause of this accuracy. Although there probably is a decent sized pool of accurate numerical models for composite structures at the current moment, companies will not be eager to release the model behind their programs, making a retrospective study not feasible.

Using observation would be impossible, since observation involves looking at natural phenomena, and a numerical model is always purpose-build. Also, just observing the workings of a numerical model without comparison to a or multiple physical tests would yield little to no information about the accuracy and correctness of the model.

## 0.3 Q1d. Magic

To solve an engineering question often the question consists of more factors to consider than you are able to account for. While the root of the problem does not lie in rest of the case we can solve this with introducing a 'magic' component or property. When using a thought experiment including this way of thinking we can think about a problem in a more effective manner. In this exercise three examples are given where we can justify that it is possible with this method to gain insight into an aspect of aerospace or wind energy design.

### 0.3.1 Aerodynamics in wind energy

When designing aerodynamics in wind energy, beforehand it is not known how efficient the blades, gearbox etc. will be while you do want to have an idea of how much energy it will deliver. A magical property we can introduce is that the windmill has infinite blades all without friction. Thinking about this, it causes all incoming air to be utilized to its full potential. No excess energy is used to overcome friction due to air resistance. This situation gives an ideal situation to strive for when building any wind turbine in reality. Of course it's impossible for there to be no air resistance, but the ideal situation for the wind turbine gives engineers a clear goal in mind. Actual designs can then be created that work on minimizing air resistance while delivering the maximum wind energy possible. Also, this magic experiment can be used for approximations. Doing calculations that actually factor in air resistance can be time consuming and potentially expensive, especially if one is only looking for rough estimates. When using a certain factor to compromise for this an approximation can be made to calculate energy that is extracted.

### 0.3.2 Efficient movement of passengers in an airport.

For the efficient movement of passengers in an airport a magical component we can use in a thought experiment is customs gates that can indicate everything and anyone we don't want on the airplanes. Essentially, this creates a perfectly safe and perfectly efficient airport, where all the bad actors are immediately screened out, and all other passengers are able to get to their flight without any delay. As a result of this magic gate, costs are saved as well as you don't need anyone to actually take the time to check bags, it's done by a magic gate. This creates an ideal airport design to strive for. With this in mind, one can consider how much efficiency is actually sacrificed in the name of safety, and whether or not too much efficiency or too much safety is being sacrificed. Taking into account all these factors, and how the reality differs from the ideal, one can design an airport around this system and afterwards design a more complex system consisting of more parts to attempt to fulfill the task that our magical component does as best as can possibly be done.

### 0.3.3 Cubesat

The environment of space is hard to design for when making a cubesat. To work around this we can use the magic component totally isolating foam. Using this in our thought experiment we can put our focus on what to put in the satellite and worry about how to isolate it further on in the design process.

### 0.3.4 Conclusion

What we learn out of working with introducing a 'magical' component or property is that a problem is only as difficult as you make it yourself. When working with this method we can eliminate factors that are not as important to solving the problem. After solving the main problem we can then replace this magic with a system that fulfills the requirements.

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