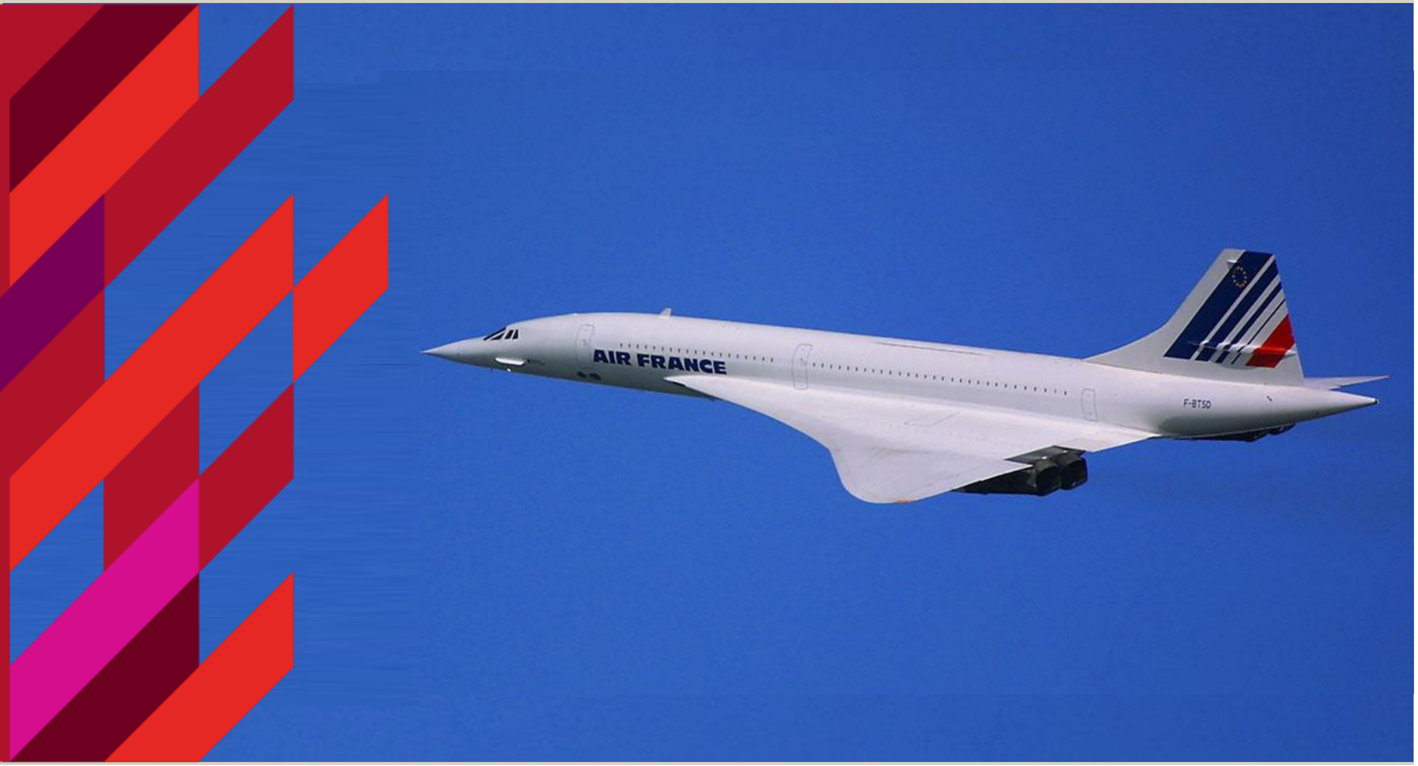
MECH203,
Mechanical Engineering Design
The Design Process



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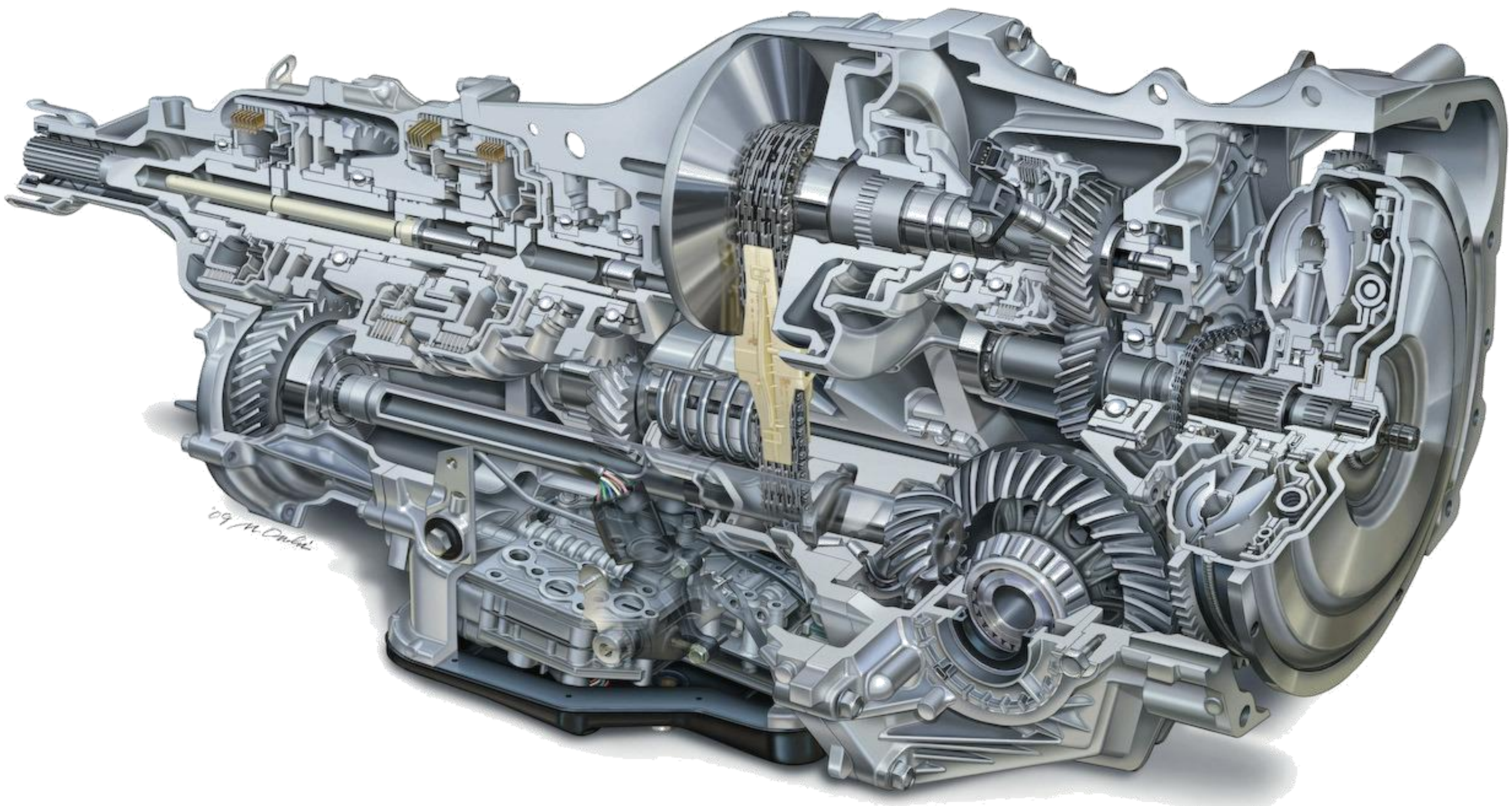
The Design Process

What is Mechanical Engineering Design?



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The Design Process

What is **Mechanical** Engineering Design?

Components that transfer or withstand forces, torques or motion.

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The Design Process

What is Mechanical Engineering **Design**?

Components that transfer or withstand forces, torques or motion.

The process in which scientific principles and the tools of engineering – mathematics, computers, graphics and English are used to produce a plan, which when carried out, will satisfy a human need.

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The Design Process

What is Mechanical Engineering **Design**?

Components that transfer or withstand forces, torques or motion.

The process in which scientific principles and the tools of engineering – mathematics, computers, graphics and English are used to produce a plan, which when carried out, will satisfy a human need.

Design is NOT trial and error – it is a process!

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The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as the Concorde…

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The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as the Hoover Dam…

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The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as the Space Shuttle…

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The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as the High Speed Trains…

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The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as the Artificial Hearts…

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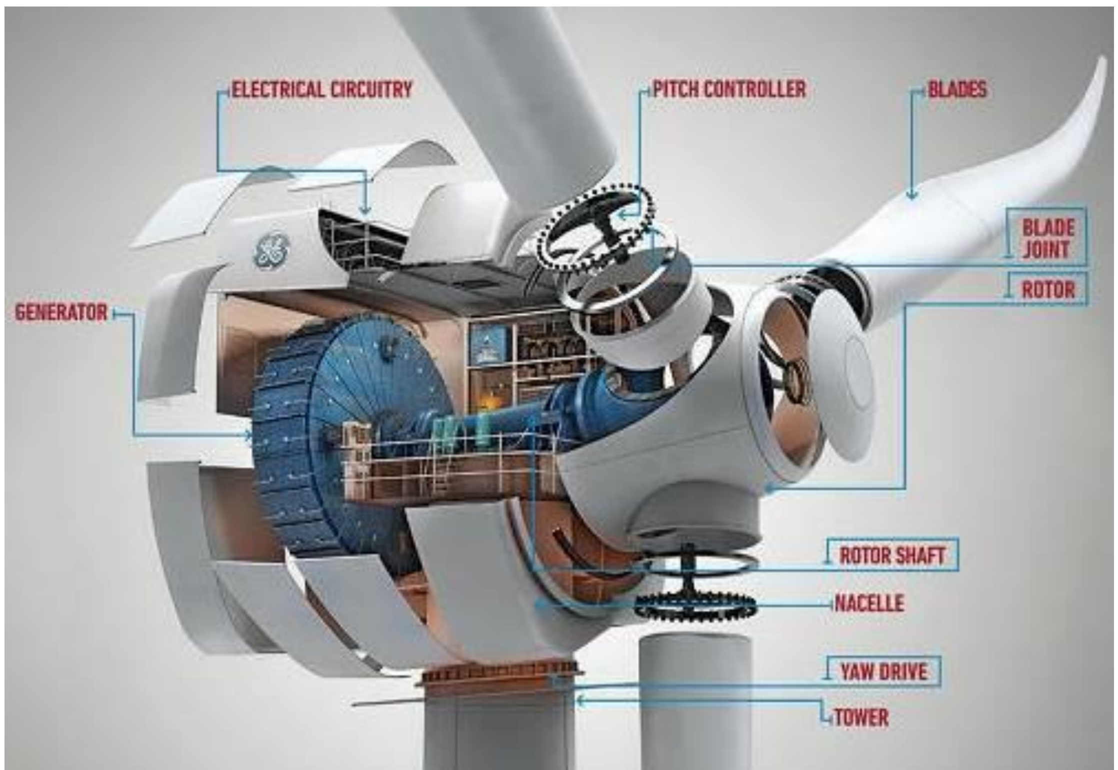
The Design Process

It is not possible to solve complex engineering problems through the process of trial and error such as Renewable Energy sources…



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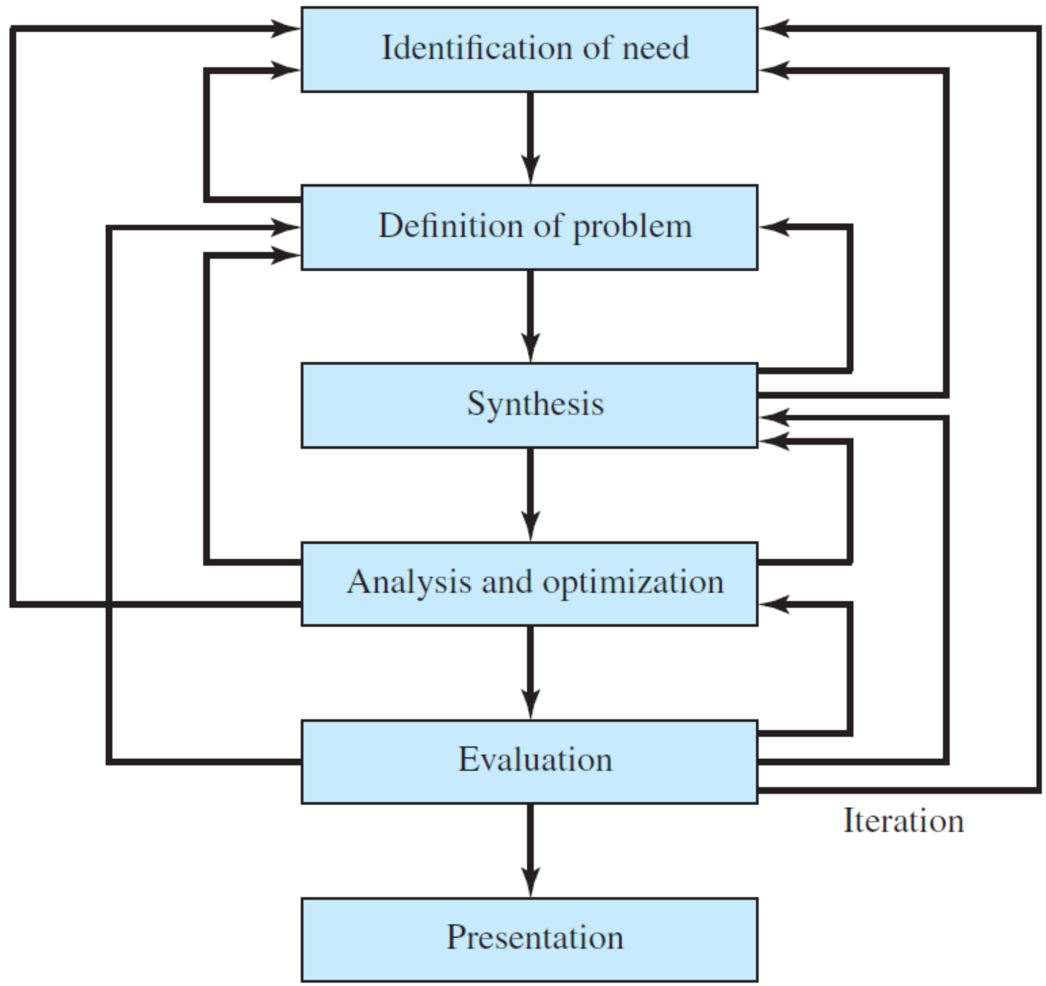
The Design Process

A process is required that will allow us to design such complex systems.

The **Design process** can be summarised by the adjacent flow chart.



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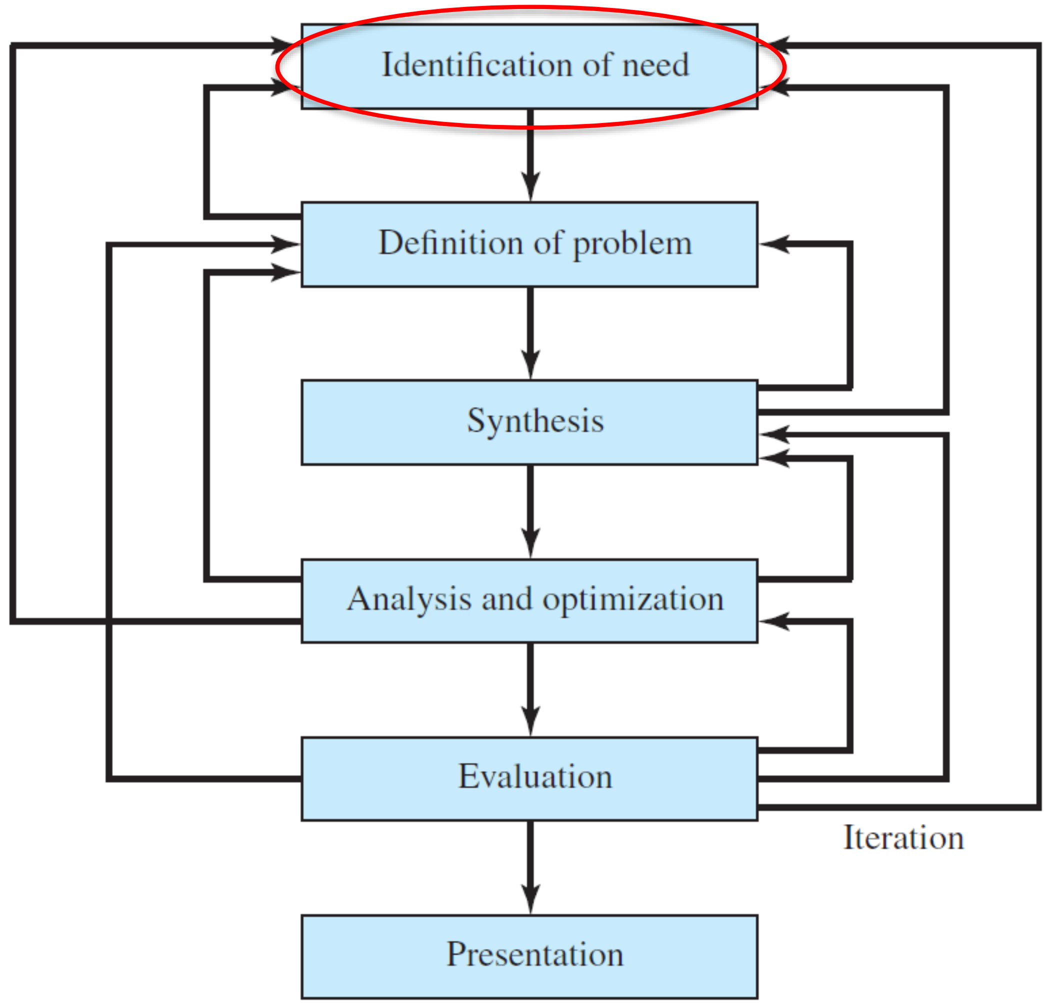
Step 1: Identification of need

The first step requires that a problem be identified that requires to be solved, this is known as the **Identification of the need**. Most challenging problems are open ended meaning that there is no single, correct solution.



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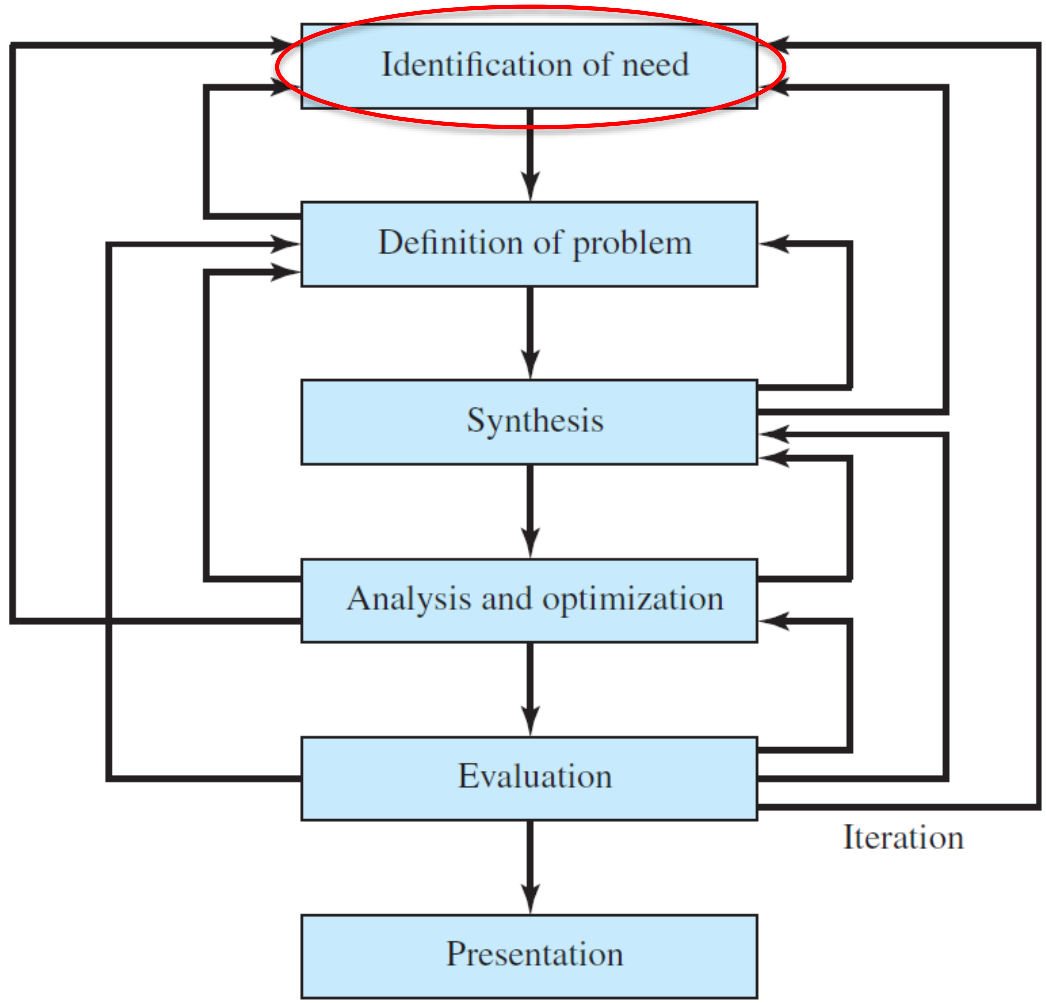
Step 1: Identification of need

Recognising what the problem may be and phrasing in a way that can be communicated to others is a complex and creative requirement. This may be difficult because of the nature with which the problem was encountered and may not have any solid proof of existing.



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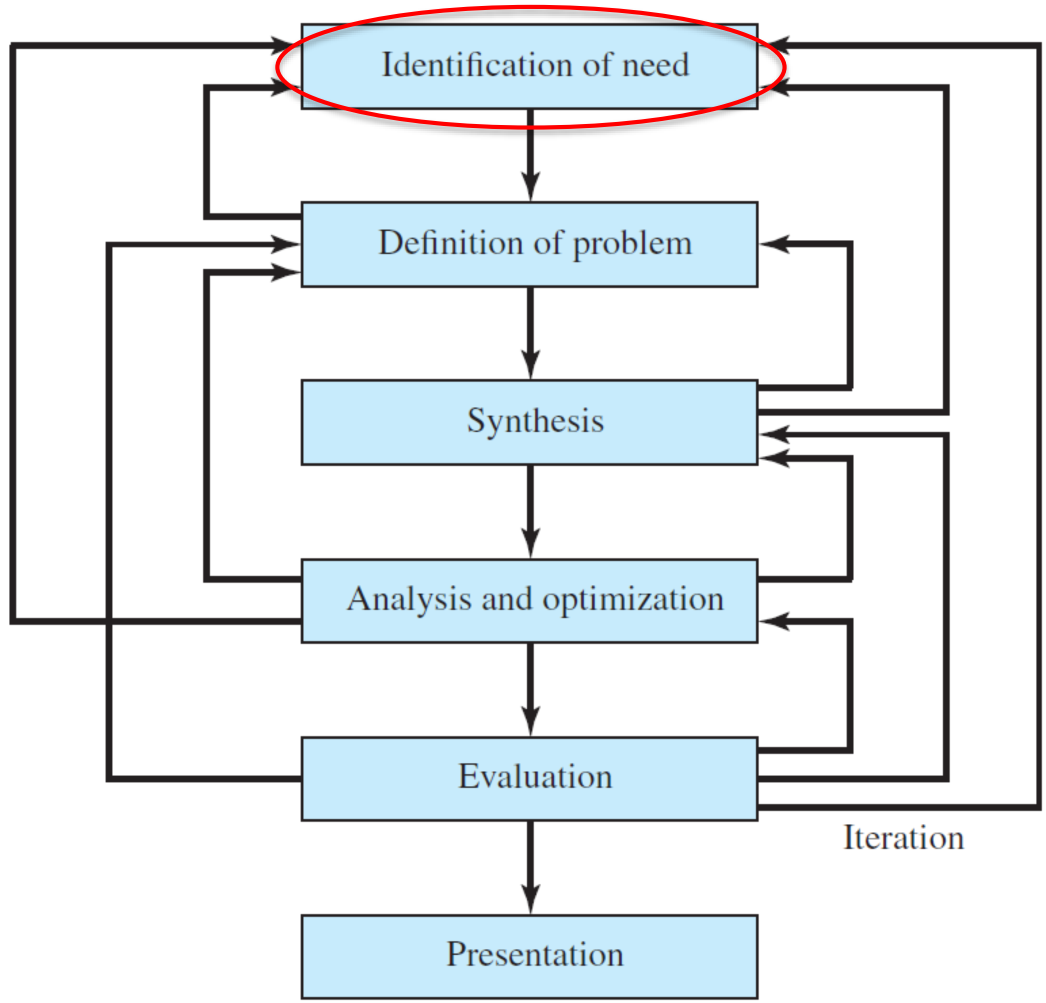
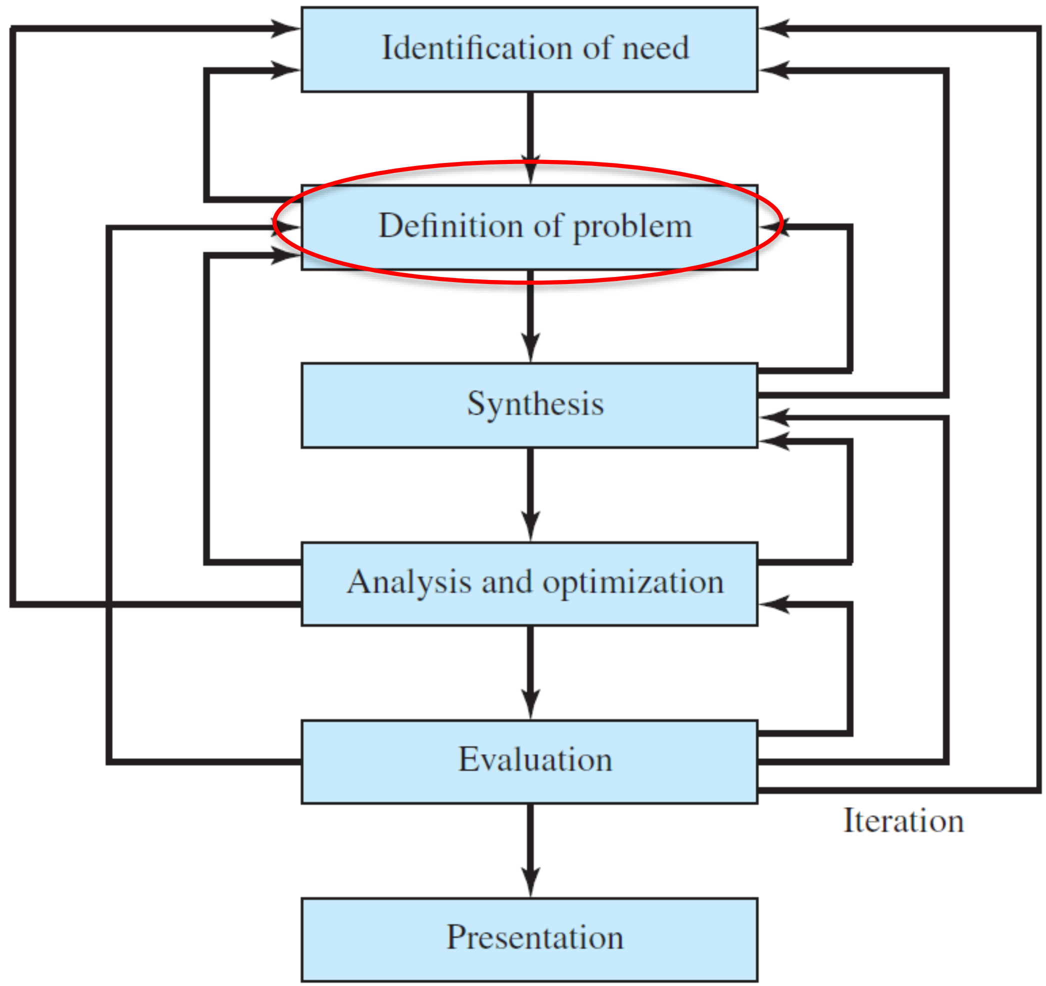
Step 1: Identification of need

At this stage, open ended problems are likely to possess conflicting requirements which are difficult to solve simultaneously. Most stake holders may be ignorant to this fact. Engineers are required to identify this and find solutions that find the best compromised for all the requirements.



Step 2: Definition of problem

The **definition of the problem** is required to be more detailed and include the specifications that the solution must comply too to solve the problem. It also incorporates what the input and the output of the engineering system should be.



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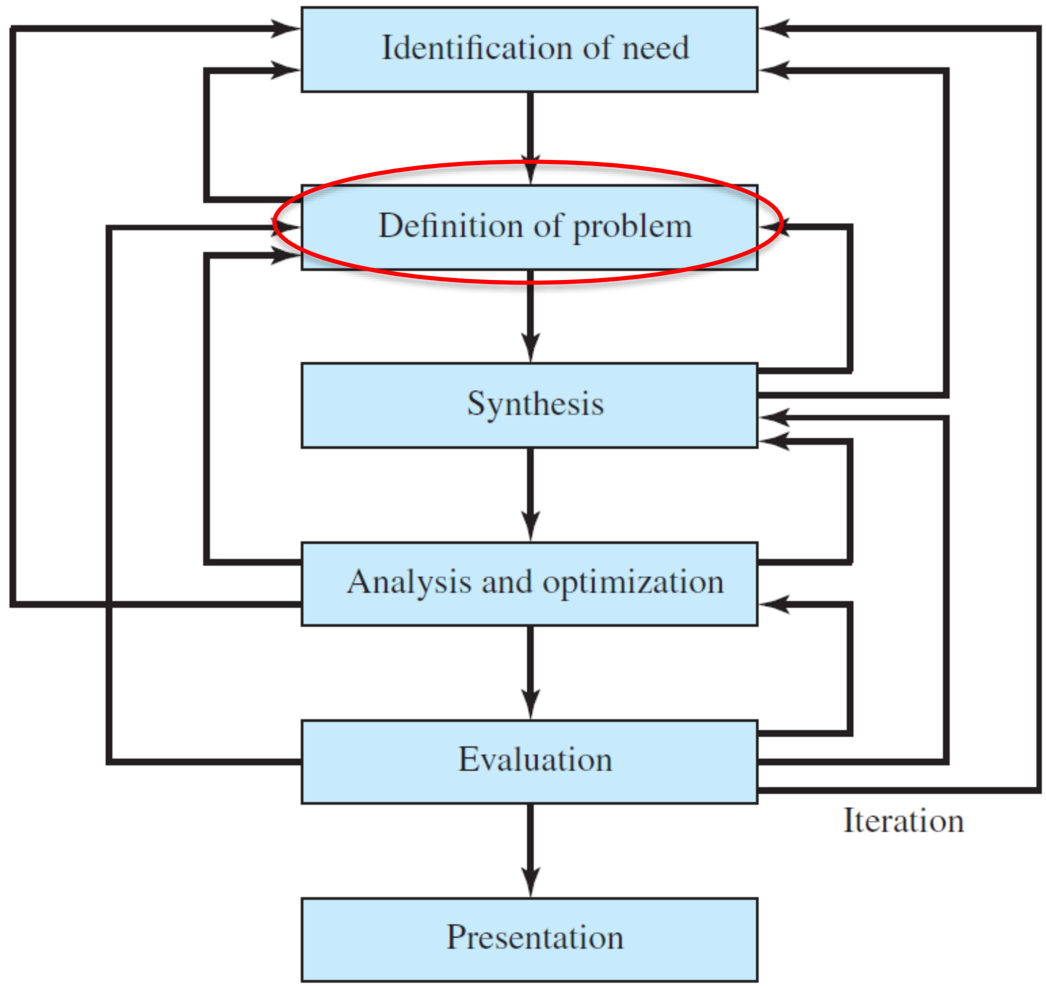
Step 2: Definition of problem

Anything that limits the designers freedom of choice may be considered as a constraint and should be outlined in the definition of the problem. Limitation may include manufacturing processors, dimensions, requirements imposed by regulatory bodies, the supply or availability of materials or components and finance.



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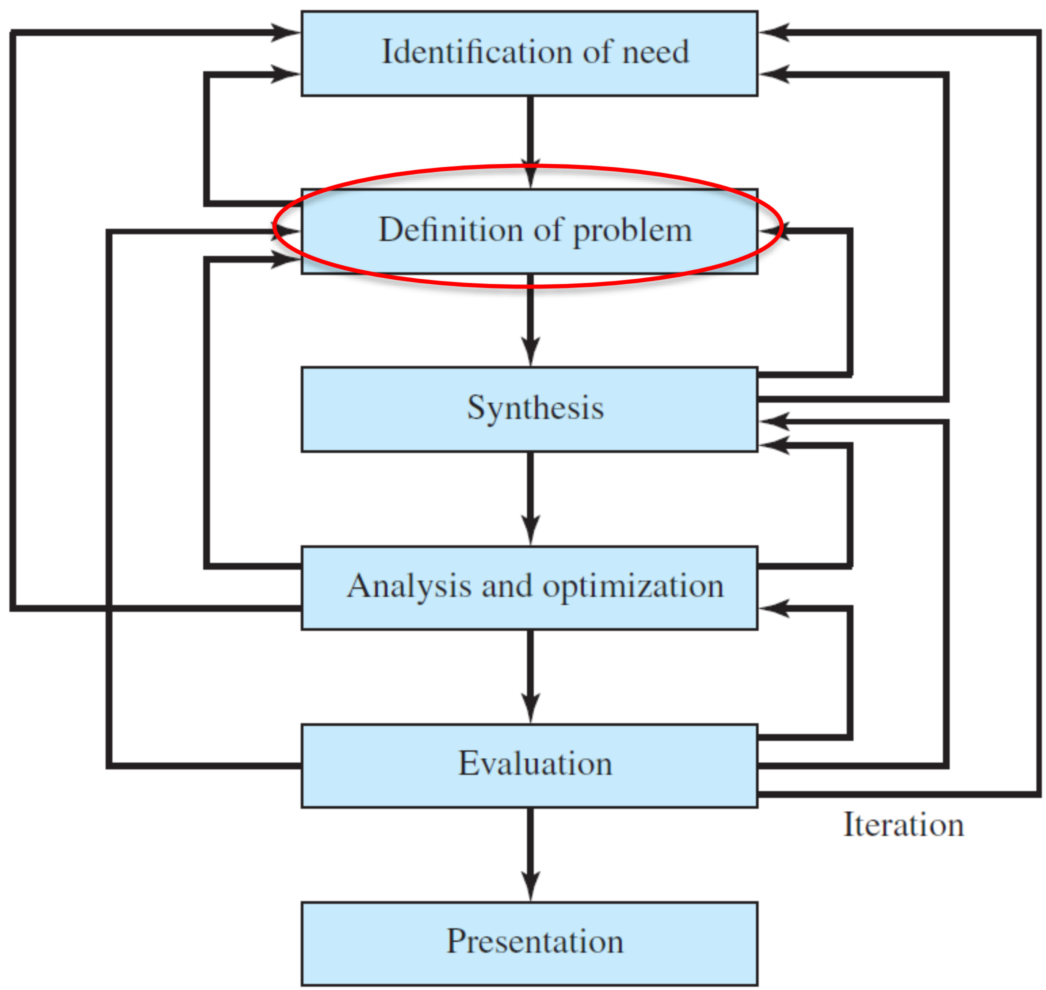
Step 2: Definition of problem

The definition of the problem should be summarised by a list of **aims** that the project should achieve. The aims should be measurable and include a date that they should be achieved by.



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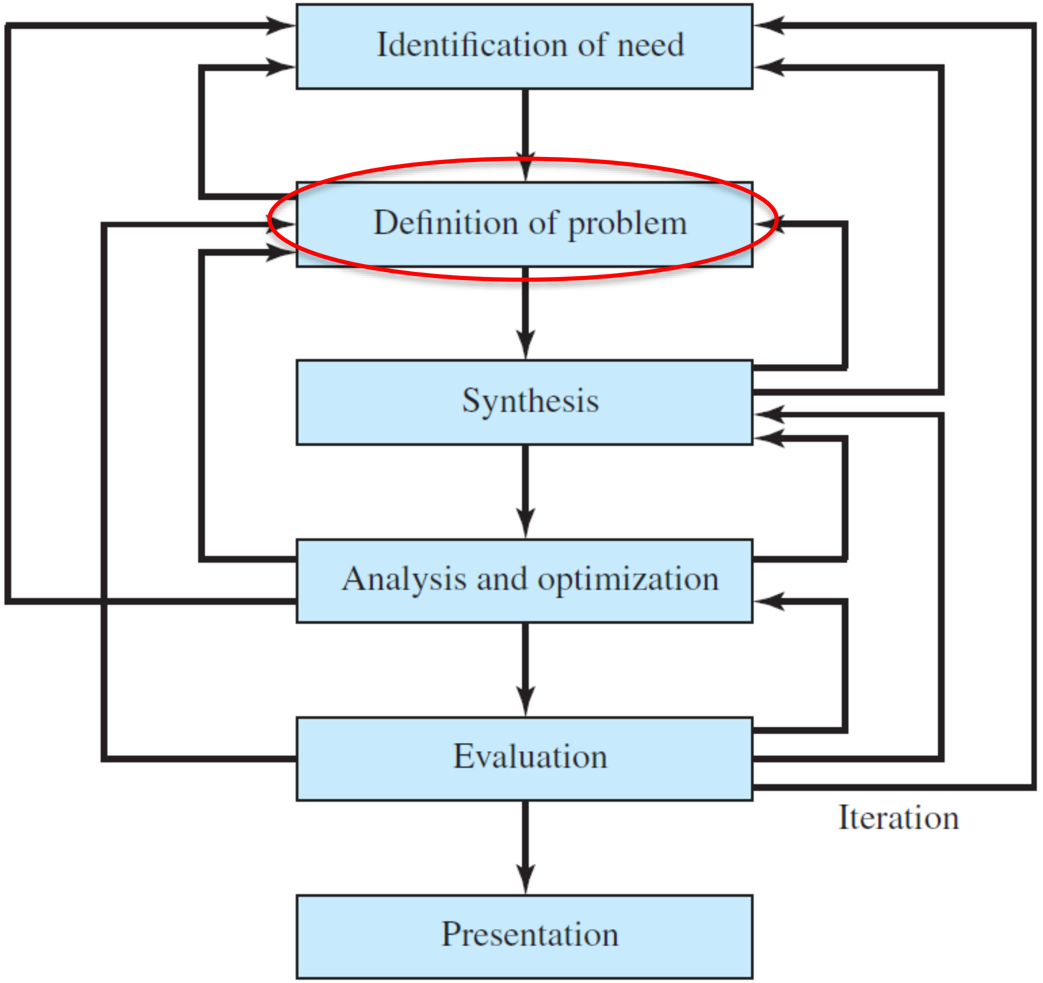
Step 2: Definition of problem

The aims should also be prioritised which will allow for the conflicting requirements to be ranked in order of importance and for metrics to be established that will allow suitable trade offs to be established.



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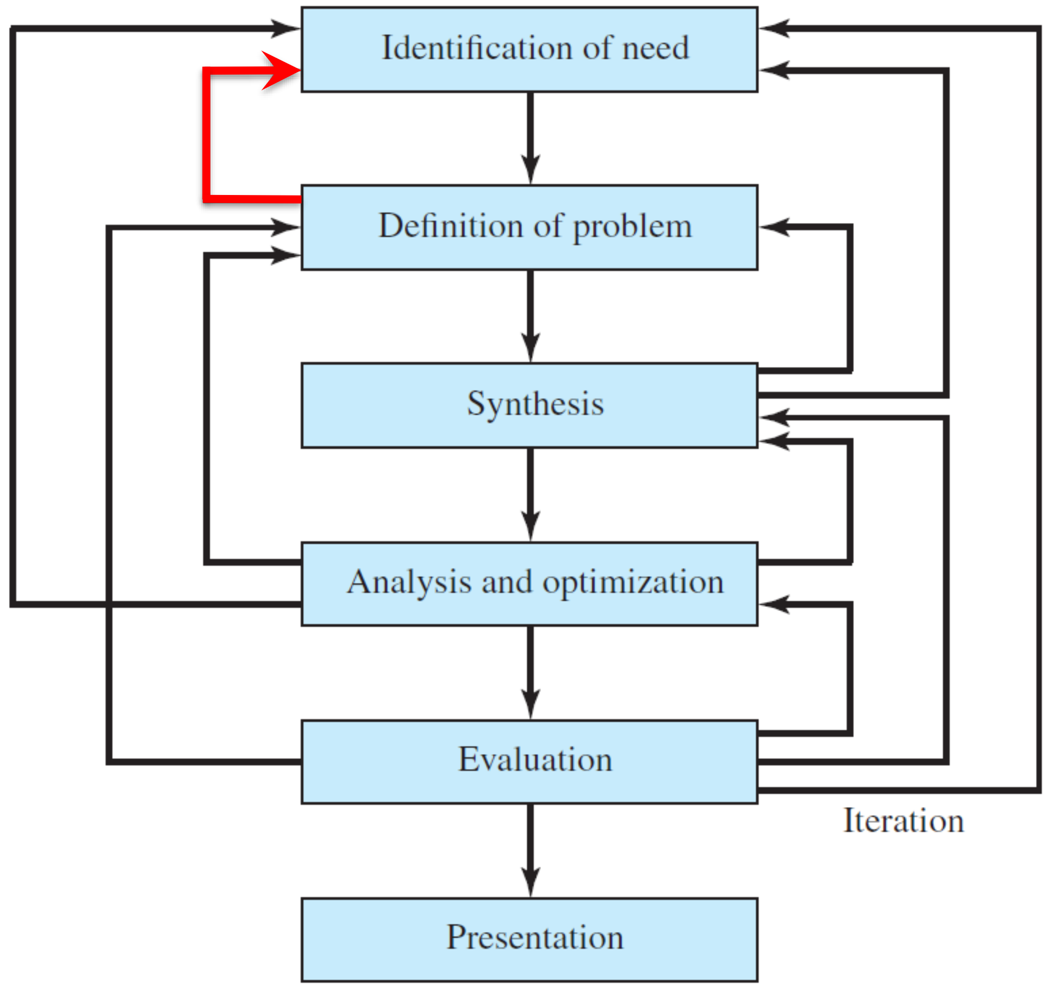
Step 2: Definition of problem

If it is difficult to establish the aims, this may require further discussion with the stakeholders to better understand what the need is. Therefore it may be necessary to revisist the **Identification of the need**.



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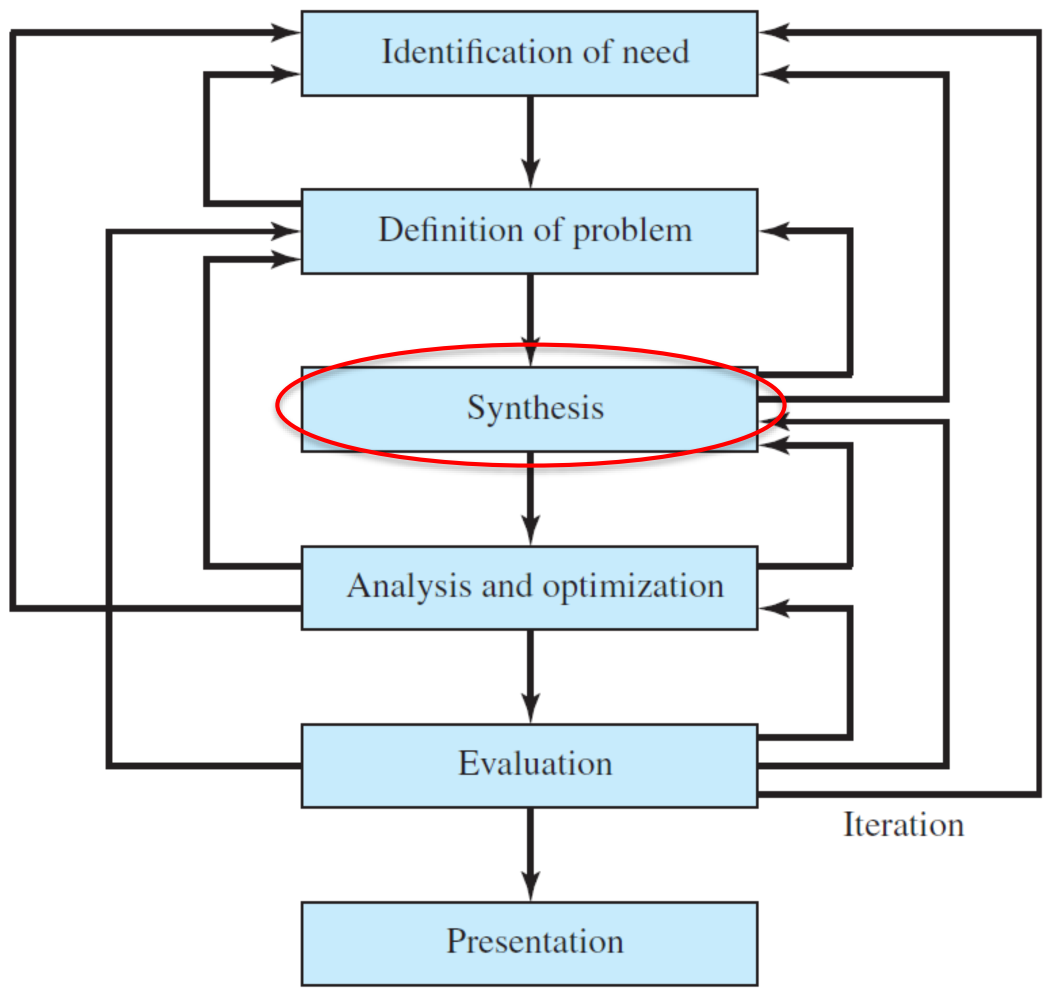
Step 3: Synthesis

The **synthesis** of a scheme connecting possible system elements is sometimes called the invention of the concept or concept design. It is a proposed strategy that will be considered to solve the problem.



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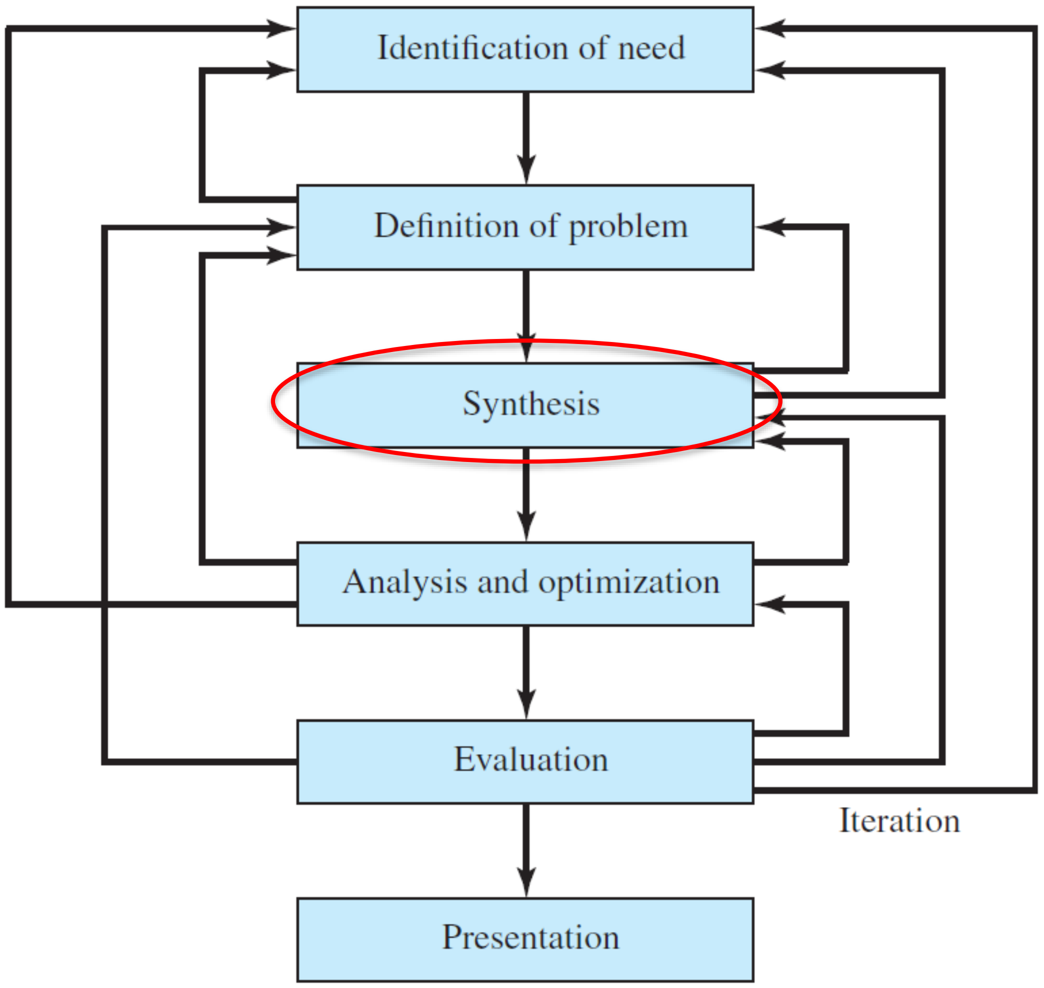
Step 3: Synthesis

This step of the process involves identifying all the possible ways of solving the definition of the problem, or brainstorming. All suggestions should be documented and some analysis be conducted to either promote or discount a suggestion.



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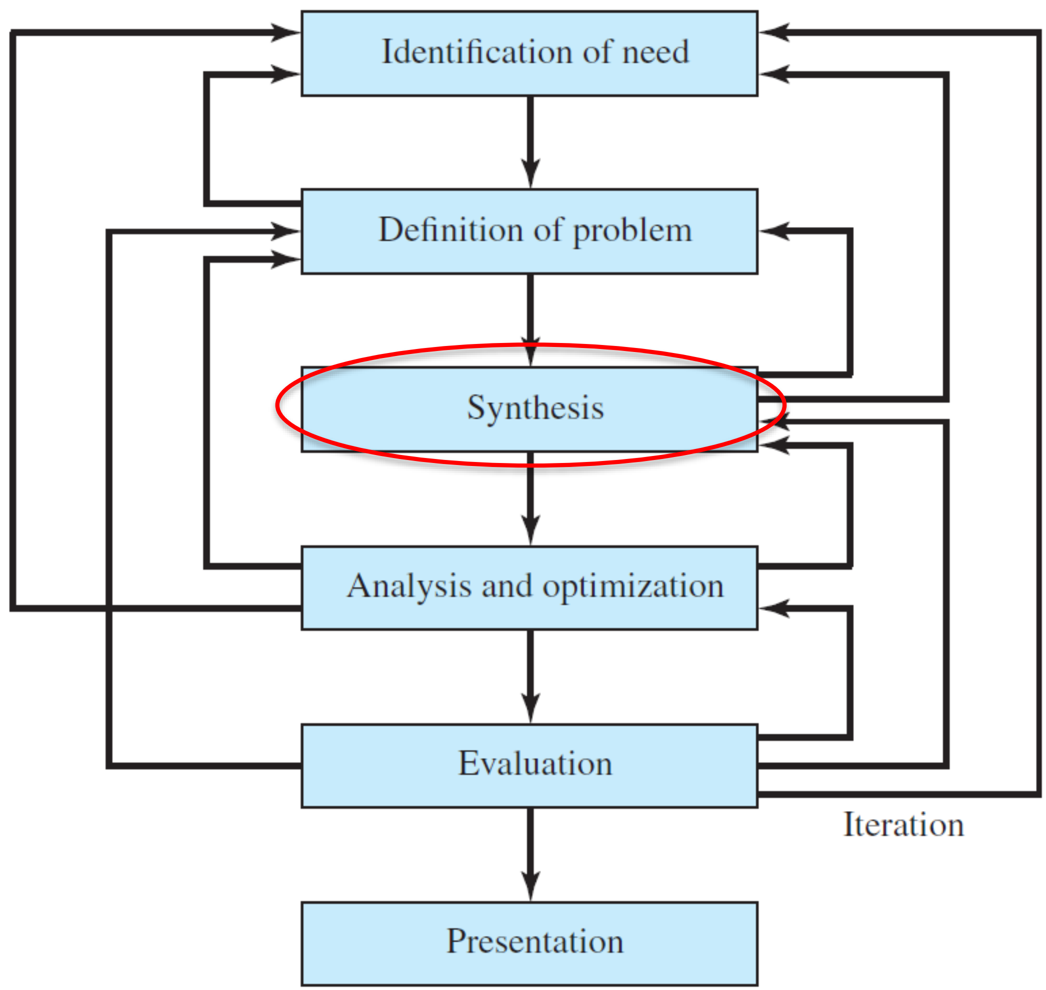
Step 3: Synthesis

This process is intrinsically linked to the analysis and optimization step as each suggestion may require several iterations to be conducted prior to being discarded.



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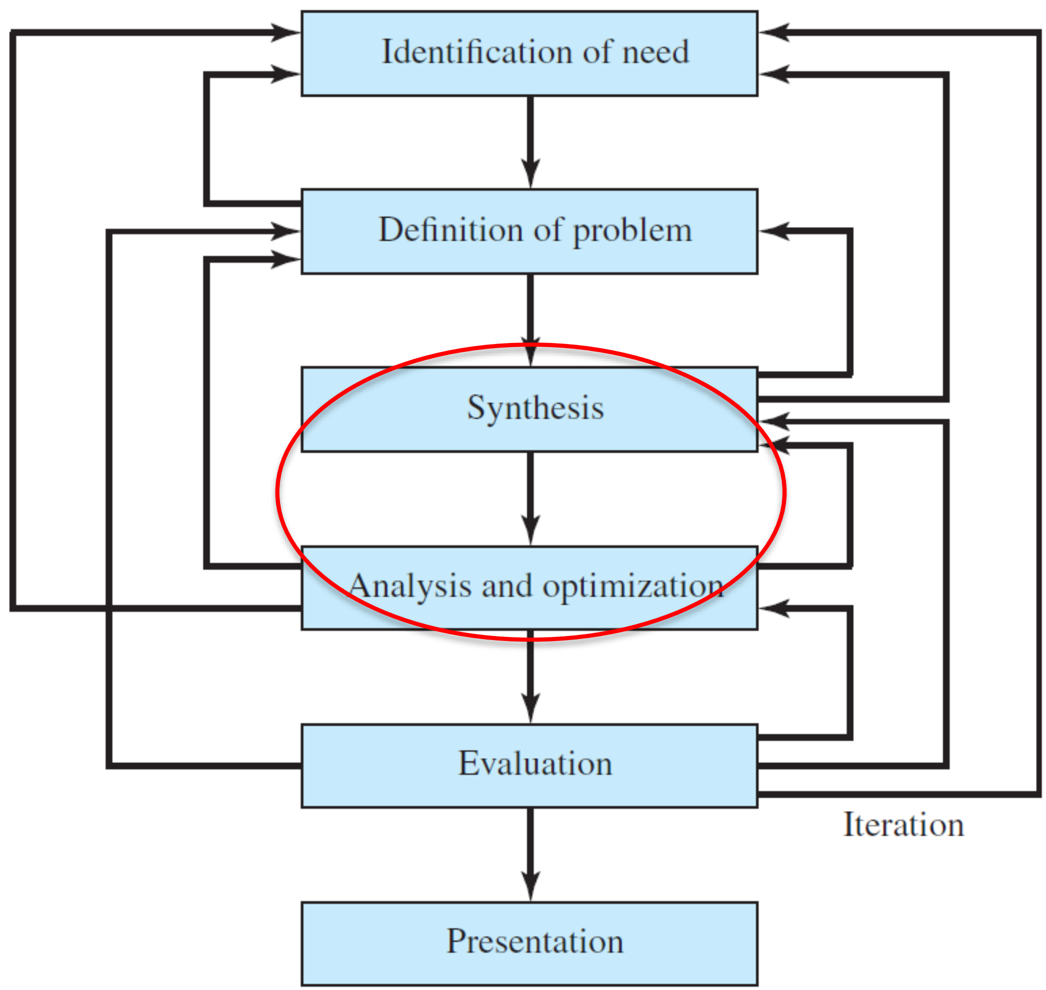
Step 3: Synthesis

At this stage, all the inputs may not be known and therefore the analysis being conducted may require some rough estimates in order to proceed. These should be clearly identified, communicated to others involved in the project and refined once the necessary information becomes apparent.



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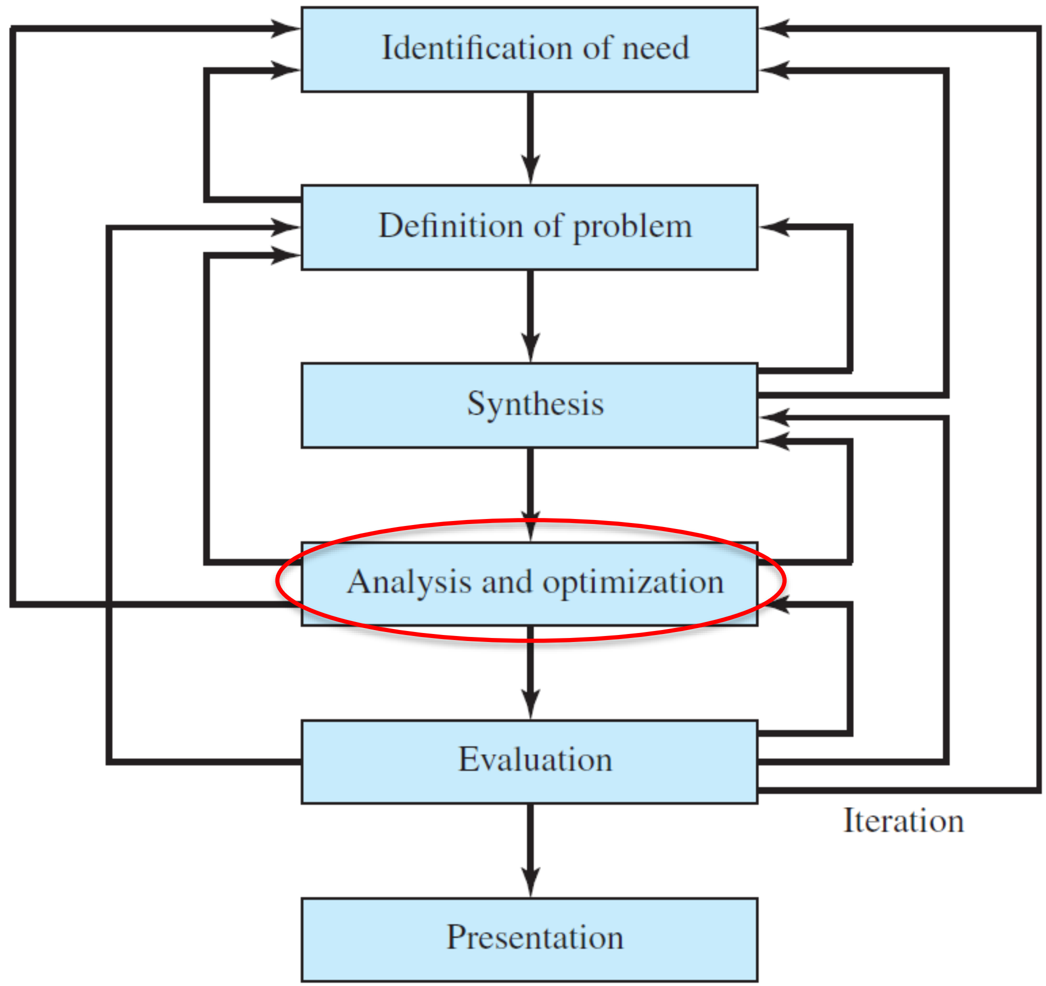
Step 4: Analysis and Optimization

Analysis and Optimisation requires that some sort of mathematical models be created/utilised that will assist with predicting the performance of the system relative to the aims outlined as part of the definition to the problem. We are predicting if the system will satisfy the existing need.



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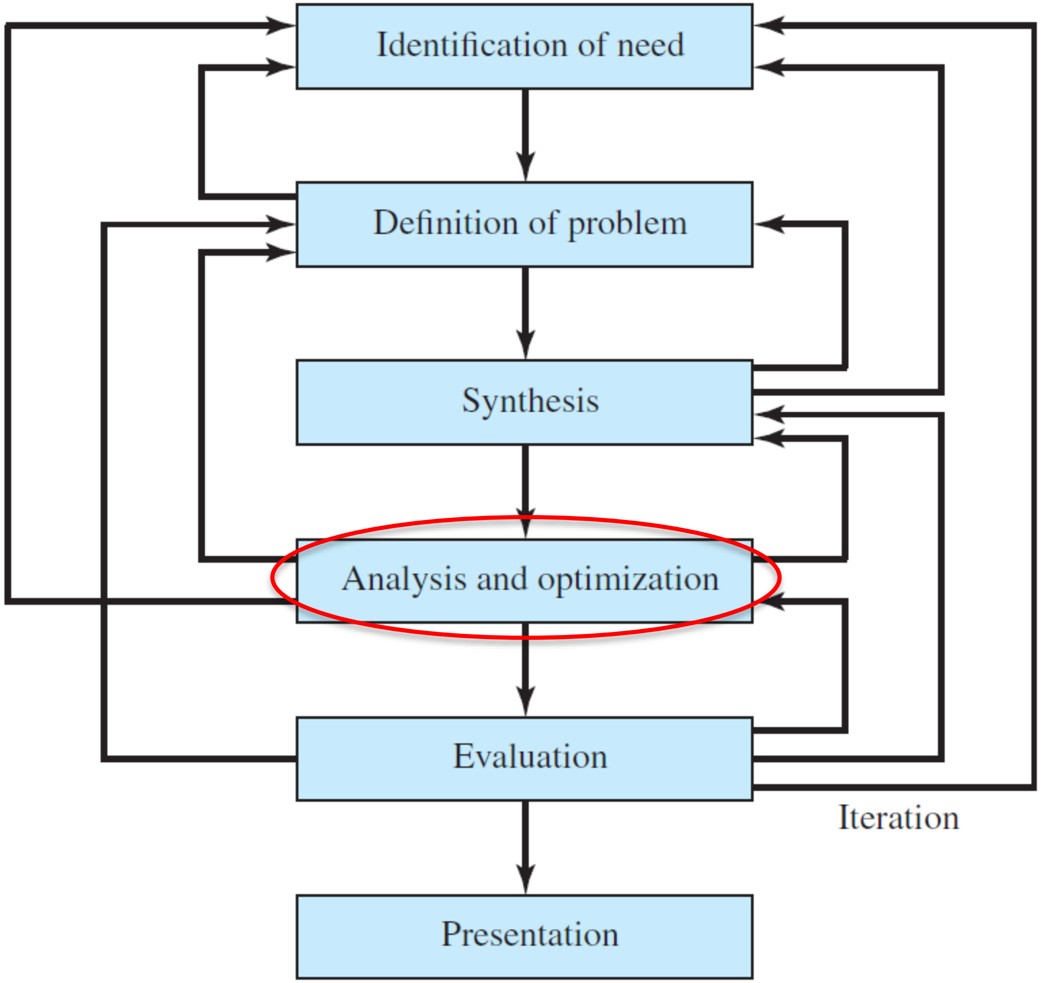
Step 4: Analysis and Optimization

The analysis should also extend to determine if the system would be profitable and how does it compare to competing designs in the market place.



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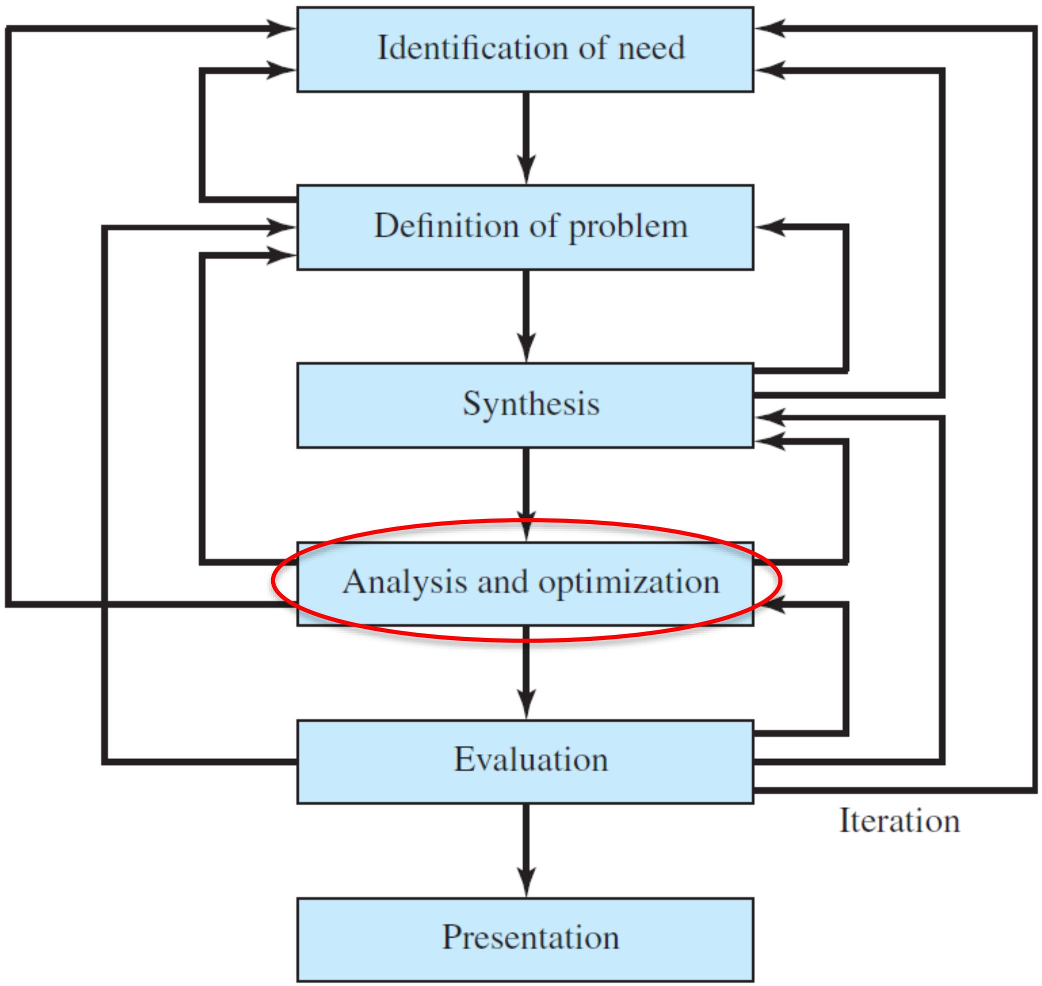
Step 4: Analysis and Optimization

The risks associated with the system should also be identified which would impact what insurances would be required or what legal liability may result in the implementation of the system. The risks could be relevant too; the operator, the community, the environment, etc.



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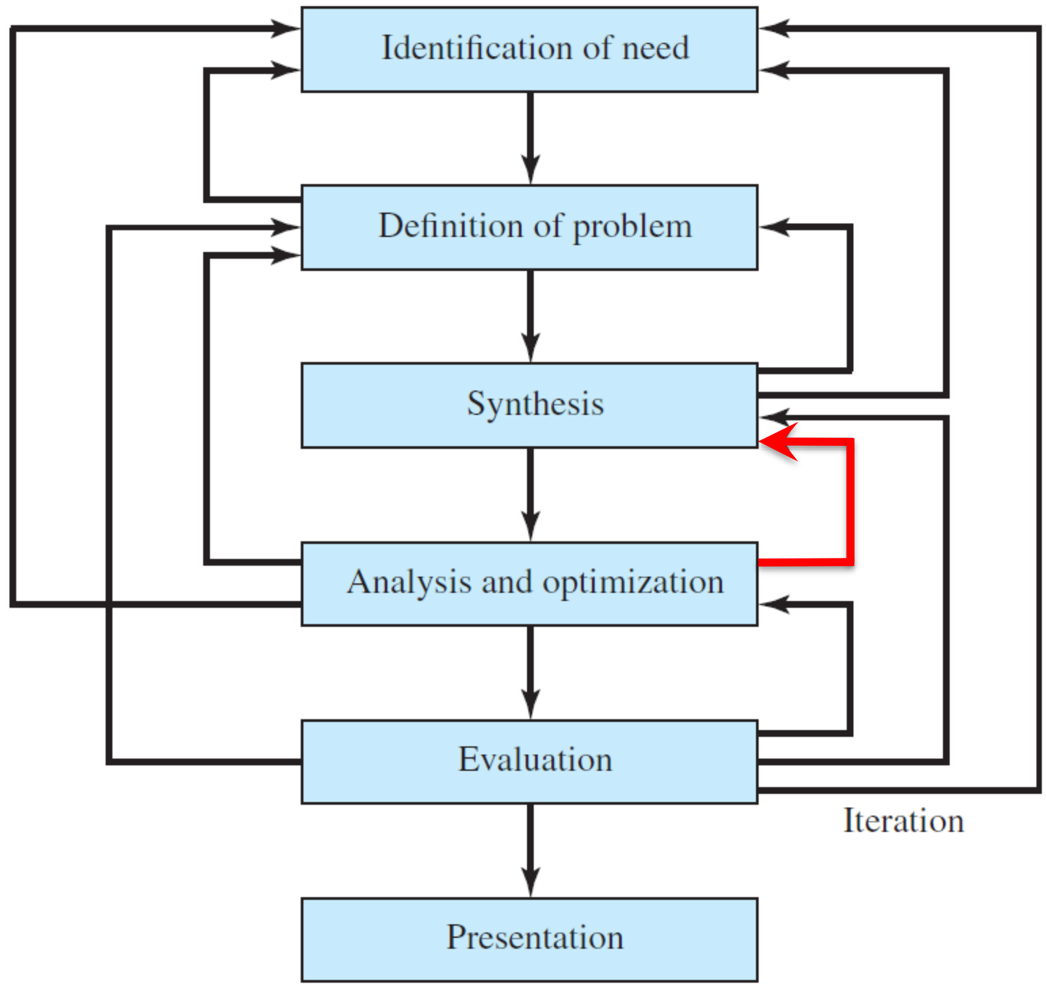
Step 4: Analysis and Optimization

In the event that the analysis demonstrates that the need is not met, it would be required to reconsider the design synthesis and determine an alternative strategy for addressing the definition of the problem. It is normal that this should take place several times.



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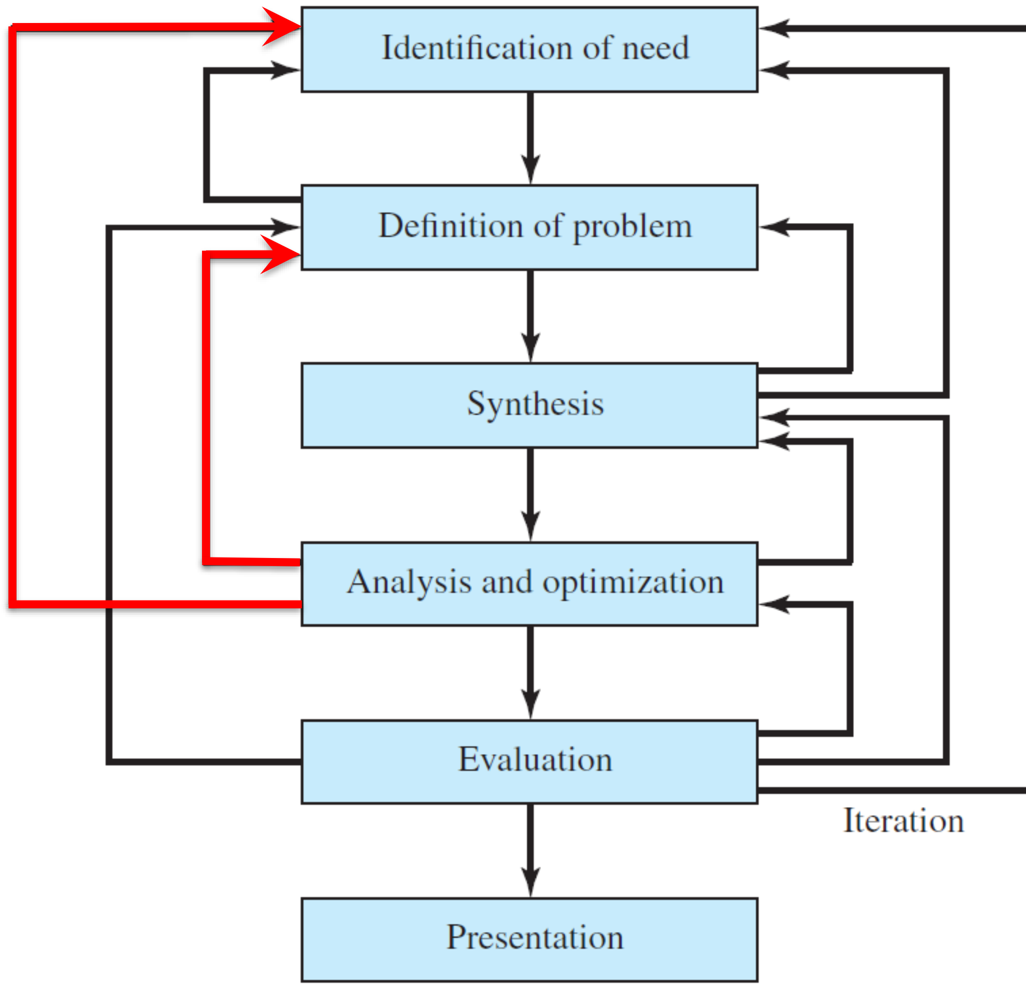
Step 4: Analysis and Optimization

The analysis may also demonstrate that it is not feasible to address the aims that have been defined. In this situation, it may be necessary to revisit the **Definition of the problem** or the **Identification of the need** as a result. Some of the constraints may have to be lifted as a result.



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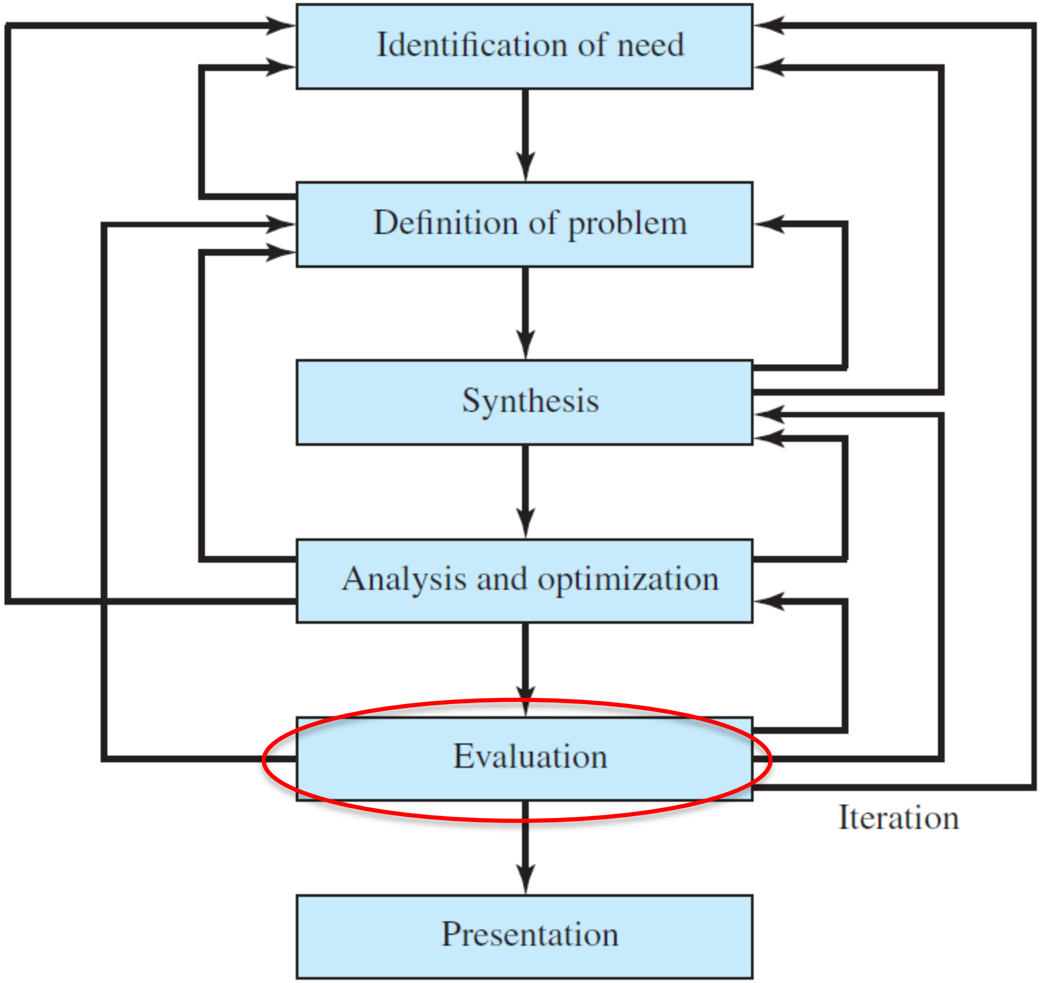
Step 5: Evaluation

During the **evaluation** stage, physical testing is conducted that allows the mathematical models to be validated with the aid of prototypes.



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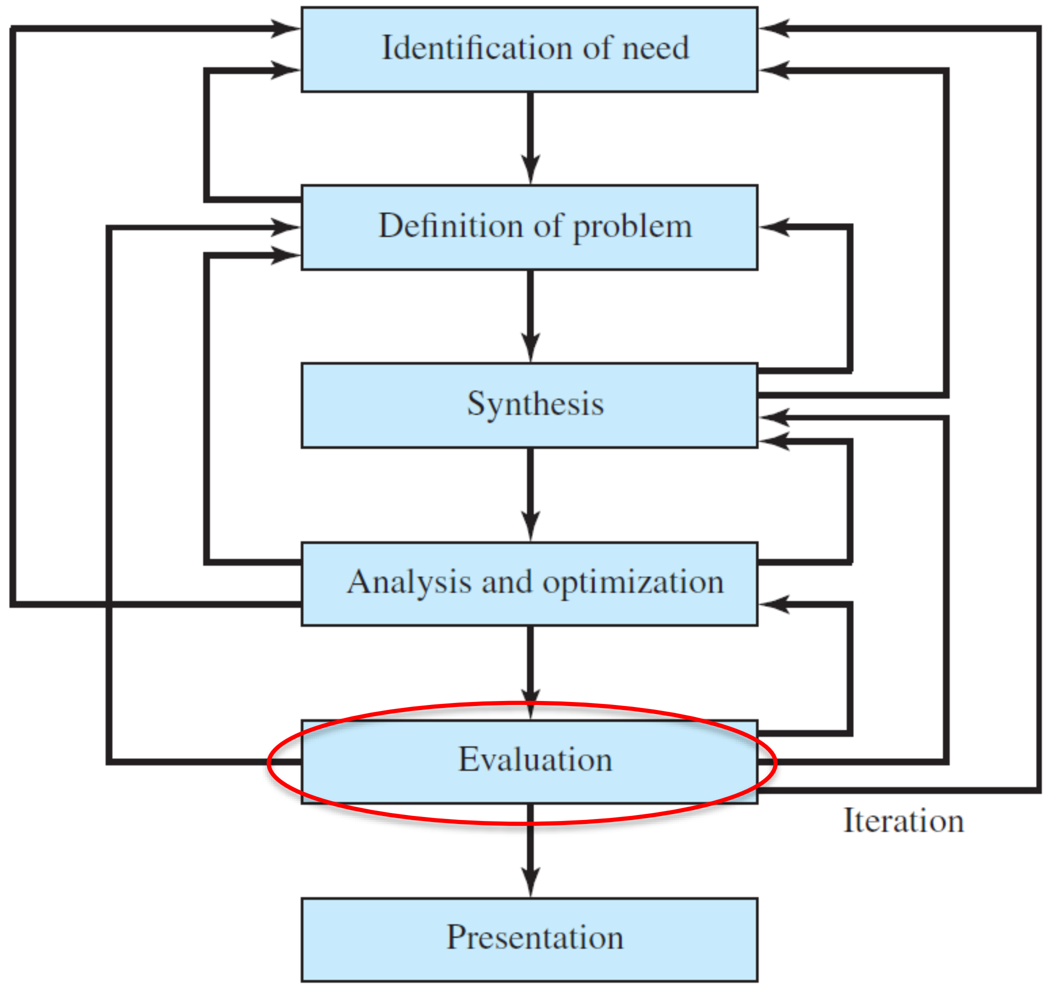
Step 5: Evaluation

This step may prove that the mathematical models were not adequately representative of reality due to assumptions made being more significant than what was anticipated.



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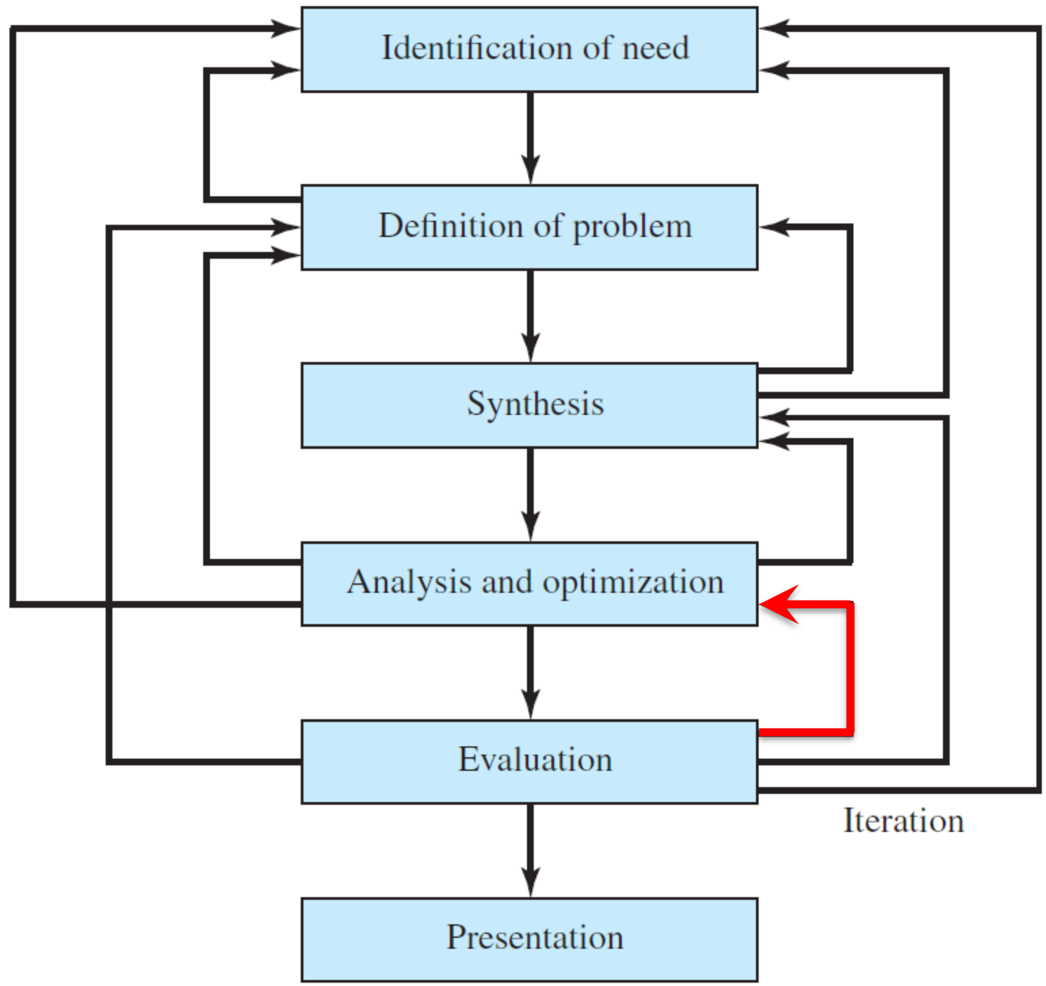
Step 5: Evaluation

If this was the case, it would be necessary to repeat the Analysis and Optimization stage with more robust mathematical models or redefine the definition or the problem that will be solved.



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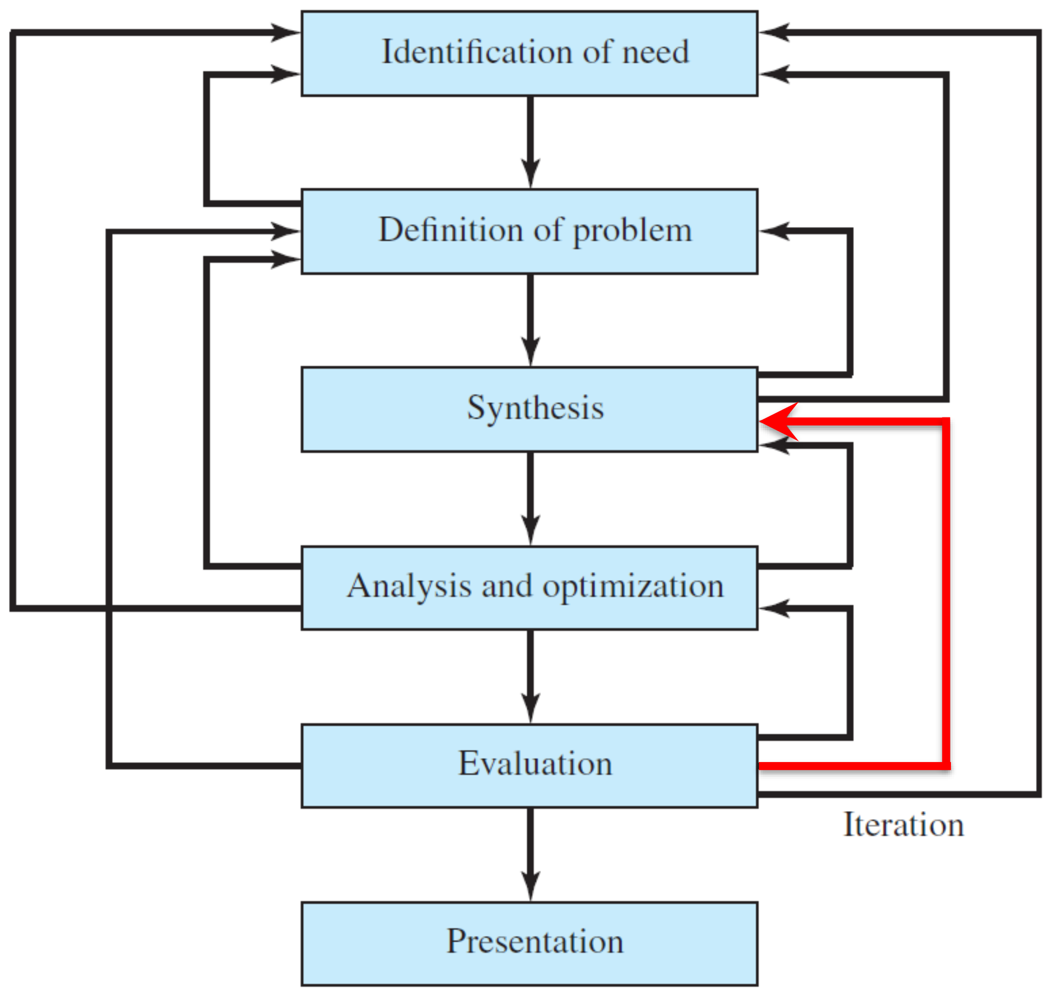
Step 5: Evaluation

In the event that repeating the analysis and optimization still does not yield a suitable result, then it wold be required to revisit the synthesis and determine an alternative design strategy for solving the problem.



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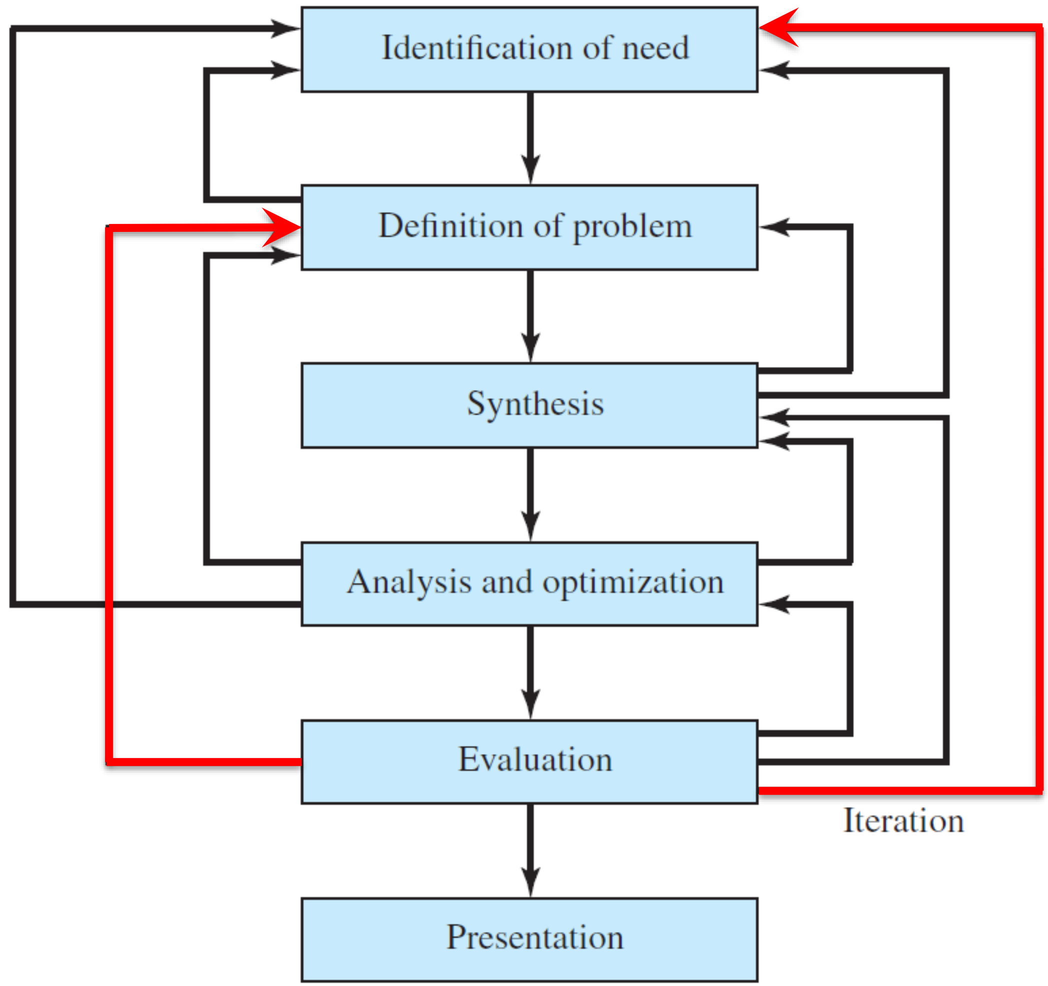
Step 5: Evaluation

This may still be insufficient and will therefore require that the Definition of the problem or Identification of the need be re addressed.



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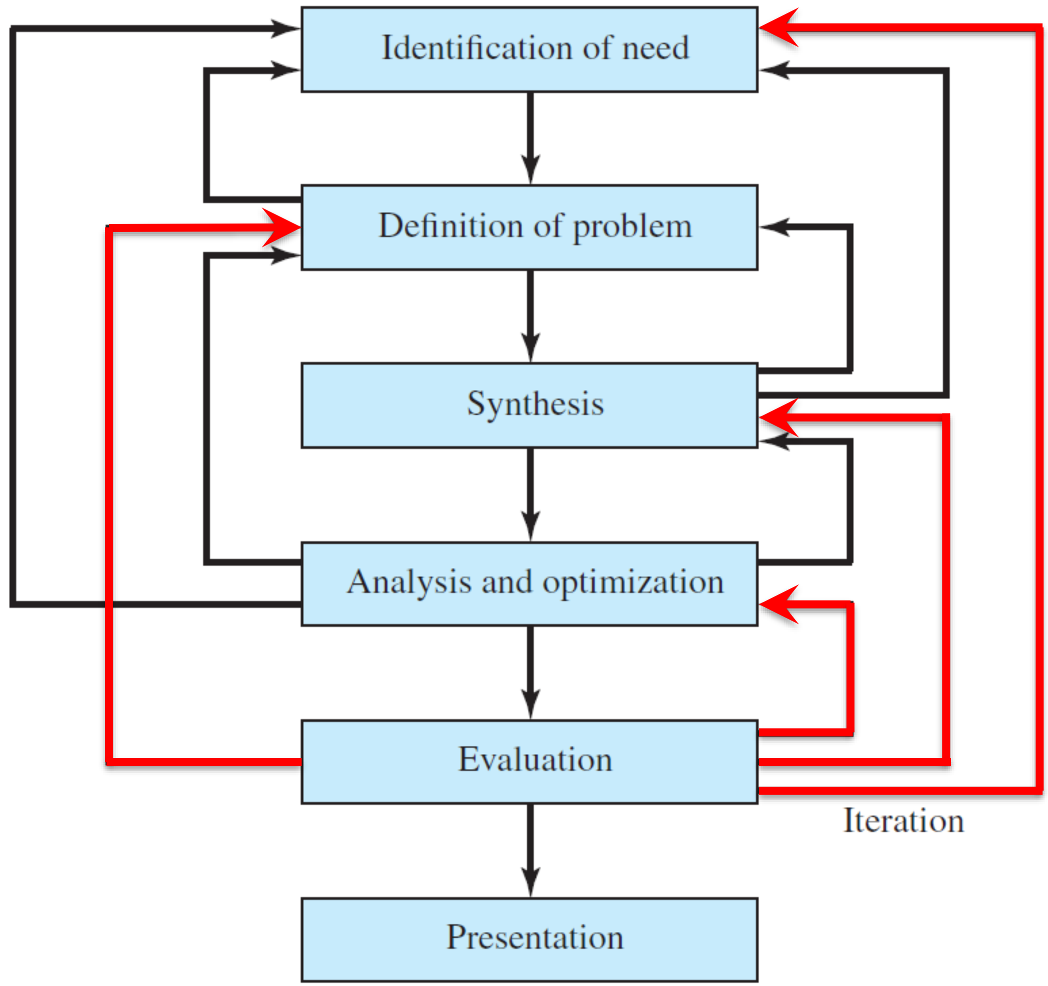
Step 5: Evaluation

Each cycle attempted is referred to as a **design iteration**. It should be expected that several design iterations will be required in order to come to a suitable solution for a complex, open ended engineering problem. Ensure that the design iterations are well documented to prevent unnecessary repetition of work.



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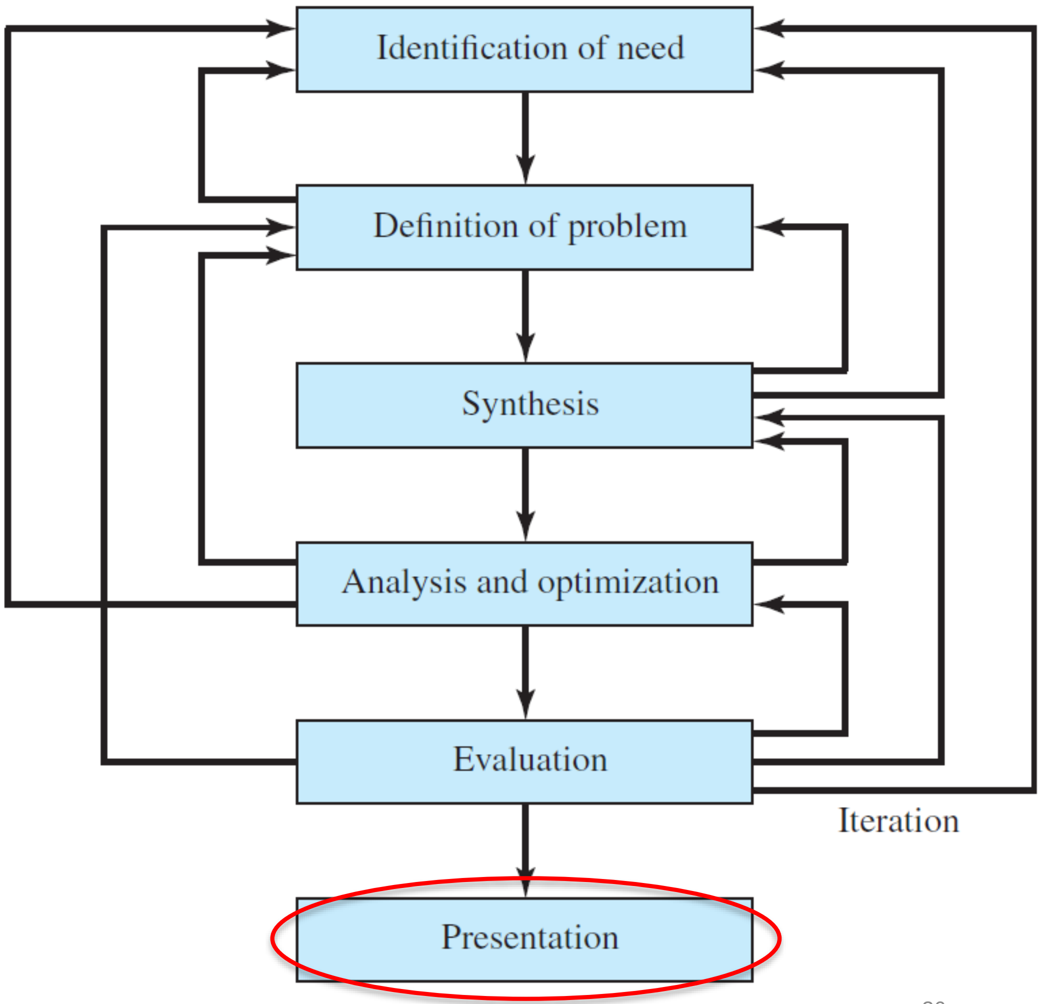
Step 6: Presentation

Once the evaluation has demonstrated that the need has been satisfied, then the design process requires the solution to be **Presented** to either the stakeholders or potential customers.



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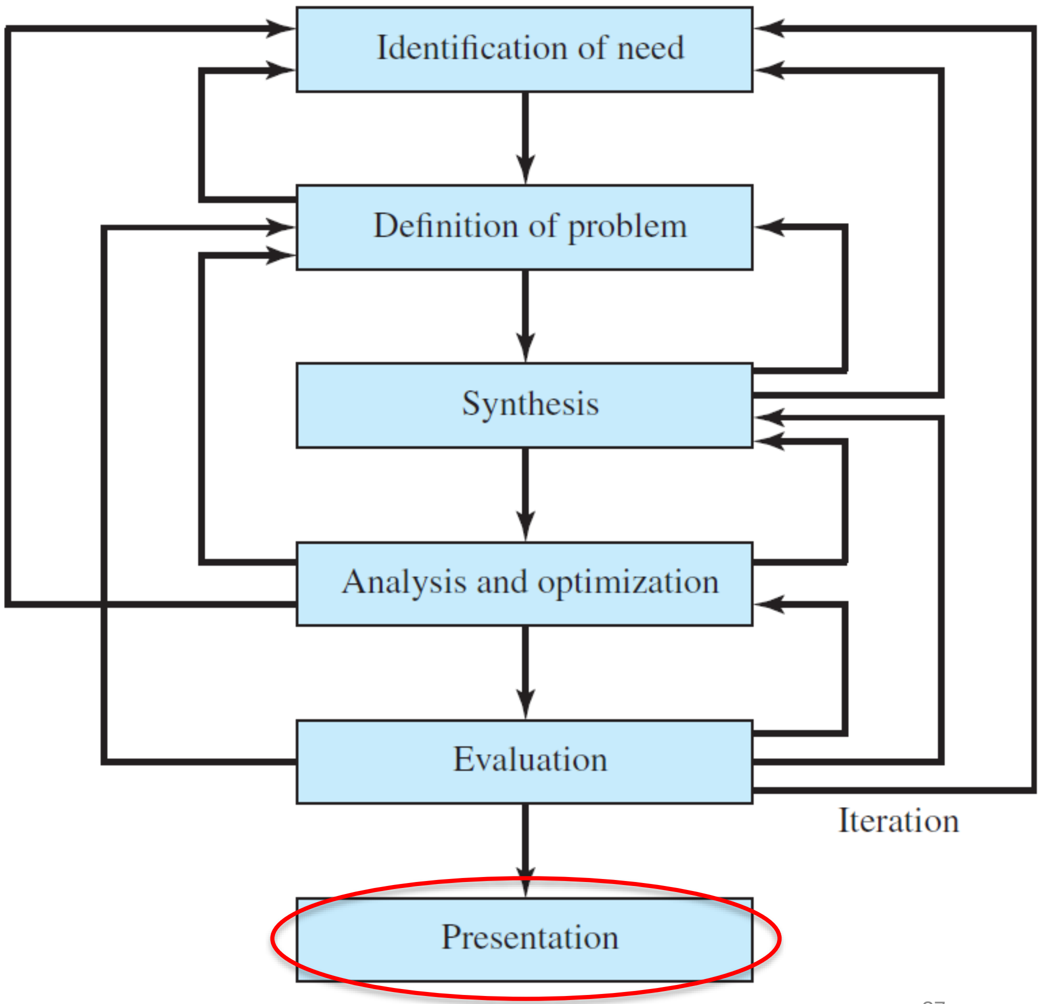
Step 6: Presentation

The **Presentation** of the solution is a critical step for ensuring the design is successful. If the design is not widely recognised as solving the need that has been addressed, then there is little value in having addressed the need.



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Case study: Concorde

So how was the design process implemented on a project such as the Concorde?

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Step 1: Identification of need - Concorde

During the 1950's, the main objective of aircraft was to increase cruising speed. Aircraft at the time were approaching a limit that prevented them from surpassing the sound barrier.

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Step 1: Identification of need - Concorde

The sound barrier was broken by the X-1 on October 14, 1947. The aircraft was piloted by Charles Yeager and was able to achieve a speed of Mach 1.06 in level flight for the first time .

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Step 2: Definition of problem - Concorde

Once this was achieved, there was a desire to produce a supersonic airliner that would reduce travel time around the world.

In 1956 a the Supersonic Transport Aircraft Committee was established in England to study the possibility of a supersonic aircraft.

In 1959, they set the aim of the project; to transport 100 people, 6000 miles at speeds greater than Mach 2.

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Step 3: Synthesis - Concorde

It was quickly determined that England alone did not have the necessary resources to complete the design and construction of a supersonic airliner. An agreement was therefore signed with France for the two countries to work together to achieve the aims of the project – an example of a critical strategic decision.

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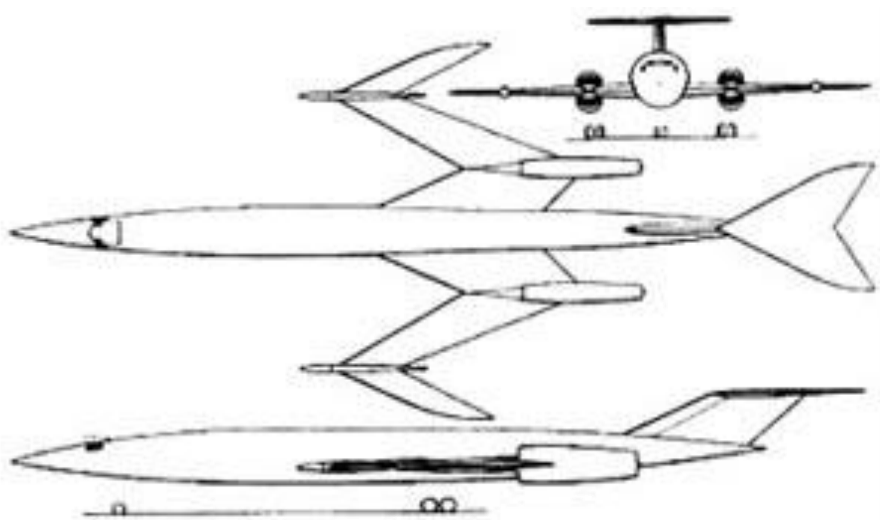
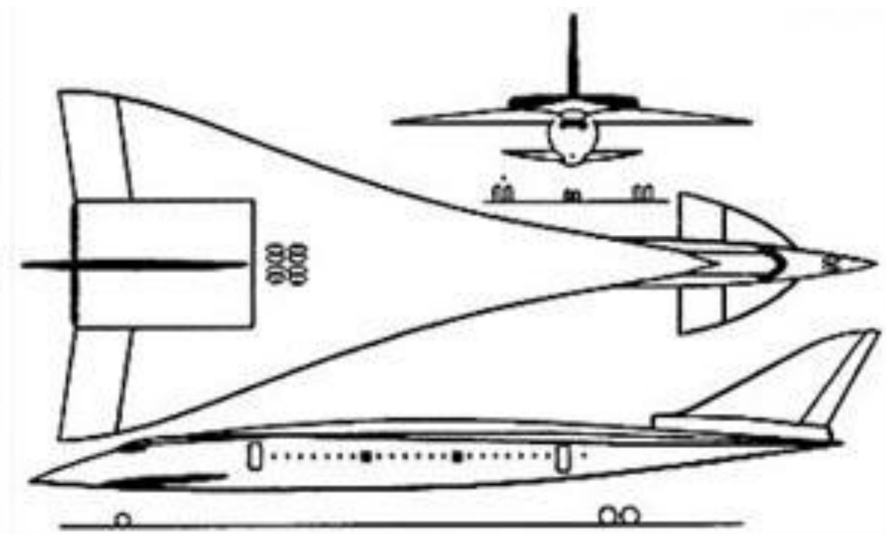
Step 3: Synthesis - Concorde

Numerous different proposals were made for what shape the airframe should be and the development should focus on. A large variety of configurations were originally considered.





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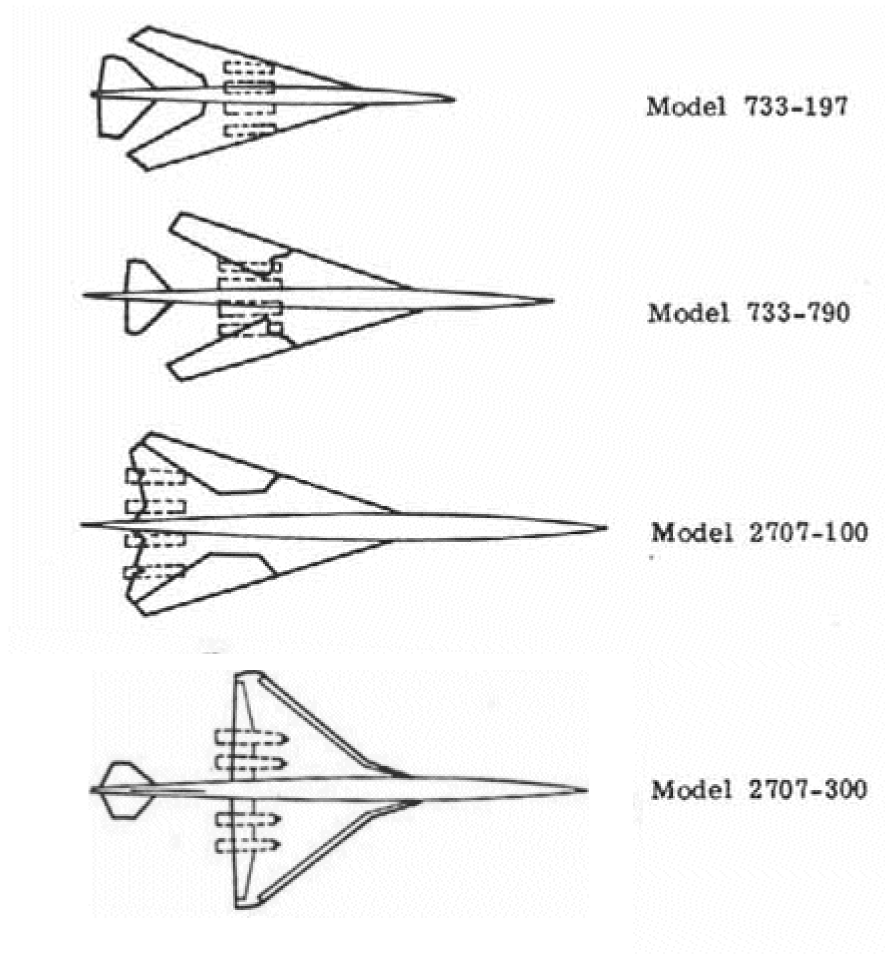
Step 3: Synthesis - Concorde

It was soon apparent that a supersonic airliner would have to compromise slow speed stability for minimal drag to achieve outright speed. Several fundamental designs were considered to combat this which included wings that would retract vs a pure delta wing as well as the necessity to include tail wings.



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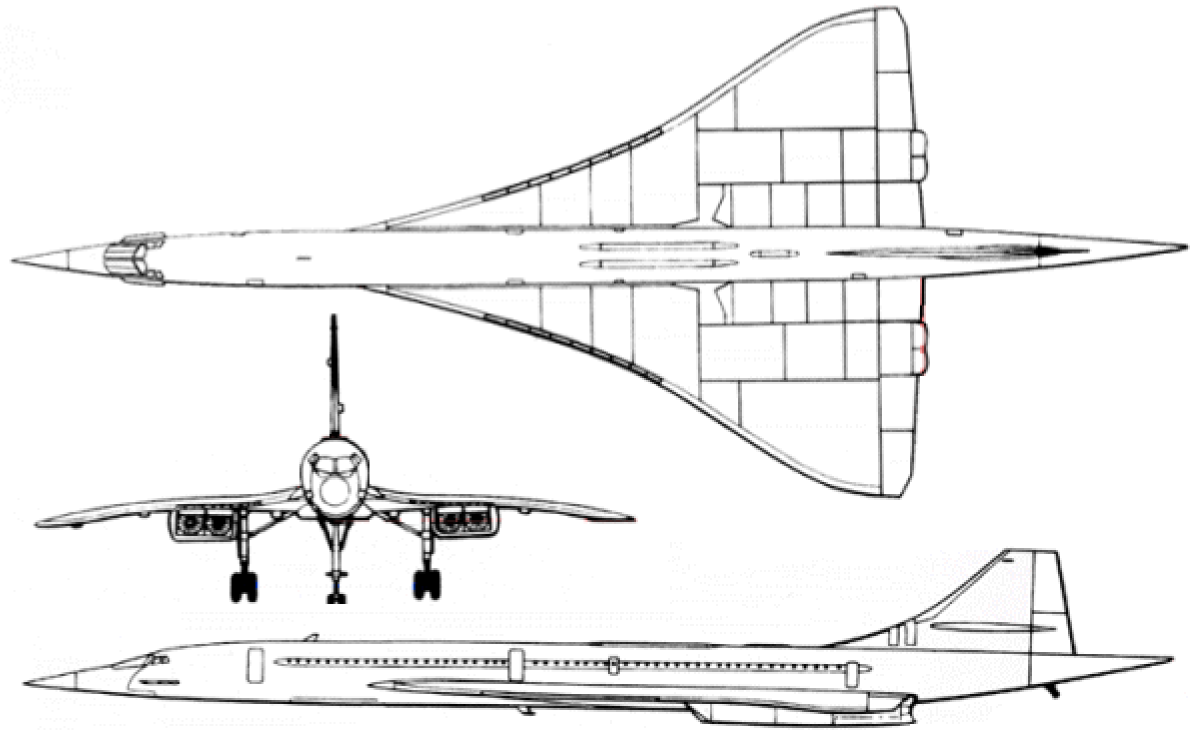
Step 3: Synthesis - Concorde

Very early on, a decision was made to pursue development of an aircraft that adopted a delta wing and did not utilise a horizontal tail – another example of a strategic decision made.



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Step 4: Analysis and Optimization

Once the airframe shape was established, analysis and optimisation began. During this process the most significant areas of development centred around materials, aerodynamics dynamics and propulsion.

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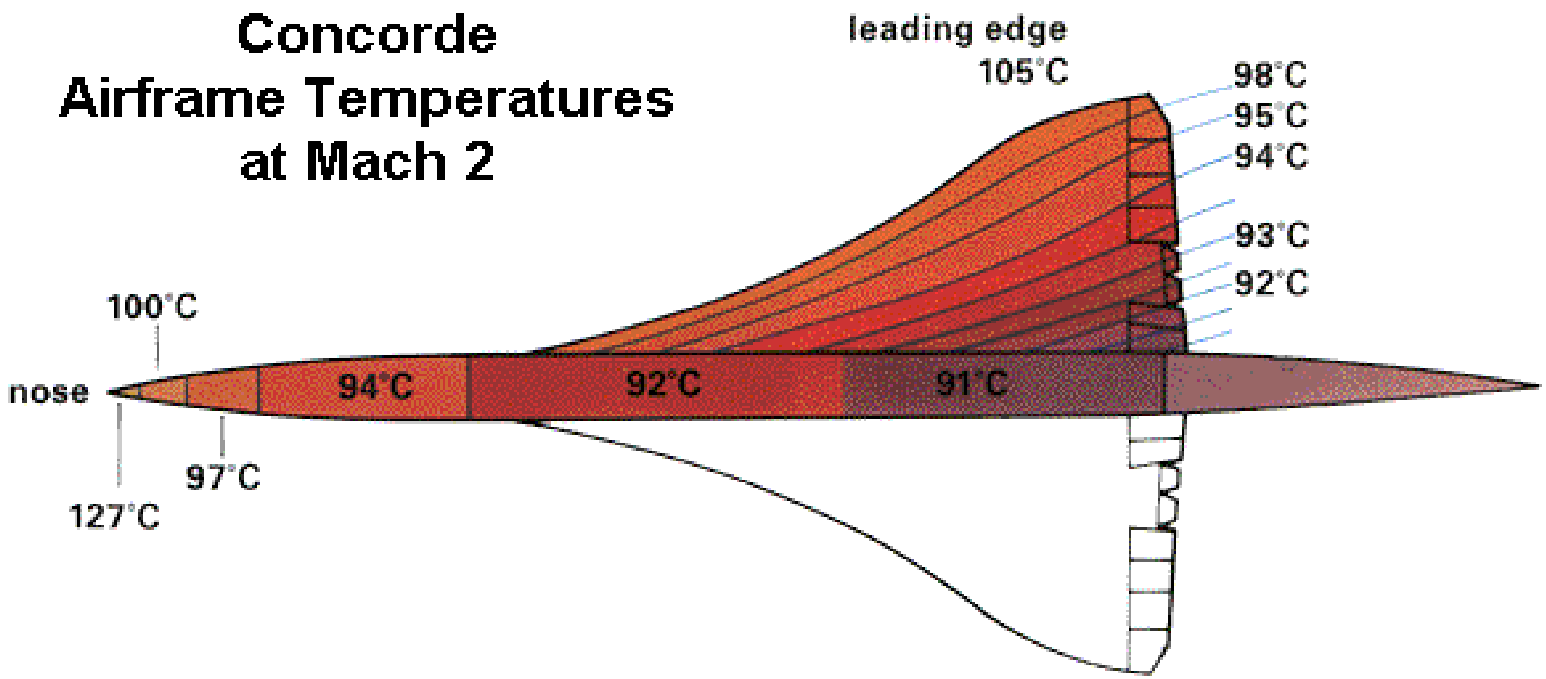
Step 4: Analysis and Optimization - materials

Analysis determined that an aircraft that would fly at Mach 2 will experience such high levels of friction with the air, that the fuselage would be heated enormously.



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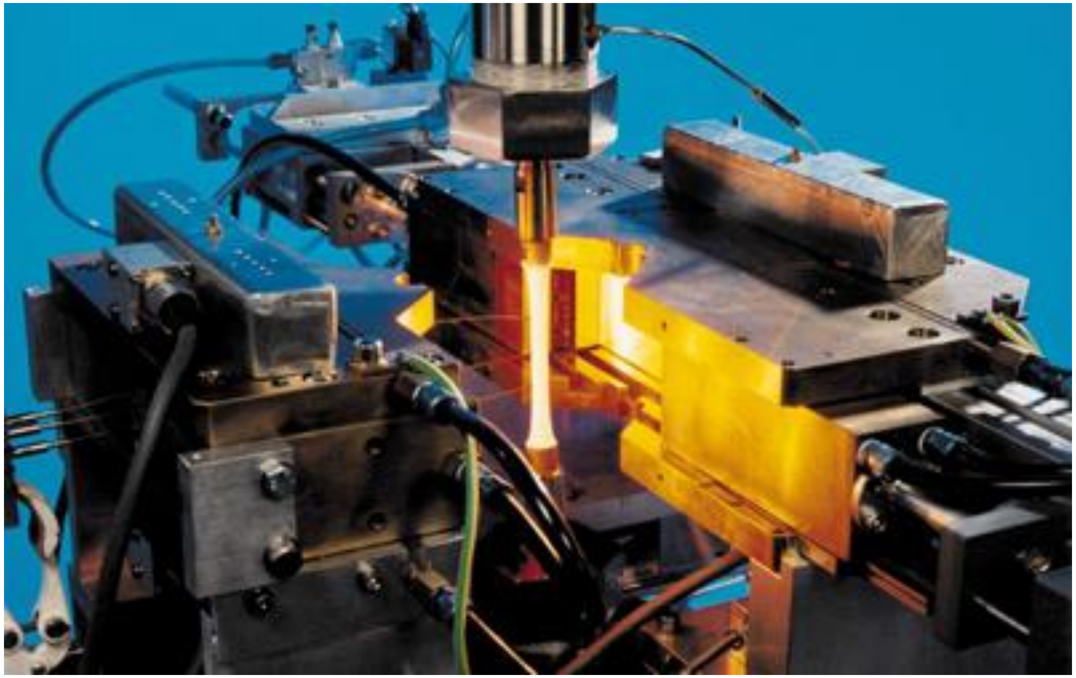
Step 5: Evaluation - Materials

This meant that a new property of materials would have to be understood known as creep, the effect a materials properties has by experiencing elevated temperatures while stressed over prolonged periods.



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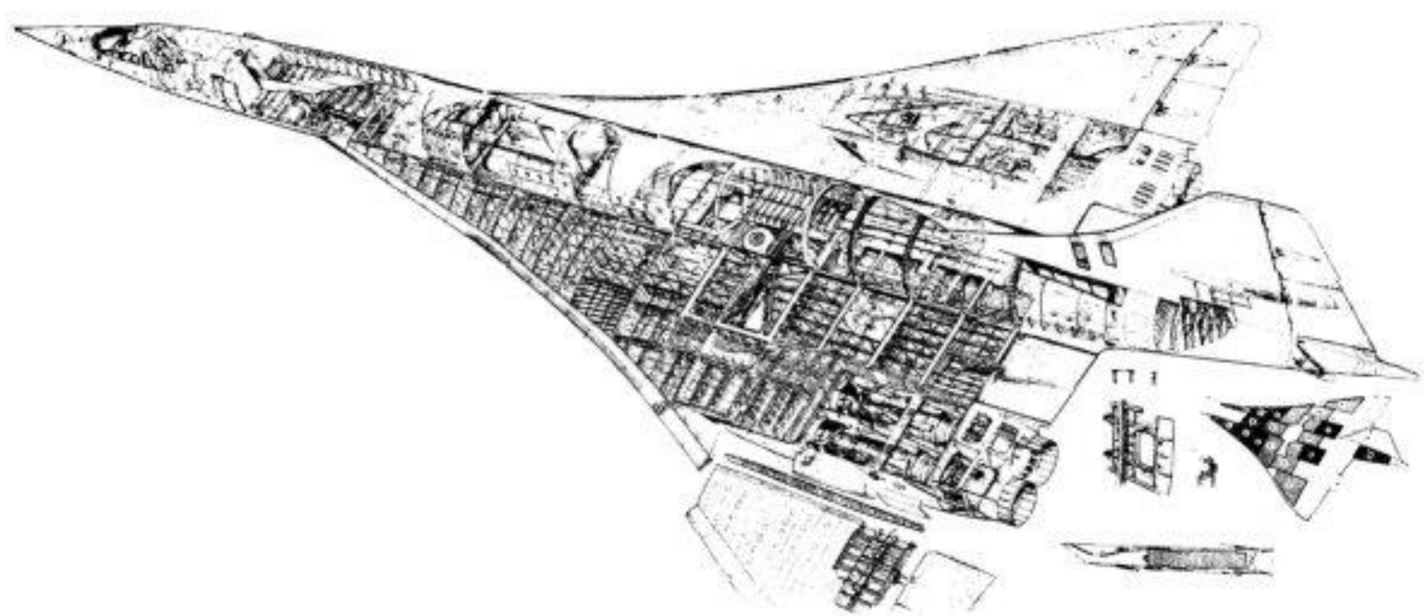
Step 4: Analysis and Optimization - materials

The research undertaken during the design of Concorde allowed a suitable aluminium to be selected for the skin and internal structure of the aircraft that would maintain its structural integrity at Mach 2.



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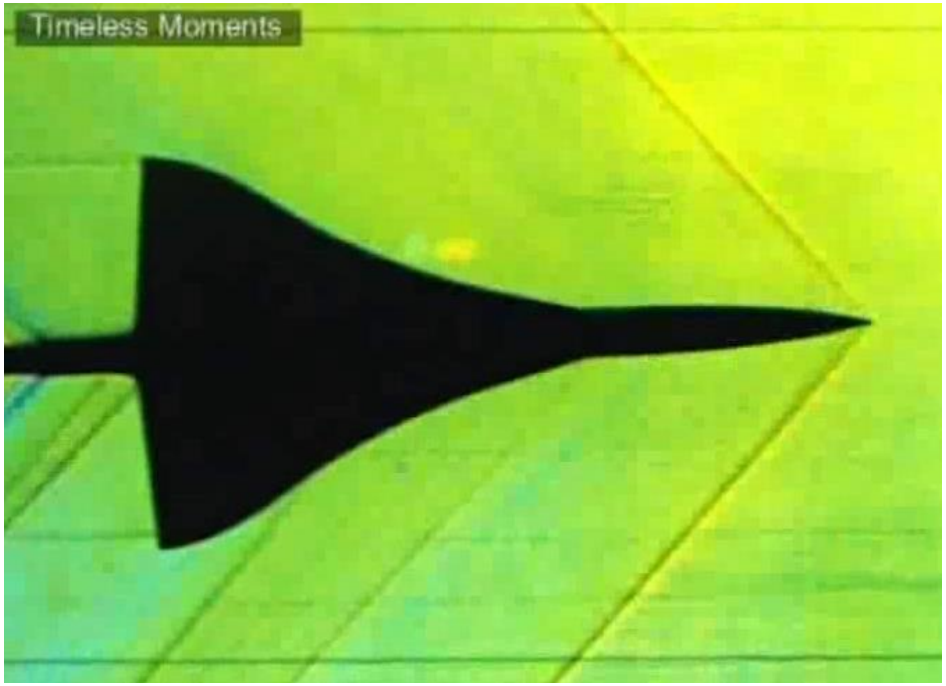
Step 4: Analysis and Optimization - Aerodynamics

To achieve a cruise speed of Mach 2, the aerodynamic shape had to be refined to maximise the lift to drag ratio. Countless simulations and wind tunnel testing was conducted to achieve the necessary performance.



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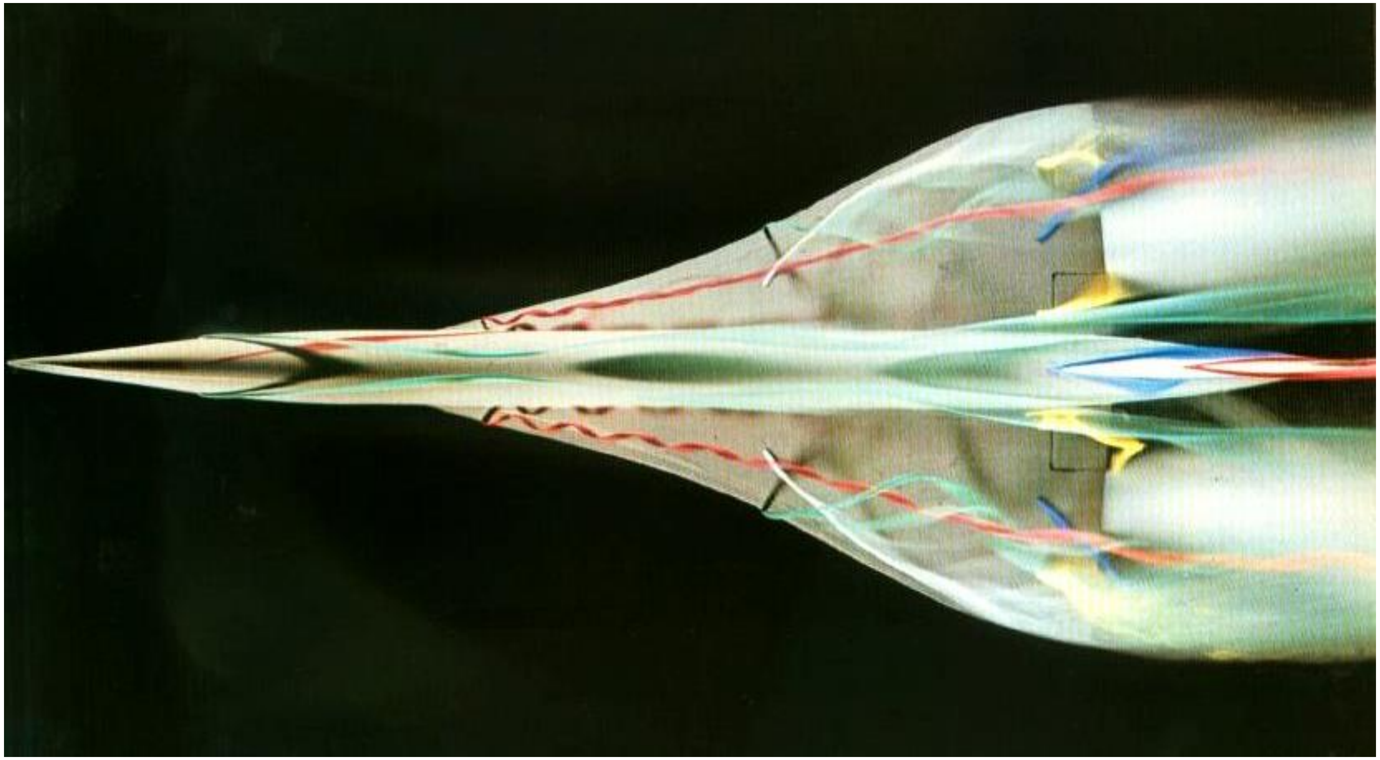
Step 5: Evaluation - Aerodynamics

Wind tunnel testing also demonstrated that the delta wing shape was less prone to stalling than conventional wings due to the formation of vortices along the leading edges.



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Step 4: Analysis and Optimization - Aerodynamics

This allowed the aerodynamicists to eliminate conventional ailerons on aircraft and allow it instead to land and take off with much more aggressive angles of attack.

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Step 4: Analysis and Optimization - Aerodynamics

But with the long sleek nose, the pilots would not be able to see the runway during take off and landing. A folding nose design with retracting wind shield was employed to overcome this problem.

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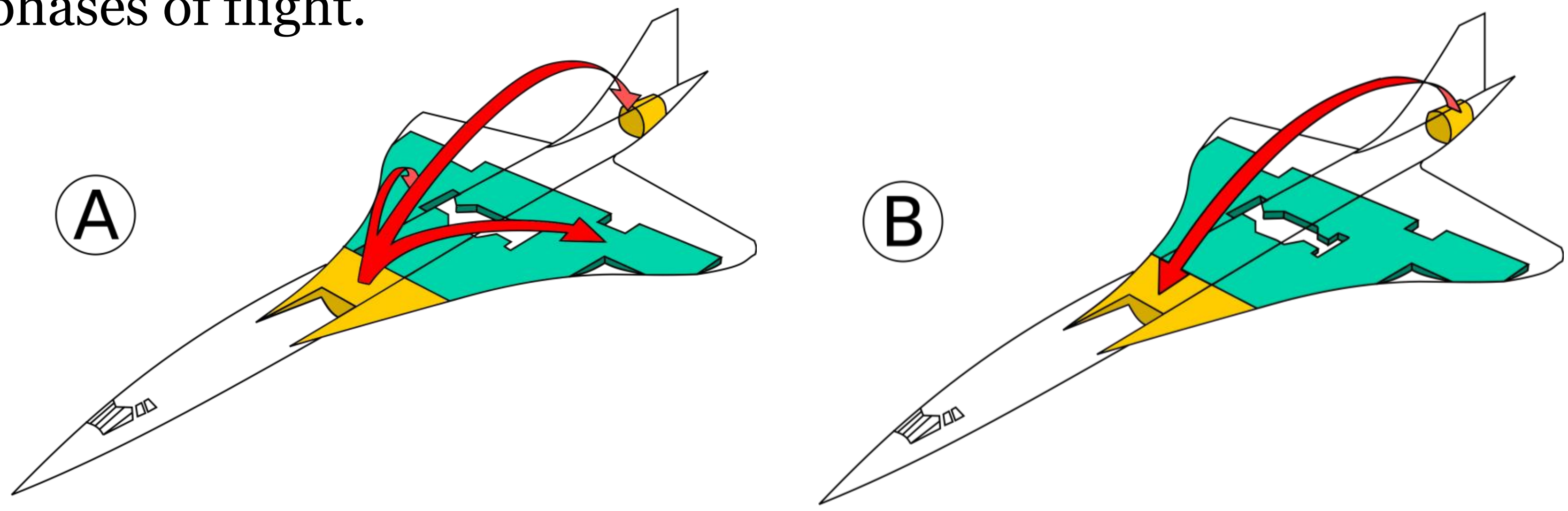
Step 4: Analysis and Optimization - Dynamics

Analysis conducted demonstrated that an inherent problem of breaking the sound barrier is a fundamental change in the aerodynamic properties of the aircraft. To address this fuel was pumped around the aircraft to maintain stability during different phases of flight.



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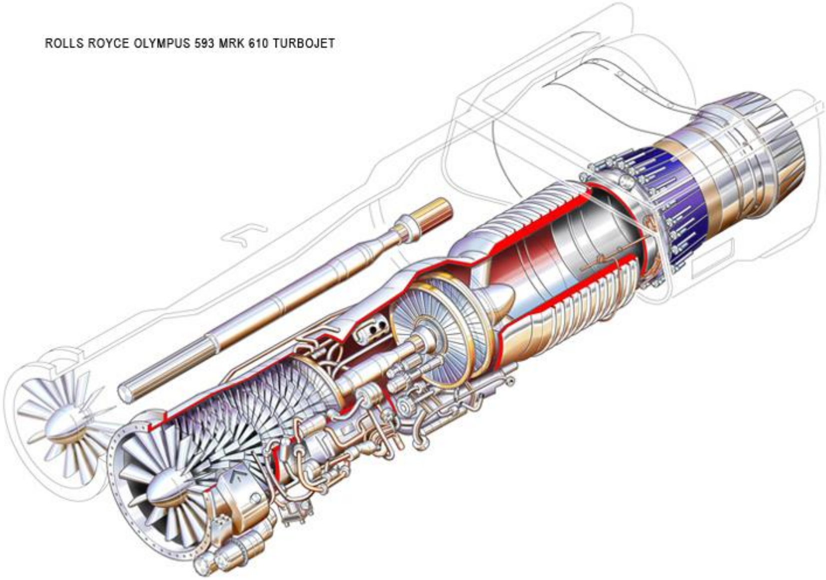
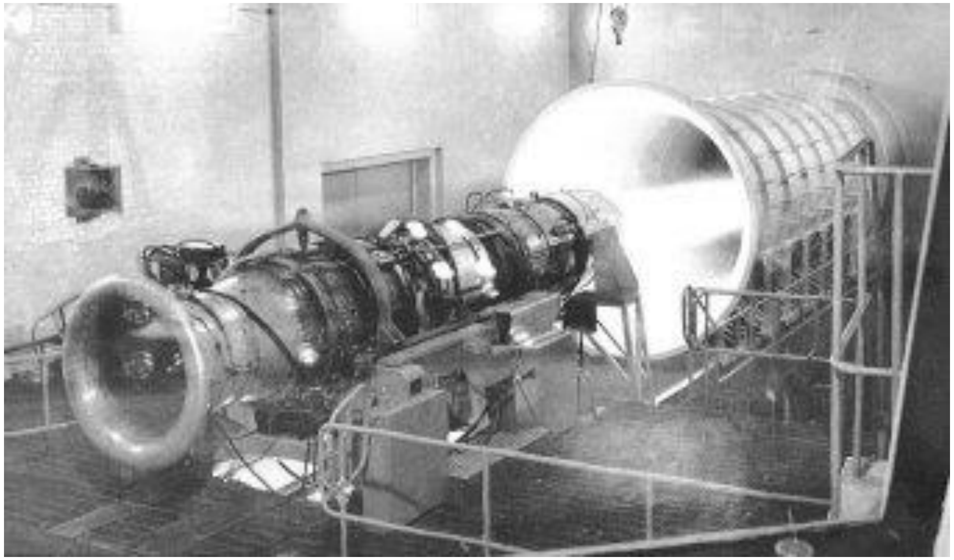
Step 4: Analysis and Optimization - Propulsion

Engines were required that could work at subsonic speeds and supersonic speeds. Analysis demonstrated that shockwaves would have to be created at the engine inlets to slow the air down when flying at speeds greater than the speed of sound.





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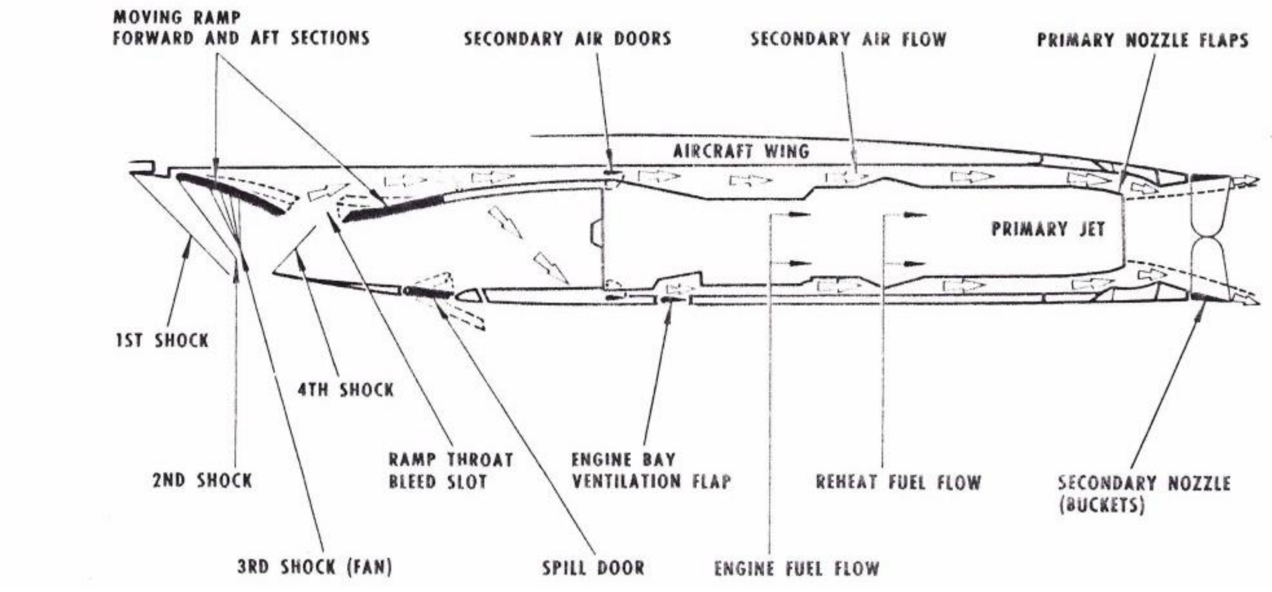
Step 4: Analysis and Optimization - Propulsion

This required a flap at the inlet of the engine that self adjusted depending on the pilots commands and the conditions. These were controlled by analysing measurements taken on the nose. For this communication to occur adequately quickly enough, digital signal processing was used for the first time.



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Step 4: Analysis and Optimization - Propulsion

To accelerate the aircraft for take off, Concorde would require even more thrust than conventional airliners. It remains the only airliner that utilised afterburners on take off.

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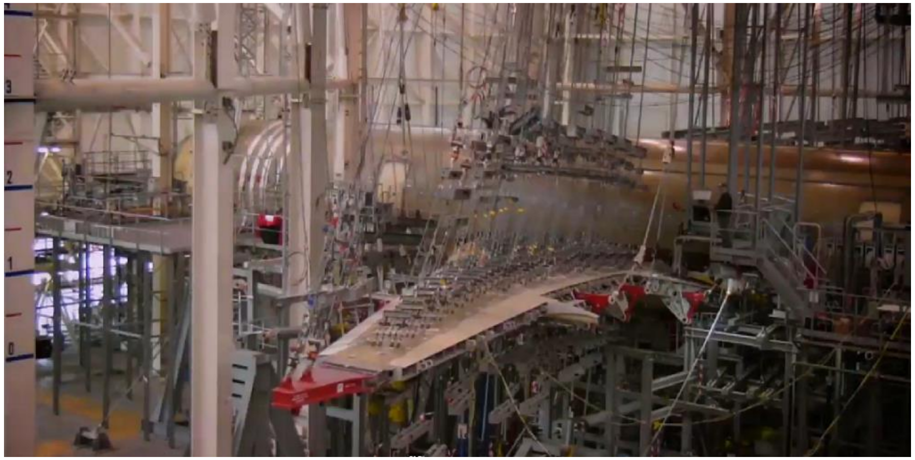
Step 5: Evaluation

Prior to flying for the first time, a complete aircraft structure under went structural tests that utilised UV lights to replicated the temperatures that the aircraft was expected to experience while flying at Mach 2.



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Step 5: Evaluation

The engines were tested for over 5000 hours in pressure chambers and then an additional 5000 hours on a Vulcan bomber before being fitted to a Concorde for the first time.

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Step 5: Evaluation

Concorde flew for the first time March 2 1969, approximately 10 years after the identification of the need was established. It flew only for 29 minutes and it took another 50 flights before it would break the sound barrier for the first time.

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Step 5: Evaluation

Three prototype concordes were built for evaluation in total. By November 1970, the prototypes were regularly breaking the sound barrier and had achieved a cruise speed of Mach 2.05.

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Step 6: Presentation

Now that the Concorde had achieved its target, the focus changed to presenting it to the public and demonstrating its capabilities. It began a world tour breaking time records everywhere it flew.

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Step 6: Presentation

The tour was a huge success with multiple airlines ordering Concordes. These were later cancelled as it became apparent that the sonic boom created when travelling faster than the speed of sound meant that flights over land would be restricted to subsonic speeds.

Airline	Number	Reserved	Cancelled	Remarks
Panair do Brasil	3	Oct 1961	10 Feb 1965	
Pan Am	6	3 Jun 1963	31 Jan 1973	2 extra options in 1964
Air France	6	3 Jun 1963		2 extra options in 1964
BOAC	6	3 Jun 1963		2 extra options in 1964
Continental Airlines	3	24 Jul 1963	Mar 1973	
American Airlines	4	7 Oct 1963	Feb 1973	2 extra options in 1965
TWA	4	16 Oct 1963	31 Jan 1973	2 extra options in 1965
Middle East Airlines	2	4 Dec 1963	Feb 1973	
Qantas	6	19 Mar 1964		2 cancelled in May 1966
Air India	2	15 Jul 1964	Feb 1975	
Japan Airlines	3	30 Sep 1965	1973	
Sabena	2	1 Dec 1965	Feb 1973	
Eastern Airlines	2	28 Jun 1966	Feb 1973	2 extra options on 15 Aug 1966 2 other extra options on 28 Apr 1967
United Airlines	6	29 Jun 1966	26 Oct 1972	
Braniff	3	1 Sep 1966	Feb 1973	
Lufthansa	3	16 Feb 1967	Apr 1973	
Air Canada	4	1 Mar 1967	6 Jun 1972[35]	

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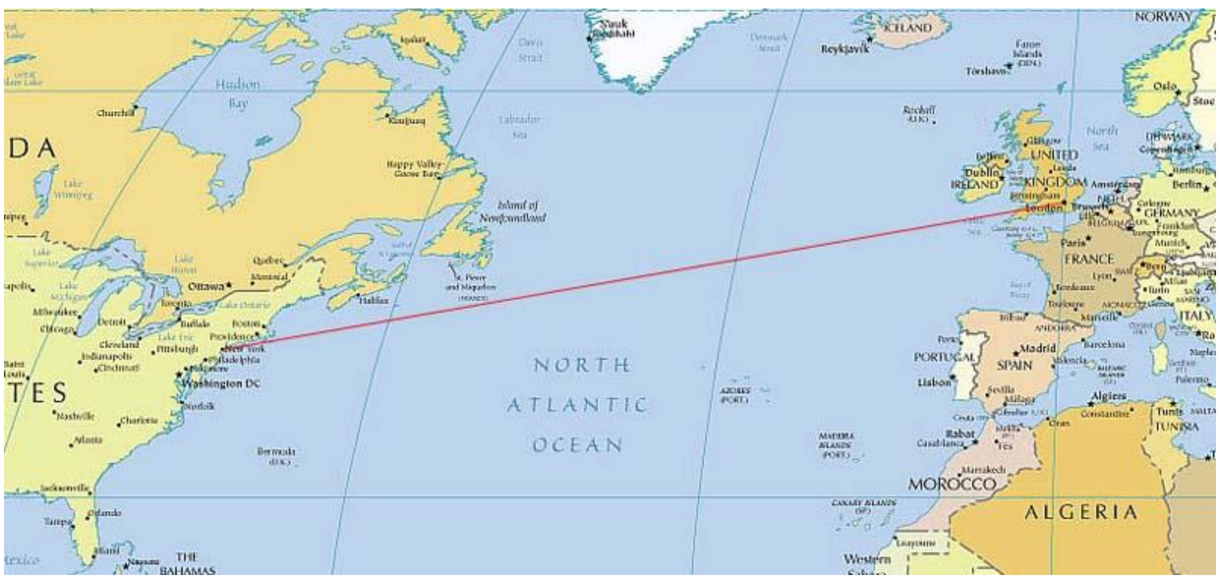
Step 6: Presentation

Concorde currently holds the record for the fastest transatlantic crossing in a little over 2.5 hours. This was achieved at a cruising speed of Mach 2.02 and also with favourable winds increasing its ground speed.



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Step 6: Presentation

In the end, only British Airways and France purchased Concordes and mainly flew on routes that took them over sea and the shock wave would not be able to disturb people on the ground. Flights were expensive resulting in VIP’s and royalty mostly using this plane.

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Step 6: Presentation

The image of Concorde was irreversibly damaged on the 25th of July, 2000 when it crashed after take off killing all on board and four people on the ground.

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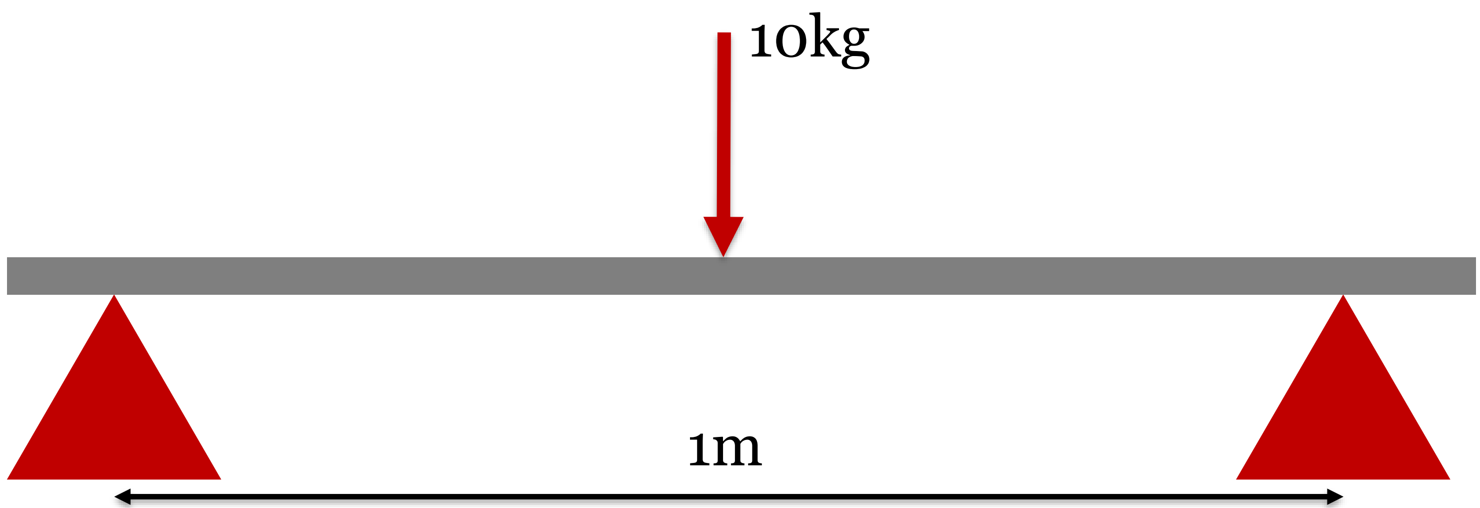
Example: Structure supporting weight

Lets discuss what the design procedure would be for designing a component that achieves the following task:

A structure is required that will be capable of supporting 10kg in the middle of two supports separated by 1m. The final structure can not deflect by more than 1mm when loaded and not be permanently damaged as a result. Weight and cost of the structure must be minimised.



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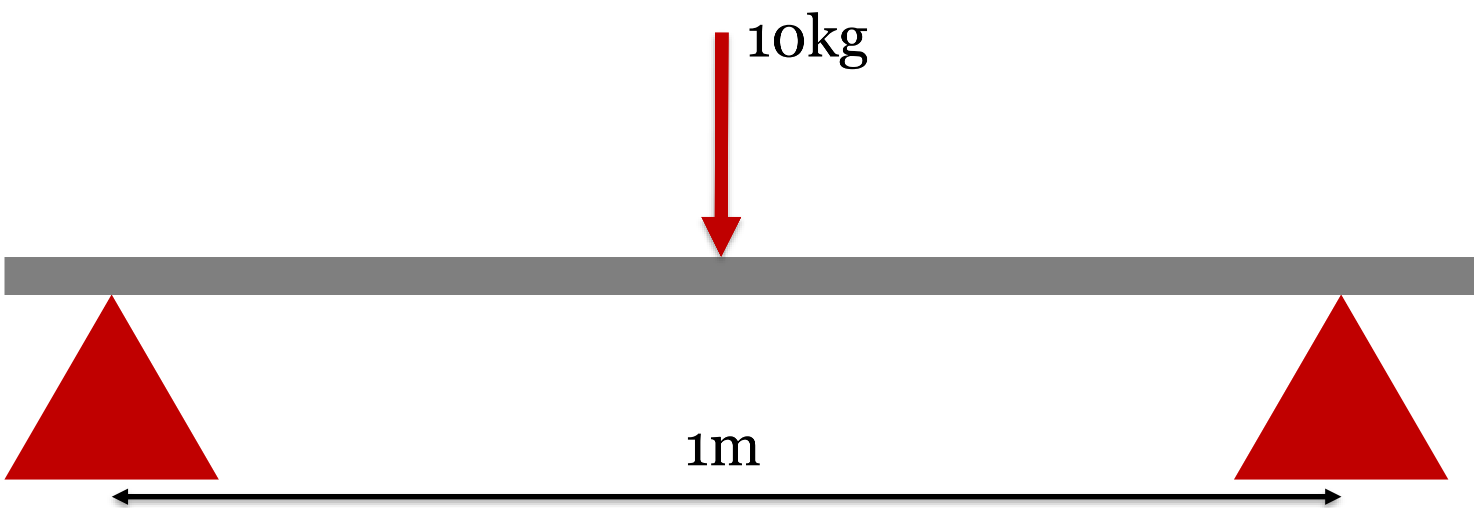
Example: Structure supporting weight

The need has been identified for us, so now we require to determine a definition of the problem through some prioritised aims?



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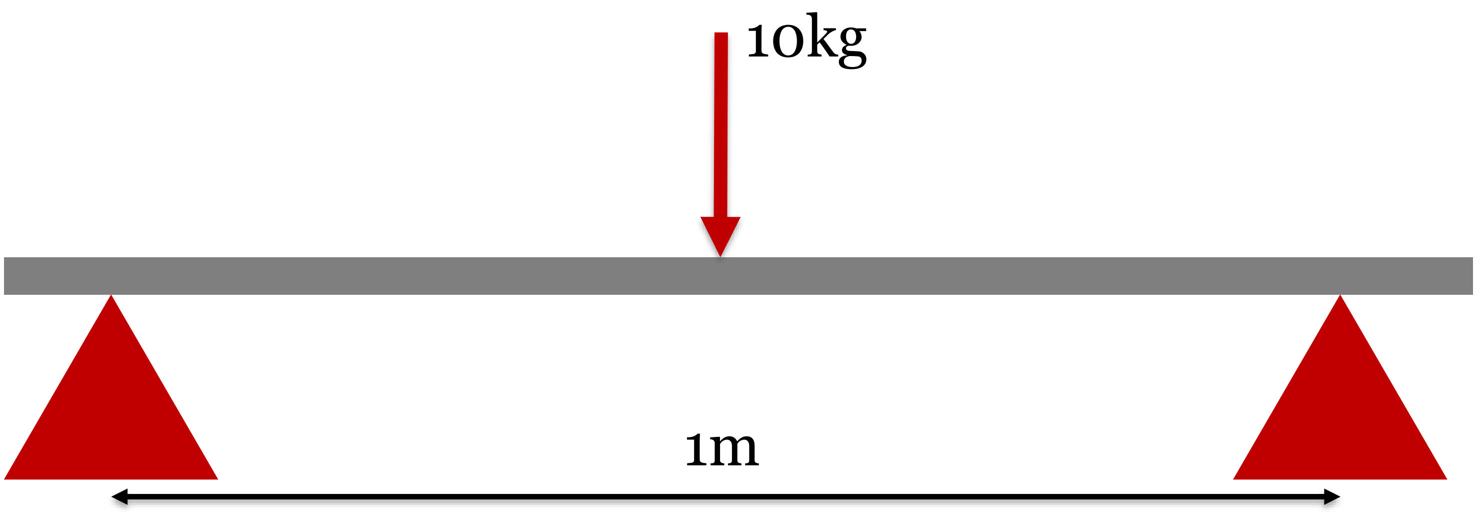
Example: Structure supporting weight

The need has been identified for us, so now we require to determine a definition of the problem through some prioritised aims:

Develop a structure that:

1) *Can support 10kg without bending more than 1mm or yielding the material*
2) *Minimises the weight of the structure*
3) *Minimises the cost of producing the structure*



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Example: Structure supporting weight

Now we need a strategy (Synthesis) that will allow us to come up with a solution for this problem, what ideas can we generate to achieve the aims?

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Example: Structure supporting weight

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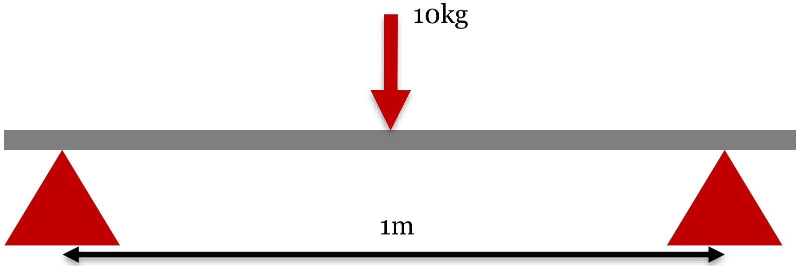
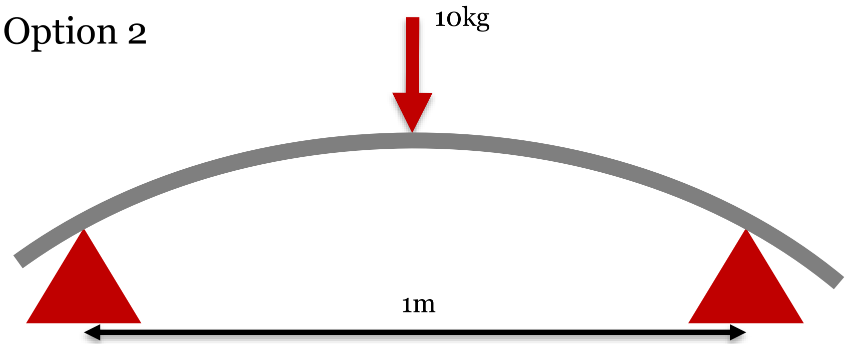
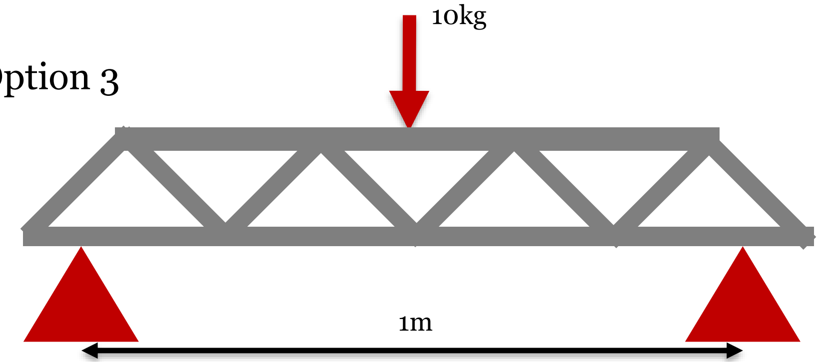
Option 1



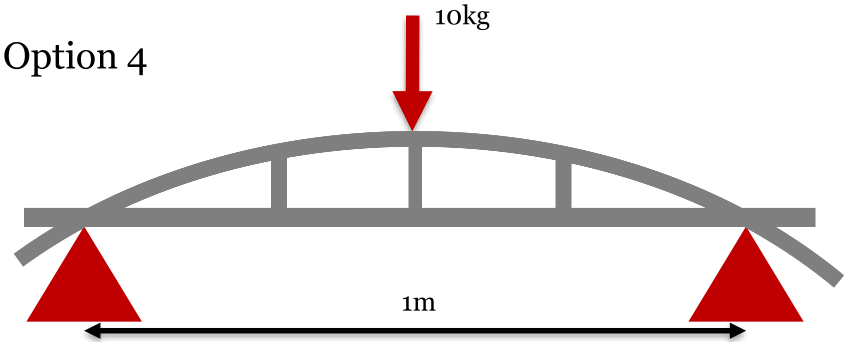
Option 2



Option 3



Option 4



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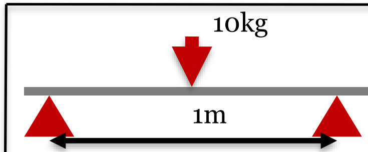
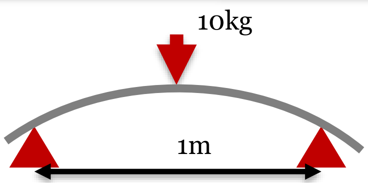
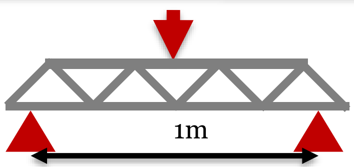
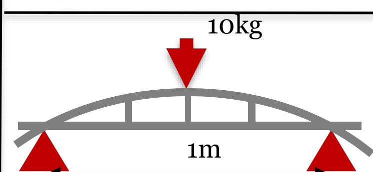
Example: Structure supporting weight

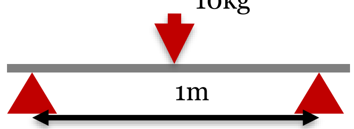
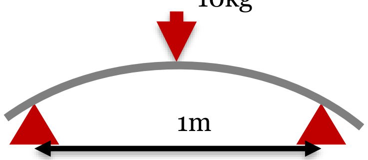
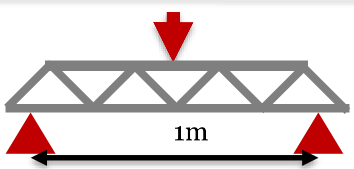
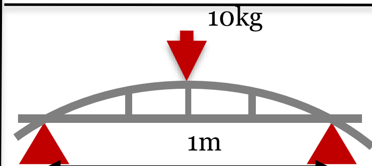
We need to decide on one of the options that have been conceived, consider positives and negatives with regard to aims of the project:

	Stiffness	Weight	Strength	Cost
				
				
				
				

MECH203: Mechanical Design

Example: Structure supporting weight

New need to decide on one of the options that have been conceived, consider positives and negatives with regard to aims of the project:

	Stiffness	Weight	Strength	Cost
	✗	✓	✗	✓
	✓	✓	✗	✗
	✓	✗	✓	✗
	✓	✗	✓	✗

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Example: Structure supporting weight

Now that a design strategy has been chosen, the analysis and optimisation can begin. How should we begin the Analysis and Optimization?

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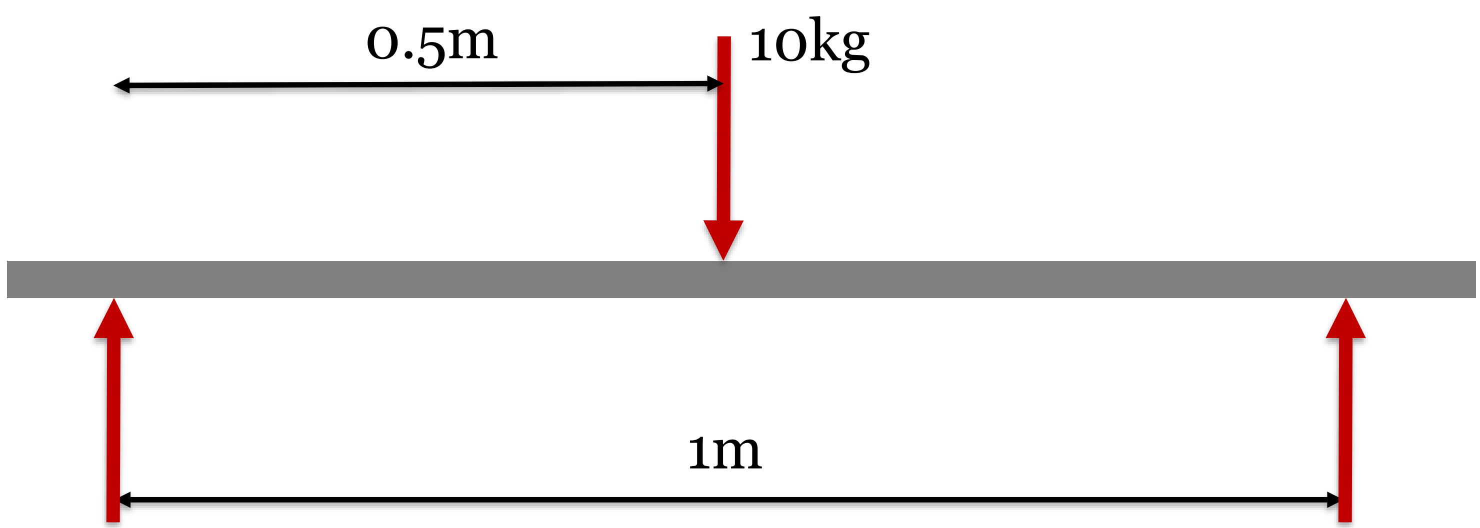
Example: Structure supporting weight

Start by doing a free body diagram of the problem to understand the forces and moments that would be experienced by the component.



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Example: Structure supporting weight

You can use your knowledge of mechanics of solids in order to determine the deflection, factor of safety and mass of a proposed section and material. What might these equations be and what source should you use?

Example: Structure supporting weight

Using text book it is possible to determine that the following equations will allow the required parameters to be estimated.

$$\sigma_{max} = \frac{yFL}{4I} \qquad \delta = \frac{PL^3}{48EI}$$

$$FS = \frac{\sigma_{yield}}{\sigma_{max}} \qquad m = \rho AL$$

MECH203: Mechanical Design

Example: Structure supporting weight

The shape alters the area and the moment of inertia, therefore we need to setup a model that allows us to enter all the possible options and determine how these will affect the aims of the project.

Mass =	10	kg	length of beam =	1	m
Gravity =	9.81	ms^{-2}	Force =	98.1	N

Material	Density	Elastic Modulus	Yield Stress
Aluminium	2700	6.90E+10	2.41E+08
Steel	7750	2.00E+11	2.50E+08

Section type	Width	Height	Thickness	Cross sectional area	Second moment of Area	Material	Density	Elastic Modulus	Yield Stress	Deflection Prediction	Maximum stress	Factor of Safety	Mass estimate
	w	*h*	*t*	*A*	*I*			E	Y	δ	ε	*FS*	*m*
	(m)	(m)	(m)	(m^2)	(m^4)		(kg/m^3)	(Pa)	(Pa)	(mm)	(Pa)		(kg)
Rectangular hollow section	0.05	0.05	0.003	5.64E-04	2.08E-07	Aluminium	2700	6.9E+10	2.41E+08	0.14	2.94E+06	81.952	1.52
Rectangular hollow section	0.07	0.05	0.003	6.84E-04	2.75E-07	Aluminium	2700	6.9E+10	2.41E+08	0.11	2.23E+06	108.036	1.85
Rectangular hollow section	0.07	0.05	0.003	6.84E-04	2.75E-07	Steel	7750	2E+11	2.50E+08	0.04	2.23E+06	112.070	5.30
I section	0.05	0.05	0.003	4.32E-04	1.87E-07	Aluminium	2700	6.9E+10	2.41E+08	0.16	3.28E+06	73.581	1.17

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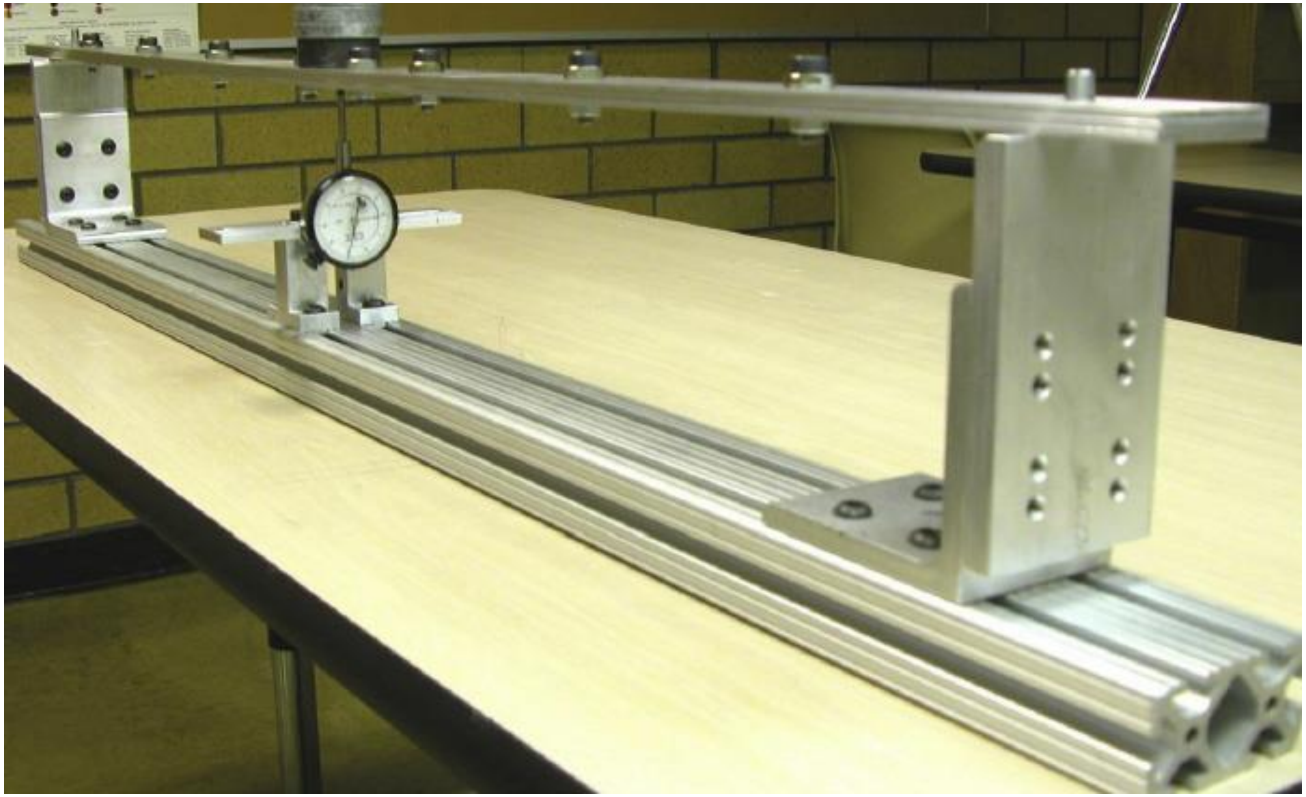
Example: Structure supporting weight

Once a solution has been determined using analysis and optimization, the result can be tested against an experiment.



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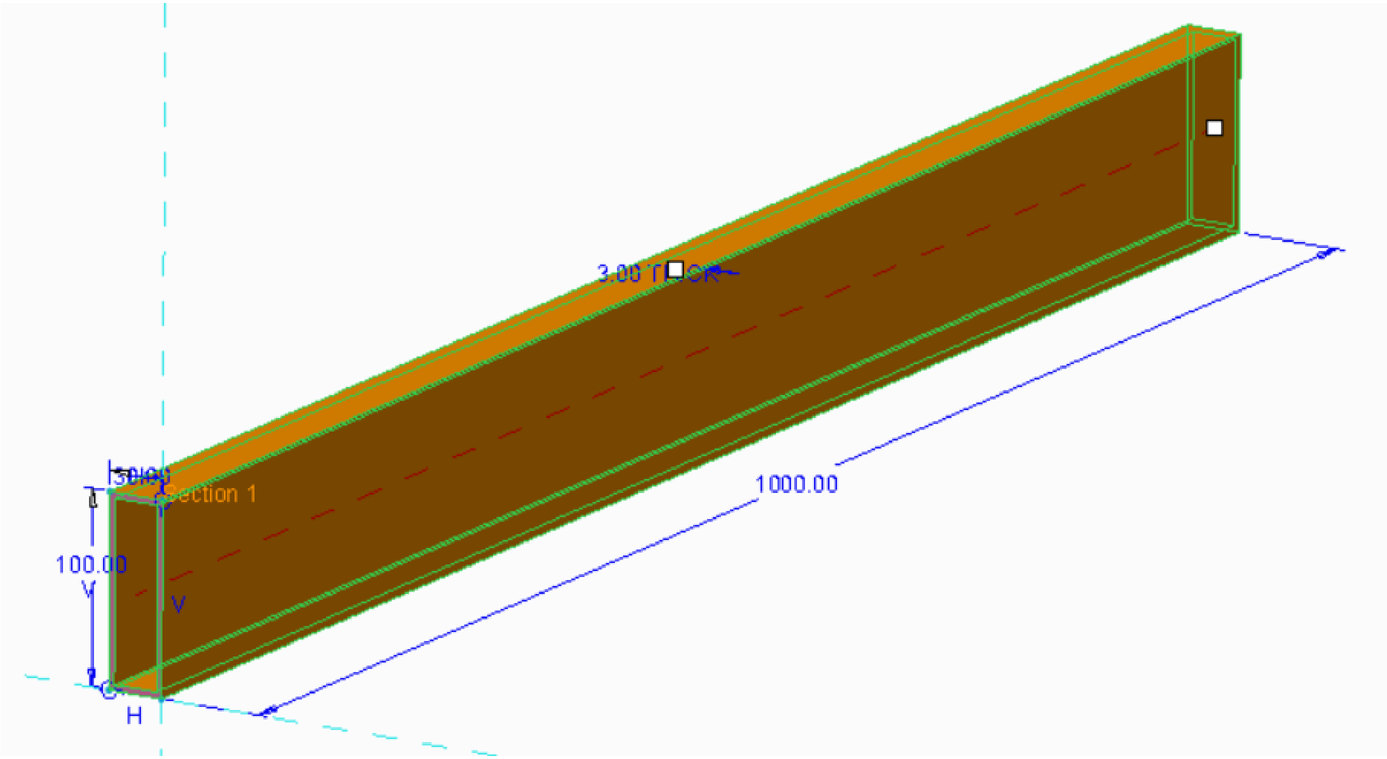
Example: Structure supporting weight

Finally the concept can be presented to the stake holders, this may be in the form of a CAD model that depicts all the details that the analysis has demonstrated would be vital to achieve the aims.



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