Aalto University
School of Engineering

# Design of cast components

*Advanced Casting Technology*

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Aalto University
School of Engineering

Patterns
Moulding
Castability
Machining
Strength Cores

# What's special about casting design?

**From an idea to a finished part is a multi-step process:**

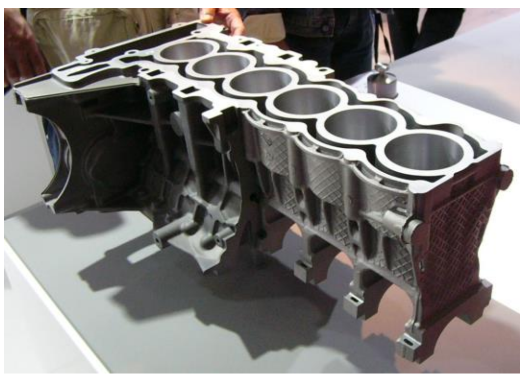
**Idea → Basic design → Design for castability** ***(and machining!)*** **→ Simulations → Design iterations →Tooling design → …**

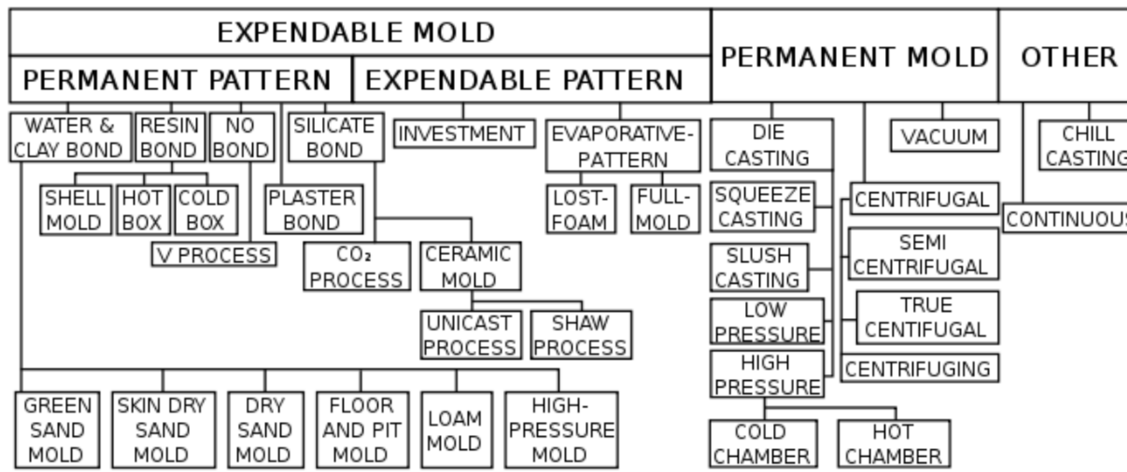
# What’s special about casting design?

**It is a manufacturing process…**

**…but there is not only one single supreme casting method…**

**..there are several possibilities with pros and cons**



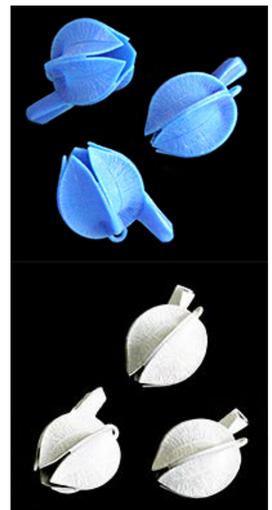


# What’s special about castings?

**It is not always the best manufacturing method for your product**

**…but in many cases it very well might be**

**Possible product weights can be from a few grams with investment casting to over ~500 tons with sand casting**



# What's special about castings?

**Is the chosen manufacturing method the only thing that matters?**

***NO, because materials will also affect your design***

**Before you start designing a product…**

***…you have to have an idea of methods and materials…***

***…or not, but it is going to save money and time if you do***

***In short, design of cast components is all about the bigger picture.***

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The relations between the drafting department and the shop, between the departments of the shop, and between individuals, from the highest to the lowest, is given far too little attention as a factor in economical shop management.

- Engineer at Brown & Sharpe, 1904

It is said that the design function has not changed. That is true. But the time factor has changed considerably. It is changing and shortening all the time. My first point concerns planning and co-ordination, which require that the whole design team and management should ensure that all designing and ancillary arrangements that can should go on in parallel rather than in series. It may be said that this is obvious; most of my comments are comparatively elementary, yet all too often these ideas are lacking in many firms.

- A British Design Engineer, some time after WW2

Concurrent Engineering presents a new team-based approach and implementation of certain technologies and methods that aims to shorten total lead time with also improved quality and market entrance capability.

- Design Engineers, 2016

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**If there is one main point you should remember attending this lecture and course, it should be;**

**Cooperation and communication is key when dealing with cast products. Get potential suppliers (read: foundries) involved as early as possible. If you don't know the specifics, ask the specialist.**

# Viewpoints

**New product → New design**

**Existing cast product → New design and variation**

**Existing product (not cast) → New cast design**

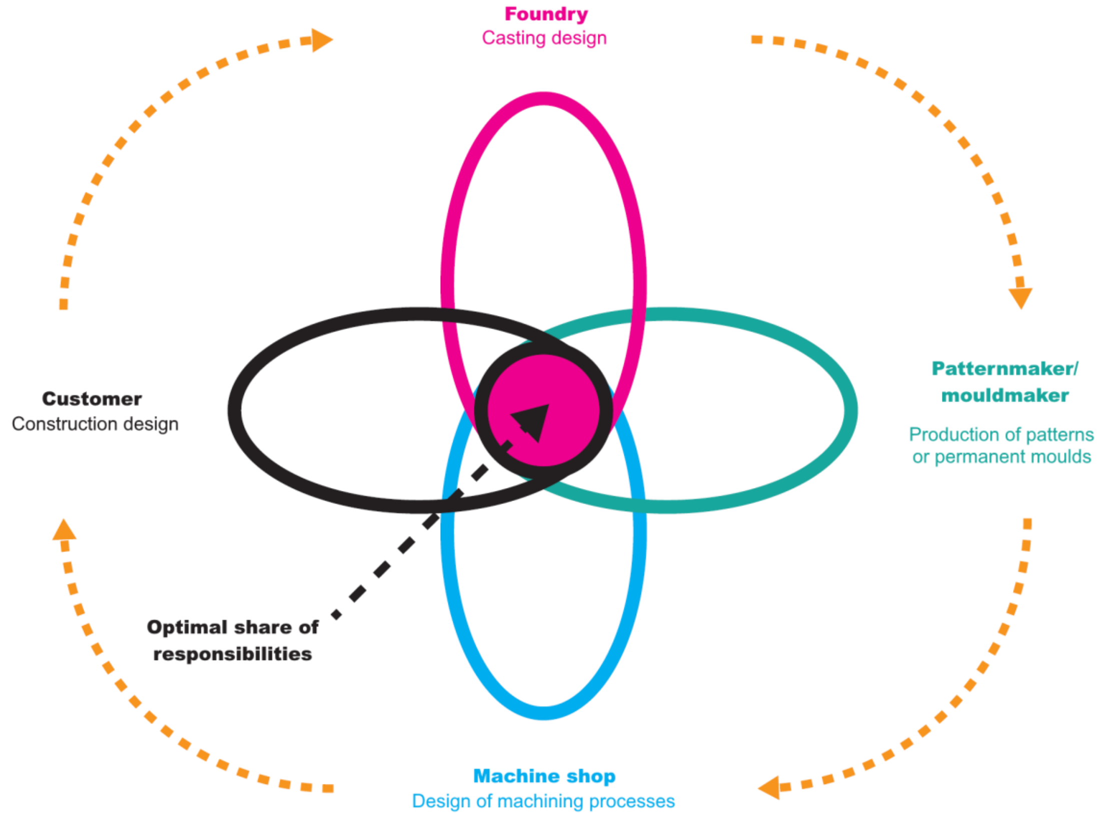
**All change how you think about:**


# Viewpoints and responsibilities

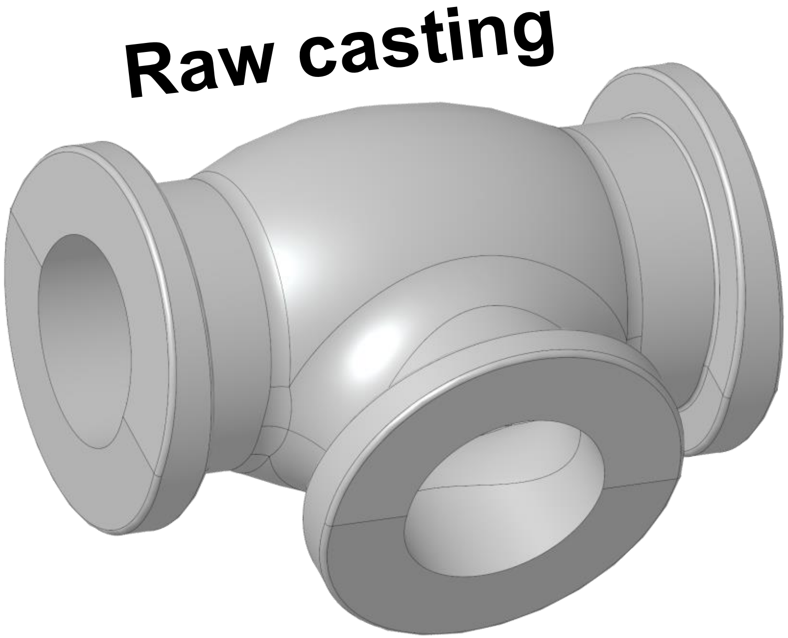
Castings are almost never final products as-is, rather than being parts in assemblies

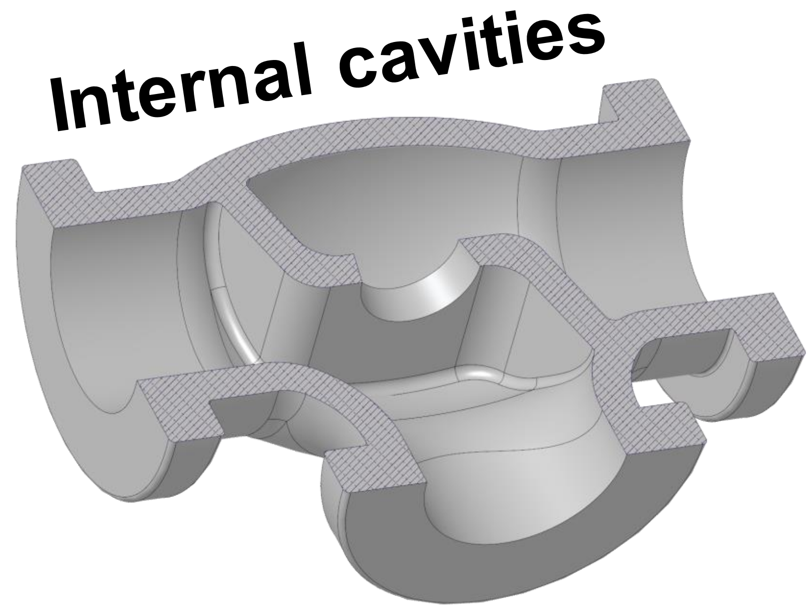
Casting can be a super-efficient way of producing complex geometries if the whole process and responsible parties is taken into consideration

Who does what?



# Basics – example of sand moulding



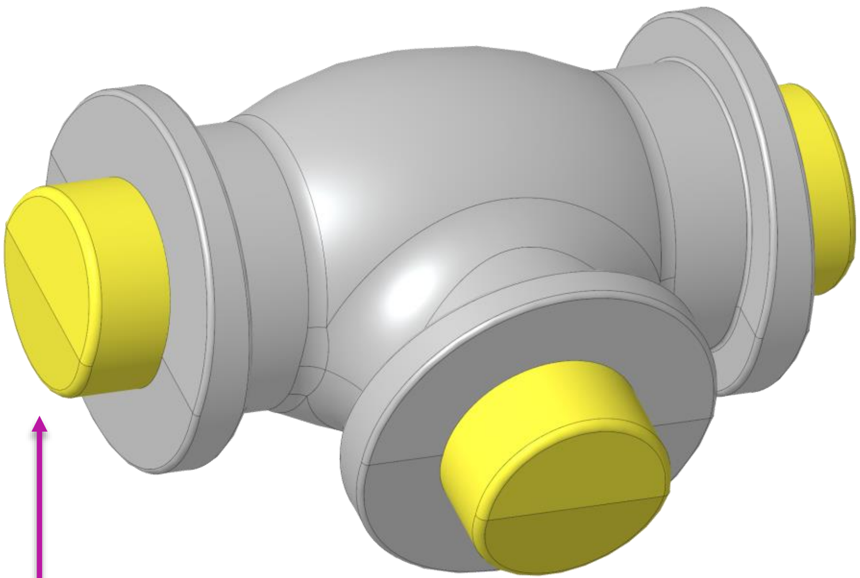



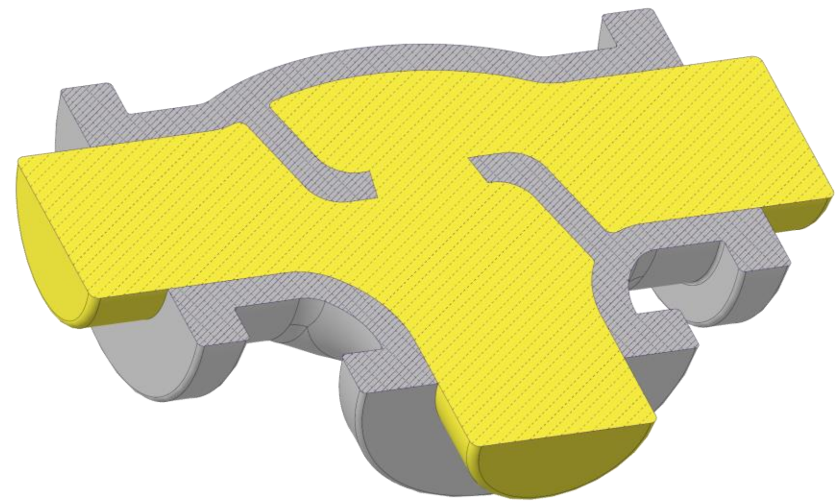

How are they made?

**PERMANENT PATTERN + EXPENDABLE MOULD**

# Basics

**The freedom of shape that often defines castings are made possible by special parts, such as cores.**



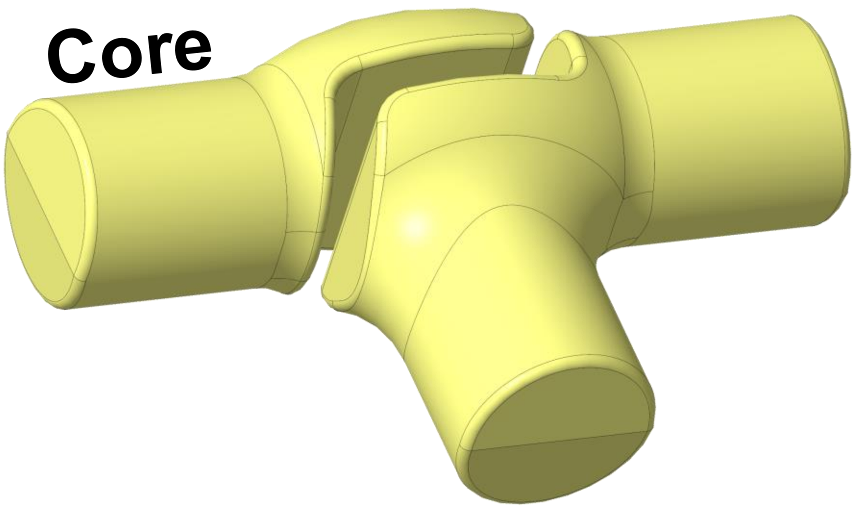


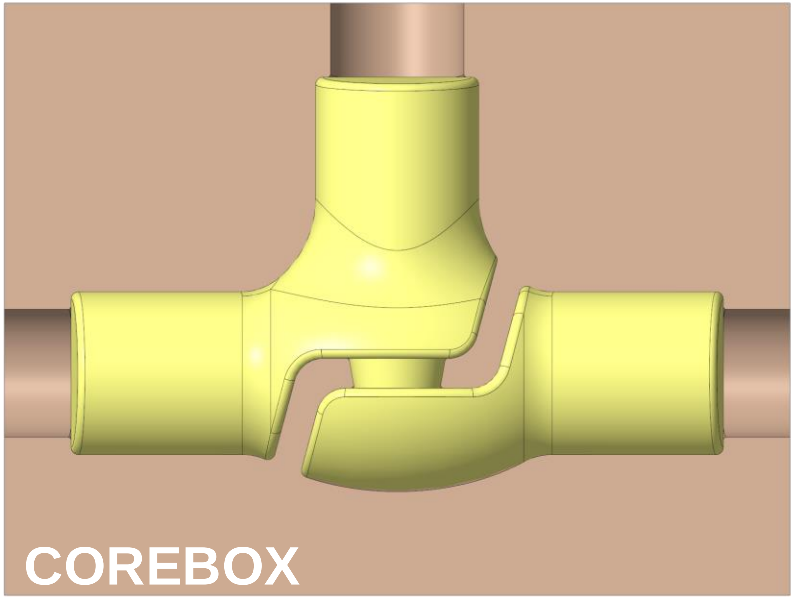
**Core prints**

**Cores are supported in between of mould halves**

# Basics

**Cores themselves are done with separate tooling/moulds**

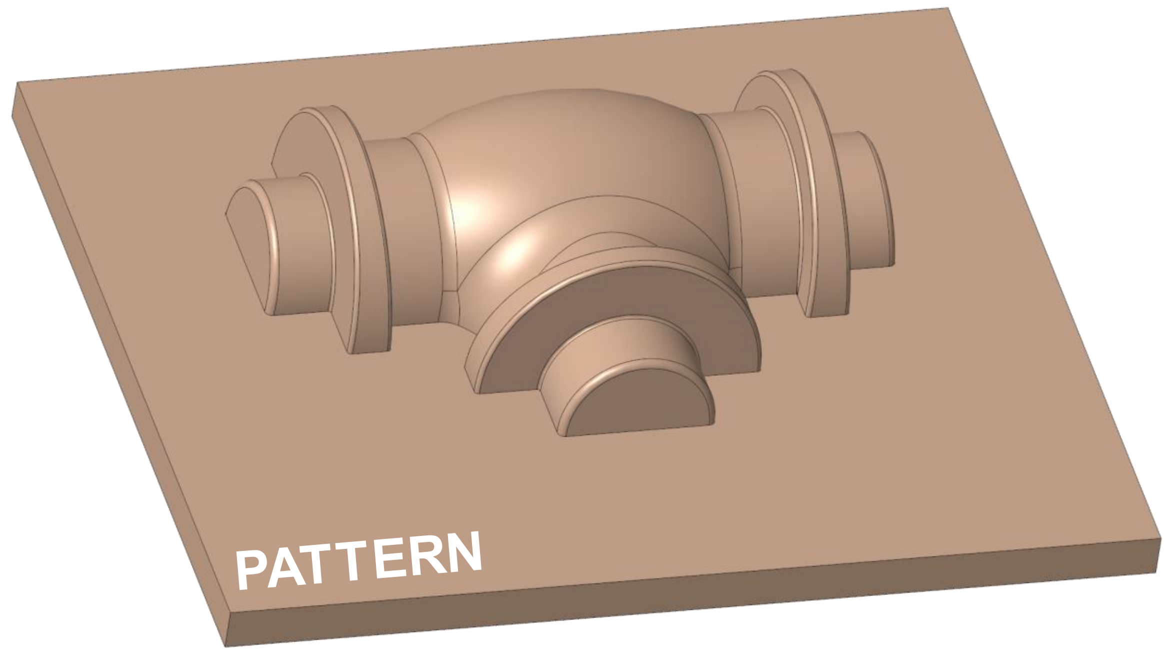


# Basics

**The negative cavities in sand moulds are done with patterns**

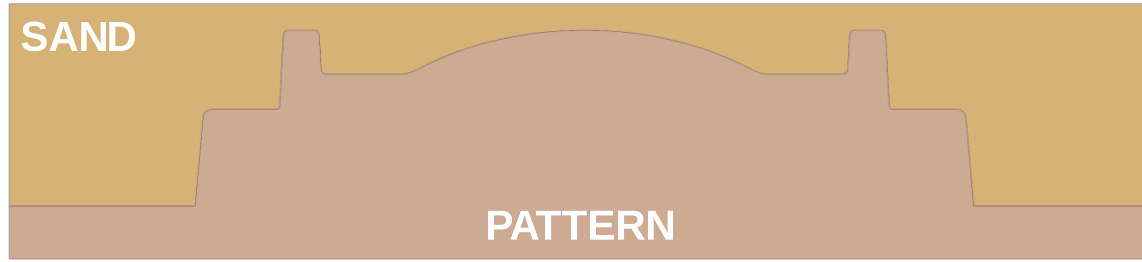
**Patterns normally contain locating pins, gating system and other features**

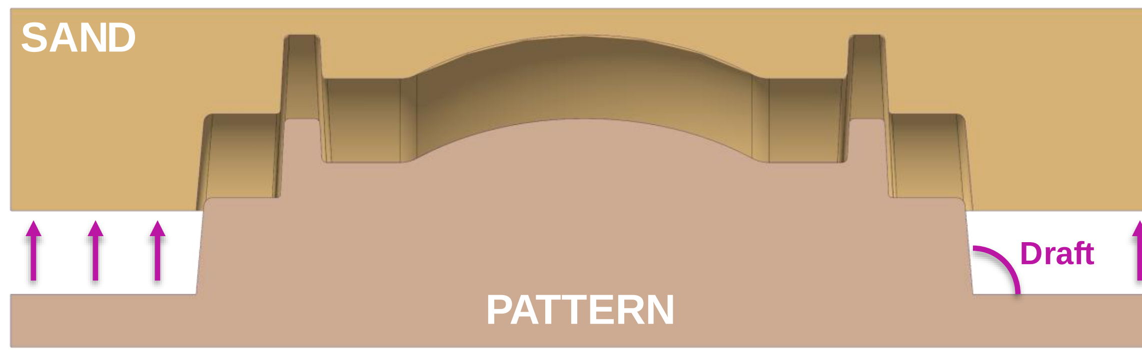


# Basics

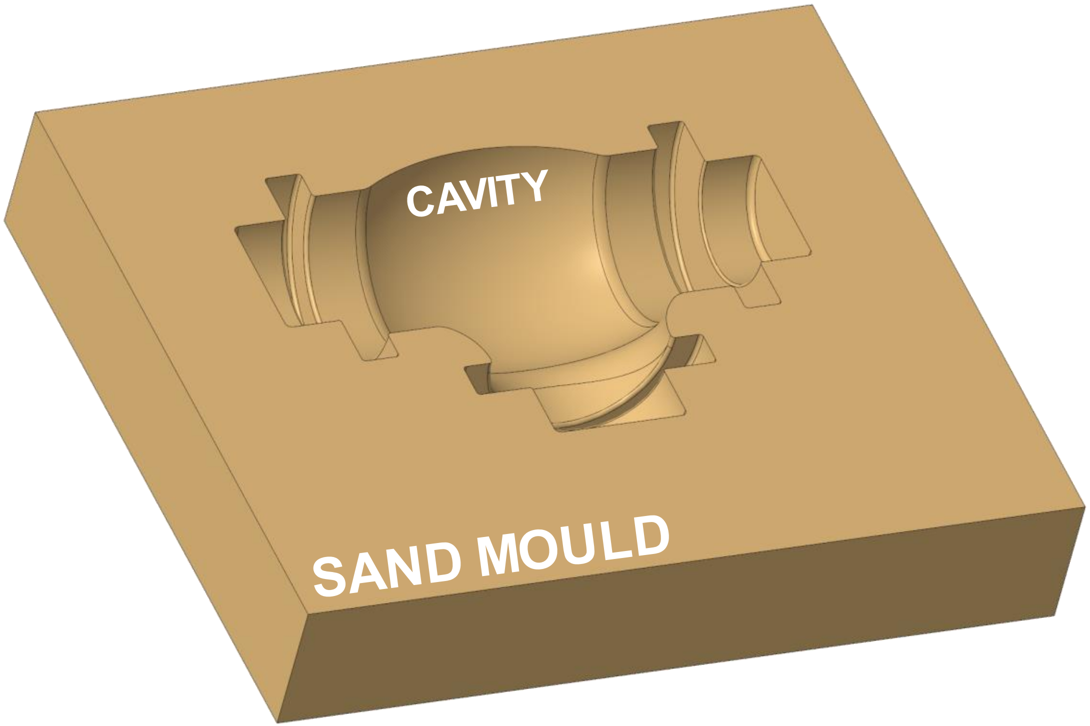
**Features like drafts are required as patterns need to be separated from moulds without damage to either**

**Especially important for permanent moulds!**



# Basics

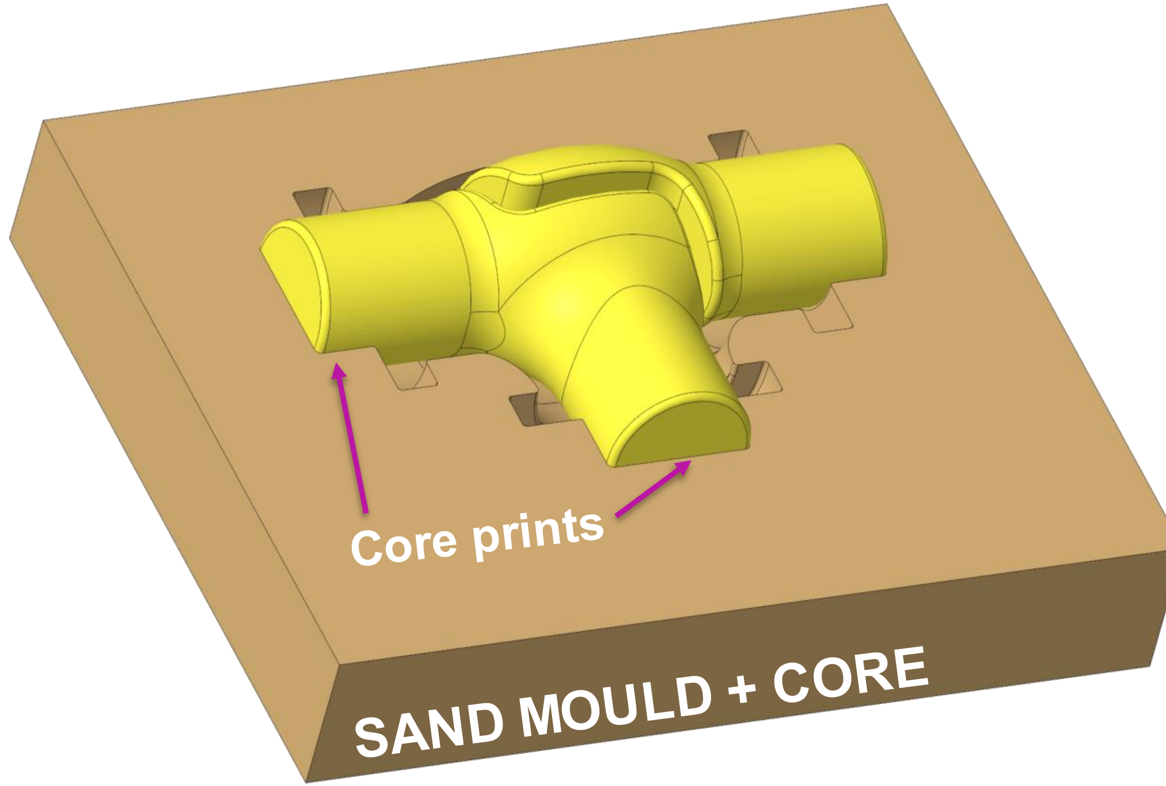



**Mould cavities are the features that actually create castings when molten metal is poured into a mould**

**Gates, runners, feeders, locating pins and other important features are not shown in this example**

# Basics

**Cores need to have some kind of locating and supporting features in-mould to prevent coreshift and other unwanted mishaps**



# Basic design process

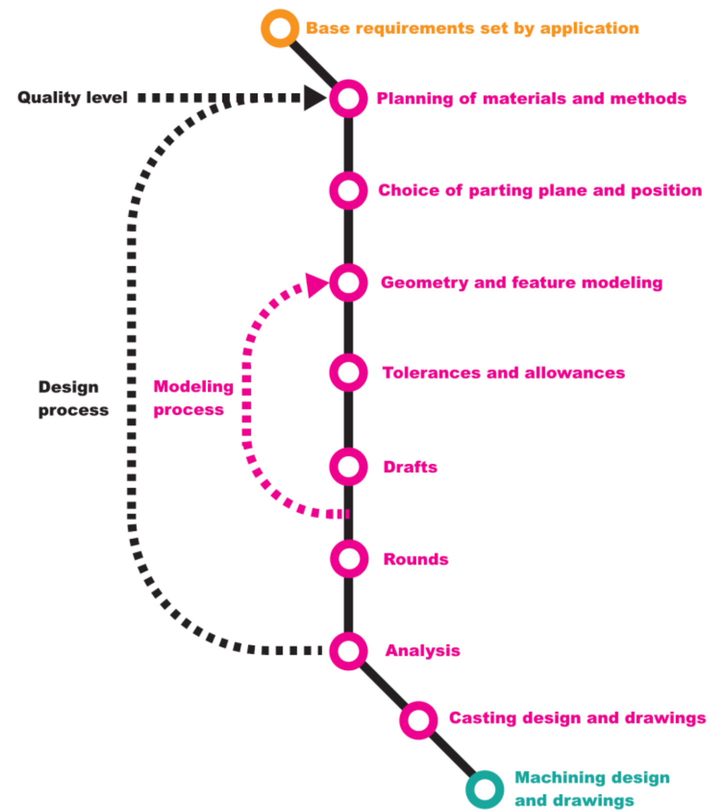
1) **Cast material**
   - What section thicknesses are possible? Design limitations? …?
2) **Casting method**
   - Permanent or non-permanent moulding? Need for cores? Surface quality? Least amount of machining wanted? Batch sizes? …?
3) **Dimensional and surface tolerances**
   - What are the attainable tolerances with chosen material and method? Can everything above be fulfilled cost-effectively and the part is still within designed dimensions? …?
4) **Make first contact with a foundry**

# Basic design process

Design of cast components is not simple

Multiple contributing factors need to be taken into account, at the right time

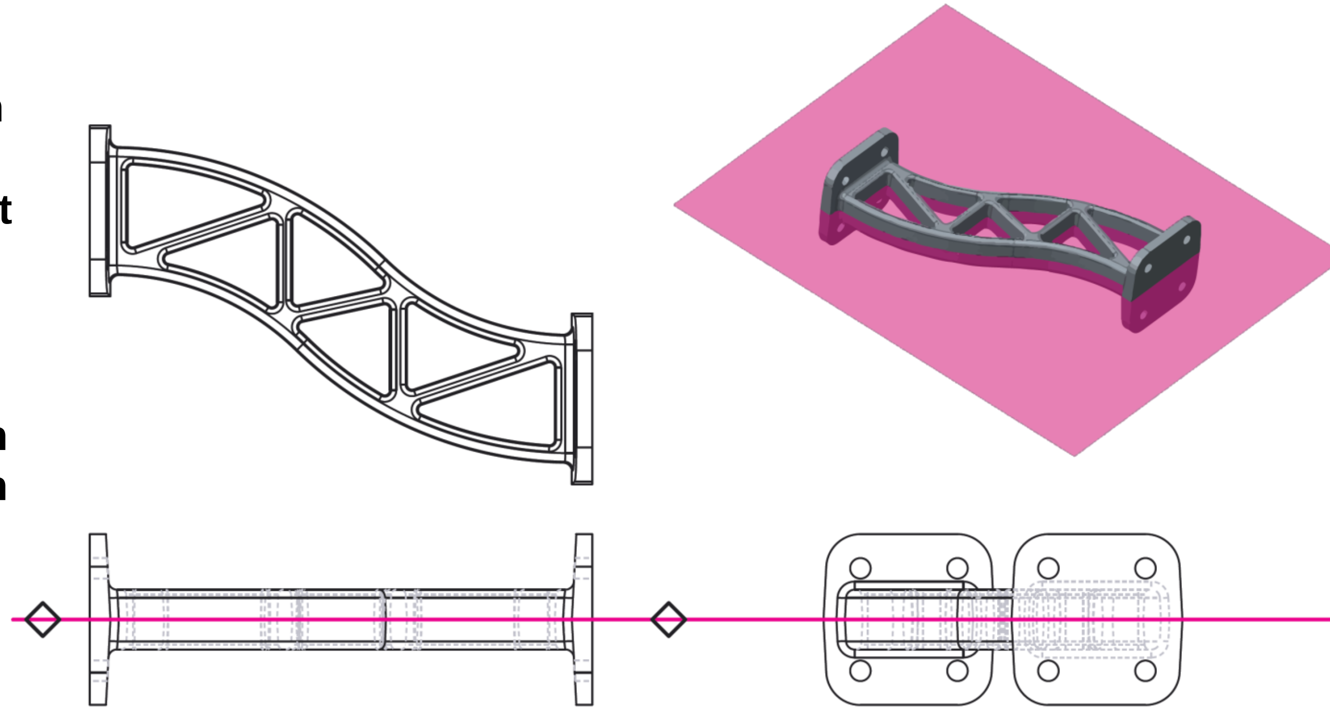
Trying to do it right the first time saves time, money and designers' sanity



# Parting surface: <u>planar</u> vs. non-planar

**Almost every step in casting design is somehow dependent on the choice of parting surfaces**

**Parting surfaces can be anything between simple planes or complex surfaces**



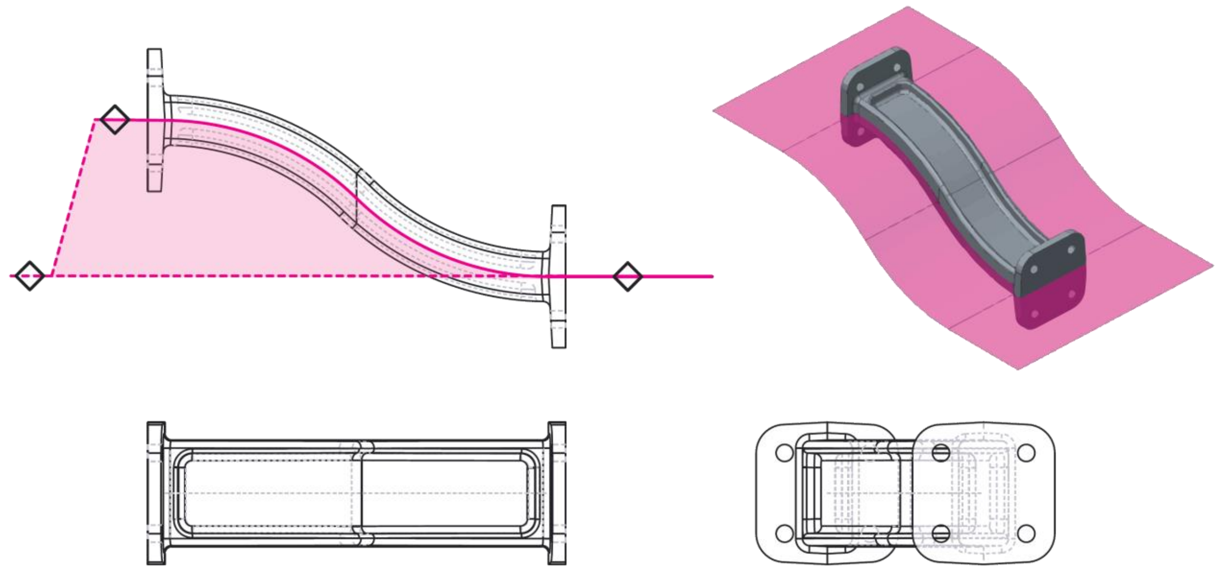
# Parting surfaces: planar vs. non-planar

**With modern pattern production techniques, non-planar parting surfaces are not a challenge to make**

**However,**

**complexity = cost**

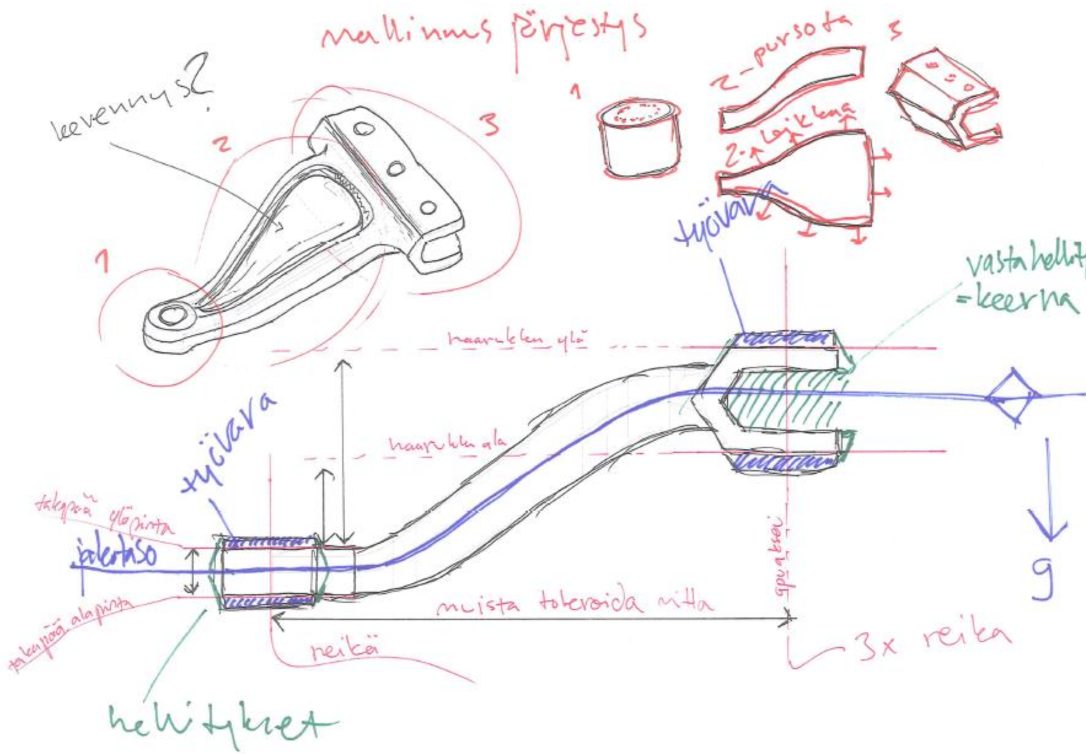
**Keep it simple as possible while using all the advantages that a manufacturing process allows**



**Geometry changed, functionality didn't**

# Sketching

**Although it's possible to just start making features in CAD, it might prove fruitful to think the whole process through and even do "outdated" things like sketching on paper**

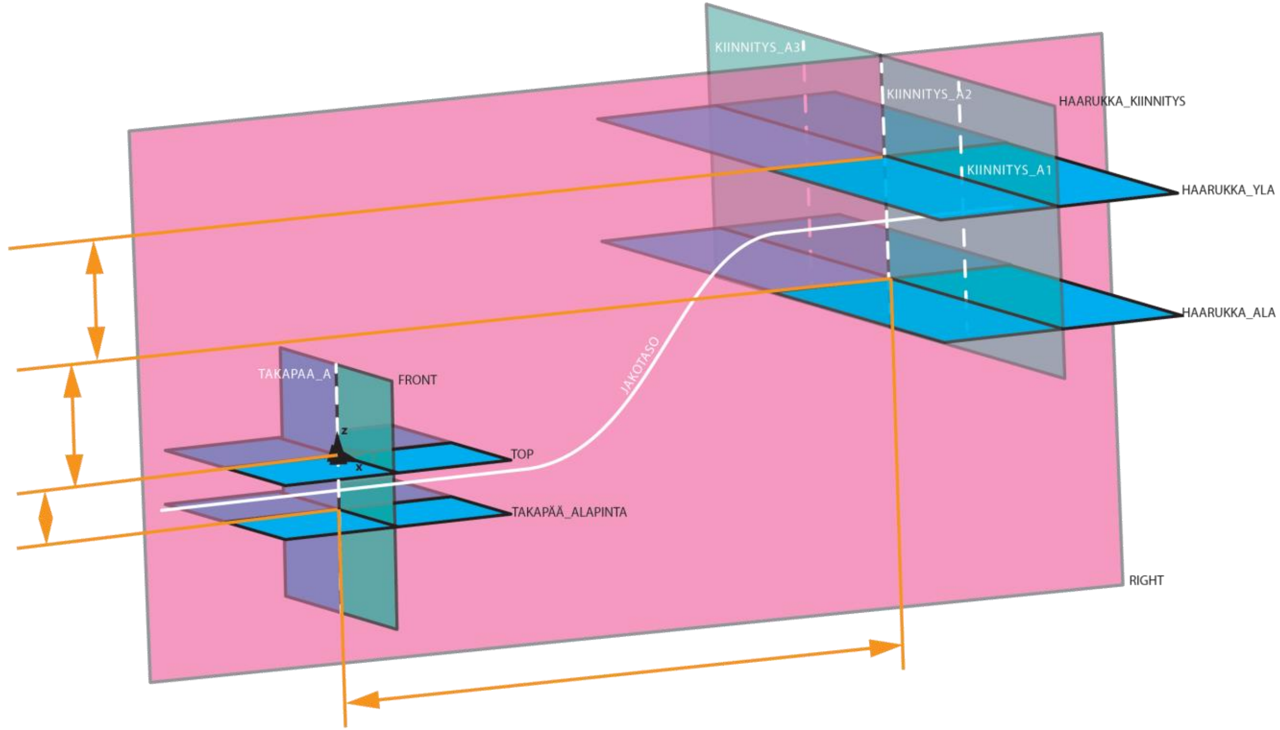


# Using planes

**Starting with placing planes on important dimensions can be a life-saver when doing casting designs**

**Tolerances and allowances are additional to base dimensions and features**

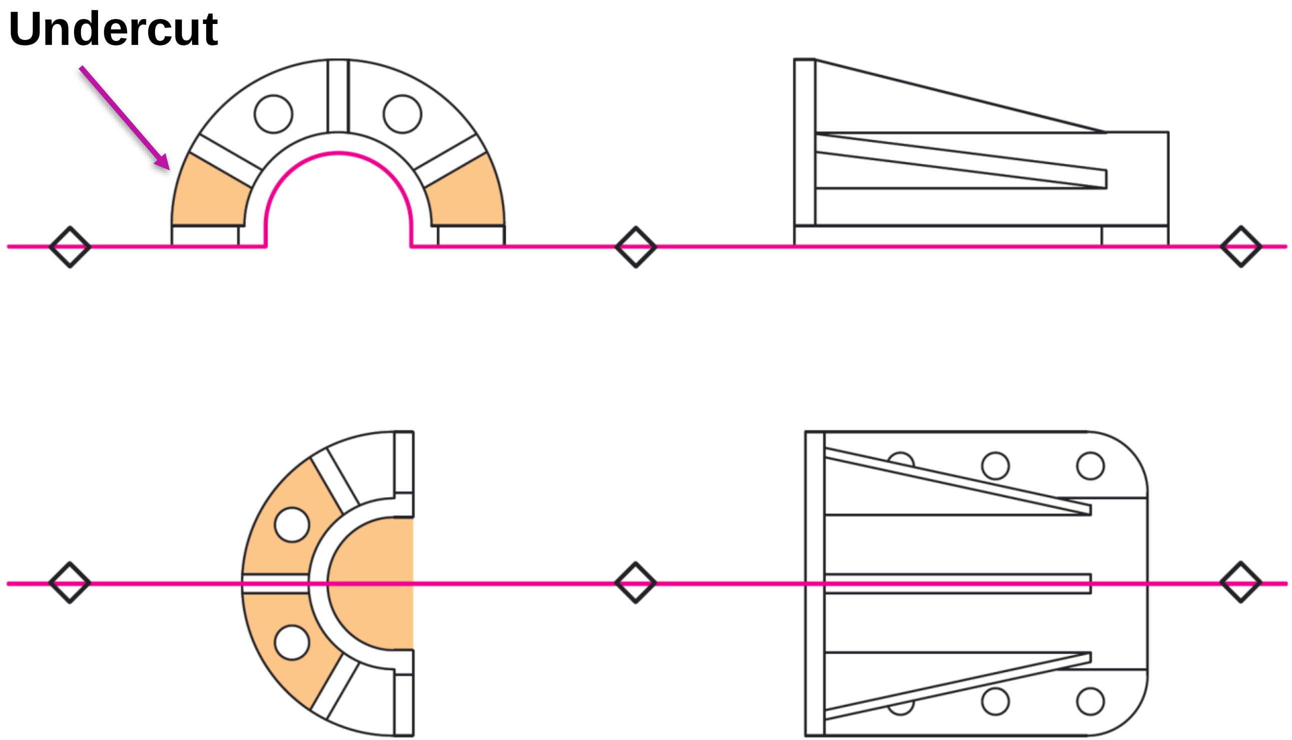
**Trying to change an incorrectly referenced dimension later on might blow up models with errors**



# Parting plane = casting position

The choice of parting surface also decides casting position according to used moulding process

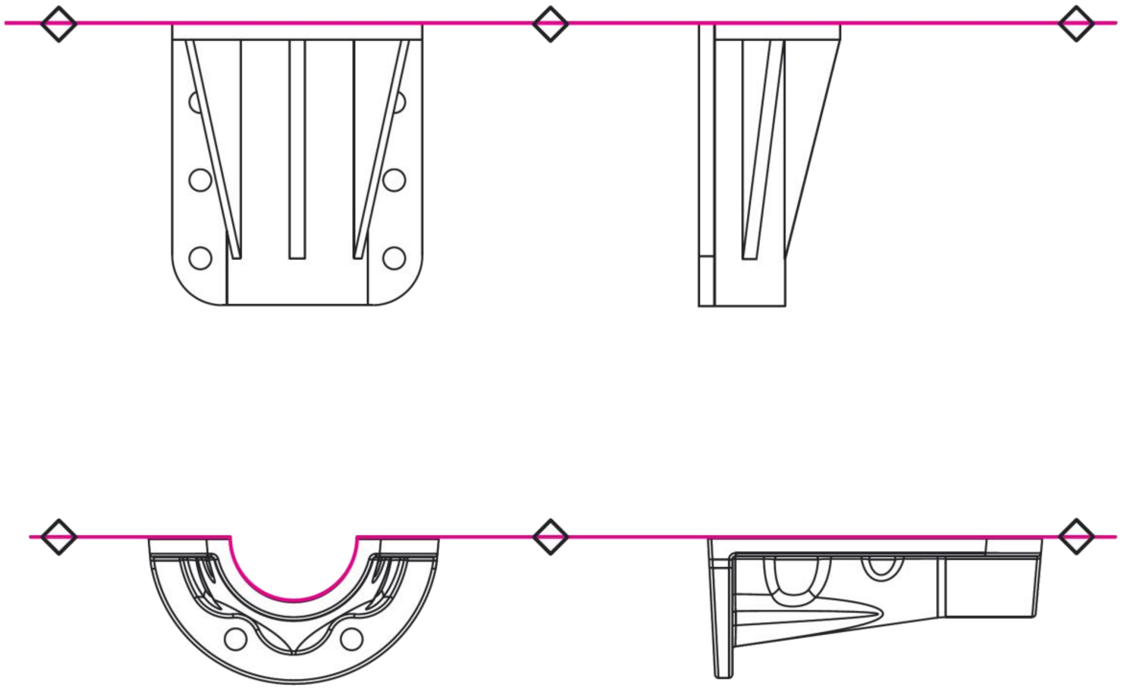
Undercuts should be avoided, although in some cases the use of cores to produce them are justified



# Parting plane

**Surfaces that need to be machined should be either horizontal or vertical if possible**

**If a geometry can be modified to use less cores without affecting functionality = profit**



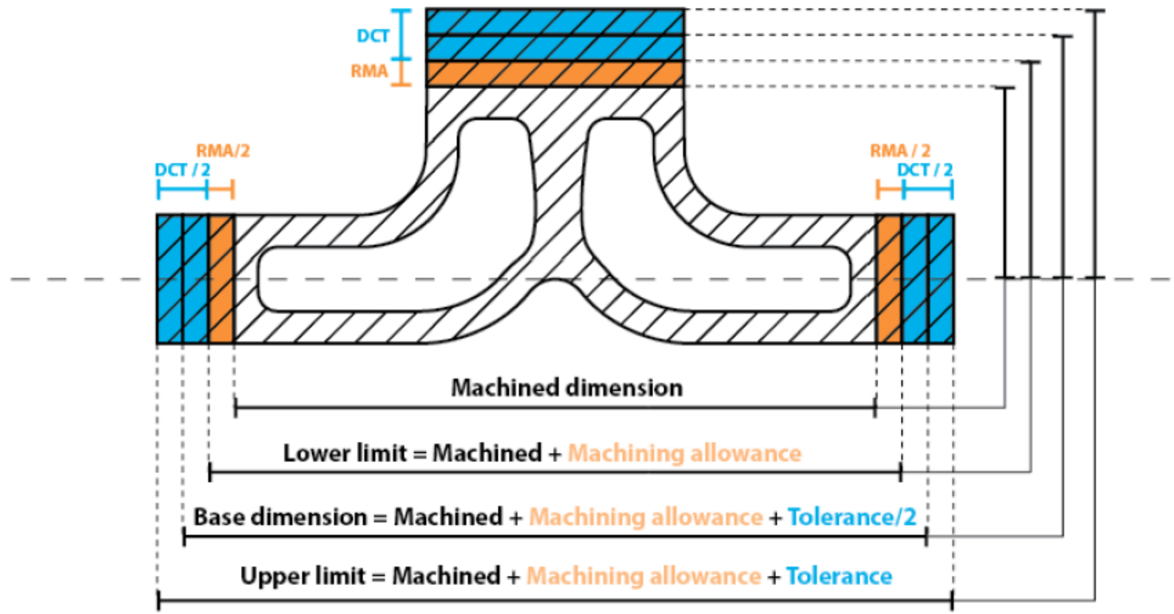
# Tolerances and allowances (DCT+RMA)

**Lots of factors affect the dimensional variability in castings**

- **Patternmaking**
- **Moulding process**
- **Cast material**
- **Solidification behavior**

**Dimensional tolerances assure that raw castings are not undersize**

**Machining allowances assure that there is enough material for machinists to actually make the part shown in drawings**

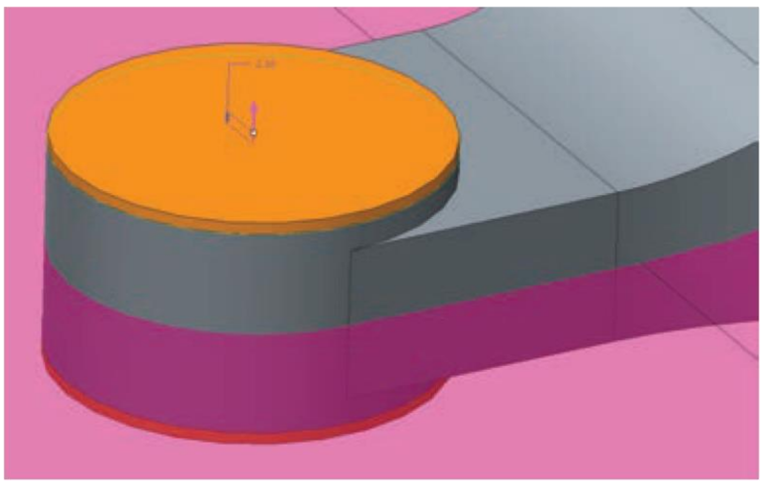


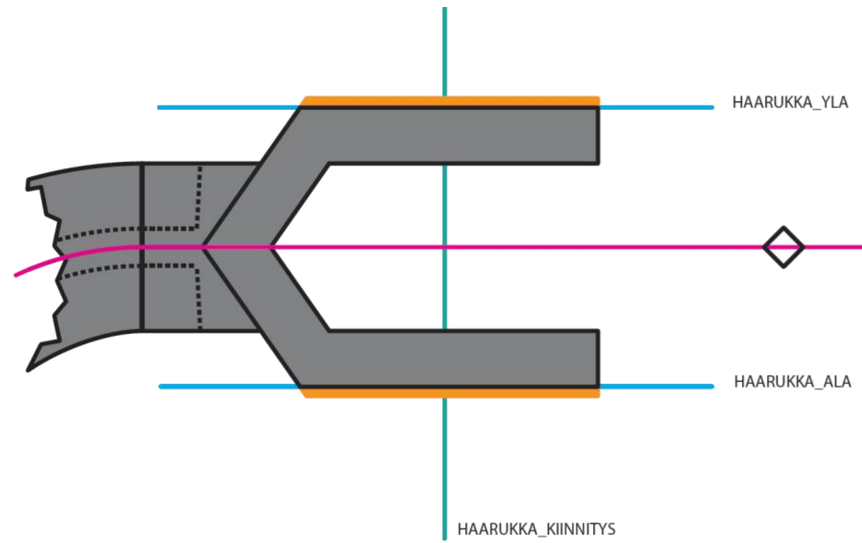

SFS EN 8062-3

# Tolerances and allowances (DCT+RMA)

**If a proper design approach is followed, adding tolerances and allowances is easy and does not mess with the model**

**Note the use of planes for this step.**

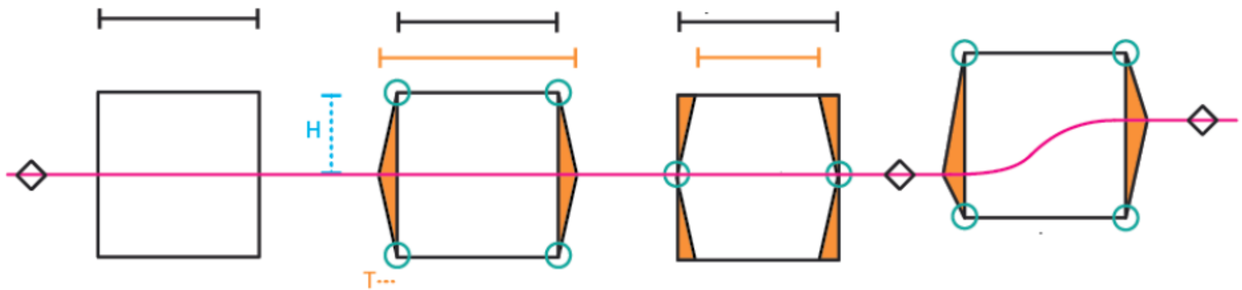




# Drafts

**Drafts are essential in making good patterns and castings. Slightly angled surfaces release easily from patterns, those normal to parting surfaces do not. Drafts should always add material rather than remove (final dimensions!).**

**Drafted features from different mould halves should meet at the parting surface to avoid odd geometries and sharp edges. Patterns without draft will likely damage moulds or itself due to friction etc.**



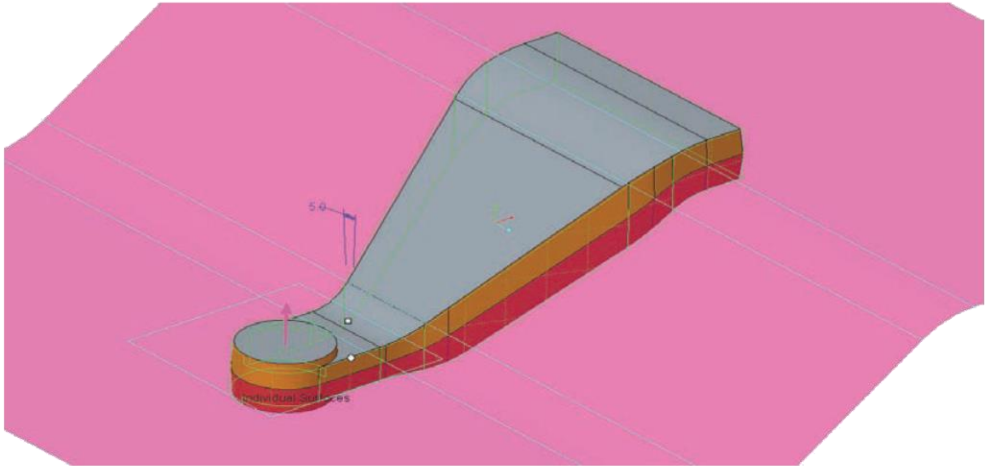

**Drafts for sand casting**

| Feature height ($H$) | $H \leq 30mm$ | $30mm < H \leq 80\ mm$ | $80mm < H \leq 180mm$ | $180mm < H \leq 250mm$ |
|---|---|---|---|---|
| Draft ($T$) | 1 mm | 2 mm | 3mm | 4 mm |
| Angle (○) | 4 ° | 3 ° | 2 ° | 1 ° |

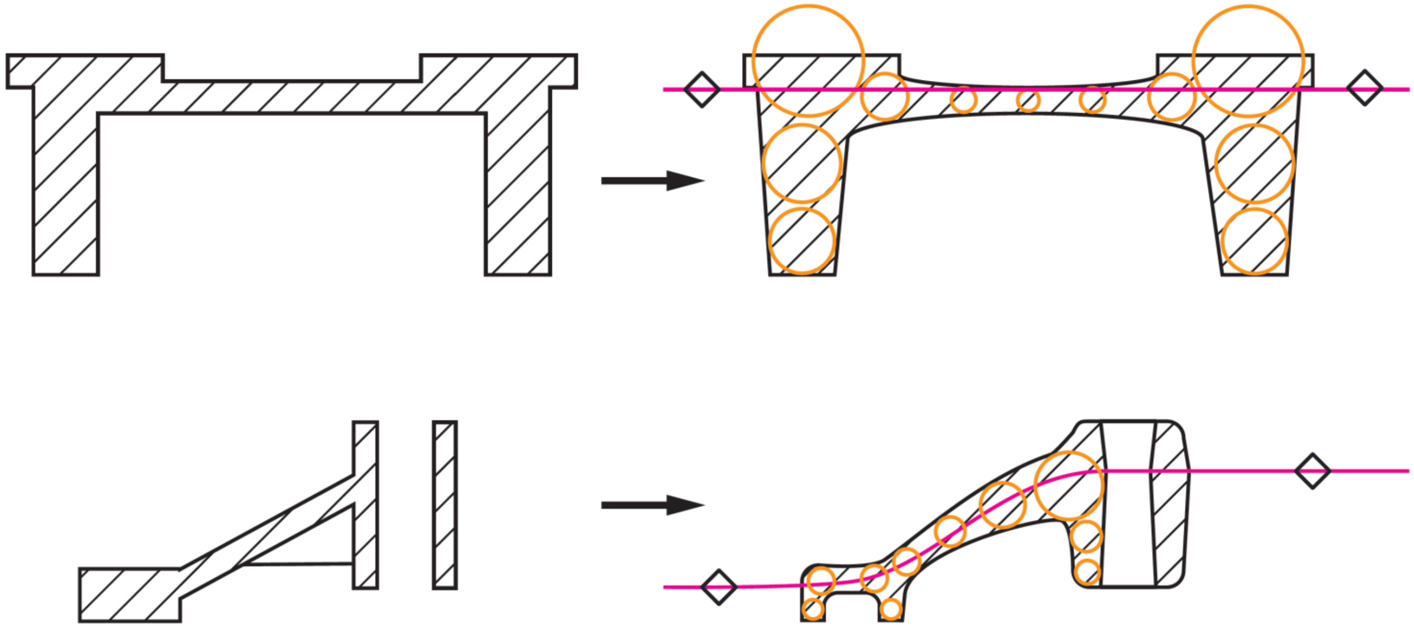
# Drafts

Foundries often have their own guidelines for using drafts, as they mostly handle the design process after the base component design is given by a customer

Some information on proper drafting can be found in SFS EN 12890



# Directional solidification



Mass concentrations should be avoided. More mass = more heat. When section thicknesses increase towards certain points in parting surfaces, components naturally solidify towards those regions. Those areas can then be aided with feeders to avoid defects, such as porosity.

# Directional solidification

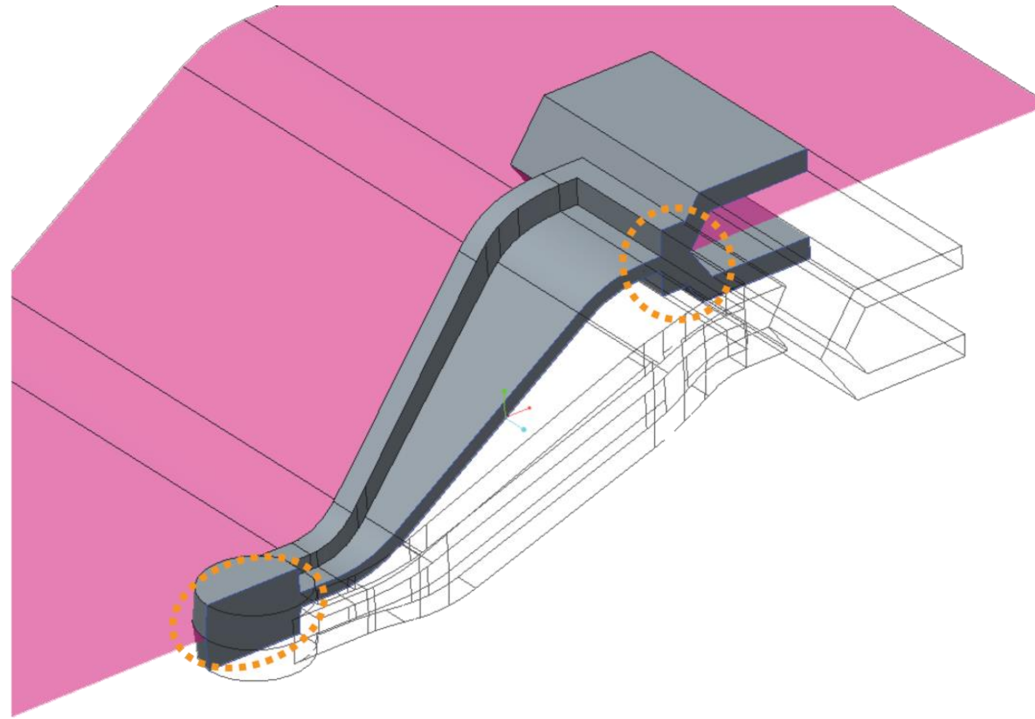
**Certain mass concentrations might not be possible to remove**

**In such cases…**

- **Feeders (more metal)**
- **Feed pads**
- **Chills (faster cooling)**

**… can be used**

**Essentially, control of heat transfer**



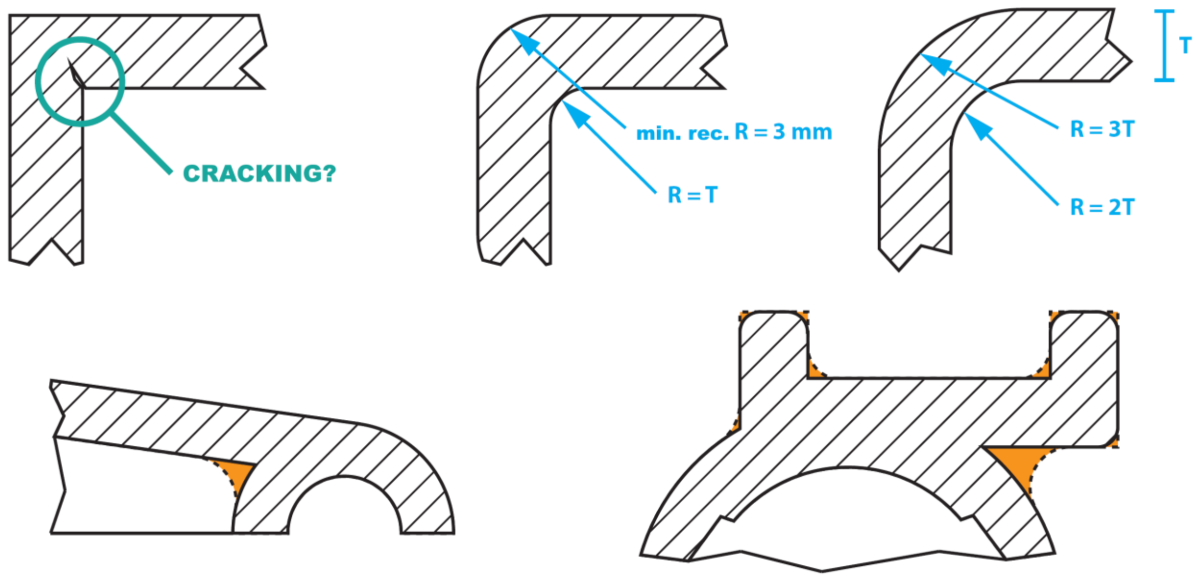
# Rounds

**Sharp corners in patterns, moulds and actual components are prone to damage**

**Rounds are as essential part of casting design as drafts**

**Adding rounds should not create mass concentrations**

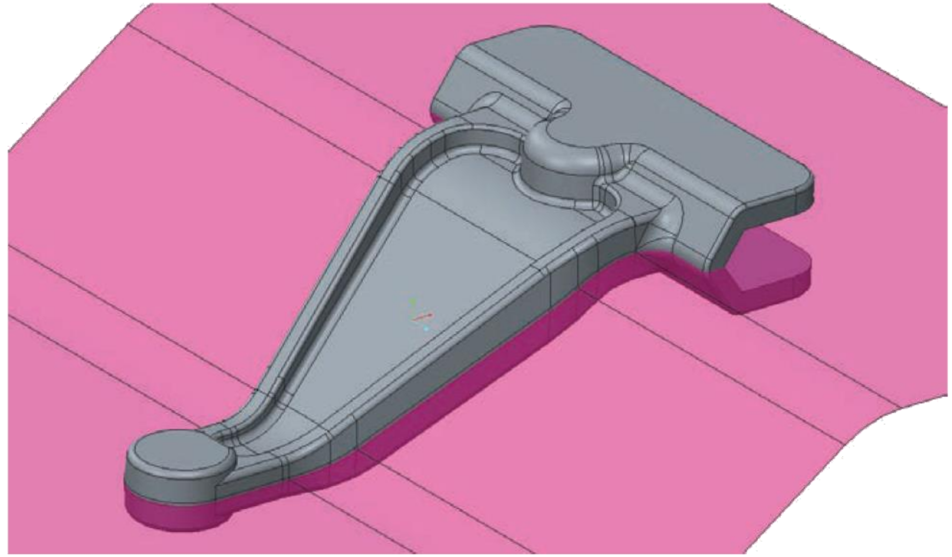
**→ R = depends on the case**



# Rounds

**Rounds should be added only after drafts and as final features due to the way CAD software handles them**

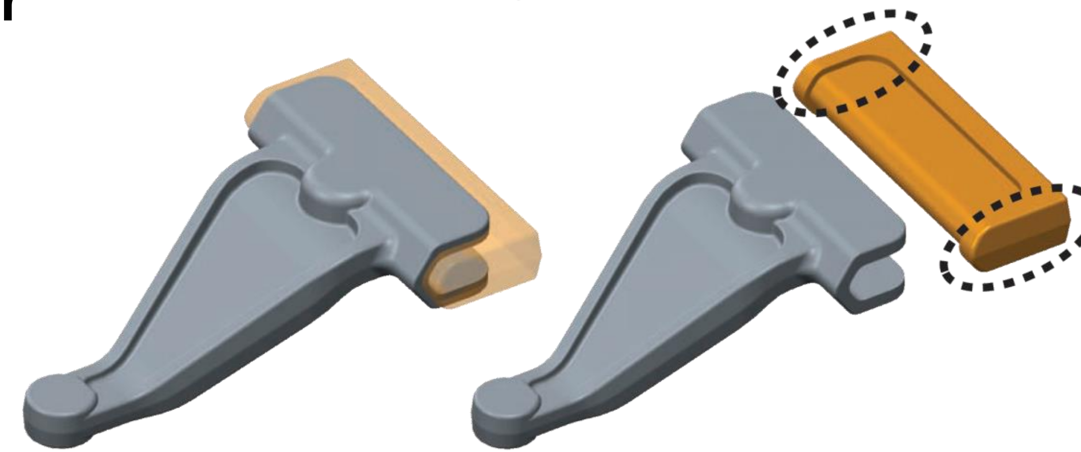
**Trying to add drafts to rounded features is in most cases futile**



# Core design

Core design is made after the component features are done

Cores always need to be supported/located properly inside moulds



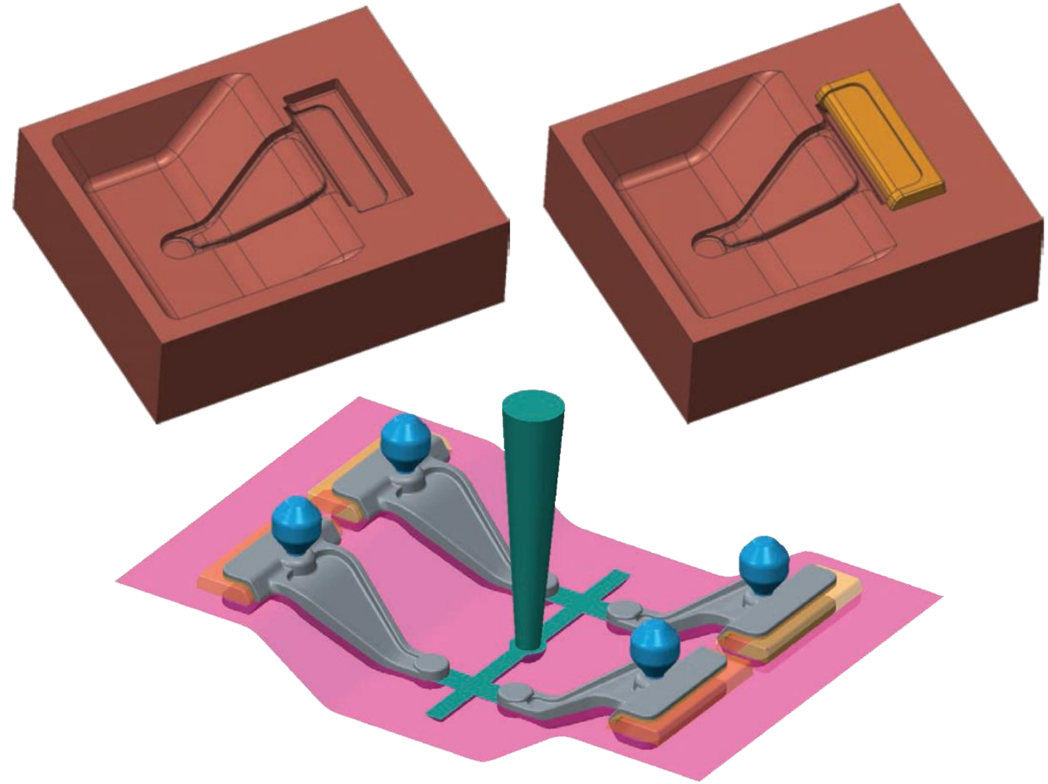
# Mould and filling system design

Mould and filling systems are designed after component designs are “finalized”

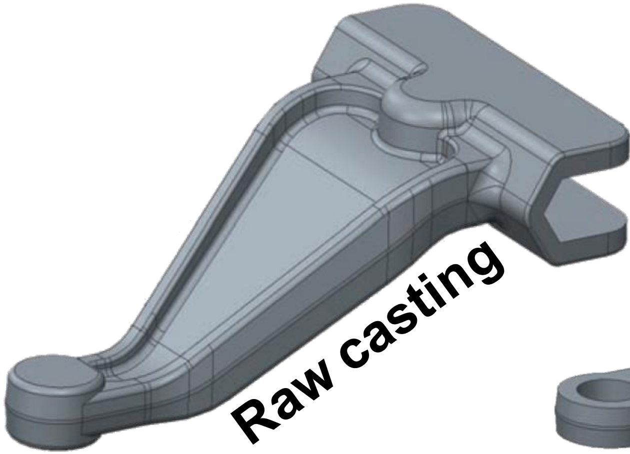
These also affect how components are designed

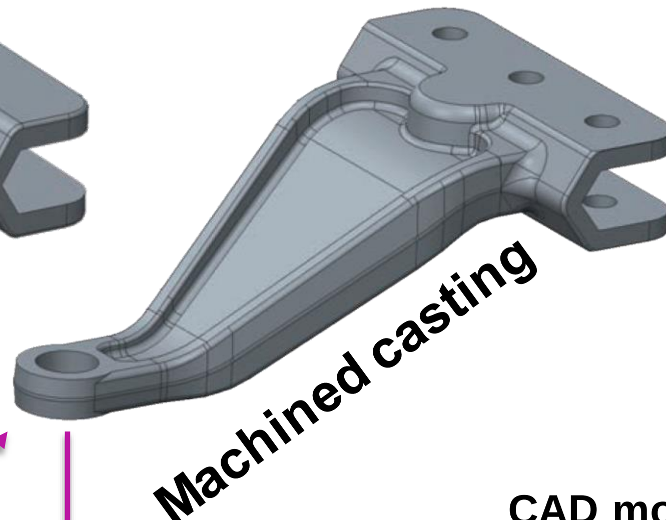
→ foundries often handle the casting + tooling design and the actual casting

However, if the designers of the end-component know casting principles = huge savings in lead time and costs



# Product states – design states





**Comes out of the foundry process**

**Comes out of a machine shop**

**CAD model of a casting can be used to make a machining design → tolerances and allowances OK?**

# Some relevant standards

**SFS EN 8062-3:** Geometrical part specifications. Tolerances and allowances.

**SFS EN 10135:** Drawing marking in technical documentation.

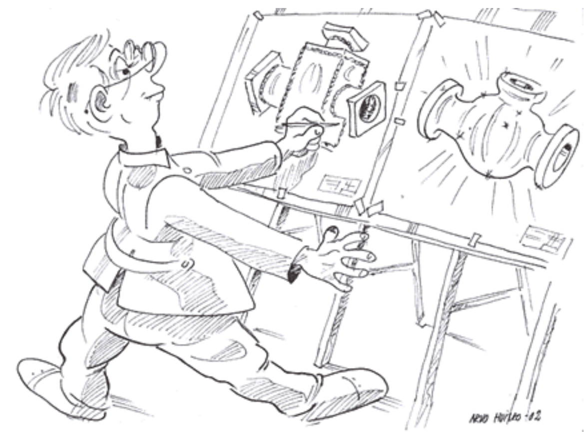
**SFS-EN 12890:** Drafts

# Examples of modifying components to be mouldable/castable

**Engineers that design machined or welded constructions often have a certain mindset/approach to passable geometries/features**

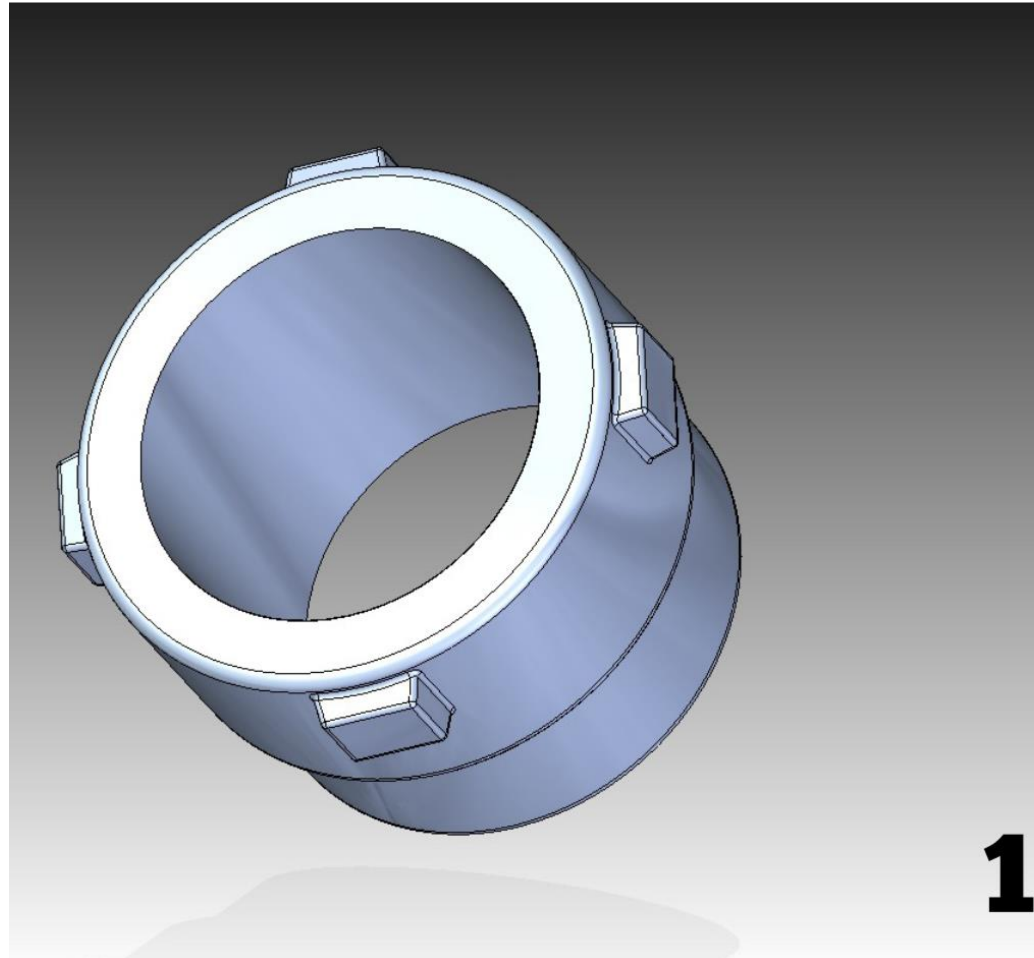
**Those that design castings also do, but often need to take more subsequent processes into account**

**Much depends on whether the design is made from ground up or if it is modified from something that was done with another process**



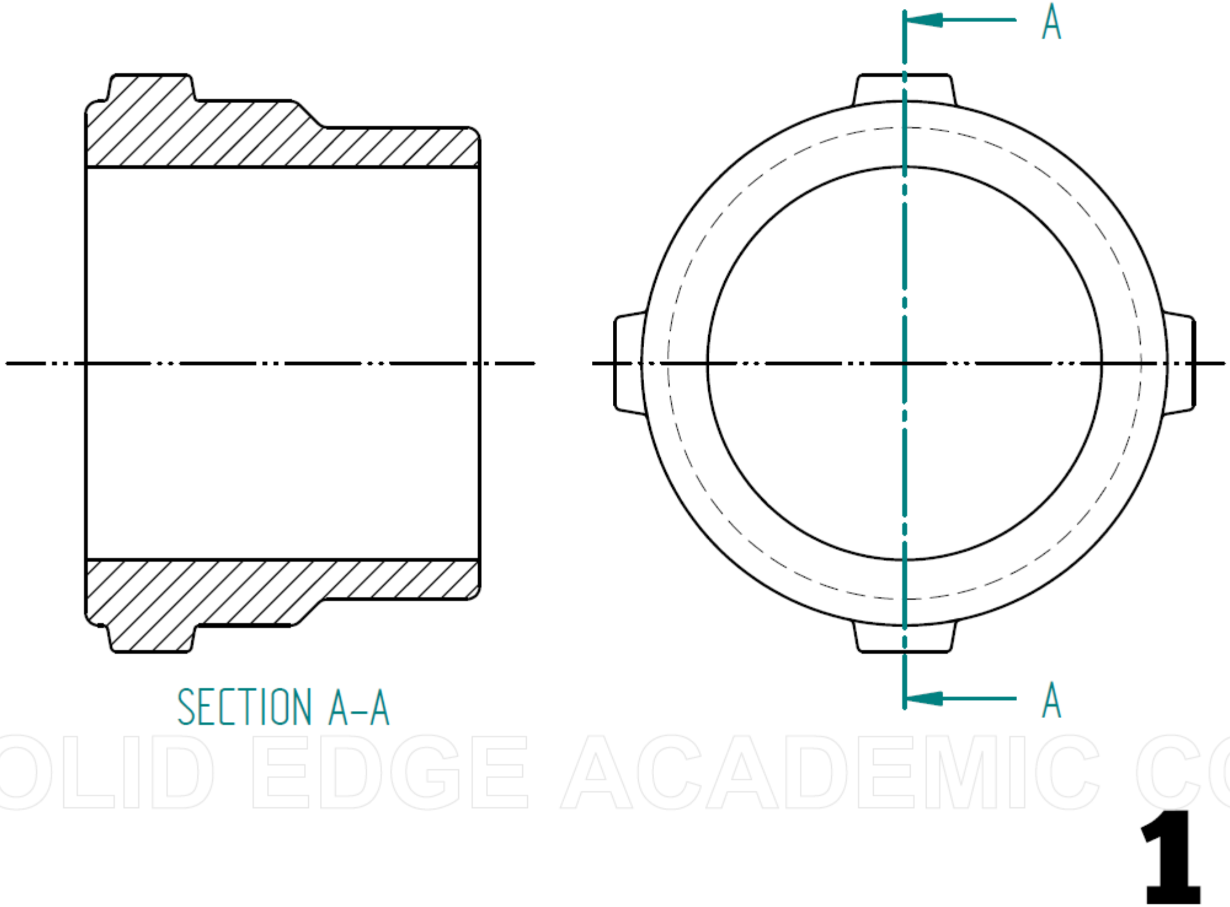
**Design considerations:**

- **Parting plane**
- **Use of cores**
- **Functionality**
- **Symmetrical features?**



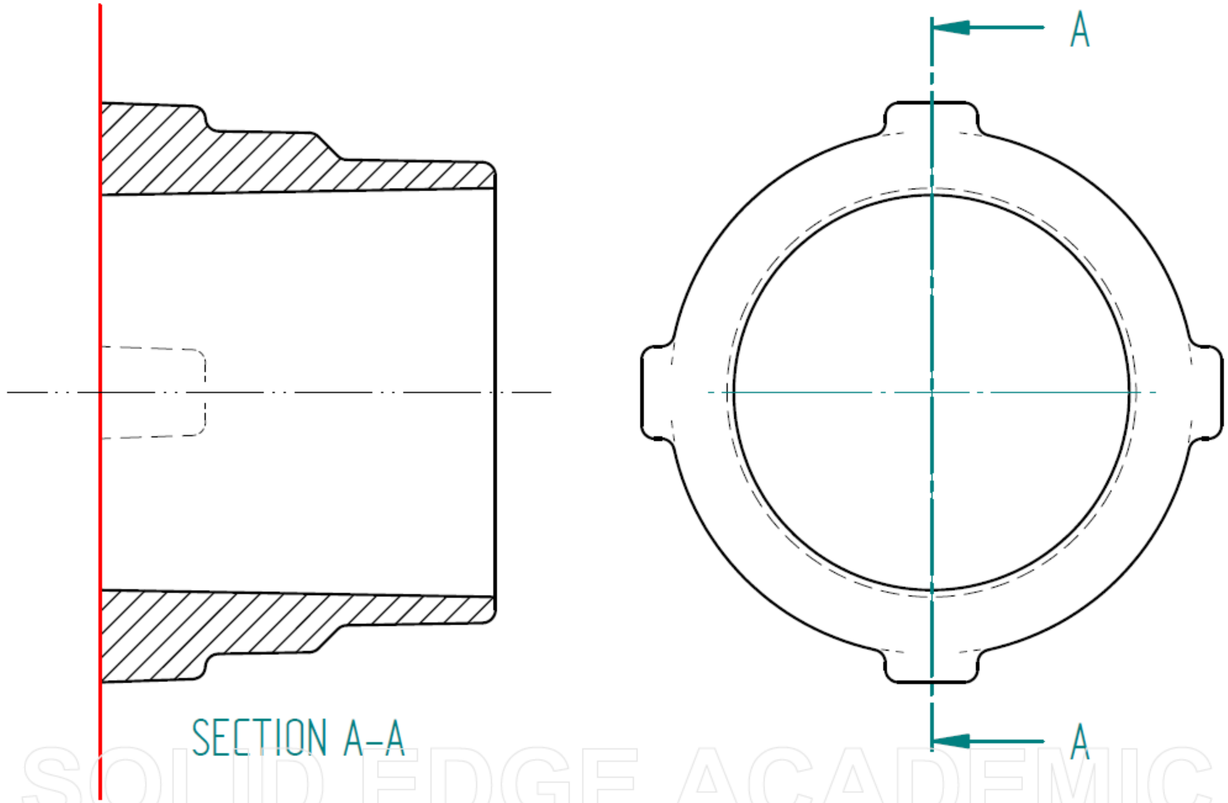
Maybe a 2 part pattern with a parting surface in the middle?

A core for the hole?



The whole part could be done with all the base geometry in one mould half, without any cores

If the hole needs to be machined to a certain dimension, the addition of draft vs. use of a core made no difference to **functionality**





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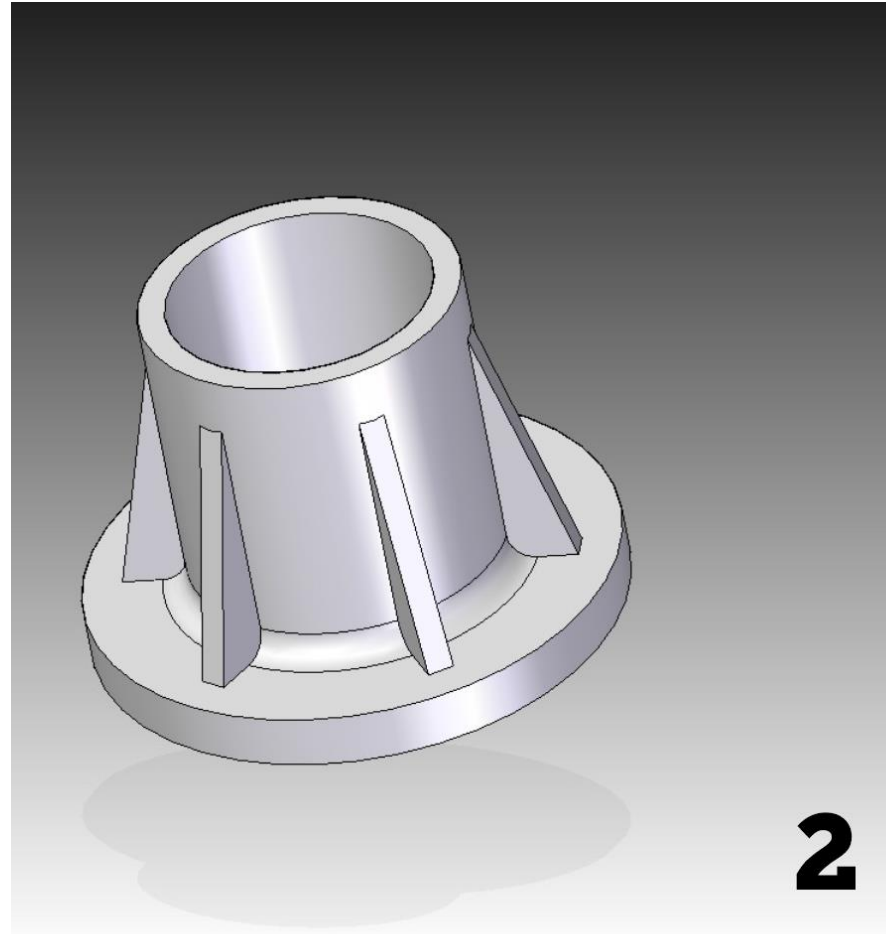
**Design considerations:**

- **Parting plane**
- **Use of cores**
- **Functionality**
- **Symmetrical features**
- **Undercuts**

**Reminiscent of a welded construction using flanges, ribs and a pipe section?**

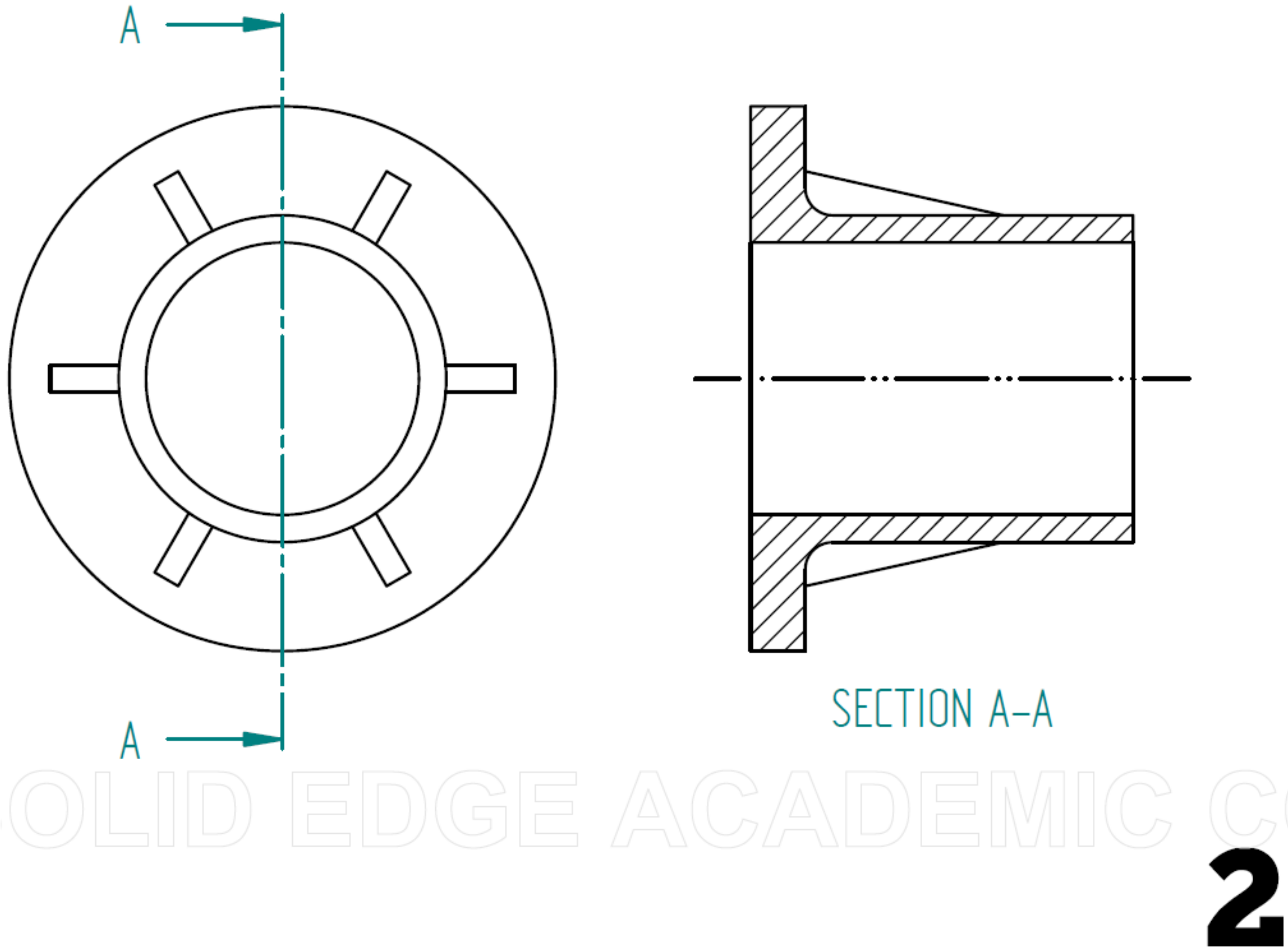
**Which parts are functional, which not?**



**If one wants to stick with the current ribs, undercuts are unavoidable**

**Could be split in two and use a core?**

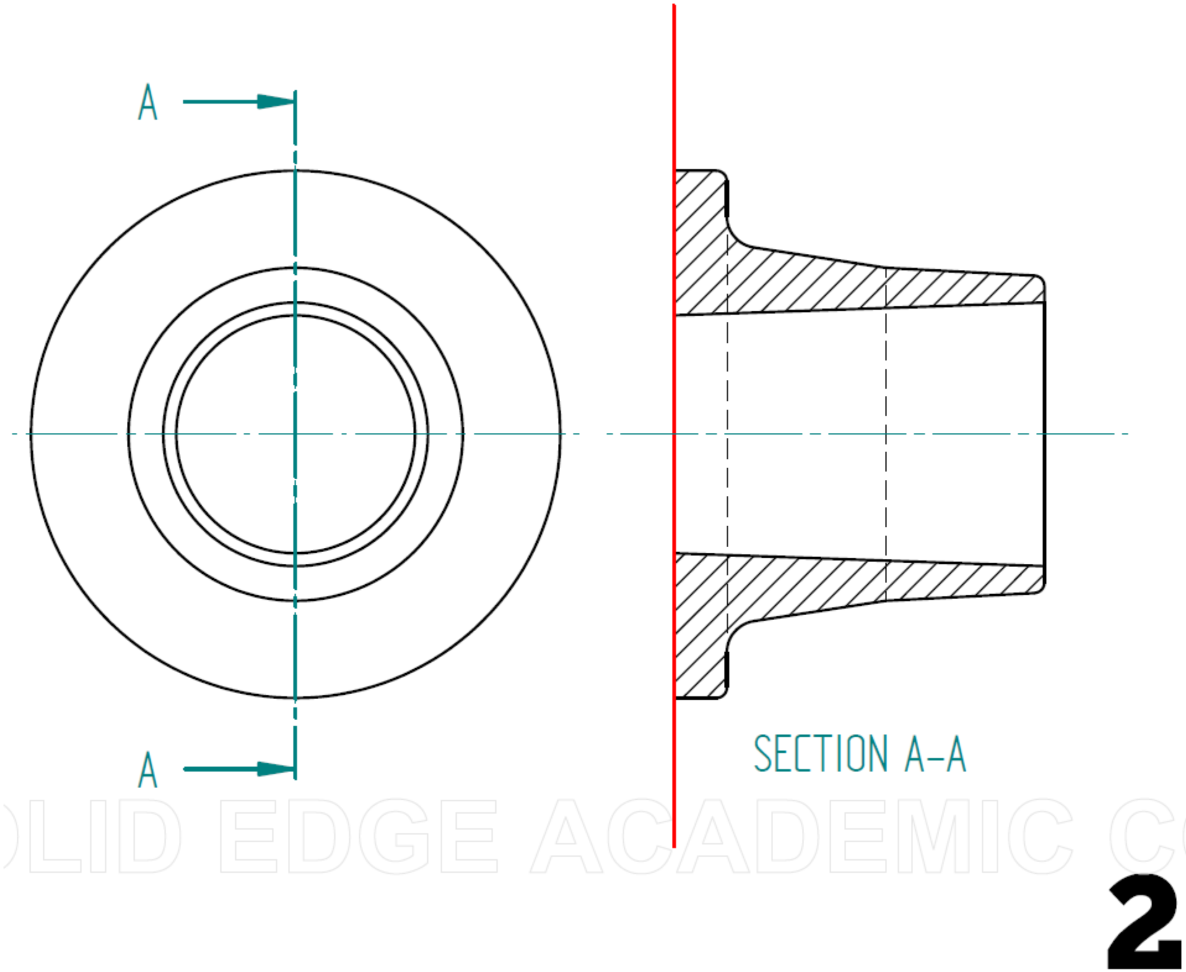
**Could the rib strengthening be done somehow else?**

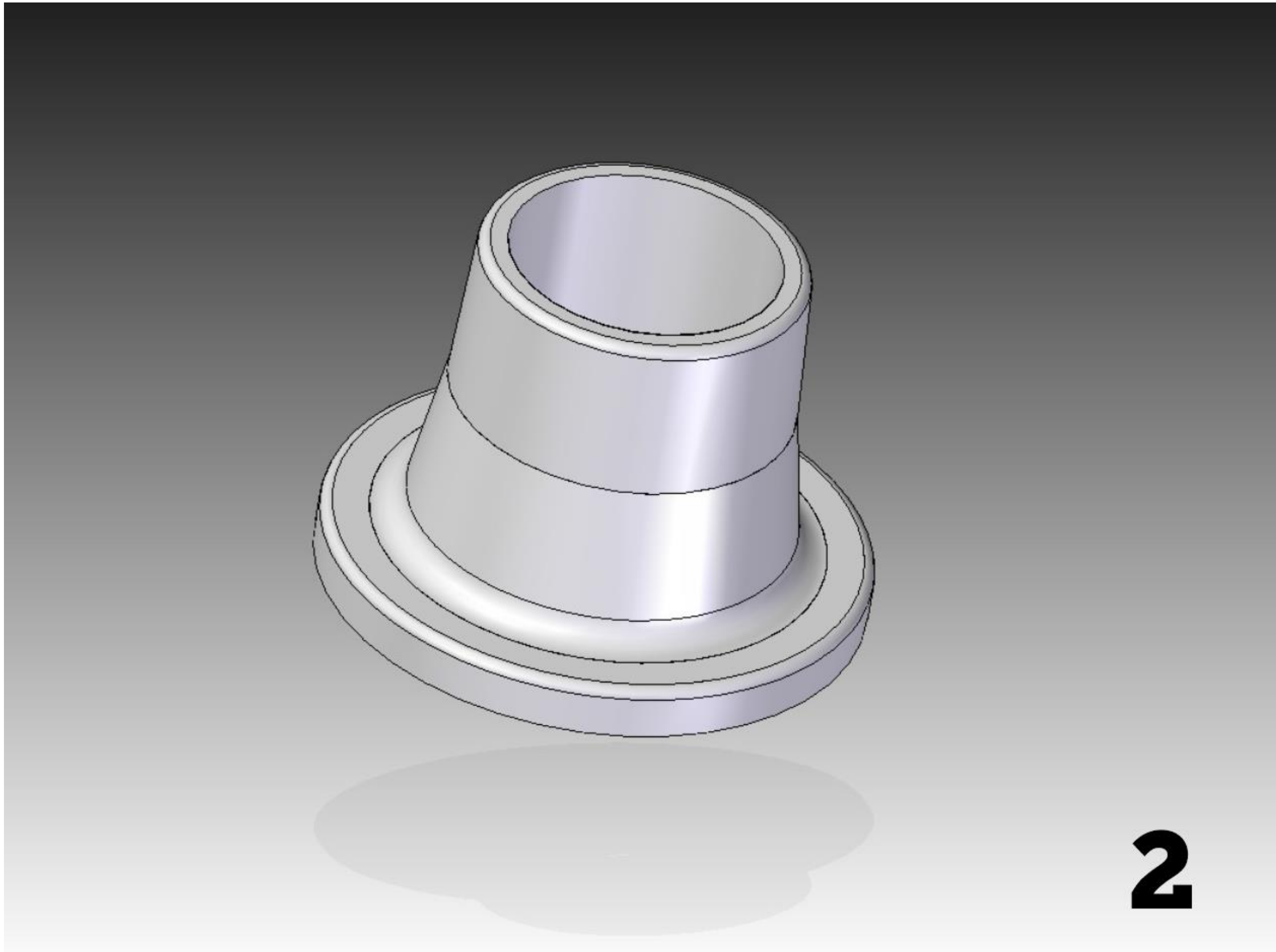


**Again, if one takes the casting design viewpoint to the extreme, the part geometry could be done single sided**

**Ribs could be replaced with material additions**

**The omission of ribs and wall thickness changes is also good for directional solidification**

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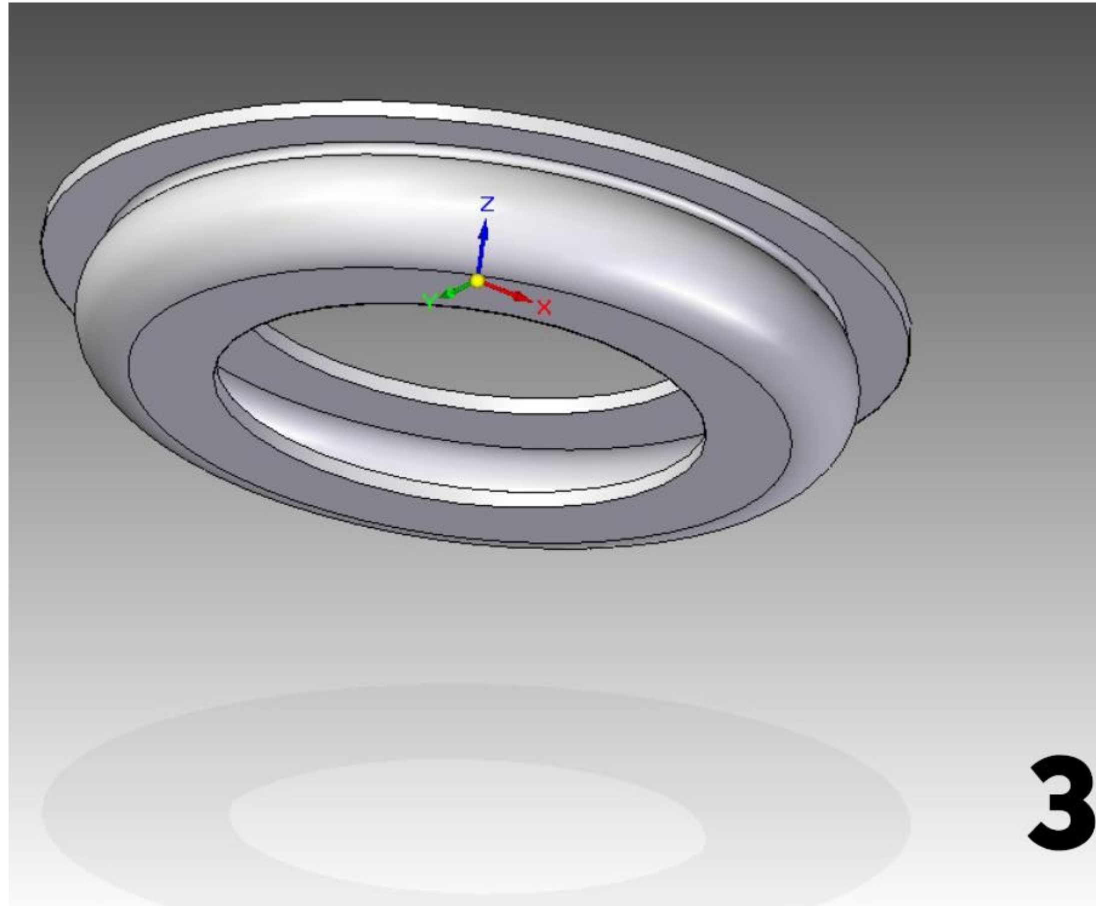
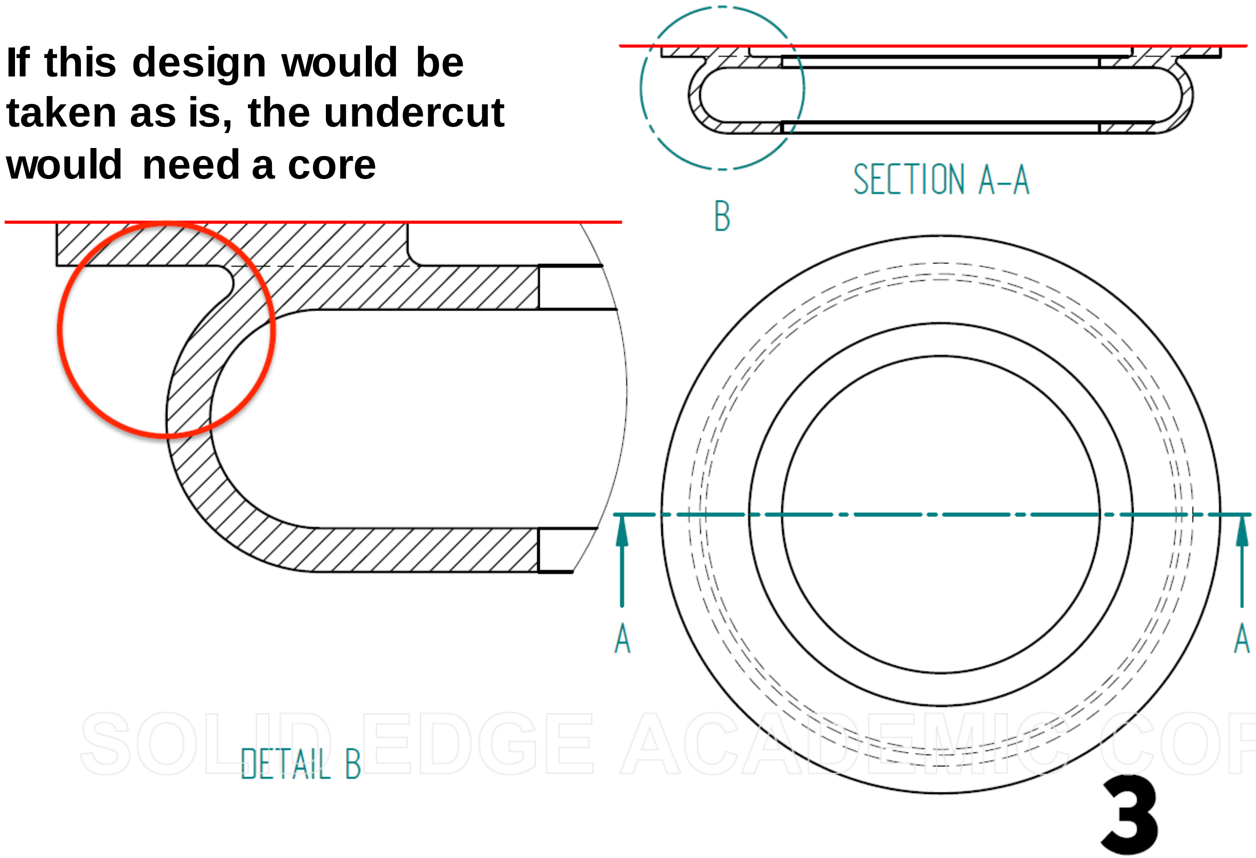
**Design considerations:**

- **Parting plane**
- **Use of cores**
- **Functionality**
- **Symmetrical features**
- **Undercuts**

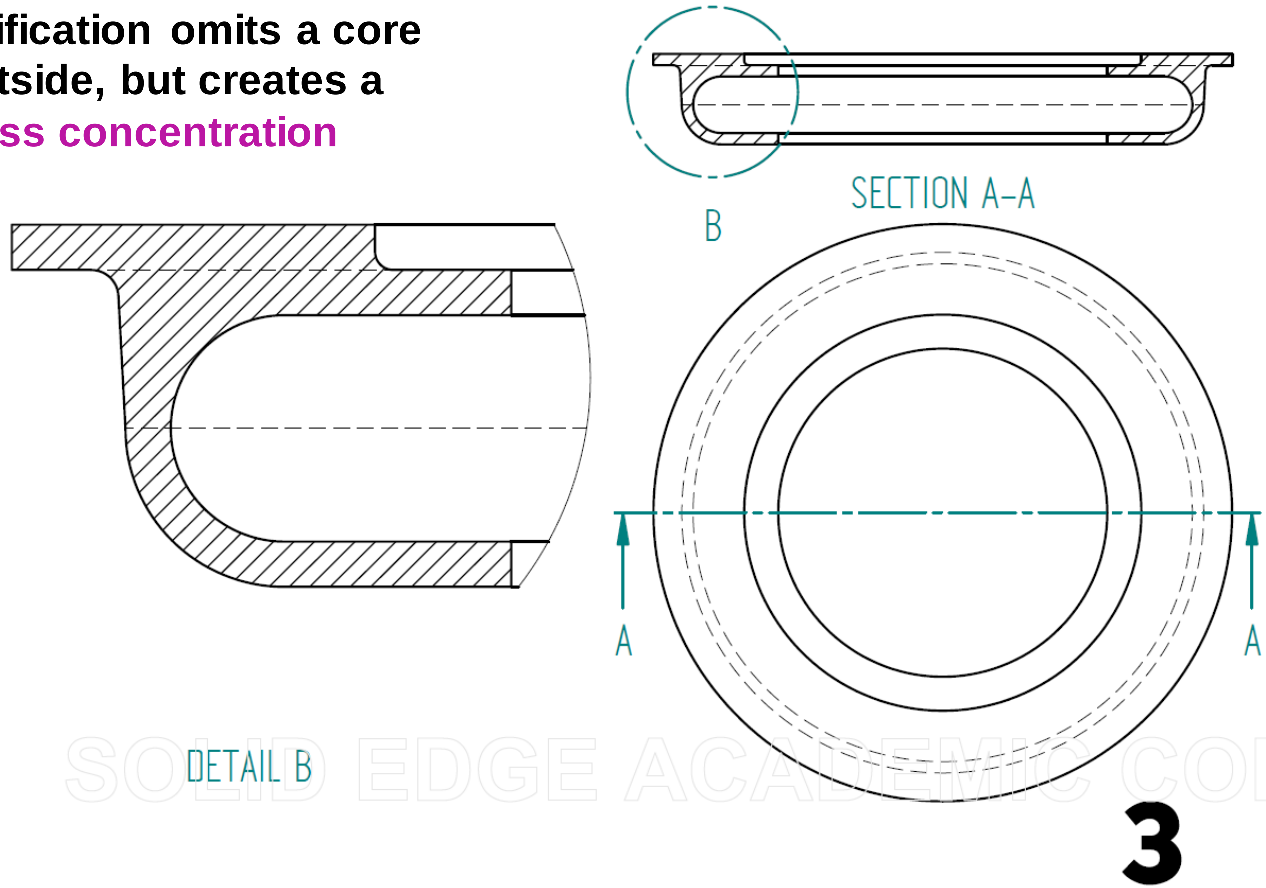
**Which parts are functional, which not?**



**If this design would be taken as is, the undercut would need a core**

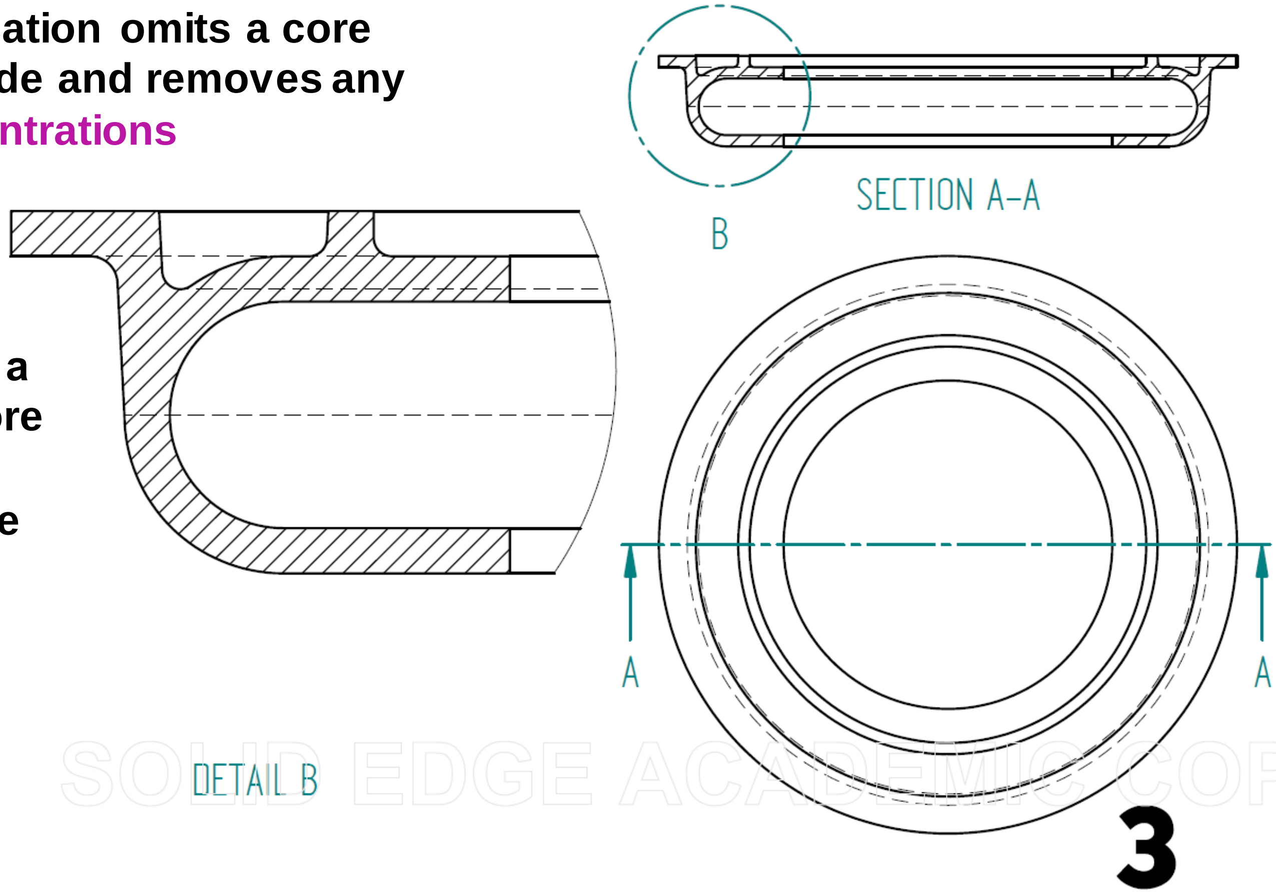


**This modification omits a core on the outside, but creates a heavy mass concentration**

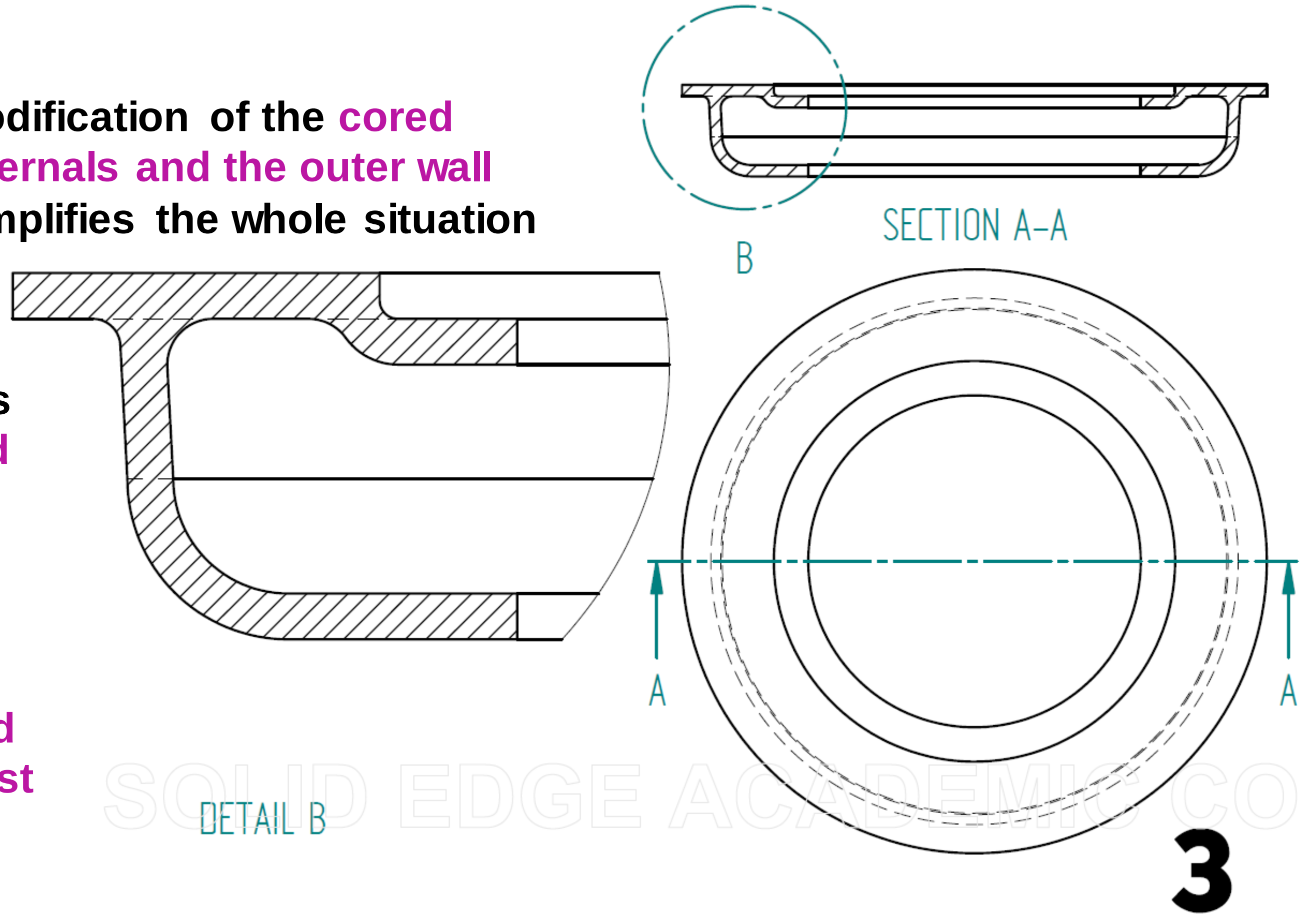


**This modification omits a core on the outside and removes any mass concentrations**

**…but creates a need for a more complicated pattern on one side**



**Modification of the cored internals and the outer wall simplifies the whole situation**





**All depends on what is allowed to be changed without affecting the functionality**

**Thus, communication between foundries and customers is of upmost importance**

# Good online resources

**A lot of e-books on material selection, casting etc. can be found on Knovel and other platforms through Aalto Learning Centre databases.**

**(2009). Casting Design and Performance. ASM International.**

**http://app.knovel.com/hotlink/toc/id:kpCDP00001/casting-design-performance/casting-design-performance**

**(1995). Investment casting. Maney Publishing**

**http://app.knovel.com/hotlink/toc/id:kpIC000011/investment-casting/investment-casting**

**(2001). Campbell, John. Castings. Elsevier. http://app.knovel.com/hotlink/toc/id:kpC0000001/castings/castings**

**(2011). Campbell, John. Complete Casting Handbook. Elsevier.**

**https://app.knovel.com/hotlink/toc/id:kpCCHMCPM1/complete-casting-handbook/complete-casting-handbook**

**For students that can read Finnish:**

**(2014). Valunsuunnitteluopas. Tapani Honkavaara.**

**https://www.valuatlas.fi/node/263**

**ValuAtlas oppimateriaalit**

**http://www.valuatlas.fi/**

Aalto University
School of Engineering

# Simulation and other computational aspects of casting design

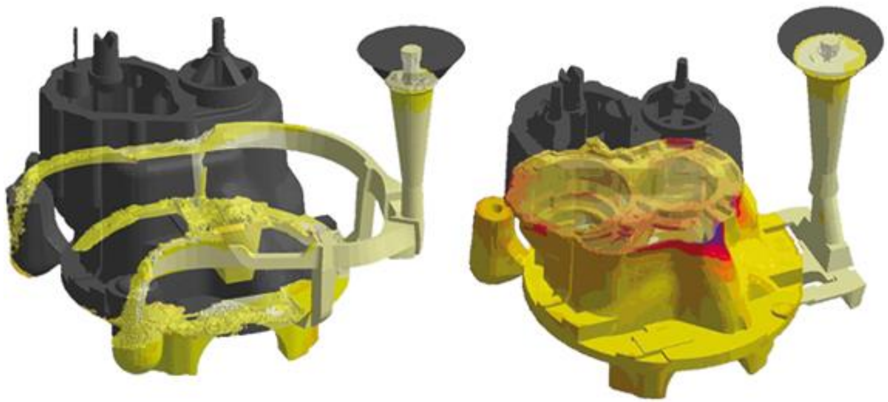
Aalto University
School of Engineering

# All models are wrong, but some are useful

# Why simulate?

**Full control of production processes:**

- **Moulding and core shooting**
- **Mould/Die preparation**
- **Pouring/filling**
- **Solidifaction/cooling**
  - Microstructures?
- **Shakeout**
  - Residual stresses?
- **Heat treatment/Distortion**

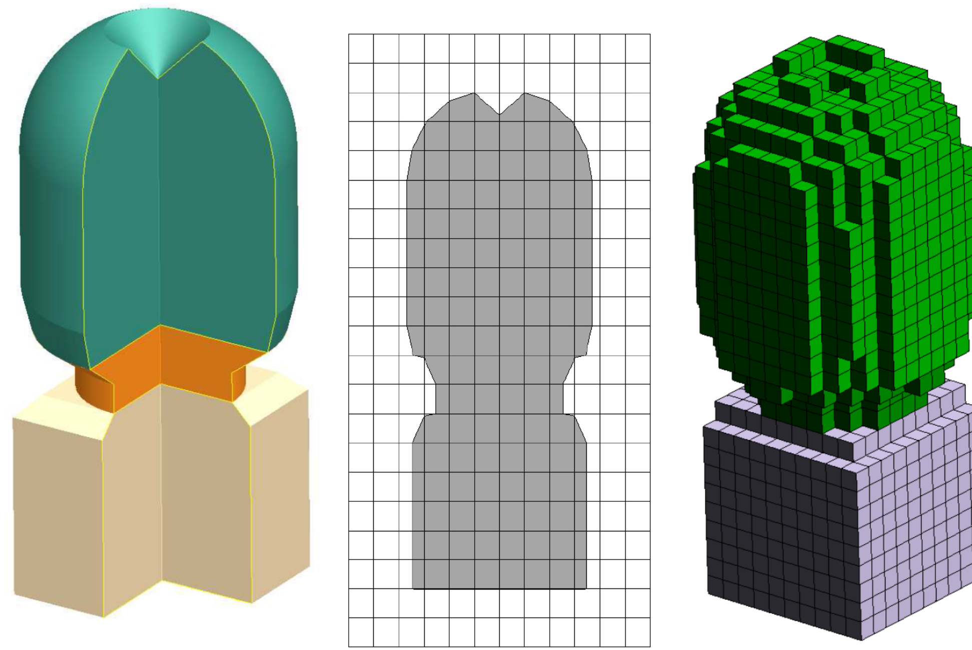


DESIGN & VALIDATE

# What is this all based on?

**Finite Element Method (FEM)**

- **CAD-models**
- **FEM meshing**



**Fluid dynamics**

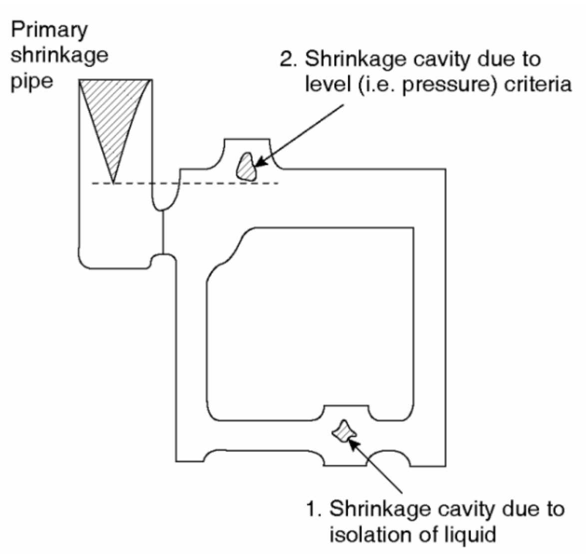
- **Melt behavior**

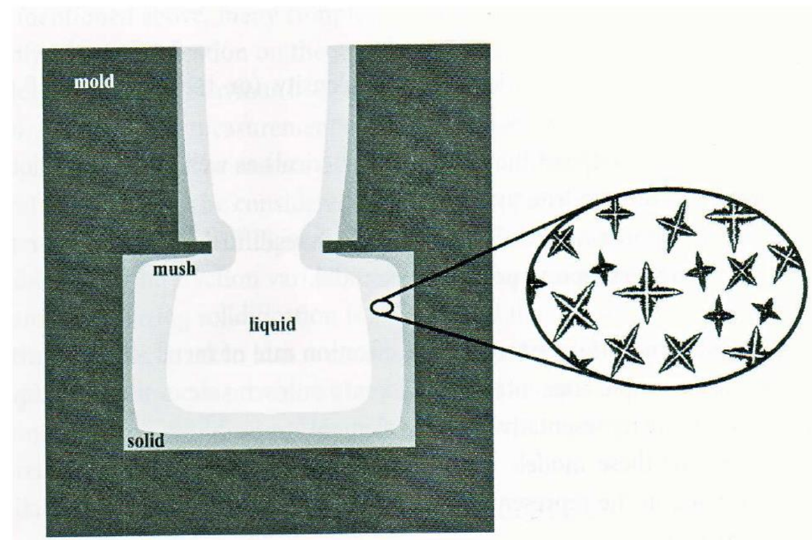
**Heat transfer**

- **Material models**

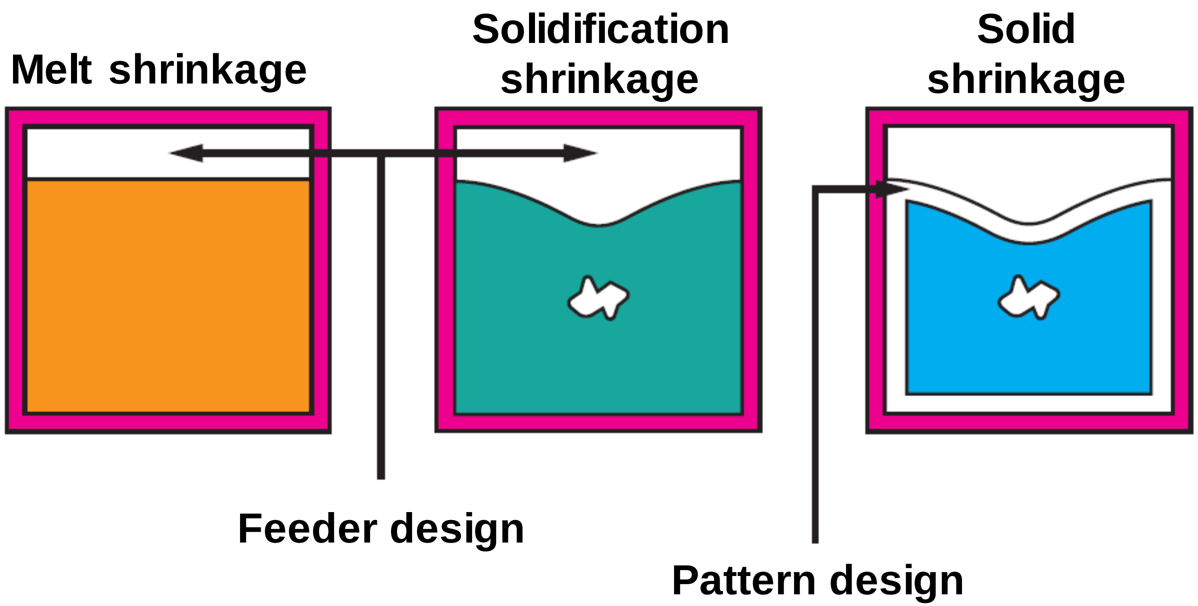
# Solidification optimization – why?

## Solidifying material contracts – need for additional feed material



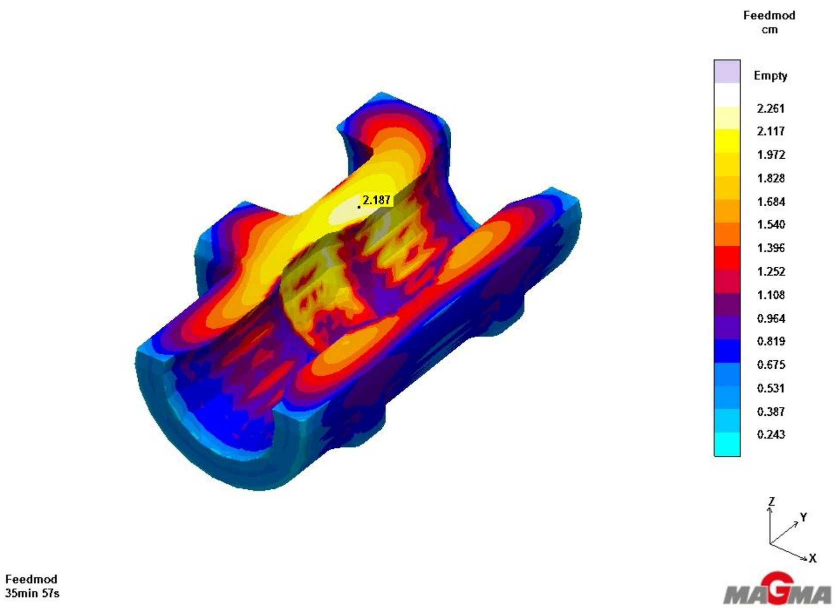
# Types of shrinkage in castings

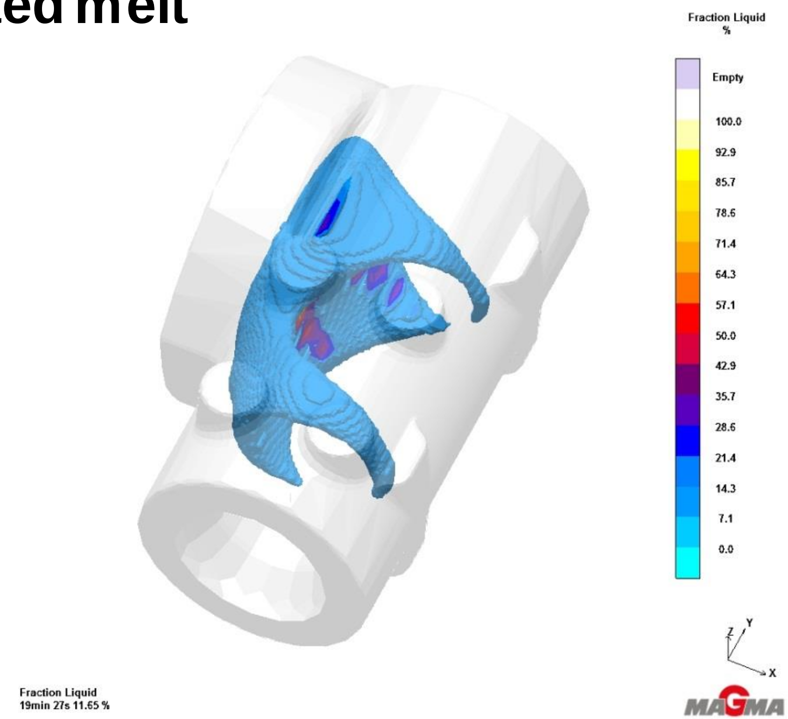



**To end up in dimensions you *actually wanted***

# Feeding optimization

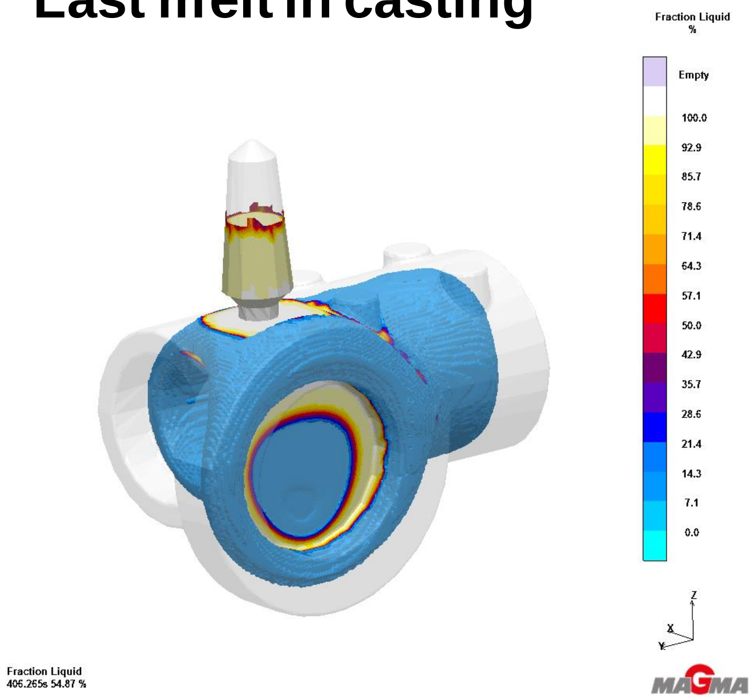
## Identification of hot spots and isolated melt



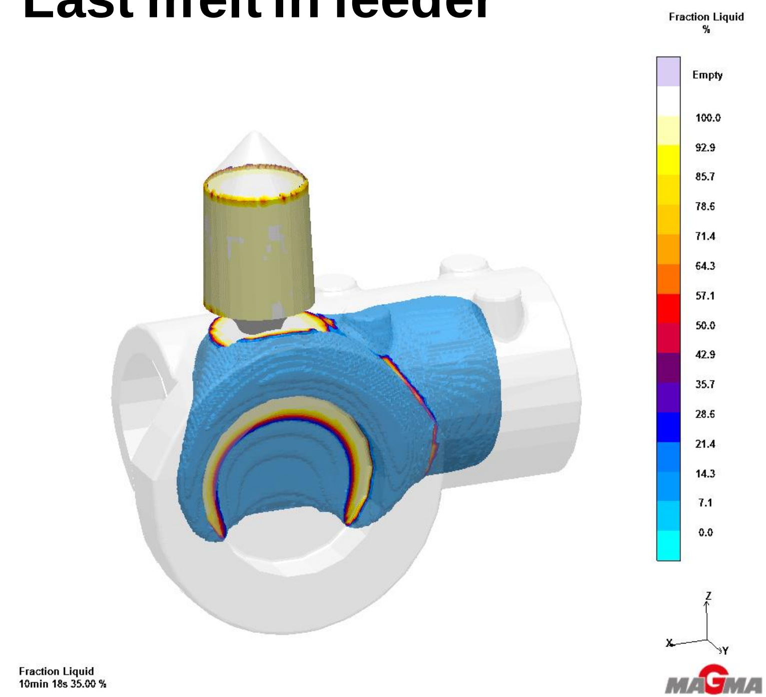



# Feeding effectivity – what is enough?

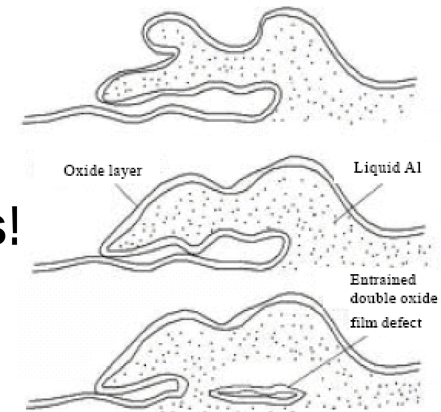
## Last melt in casting




## Last melt in feeder



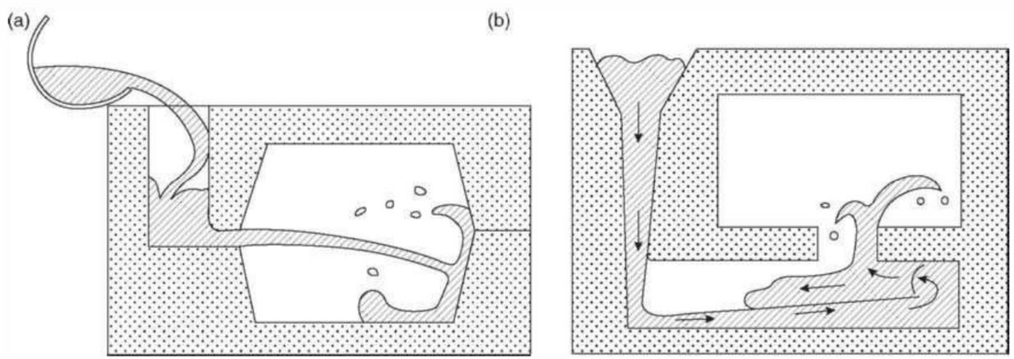
# Gating/Running/Filling

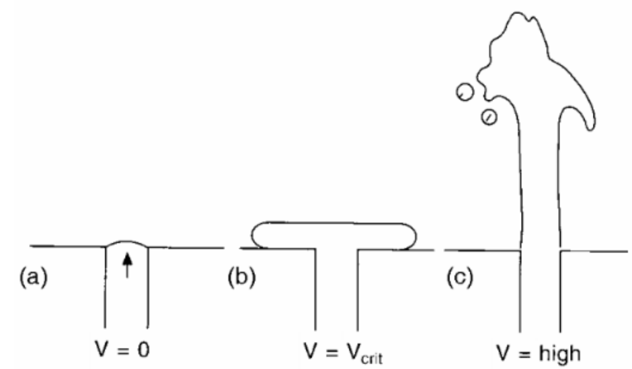



**Filling moulds as fast as possible – fully filled!**

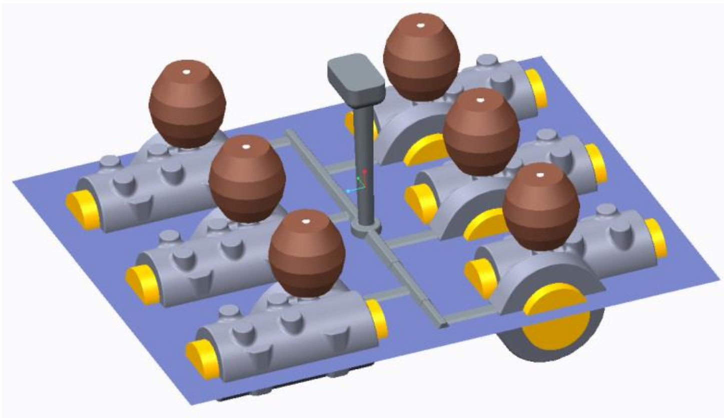
**As calmly as possible – no turbulent flow defects!**

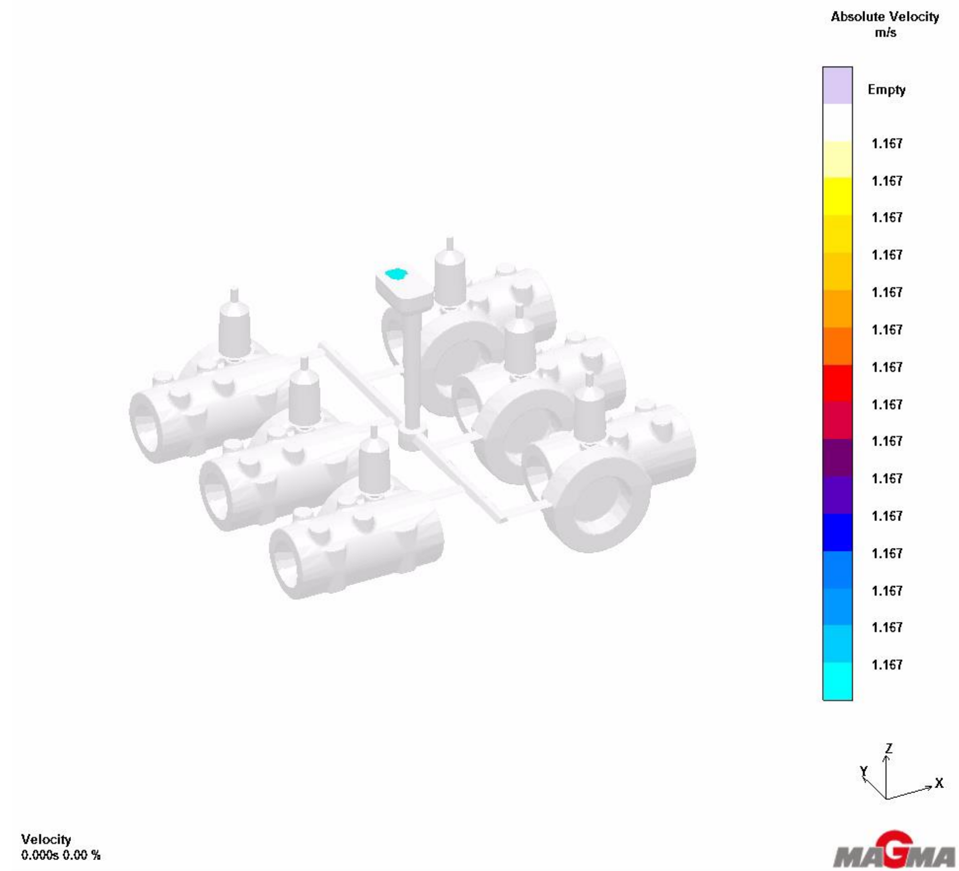
**Finding the optimal parameters with simulation**



# Mould filling






## Note melt flow and velocity

**Theoretical safe velocities are very low, but usual are somewhere between 0.5 – 1.0 m/s**

# In short

**Making tooling and casting parts that are defective is costly!**

**Simulation can be used to:**

***VALIDATE component*** **designs based on theoretical principles**
***IDENTIFY*** **problematic areas, e.g. mass concentrations**
***REDUCE*** **the need for practical casting tests**

***CONTROL PROCESS – CONTROL QUALITY***