CAMBRIDGE DESIGN PARTNERSHIP

Breaking the mould

Digital tooling to reduce time to market

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> “Getting new products to market efficiently is crucial to maximising your return on investment.”

Mike Cane
FOUNDING PARTNER, CAMBRIDGE DESIGN PARTNERSHIP

At Cambridge Design Partnership we make hundreds of prototypes during the product innovation programs we undertake for our clients in the healthcare and consumer sectors.

We are constantly searching for ways to create new products more quickly and efficiently. This is particularly challenging where component design is highly optimised, for example when developing complex medical consumables where material compatibility and secondary assembly processes such as welding are needed. In these programs prototyping accurate injection moulded parts in the correct material is essential to fully test the design.

This paper summarises our initiative to significantly reduce the lead time and cost for these parts. By making them available at the earliest point in the development program we can both reduce time to market and optimise the quality of the finished product.

The need for fast prototyping

Innovation is high on today's agenda because of the pace of technical and market change. It is crucial for brand owners and manufacturers to deliver new products to market quickly and economically, and prototyping plays a major role in this.

Product development can be understood as a learning process. The design engineer is finding out what the customer needs, what technology best delivers that functionality and how it can be embodied into a new product that offers a great user experience yet can be manufactured economically.

After a design is conceived it is detailed, prototyped, tested and iterated. This cycle is repeated many times as different configurations are tried and optimised. Even with today's sophisticated math modelling and computer simulation, the only way to be sure a new design works is to prototype and test it. The faster and more accurately these prototypes are made, then the quicker the design process can play out.

Image: Typical casework prototype stages for consumer electronics

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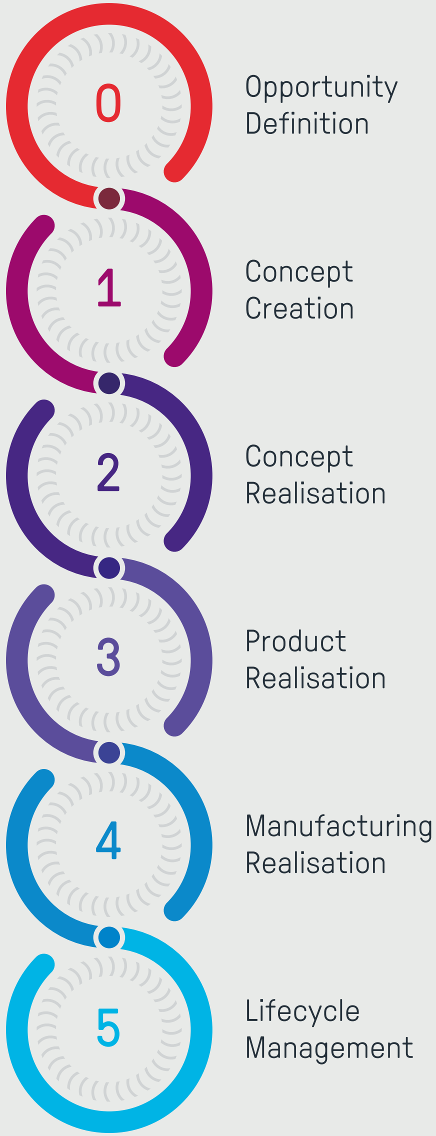
Innovation is high on today’s agenda because of the pace of technical and market change.

Potential Realised™ innovation process

At Cambridge Design Partnership we plan new product development using our generic process called Potential Realised. We believe the key to minimising time to market and development cost is to first collect evidence to understand exactly what customers need, and then to create appropriate concepts around them. Once they are validated, design engineers can start to learn first how to solve the technical challenges that have the widest implications, and then focus down one by one on smaller, more constrained problems. Once the design meets user, technical and production requirements it can be fully tested and certified ready for transfer to manufacture.



Plastic injection moulding

Plastic injection moulding is the most common manufacturing process for small mechanical parts. It makes tough, low cost components in high quantities from a wide range of polymers with different physical properties.

In early development phases components can be 3D printed to test their design, this makes accurate one-off parts straight from 3D CAD data with little manual intervention. It has been a game changer for product developers, providing the ability to move from the virtual CAD domain into the real world quickly, giving the designer a valuable insight into how the manufactured system will perform.

However, the polymers used in 3D printing have different properties to thermoplastics and there comes a point where the final production material is needed for high fidelity testing. For example, biocompatibility, creep, thermal performance and properties resulting from the moulding process itself cannot be mimicked accurately with 3D printing.

A traditional solution is to machine the component from a block of thermoplastic. While this is easy for simple shapes, the forces and heat generated by the machining process make it difficult and expensive to manufacture complex features.

Image: Nozzles assembled from three injection mouldings

Injection mould tool design

Tool design has matured over the last 70 years to meet the needs of mass production with short cycle times, long tool life and reliable automatic operation. The resulting format is relatively complex, time consuming and expensive to both design and make. The ratio of tool cost to part cost ranges from 1,000:1 to 2,000,000:1 in high volume. While this is fine for mass production, it does not make sense when only a few parts are needed and the design is likely to be changed.

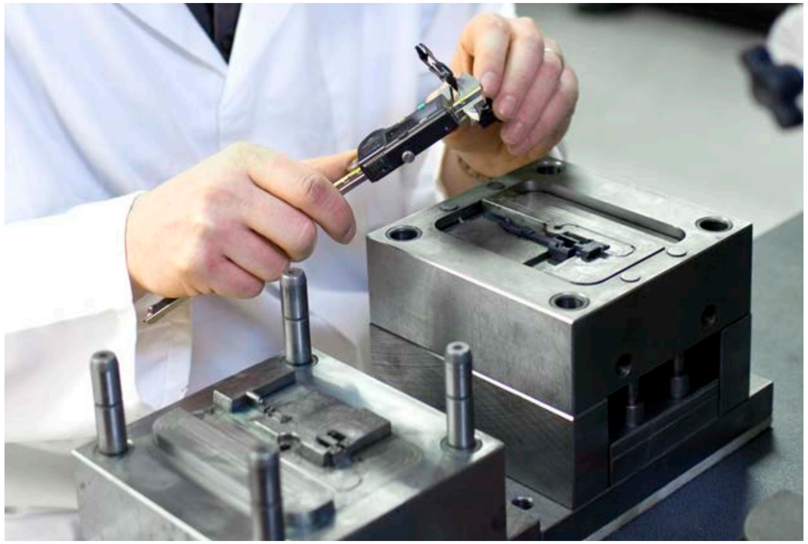
For plastic components to be manufactured efficiently they must be designed within the limitations of the injection moulding process (Design for Manufacture). For example, they should avoid features that add cost such as undercuts and thick sections, and address issues like gate location and draft that can create quality issues. These requirements must be finalised and qualified before the design is complete and expensive production tools are commissioned.

Image: Prototype mould tools made from CNC machined aluminium and steel

The development of prototype tooling

In the 1980's the widespread adoption of Computer Aided Manufacture (CAM) software combined with fast CNC Machining Centres reduced the time taken to manufacture mould tools by machining from softer materials such as aluminium alloy or mild steel. This resulted in the rapid growth of 'soft tooling' with some suppliers creating fully automated cells so lead times of a few weeks from design to moulded part became common.

But recently 3D printing has changed timescale expectations once again. The opportunity is to use additive manufacture to make geometrically complex tool cavities more quickly and at significantly lower cost compared to traditional processes.



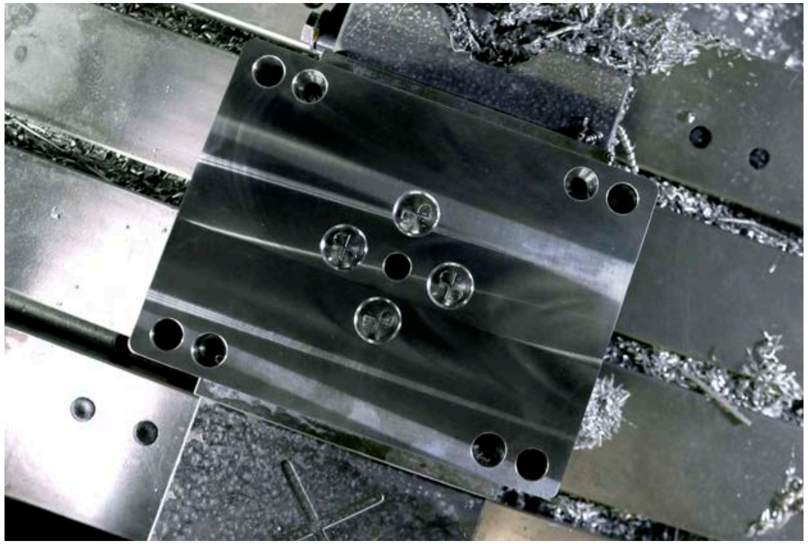


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Image: Insert component during printing

The potential of 3D printing

As polymer based 3D printing has developed, some manufacturers such as Formlabs and Objet have experimented making 3D printed mould tools and have developed optimised materials. The aim is to print conventional mould components that otherwise would have been made in metal.

In addition, some alternative approaches have been launched. For example AddiFab's system prints a single piece tool insert with a cavity inside. The mould is dissolved away to release the plastic part.

Metal 3D printing such as laser sintering lends itself to making conventional mould tools, but to achieve the precision required these parts are post machined. For example, the Matsuura Lumex system does both processes in a hybrid machine, where each new layer of sintered metal is machined as it is formed. This can create features such as deep ribs and undercuts that are impossible to machine because of tool access limitations. This allows mould cavities to be made in one piece, fully exploiting this automated approach.

The prototyping gap

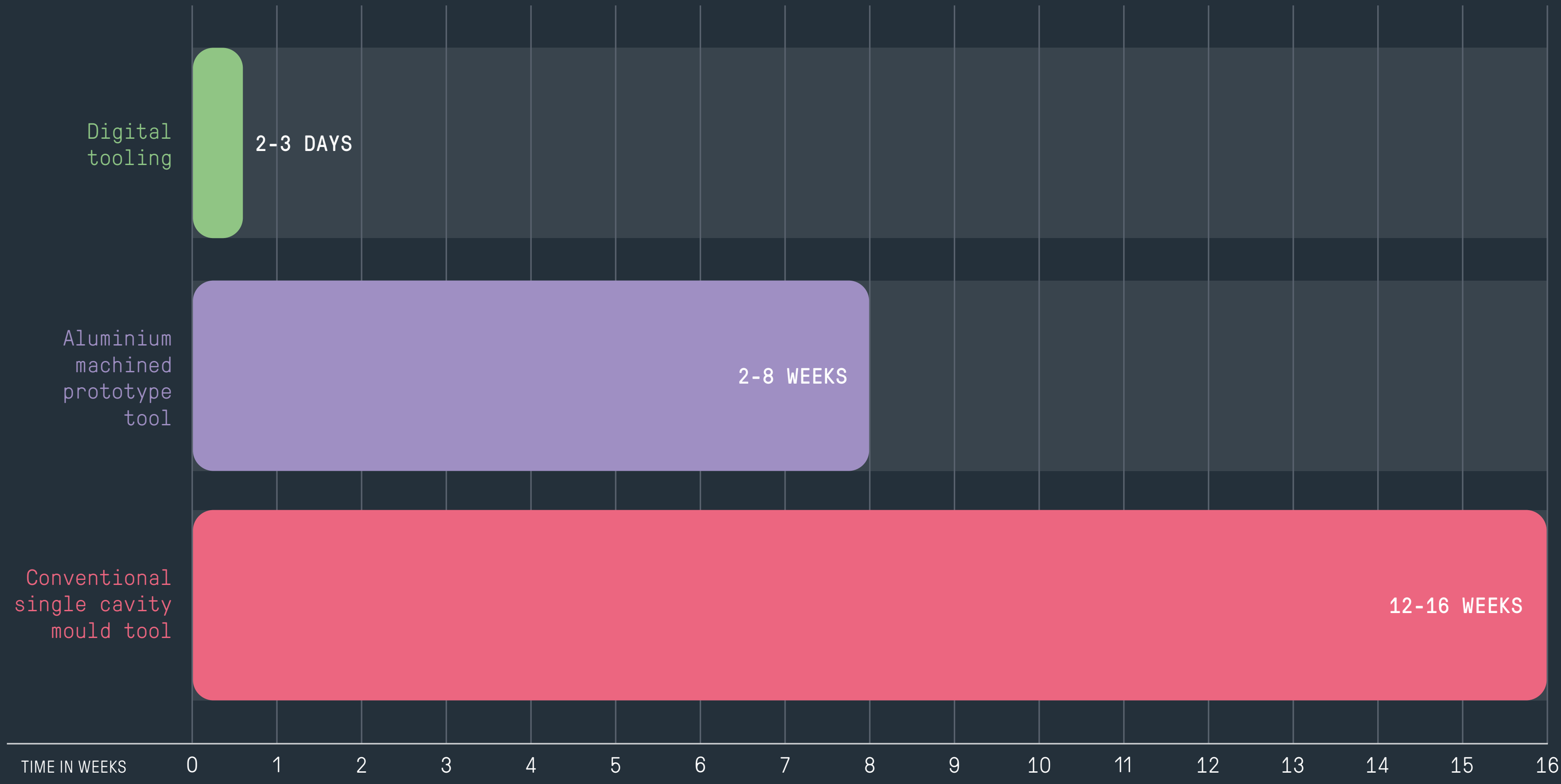
There is a clear need to bridge the gap between fast 3D component printing and relatively slow prototype injection moulding. This requirement is often highlighted in medical device development where chemical properties can be critical to performance. It may be that to even test a device a biocompatible part is needed, or that the interaction between part and a drug or a biological sample is critical. In these situations, a moulded part is the starting point for testing.

To address this challenge, CDP have developed their own digital tooling process.

The faster you can make an accurate prototype part in the real material, the faster you can run representative tests and experiments and the faster you can find out the parameters that make the design work.

Fig. 1 – Prototype lead times

Chart: Comparison between tooling strategies



Our digital tooling approach

While others had demonstrated 3D printed tooling was feasible for simple parts, we wanted to go further so we started again from a clean sheet. There are many 3D printing technologies available, and the latest Formlabs machines are both accurate and cost effective, so we wanted to use them as a starting point. However, the materials they use are much weaker (especially at higher temperatures) and have lower thermal conductivity and heat capacity compared with the metals used in conventional mould tools. So the tooling design had to mitigate this limitation. We also felt it made sense to use a modular approach, 3D printing the smallest possible volume around the part and fitting it into a standardised metal mould plate.

Image: Example part moulding using digital tooling

Conventional tools use moving parts to release the moulded component when its geometry is more complex. These can be made using 3D printing, but limited material strength and hardness make them problematic. Since tool automation is not required for prototypes, the part can be removed manually, so the printed insert can be split up in any way that is easy to design in a 3D CAD environment.

We realised that if there were no voids in the printed insert, except for those to be filled with polymer, and its external surfaces were pressed against ridged metal faces during injection, then the insert is largely in compression due to the pressure of the molten plastic inside it. In this mode the 3D printed material performs better, deflections are less and accuracy is higher.

Finally, we realised that moulding was only part of what was needed to make an accurate, verified part. So it was important to make sure each process step was also efficient using the latest technology.

Since automation is not required for small volumes, the printed insert can be split up in any way that is easy to design in a 3D CAD environment.

Image: Moulded part and digital tool insert

Digital tooling process steps

Fig. 2 – Workflow diagram

Diagram: Showing the steps from design to verified prototype part

STEP 1 — Design the part

STEP 2 — Design the printed insert

STEP 3 — 3D print insert components

STEP 4 — Fill with LMPA

STEP 5 — Verify insert dimensions

STEP 6 — Stabilise moulding machine process

STEP 7 — Mould part and trim

STEP 8 — Verify part dimensions

Multi-dose syringe case study

To demonstrate our digital tooling process, we designed and prototyped a precision, multi-dose syringe. It is intended for the injection of small quantities of drug into multiple sites on a patient, such as might be used for local anaesthesia or cosmetic surgery.

It features a fingertip lever that operates a pawl against a ratchet on the syringe plunger, moving it forward by a small amount each time the lever is operated. The lever rotates on the body moulding that supports a standard syringe barrel. It has a return spring so the lever pops back up after it is pressed. Pulling the lever up over a detent releases the ratchet and allows the syringe plunger to be withdrawn to fill the syringe.

Like many medical devices, the syringe is disposable and made from moulded plastic parts, ABS in this case.

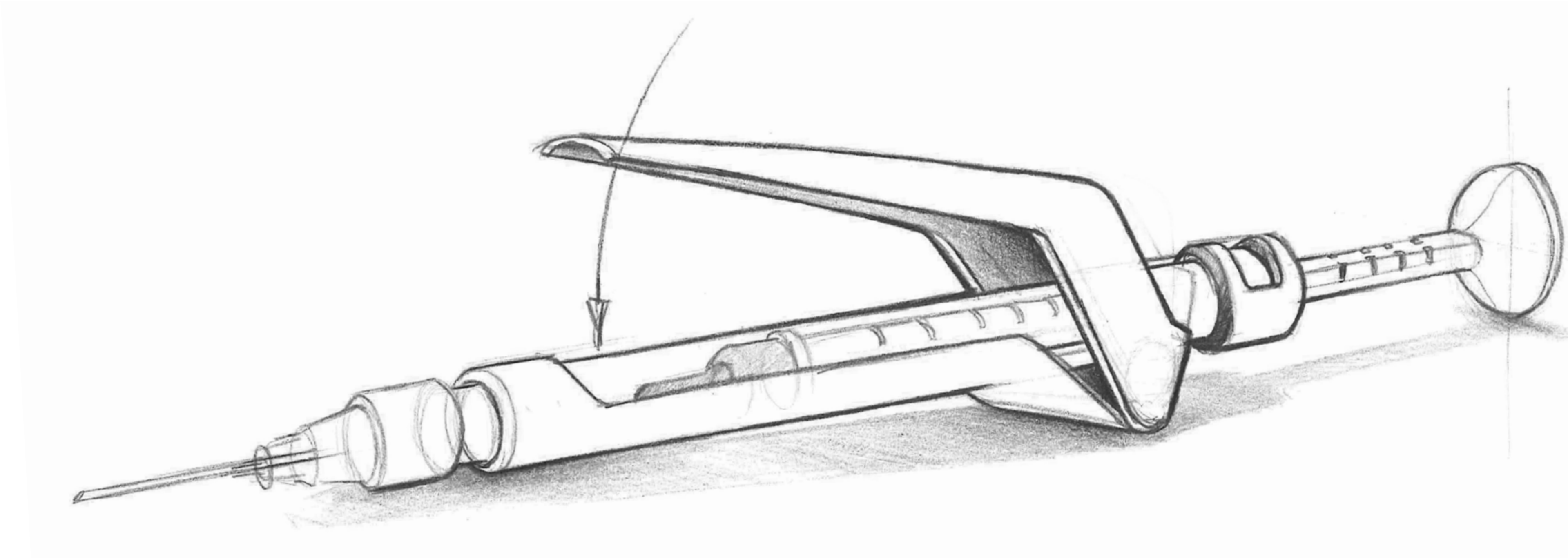
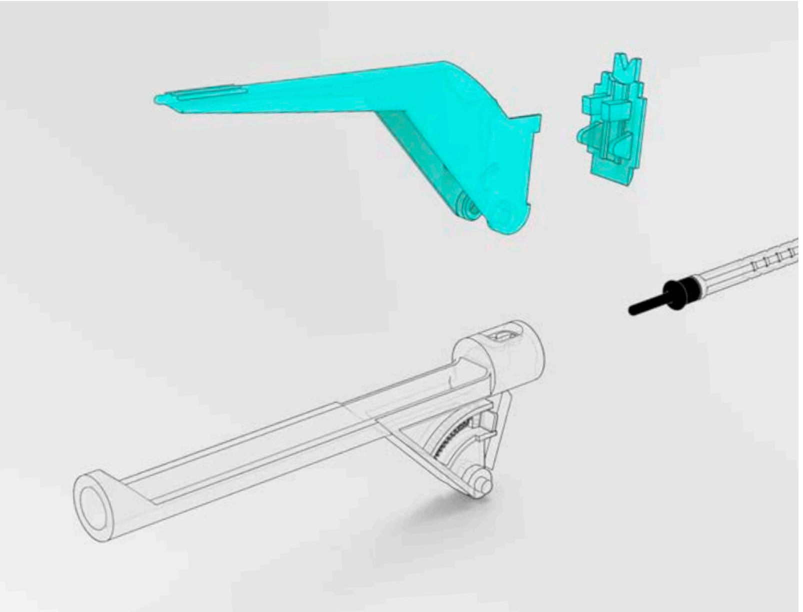


Image: Design sketch of multi-dose syringe concept

STEP 1:

Design the part

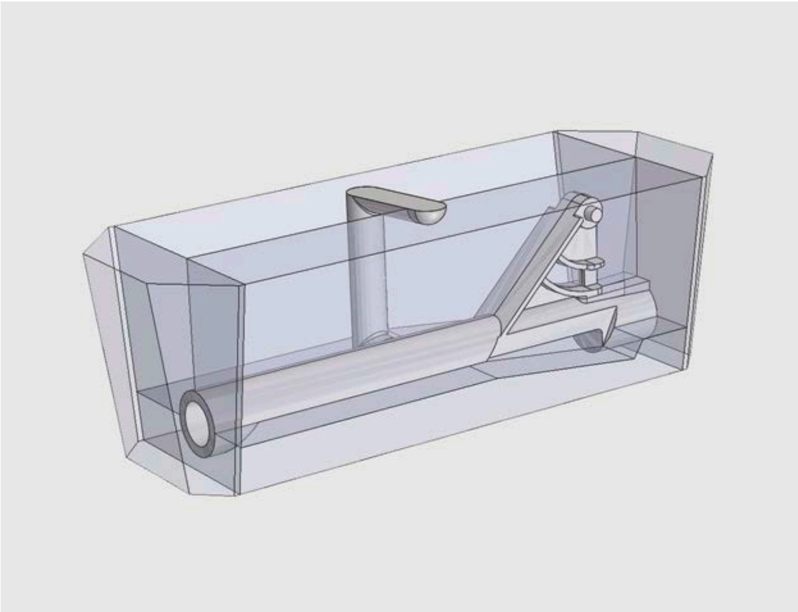
The syringe was sketched to work out the design, and then modelled in 3D CAD to a level that included functional clearances. Basic 'design for manufacture' was applied to ensure it could be refined for production later, but no draft was added to reduce design complexity at this stage. Finally the CAD model is scaled for shrinkage and a gate and runner added to match the sprue location in the tool plate.



STEP 2:

Design the printed insert

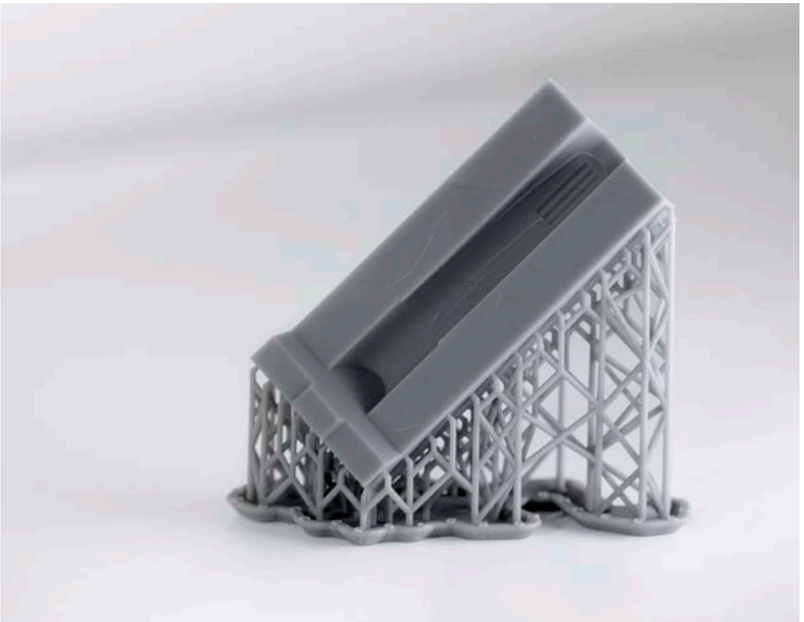
To minimise tool design time, our approach exploits the powerful automated functions available in 3D CAD systems. We subtract the part from a standard tapered insert and split the result into multiple components that will allow the moulded part to be recovered. The insert looks more like a toy puzzle block than an injection mould tool, but that complexity is easily created and is simple for a 3D printer to make.



STEP 3:

3D print insert components

The print material chosen is dictated by the preferred mould temperature as the amount of heat added by a single shot is relatively low. Material compliance is important as it allows the insert to slightly compress as the tool closes, providing additional strength.



STEP 4:

Fill with LMPA

When moulding higher melt temperature plastics we can increase the heat capacity of the tool by casting low melting point alloy (LMPA) into the printed insert components. Before printing, the tool parts are 'shelled' by the CAD system allowing the LMPA to be poured into the printed insert.

STEP 5:

Verify insert dimensions

Inspection by photometric scanning is a great fit in this digital workflow. We inspect the insert using a high resolution GOM 3D scanner and compare the scan and CAD model, using colours to visualise deviations.

For very high accuracy parts, we can compensate for systematic errors by updating the parametric 3D CAD models.

STEP 6:

Stabilise moulding process

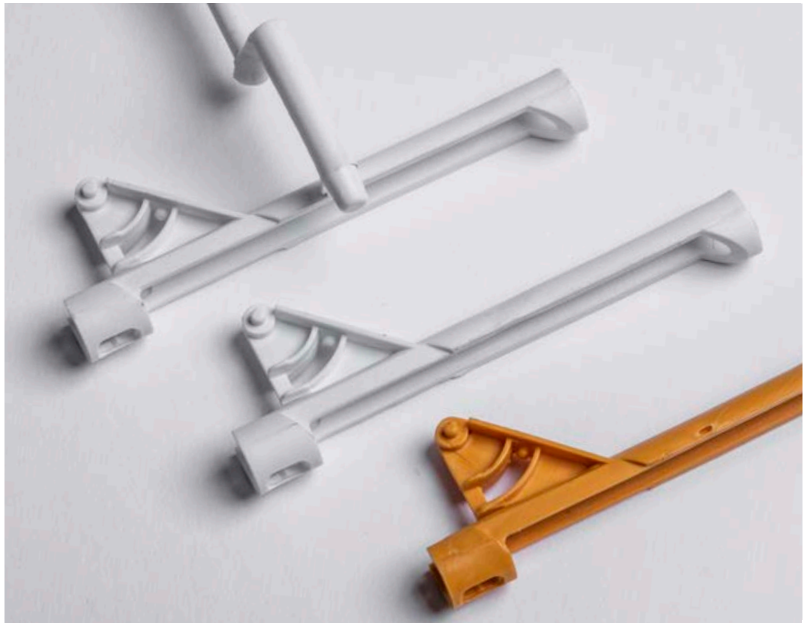
At CDP we use a standard BOY 22 tonne injection moulding machine. We generally select high melt flow thermoplastics to minimise injection pressure and tool forces. Whilst cycle time is not important, thermal management of the insert ensures the mould fills and freezes repeatably.

Moulding machines are designed for continuous production so a dummy insert is used so the machine can be operated automatically to stabilise moulding parameters.

STEP 7:

Mould part and trim

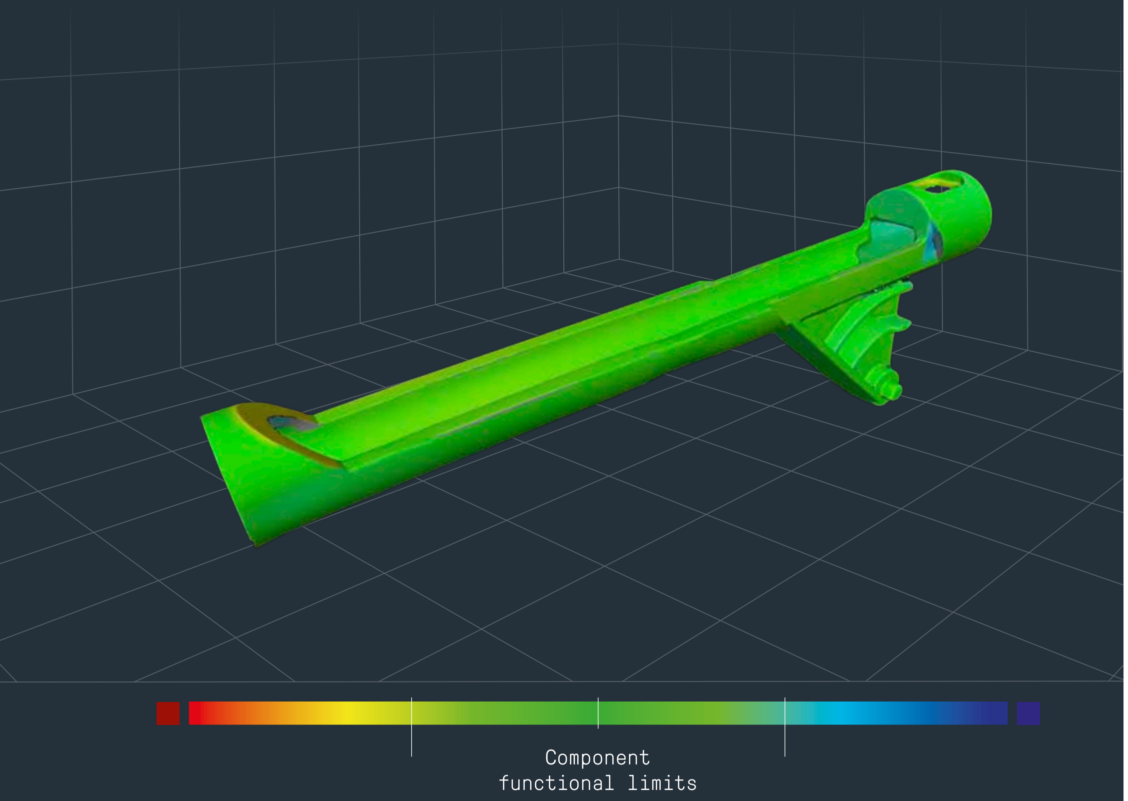
Finally, the 3D-printed insert is swapped with the dummy and the part is moulded. The insert is then removed and opened manually to remove the part.



STEP 8:

Verify part dimensions

Just as the tool is inspected using photometric scanning, so is the finished component. This is essential because without confirmation of the part dimensions the success of the prototype cannot be interpreted correctly.



Other considerations

Complex mouldings

The nature of our process makes it simple to make complex parts as well as implementing techniques such as over moulding. This is a two stage process in which the first insert creates the core moulding, which is then placed in a second where another material is moulded to complete the component.

Biocompatible mouldings

Biocompatible 3D print resins and thermoplastics can be printed and moulded in a clean environment to create biocompatible components. However, the use of biocompatible materials does not in itself guarantee a compliant part and additional process control and validation is needed.

Medical devices for clinical trials

Clinical trials for medical devices and drug/device combinations are expensive because of the need to first demonstrate to regulators both safety and performance, and then test devices in a highly supervised and monitored environment. This is especially the case where single use consumables are concerned, where not only the system must function, but the manufacturing processes have to be shown to be repeatable and reliable.

Digital tooling offers the opportunity to create devices for early pilot trials that will reduce design and tooling uncertainty and make sure that when clinical trials go ahead, the chance of a successful outcome is significantly enhanced.

Summary

This paper explains how we use 3D printing to create accurate injection moulded prototype parts.

Taking innovative new products to market quickly requires precise, high-quality prototypes. Making these parts available earlier in the development cycle means that design challenges are uncovered when they can be more easily and cheaply resolved. Overall this reduces time to market and increases the quality of the final design.

If you would like to learn more about how we use digital tooling to accelerate product development, please get in touch.

Image: Prototype syringe made using injection moulded parts from digital tooling.

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We are a leading product and technology innovation partner, focused on helping our customers realise new opportunities. With offices in the UK and USA, we specialise in the healthcare, consumer, and energy sectors. Our solutions start at the point a business decides upon the need for innovation, and finish with the launch of a breakthrough new product that is customer focused and commercially effective. Our product development and prototype manufacturing quality systems are certified to ISO 13485/9001.

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