FORMLABS WHITE PAPER:

Designing 3D Printed Jigs and Fixtures

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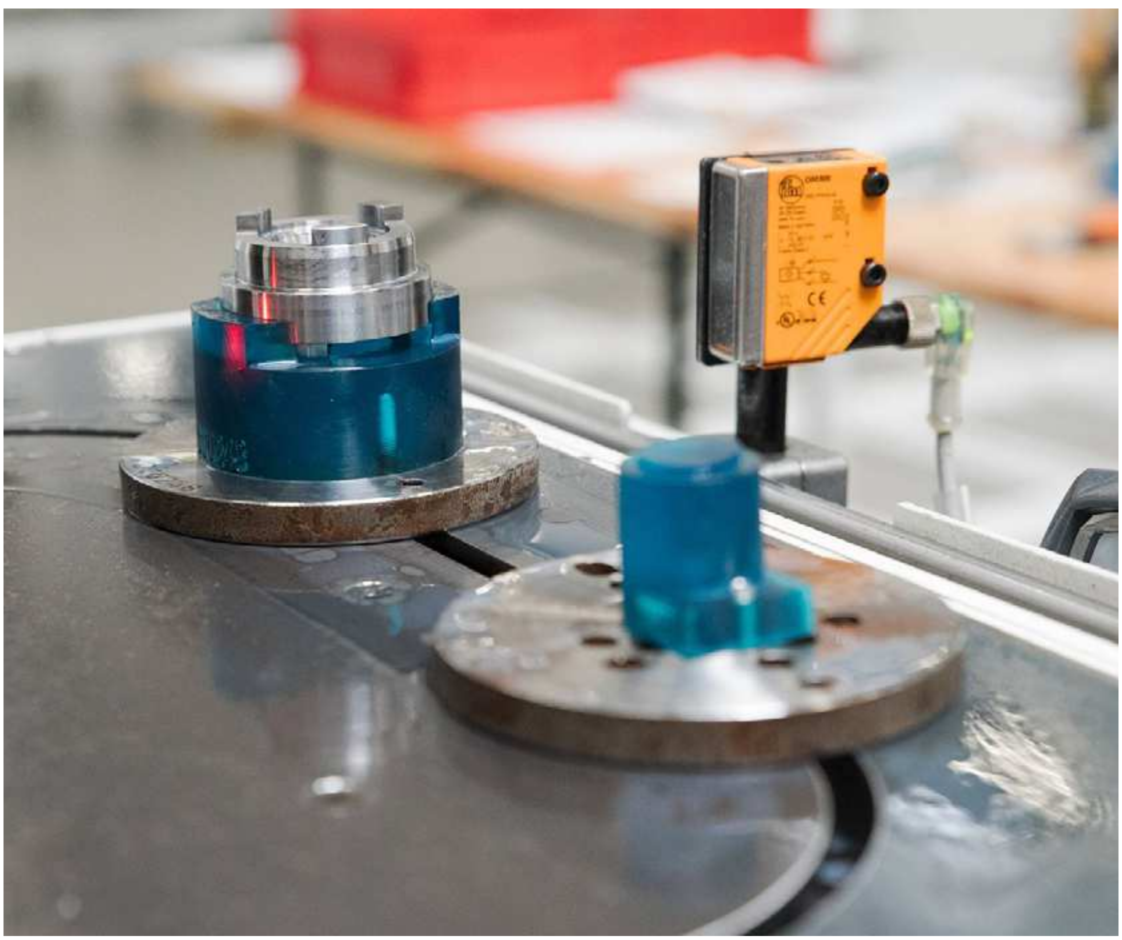
Abstract

This white paper outlines the principles behind creating effective jigs and fixtures, with an emphasis on how to leverage 3D printing to reduce costs, shorten development time, and create more efficient production workflows from design engineer to manufacturing floor technician.

Introduction

For manufacturers, maximizing production speed while maintaining high part quality is critical for success. Jigs and fixtures are used to make manufacturing and assembly processes simpler and more reliable, reducing cycle times and improving worker safety. In this white paper, we will explain basic principles and concepts of fixture and jig design, look at how to adapt features typical to machined fixtures for success with 3D printing, and discuss how to leverage the unique benefits of stereolithography (SLA) materials to cut fabrication costs and reduce lead times.

Typically, manufacturers create tooling in metal as needed by machining it in house or outsourcing it. Depending on the forces experienced by the part, it may not always be necessary to produce these tools in metal. SLA 3D printing materials have advanced significantly, and there are a number of functional resins well suited to 3D printing jigs and fixtures, most notably Formlabs Standard Resins and Formlabs Engineering Resins, particularly Tough, Durable, and High Temp. Manufacturers around the world have used these materials to replace metal fixtures in automated machining operations, electronics assembly lines, foundries, and other production facilities.



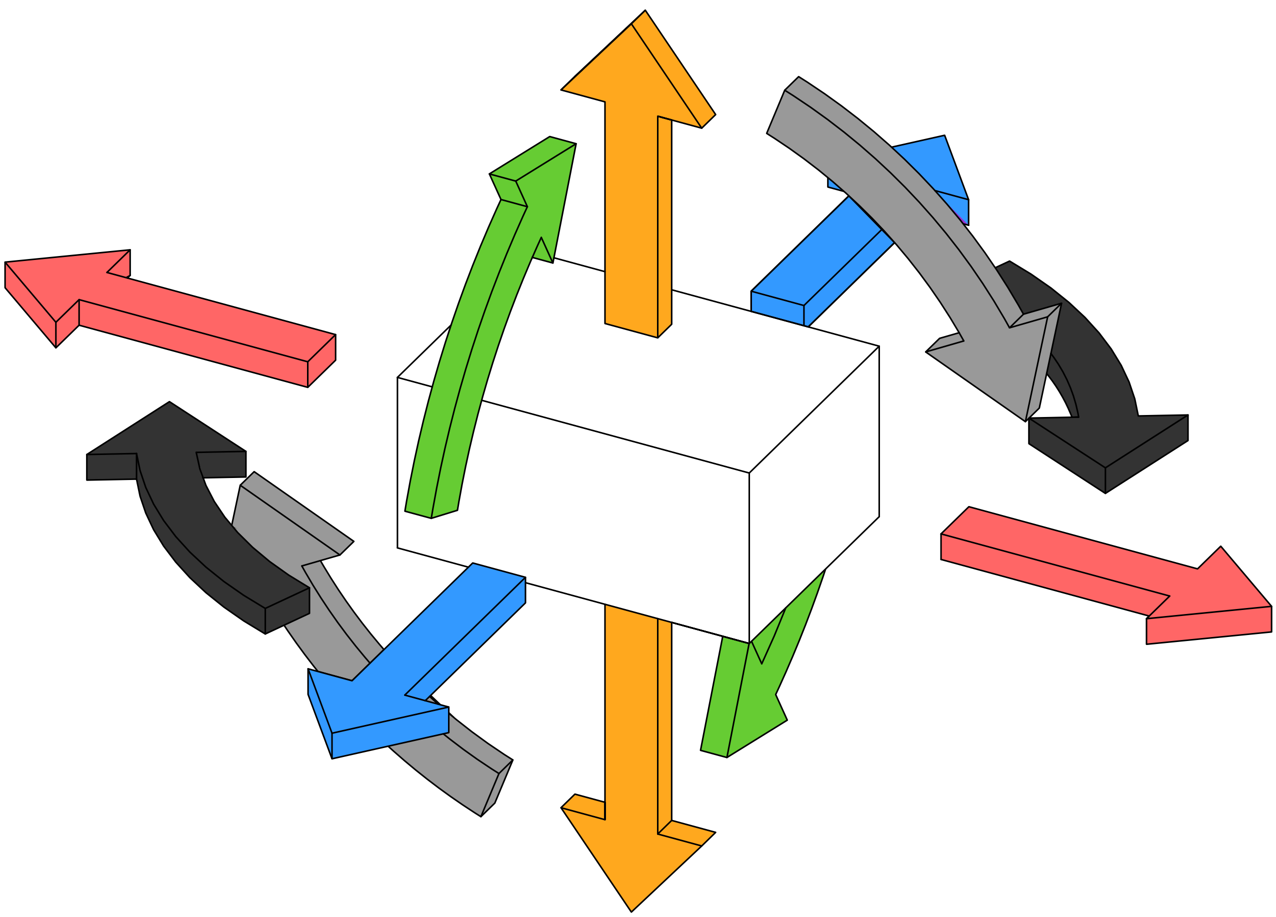
3D printed jigs in an automated production line at Pankl Racing Systems.

Jig and Fixture Design Basics

UNDERSTANDING DEGREES OF FREEDOM AND CONSTRAINT

In their most basic form, fixtures hold a part in a specific position while withstanding forces from a secondary operation, without the held part undergoing an unacceptable amount of deflection, movement, or rotation. To understand how this is achieved, one first needs to understand how degrees of freedom work.

A rigid body in space has six degrees of freedom: up/down movement, left/right movement, forward/backward movement, and the ability to rotate along one or more axes, termed pitch, roll, and yaw.



A part with all six degrees of freedom.

The principles of good fixture design require constraining those degrees of freedom as much as possible for accurate location and safety of secondary operations. It is equally important not to over-constrain the part. Excess constraints introduce unnecessary forces and accuracy problems by requiring higher precision across the fixture or jig.

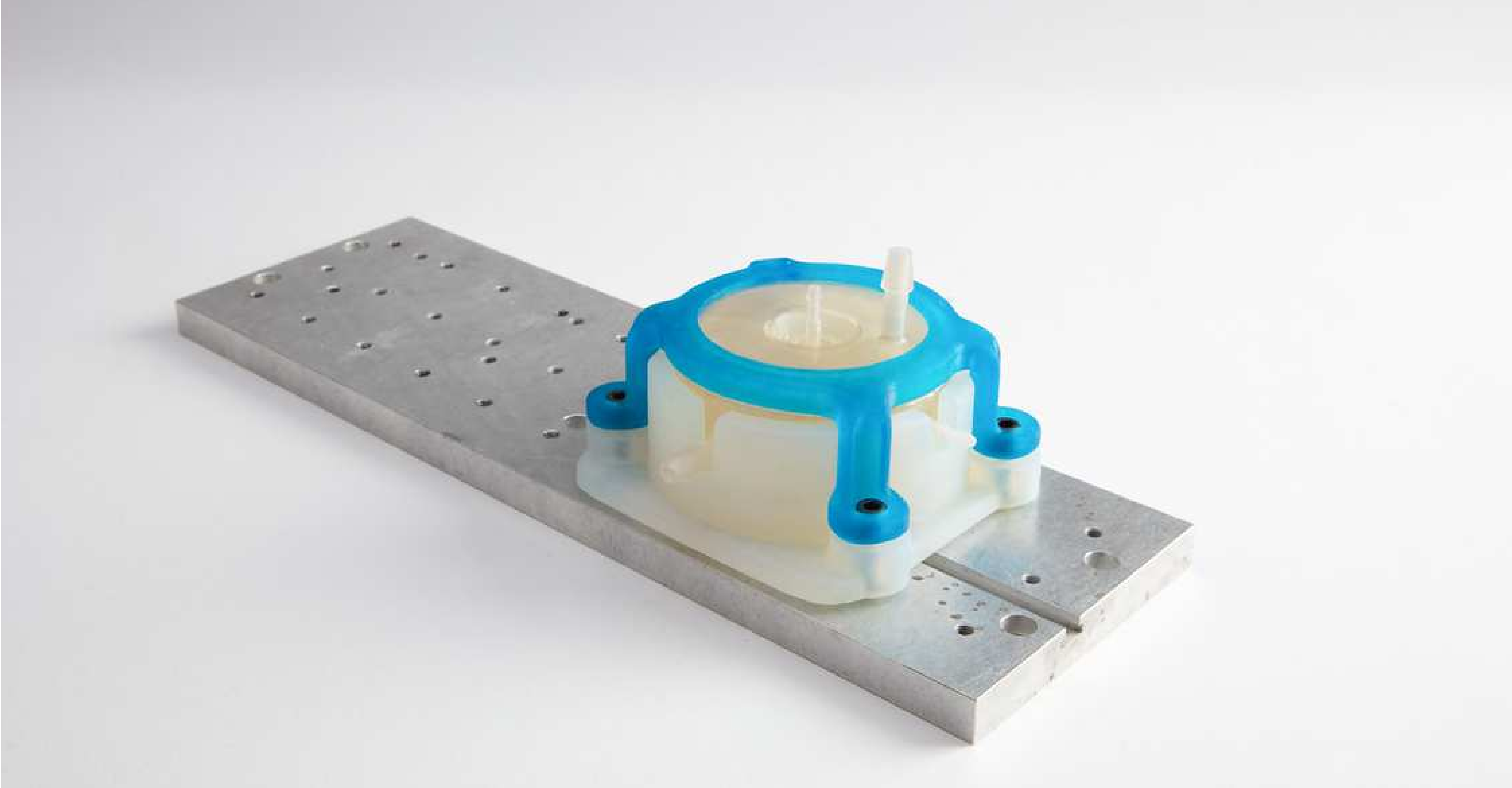
To explain this principle, consider a stool. A stool with three legs has just the right amount of constraint: when loaded with weight from its top surface, the stool cannot move vertically. Friction prevents the stool from sliding in any direction, and each leg is constrained by the others to prevent rotation of individual legs or the entire stool.

- **Exact constraint** is when there is one constraint for each degree of freedom required for correct operation.
- **Underconstraint** happens when a part is free to rotate, shift, or slide in one or more directions or along one or more axes. In fixturing, underconstraint of a part prevents proper function and can pose a significant danger to machine operators and equipment. Depending on the application, however, some tasks may require underconstraint: e.g., a plank of wood that is free to move through a planer.
- **Undersupported** parts have sufficient constraints to prevent shifting and rotation of the object, but not enough support to prevent the part deflecting significantly during secondary operations like milling and drilling.
- **Overconstraint** occurs when a structure has redundant constraints. One way to think of it is that when multiple forces work to do the exact same job, those forces come into conflict, and one of those forces will always "win" and end up doing the intended job. Redundant forces will in the best case do nothing, or in the worst case undermine the intended function of the structure, resulting in poor part quality and increased risk for the operator.

In practice, using "too many" constraints is sometimes necessary.

A four-legged chair is an example of an overconstrained design. The fourth leg is redundant, and introduces a new problem of rocking if it is resting on a surface that is even slightly uneven.

The tradeoff is greater overall stability at the cost of a requirement for flatter floors. To put this in a manufacturing context, a more forgiving (less constrained) fixture design is useful to deal with parts that have more variation (like castings), while a tighter fixture will work better for parts with more precise surfaces (machined or injection molded parts).



3D printed bonding jig mounted to a fixture plate.

3D Printed Jigs and Fixtures

Advanced design tools have enabled engineers to create products highly optimized for end use, but that same design freedom and increased part complexity makes building jigs and fixtures for secondary operations more difficult. Traditional workholding systems like vises and clamps can't secure and support amorphous shapes or parts with very fine details. 3D printing allows engineers to create objects without limitations like tool access and wear that come with machining.

Producing jigs and fixtures through an additive process saves significant time and cost, eliminating the skilled labor steps involved in machining from solid billet or fabricating tools from tube and sheet metal. Even if end use fixtures require metal components, accessible, low cost 3D printing enables manufacturing engineers to test those concepts before committing to having more durable setups machined.

Particularly for parts with curved or complex surfaces, in-house production with 3D printing costs significantly less than outsourcing milling, even in low cost plastics like high density polyethylene. Formlabs 3D printers, with high resolution and excellent surface finish, are well suited to creating jigs and fixtures with curved surfaces and fine features.

COST OF A SIMPLE FIXTURE	Milled from Aluminium	Milled from HDPE	Printed in Tough Resin
Price	$475	$360	$46
Lead Time	3 – 5 days	3 – 5 days	printed in <1 day

Applications for 3D Printed Jigs and Fixtures

SOFT JAW INSERTS FOR VISES

Soft jaw inserts are customized to closely match the unique geometry of a particular part, allowing for workholding of more complex parts and preventing marring of softer metal or plastic parts. 3D printing works well for producing soft jaw inserts and jigs because of the quick build speed and low fabrication cost for dealing with complex shapes.

A part being clamped between soft jaw inserts, printed in Formlabs Tough Resin.

DRILL GUIDES

Drill Guides help prevent a drill bit from deflecting or wandering, maintaining angular and cylindrical tolerance requirements.

A press fit bushing in a drill jig, printed in Formlabs Tough Resin.

Drill guide bushings come in press fit or screw-in varieties, and can be purchased from industrial suppliers like McMaster-Carr. Bushings that have been designed specifically for use in plastics work best for SLA-printed jigs.

> Use the tolerancing guidelines from our **Engineering Fit White Paper** to determine correct hole sizing for press fitting.

GO/NO GO GAUGES

A simple tolerance check using a template or gauge can quickly help a quality control inspector determine whether a part will work for its end use. 3D printed go/no go gauges are useful when the parts successful function is determined by small differences in form and dimension, and those dimensions can't easily or quickly be assessed using calipers, micrometers, or other standard metrology tools, as in the case of complex rubber parts.

A go/no go gauge for inspecting a rubber gasket, printed in Formlabs Clear Resin.

Go/no go gauges are a fast, low-cost way to implement additional quality control checks for an assembly or manufacturing line.

> **TIP** In certain applications, gauges can wear over time, leading to QC failures. Because of their low cost and ease of manufacture, 3D printed gauges can be easily reprinted and replaced on a predetermined schedule or as needed, to prevent quality drift from worn out gauges. This is most pronounced where the parts that are contacting the go/no go gauge are hard metals.

ASSEMBLY JIGS

For many products, connecting parts and adding fasteners to create sub-assemblies or full assemblies is the most labor intensive part of the process. 3D printing part-specific assembly jigs reduces cycle times, improves ergonomic workflow for assembly technicians, and improves consistency across production units.

An assembly jig used for manufacturing the Formlabs Form 2 3D printer.

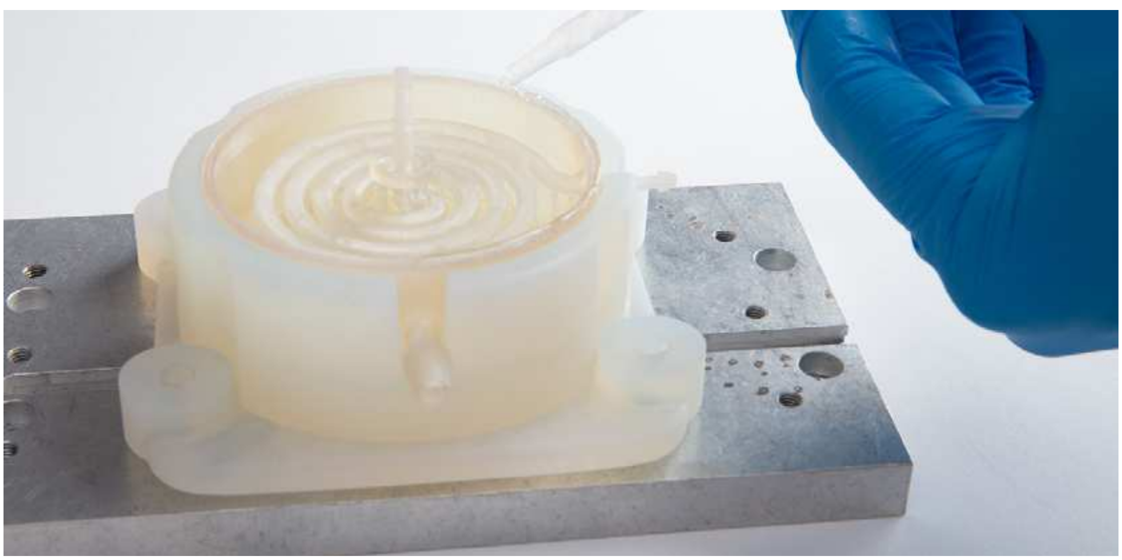
DISASSEMBLY JIGS

Conversely, disassembly is required to examine a product that has failed inspection, correct an error, or access a device for refurbishment and repair. Using a disassembly jig makes this process faster and reduces the risk of breakage. For instance, separating an enclosure with snap fits requires each of the snaps to open simultaneously to prevent damage to the parts.

Disassembly jig for separating a snap-fit enclosure in Formlabs White Resin.

BONDING JIGS

Using 3D printed jigs and fixtures for bonding operations is appealing because their low cost makes the regular replacement associated with their usage much more acceptable.



Adhesive being applied to a part in a bonding jig printed in Formlabs Durable Resin.

> **TIP** Coating a bonding jig with a release agent will make it easier to clean up any solidified adhesive that may spill onto the jig.

LABELING, MARKING, AND MASKING TEMPLATES

3D printed jigs are useful for low-force applications; for example, making sure a label is placed in the exact same location across multiple units or masking off an area for marking.

Using Formlabs Flexible Resin, a conformal masking template can be designed to perfectly match the part surface. For applications where a stiffer template is required, Durable Resin works well.

Hinged jig for applying volumetric markings, printed with Formlabs Tough Resin and Durable Resin.

SURROGATE PARTS

While not a fixture or jig per se, surrogate parts are commonly used to test fixtures or jigs in advance of final production parts, so that manufacturing and assembly lines can come online faster and iron out process kinks before the pressures of production are in place.

Surrogate parts allow manufacturing process validation with low-cost 3D prints instead of risking delicate high value components like electronics assemblies.

SLA prints work well for surrogate parts because of their high dimensional accuracy and ability to replicate fine features relevant for solving manufacturing or usability aspects that FDM or other print processes may miss. Additionally, since SLA printed parts are highly isotropic, they will behave more similarly to their injection molded counterparts than anisotropic FDM part parts.

Best Practices for Designing & Using 3D Printing Fixtures

COMPLEXITY IS (ALMOST) FREE

Since 3D printing allows for “free” complexity (increased complexity doesn’t increase part cost), take some time to consider what additional functionality can be built into the jig or fixture at the design stage to take advantage of this principle. Small features that would be difficult to machine, as well as geometries considered impossible due to tool clearance in milling or turning, are all within the scope of additive processes. Serial numbers, fabrication dates, and other relevant data can be built into the part for digital inventory management and easy tracking without requiring secondary engraving steps.

What would typically be two components in a machined fixture can be built into a single part, which helps prevent buildup of dust or chips by eliminating gap space.

For instance, instead of using inserted straight dowels or cylinders for part location, spherical or diamond-shaped structures are built into a single, gapless part. Using diamond- or sphere-shaped locators reduces or eliminates binding of parts during loading on and off by minimizing the contact area.

A locating jig designed for minimal contact, printed in Formlabs Tough Resin.

BUILD DATUM FEATURES INTO FIXTURES AND JIGS

Part of the process of implementing jigs and fixtures in an assembly or manufacturing context is verifying the dimensional accuracy of the fixture. The amorphous part structures that 3D printed fixtures are often designed to address can mean that the fixtures themselves tend towards more esoteric forms. These designs can be difficult to easily inspect with standard metrology tools like calipers and micrometers. Building datum features into printed jigs and fixtures makes inspection easier and more accurate.

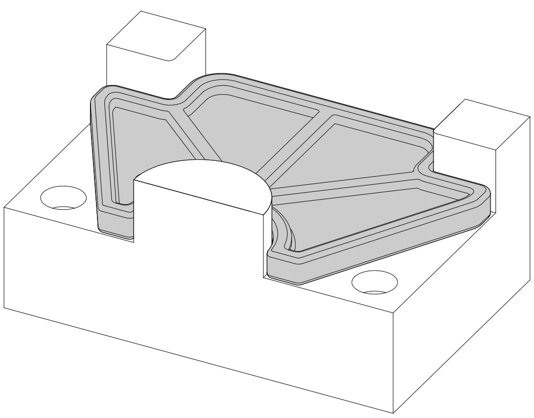
A datum is a theoretically geometrically perfect reference — a totally flat plane, the axis of a cylindrical hole, etc. A datum feature is the reality of that concept in the context of the part, which is used as a principle reference point for other measurements. Datum features should be relevant to the requirements of secondary operations, and to the functional requirements of the part in end use.

Whenever possible, include flat faces or right angle geometries within the fixture to aid inspection and determine overall accuracy. With any jig or fixture, accuracy is proven when inspecting parts after processing, as operating conditions like deflection in the part or tool can create errors requiring alterations to the fixture design.

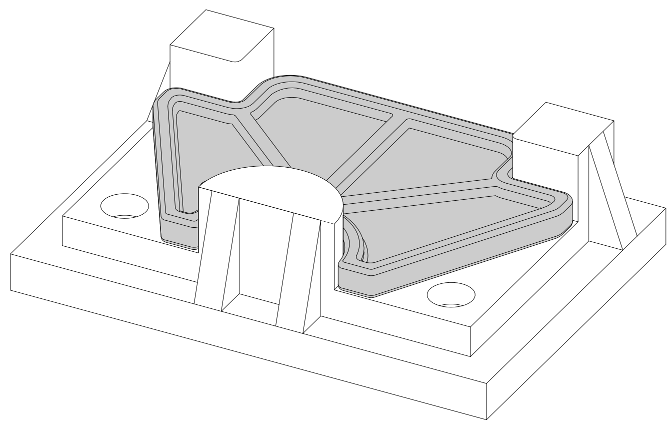
In applications where precision is of utmost importance, use digital metrology tools like 3D scanners or touch probes to inspect more organic geometries.

INCREASING RIGIDITY

The typical way to increase stiffness of a machined fixture is to leave extra material in locations prone to bending under loading. In additive processes, minimizing material consumption keeps part costs low. Using reinforcing ribs and fillets provides additional structure without dramatically increasing the cost or build time of the part.



A typical milled geometry for minimizing material removal and machining time.



A typical printed geometry for maximizing stiffness and minimizing material usage.

INCREASING DURABILITY OF MECHANICAL CONNECTIONS

Using tapped holes in 3D printed plastic parts is an ineffective method for joining parts for fixturing; these parts are more prone to breakage or wear with repeated use than metals. Instead, use more resilient assembly methods, like threaded inserts or a pocket to restrain a nut while a bolt is tightened. Alternatively, a 3D printed fixture may have clearance holes to run bolts through to T-nuts or a fixture plate below. To prevent elastic deformation of the part when bolted down to the work surface, through holes should use clearance-fit tolerancing.

MAKING PRINTED PARTS GO FARTHER

In many cases, 3D printed parts for jigs and fixtures are augmented using stock parts from industrial supply companies. This approach works well when some components need the specificity and design flexibility of 3D printing, but the overall working envelope or other requirements like stiffness or conductivity cannot be met through an additive process.

Common stock parts to add extra functionality to printed jigs and fixtures include metal shaftings for spanning greater distances while maintaining rigidity, or washers for distributing screw clamping loads over a larger footprint. Stock parts in combination with additive processes quickly add mechanical functionality like linear or rotary indexing at a much lower cost than machining.

The drill jig slides smoothly across the steel rails by using Formlabs Durable Resin bushings pressed into the Tough Resin guide.

CONSIDER CREEP

Some SLA resins experience creep (permanent elastic deformation) if continually loaded, as in the case of a printed fixture clamped to a work table for long periods of time. To avoid warping of parts due to continued loading, it's best to loosen any bolts and relieve clamping forces after completing secondary operations.

ON DEMAND REPLACEMENT FOR WEAR COMPONENTS

Even under normal usage conditions, fixtures, assembly tools, and jigs commonly become broken or worn to the point where they are no longer effective.

By creating jigs and fixtures with additive fabrication, a facility takes control of its own production and gains the ability to replace tools on-site on an as-needed basis, rather than counting on external vendors with minimum order quantities. Replacing worn fixtures with in-house equipment shortens the supply chain and reduces downtime risk.

> **TIP** Certain coolants, solvents, and cutting fluids can degrade SLA prints. Perform a small test to validate overall processing requirements before implementing printed parts in a new application.

Inspecting a 3D printed part with a caliper to verify dimensional accuracy.

Validating a Printed Fixture

Once the fixture has finished printing, clean and cure it according to the material specifications. Formlabs' Form Wash and Form Cure post-processing systems are the best way to make sure parts do not distort from sitting too long in solvent or uneven curing.

If Formlabs' PreForm software is used to generate support structures on the model, remove the supports and carefully file or sand away any remaining bumps, maintaining a flat, even base.

TIP Mount a sheet of sandpaper to a known flat surface and run the part against the sandpaper using firm, even pressure to achieve a consistent finish.

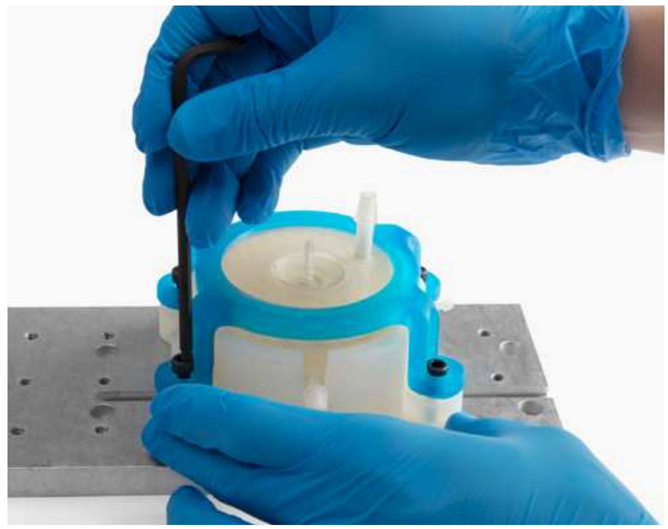
At this point, inspect the printed part against the original CAD model. Use a caliper or micrometer to check dimensions of the print against a dimensioned drawing or annotated CAD model and take note of any discrepancy that could negatively affect the performance of the jig or fixture.

If everything is dimensionally sound, the next step is to test the functional performance of the fixture.

When the part is loaded onto the fixture, pay close attention to how well it is seated against locating surfaces and supports. A properly designed and built fixture will support the part, eliminating any movement once clamping force is applied.

Clamping forces should push the part into the fixture evenly without any tilting, shifting, or bending of the part.

A part properly seated in a pocket jig printed in Formlabs Durable Resin.



A component printed in Formlabs Tough Resin aligning and securing a bonded assembly during curing.

For processes with higher operating forces, like milling or drilling, calculate clamping requirements based on feeds and speeds, the power of the machine, and the selected material, as well as safety. During initial use, take light cuts to ensure everything functions as planned.

After performing any secondary operations on the part, another inspection will verify tolerances held, along with fitting an acceptable cycle time. When first deploying a new fixture or jig, more frequent quality checks will reveal any unpredicted operator errors or wear that might result in quality failure. Those errors can be caught early and corrected either through training or modifications to the fixture design.

Of course, not all fixtures or jigs can or should be 3D printed. Always select materials on the basis of functional requirements of the task to be performed. In cases where 3D printed material is not suitable for end use, SLA-printed parts can still be used for validating fit and function instead, saving time and money compared to milling solid blocks of aluminum.

Workflow Considerations

EJECTING PARTS

If a jig or fixture is to truly function as a time-saving tool, figuring out how to quickly remove parts from the setup is as critical as loading and clamping.

To assist part ejection, use springs, ramped slides, or levers to raise the part up from the fixture surface.

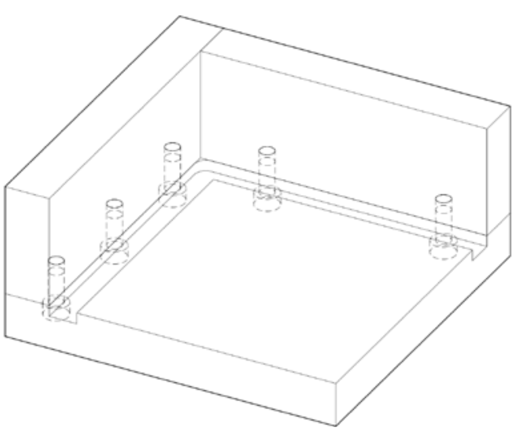
By placing springs into the fixture, when the clamping force is removed the part will be brought up away from the surface of the fixture, giving the operator easier access for part removal. The same can be achieved with a movable slider or lever, though with an additional step required by the operator. Determining the right approach depends on the application, the tooling setup, and cycle time requirements.

TOOL OPERATION CONSIDERATIONS

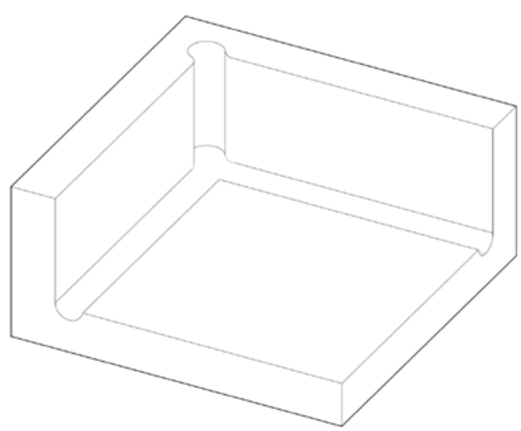
Any kind of machining operation will produce debris. Good fixture and jig design makes allowances to manage the effect of such debris. When drilling a hole, for example, a small burr will be created. Leaving a gap space within the jig allows space for a burr to form without interfering with the part or tool operation.

Similarly, with milling operations, small chips of material can accumulate on the jig or fixture. Whenever possible, minimize or eliminate small gaps, grooves, and pockets where chips can become wedged. Creating recessed channels improves the function of the fixture or jig, allowing stray chips to fall out of the path of the part during loading and unloading.

Rounding corners and grooves creates ramped surfaces, easing sweeping, blowing, or washing away of debris from the work area. Milling surface fillets is time-consuming and costly, requiring either extensive material removal or an assembly of parts that introduces new seams.



A typical milled and assembled corner locator, composed of three bolted plates, creates more opportunities for chips to become wedged.



A typical geometry for a 3D printed corner locator with eased edges, smooth relief pockets, and no seams, all without increasing the cost of the part.

IMPROVING THE USER EXPERIENCE OF JIGS AND FIXTURES

Fixtures and jigs are as much tools for reducing the level of skill and intense focus required of the human operator as they are tools for speeding along production of parts.

Well-designed fixtures improve worker safety and contribute to an ergonomic workstation for the person tasked with running through that particular step repeatedly. A successful manufacturing operation considers not just how parts are processed with jigs and fixtures, but also how workers mentally and physically experience the tools they use.

While every application carries different considerations and trade-offs, a few common concepts will reduce labor pains and improve performance:

- Whenever possible, design jigs and fixtures to operate with one hand, freeing the other hand for part positioning, stabilizing, or resting during changeover.
- Design the fixture or jig for secure holding of the part during secondary operations without human assistance.
- Use geometries that magnify placement errors to make misalignment obvious.
- Consider not just the part in the context of the fixture, but the overall flow of work, from loading in the part and performing secondary operations to removing the part and sending it onto the next station.
- Always strive for the fewest steps required to operate the jig or fixture to keep cycle time and fatiguing worker motion to a minimum. Pantomime the steps involved while designing to make sure all necessary motion and spatial affordances are included.

Learn how other companies are implementing 3D printed jigs and fixtures in highly automated manufacturing lines in our **case study featuring Pankl Racing Systems**. By bringing jigs fabrication in house with 3D printing, Pankl Racing Systems cut lead times and reduced costs, all without tying up valuable CNC center production capacity.

Conclusion

The modern factory must continually adjust and adopt new technologies to maintain a competitive edge, achieve production and profitability goals, create a safe environment for staff, and reduce worker strain. Additive manufacturing helps achieve these goals by putting the design and production of jigs and fixtures as close to the manufacturing floor as possible. Engineers familiar with the exact context of jigs and fixtures in production do a much better job of building the right tools, the right way. Low cost, high-precision 3D printers like the Formlabs Form 2 make it possible for even small organizations to close the gap between concept and reality to improve manufacturing performance and remain competitive.