How to match tolerances on a 3D printed replacement part

Asked 3D Content Team
Published September 23, 2026 · Updated October 13, 2026 · Last verified September 23, 2026

Abstract. Design in clearance instead of copying the measurement: 0.15 to 0.20 mm for a snug fit, 0.20 to 0.25 mm sliding, 0.30 to 0.40 mm loose, then check with a tolerance print.

Keywords: replacement-parts, reverse-engineering, home-repair

Table 1. The clearances

Fit	Clearance	Used for	Source
Snug / alignment	0.15 to 0.20 mm	Locating features	Marston Makerspace, University of Florida
Standard sliding	0.20 to 0.25 mm	Tabs, rails, enclosures	Marston Makerspace, University of Florida
Loose	0.30 to 0.40 mm	Covers, adjustable components	Marston Makerspace, University of Florida
Print-in-place	The larger end of the sliding and loose ranges	Hinges printed assembled	Marston Makerspace, University of Florida
Snap-fit clip	0.5 mm	The moving arm of a cantilever clip	Protolabs Network

1 How do you match the tolerances of a replacement part?

Design in clearance rather than copying the measurement. The University of Florida makerspace guide gives 0.15 to 0.20 mm for a snug locating fit, 0.20 to 0.25 mm for a sliding fit and 0.30 to 0.40 mm for a loose one. Print a tolerance test in the part's filament first, since Prusa quotes 0.3 mm accuracy in X and Y.

1.1 The clearances

The clearance is the gap between the two parts. Which part gives it up depends on which one you print. A bought shaft keeps its size, so the printed hole carries the whole gap.

1.2 Why you cannot copy the measurement

The printer's error is larger than the caliper's. Prusa Research puts a well-assembled Original Prusa at 0.1 mm on Z and 0.3 mm on X and Y, improvable to 0.05 mm on all axes after extrusion multiplier and extruder linearity calibration. The measuring procedure reads far finer than the printer's band. The printer then places the surface anywhere inside that band.

A bore modeled at exactly the measured diameter therefore prints too small half the time. Bambu Lab's wiki names two settings that pull holes back to size: filament shrinkage and XY hole and contour compensation. They are corrections to calibrate, not values to assume. Once a test part is measured, a shrinkage scale-factor calculator turns the error into the value each slicer expects. Clearance leaves the fit loose when the errors stack the wrong way, instead of jammed.

No cited source gives an interference value for a true press fit, where the peg is larger than the hole. Start from the snug band and close it on a test coupon.

1.3 The procedure

1. Decide what each fit does. A locating peg wants snug, a lid wants sliding, a cover wants loose.

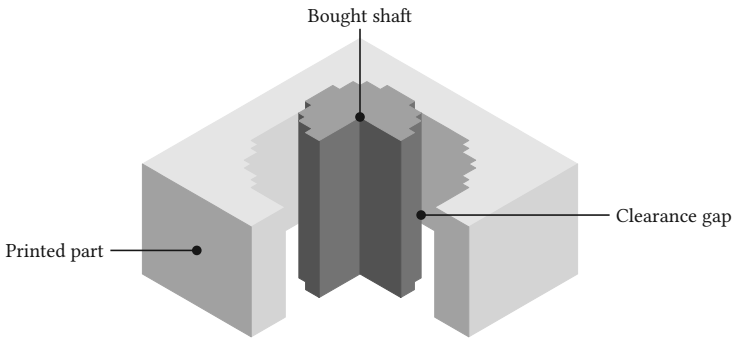


Figure 1. The shaft keeps its size, so the printed hole is modeled larger and carries the whole gap, drawn here much wider than it is.

2. Add the clearance from the table on the printed part. Holes get it as extra diameter, pegs as reduced diameter.
3. Print the fit before the part. Bambu Studio ships a built-in model, added as the primitive ksmFDMTest, whose nested cylinders are there to inspect fit tightness and whose pins must all come out. On any other printer, a downloaded tolerance test model with stepped clearances does the same job.
4. If the cylinders stick, work through Bambu Lab's checks in order: cleaning and lubrication, then belt tension, then machine accuracy calibration, then filament shrinkage, then hole and contour compensation. Only after those does the clearance itself need to change.
5. Print a coupon of the real feature in the real filament and orientation, then measure it against the mating part. A coupon costs minutes; a full part costs hours.
6. Design in compliance where you can. The University of Florida guide's tools are lead-ins on pegs and tabs, mouse ears at internal corners and flexible arms, all of which forgive a tenth of a millimeter that a rigid fit will not.

1.4 Holes and orientation

Round holes print best with their axis vertical. The University of Florida guide's fallback for a horizontal hole is the teardrop shape, so the roof does not sag. A hole that must be exact can also be drilled or reamed after printing: model it a step small and finish it with the tool, which takes the printer's XY band out of the fit altogether.

Orientation also moves the numbers. Prusa's 0.1 mm Z figure and 0.3 mm XY figure mean a fit-critical dimension is held tighter when it runs along Z. That competes with strength, which wants the load along the layers, so read the orientation rule before committing.

2 Why do 3D printed parts not fit together?

Six causes stop printed parts fitting: no clearance designed in, elephant's foot flaring the first layer, over-extrusion, holes printing undersized, shrinkage as ABS, ASA or nylon cools, and warped corners. Each leaves its own mark, so a few caliper readings on a test cube or hole show which one to fix first.

2.1 Causes, checks and fixes

Values come from the Prusa Knowledge Base and the OrcaSlicer wiki; Bambu Studio has the same compensation settings. A part lifted at one corner only has its own diagnosis.

2.2 Why printed holes come out small

Exported CAD turns a cylinder into a polygon whose flats sit inside the true circle, and the nozzle cuts corners as it drags filament round the curve, per nophead's HydraRaptor polyhole write-up. OrcaSlicer's polyhole conversion prints the hole with fewer sides set on the circle.

2.3 Which cause to check first

Print a small cube with a round hole in the part's filament, then take three caliper readings:

1. First layer against mid-height. A wider base means elephant's foot.
2. Mid-height against the model. Oversized points to flow; undersized in ABS, ASA or nylon points to shrinkage.
3. The hole against the model. Small with true outer sizes means hole compensation.

If all three read true and parts still bind, the design needs clearance.

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Table 2. Causes, checks and fixes

Cause	What you see	Check	Fix
No clearance designed in	Every fit binds, even off a tuned printer	Compare the model's hole and peg sizes	Add the gap from the clearance table above
Elephant's foot	The bottom layer sticks out, so parts jam only at the base	Calipers across the first layer, then mid-height	Elephant foot compensation, under Print settings, Advanced in PrusaSlicer; Prusa says around 0.2 mm suits a 0.4 mm nozzle
Over-extrusion	Rough top surfaces and oversized walls	Measure the wall of Prusa's 40 mm single-wall cube	Set the extrusion multiplier to 0.45 divided by the measured wall; Prusa's adjusted values usually run 0.9 to 1.1
Undersized holes	Outer sizes are right, holes are small	Measure a printed hole against the model	X-Y hole compensation (positive enlarges) or polyhole conversion
Shrinkage	The whole part reads small in acrylonitrile butadiene styrene (ABS), acrylonitrile styrene acrylate (ASA) or nylon	Measure a known length against the model	Scale by the filament shrinkage setting; Prusa puts ABS shrinkage at about 1 to 2%
Warping	Lifted corners, so mating faces rock	Lay it on a flat surface	An enclosure, a brim, and a bed wiped with 90% or stronger isopropyl alcohol

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Cite as: Asked 3D. "How to match tolerances on a 3D printed replacement part." October 13, 2026. https://asked3d.com/answers/match-tolerances-replacement-part. Last verified September 23, 2026.