
The Design for Additive Manufacturing Worksheet

Joran Booth, Jeffrey Alperovich, Tahira Reid, Karthik Ramani

FABORATORY



C DESIGN LAB

REIID
Research in Engineering and Interdisciplinary Design

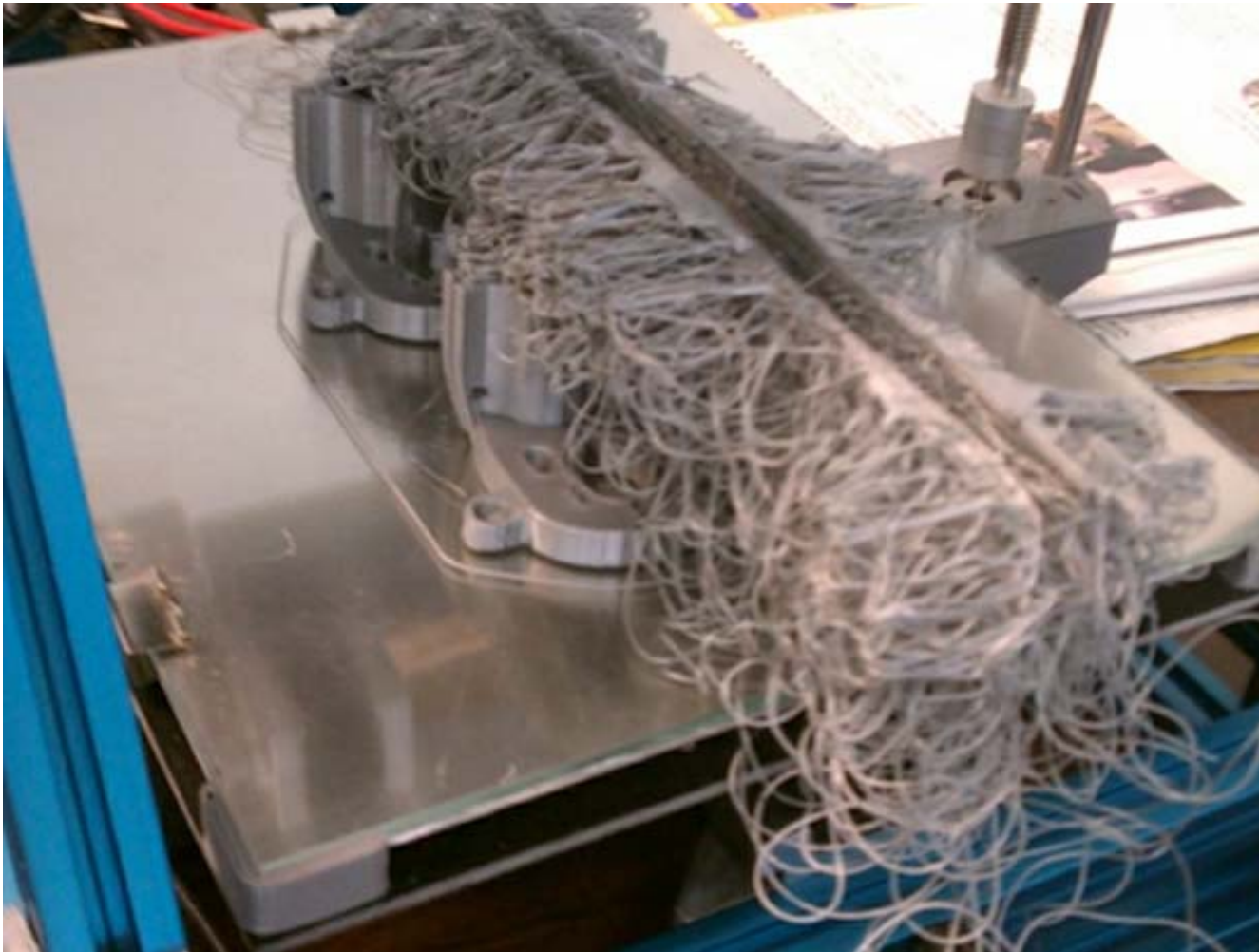
School of Mechanical Engineering
Purdue University, West Lafayette

Adapted from The Design for Additive Manufacturing Worksheet, in the Proceedings of IDETC, 2016, #60407

FABORATORY



Failures in 3D Printing are Common



<https://makezine.com/wp-content/uploads/2013/08/3dprintfail41.png>

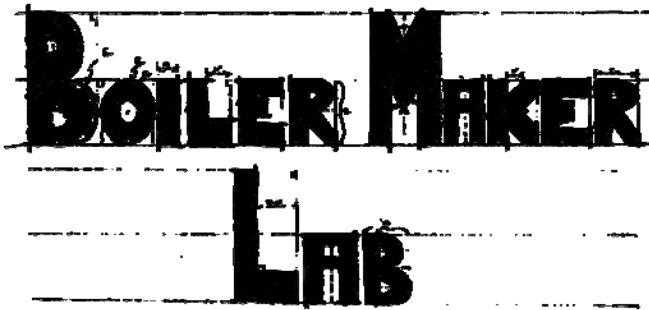
Some Failures are Due to Bad Design



http://thingiverse-production-new.s3.amazonaws.com/renderers/5b/e3/74/e9/e1/IMG_4103_preview_featured.jpg

Collaborators

- Mike Sherwood, 20 years in AM
- Boilermaker Lab, high-volume printing lab
- Faboratory, advanced AM lab



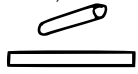
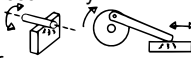



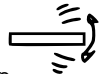



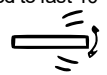



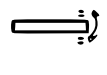








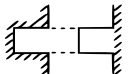

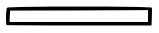

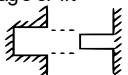





FAB**RATORY**

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Design for Additive Manufacturing

A quick method for reducing the number of printing and prototyping failures, by Joran Booth
Instructions Mark one for each category for the part you plan to print. Check da ggers and stars first, then scores

Mark One	Complexity Simple parts are inefficient for AM	Mark One	Functionality AM parts are light and medium duty	Mark One	Material Removal Support structures ruin surface finish	Mark One	Unsupported Features Unsupported features will droop	Sum Across Rows	Totals
<input checked="" type="radio"/>	The part is the same shape as common stock materials, or is completely 2D 	<input checked="" type="radio"/>	Mating surfaces are bearing surfaces, or are expected to endure for 1000+ of cycles 	<input type="radio"/>	The part is smaller than or the same size as the required support structure 	<input type="radio"/>	There are long, unsupported features 	x5 =	
<input checked="" type="radio"/>	The part is mostly 2D and can be made in a mill or lathe without repositioning it in the clamp 	<input checked="" type="radio"/>	Mating surfaces move significantly, experience large forces, or must endure 100-1000 cycles. 	<input type="radio"/>	There are small gaps that will require support structures 	<input type="radio"/>	There are short, unsupported features 	x4 =	
<input type="radio"/>	The part can be made in a mill or lathe, but only after repositioning it in the clamp at least once 	<input type="radio"/>	Mating surfaces move somewhat, experience moderate forces, or are expected to last 10-100 cycles 	<input type="radio"/>	Internal cavities, channels, or holes do not have openings for removing materials 	<input type="radio"/>	Overhang features have a sloped support 	x3 =	
<input type="radio"/>	The part curvature is complex (splines or arcs) for a machining operation such as a mill or lathe 	<input type="radio"/>	Mating surfaces will move minimally, experience low forces, or are intended to endure 2-10 cycles 	<input type="radio"/>	Material can be easily removed from internal cavities, channels, or holes 	<input type="radio"/>	Overhanging features have a minimum of 45deg support 	x2 =	
<input type="radio"/>	There are interior features or surface curvature is too complex to be machined 	<input type="radio"/>	Surfaces are purely non-functional or experience virtually no cycles 	<input type="radio"/>	There are no internal cavities, channels, or holes 	<input type="radio"/>	Part is oriented so there are no overhanging features 	x1 =	
Mark One	Thin Features Thin features will almost always break	Mark One	Stress Concentration Interior corners must transition gradually	Mark One	Tolerances Mating parts should not be the same size	Mark One	Geometric Exactness Large, flat areas tend to warp		+
<input type="radio"/>	Some walls are less than 1/16" (1.5mm) thick 	<input type="radio"/>	Interior corners have no chamfer, fillet, or rib 	<input type="radio"/>	Hole or length dimensions are nominal 	<input type="radio"/>	The part has large, flat surfaces or has a form that is important to be exact 	x5 =	
<input type="radio"/>	Walls are between 1/16" (1.5mm) and 1/8" (3mm) thick 	<input type="radio"/>	Interior corners have chamfers, fillets, and/or ribs 	<input type="radio"/>	Hole or length tolerances are adjusted for shrinkage or fit 	<input type="radio"/>	The part has medium-sized, flat surfaces, or forms that are should be close to exact 	x3 =	
<input type="radio"/>	Walls are more than 1/8" (3mm) thick 	<input type="radio"/>	Interior corners have generous chamfers, fillets, and/or ribs 	<input type="radio"/>	Hole and length tolerances are considered or are not important 	<input type="radio"/>	The part has small or no flat surfaces, or forms that need to be exact 	x1 =	

Starred Ratings

- * Consider a different manufacturing process
- † Strongly consider a different manufacturing process

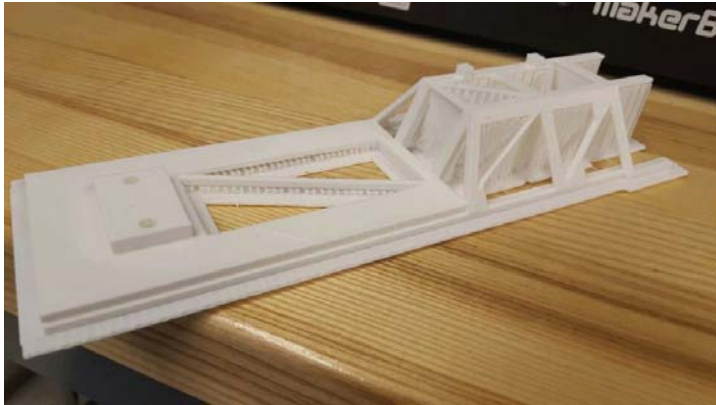
Total Score

- 33-40 Needs redesign
- 24-32 Consider redesign
- 16-23 Moderate likelihood of success
- 8-15 Higher likelihood of success

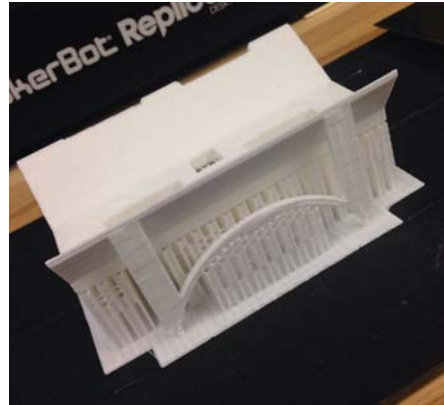
Overall Total

||

Examples – Lower is Better



Score = 24 (Needs redesign)



Score = 22



Score = 19



Score = 16



Score = 15



Score = 11 (better)

Validation

- Boilermaker Lab
 - Makerbot Replicator 2, 1000+ hrs / machine



Results

Time spent on worksheet

Median: 2.7 min

Mean: 5.4 min

	w/o DfAM	w/ DfAM	Change	p (X ²)	Odds Ratio
N	181	33			
Failed Prints and Reprints	33.1%	6.0%	81.7% ↓	0.007	7.69 (large)

Those who used worksheet 7.7 times more likely to make a successful print

Most common problems (self-report)

1. Stress concentrations
2. GD&T considerations
3. Thin features
4. Tolerances
5. Unsupported features

Challenges

- Dissemination
 - Digital
 - Awareness
- Drilling down
- Machine-specific guidelines
 - Right guideline to right person
 - Keeping it simple

<https://joranbooth.com/projects/the-design-for-additive-manufacturing-worksheet/>

THANK YOU

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