PennState

Designing for Additive Manufacturing: Three Use Cases in Industry

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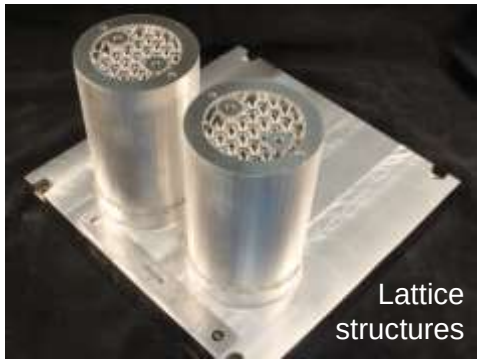
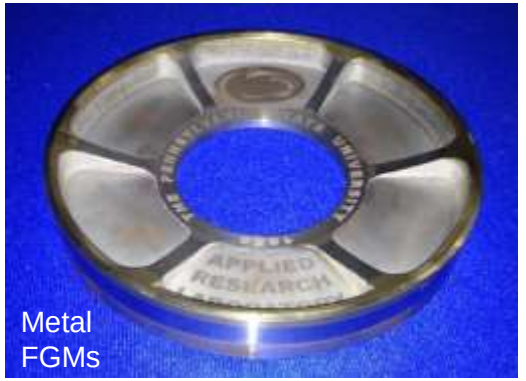
- **CIMP-3D is a world-class facility for developing and implementing additive manufacturing technology for *engineered* components**

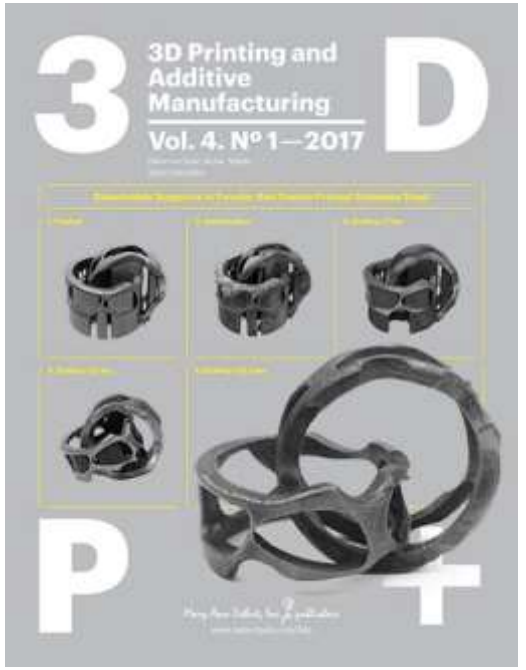
- **Mission**
  1. Advance enabling technologies required to successfully implement AM technology for critical metallic components and structures
  2. Provide technical assistance to industry through selection, demonstration, and validation of AM technology as an “honest broker”
  3. Promote the potential of AM technology through training, education, and dissemination of information

- **CIMP-3D served as the DARPA Open Manufacturing Program’s Manufacturing Demonstration Facility for Additive Manufacturing**

AM Demonstration Projects







Dissolvable metal supports

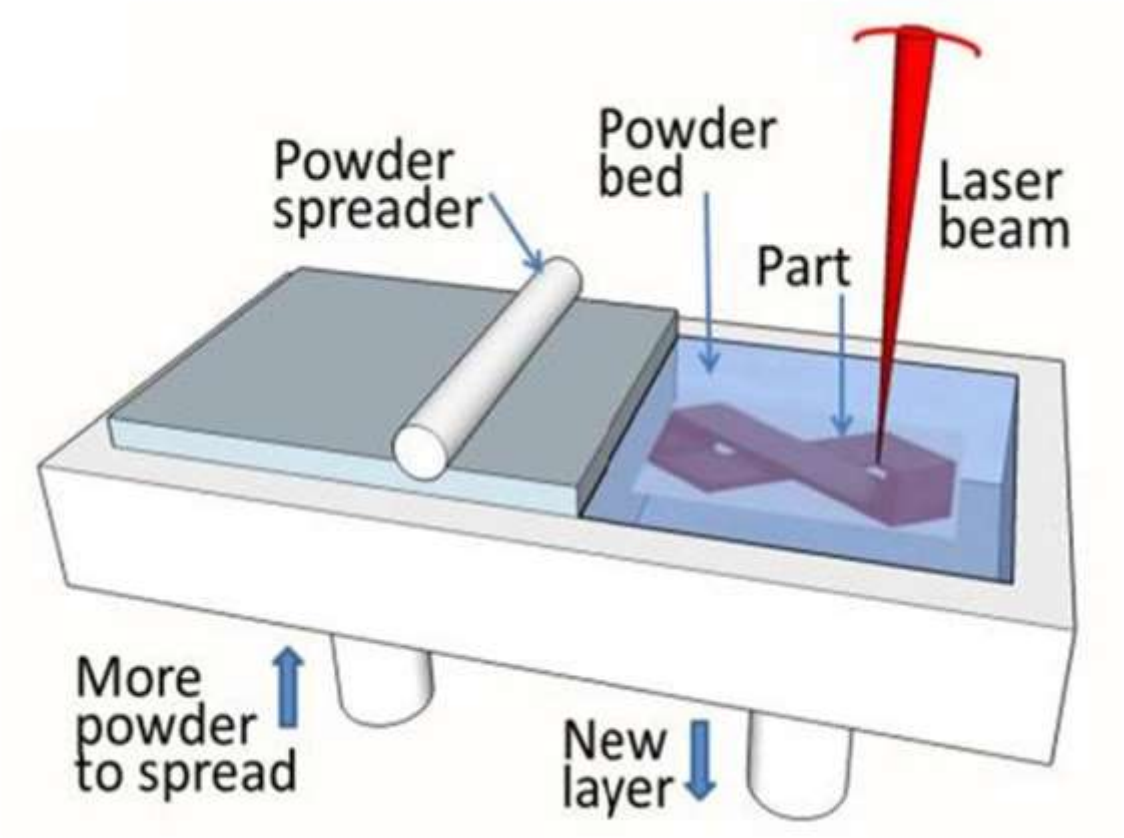
CIMP-3D's Metal 3D Printing Expertise

Energy Source		Powder Bed Fusion	Directed Energy Deposition	
			Powder	Wire
	Laser	   	  	

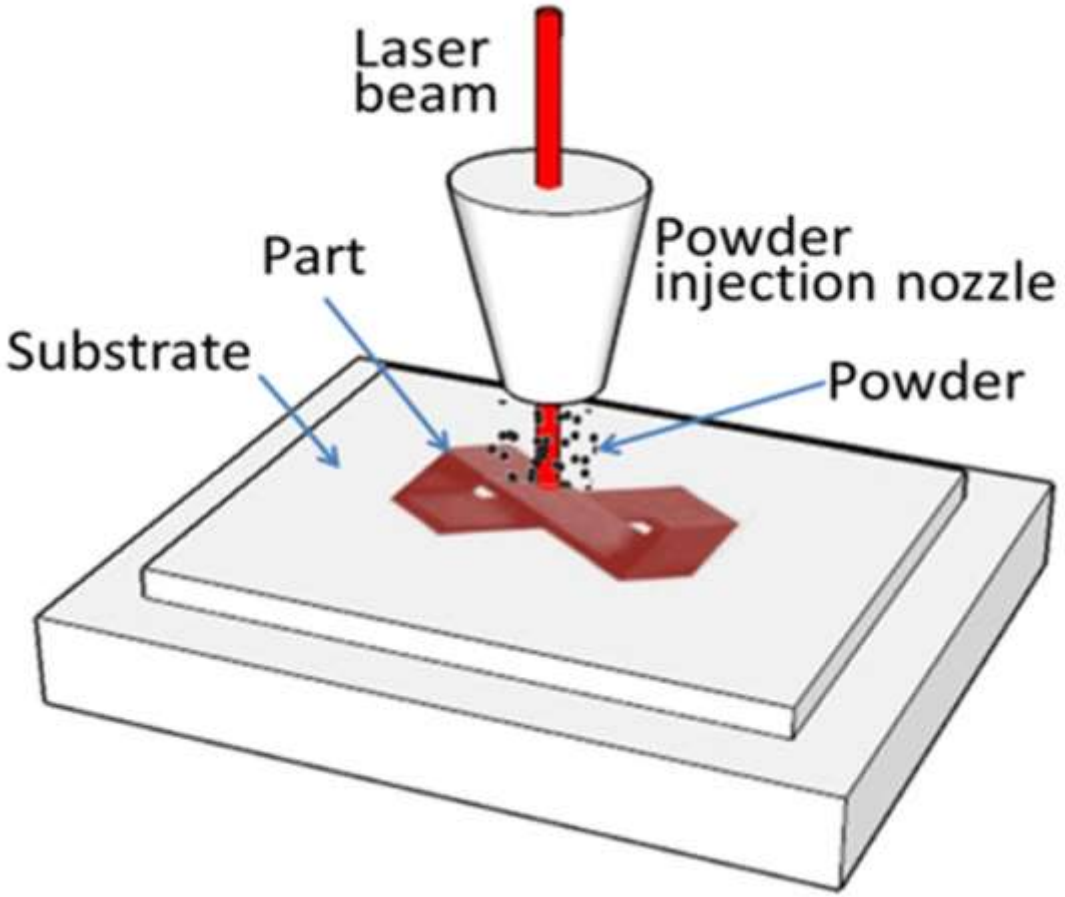
For more details, see:
http://www.cimp-3d.org/

Powder Bed Fusion vs Directed Energy Deposition

PBF



DED



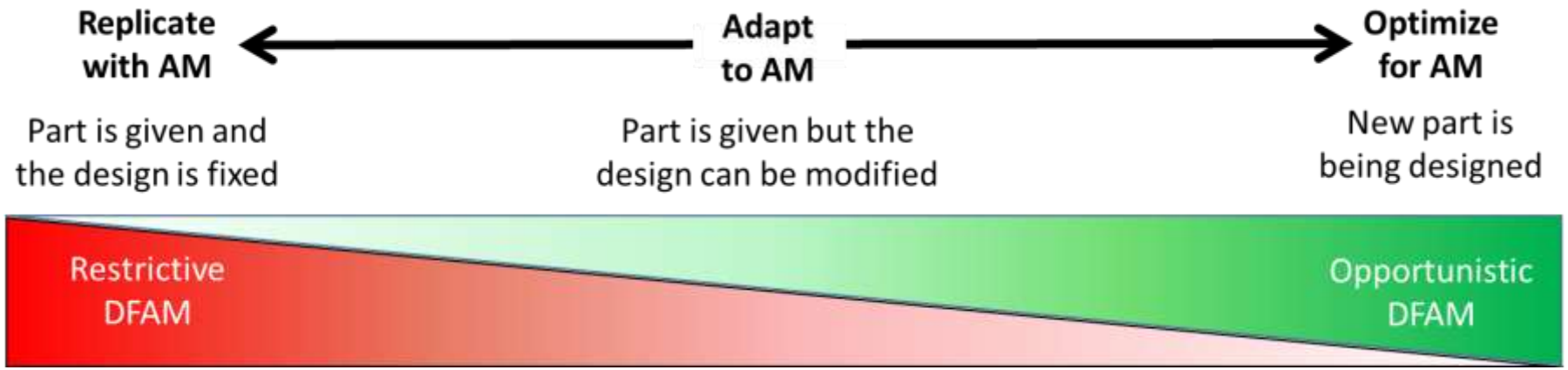
T. DebRoy et al./Progress in Materials Science 92 (2018) 112–224

“We aren’t going to fly a 3D printed part because it’s cool. It has to buy its way onto an engine just like any other part.”

– William Brindley, Pratt & Whitney, 2016

Three DFAM Use Cases

Three DFAM Use Cases



Restrictive DFAM

Aspects of an AM process that limit what can be built

Opportunistic DFAM

Aspects of an AM process that enable unique geometries or materials to be built

Restrictive DFAM Examples

Warping/ distortion

Surface roughness

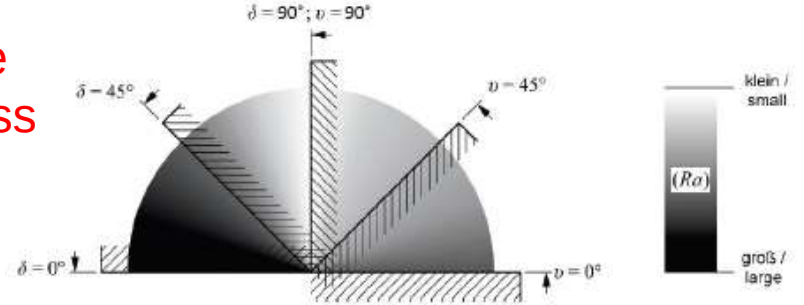


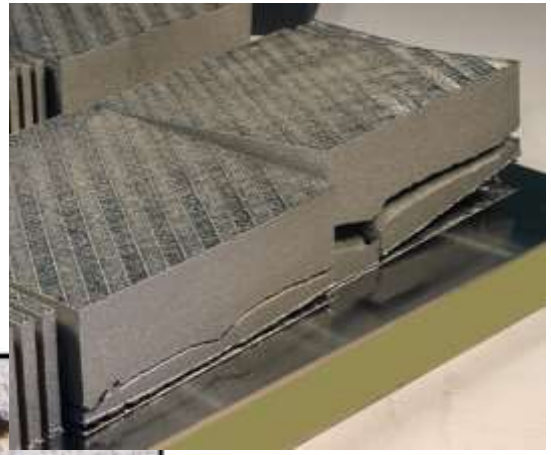
Fig. 3-2: Relationship between up skin-angle, down skin-angle and roughness R_a for LBM [5]

Restrictive DFAM

Overhanging features

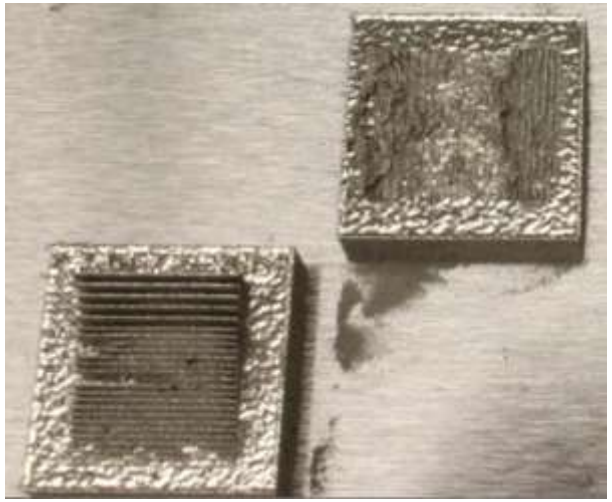
Inconel / 316L

15-5PH



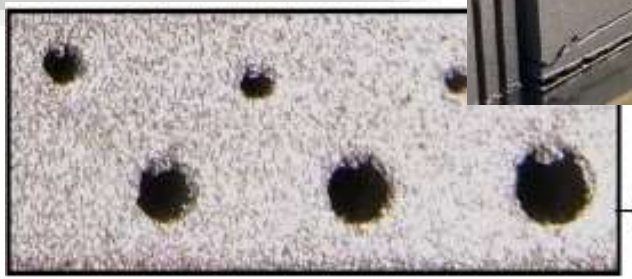
Too thick

Minimum wall thickness



Build orientation effects

Minimum feature diameter



EOS 2011 - DMLS Technology principles - Bruno LE RAZER

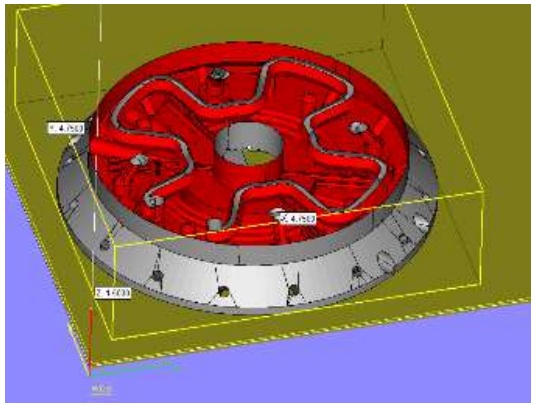
Opportunistic DFAM Examples

Mass customization
Small Batch Sizes
No Tooling/Fixtures

Organic Shapes

[EOS]

Opportunistic DFAM



Lattice structures

Metallic "Foam"

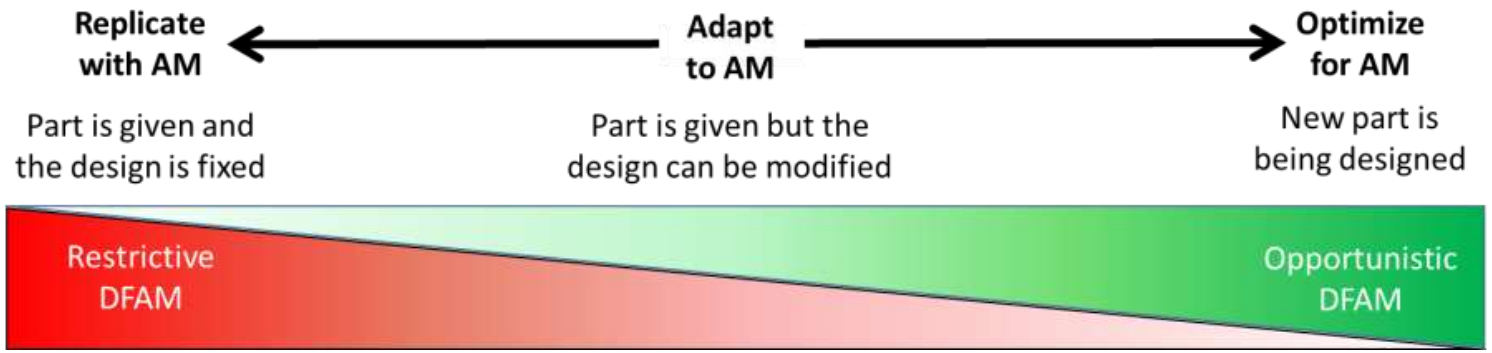
[GE]

Conformal Cooling

Topology Optimization

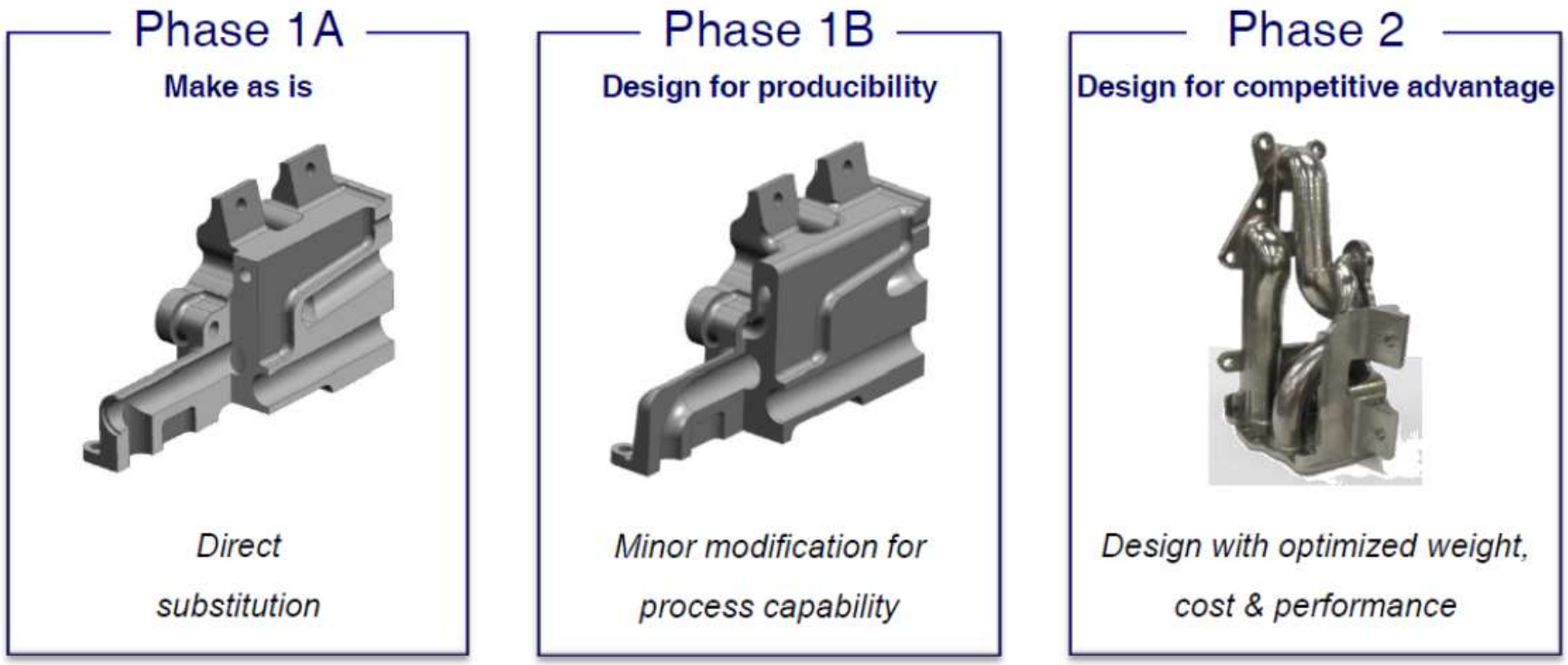
Part Consolidation

Crawl, Walk, Run Strategy



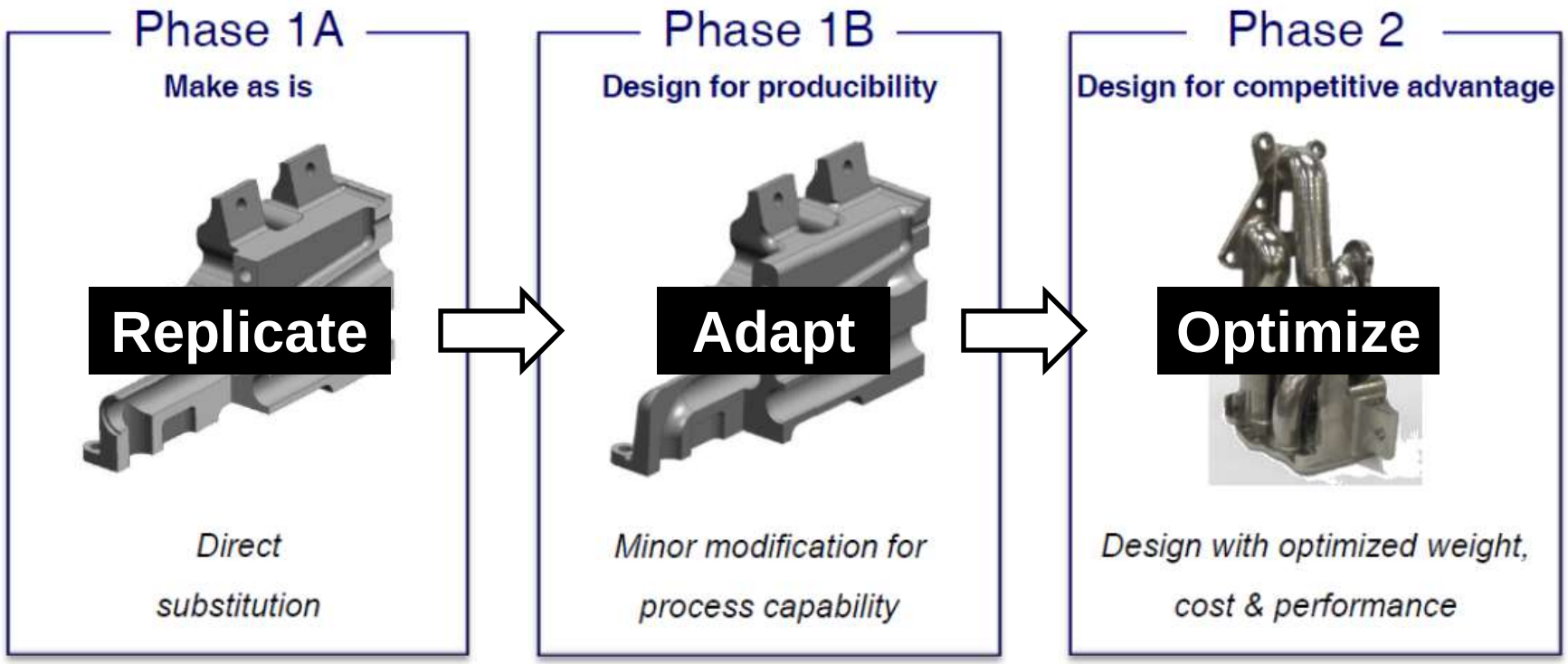
Crawl ⇨ **Walk** ⇨ **Run**

Example from Pratt & Whitney



Source: William Brindley, 2016, Pratt & Whitney, approved for public release

Example from Pratt & Whitney



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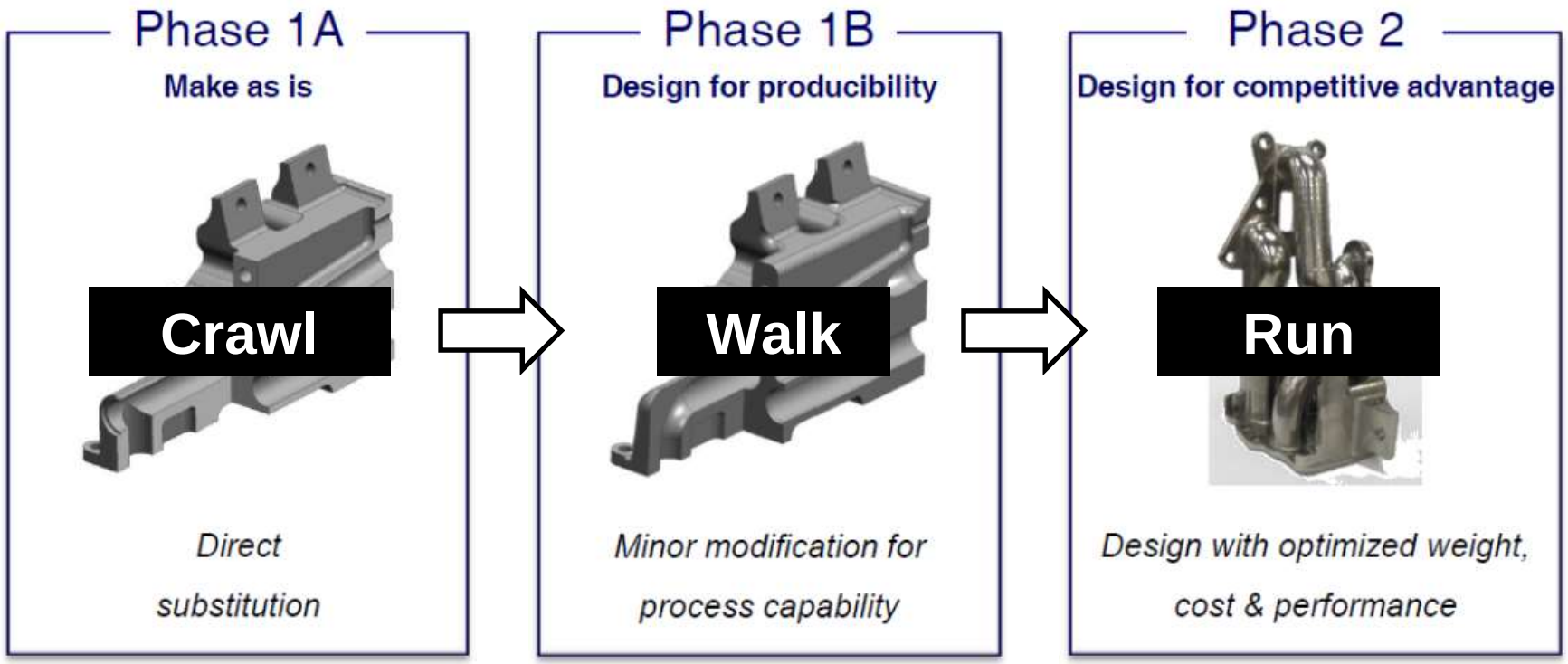
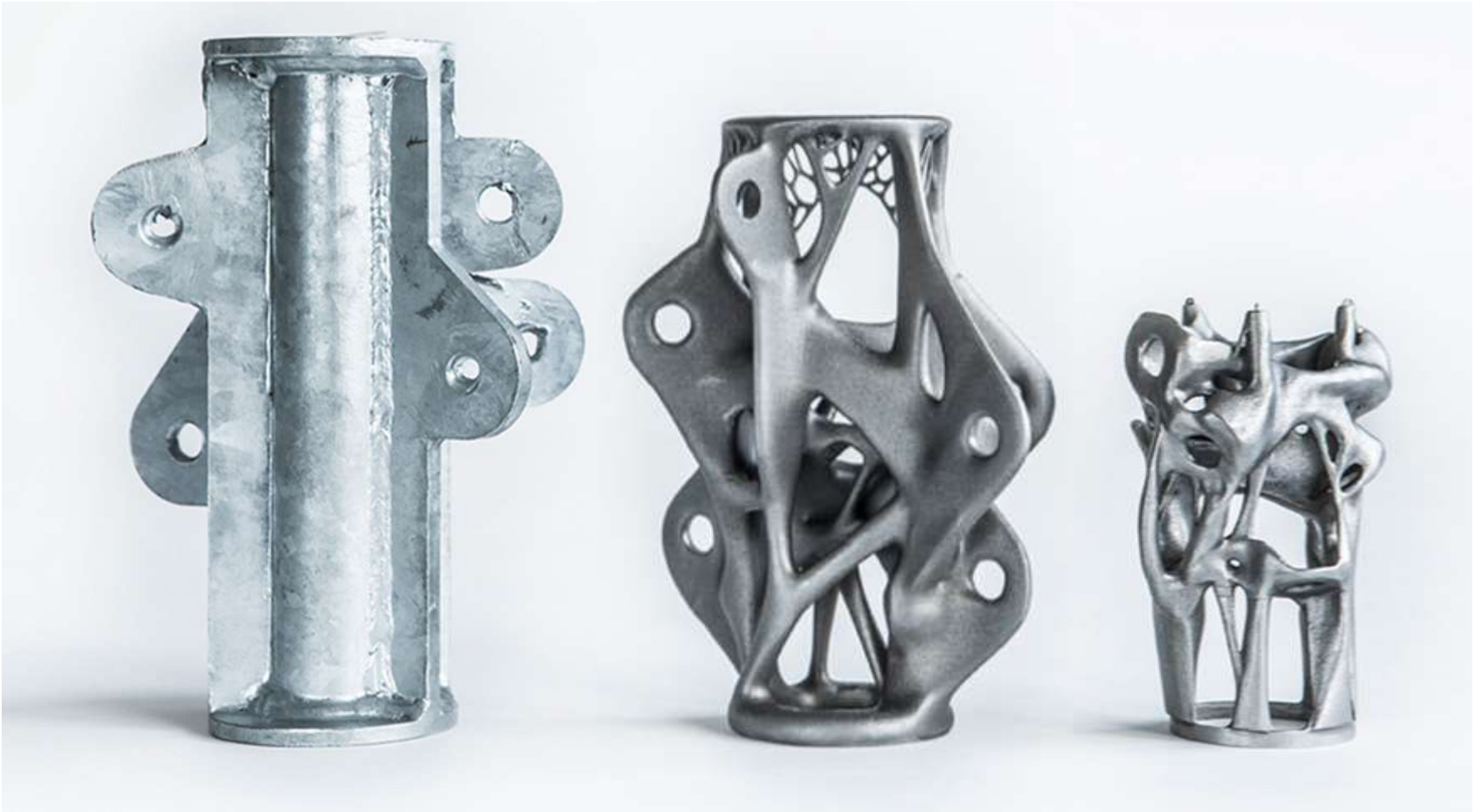


Source: William Brindley, 2016, Pratt & Whitney, approved for public release

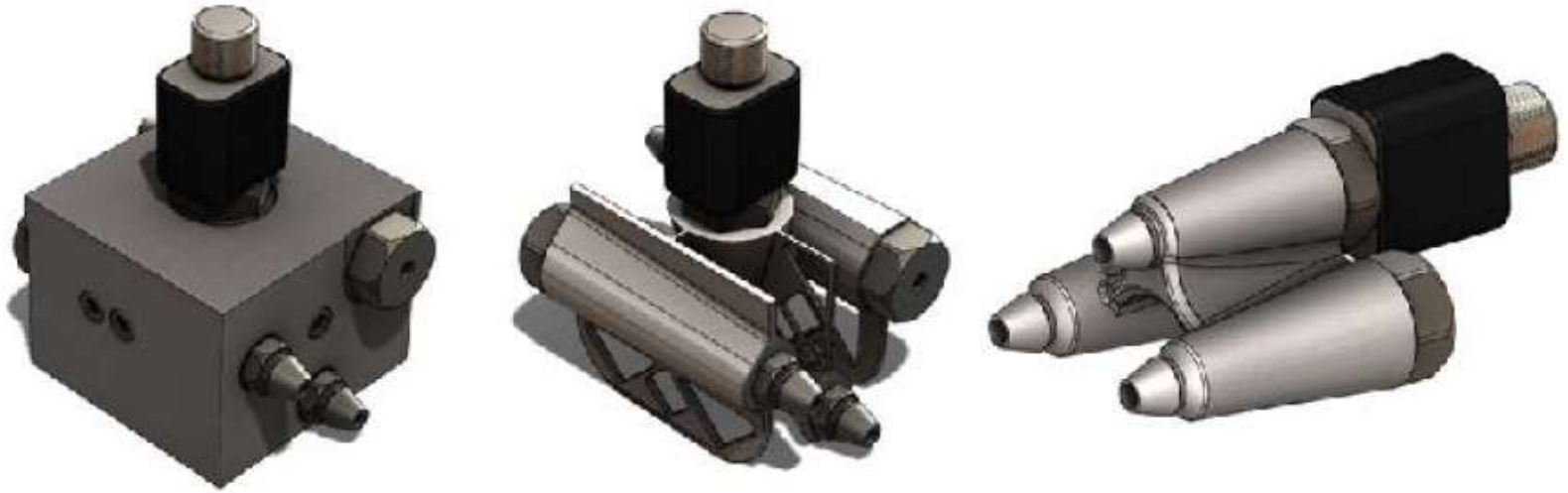
Example from Arup



Source: http://www.arup.com/news/2015_05_may/11_may_3d_makeover_for_hyper-efficient_metalwork

Renishaw's Adapt for AM

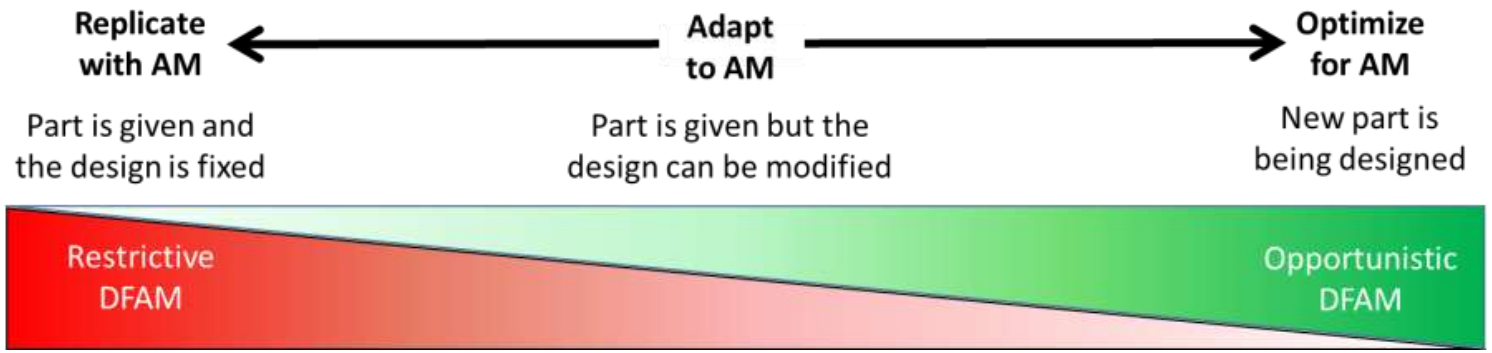
Renishaw distinguishes between Adapt for AM (AfAM) and Design for AM (DfAM); both provide benefits over replicating a conventional part with AM



Conventional	AfAM	DfAM
Mass: 4.6kg	Mass: 1.0kg (78% lighter)	Mass: 0.4kg (91% lighter)

Source: https://www.renishaw.com/en/dfam-strategy-create-design-space-for-maximum-am-impact--43420

Crawl, Walk, Run Strategy



Crawl

Spares and Repairs

Porsche Classic now supplies 3D printed parts for its classic cars (2/12/18)

Examples of replacement parts so far

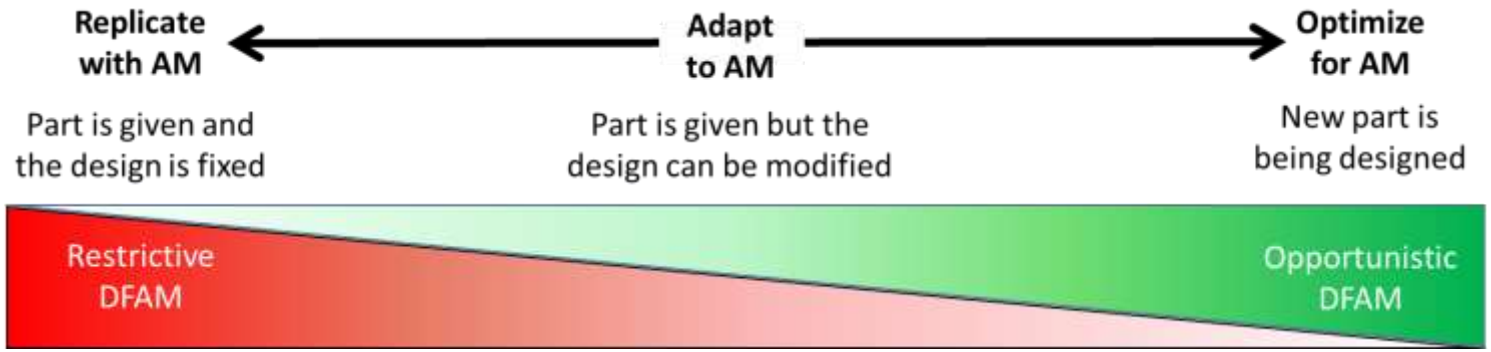
Source:
https://newsroom.porsche.com/en/company/porsche-classic-3d-printer-spare-parts-sls-printer-production-cars-innovative-14816.html

Improved Logistics

Source: NAVAIR (Bill Frazier, Liz McMichael, et al.) & Penn State CIMP-3D (Ted Reutzel, Wes Mitchell, et al.)
Images from 2016, *FF Journal*: http://www.ffjournal.net/item/14034-the-latest-in-metal-additive-manufacturing-fabrication-and-forming-keeps-troops-well-equipped-and-prepared.html

As Built vs. Finished Part

Crawl, Walk, Run Strategy

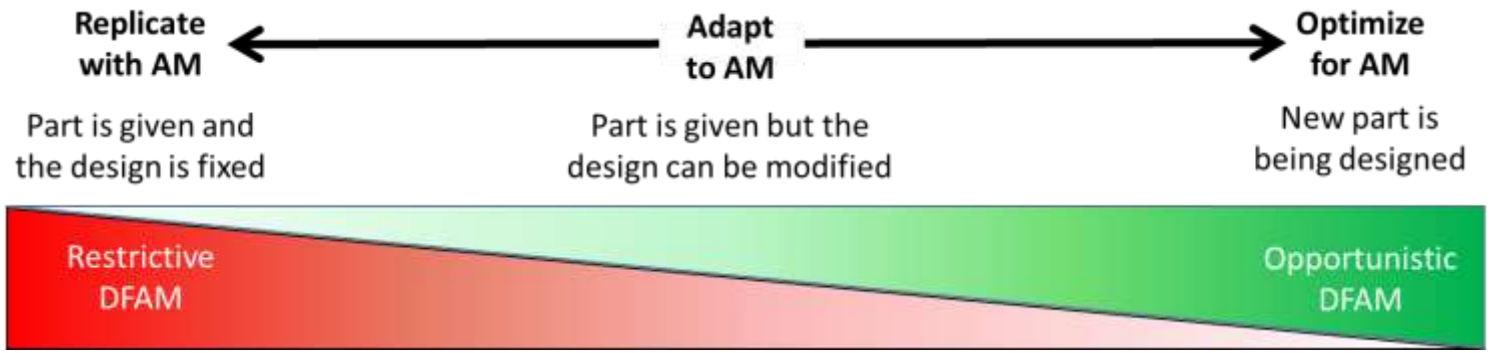


Crawl

Why?
Agility

Examples:
Spares & Repairs
Legacy Parts & Tooling
Functional Prototypes
Supply Chain Leverage

Crawl, Walk, Run Strategy



Crawl ⇨ **Walk**

Why?
Agility

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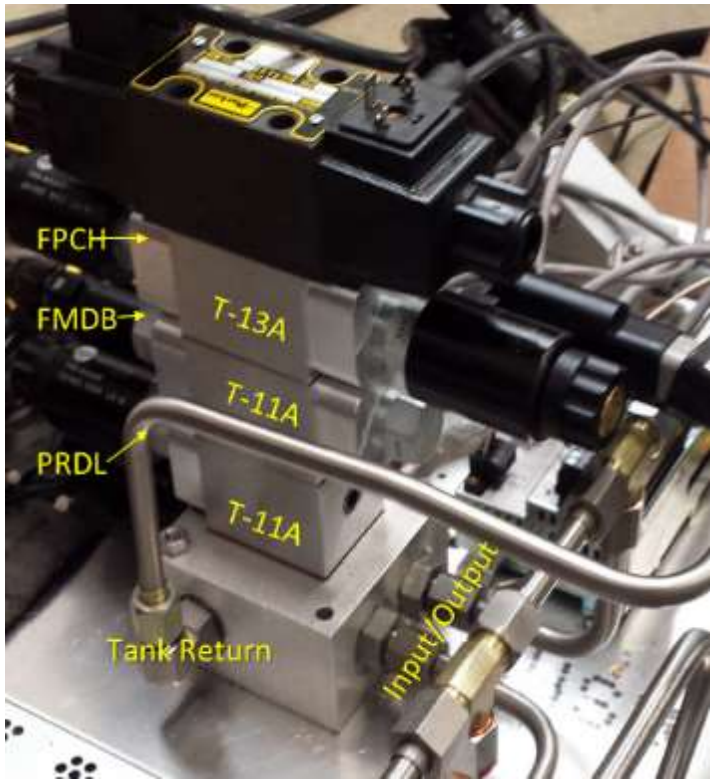
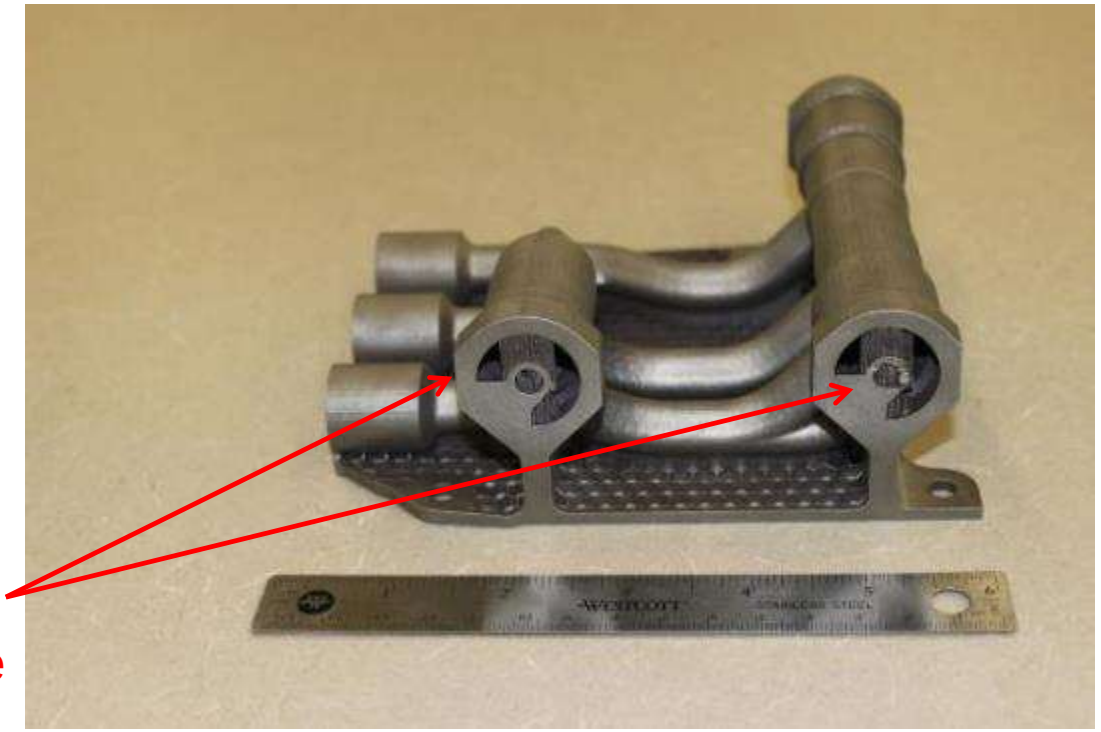
Spares & Repairs
Legacy Parts & Tooling
Functional Prototypes
Supply Chain Leverage

Part Consolidation



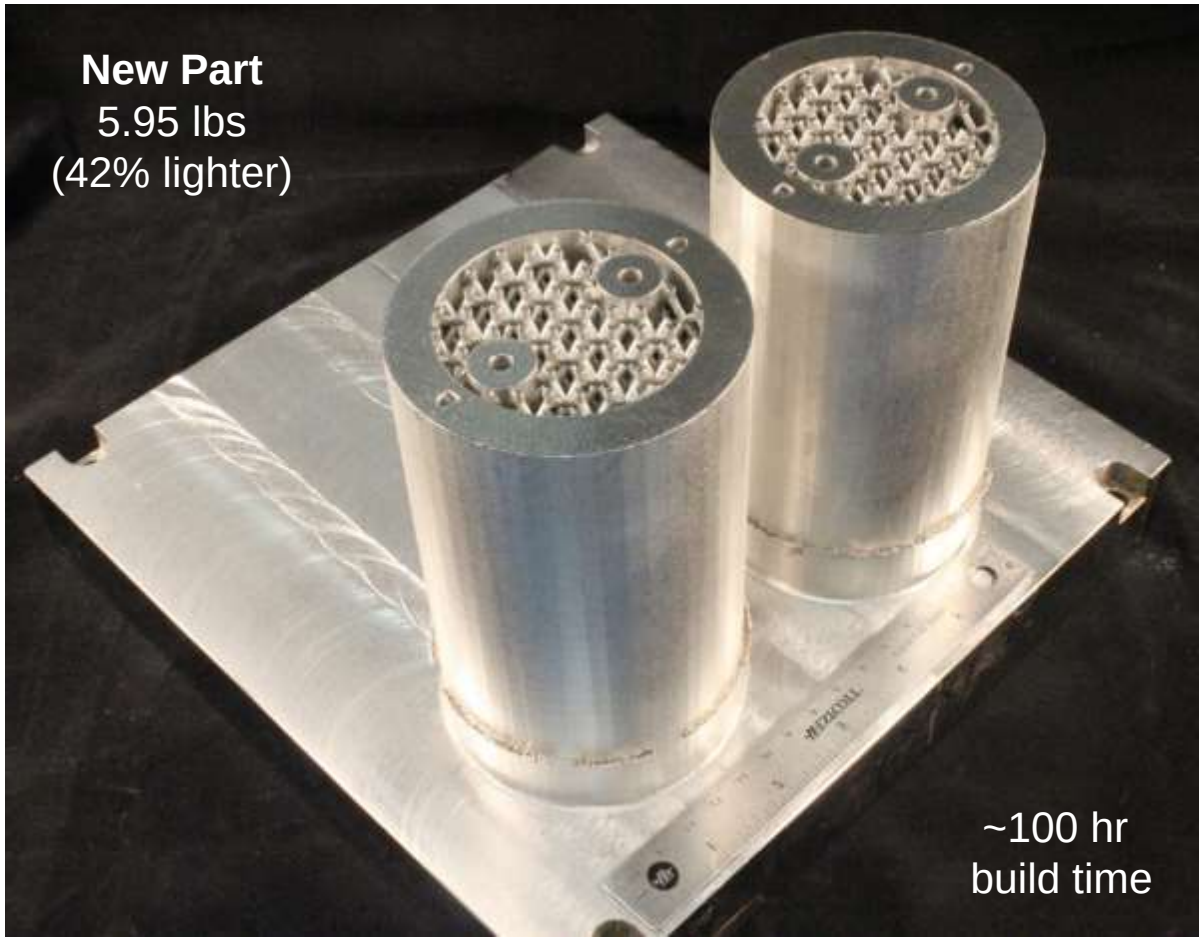
One AM part replaces 17 assembled parts
New manifold is 70% lighter than original



Support design and drill guides added to facilitate finishing and assembly

Joint PSU-Navy project funded by DARPA
Courtesy John Schmelzle, NAWC Lakehurst

Lattice Structures



Improved Implants and Custom Devices

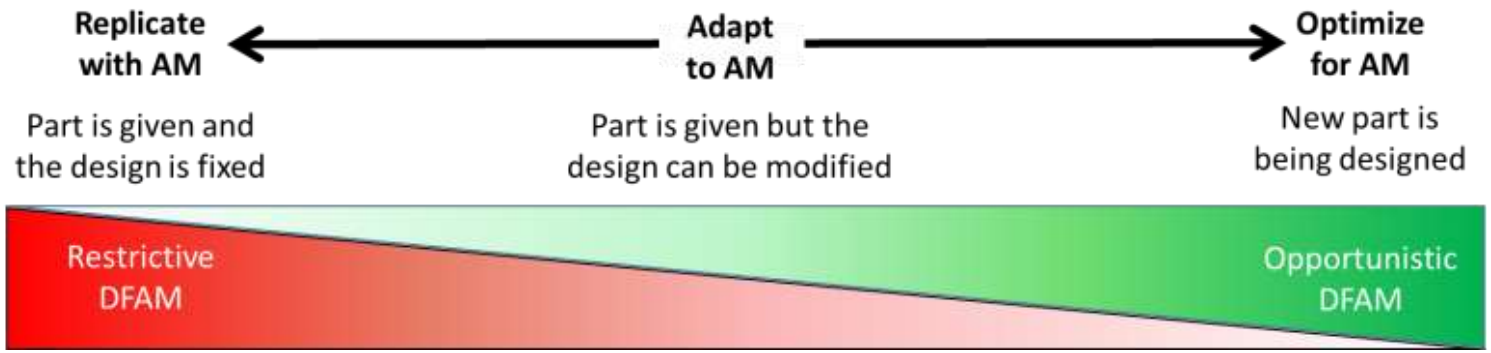
1st FDA-approved 3D printed Titanium Acetabular Cup

By: Pipeline Orthopedic
(Acquired by Stryker)

Source: Robert Cohen

Titanium “foam” speeds recovery and improves fixation of implant

Crawl, Walk, Run Strategy



Crawl ⇨ Walk

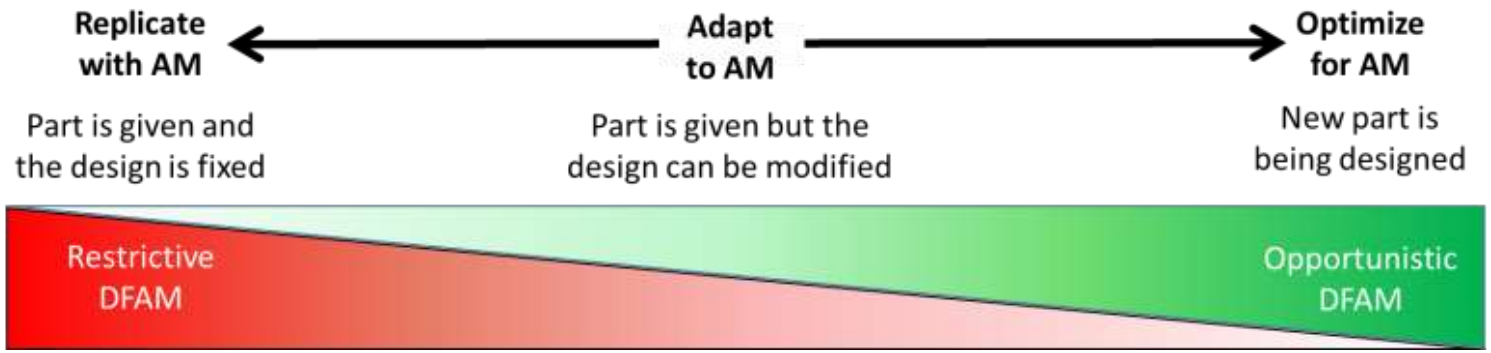
Why?
Agility

Examples:
Spares & Repairs
Legacy Parts & Tooling
Functional Prototypes
Supply Chain Leverage

Why?
Viability

Examples:
Part Consolidation
Lightweight Lattices
On-Demand Printing
Reduce Buy-to-Fly Ratio

Crawl, Walk, Run Strategy



Crawl ⇨ **Walk** ⇨ **Run**

Why?
Agility

Examples:
Spares & Repairs
Legacy Parts & Tooling
Functional Prototypes
Supply Chain Leverage

Why?
Viability

Examples:
Part Consolidation
Lightweight Lattices
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Reduce Buy-to-Fly Ratio

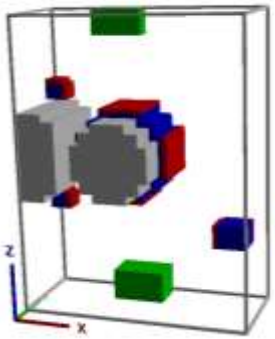
Topology Optimization

2012

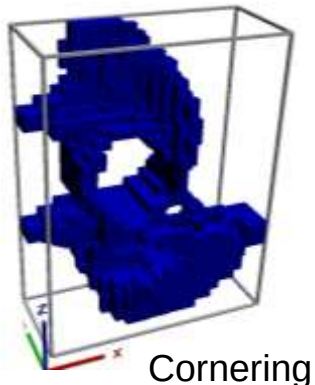
New Formula SAE Upright:

- Same weight as older version
- Withstands larger loads
- Solidworks, TopOpt, and Ansys used for CAD, topology optimization, and FEA modeling

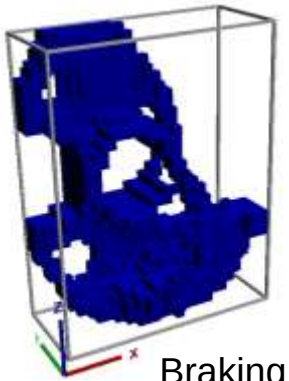
2013



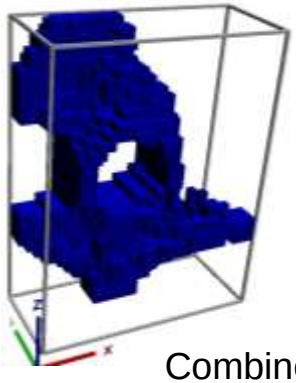
Specify design space, voids, and boundary conditions



Cornering



Braking



Combined

Source: (Maranan, 2013)

Upright with Support Structures

Source: (Maranan, 2013)

Build Time and Cost Estimates

Part	Z-Height	Exposure Volume (cm^3)	Exposure Time (Hrs)	Recoat Time (Hrs)	Build Time (Hrs)
Right Support	148.59	412.28	24:48	5:35	30:23
Right Part	171.75	175.02	16:54	7:20	24:14
				Total	54:37

Part	Material	Volume (cm^3)	Loose Powder Inside Supports (cm^3)	Weight Total (Kg)	Cost ($)
Right Support	Ti64	412.28	82.45	2.18	1482.40
Right Part	Ti64	175.02	N/A	.772	524.96

Note: More than 1/2 the build time and 3/4 of the cost is in the supports

Source: (Maranan, 2013)

Removed Supports

Source: (Maranan, 2013)

Generative Design

Generative Design tools help “grow” parts that are optimized for AM

Customizing Performance

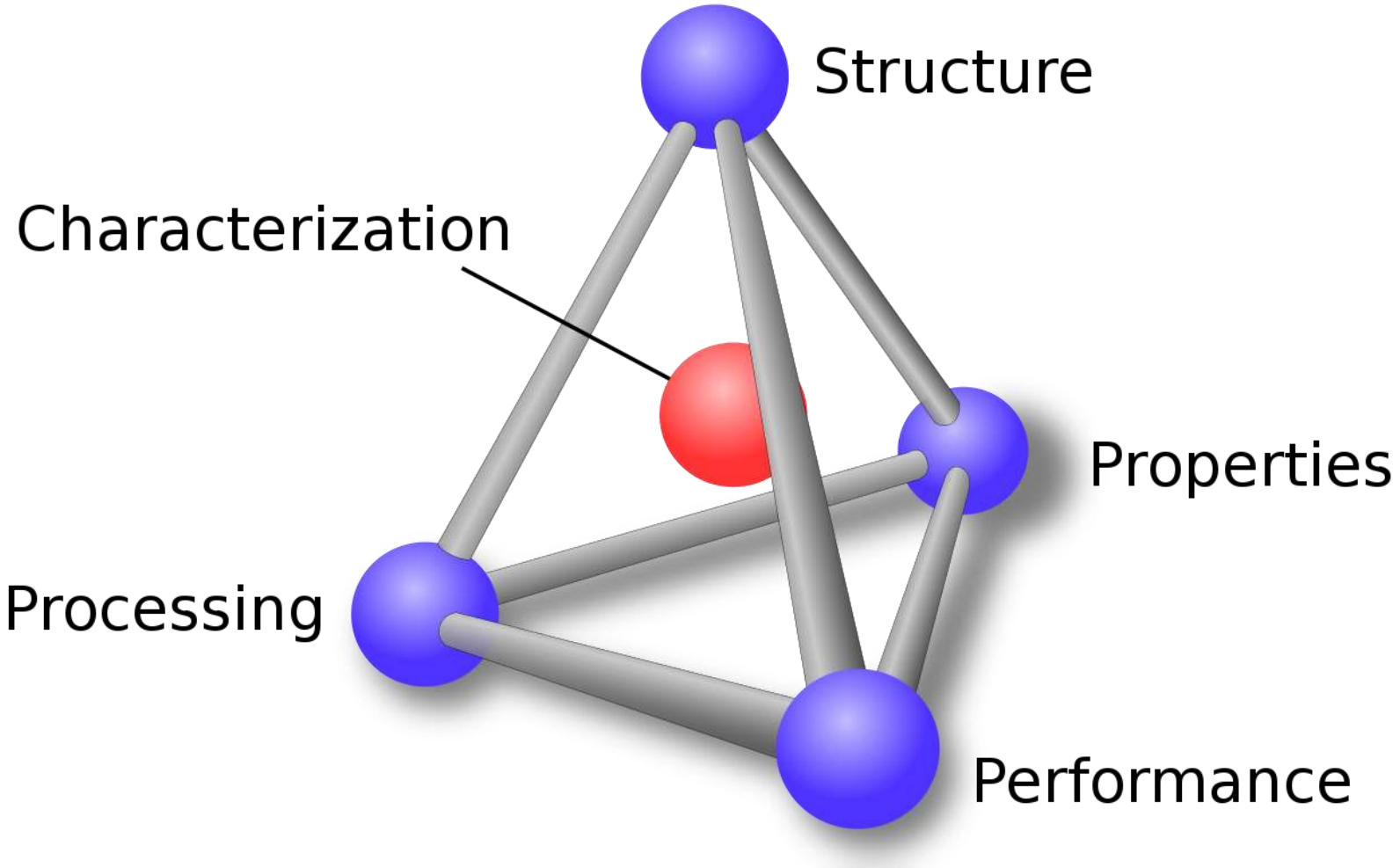
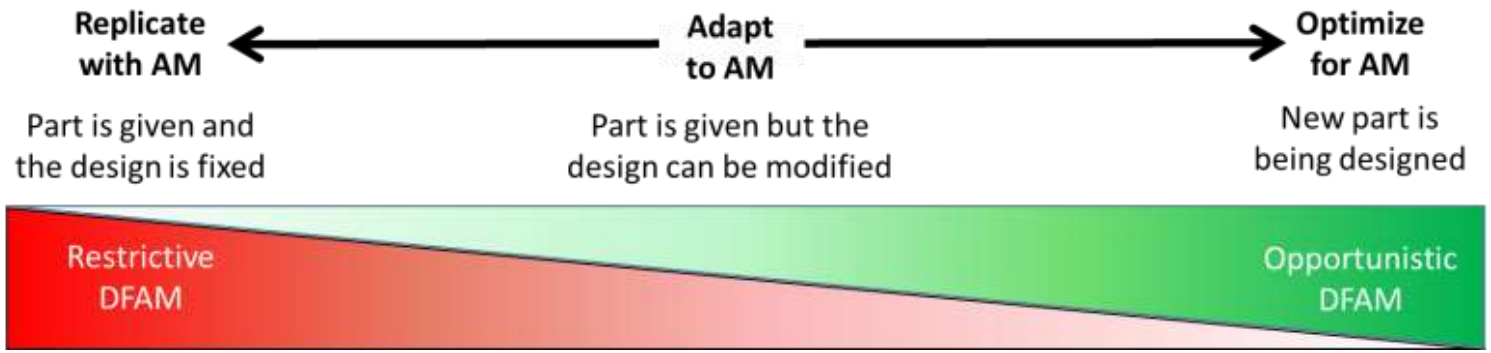


Image Source

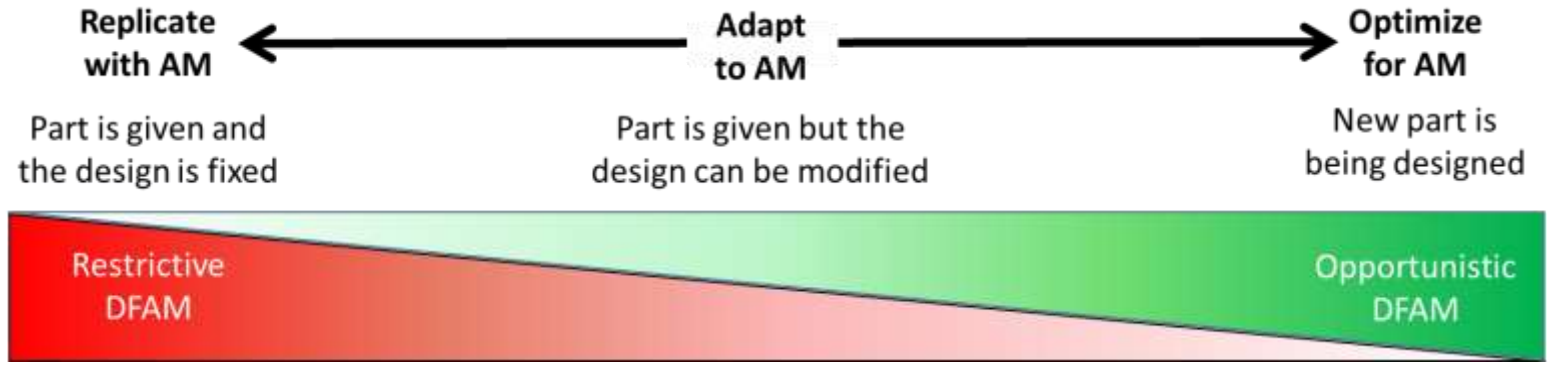
Crawl, Walk, Run Strategy



Crawl ⇨ **Walk** ⇨ **Run**

Crawl	Walk	Run
Why? Agility	Why? Viability	Why? Optimality
Examples: Spares & Repairs Legacy Parts & Tooling Functional Prototypes Supply Chain Leverage	Examples: Part Consolidation Lightweight Lattices On-Demand Printing Reduce Buy-to-Fly Ratio	Examples: Topology Optimization Generative Design Mass Customization Functional Grading

Next Step: Mapping Tools to Use Cases



Steps/Tools			
3D scanning	●	○	
CAD modeling	●	●	●
Design guidelines	●	●	●
Lattice structures		●	●
Topology opt			●
FEA/CFD analysis		○	●
Build planning	●	●	●
Process planning	●	●	●
Post-processing	●	●	○
Cost estimation	●	●	●

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