Additive Manufacturing and certification of Aircraft Interior components

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Agenda

Inam
1. AM technology
2. Research
3. Development

Doug
4. Applications
5. Certification
6. Future Prospects

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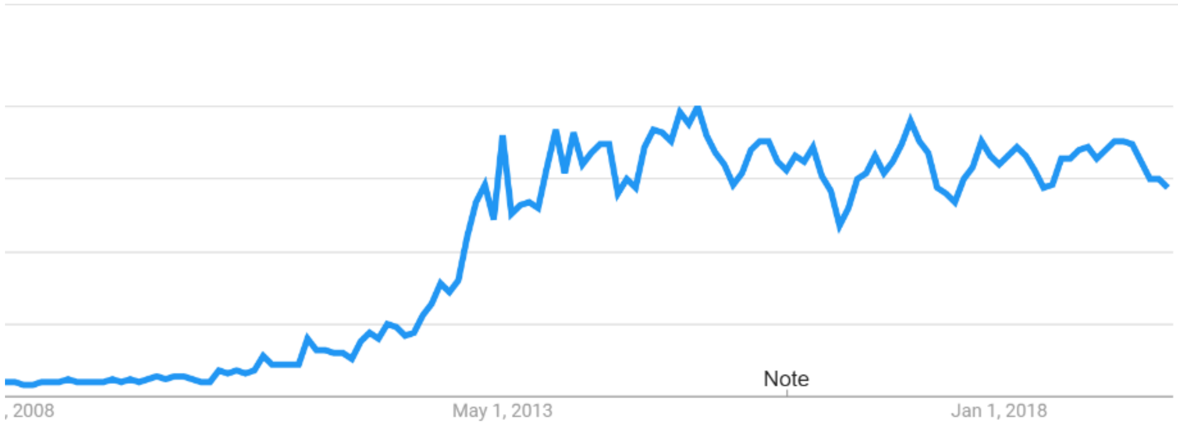
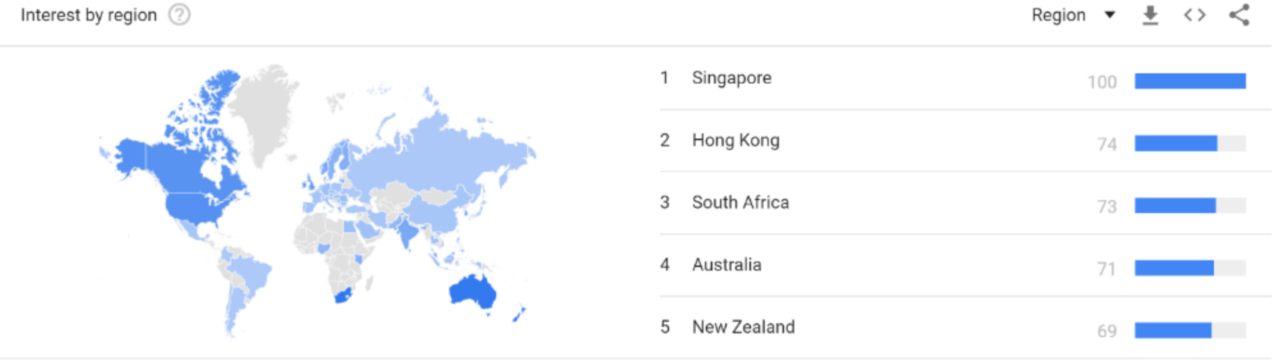
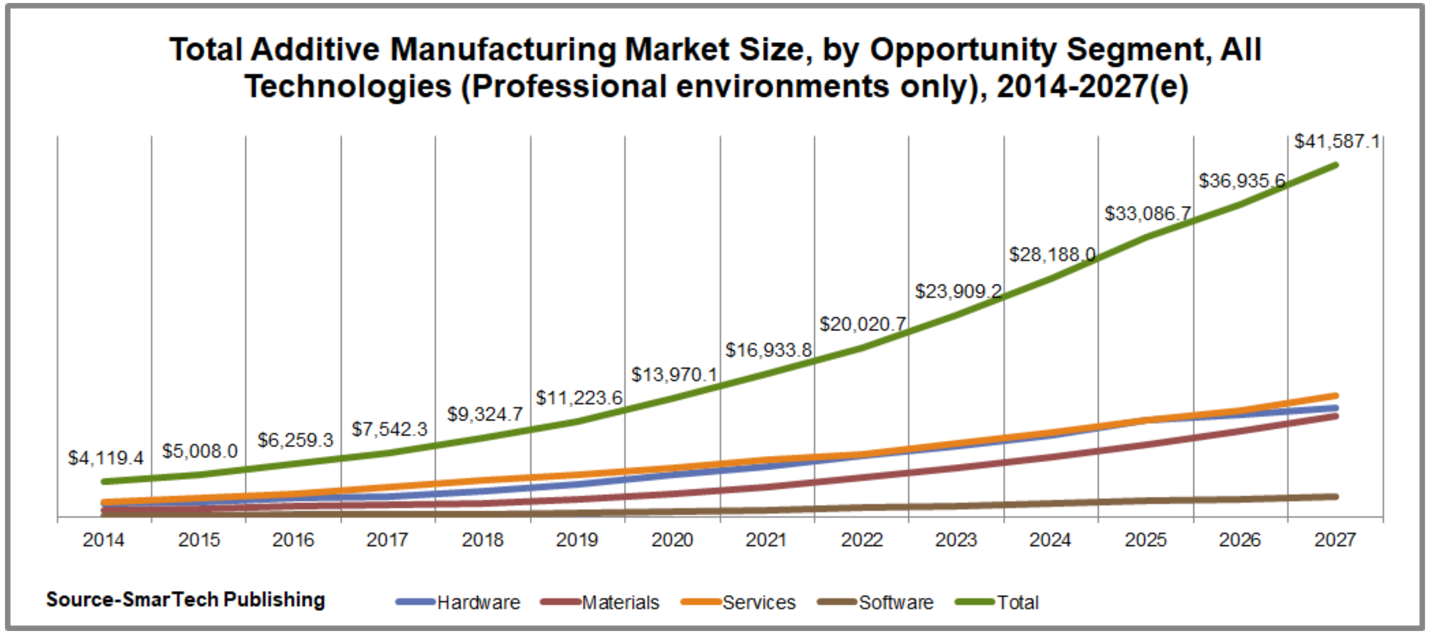
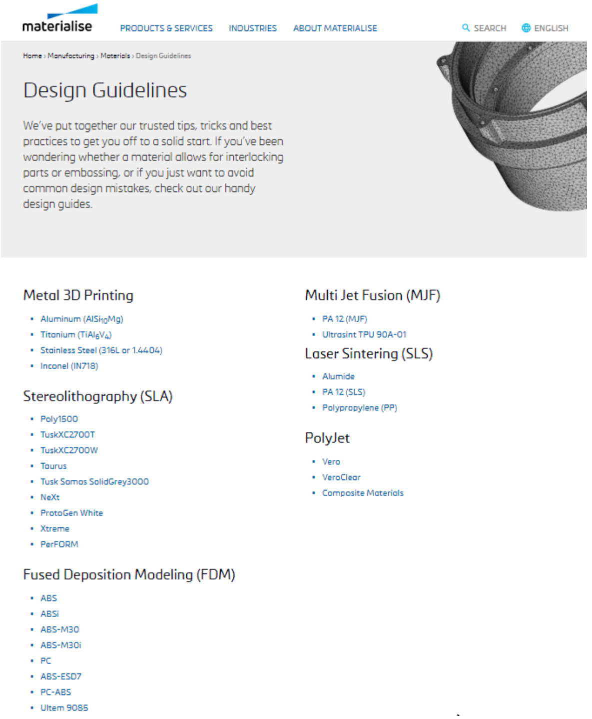
Additive Manufacturing/ 3D Printing Trend



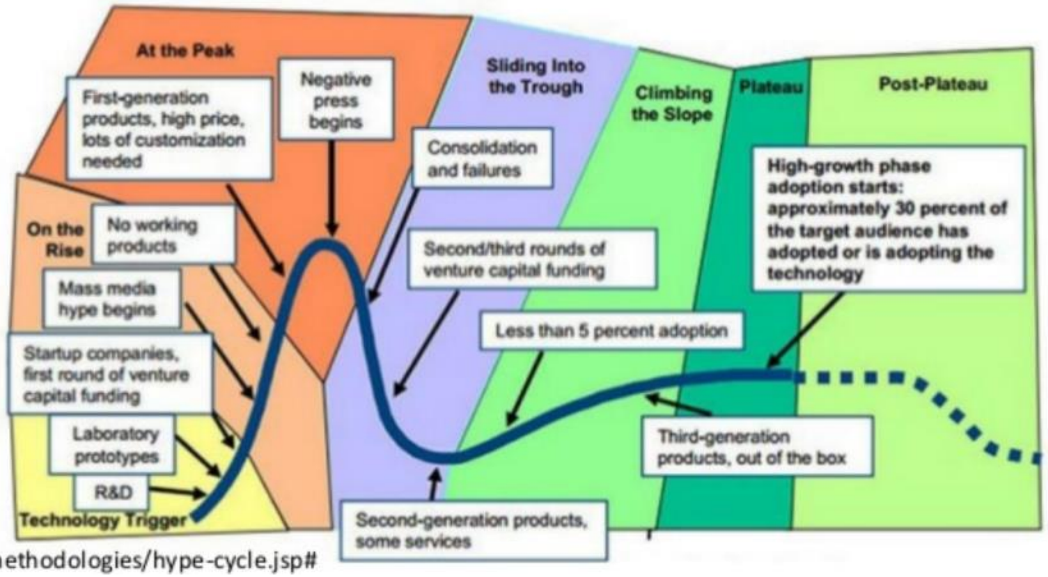






Gartner Hype Cycle

- Gartner Hype Cycles provide a graphic representation of the maturity and adoption of technologies and applications
- Gartner Hype Cycle methodology gives you a view of how a technology or application will evolve over time
- Each Hype Cycle drills down into the five key phases of a technology's life cycle.
  - Technology Trigger
  - Peak of Inflated Expectations
  - Trough of Disillusionment
  - Slope of Enlightenment
  - Plateau of Productivity



http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp#

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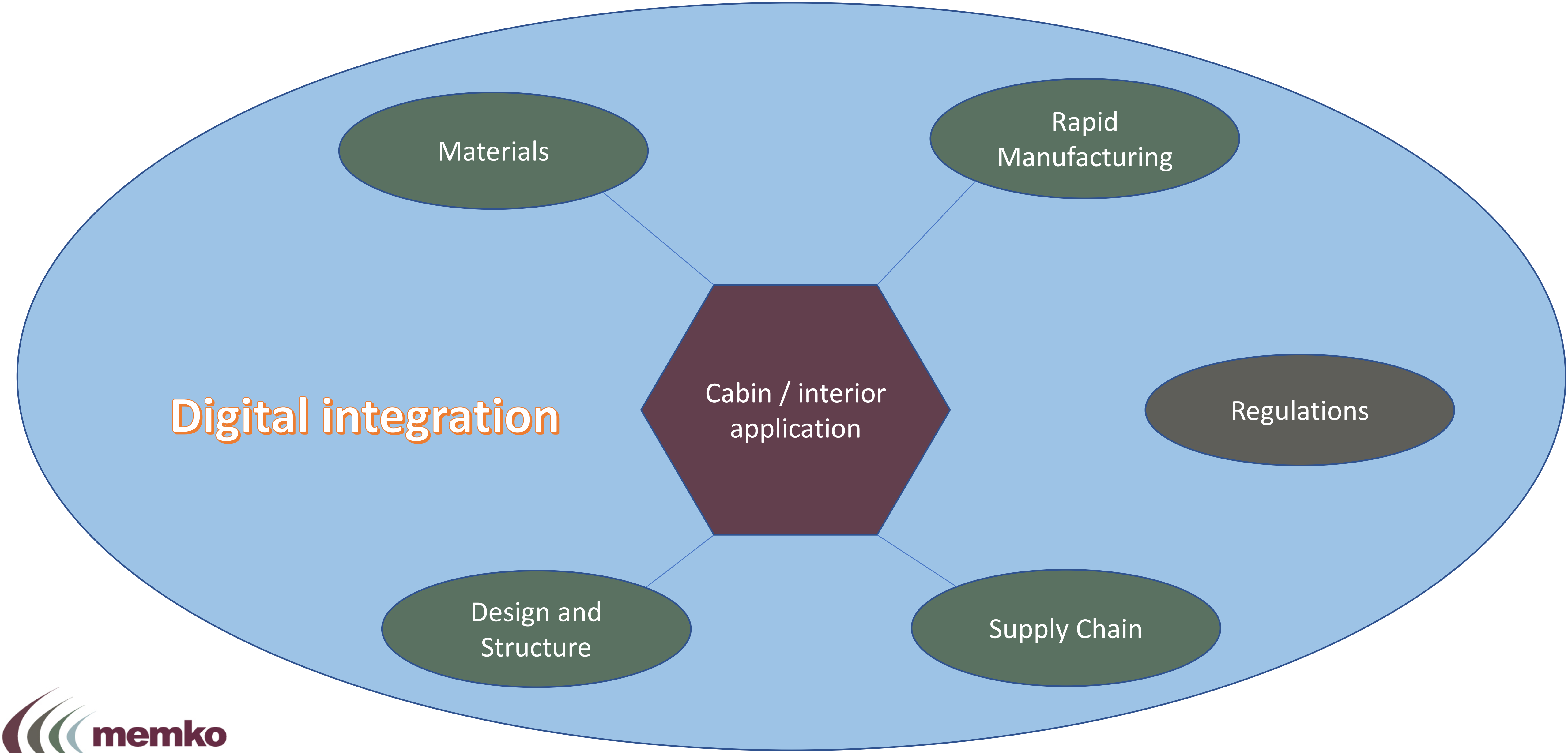
3D Printing Hype Cycle 2019

Characteristics of aircraft interiors
Demand Perspective

- Aesthetics
- Ergonomics
- Durability
- Maintainability
- Safety

➢ Innovation and Trends
  - Multipurpose components
  - Integrated parts
  - Custom components
  - Just in time availability for replacement

Supply Perspective



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Materials: Plastics in A/C Interiors

- Freedom in Design
- User Interaction
  - Surface finishes
  - Feel
  - Look
- Lightweight
  - Lesser fuel per flight
- Stability against:
  - Fire-flammability
  - Radiation
  - Corrosion
  - Low temperature
- Environmentally Friendly
  - Durable
  - Recyclable

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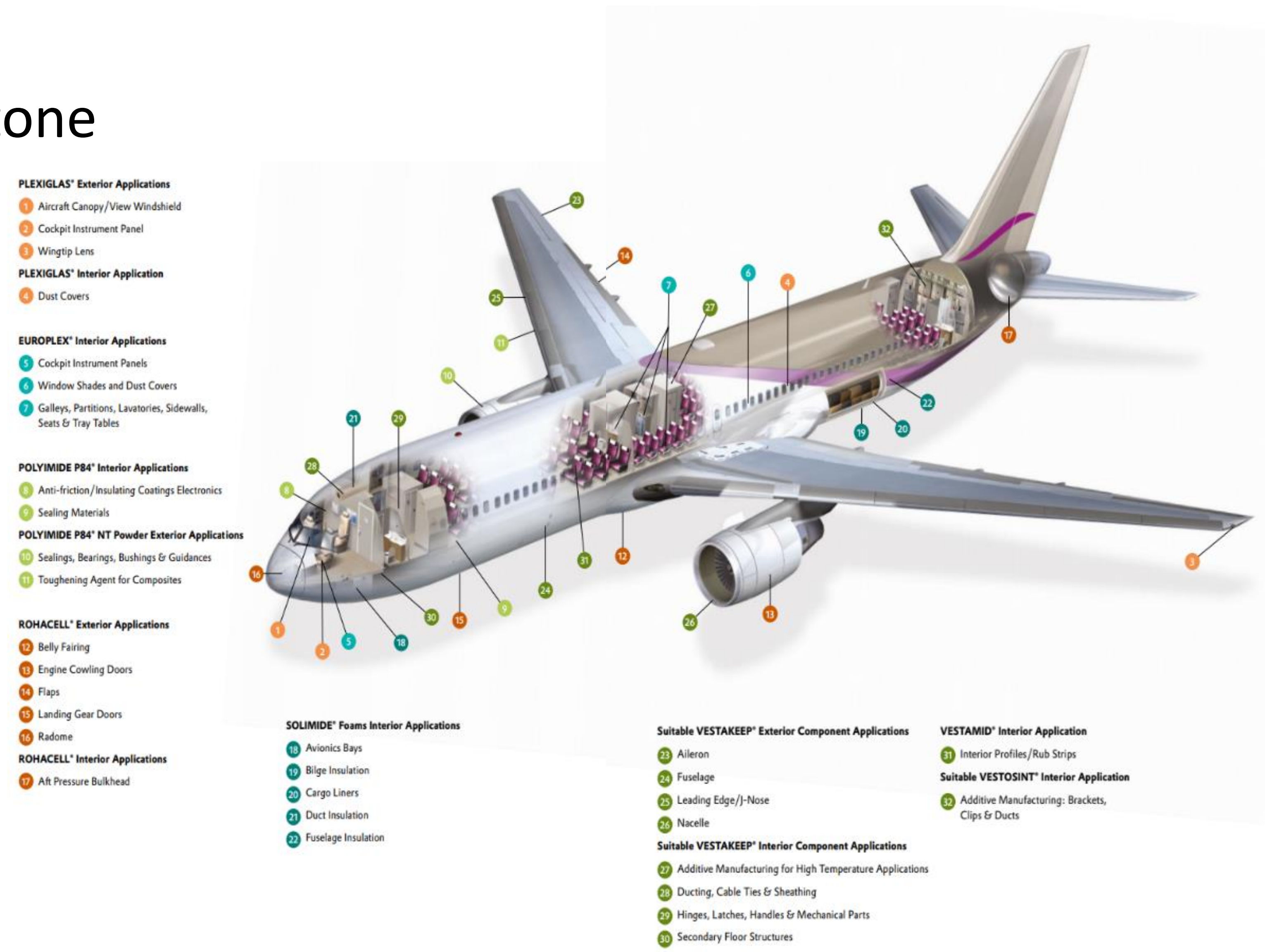
Plastics in aerospace applications

- PEEK - Polyether ether ketone
- PEI – Polyetherimide
- PPSU – Polyphenylsulfone
- PI - Polyimide



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Commercial Products

Technical Data Sheet

SOLVAY
asking more from chemistry®

Radel® R-7159
polyphenylsulfone

Radel® R-7159 polyphenylsulfone (PPSU) was developed specifically for aircraft interior applications. The product complies with the FAA regulation 14CFR Part 25 Appendix F, offering vertical burn resistance, very low smoke generation and, through the use of proprietary additives, low heat release values in the Ohio State University (OSU) rate of heat release method. It also generates low flaming-mode toxic gas emissions.

match OEM color standards and in a natural-color grade that is designed to accept aircraft paint systems for aesthetic parts. Painting enhances the chemical resistance of the polymer and provides the final step in color coordination.

- Natural: Radel® R-7159 NT 50
- Black: Radel® R-7159 BK 937

INNOVATIVE PLASTICS
PRODUCT LINE GUIDE:
ULTEM™ RESINS PORTFOLIO

sabic

MVR: 360℃/5kg, cm^3/10min; Flexural Modus, 2mm/min, MPa; IZOD Impact, unnotched, +23℃ kJ/m^2; VICAT Softening Temp , Rate B/120℃; UL94 Flame Class Rating

ULTEM 1000 resin series	MVR	Flex Mod.	Vicat	IZOD	UL94*
General Purpose, Unreinforced					
1000 (R,F,E,EF,P) Standard, Extrusion	13	3300	212	6	V-0/0.75
1010 (F,R) Easy flow	25	3300	212	5	V-0/1.5
ULTEM 2000 resin series					
Glass reinforced, greater rigidity					
2100 (R,F) Standard, 10% glass reinforced	9	4500	217	30	V-0/0.41
2200 (R,F) Standard, 20% glass reinforced	7	6500	218	30	V-0/0.41
2300 (R,F) Standard, 30% glass reinforced	6	8500	220	40	V-0/0.25
ULTEM 4000 resin series					
Wear Resistant, reduced coefficient of friction					
4000 Reinforced, 25% glass reinforced	5	7000	220	15	V-0/0.84
4001 Unreinforced	13	3000	210	10	V-1/1.6
ULTEM CRS5000 resin series					
Superior chemical resistance					
CRS5001 (R) Unreinforced	7	2500	222	-	V-0/1.5
CRS5311 30% glass reinforced	7	8200	220	35	V-0/1.5
ULTEM 9000 resin series					
Fulfills aircraft regulations (ABD, FAR, OSU, NBS), delivered with individual lot certification					
9075 OSU 65/65, unreinforced, injection molding	15	3200	200	7	V-0/1.6
9085 OSU 55/55, unreinforced, high flow	65	2750	173	13	-

ULTEM® resin is chosen because it offers:

- The ULTEM® 9000 resin series for full compliance with aircraft industry regulations for aircraft interiors including ABD 0031, FAR 25.853, OSU 65/65 heat release tests and NBS smoke density tests
- The ULTEM® 1000, 2000, CRS 5000, 6000 and 7000 resin series for compliance with aircraft industry regulations such as ABD 0031, FAR 25.853, OSU 100/100 heat release tests and NBS smoke density tests
- Very low smoke and toxic gas emission, which makes it a material of choice for aircraft interiors
- Chemical resistance against most fuels and fluids
- Excellent processibility with a very good part reproducibility
- ULTEM® CRS 5000 resin series for better resistance against hydraulic aircraft fluids, such as Skydrol, compared to ULTEM® 1000 resin
- Ability to manufacture ULTEM® resin based thermoplastic composites which allow increased productivity in component manufacturing over traditional composite materials
- Ability to manufacture ULTEM® foam cores for tough, light-weight sandwich panels

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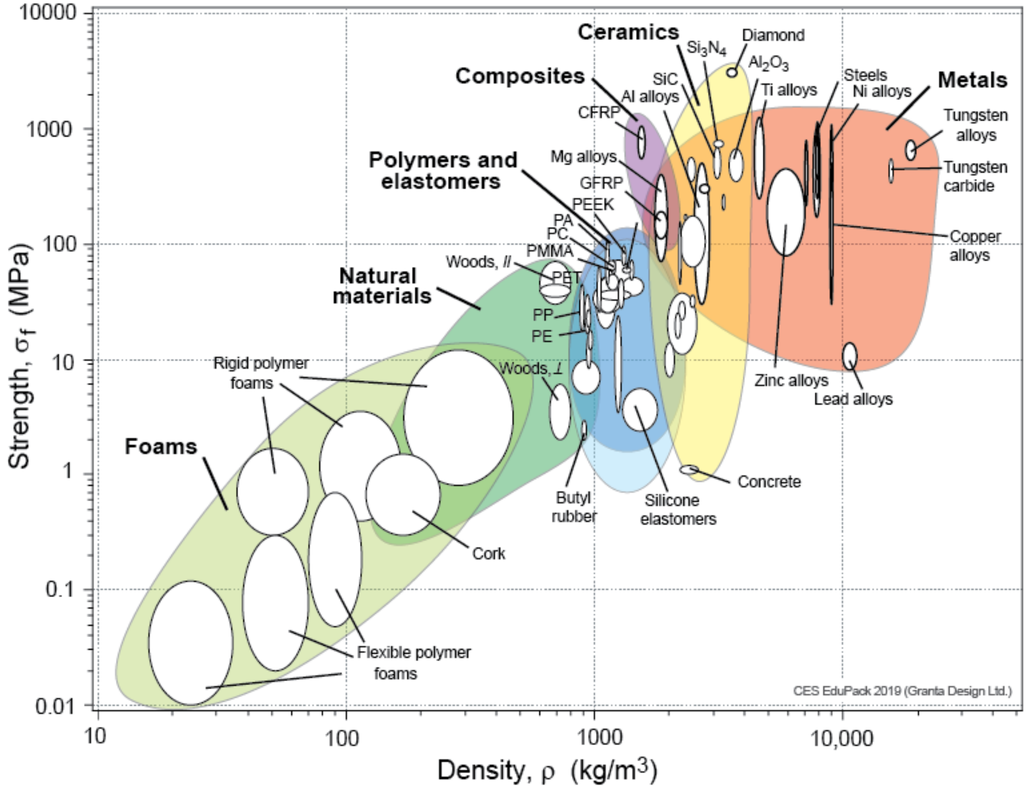
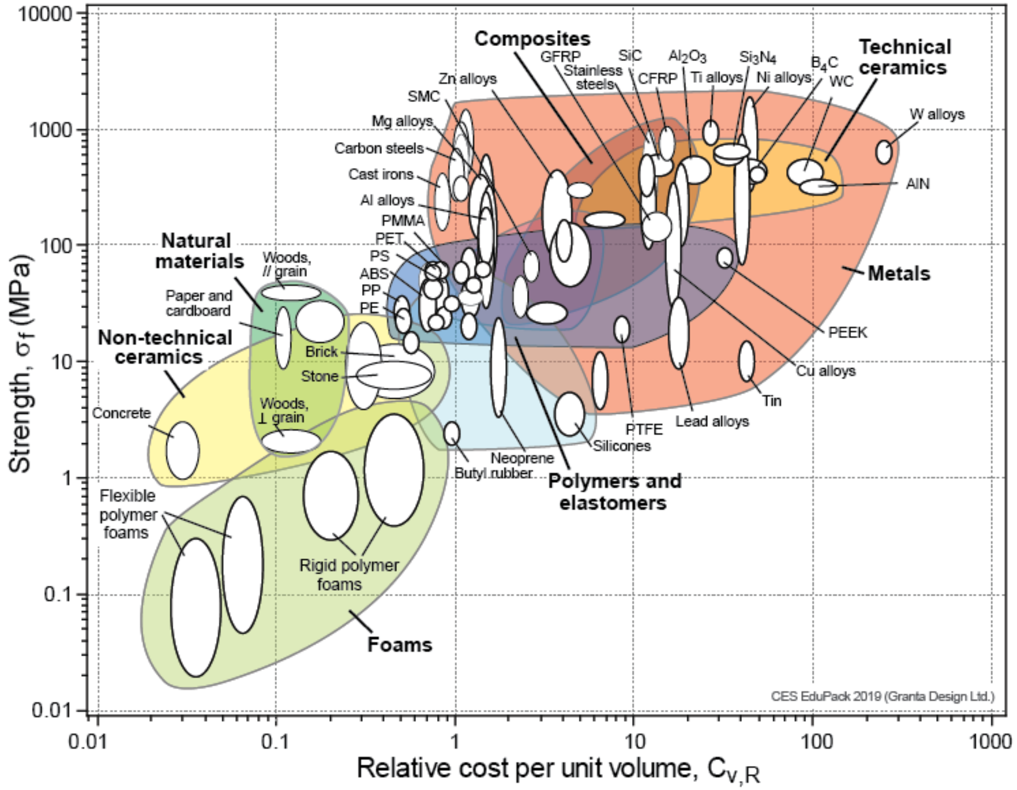
Materials: Plastics in A/C Interiors





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Fire Smoke Toxicity

- FAR 25.853, (a) i & ii, (d)
- Flame: spread-speed, heat generated
- Smoke: density
- Toxicity: ppm of carbon monoxide (CO), hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen cyanide (HCN), nitrogen oxides (NOx), sulfur dioxide (SO2), carbon dioxide (CO2) and hydrogen bromide (HBr)
- Improvement: halogen based resins, phenolics, alumina trihydrate (ATH, Al[OH]3)

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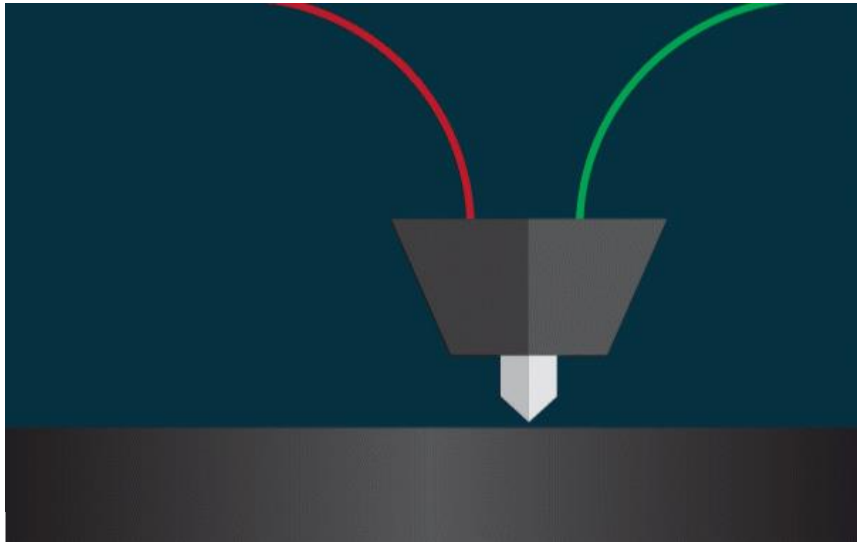
Additive Manufacturing

- Additive manufacturing, also known as 3D printing, is a transformative approach to industrial production that creates a physical object from a digital design which enables the creation of lighter, stronger parts and systems. (GE Additive)



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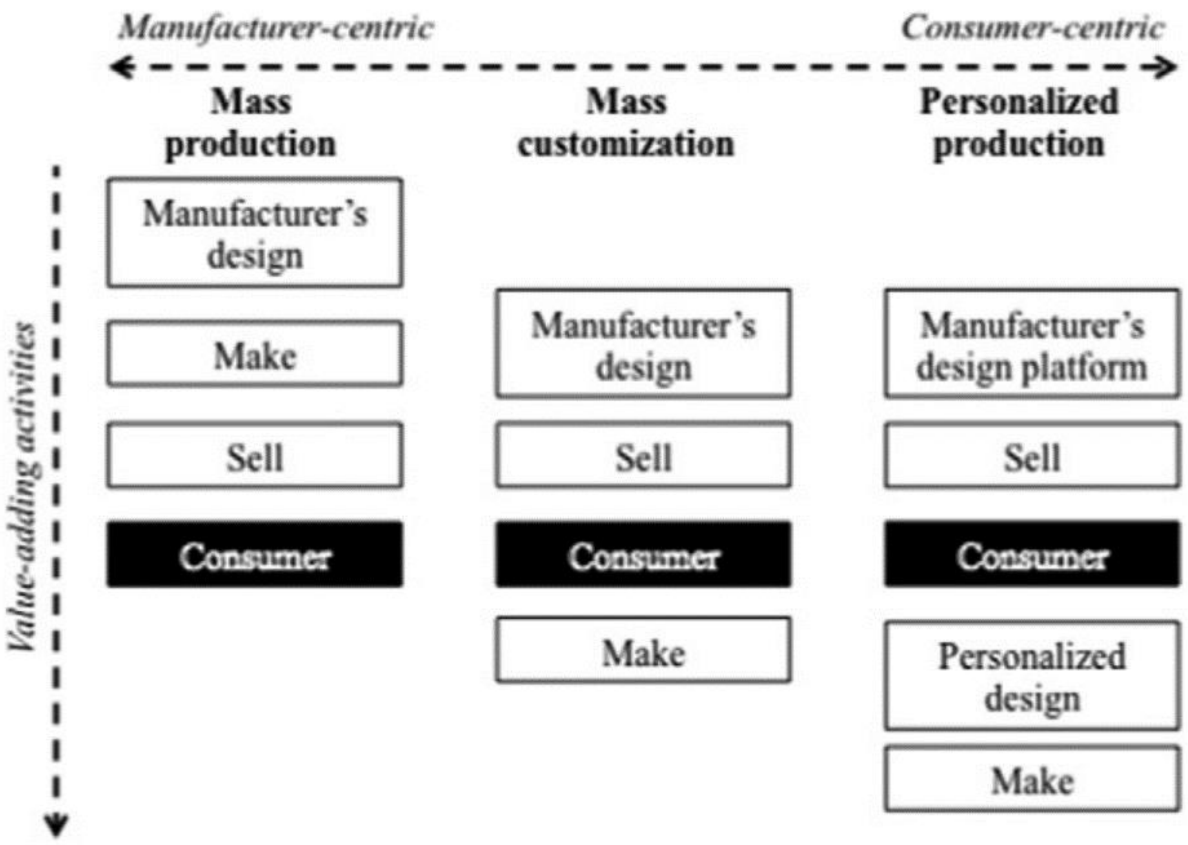
Paradigm shift



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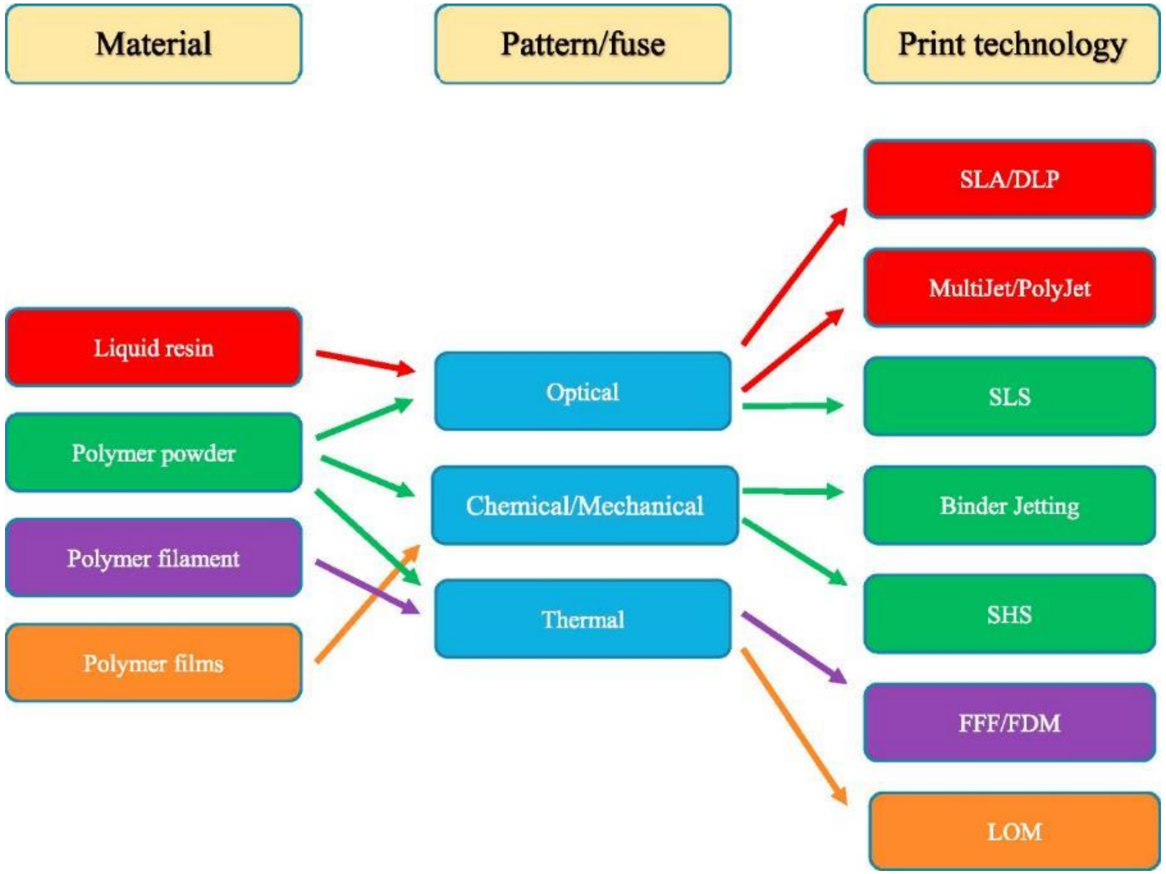
Additive Manufacturing Method of Production

SLA	Stereolithography apparatus
DLP	Digital light projection
CLIP	Continuous liquid interface production
SLS	Selective laser sintering
SHS	Selective heat sintering
BAAM	Big area additive manufacturing
FFF/FDM	Fused filament fabrication/fused deposition modelling
LOM	Laminated object manufacturing



Stansbury and Idacavage 2016

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Material selection for Makers

SIMPLIFY3D®

	 ABS	 Flexible	 PLA	 HIPS	 PETG	 Nylon	 Carbon Fiber Filled	 ASA	 Polycarbonate	 Polypropylene	 Metal Filled	 Wood Filled	 PVA
	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More
Compare Selected													
Ultimate Strength	40 MPa	26 - 43 MPa	65 MPa	32 MPa	53 MPa	40 - 85 MPa	45 - 48 MPa	55 MPa	72 MPa	32 MPa	20 - 30 MPa	46 MPa	78 MPa
Stiffness	5 / 10	1 / 10	7.5 / 10	10 / 10	5 / 10	5 / 10	10 / 10	5 / 10	6 / 10	4 / 10	10 / 10	8 / 10	3 / 10
Durability	8 / 10	9 / 10	4 / 10	7 / 10	8 / 10	10 / 10	3 / 10	10 / 10	10 / 10	9 / 10	4 / 10	3 / 10	7 / 10
Maximum Service Temperature	98 °C	60 - 74 °C	52 °C	100 °C	73 °C	80 - 95 °C	52 °C	95 °C	121 °C	100 °C	52 °C	52 °C	75 °C
Coefficient of Thermal Expansion	90 µm/m-°C	157 µm/m-°C	68 µm/m-°C	80 µm/m-°C	60 µm/m-°C	95 µm/m-°C	57.5 µm/m-°C	98 µm/m-°C	69 µm/m-°C	150 µm/m-°C	33.75 µm/m-°C	30.5 µm/m-°C	85 µm/m-°C
Density	1.04 g/cm³	1.19 - 1.23 g/cm³	1.24 g/cm³	1.03 - 1.04 g/cm³	1.23 g/cm³	1.06 - 1.14 g/cm³	1.3 g/cm³	1.07 g/cm³	1.2 g/cm³	0.9 g/cm³	2 - 4 g/cm³	1.15 - 1.25 g/cm³	1.23 g/cm³
Price (per kg)	$10 - $40	$30 - $70	$10 - $40	$24 - $32	$20 - $60	$25 - $65	$30 - $80	$38 - $40	$40 - $75	$60 - $120	$50 - $120	$25 - $55	$40 - $110
Printability	8 / 10	6 / 10	9 / 10	6 / 10	9 / 10	8 / 10	8 / 10	7 / 10	6 / 10	4 / 10	7 / 10	8 / 10	5 / 10
Extruder Temperature	220 - 250 °C	225 - 245 °C	190 - 220 °C	230 - 245 °C	230 - 250 °C	220 - 270 °C	200 - 230 °C	235 - 255 °C	260 - 310 °C	220 - 250 °C	190 - 220 °C	190 - 220 °C	185 - 200 °C
Bed temperature	95 - 110 °C	45 - 60 °C	45 - 60 °C	100 - 115 °C	75 - 90 °C	70 - 90 °C	45 - 60 °C	90 - 110 °C	80 - 120 °C	85 - 100 °C	45 - 60 °C	45 - 60 °C	45 - 60 °C
Heated Bed	Required	Optional	Optional	Required	Required	Required	Optional	Required	Required	Required	Optional	Optional	Required
Recommended Build Surfaces	Kapton Tape, ABS Slurry	PEI, Painter's Tape	Painter's Tape, Glue Stick, Glass Plate, PEI	Glass Plate, Glue Stick, Kapton Tape	Glue Stick, Painter's Tape	Glue Stick, PEI	Painter's Tape, Glue Stick, Glass Plate, PEI	Glue Stick, PEI	PEI, Commercial Adhesive, Glue Stick	Packing Tape, Polypropylene Sheet	Painter's Tape, Glue Stick, PEI	Painter's Tape, Glue Stick, PEI	PEI, Painter's Tape
Other Hardware Requirements	Heated Bed, Enclosure Recommended	Part Cooling Fan	Part Cooling Fan	Heated Bed, Enclosure Recommended	Heated Bed, Part Cooling Fan	Heated Bed, Enclosure Recommended, May Require All Metal Hotend	Part Cooling Fan	Heated Bed	Heated Bed, Enclosure Recommended, All Metal Hotend	Heated Bed, Enclosure Recommended, Part Cooling Fan	Wear Resistant or Stainless Steel Nozzle, Part Cooling Fan	Part Cooling Fan	Heated Bed, Part Cooling Fan

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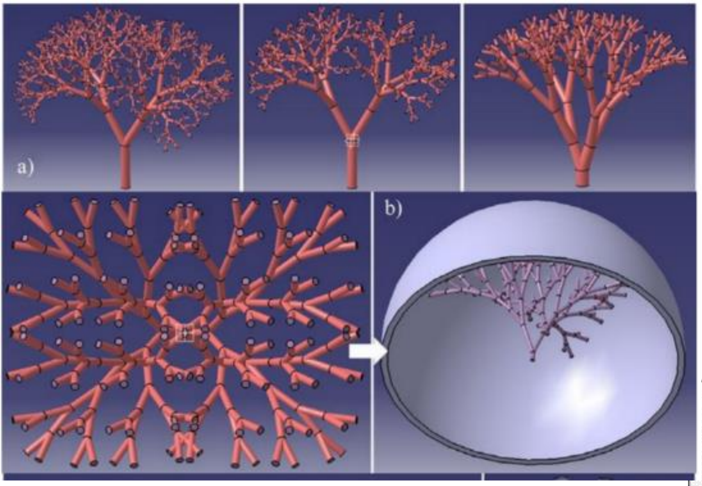
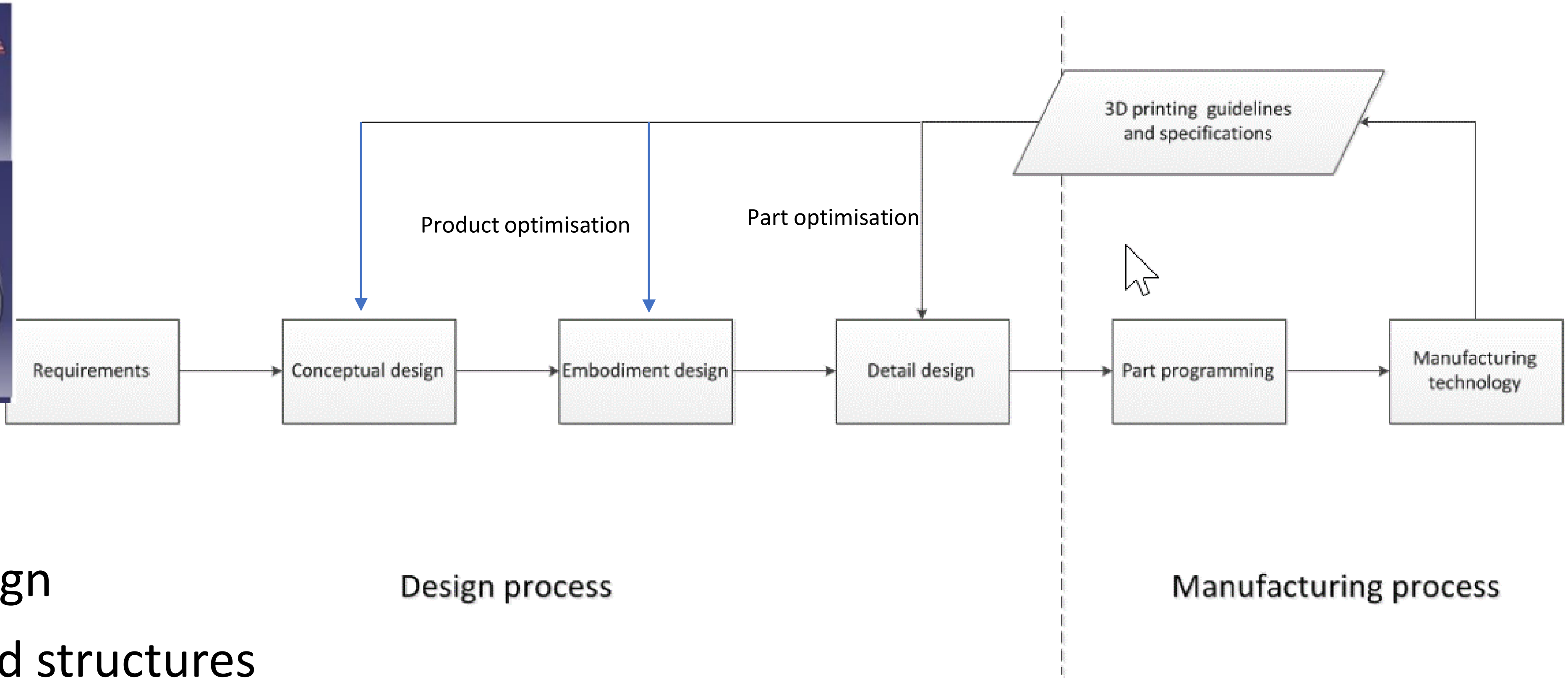
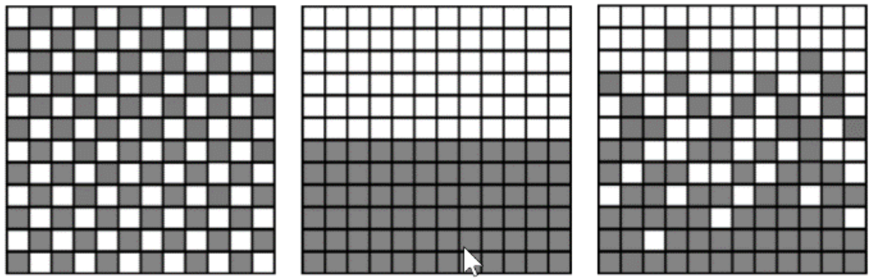
Design for Additive Manufacturing



Lantada et al. 2017

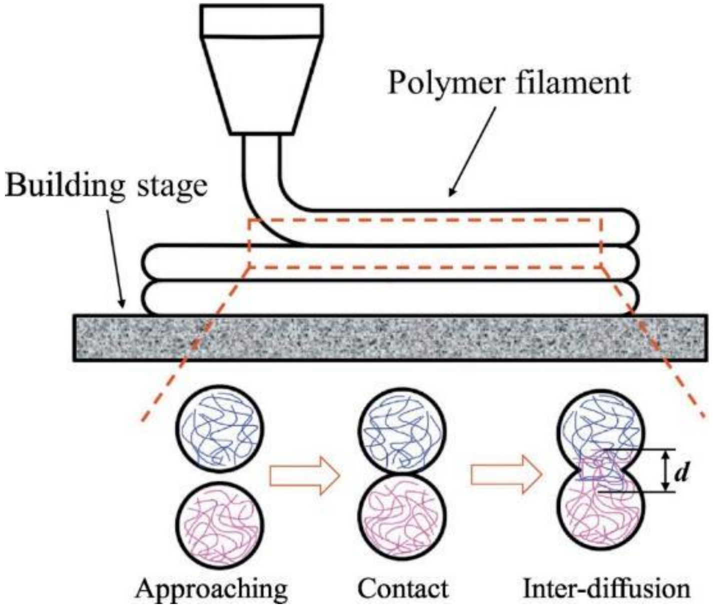


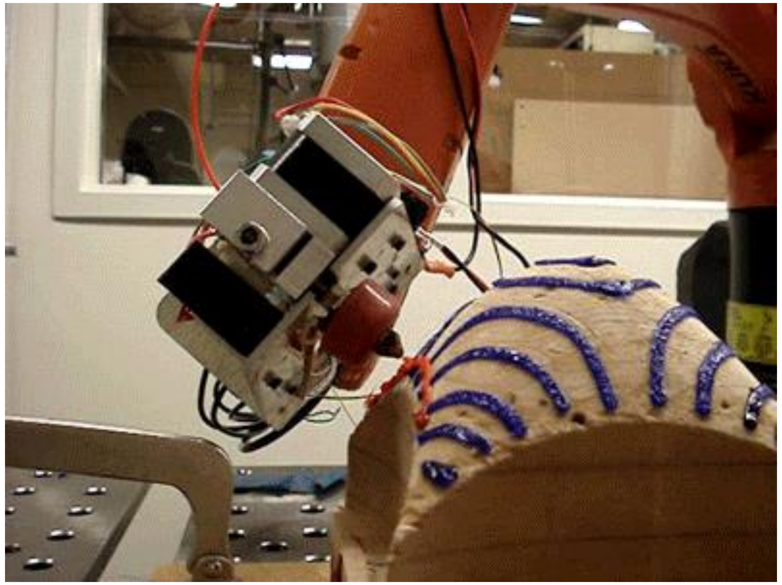
- Bio-Inspired Design
- Functional graded structures
- Hierarchical micro structure

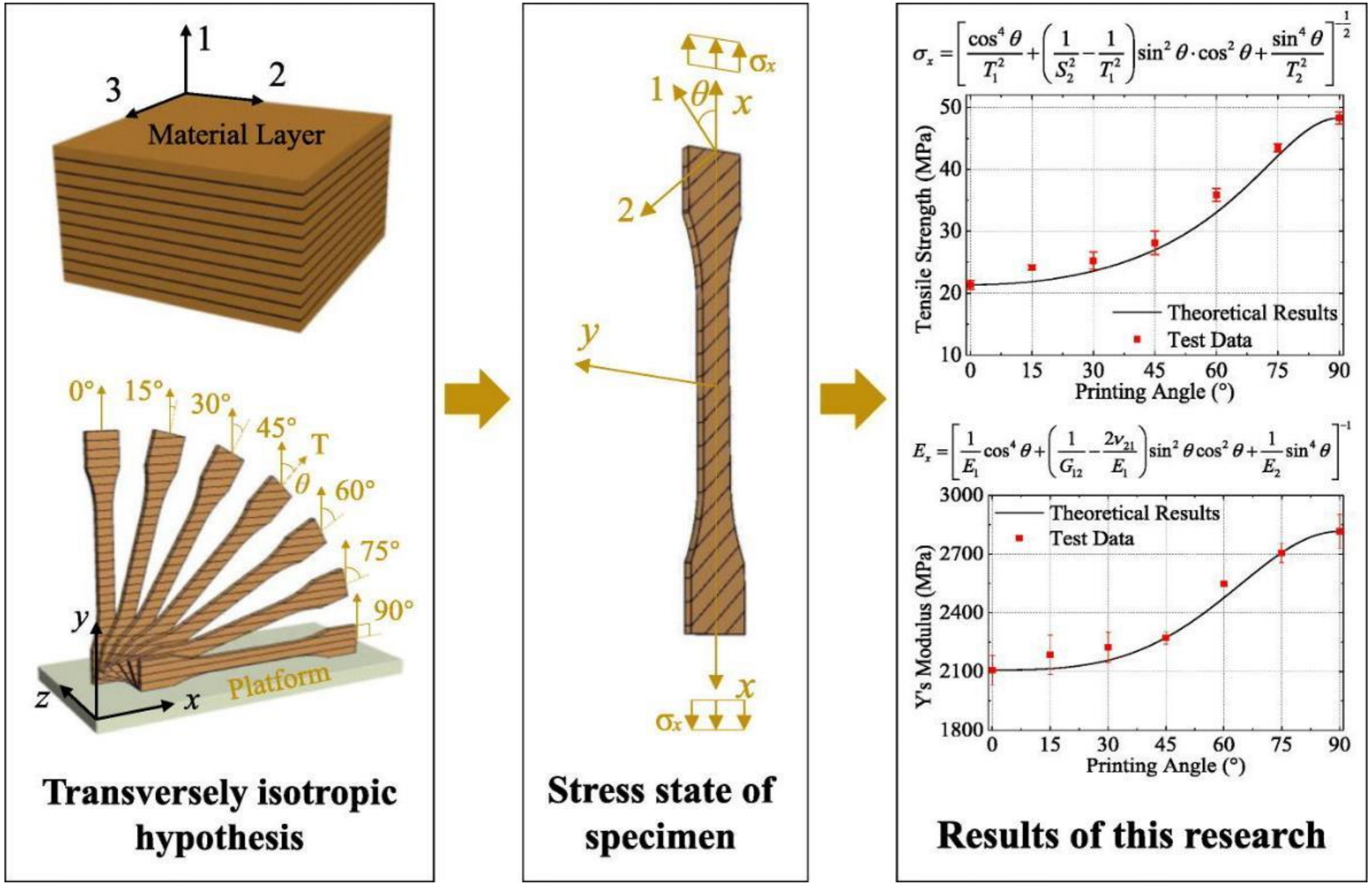


Mognol et al. 2011

Mechanical Properties



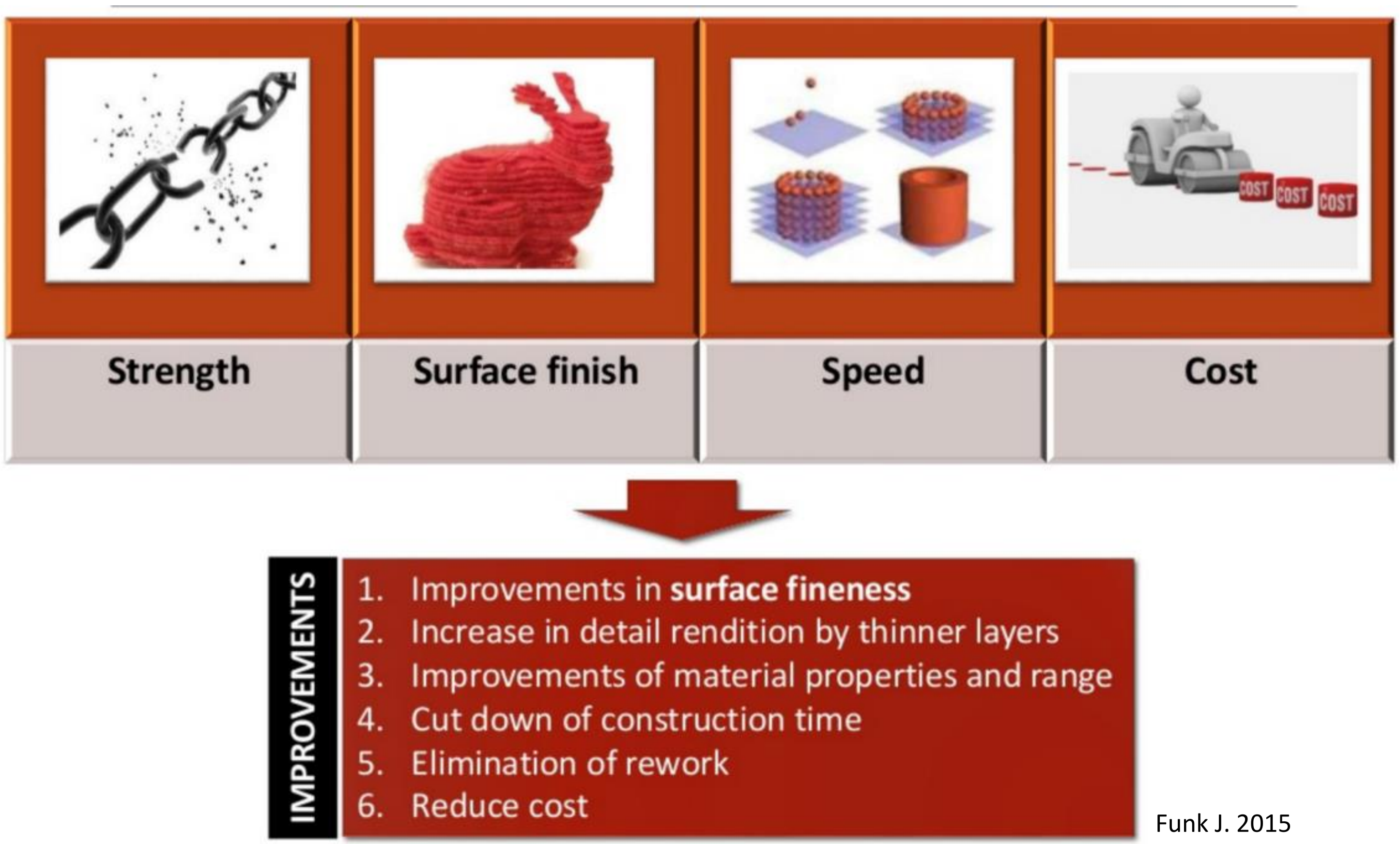




Zhao et al.

https://doi.org/10.1016/j.matdes.2019.108089

Limitations & Quality of AM Products



Funk J. 2015

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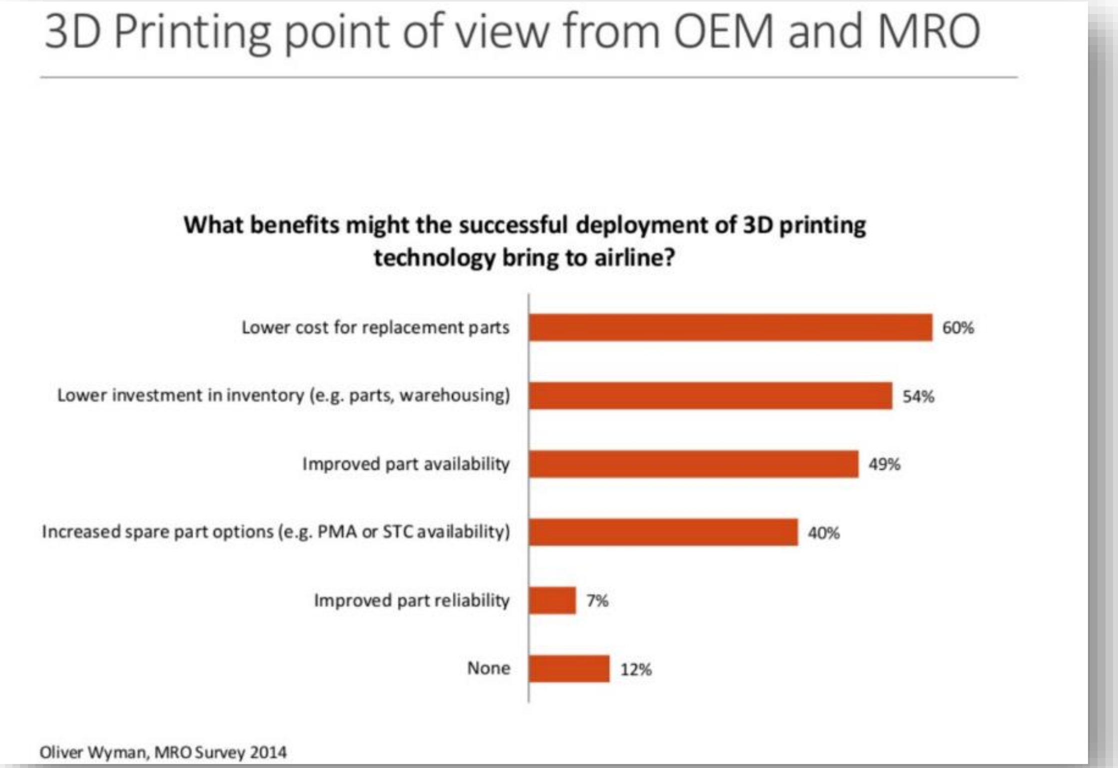
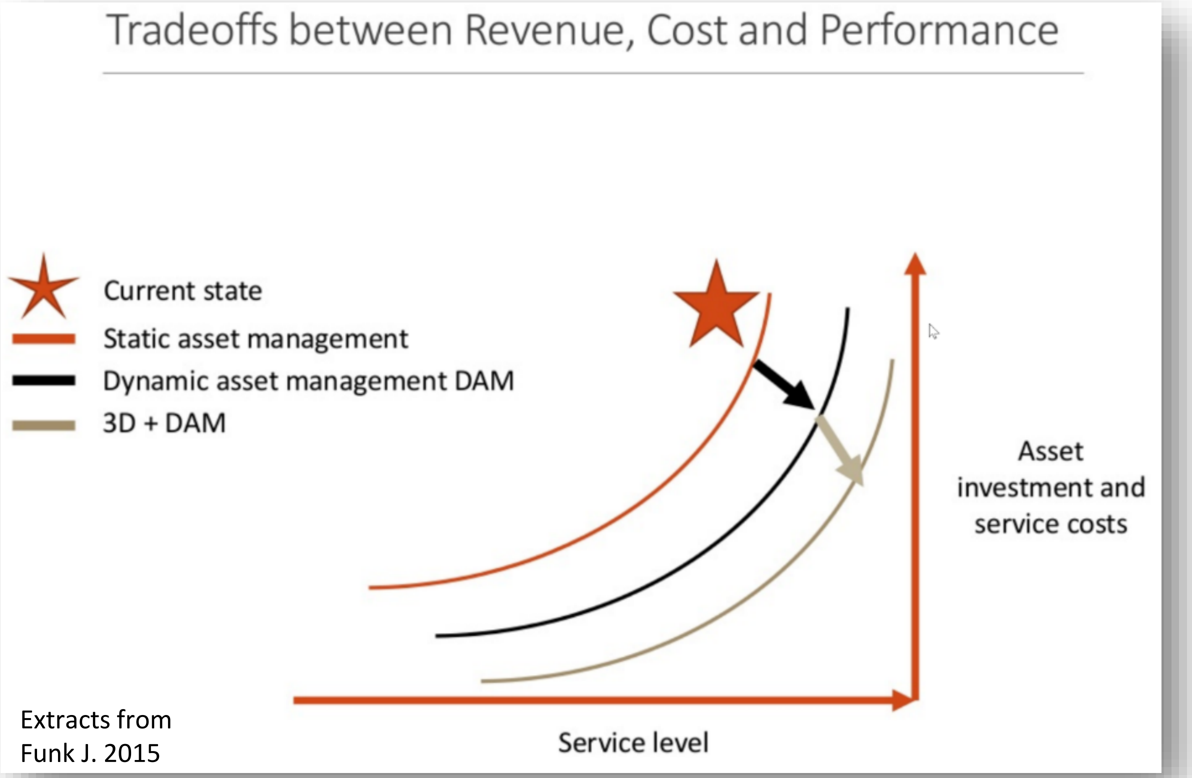
Challenges in Supply for Maintenance Parts

- Time – when a component is needed – available when needed
- Location – need to be available near critical locations





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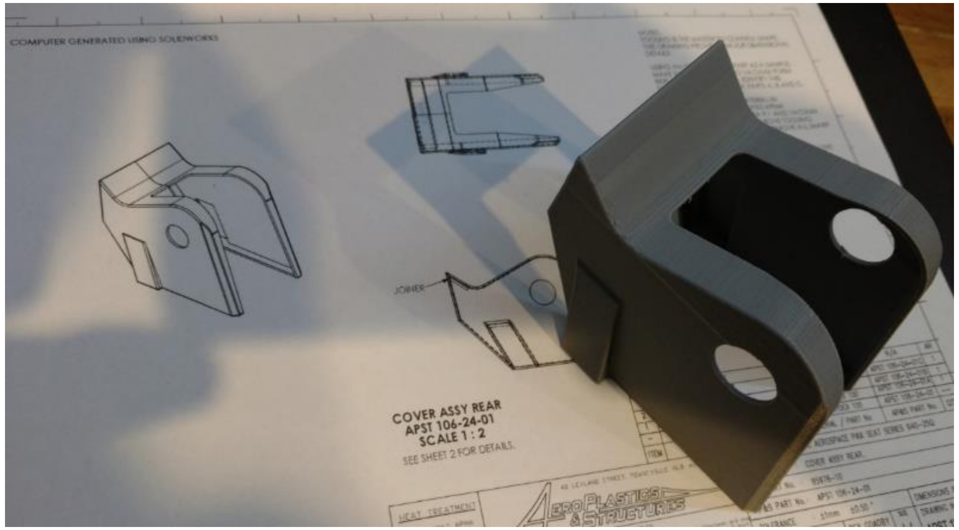
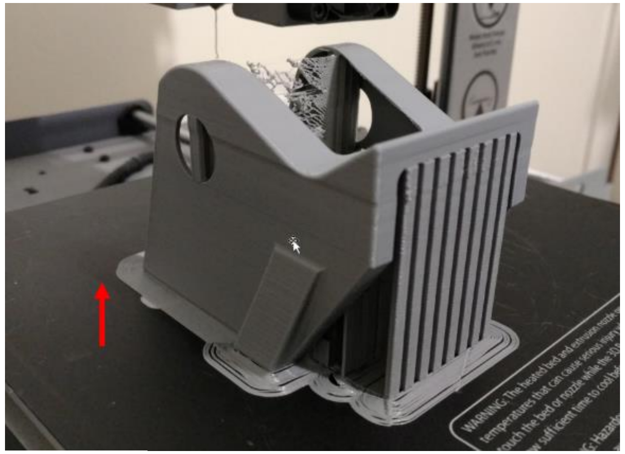
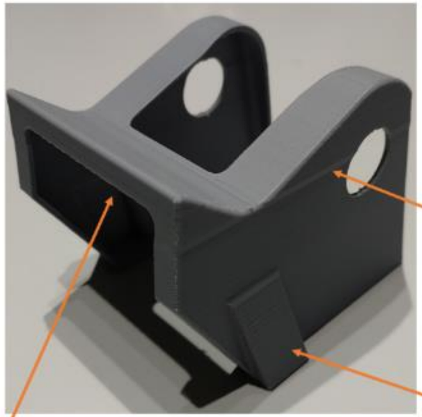
Armrest cover







Walls contracting inward
A temporary link between walls could add stability

Surface finish: layer thickness marks are visible

finishing of flatter down facing surfaces have some unremoved support pieces, a finer tool can be used to clean them

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Other concepts in AM supply chain:

- Decentralized supply chain
- Reduce material inputs for leaner manufacturing
- Simplify production processes, reducing costs
- Lower risk by providing a contingency plan
- Improve process flexibility, reacting faster to demand
- Reduce the capital cost of entry into new markets

Marchese K. (Deloitte)

Case study: Tray Table

- Materials in tray tables
- General specs of
- Potential damage in tray tables
- General replacement procedure + supply chain +time line
- Proposed rapid maintenance solution:
  - Reverse engineering / OEM data
  - Supply chain
  - Material
  - Replacement method
  - Lifespan/ temporary AW approval

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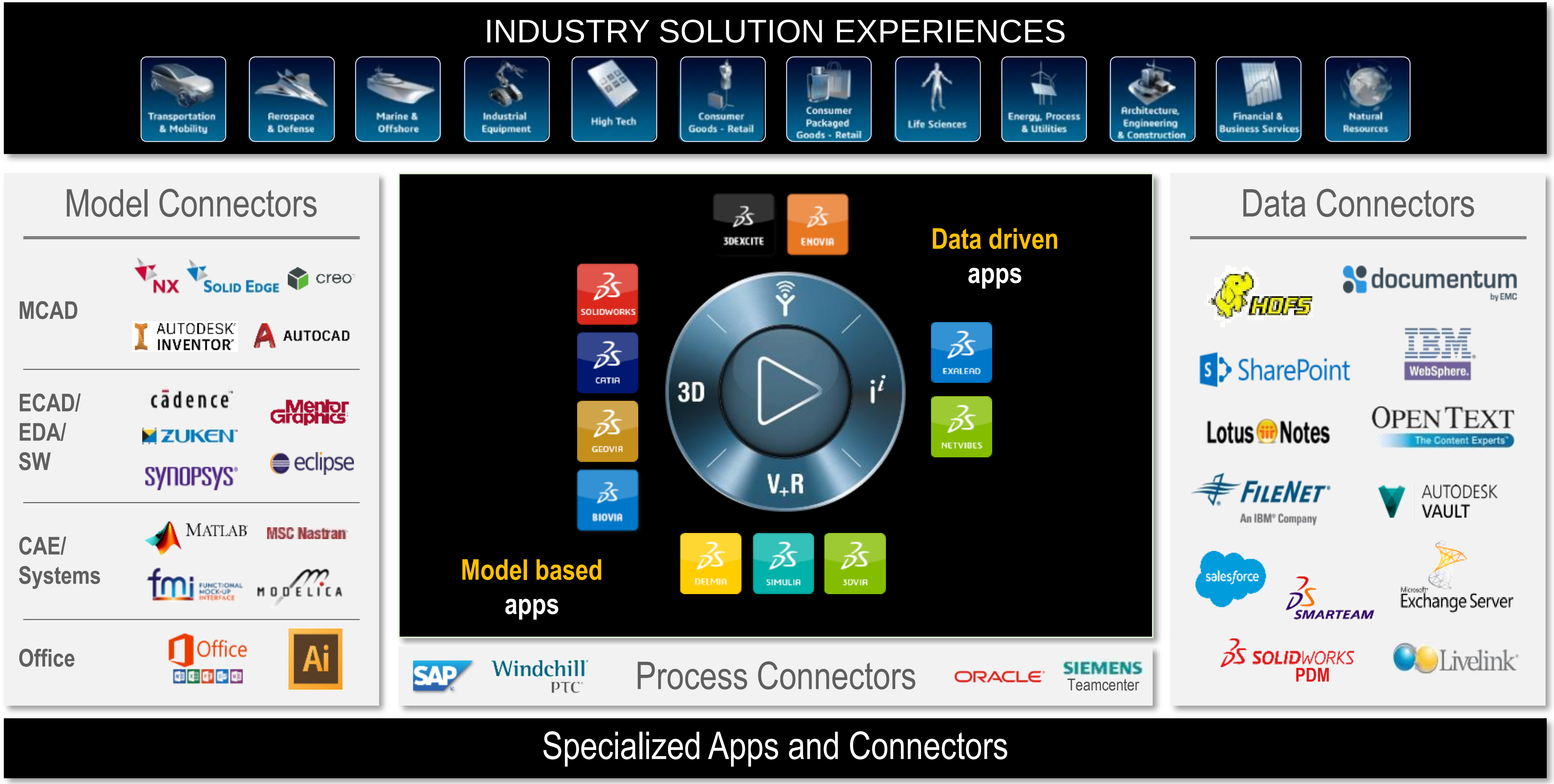
The Digital Enterprise powered by 3DEXPERIENCE



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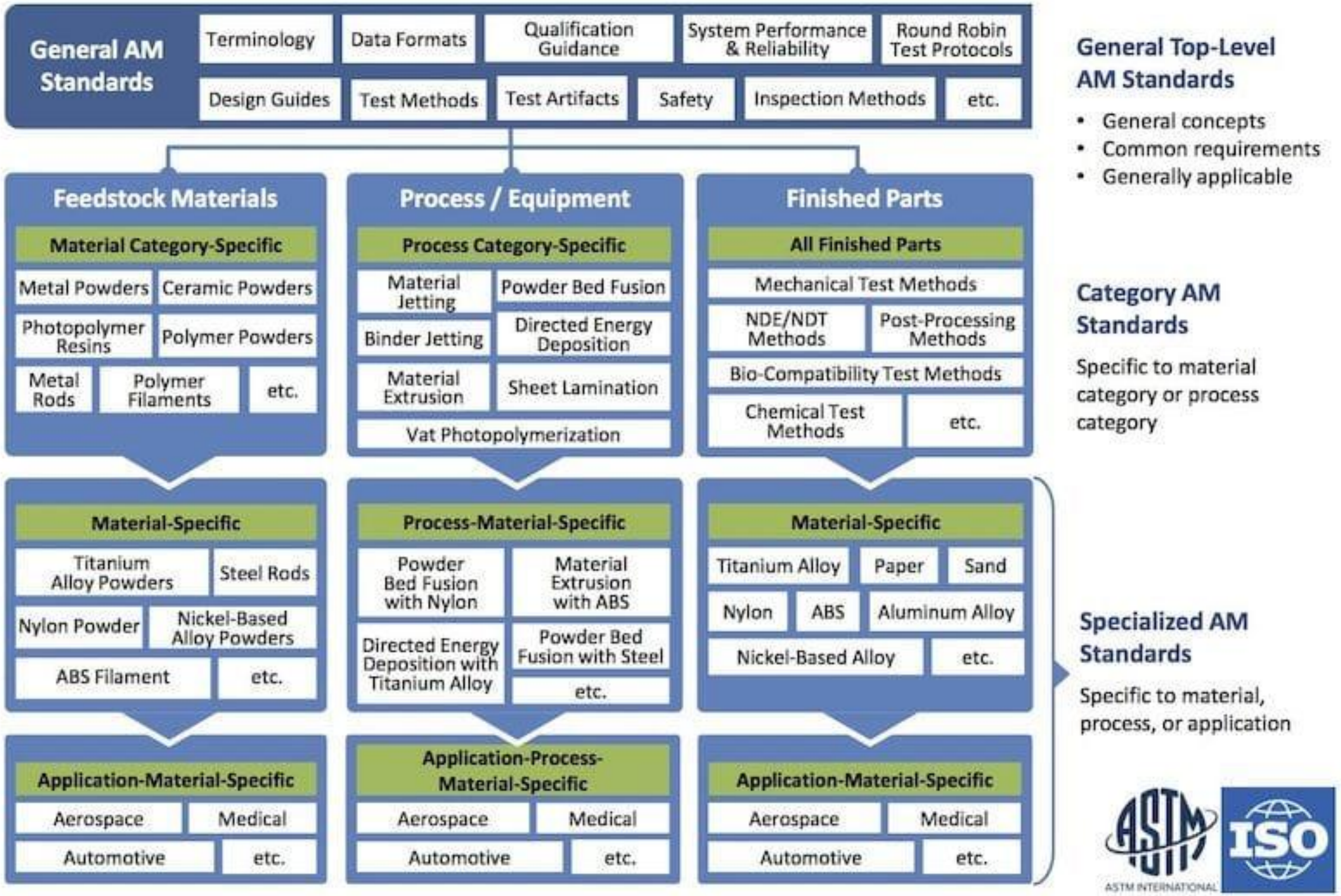
Additive Manufacturing Standards Structure



Aviation Context - Australia

Safety Regulated

- Large Aircraft – minimal new design, extensive international, domestic and regional airline fleets - FAA & EASA
- Military aircraft – minimal new design fleet of ADF aircraft – F-35
- Small aircraft – some new design FAR23 Amdt 64.

Innovative – Self regulated

- LSA (electric), experimental – some new design
- UAV – significant new design

Graduates– to have an understanding of the role of technology for local Industry
Rapid Prototyping – Stereo Lithography

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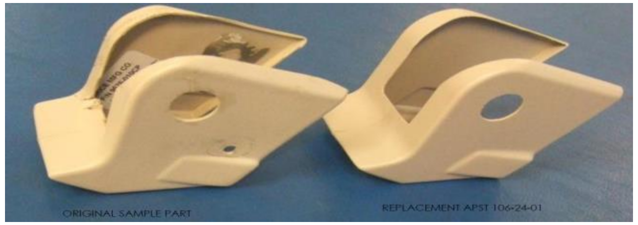
What is the Aviation context for value add AM technologies

Multi-faceted Usage in Aviation

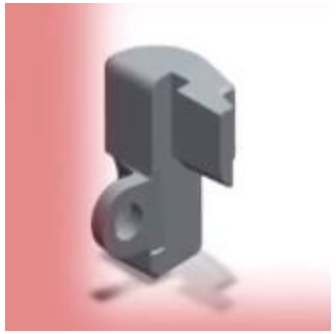
- Out of production spare and replacement parts

  Colour printing ?



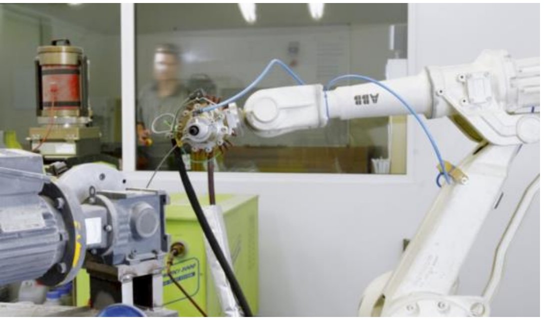
- Manufacturing – natural optimisation rather than limitations of existing machining and fabrication processes.

- Maintenance – Logistics and Lead time



- Repairs

Australia AM context vs the Rest of the world



Australia - RUAG, Quickstep, Titomic

Globally - Airlines

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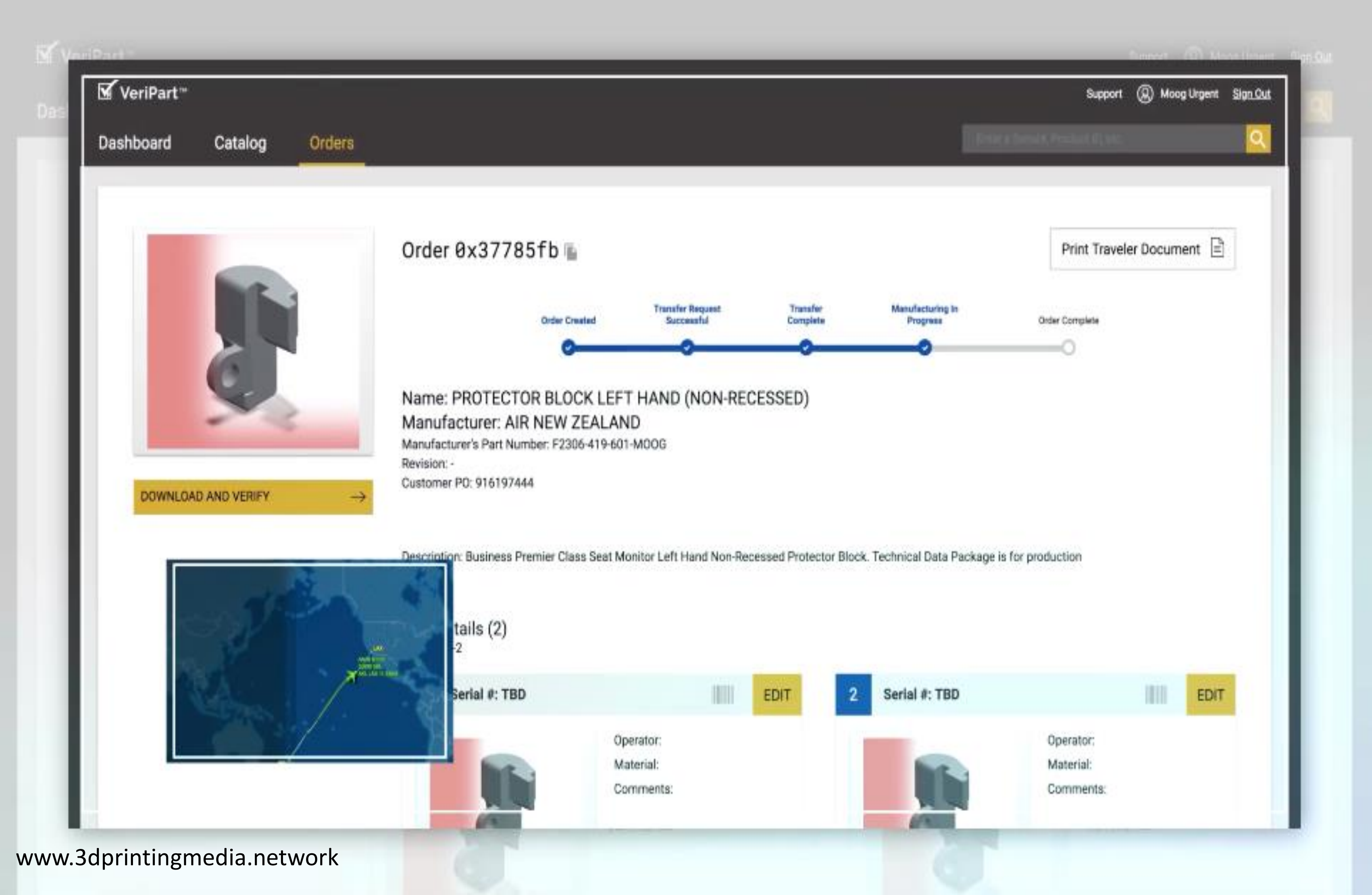
Aviation Maintenance Logistics



www.3dprintingmedia.network

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Air New Zealand – AM Innovators

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AM Certification

Conditions and Limitations:
This authorisation does not constitute approval to manufacture aeronautical products using "Additive manufacturing (3D Printing)"

The regulator seldom approves materials & processes as standalone entities.
-material & process approvals are implied when a particular design has been certificated regardless of whether this design is a component, an engine or an aircraft

User Responsibility
Ensure AM material and process determines design allowables which are reliable and have a statistical basis of derivation

Note: To manufacture AM parts you need design data and a controlled process, therefore you should have design & build capability.

Australian Government
Civil Aviation Safety Authority

Production Limitation Record

The holder of Production Certificate No.

is authorised to produce

Class III Aeronautical Products

on a one-off basis, manufactured in accordance with the following design data:

Description of Aeronautical Products	Manufacturing Location/s	Design Data	Date Production Authorised
Machined Metal Aeronautical Products Machined Plastic Aeronautical Products Sheet Metal Aeronautical Products Welded Metal Aeronautical Products Soft furnishings: Limited to covering of sidewalls and bulkheads, bags and stowage's for role equipment and loose articles. Composites: Limited to Cutting and potting of honeycomb sandwich panels Forming of metal tubing "non-fluid carrying"		Design Data approved by: • CASA, or • CASR 21.132A Authorised Person or approved design organisation; or • STC or Foreign STC approved design data; or • CASR 21.437 Authorised Person or approved design organisation; or • Foreign modification/repair designs (see CASR 21.470); or • CAR (1988) 35 Authorised person (for data approved before 27 June 2011); or • CAR (1988) 36 Authorised person (for data approved before 27 June 2011); or • CAR (1988) 36A Authorised person (for data approved before 27 June 2011).	08 June 2018
Curtains Carpets Seat Covers			

Conditions and Limitations:
This authorisation does not constitute approval to manufacture aeronautical products using "Additive Manufacturing (3D Printing)"

Revision History:
Initial issue: 08 June 2018

Date Issued: 08 June 2018

Certification– the questions

- A Part produced by AM is both a material and a process.

§25.603 Materials.
The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must—
(a) Be established on the basis of experience or tests;
(b) Conform to approved specifications (such as industry or military specifications, or Technical Standard Orders) that ensure their having the strength and other properties assumed in the design data; and
(c) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

§25.605 Fabrication methods.
(a) The methods of fabrication used must produce a consistently sound structure. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification.
(b) Each new aircraft fabrication method must be substantiated by a test program.

§25.853 Compartment interiors.
For each compartment occupied by the crew or passengers, the following apply:
(a) Materials (including finishes or decorative surfaces applied to the materials) must meet the applicable test criteria prescribed in part I of appendix F of this part, or other approved equivalent methods, regardless of the passenger capacity of the airplane.

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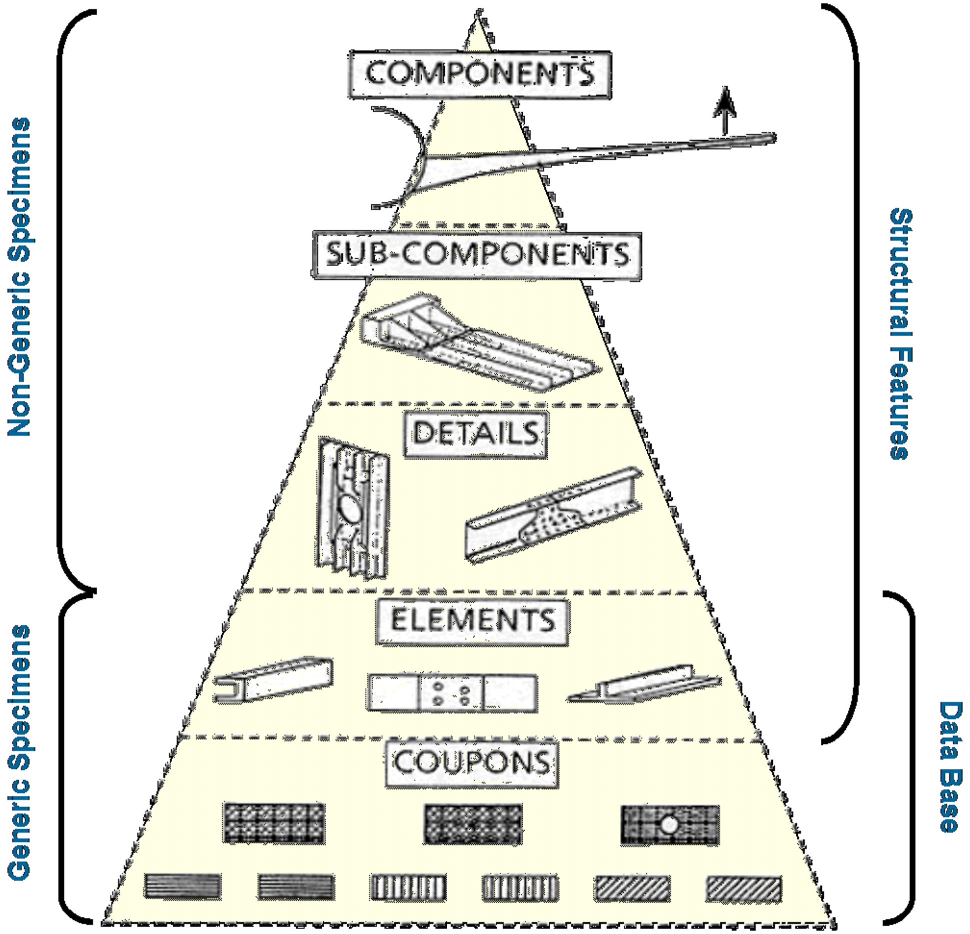
Certification - the process

§25.613 Material strength properties and material design values.

(a) Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis.



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General Aviation AM implementation

Image: Piper Aircraft
Piper has produced its first production part using additive manufacturing—more commonly known as 3D printing — according to a company announcement last week. The part, a climate control system component, was printed using an HP Multi Jet Fusion 4200 3D printer. Piper says it is currently focusing on creating and testing non-flight-critical components with the goal of achieving FAA approval and expanding the use of 3D printing in aircraft manufacturing.

Image: Russian Helicopters Holding Company
Russian Helicopter Holding Company will launch serial production of 30 different helicopter parts using 3D printing from next year. This entails construction redesign, strength testing and othere tests in an effort to ensure the part made by AM is equivalent to or superior in its characteristics to the original version.

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UAV - AM implementation

<u>Systems Engineering</u>
Capability
Mission
Performance

<u>Aircraft Engineering</u>
Safety
Cost
Reliability

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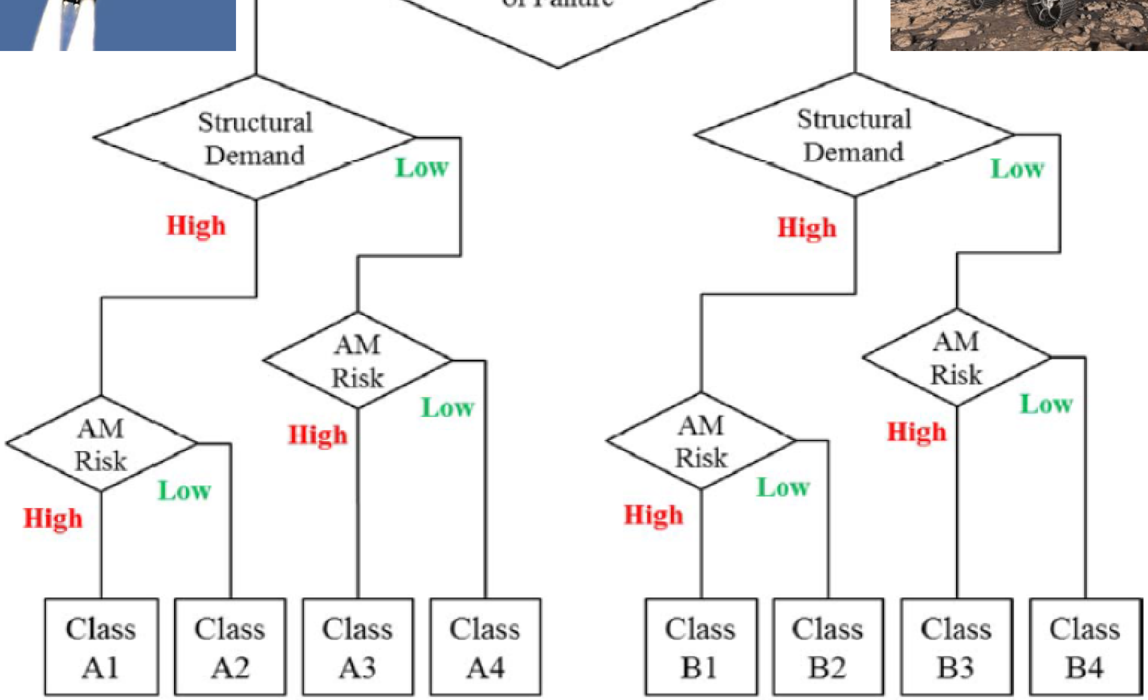
Space – NASA Standards

There are currently no NASA standards providing specific design and construction requirements for certification of additively manufactured parts. Several international standards organizations are developing standards for additive manufacturing; however, NASA mission schedules preclude the Agency from relying on these organizations to develop standards that are both timely and applicable.

- The MSFC-STD-3716 classification system was used as the starting point
- This system is risk-based and stems from the three primary questions typically asked when evaluating part risk:
  - Consequence of failure (What happens if the part fails?)
  - Structural demand (How severe is the stress environment?)
  - AM Risk (How challenging is part design and can the part be reliably inspected?)
- Part Classification in 3716 is primarily a communication tool, and does not directly inform most M&P requirements



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Future direction of Memko in AM

- AM Multi-Faceted

- Polymer 3D printing tertiary structure interiors

Recently, the 3D printing company Stratasys developed a version of ULTEM 9085 resin specifically tailored for certified aircraft parts, which includes material and process specifications, test plan samples and material properties at safe levels for aircraft interiors.

- Maintenance logistics & response time

- Spares and replacement parts

- Is AM an answer looking for a problem. Where does the application of the technology make sense?

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Thank You

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