SUPPORTING DESIGN FOR ADDITIVE MANUFACTURING

A View From The Aerospace Industry

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Additive Manufacturing (AM)

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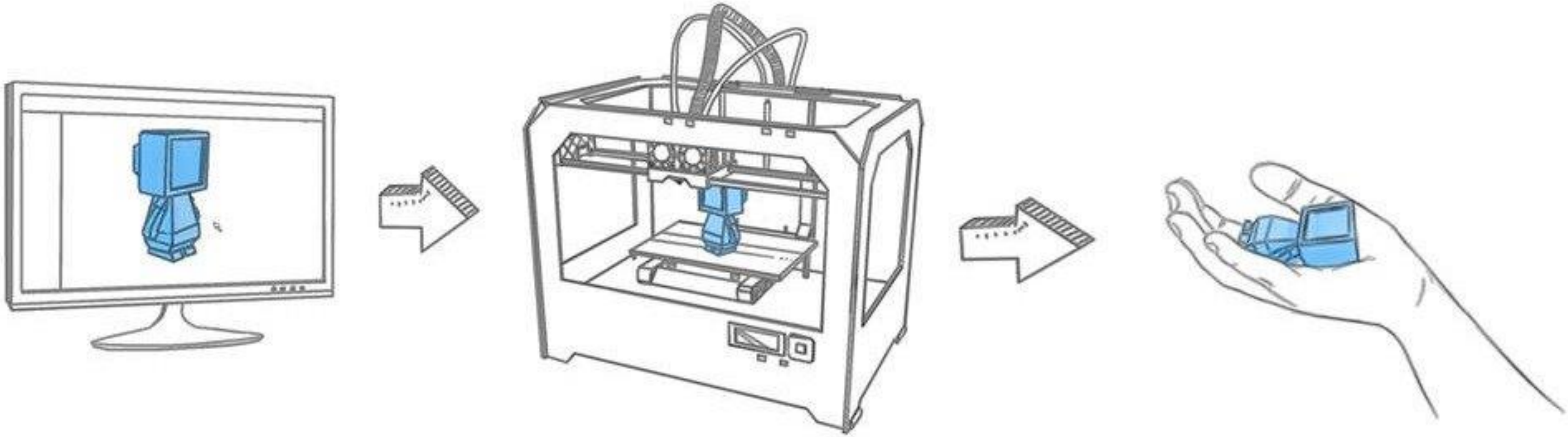


"The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining."

ASTM Committee 42 standard:
F2792 – Standard Terminology for Additive Manufacturing Technologies

Additive Manufacturing (AM)

- Laser Powder Bed Fusion (LPBF) Additive Manufacturing (AM)

New design freedoms

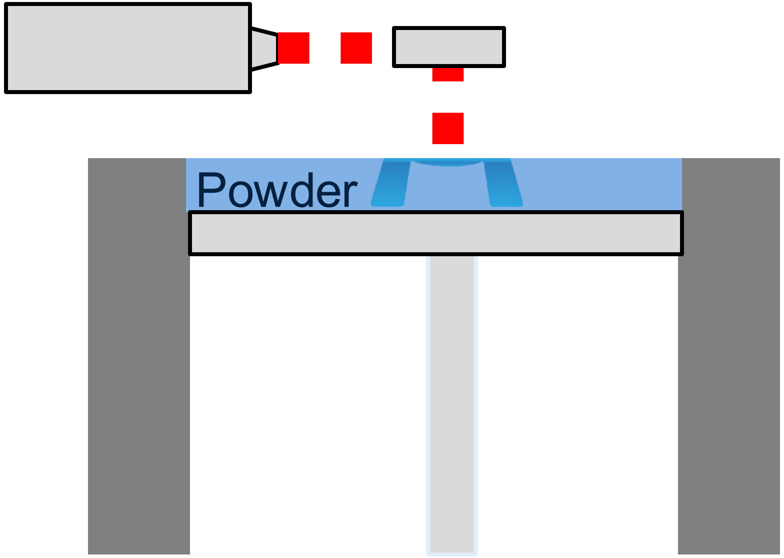
New functions

Integrated functions

Part size

Anisotropic material properties

Quality control



Laser Powder Bed Fusion

AM Part Consolidation

16 Parts

1 Part

AM for Aerospace

Optimisation through consolidation

- 30% weight
- 60% cost reduction

Aerospace cost benefits:

- Fewer parts to manufacture
- Reduced assembly costs
- Faster production times
- Shorter lead times
- Faster time to market
- Fewer interfaces, inspection & qualification

Illustration of PBF Consolidation: GE Engine Mid Frame [1]

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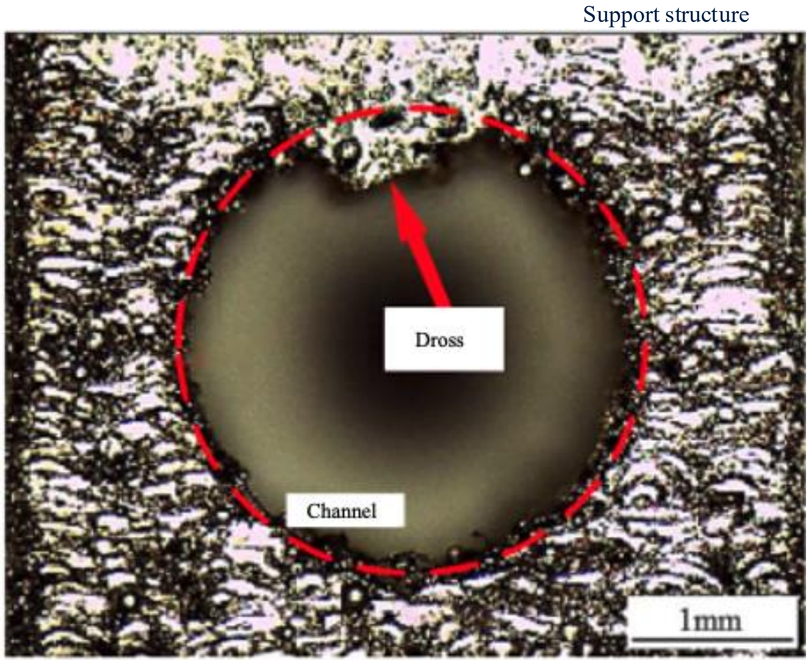
[1] Protolabs.com https://www.protolabs.com/en-gb/resources/guides-and-trend-reports/combining-part-assemblies-with-additive-manufacturing/

LPBF Design Challenges

- Process Characteristics:
  - Surface Roughness
  - Dross formation
  - Geometric inaccuracy

- Support structures increase cost & time



Dross formation at the top of a channel [2]

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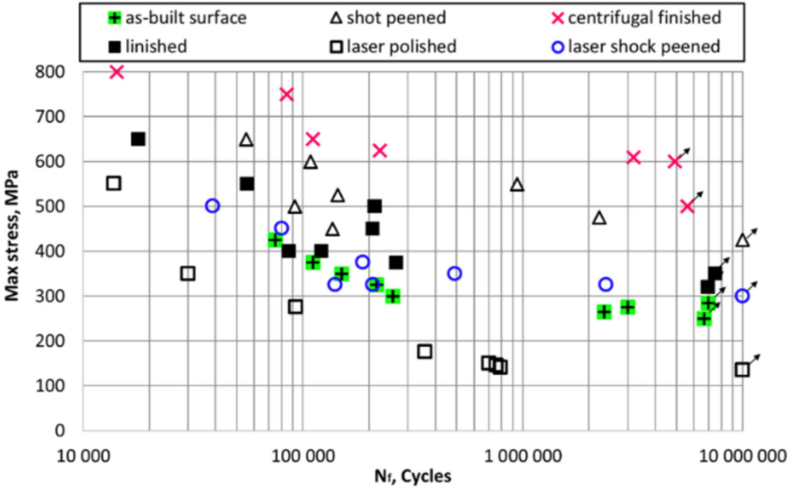
[2] Feng et al (2020) Investigation on shape deviation of horizontal interior circular channels fabricated by laser powder bed fusion (Image adapted)

Design and Surface Roughness

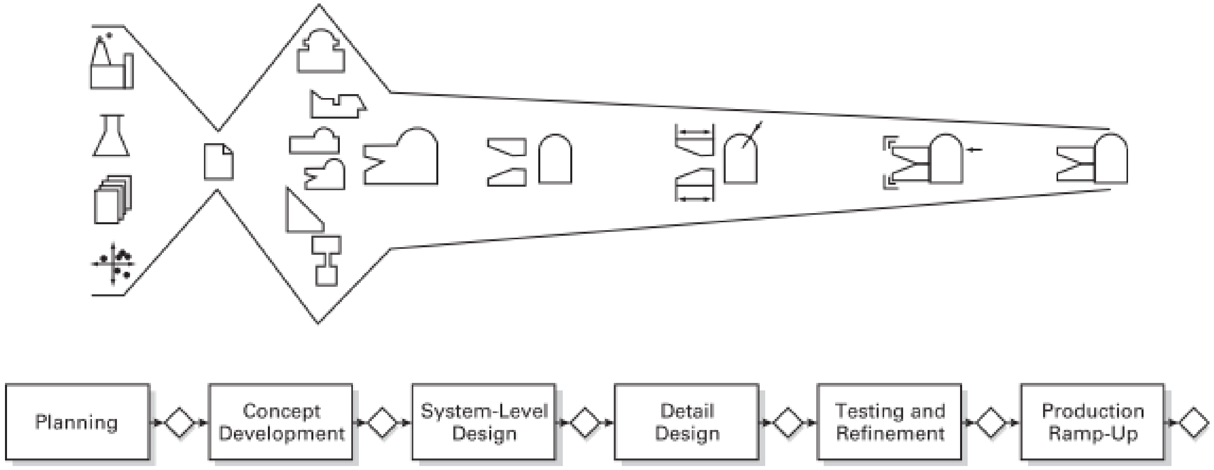
- Roughness negatively impacts fatigue
- Post-processing effectiveness & cost
- Design for AM (DfAM) understanding needed



Fatigue life for LPBF Ti6Al4V subjected to various post processes. [3]

[3] M. Kahlin, et al. (2020). Improved fatigue strength of additively manufactured Ti6Al4V by surface post processing. International Journal of Fatigue 134

The Product Development Process (PDP)

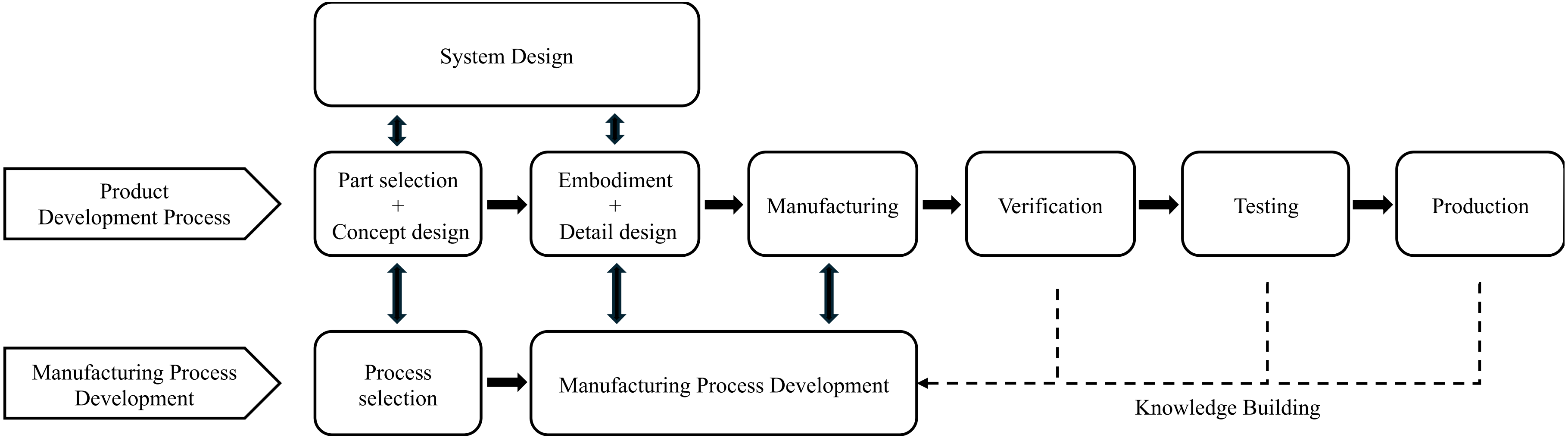


The product development process. Ulrich & Eppinger, 2012

Aerospace PDP:

- Strict function and reliability requirements for quality
- Metal AM brings uncertainty on design and quality
- Multiple process and design factor influences

The Aerospace AM PDP



A model of the PDP for AM in space applications. (Dordlofva & Törlind, 2018)

Research Purpose

Identify:

- *Opportunities and challenges of AM design for aerospace.*
- *The design supports used.*
- *The factors that make these supports effective.*
- *Model the aerospace AM design approach.*

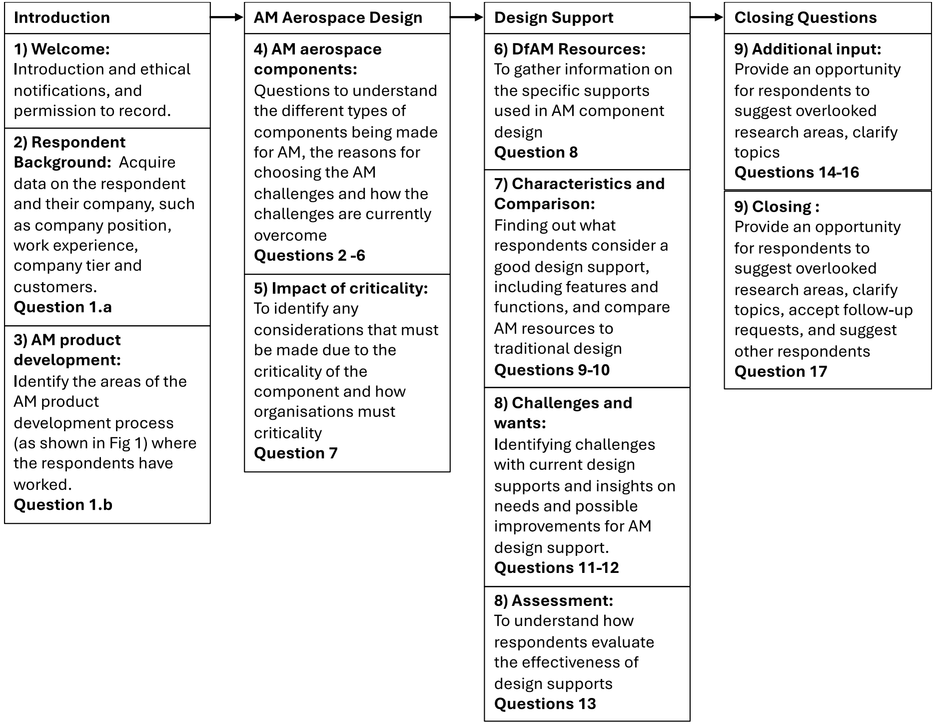
Method

Data Collection:

- Exploratory interview study
- Sampling criteria of **experts in aerospace AM** with **recent experience**
- Voluntary participation

Data analysis:

- Thematic coding using NVivo 2020



Introduction

1) Welcome: Introduction and ethical notifications, and permission to record.

2) Respondent Background: Acquire data on the respondent and their company, such as company position, work experience, company tier and customers.
Question 1.a

3) AM product development: Identify the areas of the AM product development process (as shown in Fig 1) where the respondents have worked.
Question 1.b

AM Aerospace Design

4) AM aerospace components: Questions to understand the different types of components being made for AM, the reasons for choosing the AM challenges and how the challenges are currently overcome
Questions 2 -6

5) Impact of criticality: To identify any considerations that must be made due to the criticality of the component and how organisations must criticality
Question 7

Design Support

6) DfAM Resources: To gather information on the specific supports used in AM component design
Question 8

7) Characteristics and Comparison: Finding out what respondents consider a good design support, including features and functions, and compare AM resources to traditional design
Questions 9-10

8) Challenges and wants: Identifying challenges with current design supports and insights on needs and possible improvements for AM design support.
Questions 11-12

8) Assessment: To understand how respondents evaluate the effectiveness of design supports
Questions 13

Closing Questions

9) Additional input: Provide an opportunity for respondents to suggest overlooked research areas, clarify topics
Questions 14-16

9) Closing : Provide an opportunity for respondents to suggest overlooked research areas, clarify topics, accept follow-up requests, and suggest other respondents
Question 17

Figure 3. Interview guide structure [6]

Findings

- 20 AM Aerospace experts
- 10 organisations
  - industry, government, defence, and standards organisations
- 9 countries
- Executives, R&D, and design engineers

Org.	Job Title	Affiliation	Aero/ Space
A	Co-Founder and Managing Director	AM Consultancy Company	Space
B	Principal Engineer – Research Specialist in Laser Powder Bed Simulation	Aerospace Manufacturing Company	Aero
B	AM Research Engineer – Primary Designer	Aerospace Manufacturing Company	Aero
B	AM Research Engineer – Design Simulation	Aerospace Manufacturing Company	Aero
B	Senior AM Research Specialist	Aerospace Manufacturing Company	Aero
C	AM Specialist	Rocket Manufacturing Company	Space
D	Senior Project Manager	Non-profit Technology Innovation Park	Space
B	Fatigue and Fracture Mechanics Method Specialist	Aerospace Manufacturing Company	Aero
E	Design Engineer – Additive Integrated Product Team	Defence Contractor	Aero
J	Head of Research and Development for Material and Process Development	AM Company	Aero & Space
F	Principal Engineer	Government Space Agency	Space
B	Design Leader	Aerospace Manufacturing Company	Space
G	Director of Technical Operations	International Standards Organisation	Aero & Space
I	Materials and Process Engineer	Intergovernmental Space Agency	Space
H	Chief Executive Officer	AM Company	Space
K	Lead Mechanical Engineer	Aerospace Manufacturing Company	Space
L	Customer Success Manager	AM Software Company	Aero & Space
I	Materials and Process Engineer	Intergovernmental Space Agency	Space
M	Rocket Propulsion Engineer	Aerospace Manufacturing Company	Space
M	Rocket Propulsion Engineer	Aerospace Manufacturing Company	Space

Findings – Aerospace AM Opportunities

Design Freedom

- Enables complex geometries
- Integrated cooling channels & topology optimisation

Weight Reduction

- Improves performance and efficiency

Cost & Lead-Time Reduction

- Thruster reduced from *3–6 months to <1 month*
- Fewer tools, faster iterations, less rework

Functional Integration

- Part consolidation simplifies assemblies
- Reduces failure risk, improves reliability

Product Type	Example	AM Benefit
Engine components	Thrust chambers Injectors	Cooling integration Reduced lead times
Structural parts	Brackets, Hydraulics	Wiring integration Reduced assembly
Specialised parts	Heat exchangers RF systems Satellite parts	Lightweightingg Functional integration

Findings – Aerospace AM Challenges

Certification & Qualification

- Lack of standards and data
- Extensive testing and costly CT
- Repeatability and consistency
- Regulatory pathways

Material & Process Inconsistencies

- Surface roughness & fatigue
- Inconsistent results on machines
- Material property data
- In-situ monitoring
- Surface roughness critical (60%)

Design–Manufacturing Integration

- Linking design-materials-parameters
- Lack of design support tools
- Support structures
- Post-processing
- System-level visibility of AM parts

Organisational & Industrialisation

- AM design and operation skills gap
- In-house AM capability
- High machine cost and safety
- Reputational risks if AM parts fail

Findings – Aerospace AM Support

Overcoming AM challenges requires **combined practical and computational design support** throughout the product development process.

🧩 Practical Design Supports

Iterative validation & testing
Prototypes and coupons

Collaboration & standards
Close cooperation with OEMs and certifying bodies

Cross-disciplinary expertise
Must understand materials, design, and processes holistically

💻 Computational Design Supports

Simulation & CAE tools
Predict distortion and manufacturing feasibility

Material databases
Essential for reliable simulation and material selection

Topology optimisation & build prep
Enables lightweight, consolidated designs, support generation, and optimises build quality

Findings – Aerospace AM Future Needs

Design Community of Practice

- Shared knowledge platforms (**40%**)
- Cross-organisation and institutional collaboration

Barriers

- Reluctance to share data
- Difficulty ensuring data quality

Integrated CAE

- Single integrated AM suites combining simulation, topology optimisation, and databases.

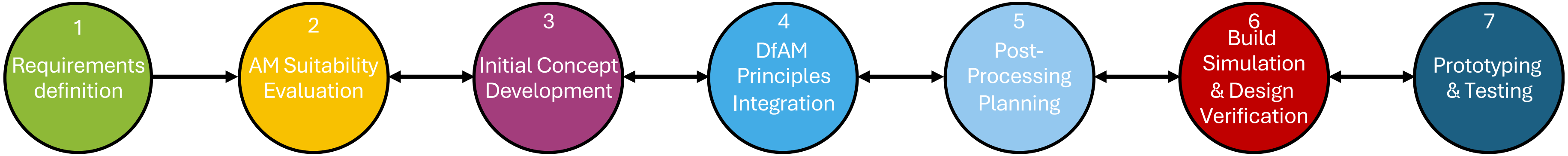
Simulation Software & Material Data

- Co-development with industry
- Push for digital twins and improved surface roughness simulation.
- Better measurement standards.

AI and Generative Design Tools

- AI is *"key to success"* for reducing dependency on specialists.
- Aimed at better integration, lower costs, and stronger traceability.

AM Aerospace Design Approach Model



1 Requirements definition

2 AM Suitability Evaluation

3 Initial Concept Development

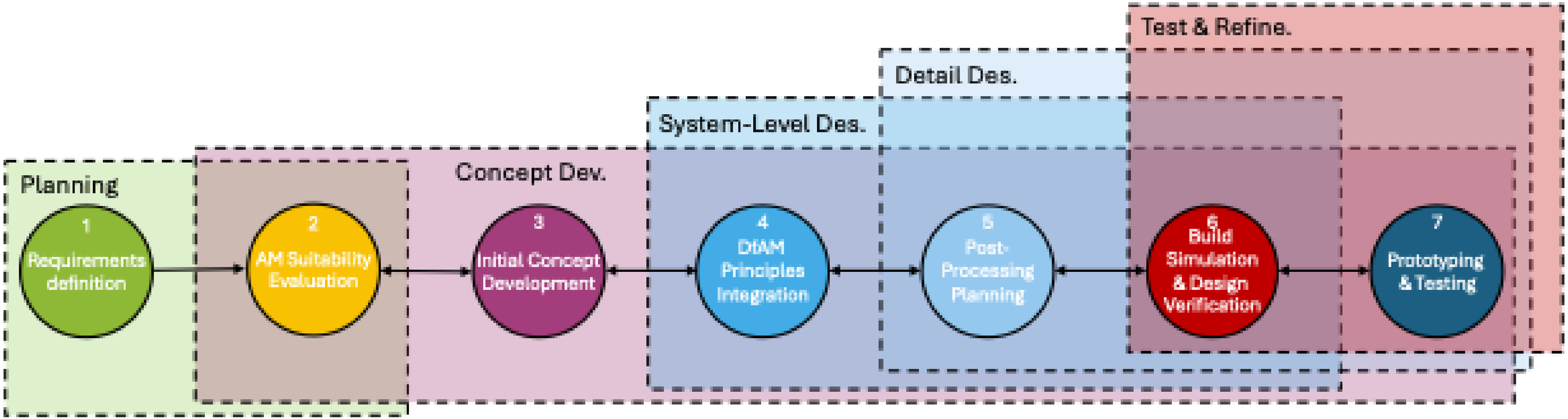
4 DfAM Principles Integration

5 Post-Processing Planning

6 Build Simulation & Design Verification

7 Prototyping & Testing

AM Aerospace Design Approach Model



Planning

Concept Dev.

System-Level Des.

Detail Des.

Test & Refine.

1 Requirements definition

2 AM Suitability Evaluation

3 Initial Concept Development

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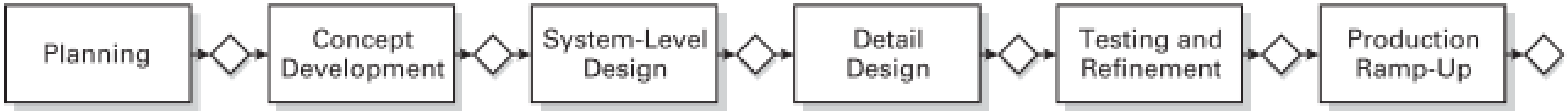

Planning

Concept Development

System-Level Design

Detail Design

Testing and Refinement

Production Ramp-Up

AM Aerospace Design Approach Detail

Summary

Findings

- Opportunities, Challenges and Future Needs for Aerospace AM Designers

Contributions:

- Provides a framework for aerospace AM design
- Identified gaps in AM design support

Full research paper currently in minor revision with **Design Science Journal** (expected late 2025 / early 2026).

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Questions?