Lightweight composite structures and additive manufacturing

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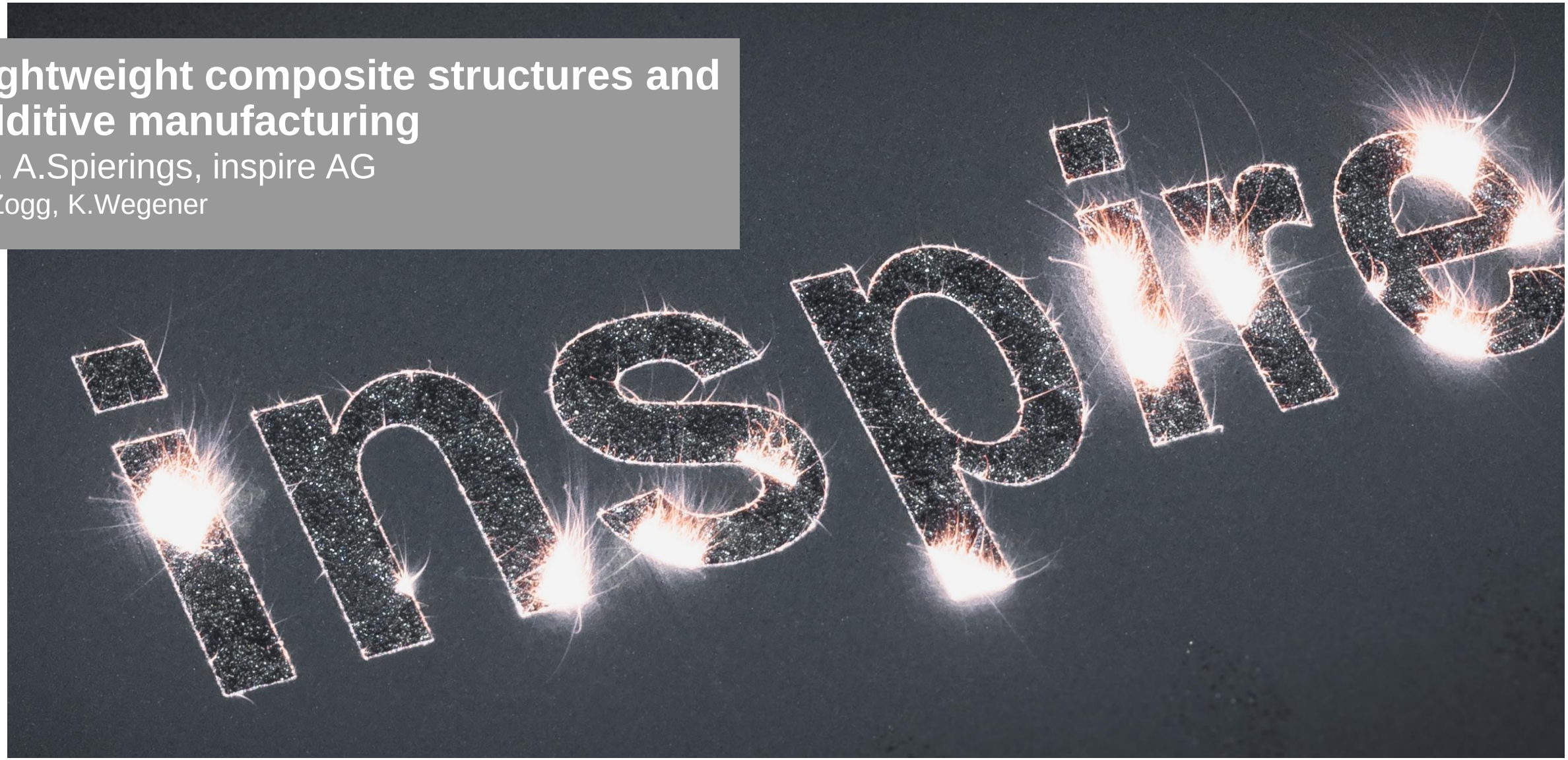
inspire

Lightweight composite structures and additive manufacturing

Dr. A.Spierings, inspire AG
M.Zogg, K.Wegener

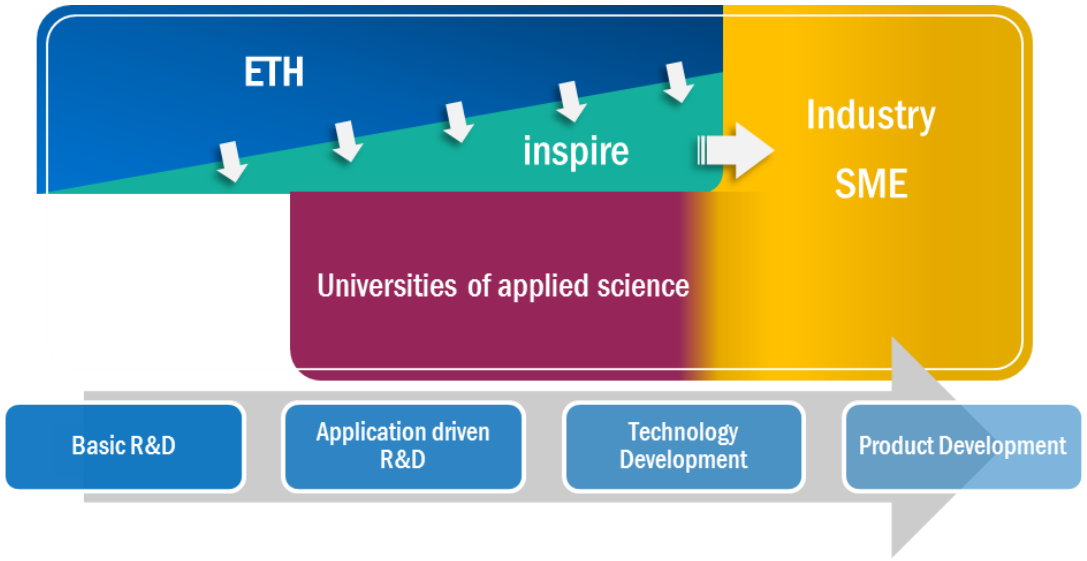


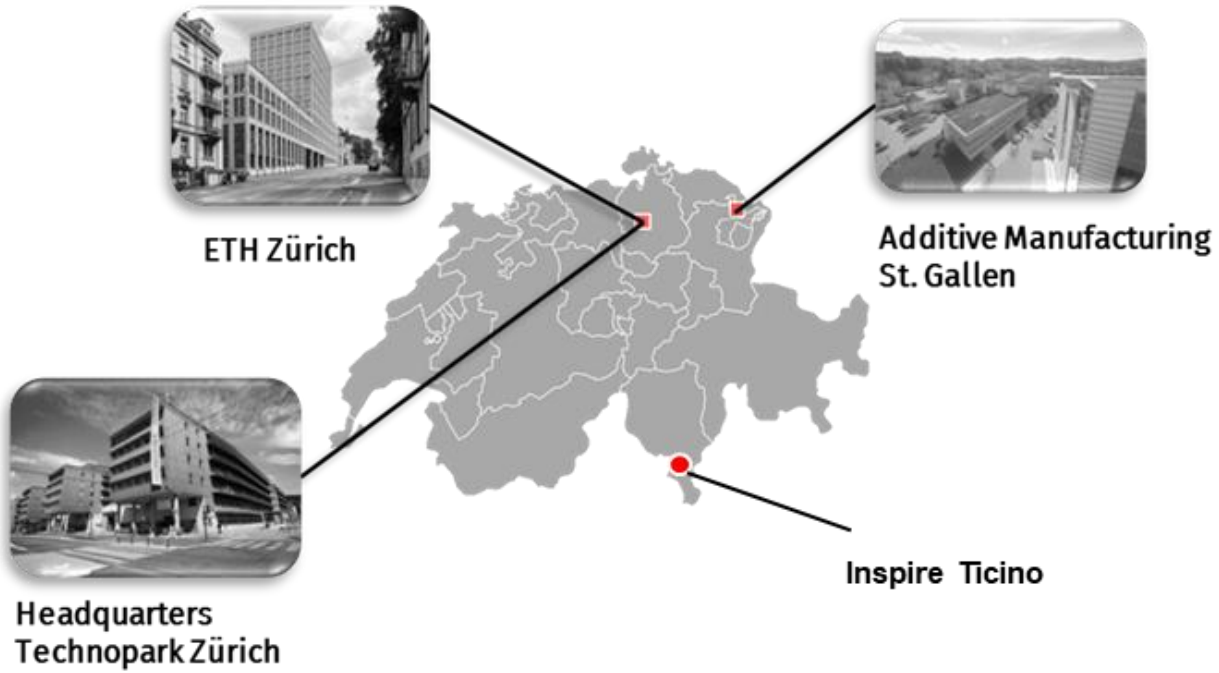
IWF
Institut für Werkzeugmaschinen und Fertigung
Institute of Machine Tools and Manufacturing

Strategic Partner
of ETH Zurich

Agenda

Who's insprie?





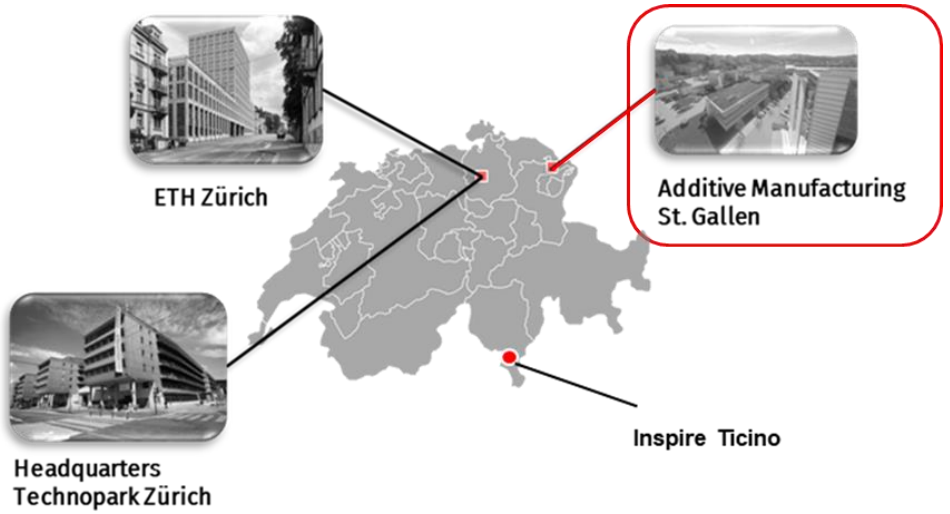
Inspire is

- a competence & research centre for the swiss machine manufacturing industry.
- a technology transfer centre with close relations to ETH in Zurich

- a common initiative of Swissmem, the Swiss Federal Institute of Technology ETH, and the State Secretariat for Education, Research and Innovation (SERI).

Inspire departments

- **Facts and figures**
  - Non-profit technology transfer centre
  - Focus on production engineering
  - ≈ 100 employees, 20+ working on AM topics
  - CHF 13+ Mio turnover



CEO (R. Gerdes)
COO / inspire Academy (M. Stöckli)

Application

- Additive manufacturing — Prof. Wegener; A. Spierings / M. Schmid
- Laser & micro fabrication — Prof. Wegener; J. Stirnimann
- Processes — Prof. Wegener; M. Kuffa
- Forming — Prof. Mohr / Prof. Bambach; J. Heingärtner
- Composite structures — Prof. Ermanni; M. Zogg
- Electro mobility — Prof. Wegener; S. Schneider; D. Vincenz

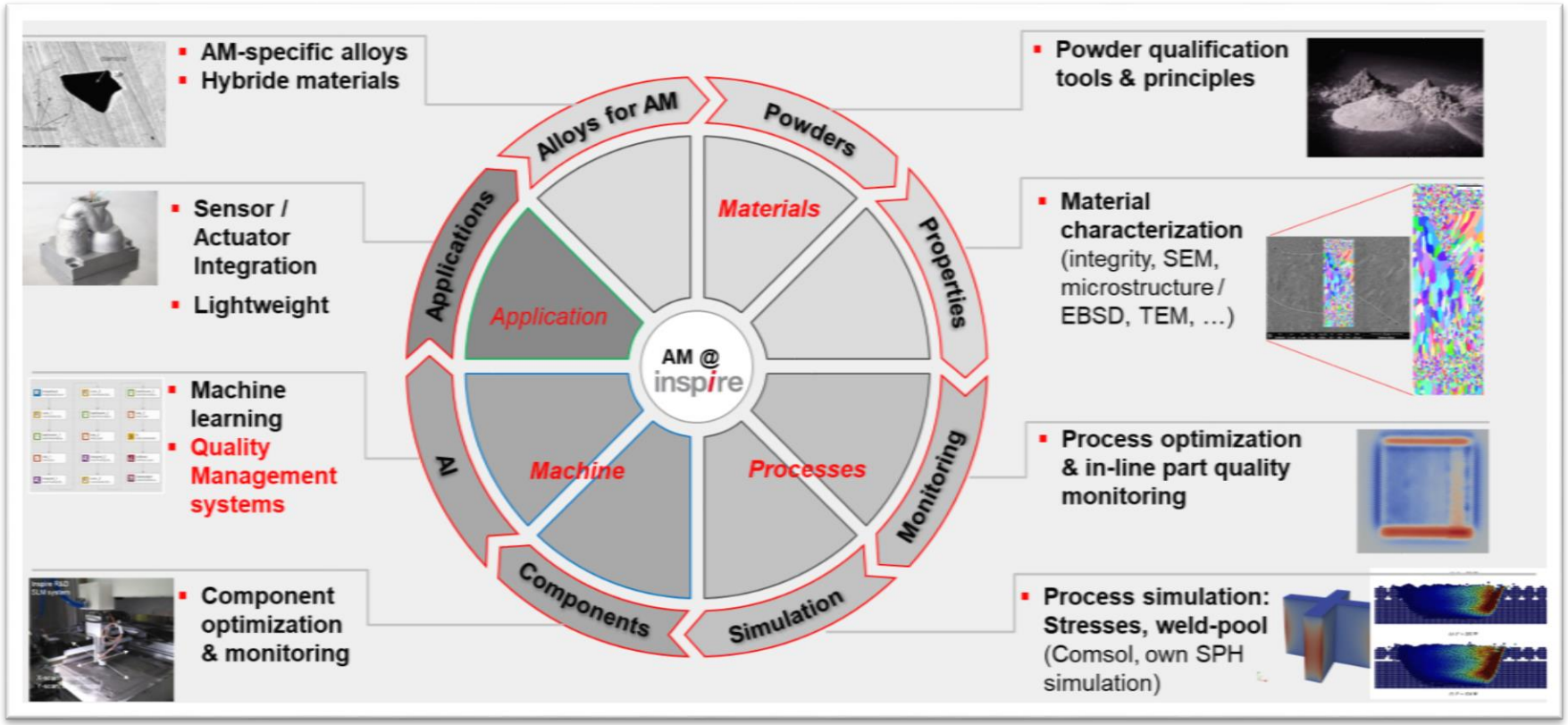
Technology Platform

- Materials & Sustainability — Prof. Bambach; K. Papis
- Design for New Technologies — Prof. Meboldt; C. Klahn
- Machines, analysis Industrie 4.0 — Prof. Wegener; L. Weiss; S. Weikert / J. Mayr
- Automatization — Prof. Lygeros; A. Rupenyan
- Artificial Intelligence — Prof. Carpanzano; J. Stirnimann
- Machine maintenence — Prof. Fink

Agenda

Inspire innovation centre for additive manufacturing (St.Gallen)

- **Icams St.Gallen**
  - R&D in AM
    - Plastics: SLS since 1996
    - Metals: SLM since 2005
  - Focus:
    Quality management in AM
    - Alloys and powders
    - Process
    - Machine
    - Applications
  - Experiences in
    - R&D along the full process chain
    - Part design and production



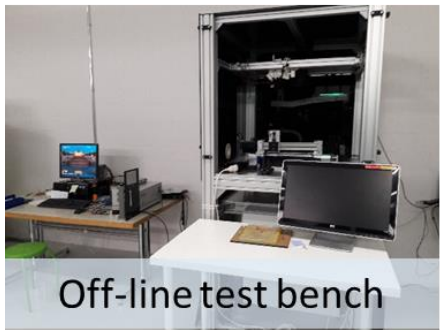
Lab tools, methods and equipment

- **Material & process development**
  - ThermoCalc alloy simulation
  - Own particle based process simulation (ETH / inspire development)
- **Powder qualification**
  - Particle size & shape distribution
  - Powder flowability: Hall flowmeter, FT4-Powder rheometer, Anton Paar Rheometer, Heatable dynamic flowability (RPA)
  - Open / flexible powder test bench
  - Microscopy
- **Material analysis**
  - Heat treatment ovens (1'300°C / vacuum oven)
  - Sample cutting, polishing, etching
  - Microstruture analysis: 2 x Leica microscopy
  - DSC
  - Static / dynamic mechanical characterization (Galdabini 10kN / W&B ± 25kN)
  - Hardness
  - Access to ETH-ScopeM for SEM, TEM etc
- **Part qualification**
  - 3D scanning / Dimensional analysis
  - 3D-surface characterization (GelSight)
  - 3D-line laser scanning


SLM: Aconity Midi+


SLM/SLS R&D machine

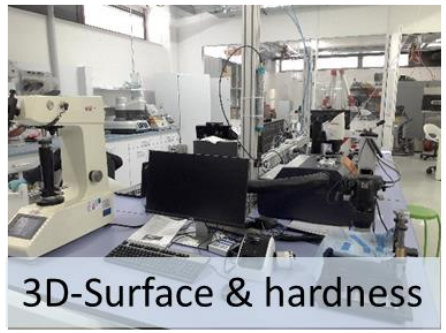

SLS R&D machine


Off-line test bench


Mechanical testing


Sample preparation


Microscopy / DSC

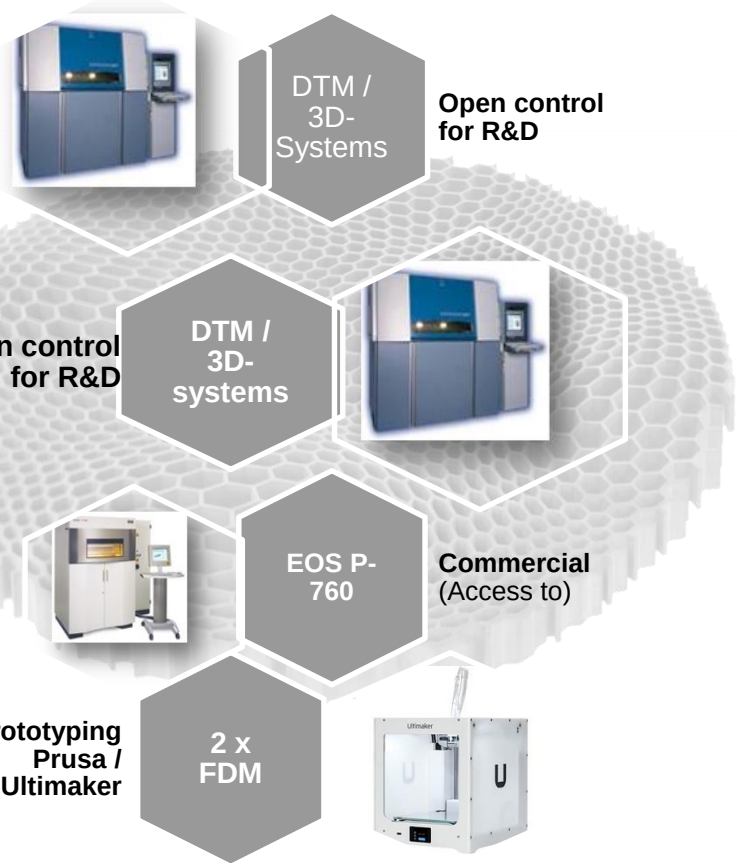

3D-Surface & hardness


Powder rheometer

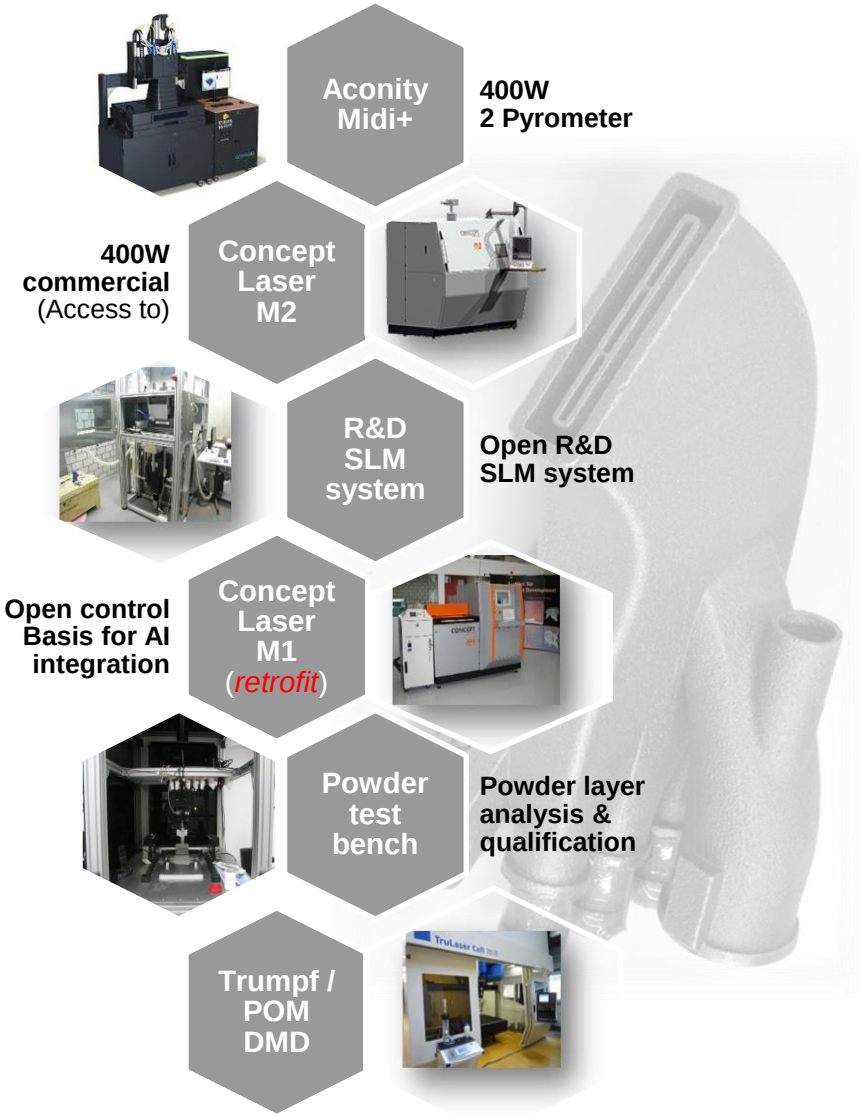
AM technologies

- AM technologies at inspire

Plastic additive manufacturing



Metal additive manufacturing

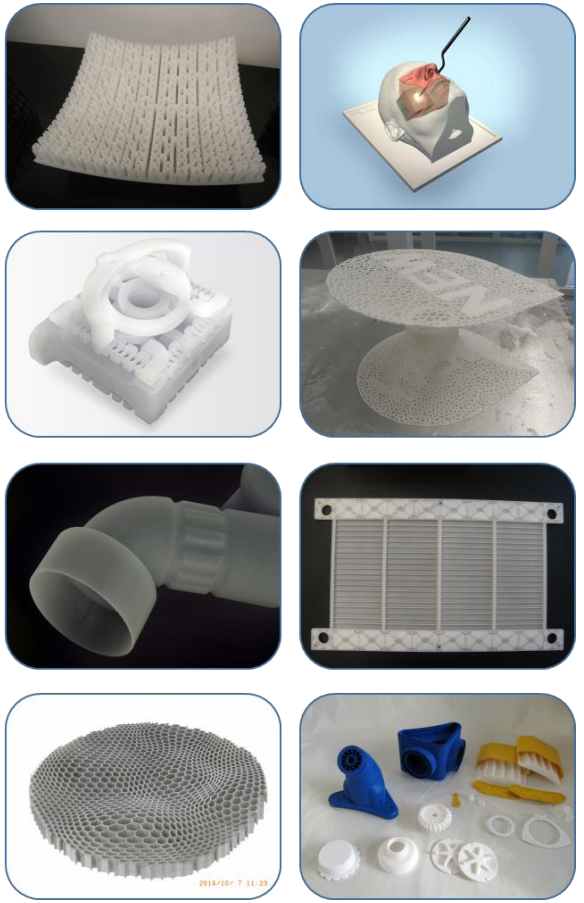


Examples

- Examples of industrial use-cases

Metal additive manufacturing

Plastic additive manufacturing



Agenda

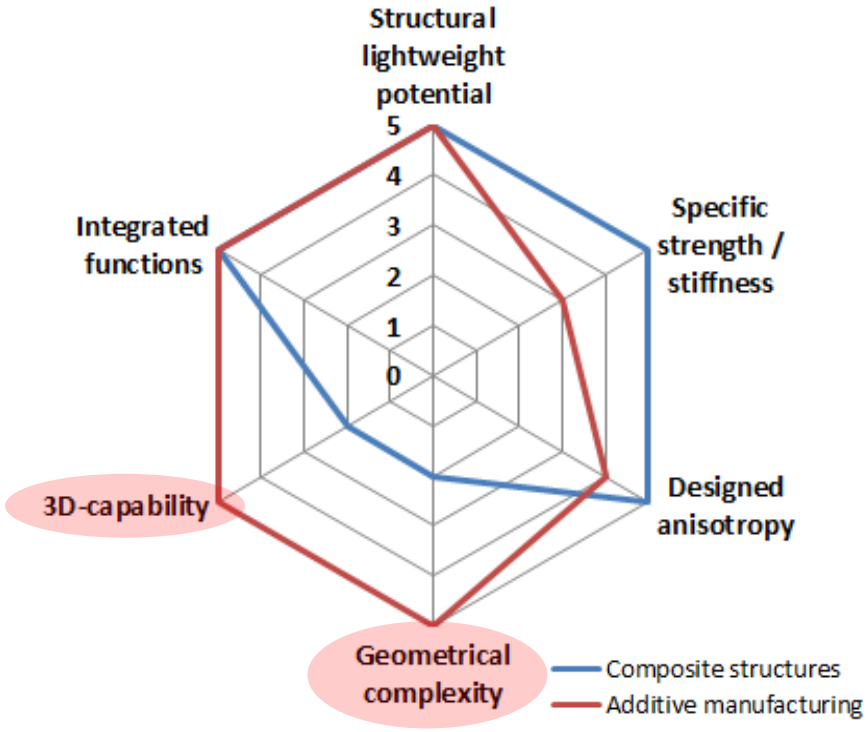
Motivation

- **Lightweight composite structures and additive manufacturing**
  - … complement each other in an optimal way

- **… for**
  - Improved design
  - Improved performance
  - Simplified manufacturing

Motivation

- **… complement each other in an optimal way**
- **… opens many opportunities to further improve…**
  - the technical potential of composites
    - fields of application
  - the performance of composites
    - strength
    - anisotropic stiffness
    - lightweight
    - Manufacturing costs
    - …
  - the industrial fields of application



Agenda

Options in combining composites & AM

Performance gain

Case 3
- Even composite strucutres
- Optimized insert structures
- Optimized assembly

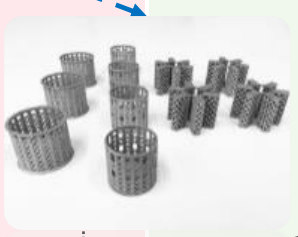
Case 2
- Even but optimized composite strucutres
- Optimized AM-core structures
- Optimized assembly

High

Medium

Low

Case 1
- Standard even composite strucutres
- Standard or AM insert
- Standard assembly



Composite shape

curved

even

The next step
- **Double curved** & optimized composite strucutres
- Optimized AM-core & insert structures
- Optimized assembly

Low | Medium | High | Very high

Complexity

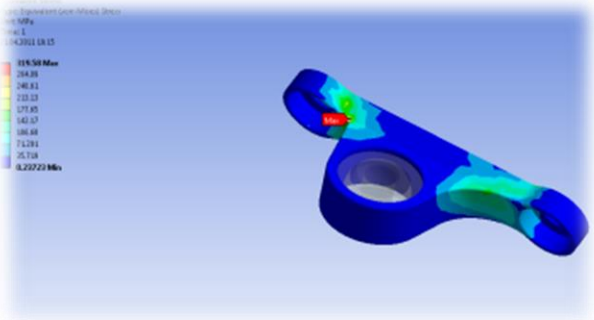
Agenda

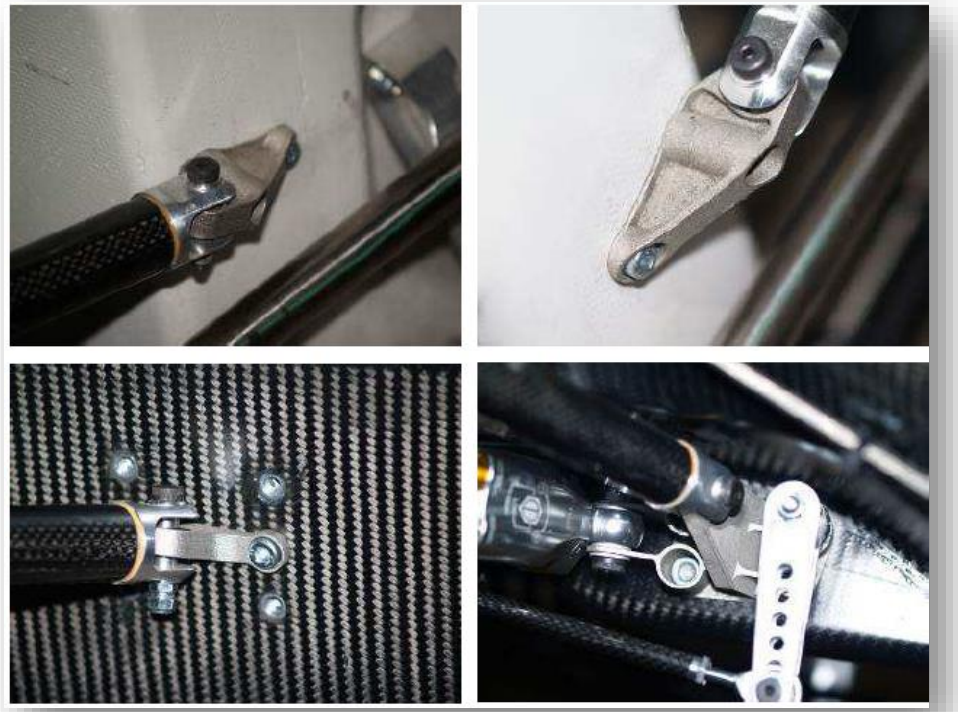
Case 1: Standard composite structure & AM-insert

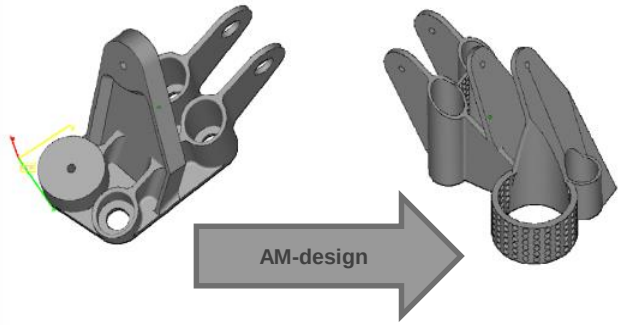
- **Application:**

  Load application point in race car

  - **AM optimized lightweight bracket structures**







Standard design lightweight design

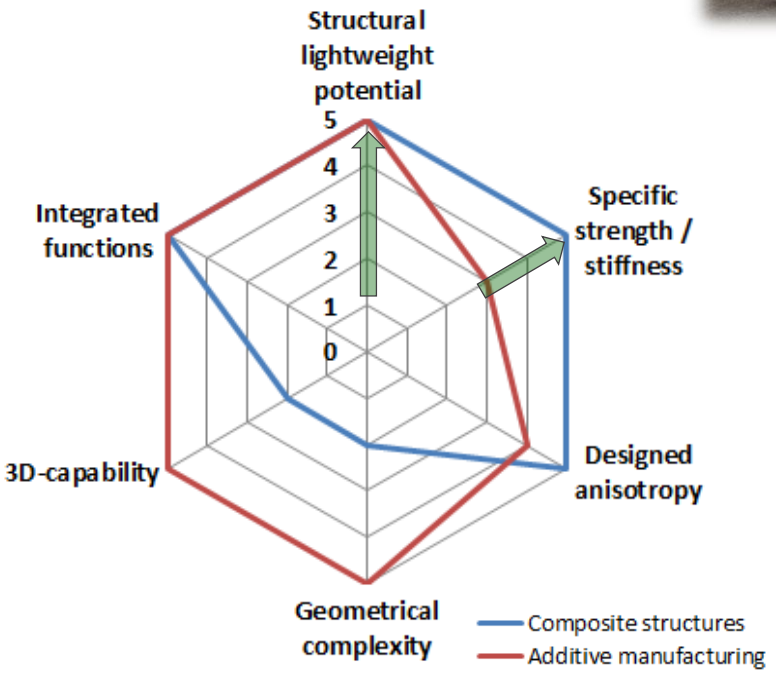
A.B. Spierings, et al. *Production of functional parts using SLM – Opportunities and limitations*, in: 5th International Conference on Advanced Research in Virtual and Rapid Prototyping, 2012, pp. 785-790.

Case 1: Standard composite structure & AM-insert

- **Application:**

  Load application point in race car

  - **AM optimized lightweight bracket structures**
    - Lightweight AM-design
      - Brackets
      - Bearing bolts
      - …
    - Limited gain in performance
      - Mean: 34% weight savings for brackets etc.
    - Standard assembly
    - No better strength



A.B. Spierings, et al. *Production of functional parts using SLM – Opportunities and limitations*, in: 5th International Conference on Advanced Research in Virtual and Rapid Prototyping, 2012, pp. 785-790.

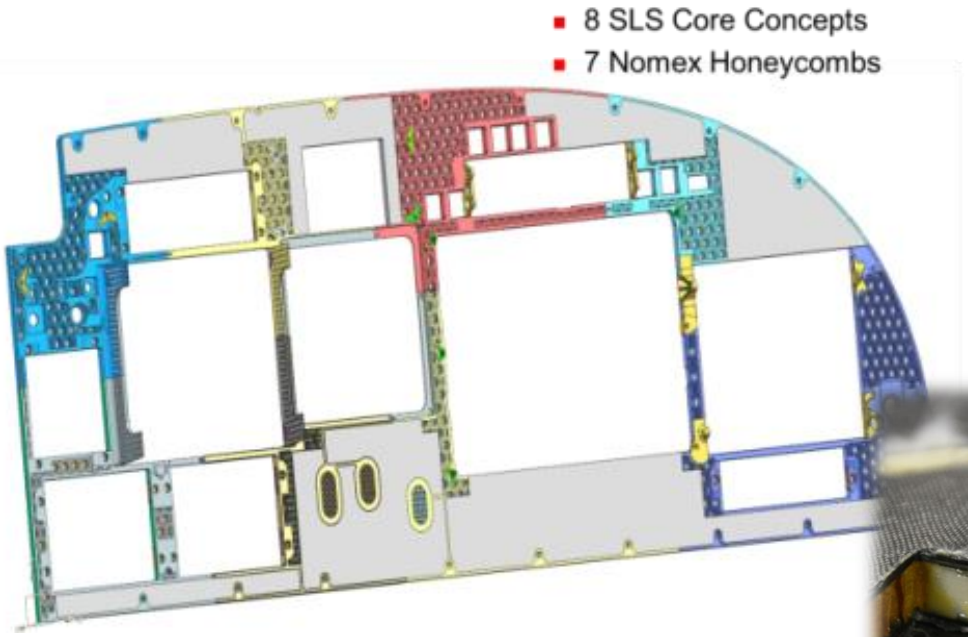
Agenda

Case 2: AM-composite core structures

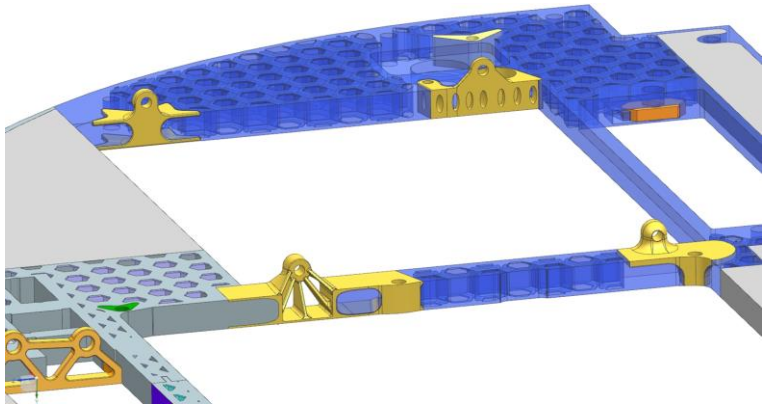
- **Application:**

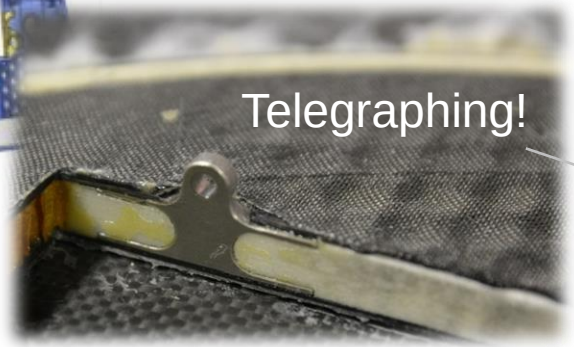
  Airplane instrument panel

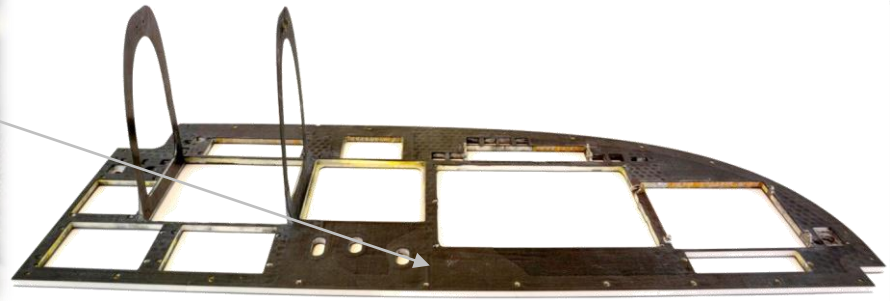
  - **Locally optimized AM-core structures** (SLS, SLM)



Innovative assembly concept





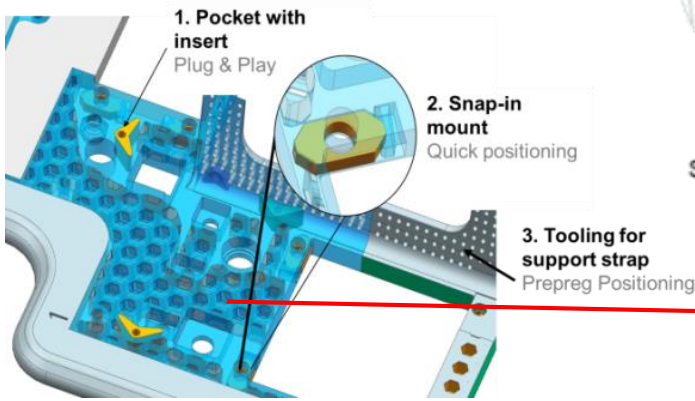


Case 2: AM-composite core structure & AM-insert

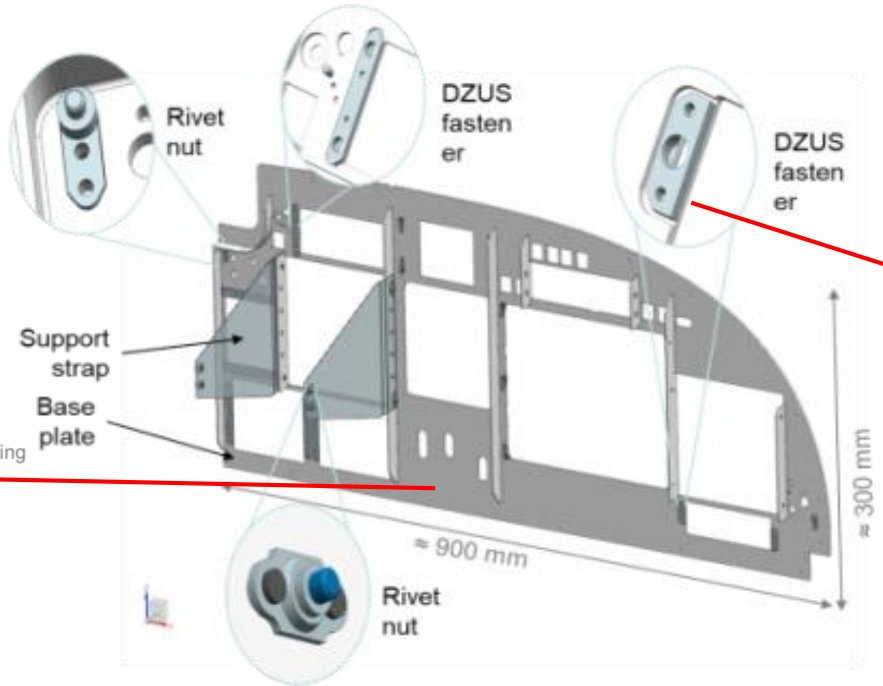
- **Application:**

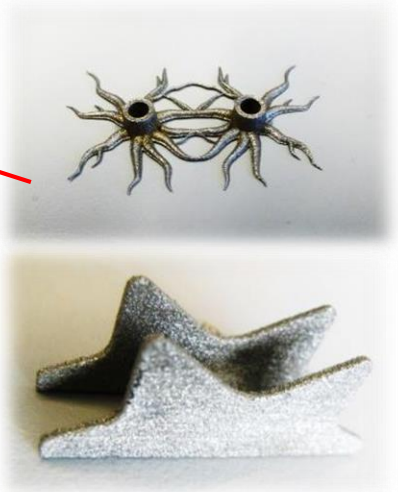
  Airplane instrument panel

- **Optimized metal AM-inserts**
  - Optimized for easy assembly
  - Optimized for function
  - Ligthweight



AM core structures





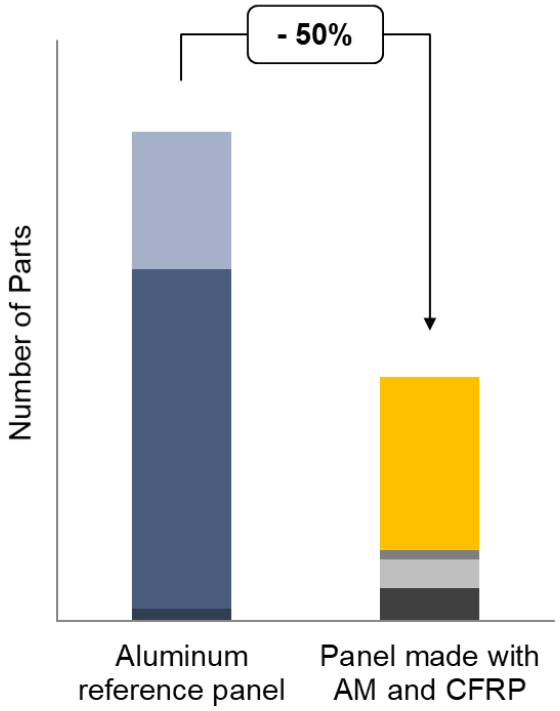
AM insert structures

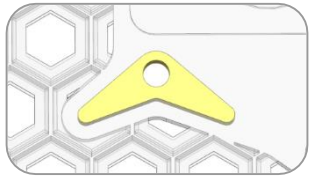
D.-A. Türk, et al. *Additive manufacturing with composites for integrated aircraft structures,* SAMPE-2016

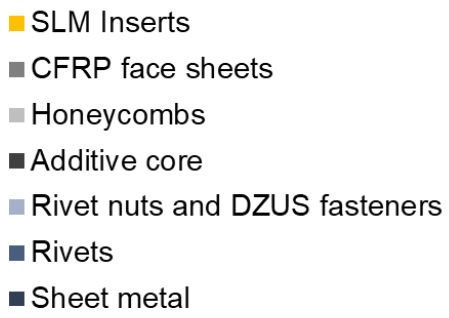
Case 2: AM-composite core structure & AM-insert

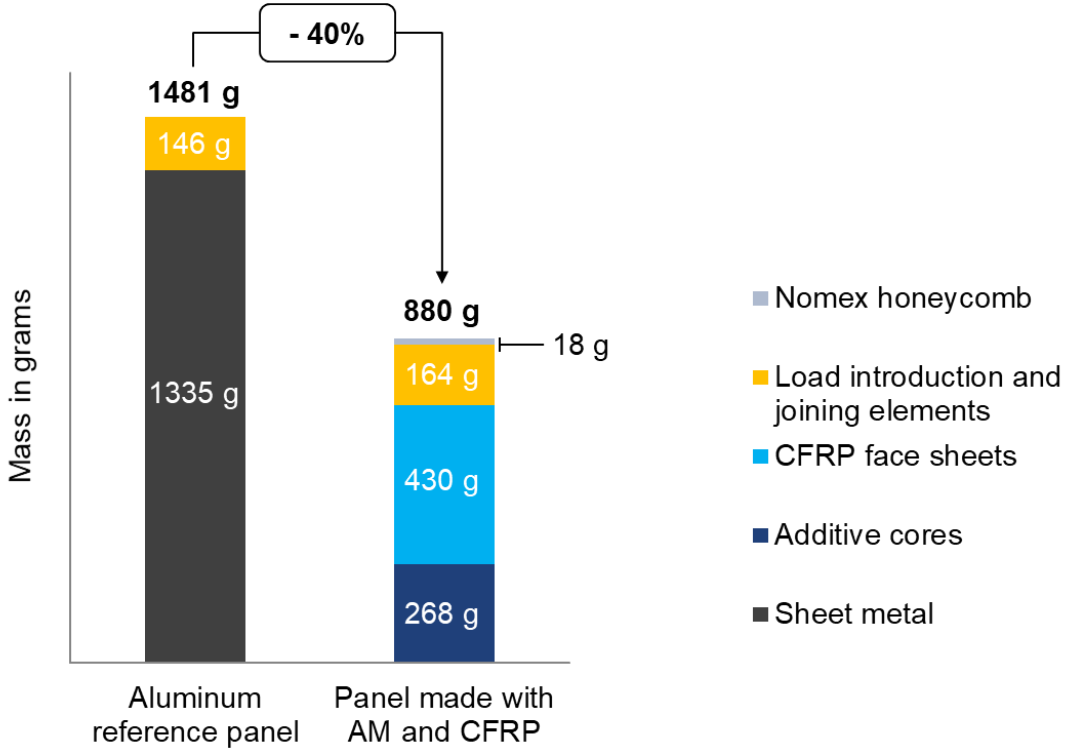
- **Application:**

  Airplane instrument panel









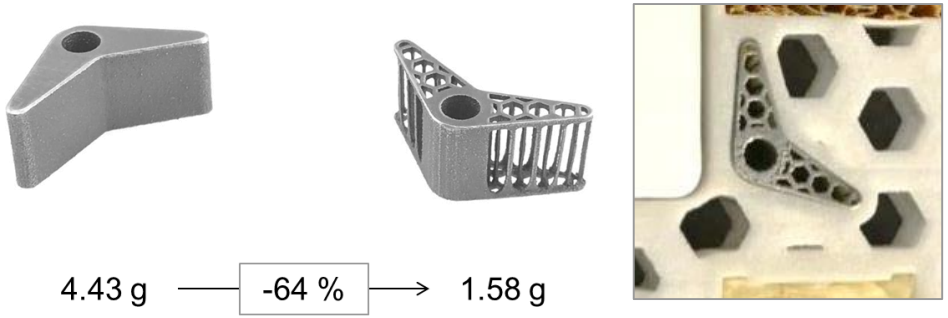
D.-A. Türk, et al. *Additive manufacturing with composites for integrated aircraft structures,* SAMPE-2016

Case 2: AM-composite core structure & AM-insert

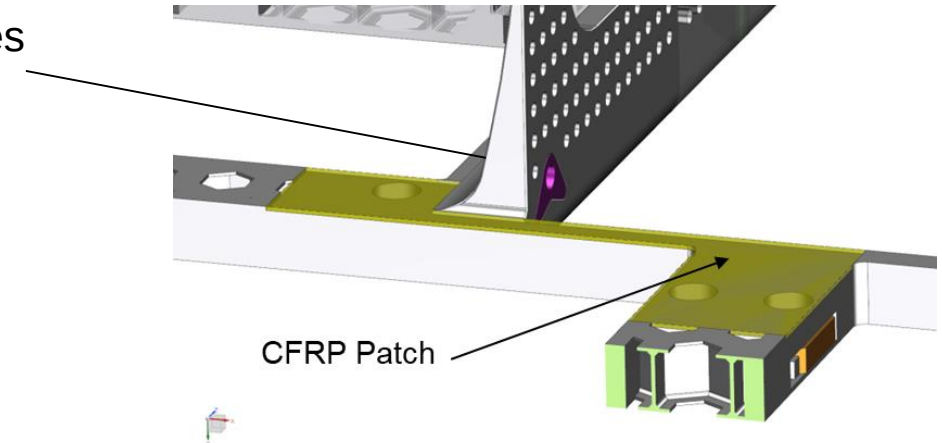
- **Application:**

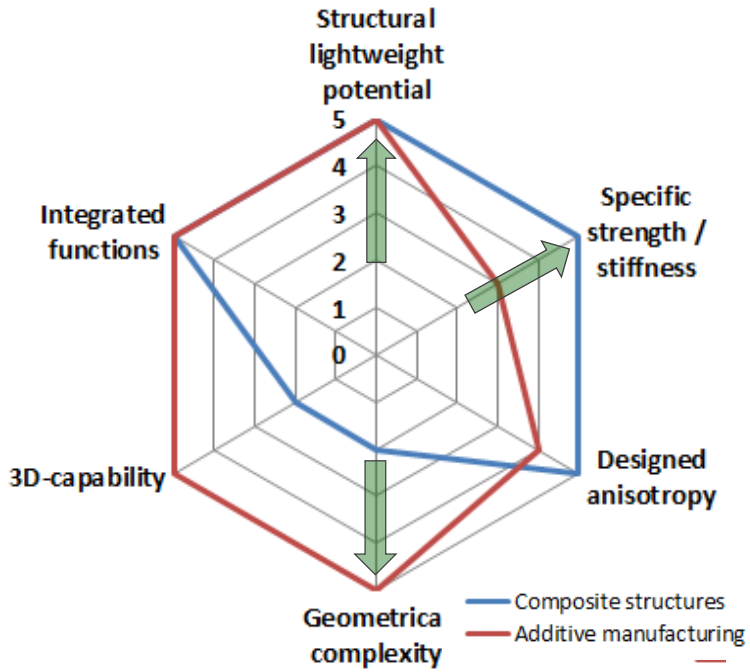
  Airplane instrument panel

Individual parts



Optimized facing,
and core structures





D.-A. Türk, et al. *Additive manufacturing with composites for integrated aircraft structures,* SAMPE-2016

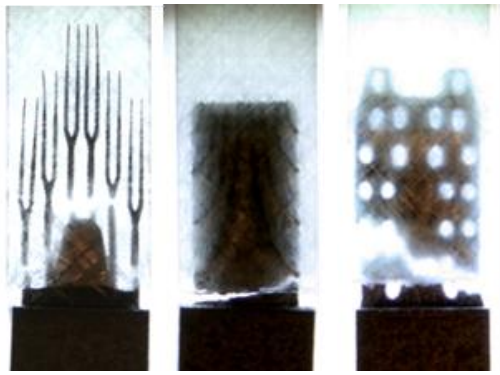
Agenda

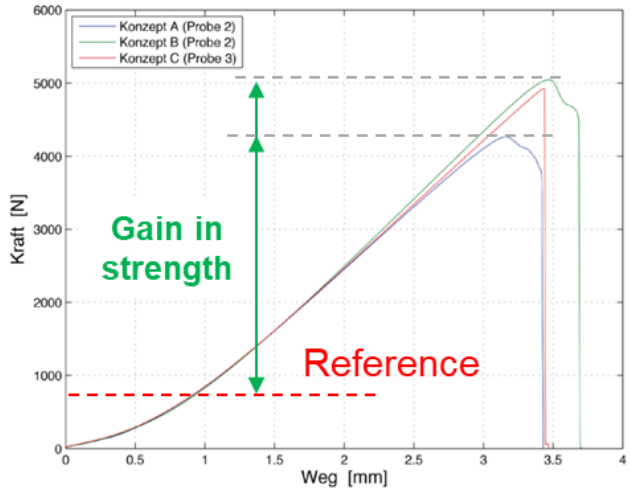
Case 3: Optimized AM-inserts

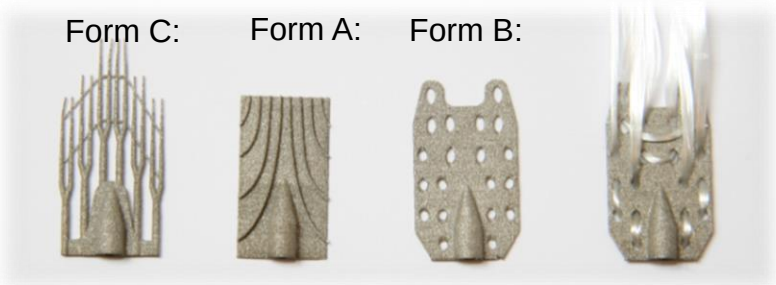
- **Application:**

  Load application points, e.g. in rotor blades

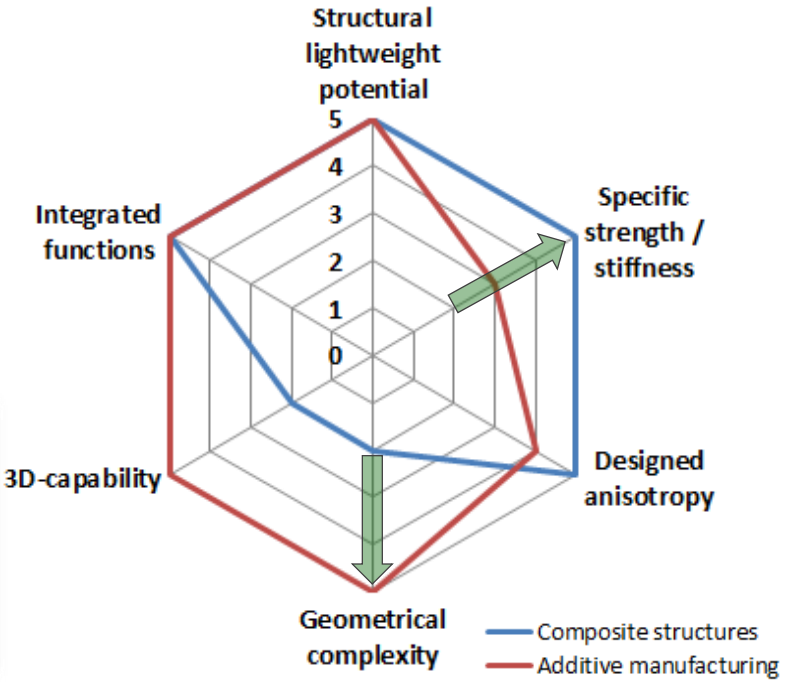
  - **AM-designed inserts**
    - Structurally optimized metal inserts
      ➔ *tailored for in-insert fracture*
    - Significantly increased load capacity
    - Standard composite manufacturing







Insert designs



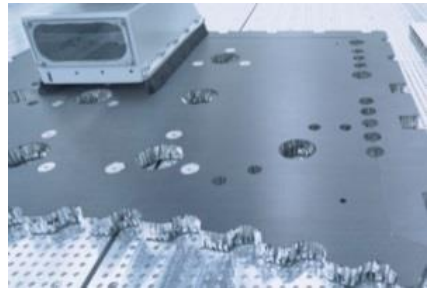
Case 3: Optimized AM-inserts

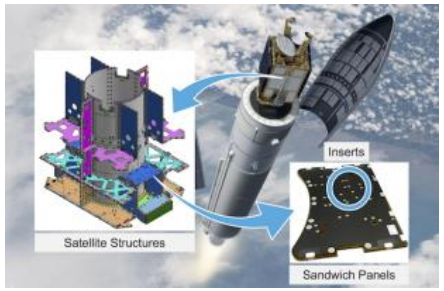
- **Application:**

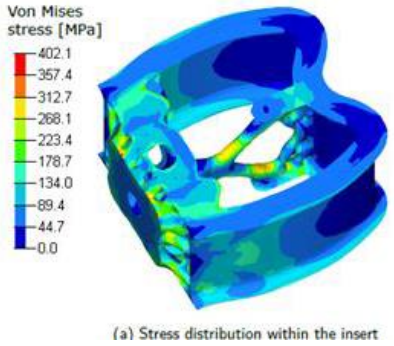
  Satellite sandwich panels

  - **Design optimization for AM inserts**
    - Design-for-AM of spool, block & edge inserts
    - Significantly improved load bearing capacity
    - Lightweight (up to - 50%)
    - Novel possibilities for insert functionalities
    - Integrated functions for easier assembly / manufacturing

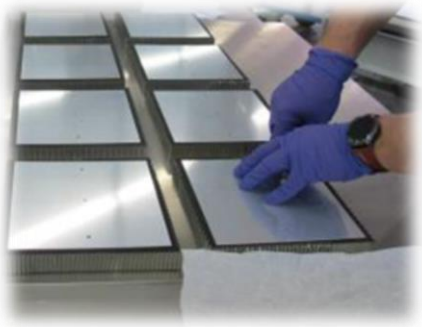
Together ahead. RUAG



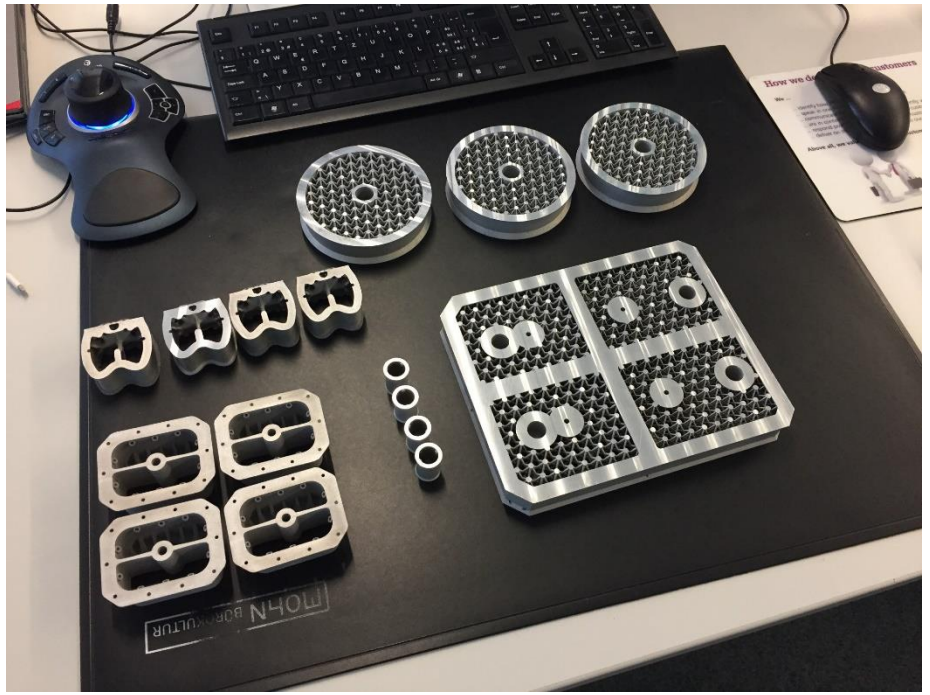




(a) Stress distribution within the insert



Assembly optimization



Various AM-optimized insert types for sandwich panels

Case 3: Optimized AM-inserts

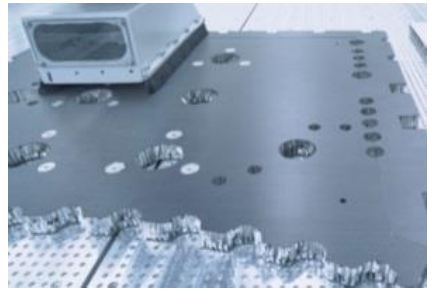
- **Application:**

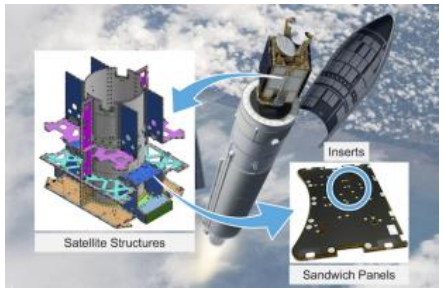
  Satellite sandwich panels

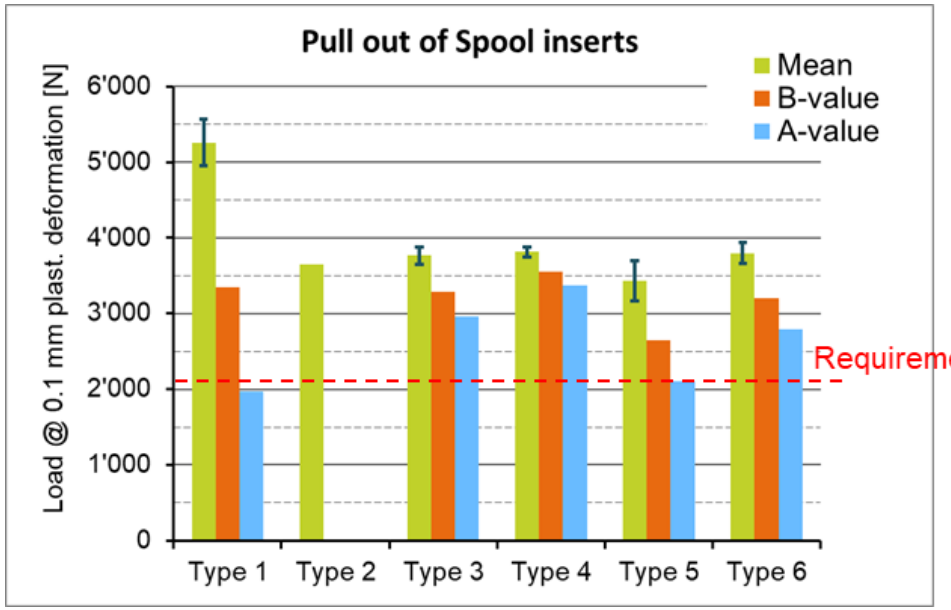
  - **Design optimization for spool inserts**
    - Improved design for spool inserts
    - Higher pull-out strengths

Together ahead. RUAG

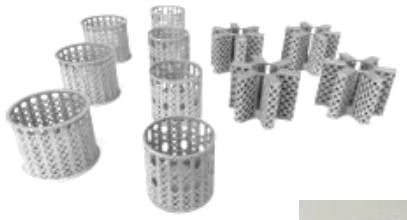
Innosuisse - Swiss Innovation Agency
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

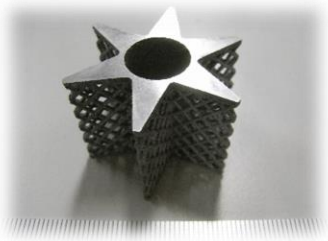


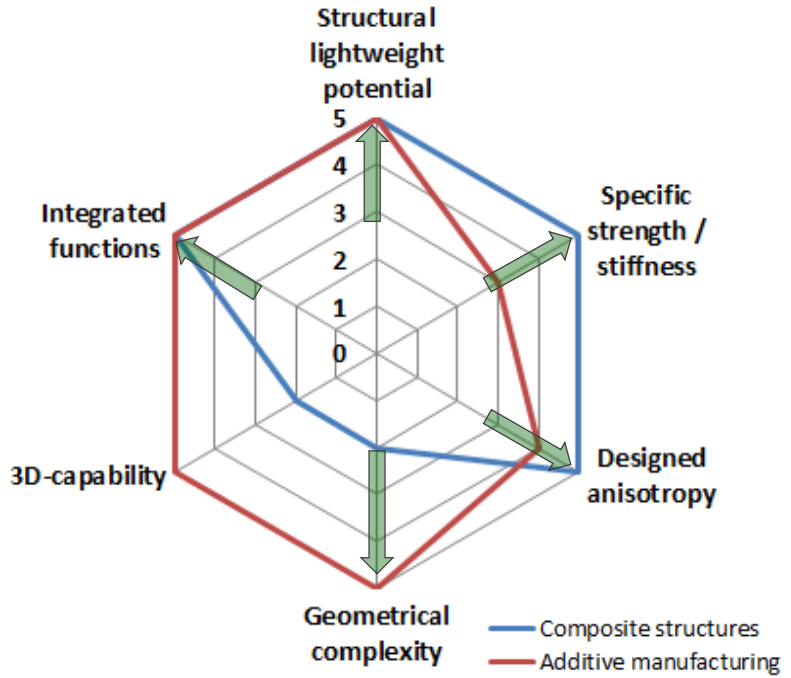




Design optimization







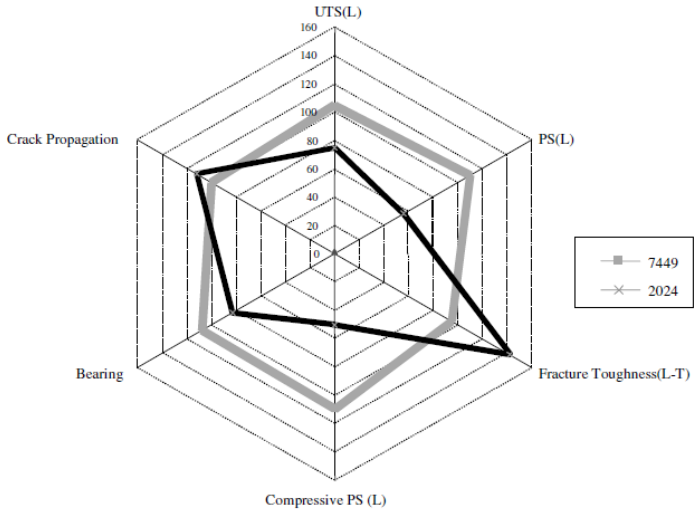
Agenda

Conclusions

- **Combining composite structures and AM**
  - **High potentials**
    - For better composite specific strengths
    - Better strength-to-weight ratios
    - Extended composite designs
  - **New insert structures with extended capabilities**
    - Integration of new functions
      - Structural flexibility e.g. to compensate for thermal distortions / elongation
      - Lightweight design
      - Higher pull-out strengths
    - Simplified integration / assembly into composite structures
  - **New 3D-curved composite structures, with simplified designs**
    - Automated design generation
    - …. Requires AM-design for core structures and inserts

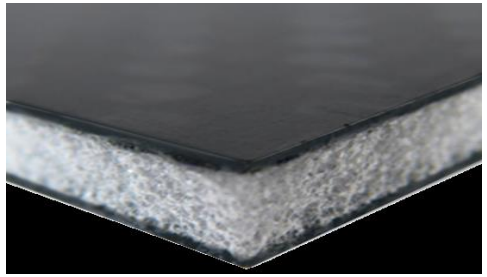
The next steps

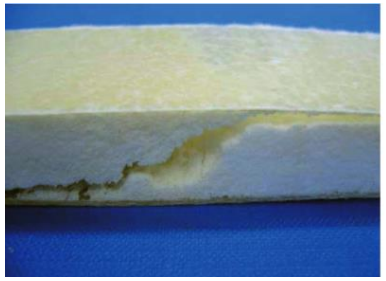
- **High-strength Al-alloy development for AM**
  - **State of the art**
    - Standard Al-alloys (90% of the market are 4xxx)
      Very few alternative alloys,
      - Expensive
      - Critical rare earth elements (e.g. Sc)
      - Do not fulfill requirements for structural applications (like 5xxx / 6xxx / 7xxx alloys)

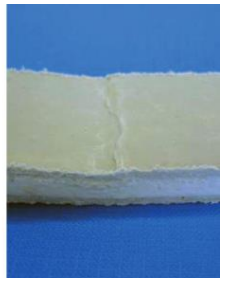


CANTOR, B. et al - Aerospace Materials (IOP, 2001)

- **Curved 3D composite structures with AM optimized cores**
  - **State of the art**
    - Most sandwich structures are planes
    - 3D curved structures are difficult to produce





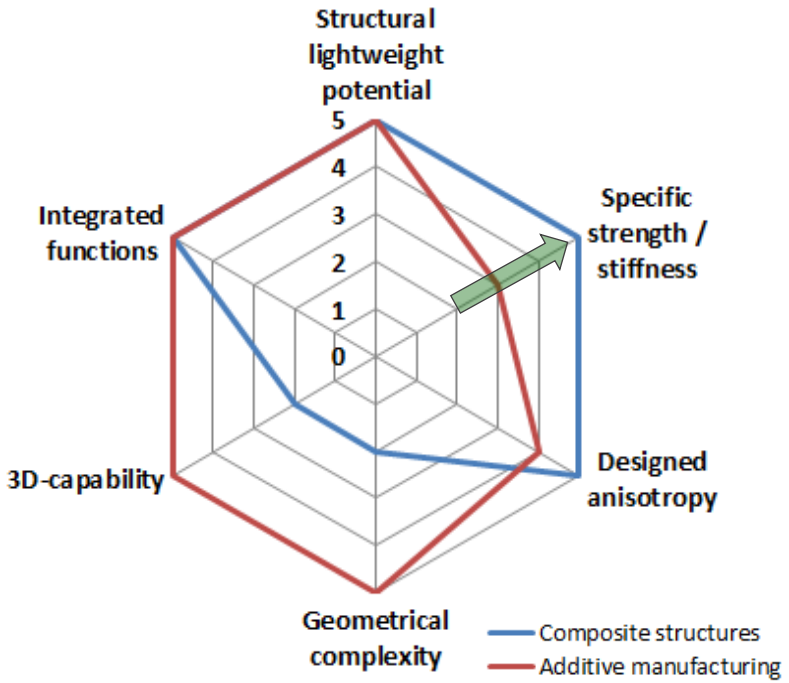


Plane sandwich strucutres cannot be bent

Industrial need for 3D shaped lightweight composite structures

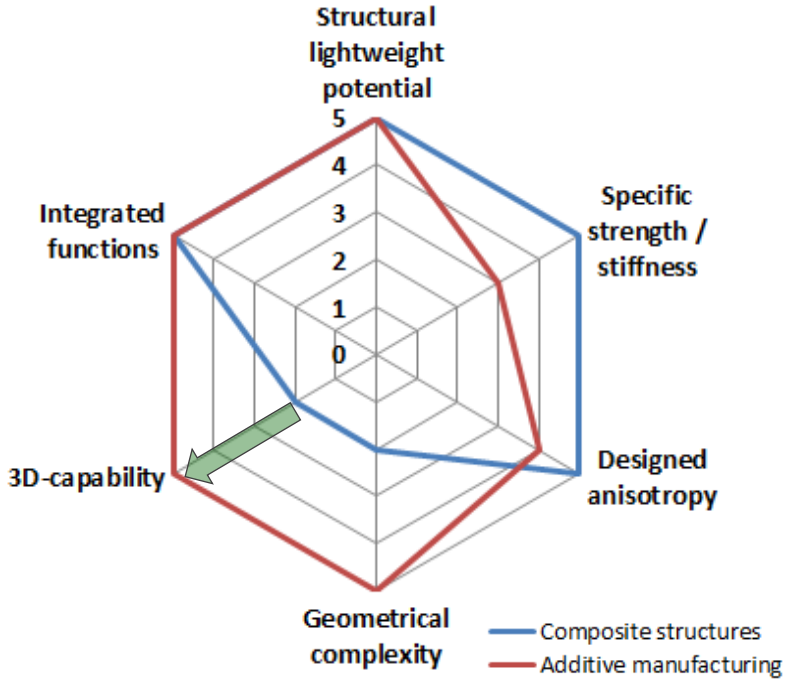
The next steps

- **High-strength Al-alloy development for AM**
  - **Goals**
    - High strength Al-alloys optimized for AM
      ➔ better strength-to-stiffness ratio
    - Cheaper than existing alternatives
    - Address structural applications in space & aerospace



Just started

- **Curved 3D composite structures with AM optimized cores**
  - **Goals**
    - Enable 3D curved composite structure manufacturing
    - Optimized core structures, and inserts
    - Simplified & automated design principles



Thank you for your attention

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