Dig4ReMan –
Digital tools & services for data driven remanufacturing value chains

Manufacturing R&D Cluster Conference 2024

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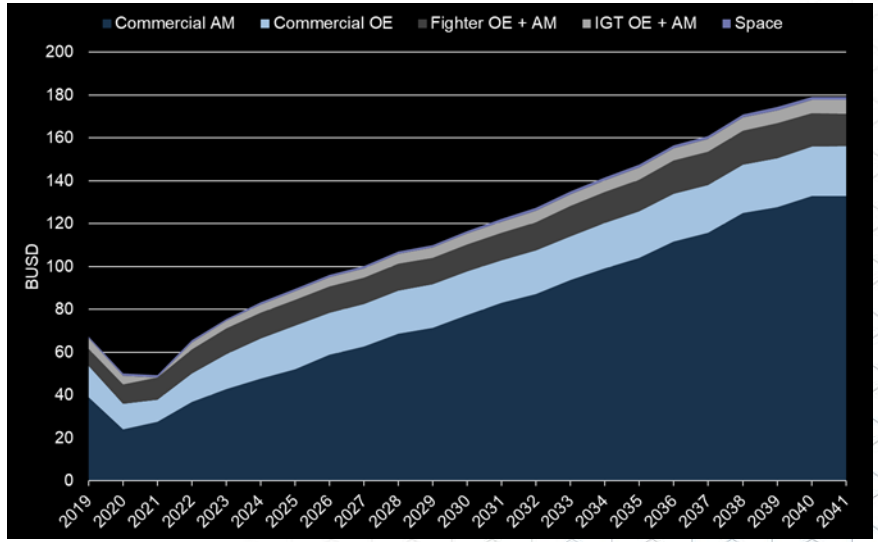
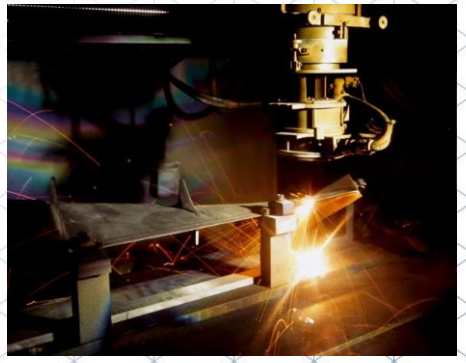
1) Background and motives 1(2)

- MRO business is big in Aerospace
  - Maintenance / Repair / Overhaul
- The Aftermarket/MRO will grow approx. 6.5% CAGR
  - Higher total volumes of engines in service
  - Backlog of parts that need new repair technologies
  - Cost and Sustainability drives MRO
- Repair can save up to 95% of materials/energy/CO2
- Cost for a repaired part is often10-20 % of a new one






Video that give an introduction to the Aerospace MRO business models: LINK

1) Background and motives 2(2)

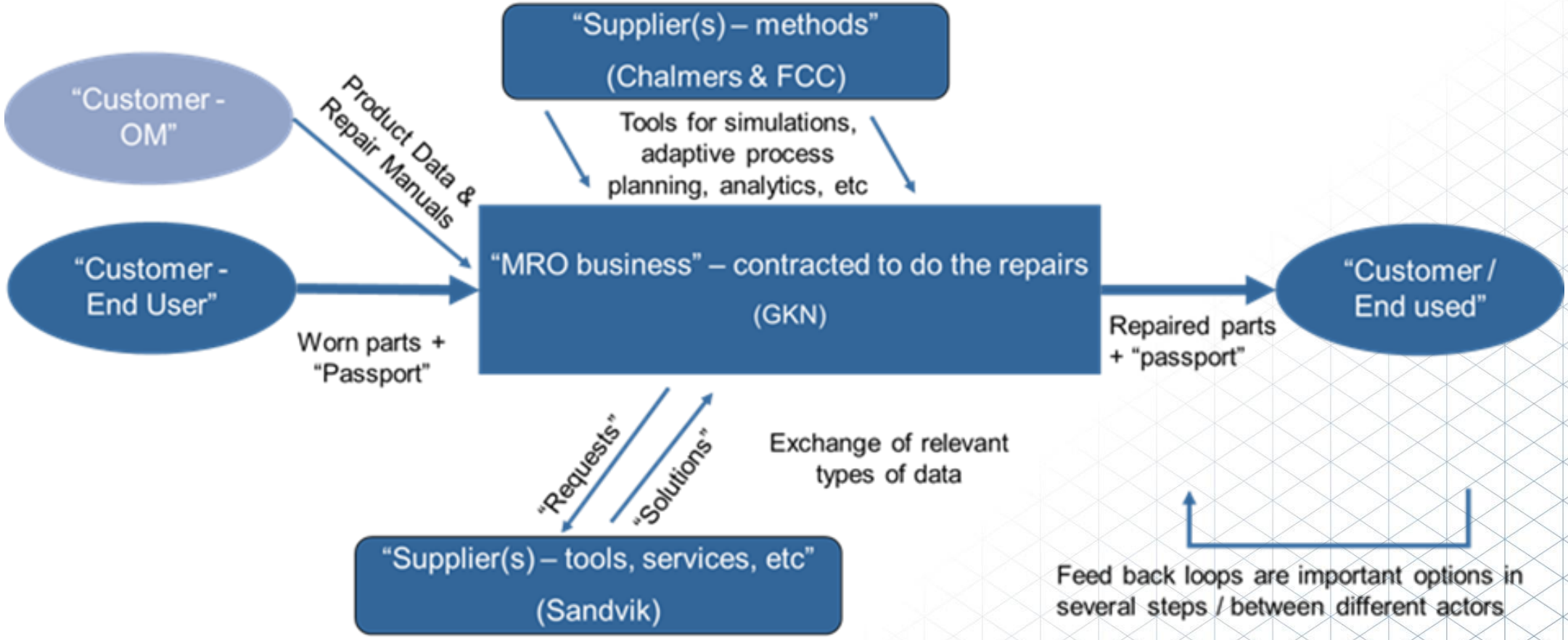
Industrial Challenges & Needs:

- Business driven Circular Economy & Sustainability
- Tools to enable new types of repairs
- Achieve higher efficiency and shorter lead times
- Supply chain integration and collaboration
- Investigate new services and value offerings

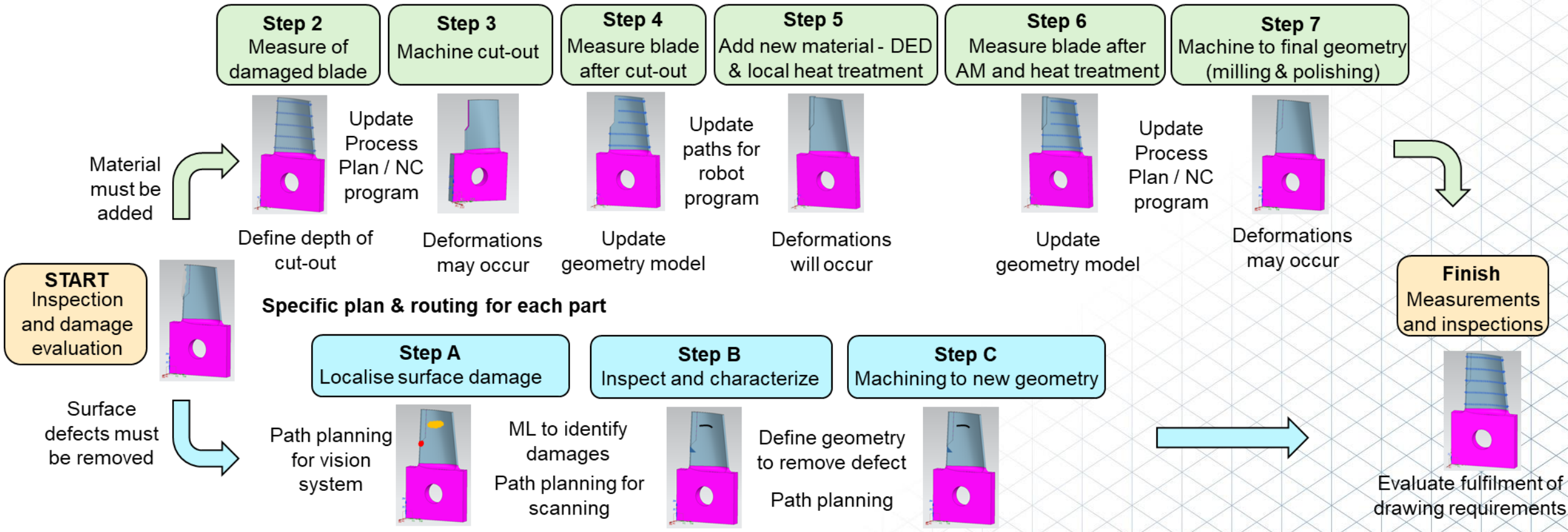
Goals:

To develop a concept for a highly automated & efficient end-to-end repair process, on complex geometries of individual parts, enabled through advanced digitalization & a collaborative service oriented value chain.

2) Overview of the approach 1(2)
– principles for a value chain in repair planning and execution



2) Overview of the approach 2(2)
– Principle steps for adaptive repair cycle of individual parts



4) Digital tools & services

a) Design of a collaborative data driven value chain

b) Simulation of tolerances & deformations (AM & machining)

c) Flexible process planning (AM & inspection)

d) Collaborative process planning (machining)

3) Design of a collaborative data driven value chain

Methods for *Business Process Mapping* and *UML/Systems Engineering* are used

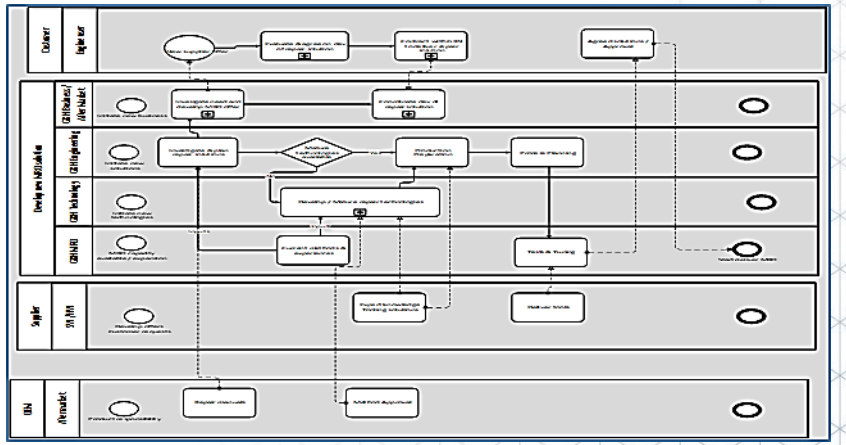
Context diagrams

Every “Entity” has a different context to other “Entities” and their “Actors”

Functional Flow diagrams

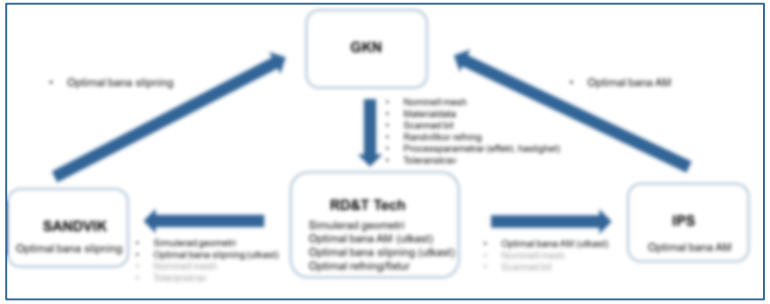
Each “Entity” need to identify their different functions involved

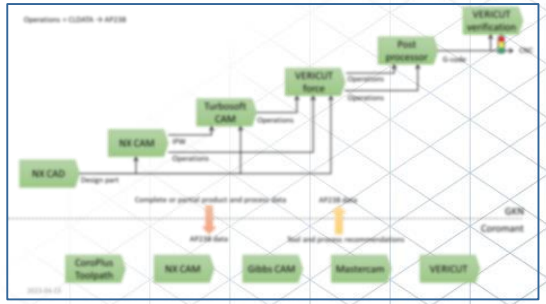
Cross Functional Flow diagrams

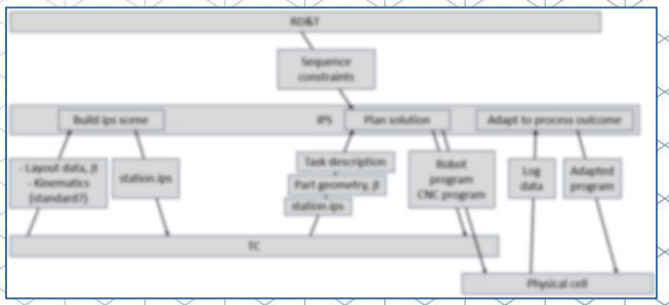


The cross functional diagrams may be complex, but cant be avoided and is a kind of reality check

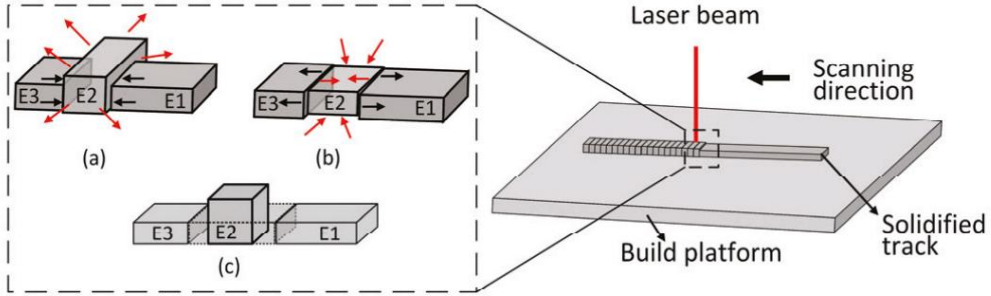
But also *Ad-hoc* models are useful, at least to focus the technical issues







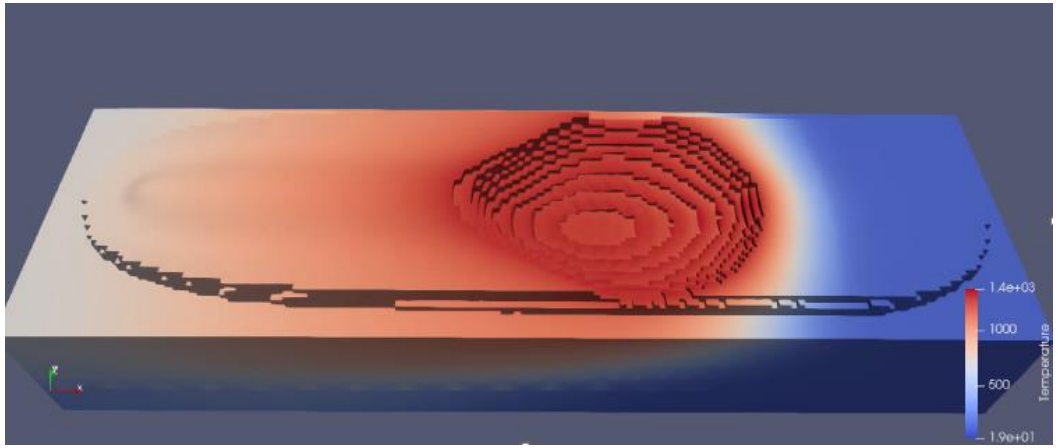
Simulation of deformations using Inherent Strain method

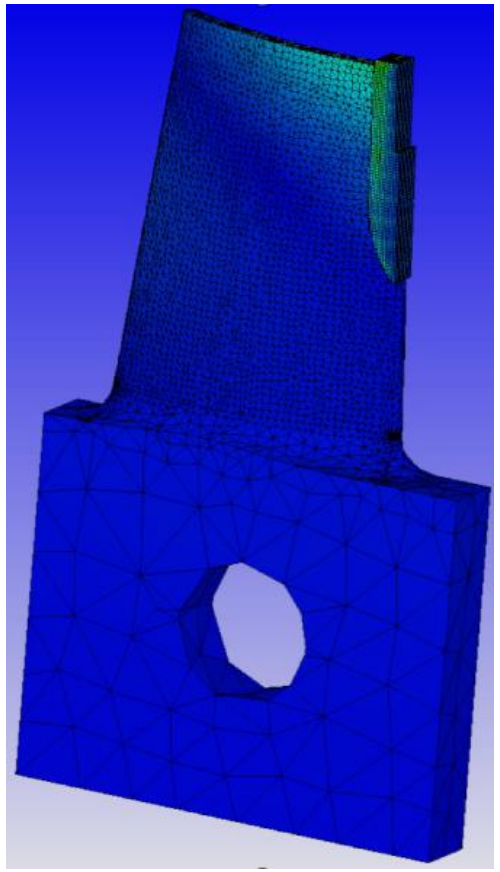


Inherent strain
(a) During heating and melting
(b) During solidification and shrinkage
(c) Inherent strain of the processed element

Simplification of AM/welding processes

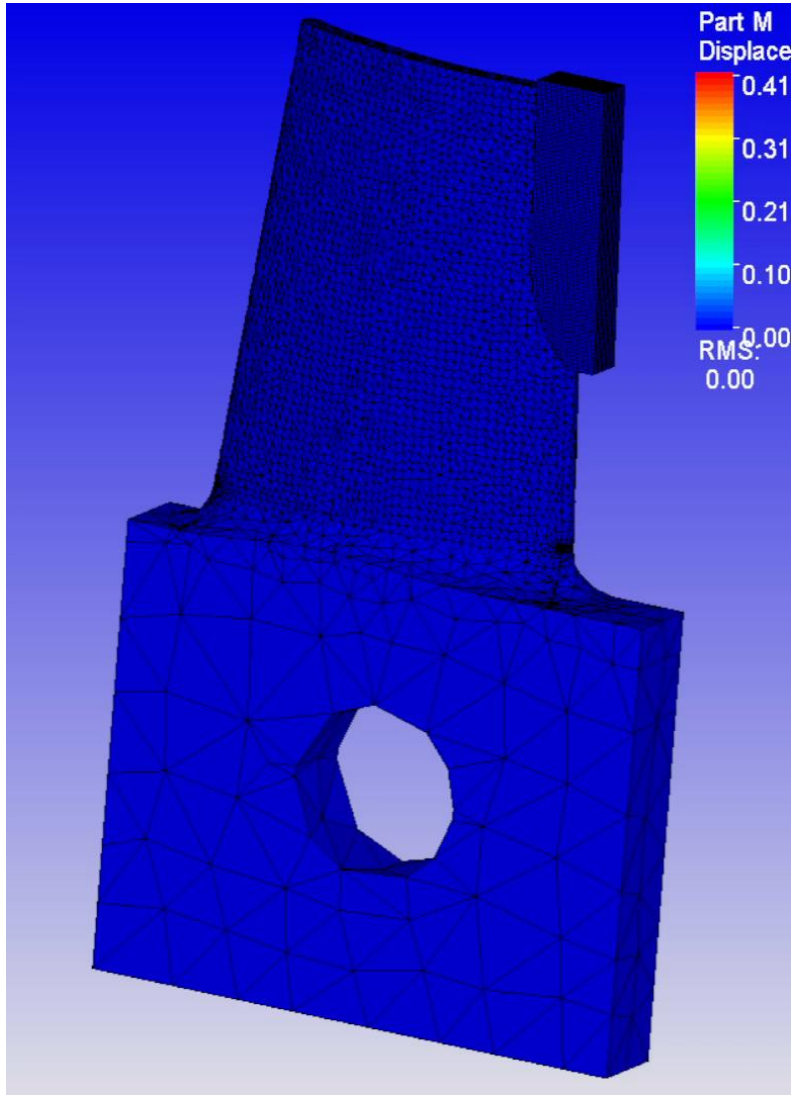
- Thermal and mechanical process is simplified to a net (inherent) strain
- $\varepsilon^{total} = \varepsilon^{e} + \varepsilon^{p} + \varepsilon^{th} + \varepsilon^{phc}$
- $\varepsilon^{inherent} = \varepsilon^{total} - \varepsilon^{e} = \varepsilon^{p} + \alpha\Delta T\ (+\varepsilon^{phc})$
- Calculated using a representative geometry





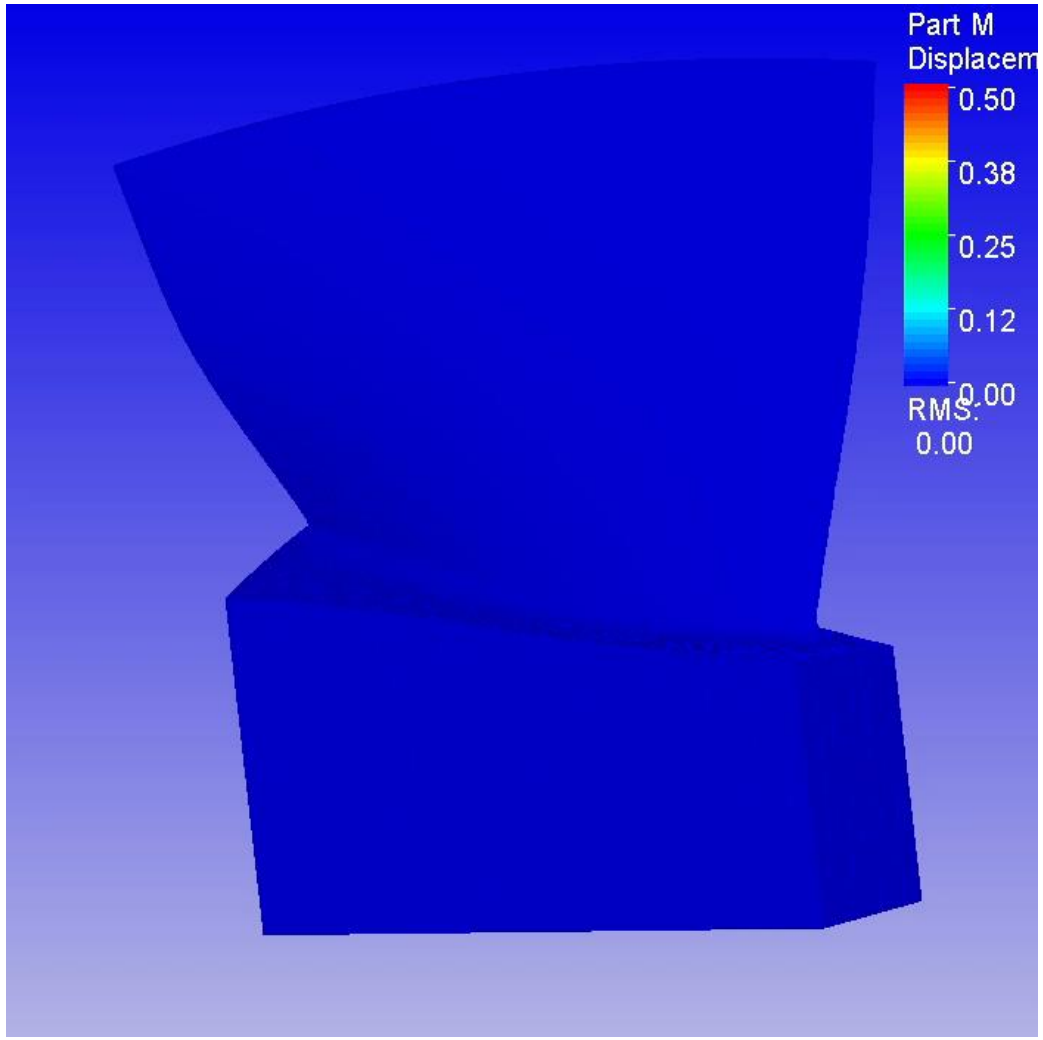
Direct Energy Deposition – Laser Metal Deposition

- Remanufacturing of turbine/compressor blades
- Reliant on both scanned/estimated and nominal CAD-geometries
- Non-flat, non-rigid substrate
- Machining excess material
- Iterative fixture optimization



Practical Applications

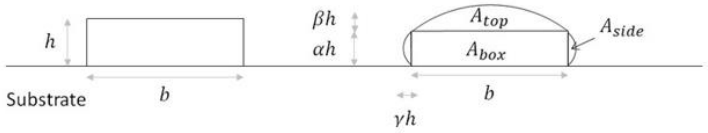
- High throughput AM simulation for remanufacturing
- Individualized predictions of distortion from AM to consider viability
- Large scale parameter optimization for blade models with common geometry
- Individualized optimization of key parameters



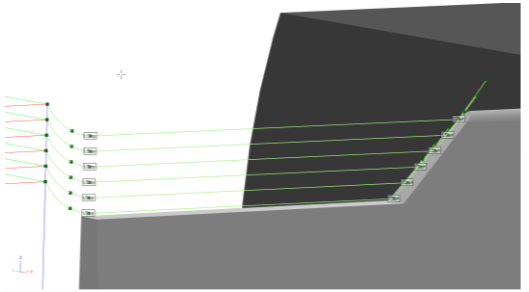
Projection-based simulation of AM deposition

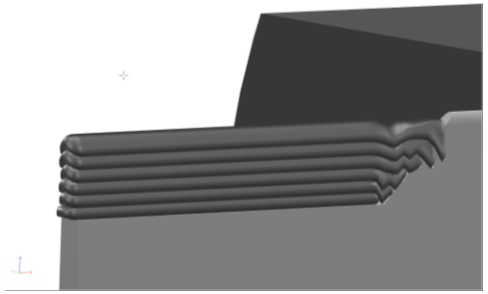
- Experimentally fitted model for bead height and width.
- Simulation runs near real time.
- Useful for fast approximation of bead shape while commissioning robot programs.

- α: <bottom_height_factor>
- β: <top_height_factor>
- γ: <side_width_factor>

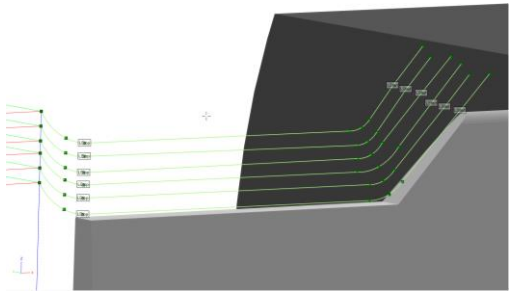


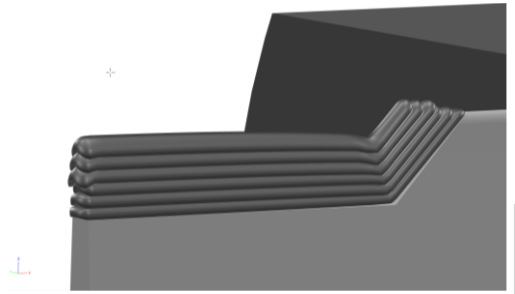
Strategy 1; Straight passes.

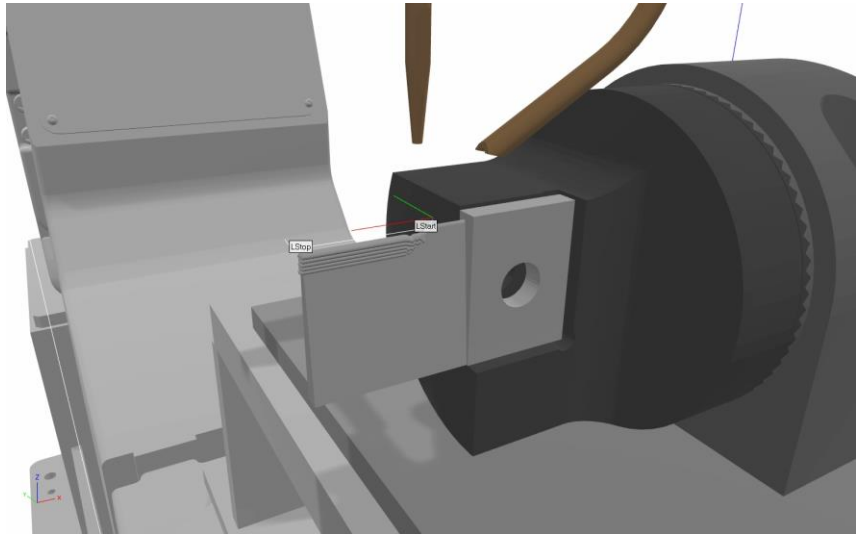




Strategy 2; Follow curvature.







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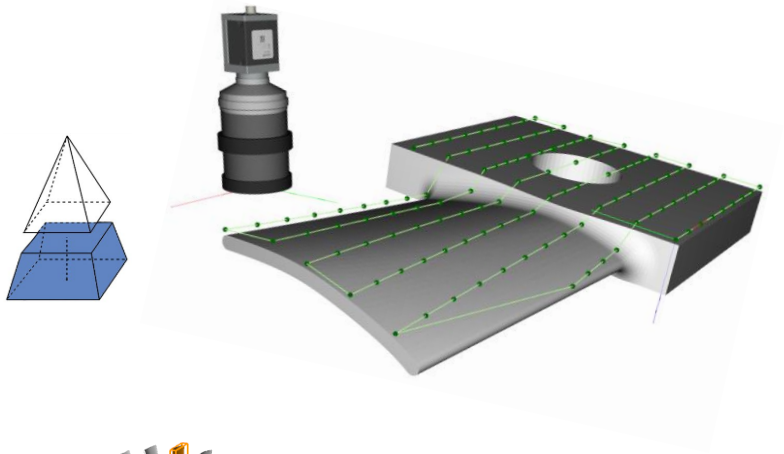
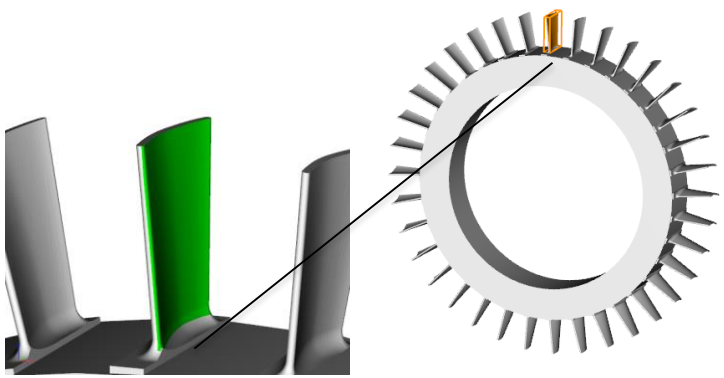
RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

Automatic path planning; Visual inspection

Sensor paths to ensure adequate surface coverage

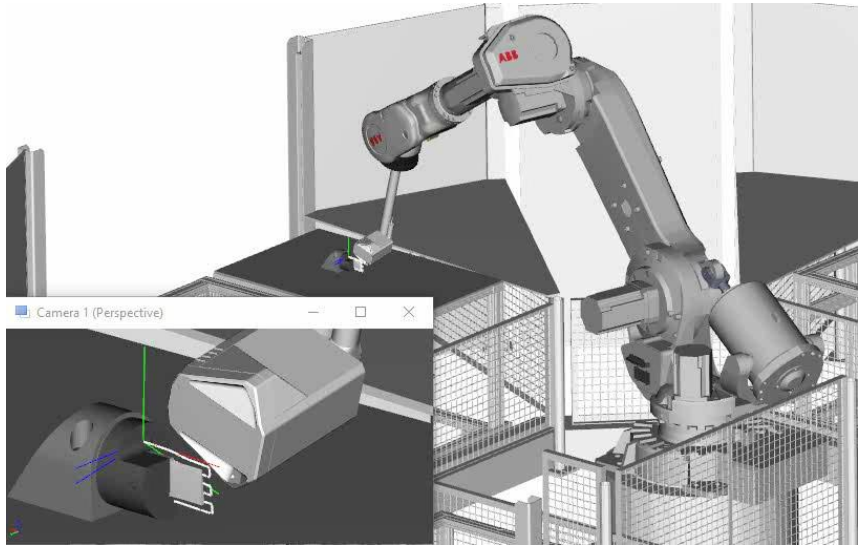
- Model sensor frustum
- Cover surface with feasible patches
- Constraints on angle to surface normal
- Consider geometric occlusion and robot kinematics

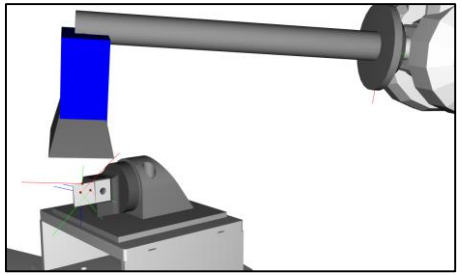




Robot path planning

- Task planning for inspection at discrete locations
- Curve following path planning along sensor paths
- Path planning and sequence optimization to generate collision free complete robot programs





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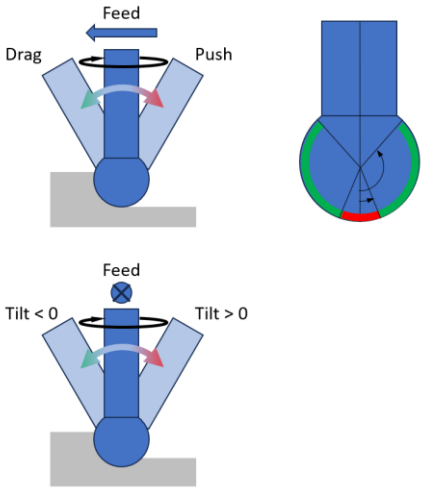
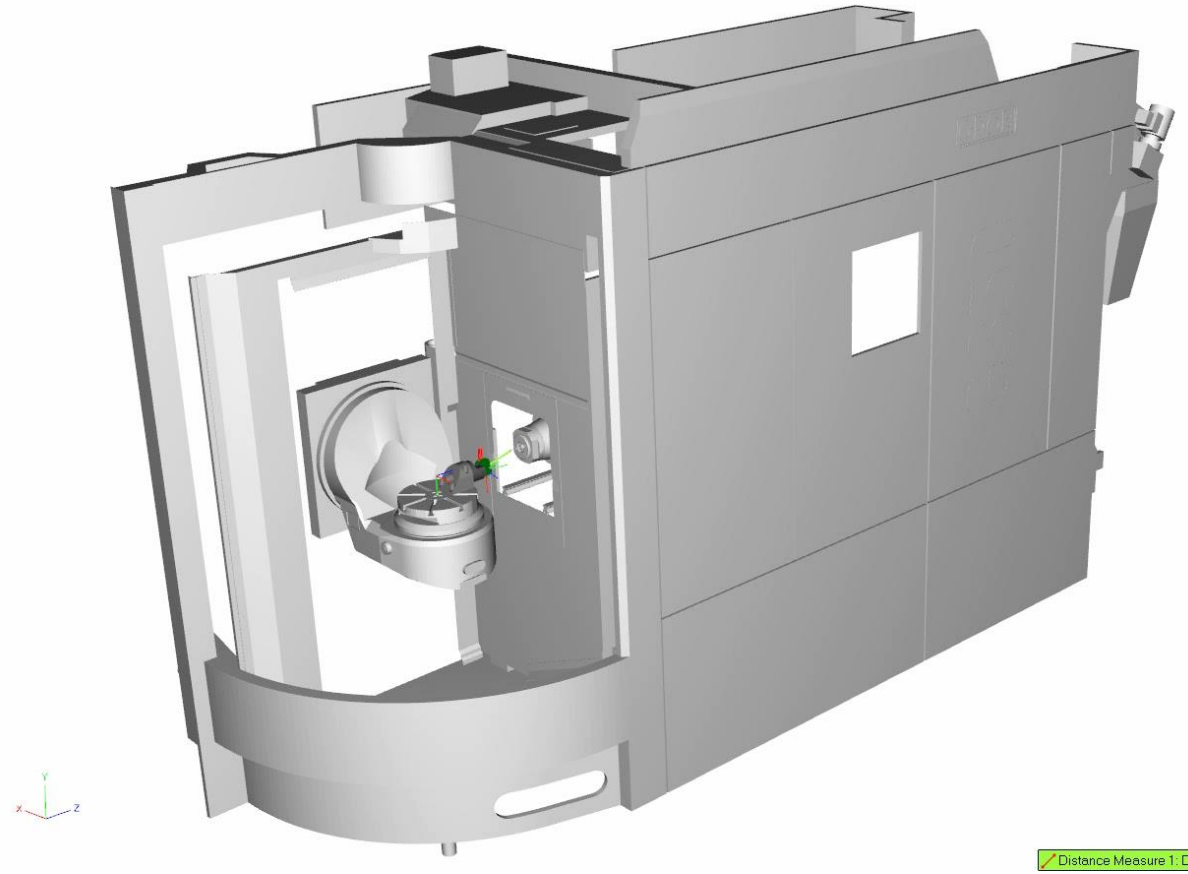
RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

Automatic path planning; CNC machine

Milling and probing

- Curve following path planning for milling and probing
- Basic process model for round cutter
  Presume given cut depth and width
- Lead versus lag preferences





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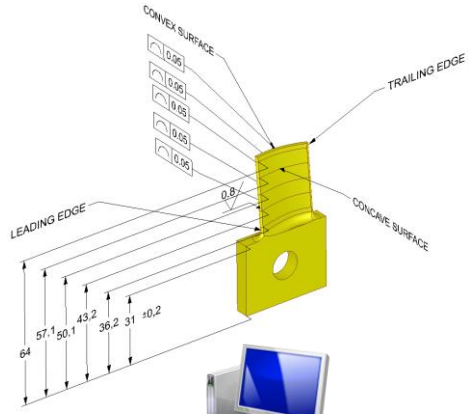
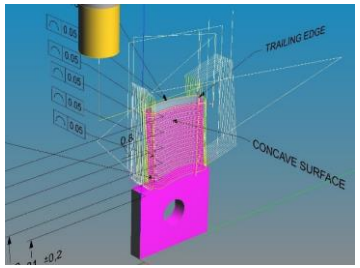
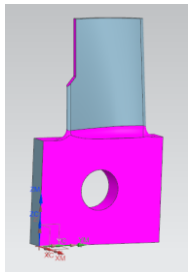
Collaborative process planning







CAD

(STEP AP242)

CAM

Work instructions

G-code

CNC

STEP AP238

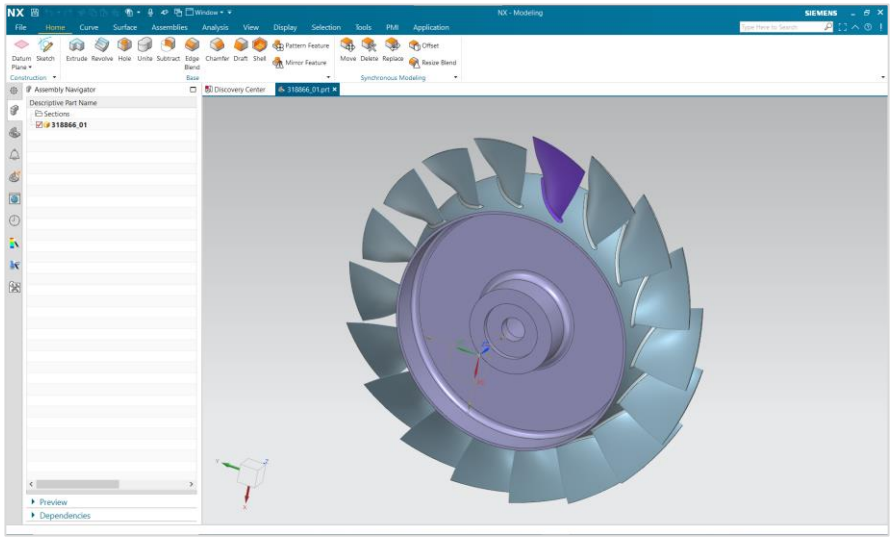
G-code

CAM

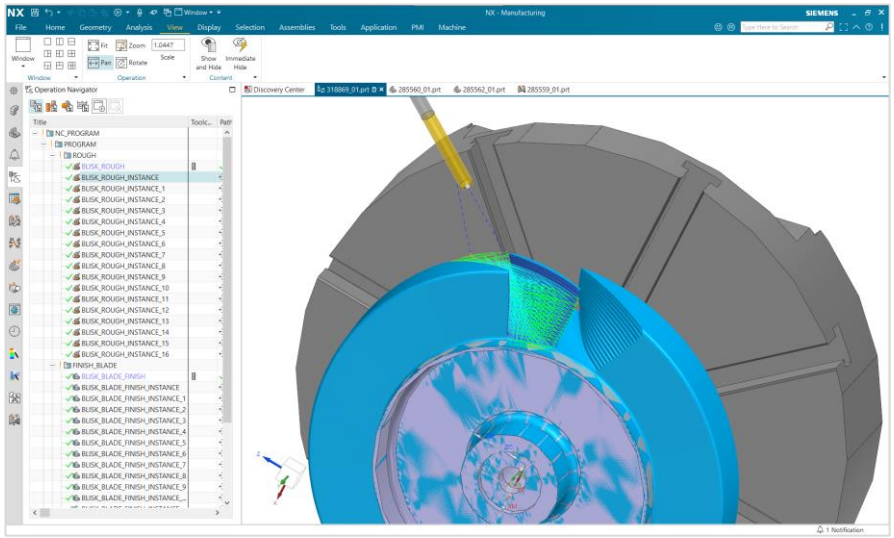
Collaborator's solutions

Operation sequence planning in receiving CAM
Feed information to work instructions
Reuse post processor (no late edits)
Tooling selection and definitions

SANDVIK coromant



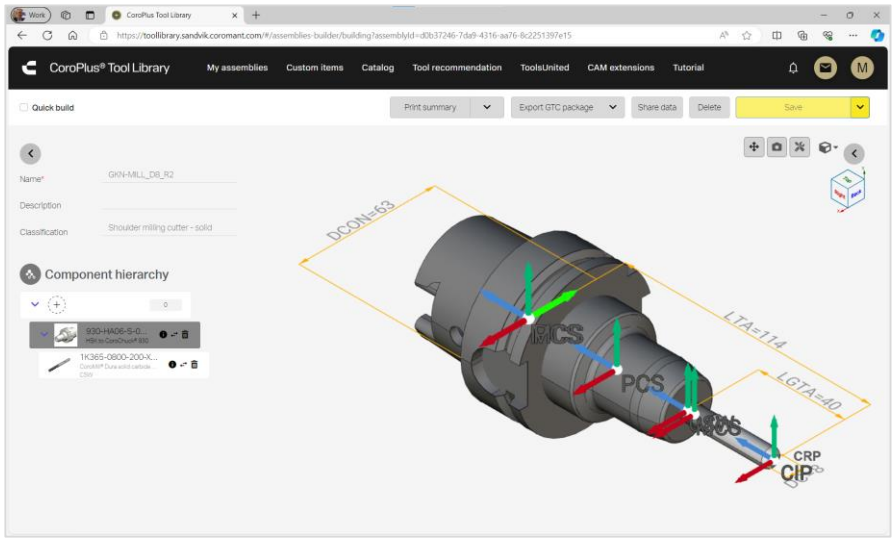
GKN Aerospace



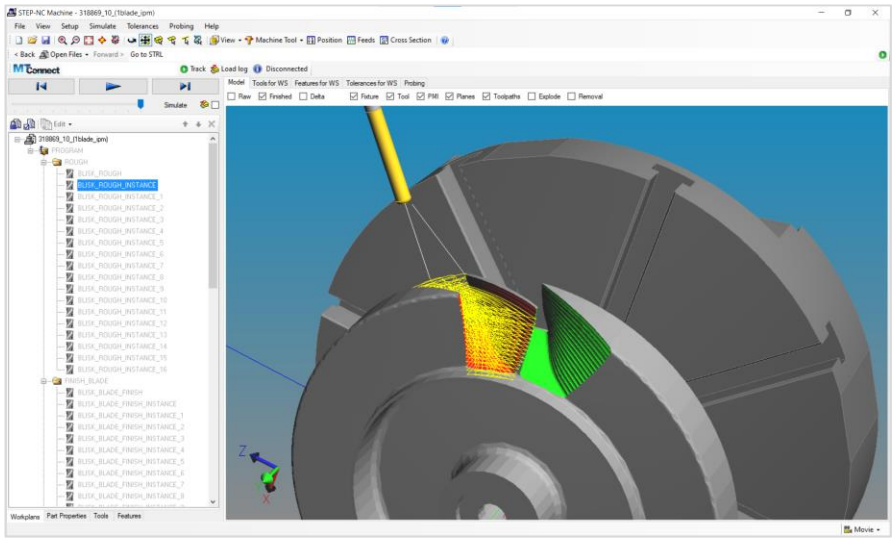
STEP AP242

Collaborative process planning

STEP-NC AP238



Sandvik Coromant



SANDVIK coromant

5) Current results & lessons learned

- Business Process Mapping identifying actors, interfaces and cross functional diagrams, etc
  - A very important part of the work to make sure everyone is aligned
  - This is not as easy as it first seem to be …
  - “The devil is in the details” – and there are quite a few
- The development of “tools” are progressing well
  - This is what everyone is used to do
  - Clear approach to test and validate
  - Its not obvious if softwares should be / can be bought or used as a service
- The integration of workflows – data exchange between users and tools under definition
  - Restrictions in export/import formats from current tools raises a lot of issues
  - Neutral formats and standards are available, but this does not automatically solves the problem
  - Many questions about data formats … e.g. is there a risk to lose quality of functionality ?
  - Can be expensive …
  - Not always obvious …

6) Summary & next steps

Summary:

- Preliminary design of a data driven value chain (based on the use case)
- Development of a set of new tools and work flows
- The project puts focus on questions and issues that are not usually addressed – cross functional

Next steps:

- Finalize the development of tools and validations
- Make a scenario for the data communication and evaluate (quality / cost / …)
- Evaluate data sharing and collaboration from a cyber security perspective
- Investigate more about data driven customer offers – which services/data and business value

Funded by Vinnova and the Advanced Digitalization program

Dig4ReMan

Digital tools & services for data driven remanufacturing value chains