RTM 4.0 – Quo Vadis?

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ADD-ITC, 25.11.2016

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Status of Today's RTM Processes

Time:

- Injection and curing cycle (aircraft: 4-6hrs / automotive: longer than TP pressforming)
- Parts modification complex with respect to molds
- Time consuming preforming
- Time consuming post processing (e.g. trimming, edge sealing)

Cost:

- High mold costs (invar injection tools, aluminum preforming tools)
- Parts modification costly

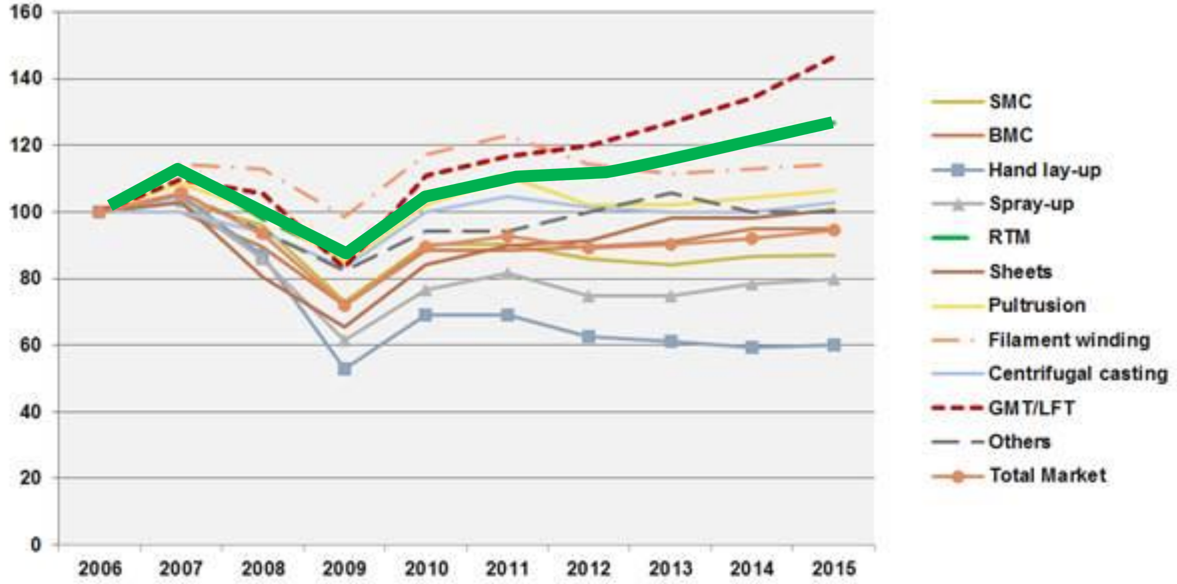
Quality:

- No reproducible preform quality due to manual draping
- Offline NDT (long-lasting backtracking of defects to process parameters)

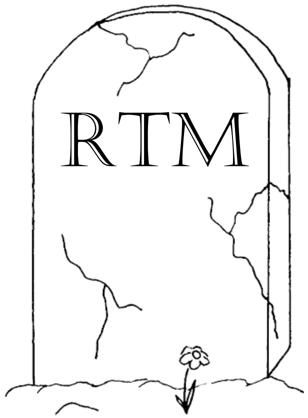
Process uncertainties:

- Process induced deformations (e.g. spring-in after curing)
- Incomplete cutting of filaments (ply cutting, fine trimming)
- Porosities after injection

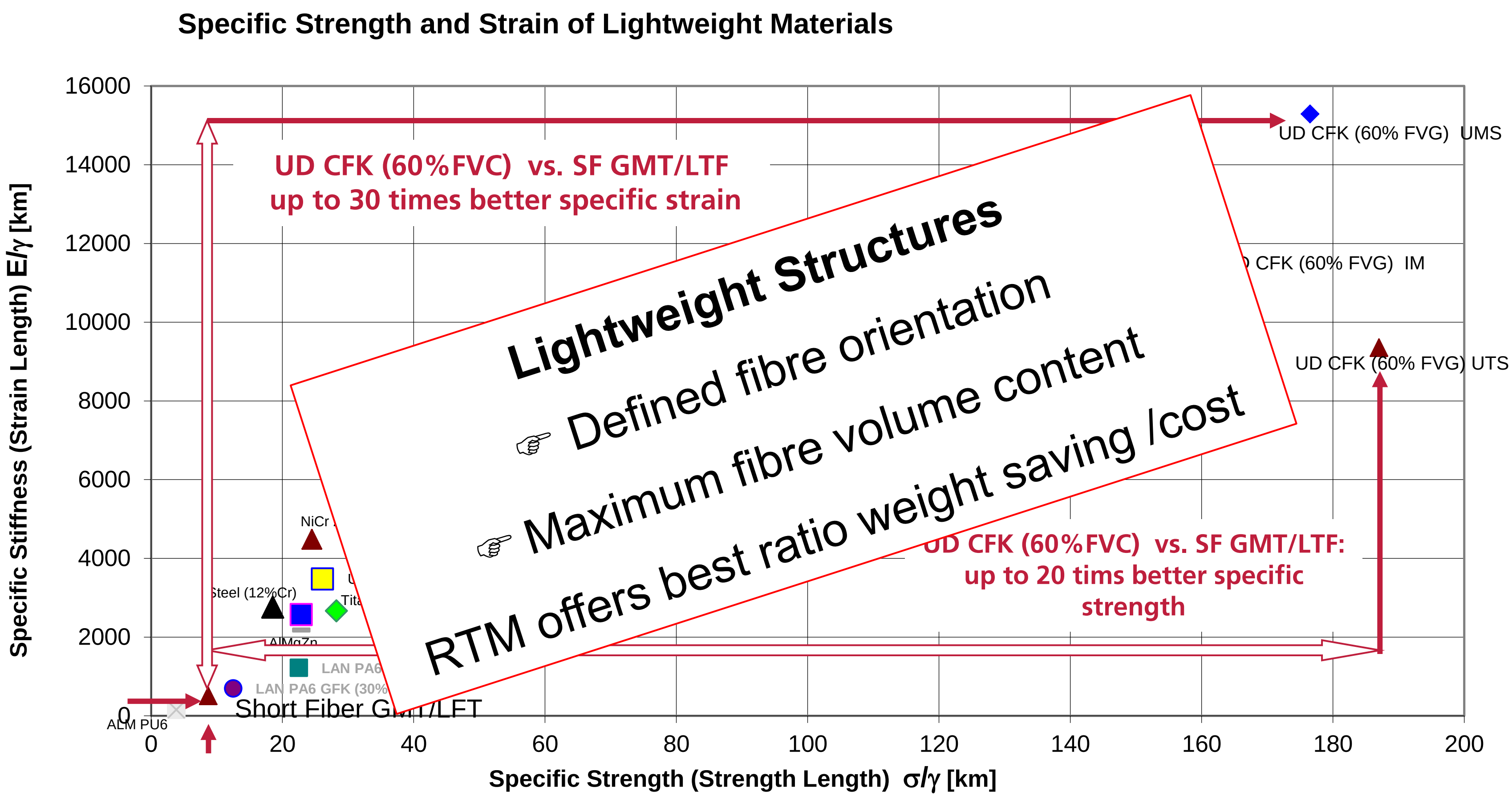
RTM technology today



Source: Composite Germany 2016



Why RTM in the future?



Further Potentials of RTM Processes - Examples

Time

- High production rates for small parts with high mechanical performance
- Faster binder activation
- Net shape preforming (no trimming, no edge sealing, no tool wearing etc.)

Cost

- Molds of cheaper material
- Modularity of molds (core/shell)
- Integration of parts and functions possible (inserts, electrical wires, SHM)

Quality

- Defined fiber volume content
- In-line quality assurance, deviation control and correction
- Avoid micro-fractures in final part due to net shape preforming

Process

- Production of hybrid parts, multi-material-systems, e.g. hybrid sandwich
- Full automation possible
- Part – process interaction and automatic process correction possible

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RTM – Transformation to next phase

RTM today

Achieved:

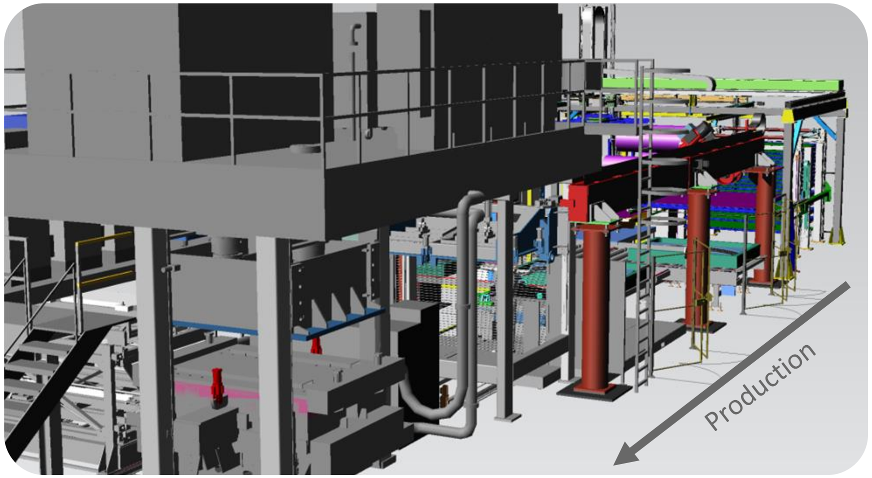
- Process chain demonstrated for parts with high production rates
- Automation of manual processes

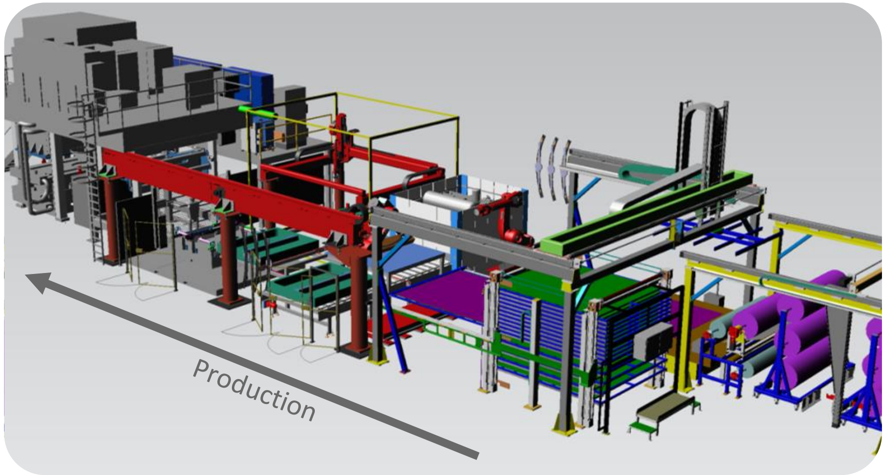
But:

- Quasi static processes
- No active draping control
- Slow (manual) layer fixation
- Human based quality assurance
- Post processing required, e.g. part trimming
- …

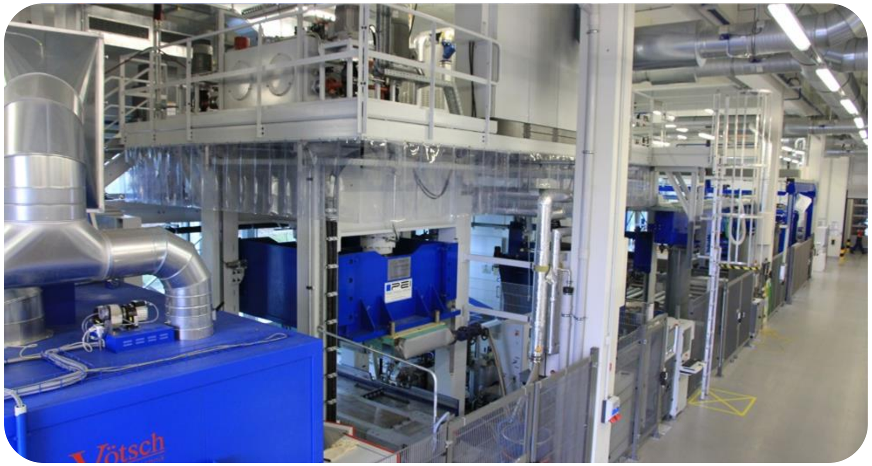
RTM 4.0?

DLR Automated modular RTM Process Chain





RTM-Area | *Preforming Area* | *Ply Preparation Area*



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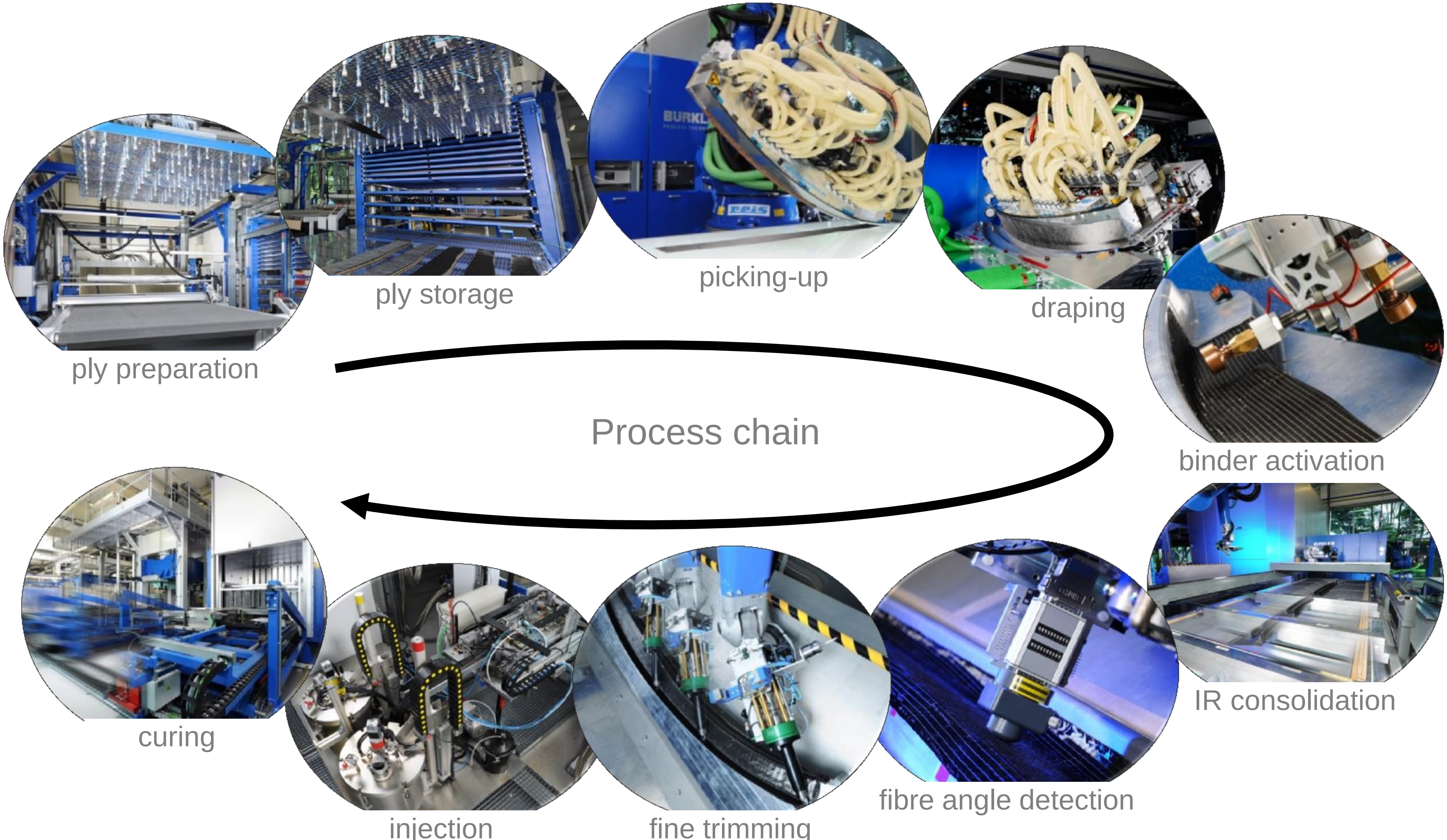

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Some DLR Solutions for RTM 4.0

Time

- Automated net shape preforming
- Efficient binder activation
- Isothermal injection and curing

Cost

- Multi purpose molds
- Modularity of molds (core/shell)
- Function Integration

Quality

- Inline QA
  - Eddy current and 3D contour scan
  - Curing sensors
- In-situ assessment of structural properties
- Compensation of process induced deformations

Process

- Adaptable production facility
- Process assessment
- Part-Process communication

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Preform-Trimming to Net-Shape

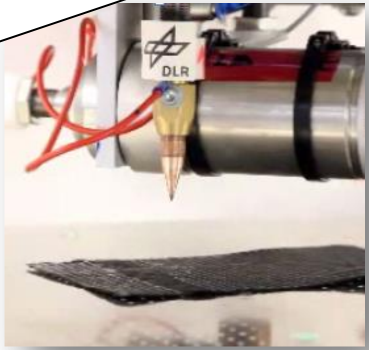
Net shape approach:
- preform shape ≙ part shape

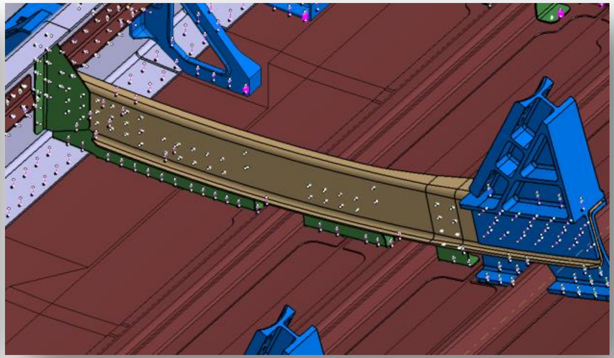
Why net-shape?
- Reducing post processes, e.g. edge sealing
- Higher RTM process stability due to defined edges
- No influence on resin by machining

Cutting of dry fibre preform
- by ultrasonic knife
- by laser (future)

Piercing of pilot holes

RTM 4.0: IMPROVEMENTS





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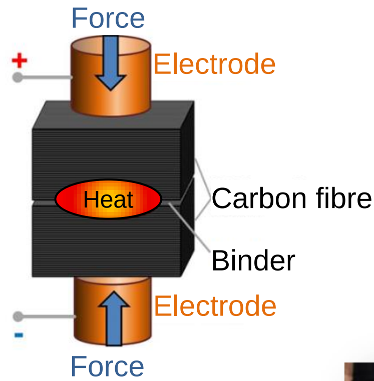
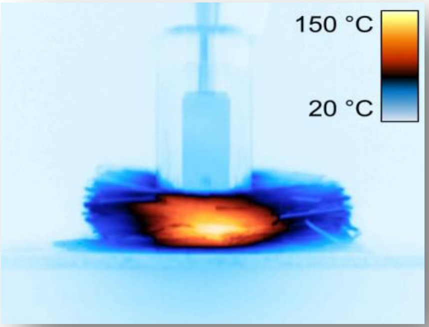
Efficient Binder Activation Systems

- Local activation of several plies
  - Electric resistance (Joule) principle
  - Required activation time: 0,3 sec

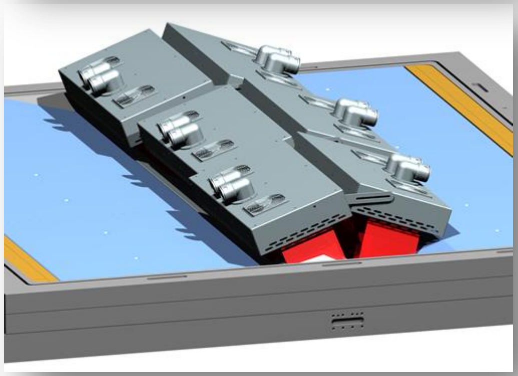




- Line activation of several plies
  - Electric resistance (Joule) principle
  - Activation time: 150 mm/sec

RTM 4.0: NEW FEATURES

- Plane activation of full stack
  - Diaphragma-membrane-press with infrared field
  - Time: 15 min (depending on mold material)



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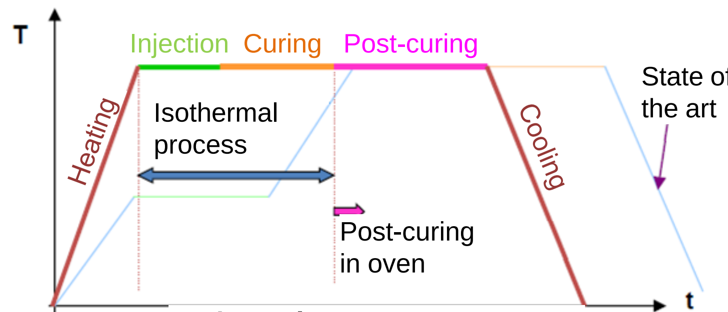
Isothermal Injection and Curing

- **Approach:** (reduction of process time)
  - Isothermal processing
  - Higher injection temperature and lower resin viscosity
  - Post-processed tempering

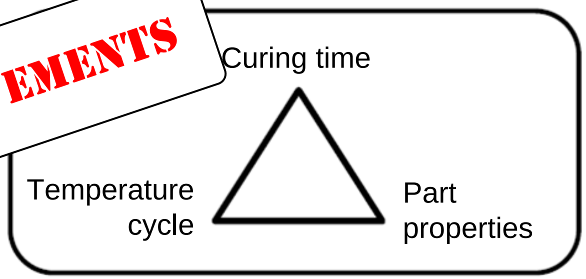
- **Procedure:**
  - Injection time determination (viscosity / gel point)
  - Demolding time determination (vitrification / curing degree)
  - Control of mechanical properties and process induced part deformation

- **Result:**
  - Description of relation between time, temperature and mechanical performance allows optimal injection and curing timing



Isothermal RTM process

RTM 4.0: IMPROVEMENTS



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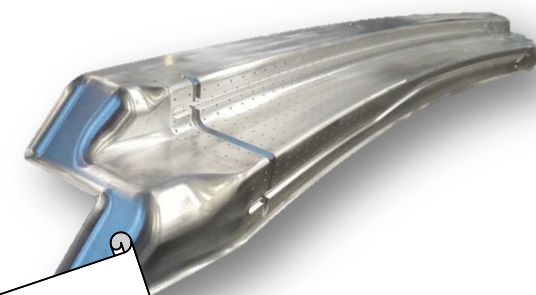
Reduced Cost of Molds

- Multi purpose preforming mold
  - Integrate process of draping, consolidation and fine trimming in one mold
    - ☞ One mold instead of three
  - Moveable mold
  - Cheaper mold material
- Design of modular mold system
  - Basic mold + specialized mold



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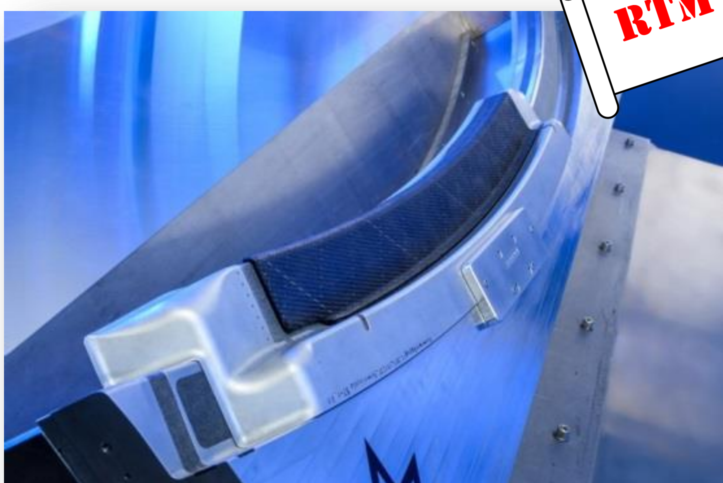

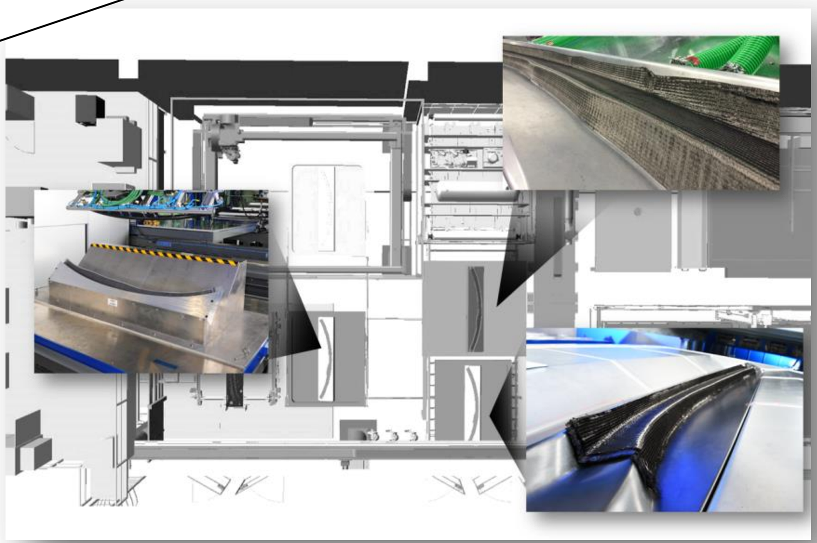

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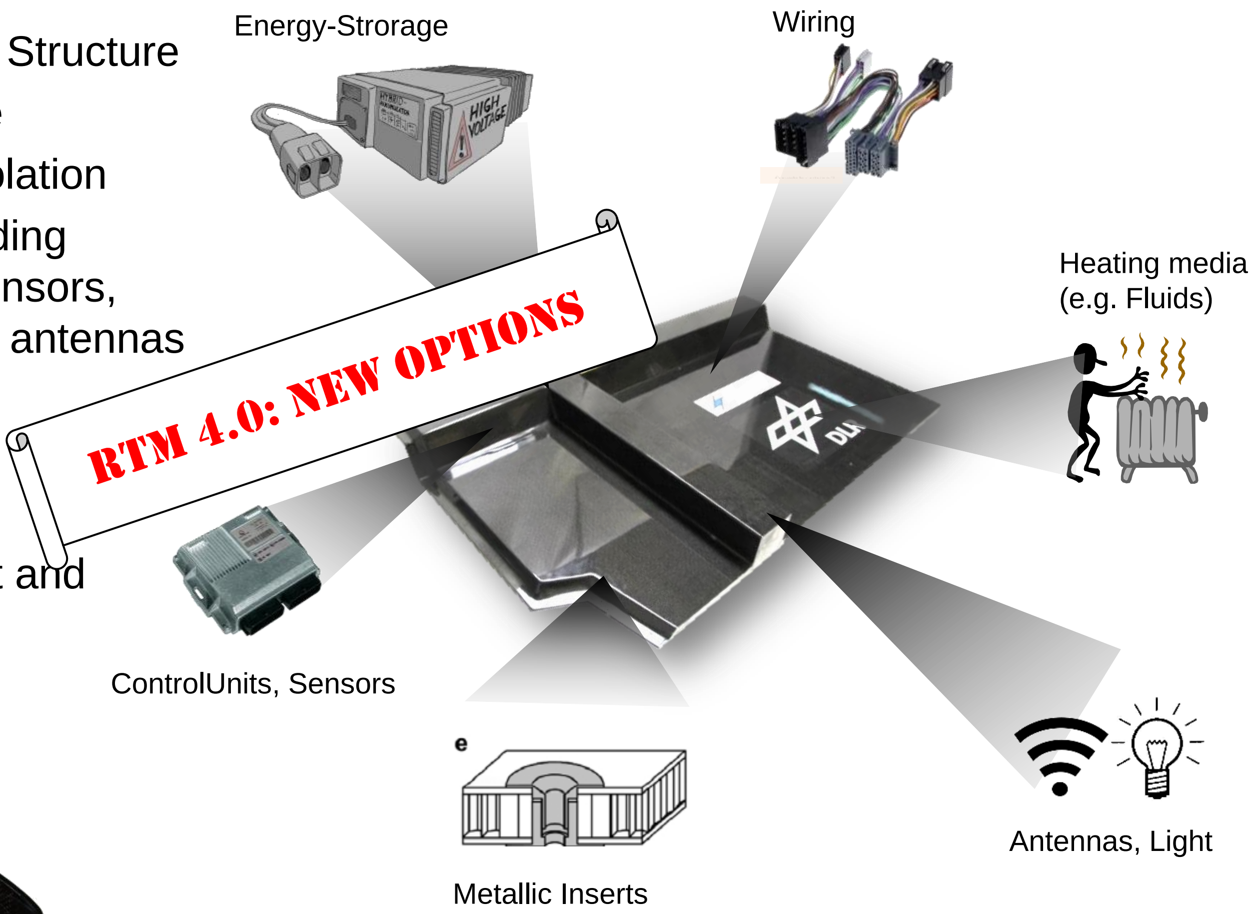
Function Integration

Example RTM Sandwich - Structure
- Multi use of core volume
- Acoustic and thermal isolation
- Integration of media guiding elements, e.g. wiring, sensors, local stiffeneres, inserts, antennas etc.

Example rearview mirror
- Integration of signal light and wiring in RTM part



[Source: A. Pototzky, DLR, FA]

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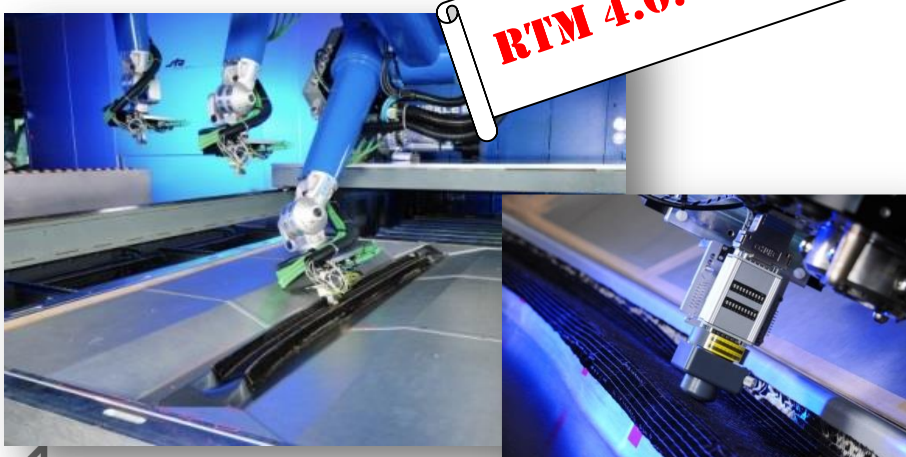
Inline Quality Assurance During Preforming

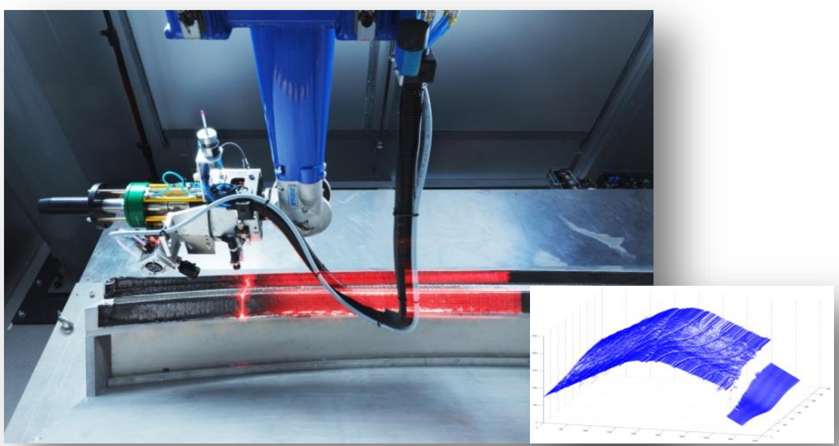
Approach:
- Reduction of NDT effort
- Process evaluation → online defect correction or part deletion

Method: Eddy current measurement
- Fibre angles of up to 6 layers simulantiously with 0,5° accuracy each
- Documentation of layup and patch positioning → digital LDS / correction?
- Detection of wrinkles, gaps, fuzzballs and ondulations on hidden layers

Method: 3D-contour scan
- Determination of geom… …er net shape fine trimming

RTM 4.0: IMPROVEMENTS





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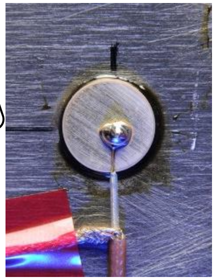
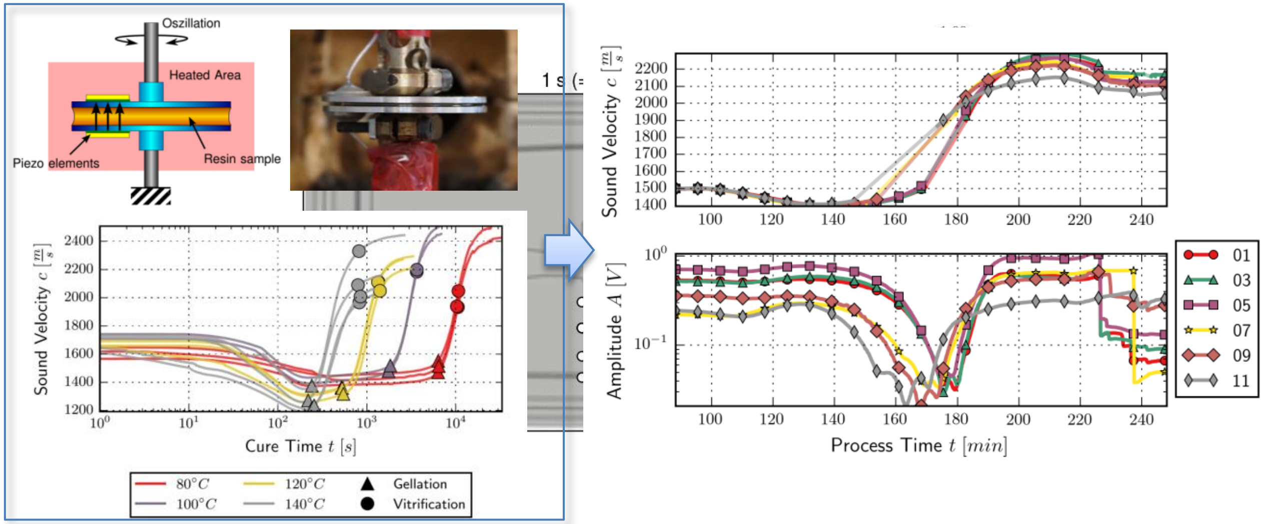
Inline Quality Assurance During Injection and Curing

Approach:
- No direct contact to part (mold integrated sensors)
- Easy mold integration (small sensors, cheap, reliable)

Method: Ultrasound PZT sensors
- Flow front monitoring
- Cure monitoring
  - Measure sound velocity for cure monitoring
  - Detect gelation and vitrification: Calibration by simultaneous measurement of ultrasound velocity in rheometer

RTM 4.0: PART-PROCESS COMMUNICATION





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In-Situ Assessment of Structural Properties

Goal:

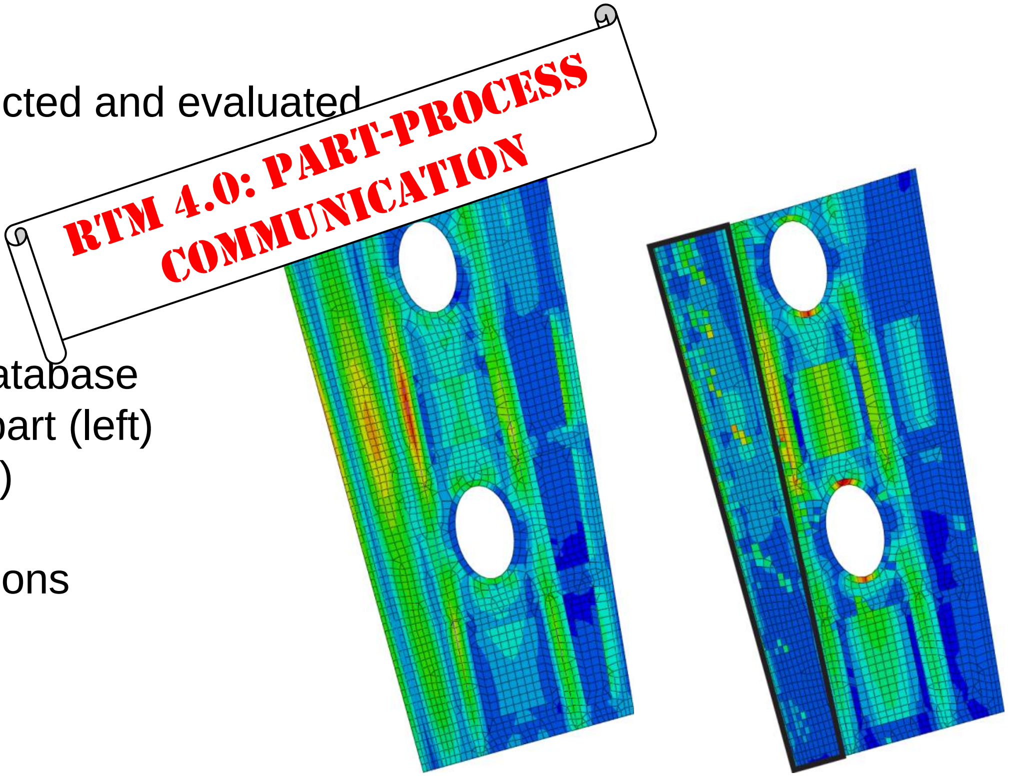
- Measurement → communication of geometric data to database → evaluation of structural properties→ process adjustment if necessary
- Avoid rework and waste at an early manufacturing stage

Approach:

- Structural properties can be predicted and evaluated

Procedure:

- Online monitoring of fibre angle, waviness, gaps and overlaps
- Deriving surrogate models and database
- In-Situ comparison of as-design part (left) properties and as-build part (right) properties containing manufacturing-induced imperfections
- Automatic correction if possible – depending on process step



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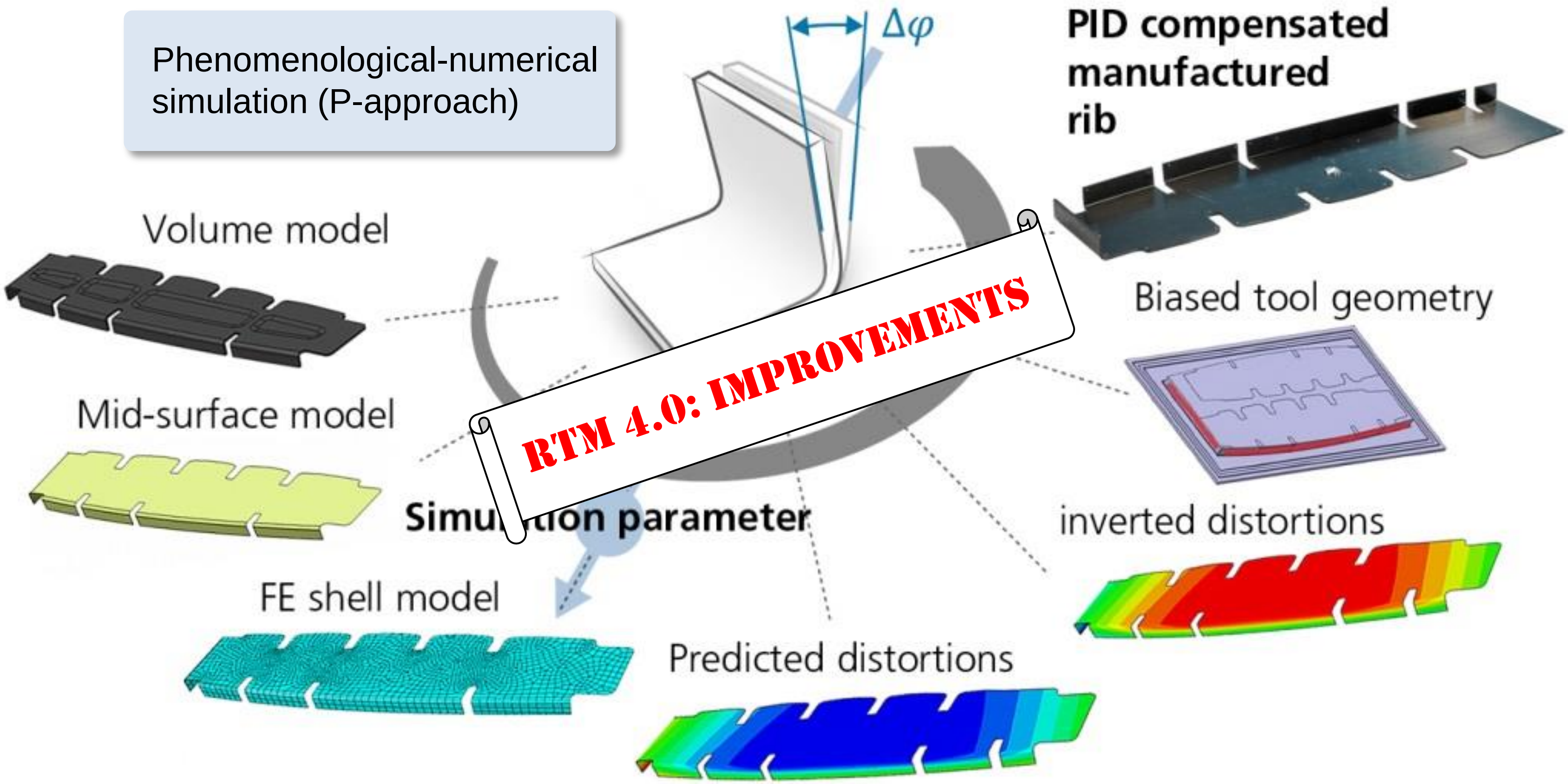
Process-Induced Deformations

Phenomenological-numerical simulation (P-approach)



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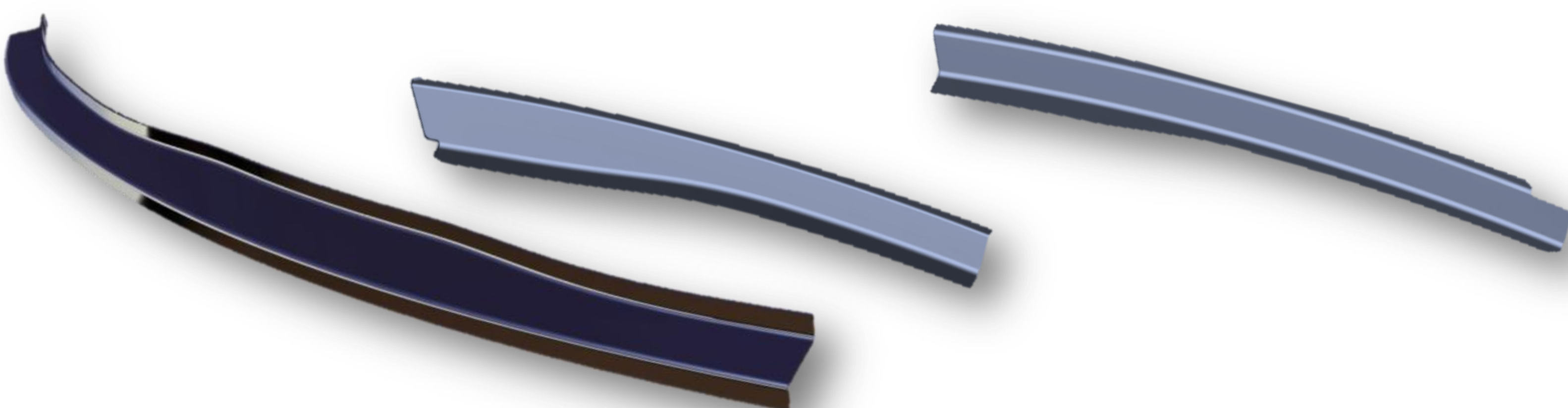
Adaptable Production Facility

Status quo:
- RTM less attractive due to low quantity of equal parts in aeronautics

Goal:
- Make RTM more individual (number of parts)

Challenge:
- Individual parts production within serial RTM process

Approach for RTM 4.0:
- Usage of adaptable end-effector for part family (similar part geometry)
- Reduced mold costs with multi purpose molds *(already mentioned)*



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Adaptable Endeffectors

Handling System

- Separate control of each vacuum gripper

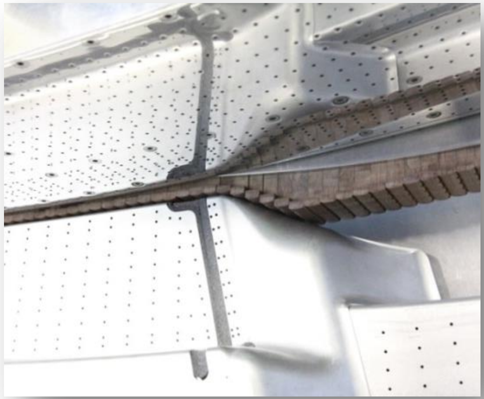
Draping endeffector

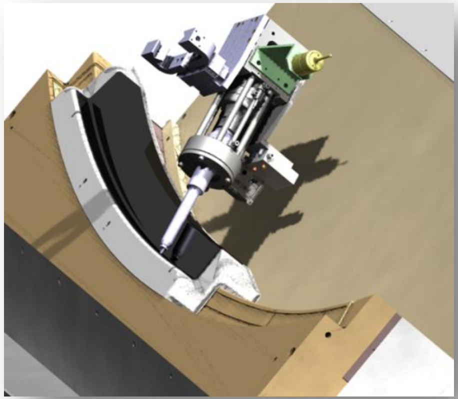
- Inner flange and web height are flexible
- Outer flange is fix
- Individual controlled suction areas

RTM 4.0: NEW OPTIONS

Robot endeffector with different functions

- Ultrasonic knife
- Gripper for additional units
- Position referencing system





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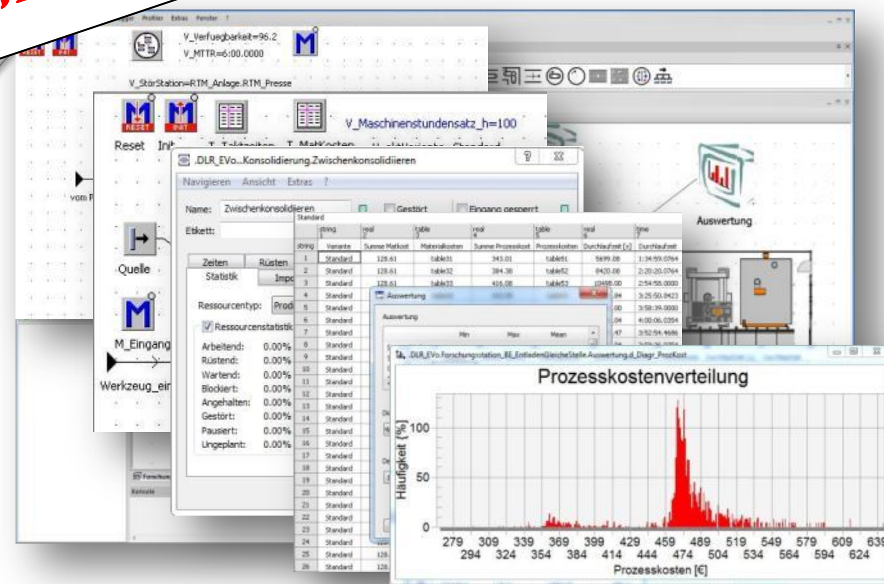
Process Assessment

RTM 4.0: NEW OPTIONS

Virtual plant

- Extension for any quantity
- Facilities and part flow optimization
- Process- and part cost and cyvle times



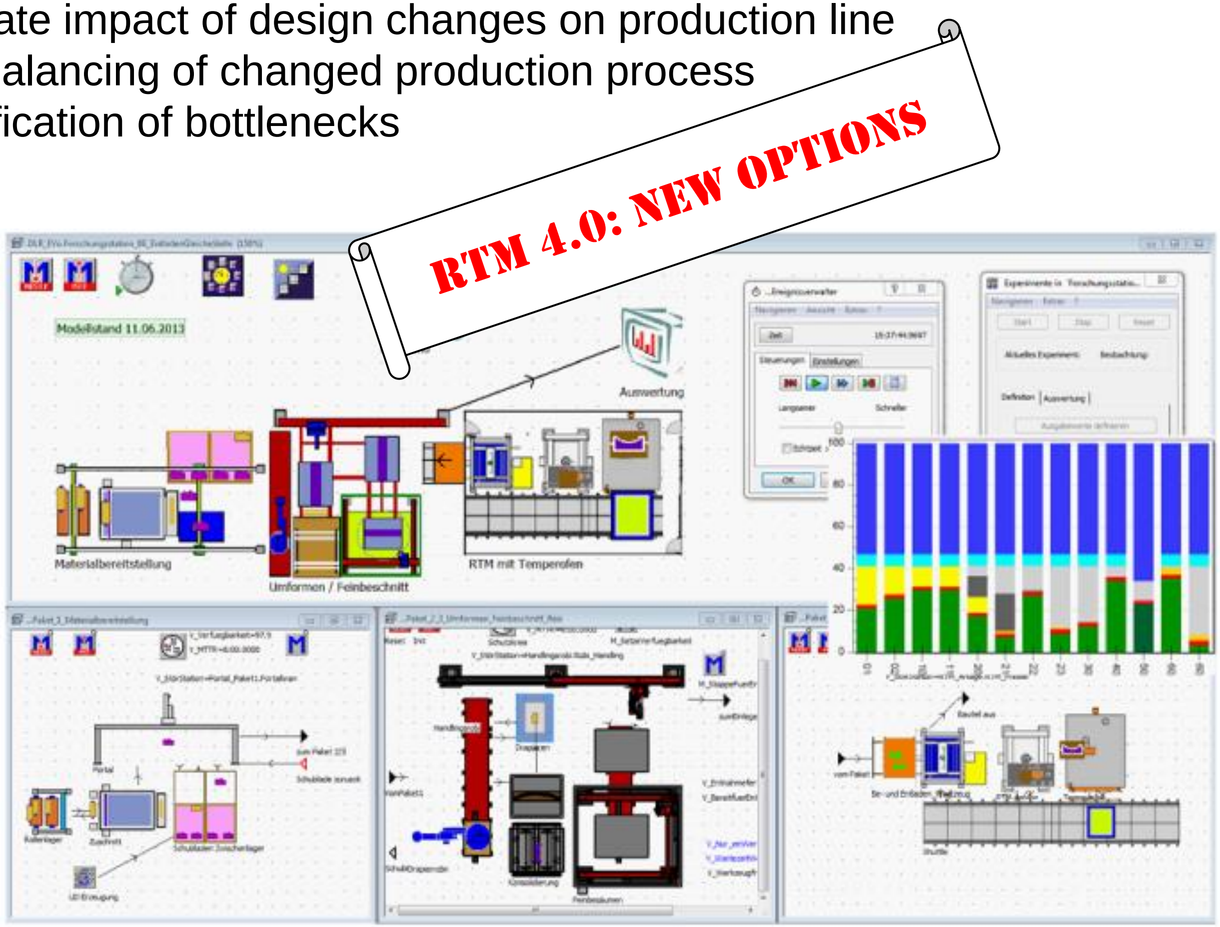
Real plant

- Technology demonstration
- Determination of cost
- Determination of cycle times

Productivity Forecast

Scenario analysis via process simulation:

- Evaluate impact of design changes on production line
- Line balancing of changed production process
- Identification of bottlenecks



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Part-Process Communication– an Outlook

Remote control of the facility via Internet

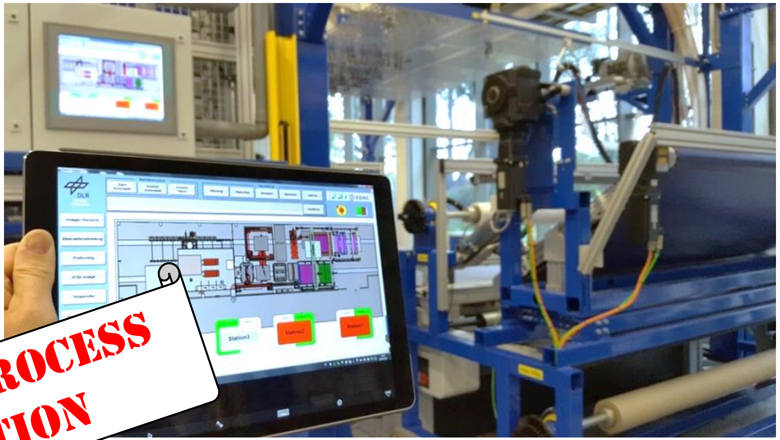
Communication between several facilities on different places

Inline digital life-data-sheet

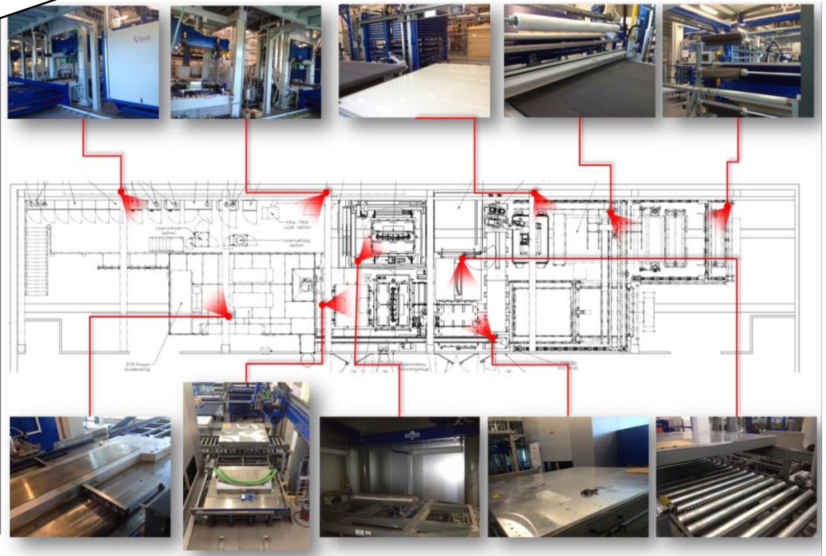
Automatic documentation per part

Continuous improvement

of process parameters due to growing database



RTM 4.0: PART-PROCESS COMMUNICATION



Conclusion

RTM 4.0

- ☞ Best process for lightweight structures at minimum cost
- ☞ Potential of function integration

Process – part interaction is improving in the direction of industry 4.0 by

- ☞ better sensors,
- ☞ more and more precise simulation and
- ☞ advanced automation capabilities.

Communication between part, process and environment enables

- ☞ process adjustment
- ☞ process optimization

Highly automated RTM process 4.0 is feasible and doffers

- ☞ Decreasing production rate and cost
- ☞ Higher process stability
- ☞ Increasing quality
- ☞ Increasing part flexibility

References

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