Enhancing the Model-Based Definition with Manufacturing Information through Linked Data for Design Exploration

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Project has not been officially awarded by DMDII. Contract under negotiation.
### MBD approach is currently one-way

- Communicate design intent to manufacturing
  - Manufacture in-house or procure from supplier
- Focus is on annotating 3D geometry with PMI
  - GD&T, surface finish, materials, etc.
- Design and Manufacturing still independent
  - Re-work is lengthy process and costly
- Design stage does not fully leverage manufacturing process information
- Design traceability is difficult

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**What problems are we addressing?**

- Communicate design intent to manufacturing
- Manufacture in-house or procure from supplier
- Focus is on annotating 3D geometry with PMI
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**3D CAD Model with PMI**

**STEP/JT accompanied by 2D drawing**

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Opportunity: Move Manufacturing Left via MBD

Extend MBD with mfg. process information

- Enable concurrent engineering
  - Consider manufacturing processes in earlier design stages
- Simultaneously consider functional characteristics, manufacturability, manufacturing costs
- In-house as well as supplier scenarios

![Diagram of Elimination of Waste through Front-Loading and Concurrent Engineering](image)

- 1. Ability to impact cost & functional capability
- 2. Cost of design change
- Time

3D CAD Model with PMI

STEP/JT accompanied by 2D drawing

Design → Manufacturing

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Project Concept

Methodology: Extend MBD with mfg. process info; Create a digital web of linked design/mfg. data, analysis tools, and DSE framework.
Extending the notion of digital thread to digital web

- Digital data and corresponding authoring and analysis tools form an interconnected network of resources and information

- Linked data: digital resources identified via URLs and linked via hyperlinks just like the WWW
  
  http://myCompany/myProduct/component1/cad.file

Advantages:
- Enables tool independence (think WWW): producers and consumers stick to data standards and communication protocols
- Integrate data and tools from multiple engineering disciplines
- Enables design traceability
Project Overview

List of technology to be advanced and integrated

- Design Space Exploration
- As-manufactured geometry creation
- Function performance analysis
- Manufacturability analysis
- Affordability analysis
- Tolerance analysis and synthesis
- Digital web development

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**Manufacturing process information**

- Identify relevant manufacturing process information such as techniques, tools, characteristics of as-manufactured geometry, costs, etc.
- Extend OpenMETA component model to include manufacturing process information
- Can be links in component model (remember: digital web)
### Design Space Exploration (DSE)

#### Exploration of Combined Design and Manufacturing Space

- Leverage DARPA AVM OpenMETA tools
- Extend component model and design space representation to include mfg. processes and parameters
- Include manufacturability constraints in design space exploration techniques
As-manufactured Shape Capture

**Generation of as-mfg. geometry using mfg. process info**

- Replace nominal surfaces with surfaces that contain manufacturing defects introduced by different manufacturing processes.

- Leverage method previously implemented using ACIS geometric modeling kernel with GIFT (Geometric modeling of imperfect forms for tolerancing).

- Extension for operating on geometry created in NX CAD system and automation of geometry conversion.

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Functional Performance Analysis

Analysis of as-designed and as-manufactured geometry

- Evaluation of functional performance on as-designed as well as as-manufactured geometry to analyze effects of manufacturing process errors
- Develop NX Open based software module for finite element analysis in NX CAE
- Extend GIFT tool to perform mating simulation between non-analytic surfaces

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Manufacturability Analysis

Checking designs for manufacturability

- Reduce manufacturing challenges and errors by avoiding designs that can cause manufacturing problems
- Leverage DFMPro for NX to evaluate manufacturability
- Checks for different manufacturing operations/processes
Affordability Analysis

Estimate Manufacturing Cost

- Leverage NX CAM
- Feature-based Machining approach to estimate manufacturing time and cost that also includes tolerance specifications
- Develop NX Open based software module to automate cost estimation

NX CAM FBM [7]
Tolerance Analysis and Synthesis

Stack-up analysis, clearance analysis, tolerance synthesis

- Leverage Teamcenter VSA, NX Assembly, GIFT

- Develop automated tools for tolerance stack up analysis and assembly clearance analysis

- Develop new tolerance synthesis tool that uses functional performance, manufacturability, and affordability modules

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Linked Data based digital web and tools

- Linked data interfaces to tools including NX, Teamcenter, OpenMETA DESERT, etc.
- Linked data management solution including RDF triple store, editor, search tool, visualization tool, data import/export, etc.
- “Google” for product design and manufacturing
Sample Use Cases

Validation of proposed framework prototype based on use case

<table>
<thead>
<tr>
<th>Unmanned Underwater Vehicle (UUV) Hull</th>
<th>High Power Active Sensor Air Cooled Structure</th>
<th>Conformal Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increasing need to develop low cost, light weight, durable, energy efficient UUV platforms for wide range of depths and temperatures&lt;br&gt;• Focus on design and manufacture of hull structures optimized for each mission and associated environmental requirements (e.g. depth, pressure, sea currents, etc.)</td>
<td>• Significant design challenge for high power applications to dissipate heat as quickly as possible&lt;br&gt;• Several design factors taken into account by cooling approaches (liquid or air)&lt;br&gt;• Goal to minimize weight of structures and provide geometries amenable to maximizing heat transfer characteristics</td>
<td>• Housing of current conformal antenna structures within a radome add weight and drag and may cause structural stress to the platform&lt;br&gt;• Patterns deposited directly onto, or embedded within composite fluid or aerodynamic surfaces by direct-write additive manufacturing technology as potential substitute</td>
</tr>
</tbody>
</table>
## Performance Improvement Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Present State (Baseline)</th>
<th>Future State (Project Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantification of the As-Designed to the As-Built (Time, Accuracy)</td>
<td>Part must be physically produced and compared against the original design.</td>
<td>Part is produced virtually according to manufacturing process and parameters. 5 times faster than manual, with improved accuracy than manual model construction.</td>
</tr>
<tr>
<td>Linked Data Linkability/Traceability (Qualitative)</td>
<td>Few proprietary formats can be linked using vendor-specific software, resulting in incomplete data integration.</td>
<td>Data can be linked regardless of their provenance with complete data integration resulting from open web standards for data.</td>
</tr>
<tr>
<td>DSE Point Designs for Manufacturability (Qualitative)</td>
<td>OpenMETA performs DSE on designs in as-designed spaces.</td>
<td>OpenMETA to perform DSE on as-manufactured spaces and on the joint design and manufacturing space.</td>
</tr>
</tbody>
</table>
| Productivity (% reduction in cycle time, out of phase rework, system requirement variance) | • Days to Weeks cycle times  
• Rework across multiple phases  
• Manual, based on inspection                                                                                                                                   | • Hours to days cycle times  
• In-phase rework based on model baselines  
• Semi-automated based on model analysis                                                                                                                             |
| Model-based Inspection (Number of design variants modeled)             | Manual process, limited by time and budget for labor                                                                                                         | Limited only by computing capacity                                                                                                                           |
| Product Customization (Number of spatial extents, number of material properties accommodated) | • Dozens of spatial extents  
• Small number of material properties                                                                                                                             | Limited only by computing capacity                                                                                                                           |
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References

[1] Pictures on Slide 2: Realizing innovation, NIST MBE Summit 2014 presentation


[3] Pictures on Slide 3, right: Realizing innovation, NIST MBE Summit 2014 presentation


[5] Picture on Slide 10: https://www.youtube.com/watch?v=2Dm01LX0bul


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