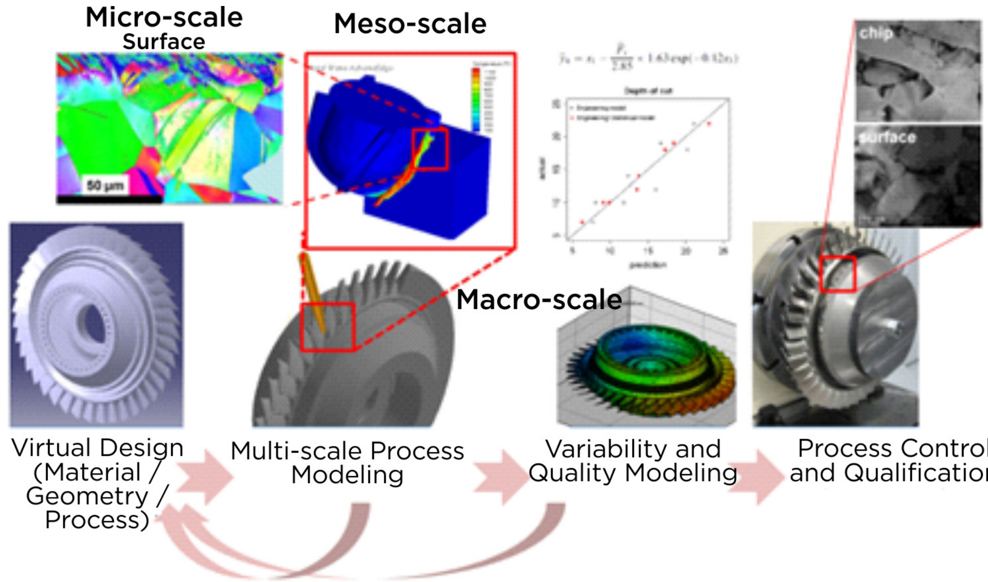
Sustainable Manufacturing via Multi-Scale, Physics-Based Process Modeling and Manufacturing-Informed Design

Improving Product and Manufacturing Process Design through a More Accurate and Widely Applicable Modeling Framework.



Multi-scale modeling tools for enabling manufacturing-informed design. *Graphic credit Third Wave Systems.*

This project aims to fill the knowledge gap between upstream design and downstream manufacturing processes by developing a manufacturing-informed design framework enabled by multi-scale, physics-based process models.

This framework will enable product and process designers to:

- Evaluate the effects of design changes and material selection on component performance, cost, and quality.
- Anticipate manufacturing quality and cost issues ahead of shop floor implementation.
- Select and tailor manufacturing processes to achieve low-waste, low-cost processes without compromising quality.

During process or product design, U.S. manufacturers understand the characteristics and capabilities of manufacturing processes but do not account for the dynamic responses and variability of tooling, materials, and equipment. The design community lacks accurate, easy-to-use, detailed physics-based process modeling tools to inform and guide the design process through a better understanding of machining processes. Consequently, products and machining processes are often over- or under-designed, and design teams must perform many process trials that are based on conservative estimates coupled with slow cycle times, frequent tool replacements, and liberal use of cutting fluid. This inefficient trial-and-error process produces significant waste streams at the unit cell and plant level and incurs unnecessary financial and energy losses.

Available at every stage of a product's lifecycle, the computational tools developed through this effort will help manufacturers accurately model machining processes, enabling improved productivity.

Benefits for Our Industry and Our Nation

The modeling advancements envisioned could potentially provide a 50% improvement in machining process productivity. This productivity increase would be achieved through the reduction of machining cycle times, waste streams, energy consumption, and carbon emissions while improving the energy efficiency of new product designs. Design engineers would use the modeling framework to develop lightweight, efficient products with optimal designs; and manufacturing engineers would be able to design optimal manufacturing processes that require less energy and raw materials while assuring quality, performance, and costs. Ultimately, the computational framework and related tools will promote sustainable manufacturing practices while preserving the economic and innovative edge of U.S. manufacturing.

Applications in Our Nation's Industry

While the design framework will initially focus on metal machining, its generic implementation will be applicable to a broad range of manufacturing processes. The expected fundamental advances in material and manufacturing science will present opportunities to improve casting, forging, stamping, extrusion, assembly, and additive manufacturing processes. The U.S. manufacturing supply base will benefit from improvements in productivity, quality, cost, and environmental impact – benefits most immediately realized by the aerospace, automotive, power generation, medical device, precision machining, and mining and heavy equipment manufacturing sectors.

Project Description

The project objective is to develop and demonstrate a new manufacturing-informed design framework that will utilize advanced multi-scale, physics-based process modeling to dramatically improve manufacturing productivity and quality while reducing the costs of machined components. A combination of advanced microstructural prediction models and physics-based modeling tools will enable the framework to more accurately predict machined component quality and engineering performance.

Barriers

- Integration of multi-scale models.
- Computational modeling at the micro- and multi-scale level.
- Accuracy of the new physics-based process modeling components.

Pathways

The design framework will be produced using an integrated approach that unites relevant aspects of material science, manufacturing science, and statistical theory. Metal machining will be used to demonstrate the framework and associated benefits. This project will deliver the following technical advancements:

- Development of advanced, first-principles-based microstructural modeling tools for metals that encounter severe plastic deformation.
- Enhancement of machining process models by incorporating university partner research results.
- Development of a multi-scale modeling framework.

Milestones

This project began in 2012.

- Demonstrate ability to predict trends in material characteristics in machined parts based on qualitative agreement of trends for extreme machining conditions (Completed).
- Establish capability to predict grain size and dislocation density based on first principles, as well as statistical models that incorporate variability into predictions of surface roughness and residual stresses (Completed).
- Demonstrate capability for advanced process optimization using algorithms that include control of workpiece surface characteristics (2015).
- Demonstrate integrated framework for predicting and designing workpiece surface characteristics and component performance (2015).

Commercialization

During the project, input from manufacturing stakeholders will be incorporated to enhance commercialization. Third Wave Systems, Inc. intends to embed computational process modeling and optimization tools developed within its commercially available software to enable immediate adoption by U.S. manufacturers. Beta launch customers will be closely involved in commercialization activities and will provide testing, technical guidance, and feedback during the entire project. The modeling architecture uses process modeling software, which will enable rapid insertion into manufacturers' computer-aided design/computer-aided manufacturing environments.

Project Partners

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