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

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THIRD WAVE SYSTEMS

Georgia Tech

PURDUE UNIVERSITY

UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA

PENNSTATE 1855

U.S. DOE Advanced Manufacturing Office Peer Review Meeting
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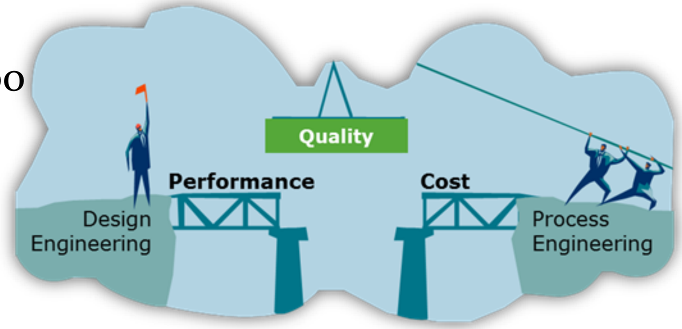
Project Objective

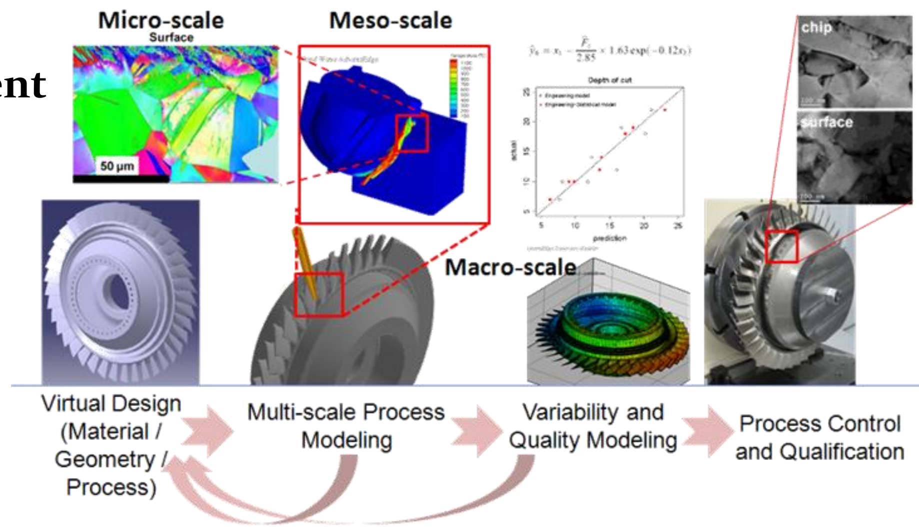
- What are you trying to do?
  - Develop and demonstrate a new **manufacturing-informed design paradigm** to dramatically improve manufacturing productivity, quality, and costs of machined components
- What is the problem?
  - Current machining processes and cutting tool designs are slow and too conservative, leading to high costs and significant waste
  - Currently, design teams are "*manufacturing-aware*," not necessarily "*manufacturing-informed*"
  - Performance, Cost and Quality problems are found too late in the Product Development Process



- Why is it Difficult?
  - Lack of sufficient fundamental understanding of process physics
  - Lack of physics-based process design and optimization tools for finish and semi-finish operations
  - High computational costs of modeling at multiple length and time scales for process optimization
  - Statistical variability of tooling, equipment, and materials

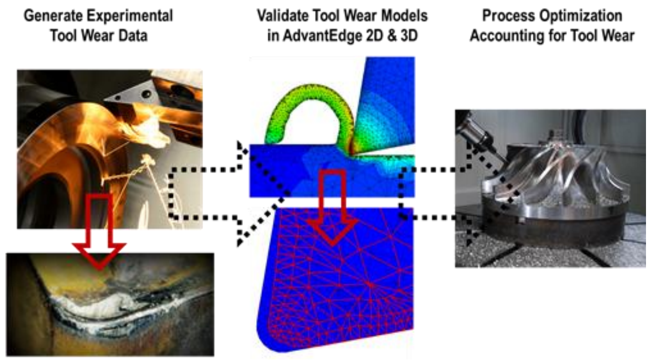
Technical Approach

- **State-of-the-art**
  - "*Manufacturing aware*" part and process design – No knowledge of process outcomes (cost, quality, performance) until manufacturing trials
  - Long and slow trial-and-error design of machining processes and cutting tools
  - Resulting manufacturing processes and cutting tool designs are conservative – unnecessarily slow, sub-optimal and expensive
- **Innovation**
  - **Multi-scale Physics-based Modeling** can provide detailed knowledge of process outcomes before manufacturing trials
  - **Physics-based Optimization** can squeeze significant productivity from state-of-the-art machining processes
  - **Reduce** (rough and finish) **machining costs and cycle times**, while **extending tool life** and maintaining **component performance**



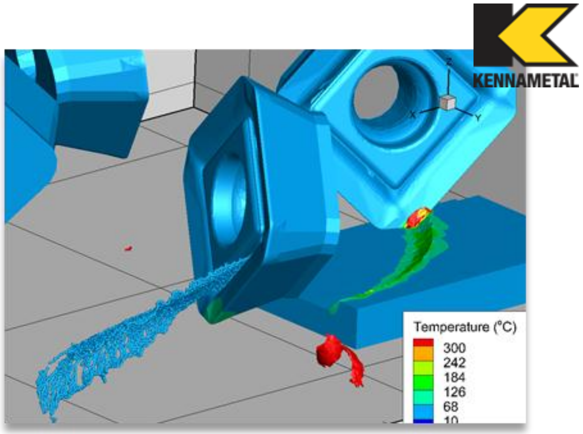
Technical Approach

- Third Wave Systems is a market leader in physics-based process modeling of machining and achieved a top SBIR Commercialization Score
- Customers include all major component and tooling manufacturers and meet quarterly with customers to review our progress, partner and get feedback
- Partnering with premier universities focused on experimental and computational methods in machining and materials science
- Utilize or develop advanced tools and techniques to achieve goals
  - **Experimental measurement** - SEM for microstructure, new cost-effective tool wear measurement techniques, etc.
  - **Computational techniques** - SPH for coolant jet modeling, parallel FEM, massively parallel programming, etc.
  - **Verification** and **validation** of every new model and process

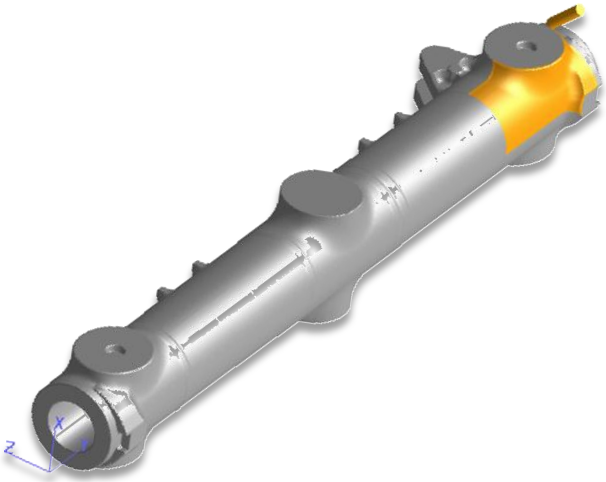


Transition and Deployment

- Technology will be incorporated into existing commercial products
- Cutting Tool Manufacturers Care
  - **Who**: Kennametal, Ceratizit, Ingersoll, Sandvik, Allied Tools
  - **Why**: Improve cutting tool designs - specifically coolant delivery and tool life–related improvements, faster tool design iterations
- Aerospace, Auto, Medical, O&G Mfgrs Care
  - Jet Engine: GE, Pratt & Whitney
  - Airframe: Boeing, GKN Aerospace, NexTech
  - Auto: GM, Ford
- **Why**: Higher tool life, reduced cycle times, reduced costs, reduced energy consumption, effective coolant usage, improved final microstructure properties and performance, accelerated insertion of new materials



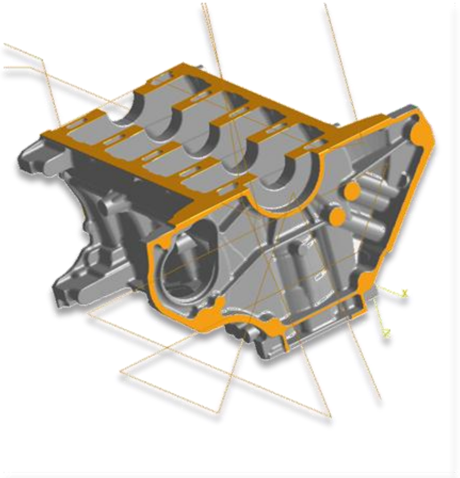
Cutting Tool Manufacturers



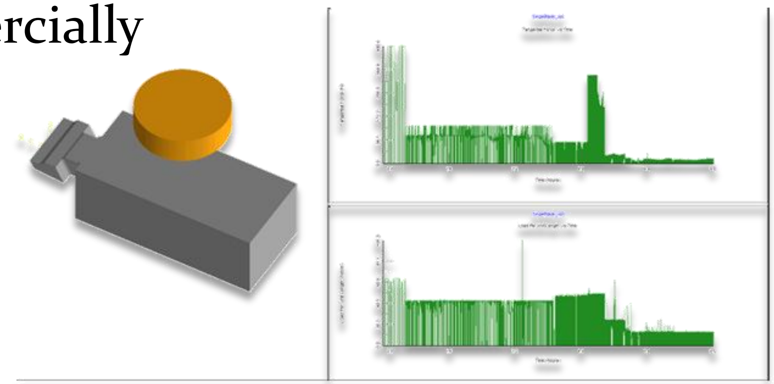
Aerospace Component

Transition and Deployment

- Heavy Equipment (Caterpillar)
- Medical Implants (e.g. DePuy Synthes)
- Oil & Gas and Power Systems (GE)
- Technology Sustainment Strategy
  - Partner with early adopters and market leaders to interface and integrate into their systems and validate the business case
  - Incorporation of technology into commercially available software and services



Automotive



Power Systems

TWS Customers

BOEING, GKN, Pratt & Whitney, Kennametal, Goodrich, Ladish Co., Inc., GM, Hamilton Sundstrand (A United Technologies Company), Nex-Tech Aerospace, GE Aviation, Cessna (A Textron Company), Spirit AeroSystems, MAG, Sandvik Coromant, Ford, Rolls Royce, Bell Helicopter (A Textron Company)

Measure of Success

- **Impact and Metrics**
  - **Metrics**: Correlation (error %) with experimental data for Forces, Torque, & Microstructure
  - **Metrics**: Achievement of 50% reduction in machining cycle time on representative components
- **Energy and Economic Impact**
  - Achieve **50 percent reduction in machine tool *tare* energy and water consumption** in machining via reduced cycle times, coolant and tooling consumption.
  - Achieve a **50 percent reduction in cycle times and energy consumption** for machining.
  - Save over **4.1 trillion BTUs per year** and **7.2 million metric tons of CO_2-equivalent per year** for machining processes.
  - Estimated savings of **$1.14 billion in tooling** costs, reduction of **$24 billion in cutting fluid** costs

Project Management & Budget

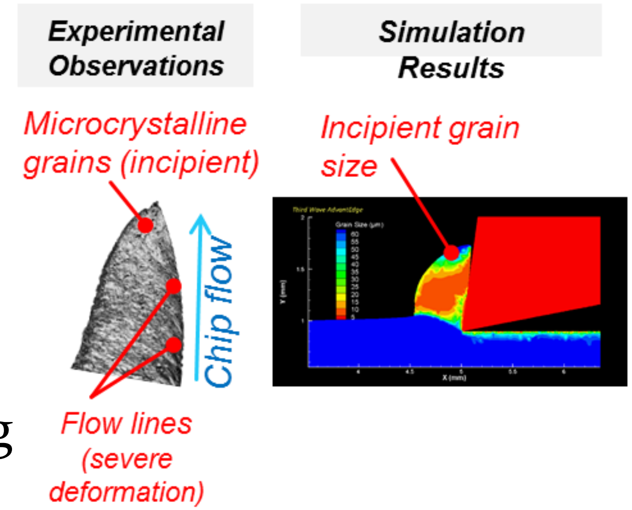
- Project Duration : 36 months
- Project task and key milestone schedule
  - Project Plan has Qualitative and Quantitative Milestones
  - Comparison against experiments (validation metrics)

Number	Go/No-go Description	Verification Method	Planned Completion Date
1	Coolant model implementation	Simulate 27 turning cases, achieve 90% completion success rate	End of Budget Year 1
2	Tool wear model prediction	Simulate 18 conditions, achieve 90% success rate of completion	End of Budget Year 2
3	Cutting force prediction	Predicted and measured forces within 30% agreement	End of Budget Year 2

Total Project Budget	
DOE Investment	$4,069,880
Cost Share	$964,719
Project Total	$5,034,599

Results and Accomplishments

- Advanced machining microstructure modeling
  - Force prediction within 15% of measurement
  - Integrated microstructure evolution models
- Tool Wear Model Development
  - Validated wear models, methodology
- Creating scale with high performance computing on multi-core, distributed memory systems



Good qualitative correlation between simulation and experiments for incipient grain size.