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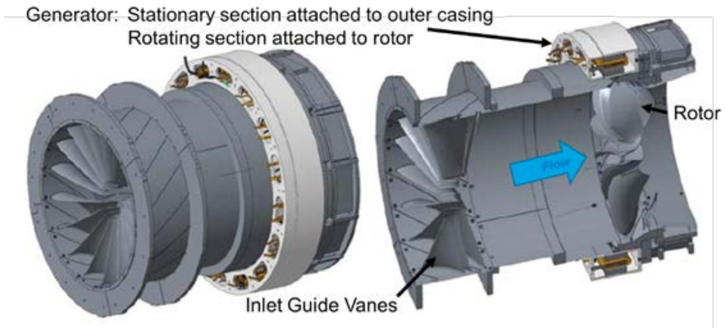

Rapidly Deployable Advanced Integrated Low Head Hydropower Turbine Prototype

EE0006928

Hydropower Program

October 8, 2019

Principal Investigator:
Dr. Arnold Fontaine
Organization:
Pennsylvania State University

Project Overview

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Project Summary

- Develop and test a rapidly deployable advanced modular hydropower turbine-generator design targeting low LCOE.
- Fabricated and tested a 0.2m prototype model in ARL's 0.305m diameter water tunnel facility under variable flow conditions.
- Developed and tested additive manufacturing capability
- Performed a cost-assessment feasibility study for advanced manufacturing including 0.9 m diameter scale IGV and rotor blade builds.

Project Objective & Impact

- The primary objective of this project is to develop and demonstrate a rapidly deployable, modular advanced integrated hydropower turbine-generator system with the potential to lower Levelized Cost of Energy (LCOE) through:
- Design for advanced manufacturing
- Scalability of design for wide range of site conditions
- Modularity to simplify installation as well as reduce costs and environmental impact
- Incorporation of CBM system to impact OpEx costs

Project Information

Project Principal Investigator(s)

PI: Dr. Arnold Fontaine
Co-PI: Jeffery Banks
Co-PI: Wesley Mitchell
Dr. Nicholas Jaffa

WPTO Lead

Rajesh Dham
Michael Carella
Erik Mauer

Project Partners/Subs

General Atomics

Project Duration

- Project Start Date: July 1, 2015
- Project End Date: June 30, 2019

Alignment with the Program

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Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Environmental R&D and Hydrologic Systems Science

- Develop better monitoring technologies to evaluate environmental impacts
- Develop technologies and strategies that avoid, minimize, or mitigate ecological impacts
- Support development of metrics for better evaluating environmental sustainability for new hydropower developments
- Assess potential impacts of long-term hydrologic variations to hydropower generation and flexibility
- Improve abilities to assess potential methane emissions from reservoirs
- Better identify opportunities and weigh potential trade-offs across multiple objectives at basin-scales

Reduced Environmental Impact Through:

- Modular in-line axial flow design allows for deployment with minimal flow passage civil works.
- Hub-less design features an open centerline designed to be self cleaning.

Self cleaning feature verified during water tunnel test

Alignment with the Hydro Program

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Technology R&D for Low-Impact Hydropower Growth

- Enable the design and development of new Standard Modular Hydropower (SMH) technologies for both existing water infrastructure and new stream-reach development. This new approach to systems design for hydropower projects incorporates ecological and social objectives for river systems earlier in design processes
- Leverage new advancements in manufacturing and materials to dramatically lower costs of SMH components and systems designs
- Support development of necessary testing infrastructure for new technologies

Reduce LCOE through:

- Modular design with scalable components for reduced initial capital costs
- Turbine designed for wide range of operating conditions for maximizing power generation
- Condition based maintenance (CBM) for reduced operations costs
- Designed for reduced O&M costs
- Design for advanced manufacturing (AM) to reduce initial capital costs
    - Blades designed and tested for metal AM processes
    - Inflow and outflow components identified as likely for potential cost reduction using AM

Alignment with the Hydro Program

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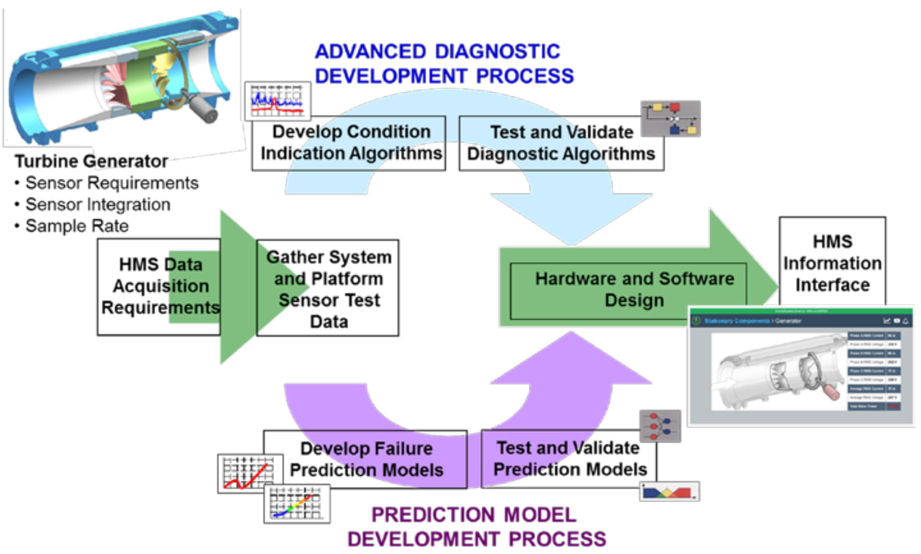
R&D to Support Modernization, Upgrades, and Security for Existing Hydropower Fleet

- Create mechanisms to classify diverse hydropower plants by mechanical and cyber-physical systems, providing better characterization of the fleet and allowing identification of exemplary facilities / practices
- Advanced instrumentation and data evaluation to improve equipment longevity and condition based repair
- Creation of cybersecurity tools and studies which help enhance the security of critical dam infrastructure by articulating the cybersecurity target, risk and recovery landscape
- Develop cross-cutting digitalization systems and advanced sensor suites to empower data driven decisions on O&M and asset management

Condition Based Maintenance (CBM) Designed and Tested:

- CBM system integrated into turbine water tunnel test over range of operating conditions and with simulated faults
- Implemented with advanced instrumentation and data analysis



Project Budget

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Total Project Budget – Award Information		
DOE	Cost-share	Total
2,200	550	2,750

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
DOE $781.933 Cost Share $253.3	DOE $501.223 Cost Share $0	DOE $282.7 Cost Share $0	DOE $1,565.856 Cost Share $253.3

- **Project scope realignment:**
  - **Model scale testing performed at 0.305m diameter scale vs proposed 0.9m scale due to cost overruns associated with large scale AM construction**

Management and Technical Approach

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- **Management Approach**
  - PI led the program and coordinated with task leads – bi-weekly and monthly update meetings
  - Four graduate students assisted with project activities on related research topics
  - Monthly progress update calls with DOE
  - Go/No-Go decision meeting (M12) webinar with DOE
  - Presentations at program reviews and hydro conferences
- **Technical Approach**
  - Task 1: Turbine hydrodynamic design
  - Task 2: Additive manufacturing feasibility study
  - Task 3: Rim-drive generator design
  - Task 4: CBM implementation
  - Task 5: Hybrid multi-material concept study
  - Task 6: Validation testing of turbine and CBM systems

End-User Engagement and Dissemination Strategy

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- **Interacted with Voith Hydro relative to possible field test installation**
  - Voith Hydro personnel visited PSU to see water tunnel test
  - Discussions underway relative to possible licensing and future teaming relative to possible field installation
  - Exploring incorporation of commercially available Voith Marine rim-drive motor/generator into modular design
- **Presented at NHA Hydro Week 2018 and 2019**
- **Presented at PSU Energy Days 2019**
- **Presented at NHA Speaker Series September 2019**
- **Planning on writing journal papers with results from water tunnel test**

Technical Accomplishments

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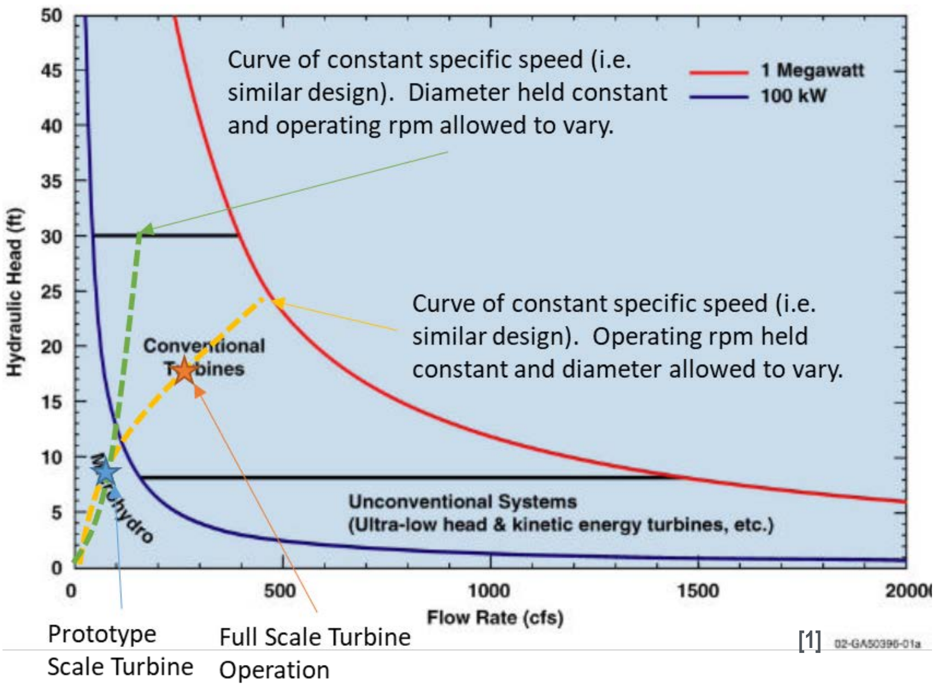
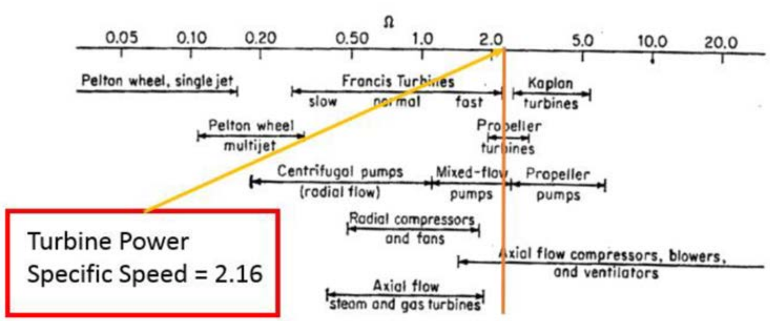
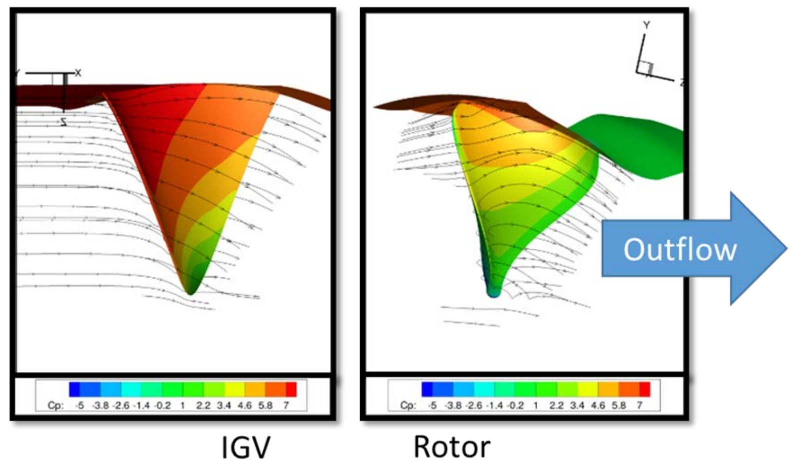
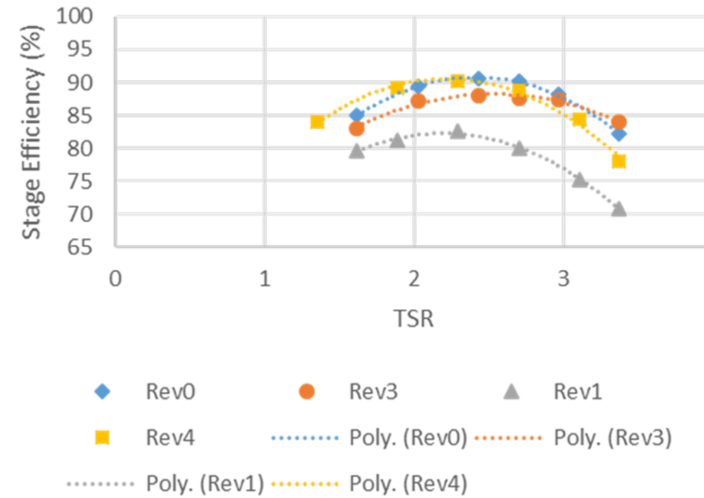
Turbine Design





[2] FIGURE 5a. Correlation of rotor design and specific speed. Suitability ranges of various designs.



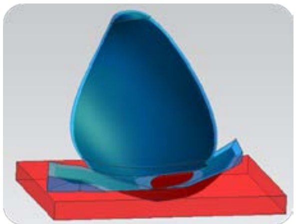


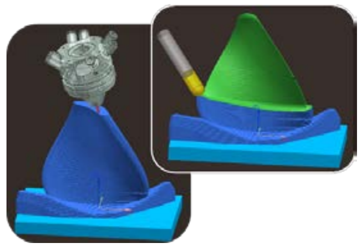
[1] Original figure from DOE/ID-11111 Report: Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources, April 2004.

[2] Original figures from: G. T. Csanady. Theory of Turbomachines. McGraw-Hill, 1964.

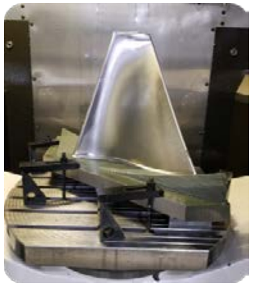
Technical Accomplishments

Advanced Manufacturing

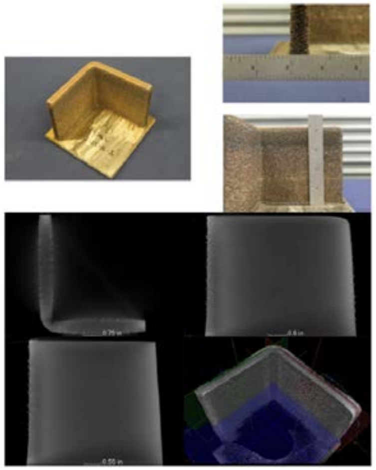

Design for Hybrid AM

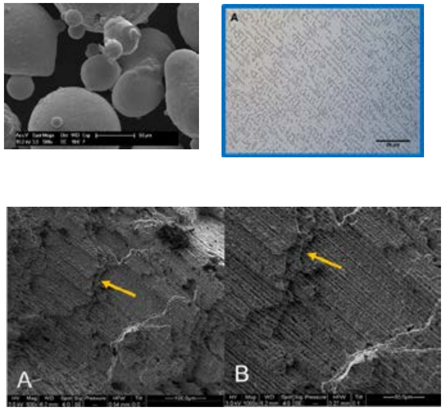

Additive and Subtractive Toolpath Generation

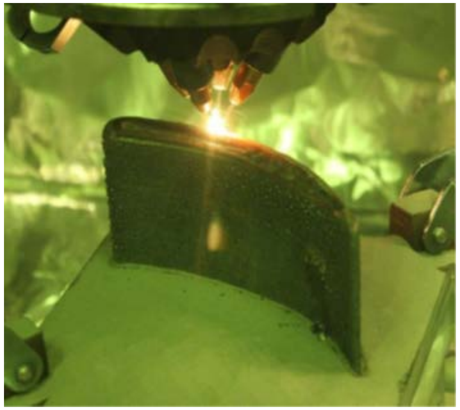

Laser Deposition


CNC Machining

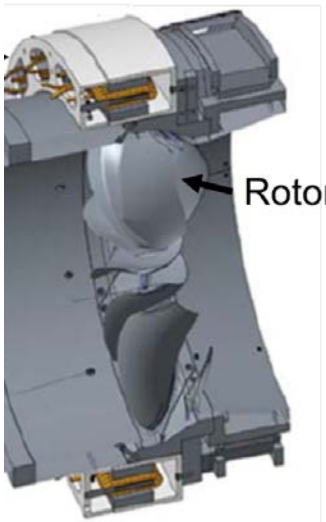

Final Part

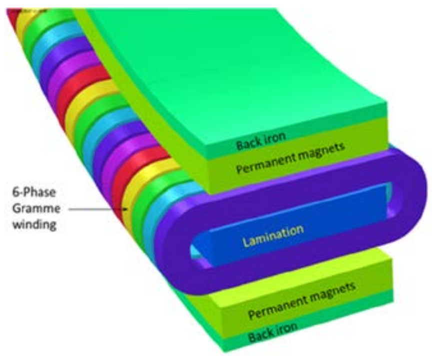


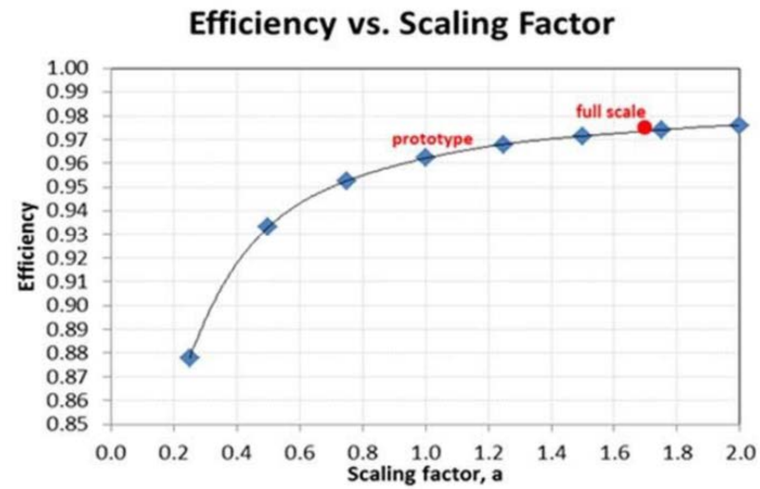




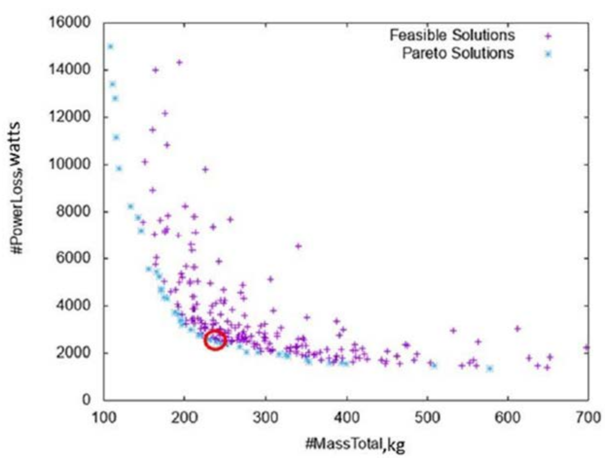
Rim-Generator Design

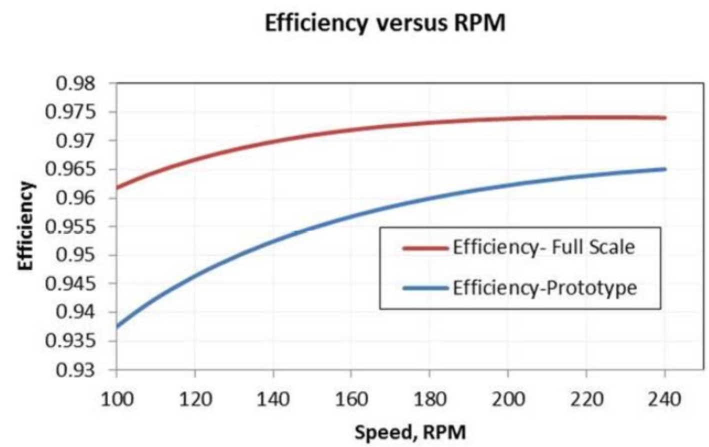






Geometric Scaling

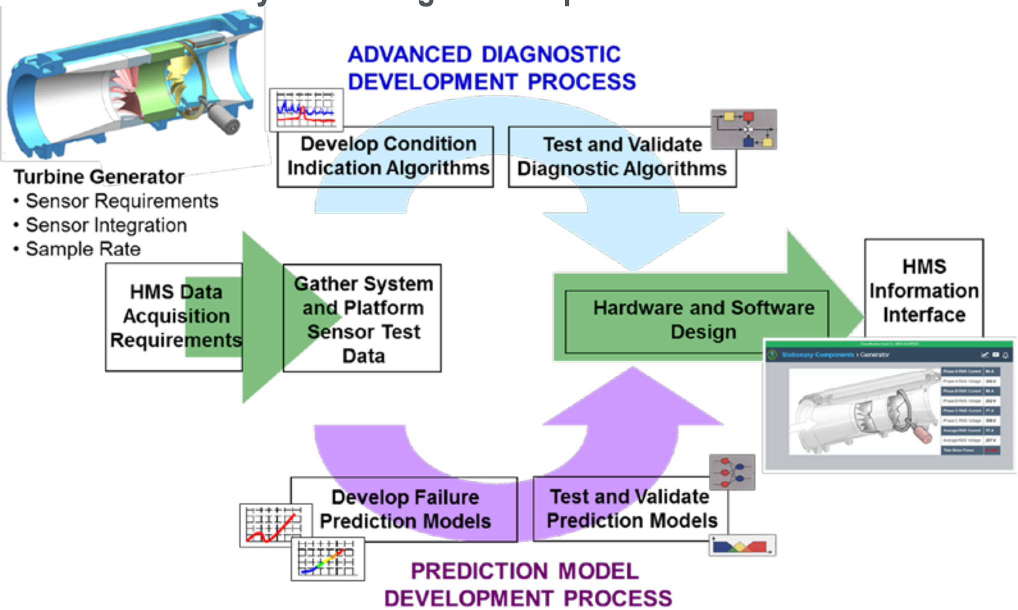


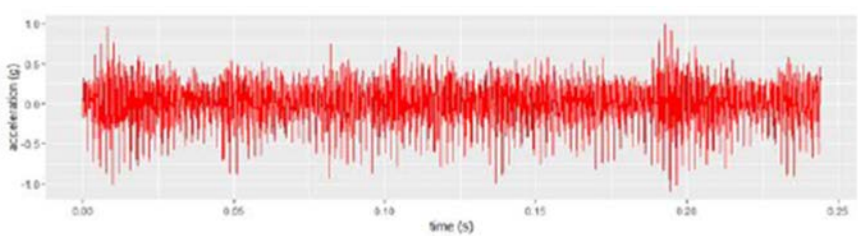


Variable RPM

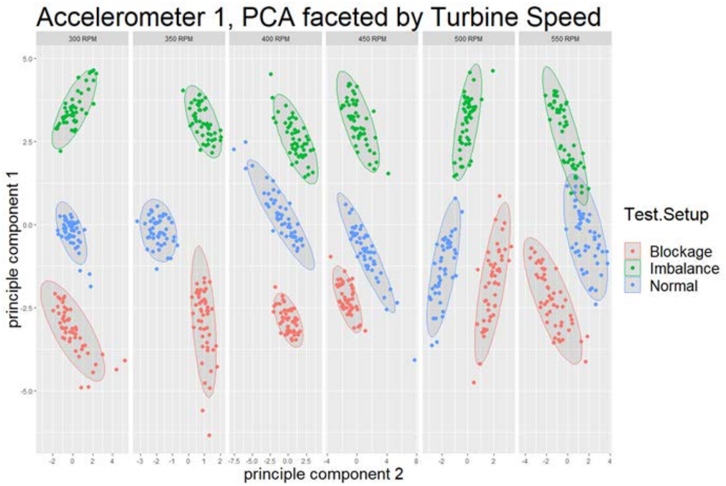
Condition Based Maintenance (CBM)

CBM System Design and Implementation

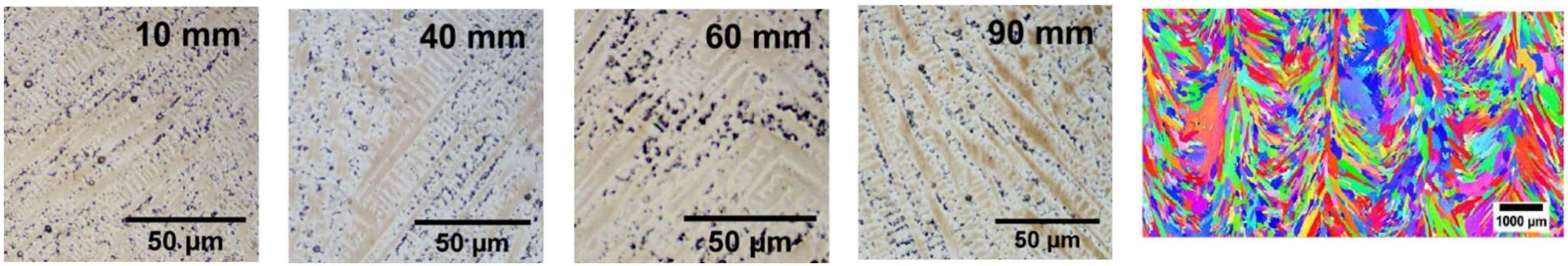




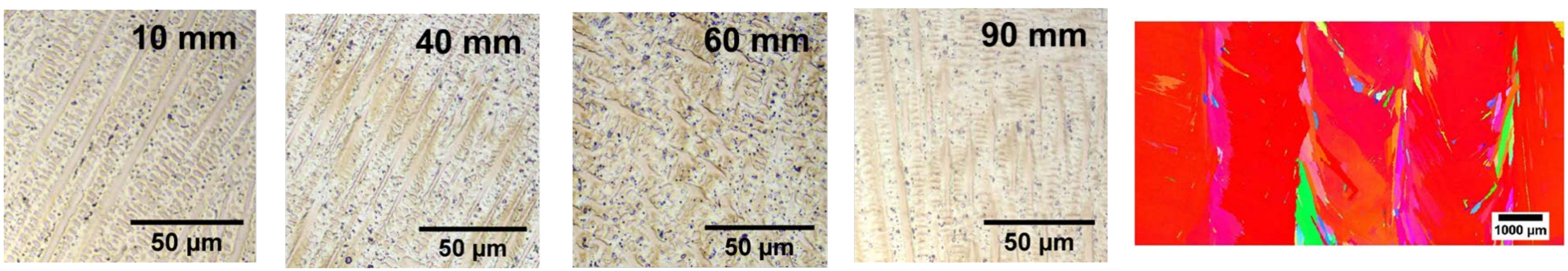
CBM System Validation Testing



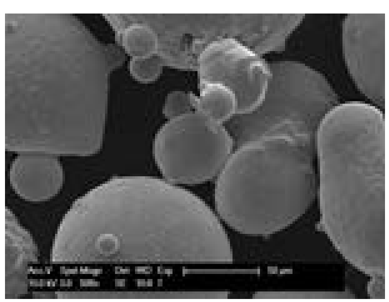
Hybrid Multi-Material Concept Study



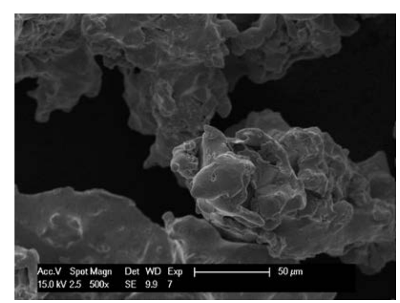
Low iron content Inconel 625



High iron content Inconel 625

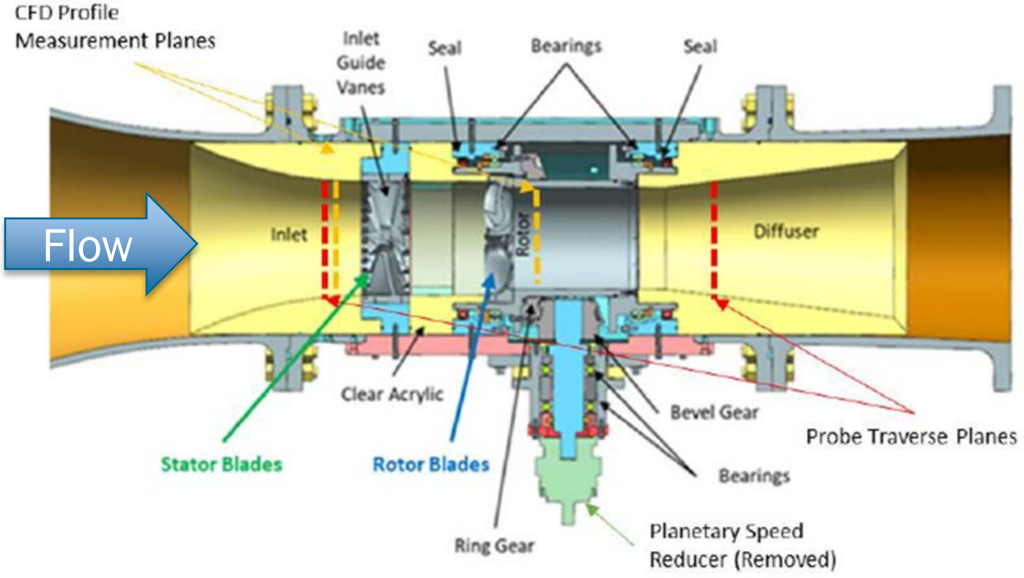


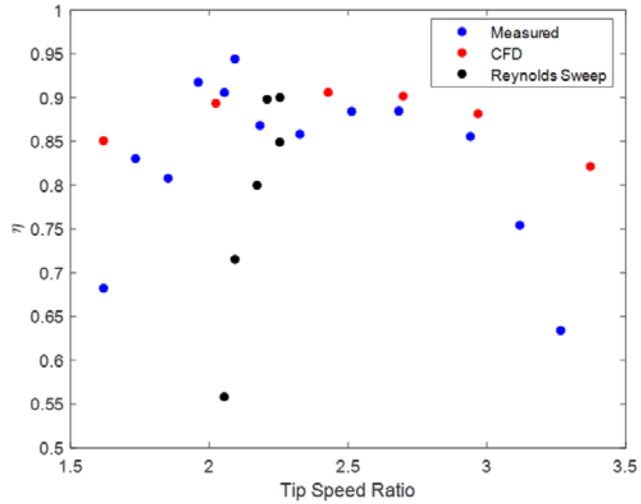
Nitrogen vs water atomized 316L stainless steel feed stock

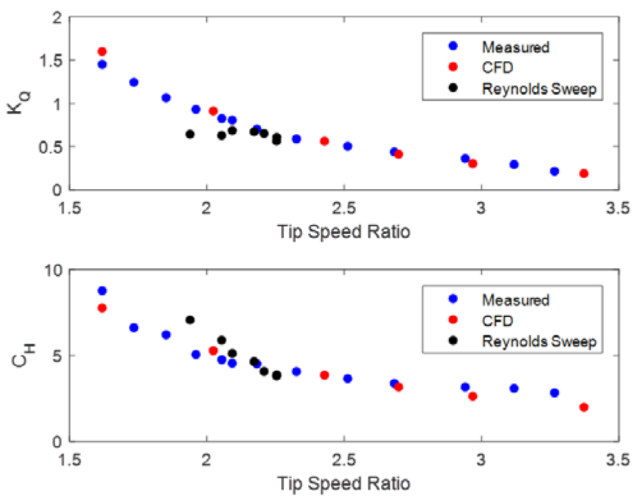


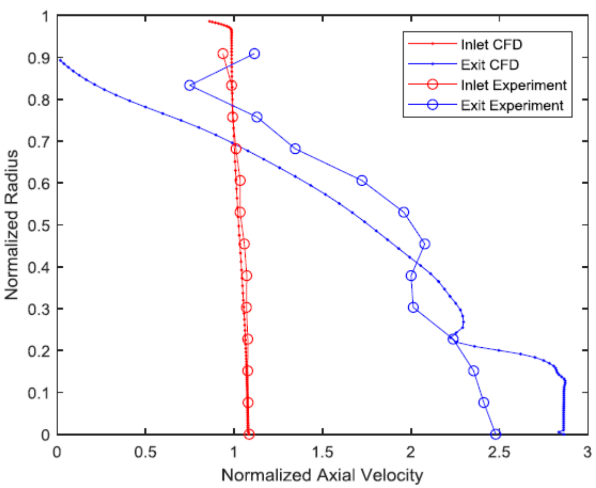
Technical Accomplishments

Turbine Validation Test









Progress Since Project Summary Submittal

- Submitted Final Report