Optimized Composite Archimedes Hydrodynamic Turbine

DOE – EE0007247

Hydropower Program

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J.L. Straalsund, Ph.D.

Percheron Power, LLC

Project Overview

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Project Summary

- The goal of the Project was to develop an optimized Archimedes Hydrodynamic Screw (AHS) turbine made of composite materials using advanced manufacturing methods. Conventional AHS turbines are made of steel and typically are shipped fully assembled from the factory.
- Lowering the equipment and installation costs should promote more rapid adoption of this promising low head technology across the U.S.

Project Objective & Impact

- Utilize new mathematical models to optimize the AHS shape/design for best performance
- Replace the steel turbine blades with newly developed composite material blades fabricated to the optimum shapes using Computer Aided Design and Manufacturing, and near net shape manufacturing processes
- Develop a novel blade segment attachment mechanism to allow field assembly and replacement

Project Information

Project Principal Investigator(s)

Dr. Jerry Straalsund

WPTO Lead

Erik Mauer

Project Partners/Subs

Dr. Rorres – Drexel University
Dr. Nuernbergk – Ernst Abbe University
Hertelendy Research Associates
Utah Water Research Lab/USU
Mid-Columbia Engineering, Inc.
PNNL

Project Duration

- Start: March 2016
- Completion: January 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

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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

- The new Optimized CAHS Turbine is modular and easy to install
- Archimedes Turbines have proven to be the most fish-friendly turbine for safe downstream fish passage
- Composite Materials and Closed Molding Manufacturing processes were used to reduce costs and provide very reproducible components
    - The same tooling can be re-used hundreds of times – means lower cost and less waste
- Water Testing of the Prototype was successfully performed at Utah Water Research Lab using a custom test stand/infrastructure

Key Tasks

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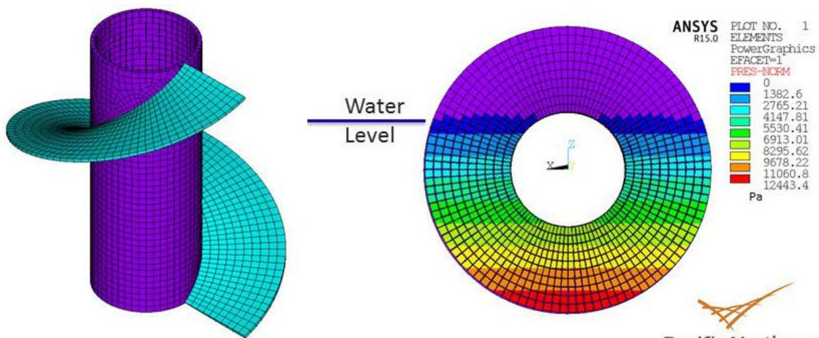
- **Blade Design – the bulk of the project work and innovation**
  - Apply newly developed Mathematical models to optimize volume flow
  - Perform Computational Fluid Dynamics (CFD) to optimize performance/efficiency and predict stresses
  - Finite Element Analysis (FEA) to support design and composite selection
  - Water Testing of Bench Scale Models to validate CFD and determine geometric effects of blade design
  - Down select to optimum blade design
  - Scale-up to full-sized prototype blades
    - Determine blade connection design and fab production process

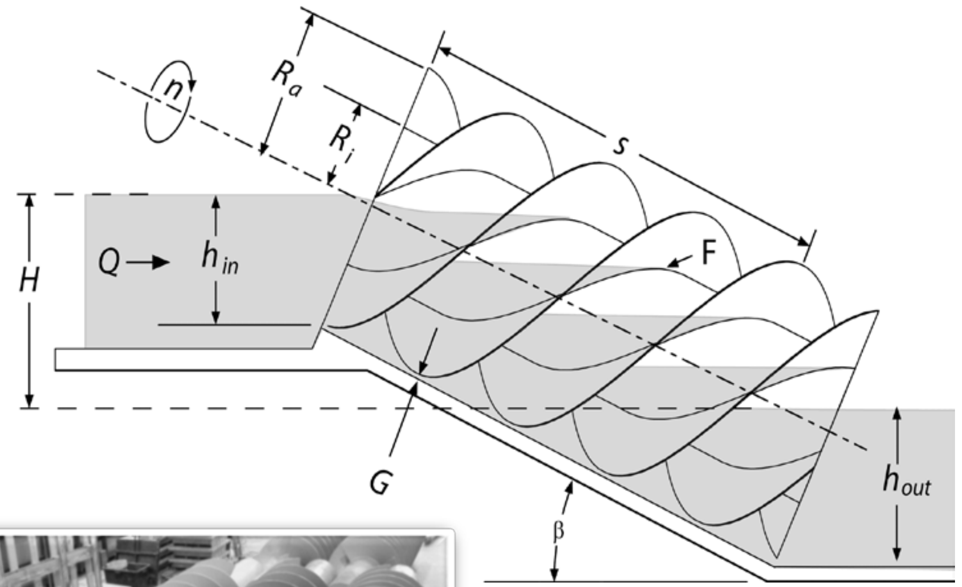


Pacific Northwest NATIONAL LABORATORY

- **Prototype Turbine Assembly**
  - Design, fabricate/procure and assemble all other system components
    - Gearbox, Generator, Variable Frequency Drive, Brake, Tray/Trough and Instrumentation
- **Water Testing of Full-Sized Prototype**

Turbine Variables Impacting Performance

- **For Same Head and Flow:**
  - Ratio of Central Tube Dia. to Outer Blade Diameter
  - Pitch of Blades
  - Number of Blade Flights
  - Shape of Blades
  - Gap between Central Tube and Trough
  - Inclination Angle of Turbine
  - Inlet and Outlet Water Level



3, 4 and 5 Blade Flight Turbines

Testing of Scale Models

Developed 4 mathematically optimized turbine designs and used CAD and 3-D printing for fabricating scale models

- Bench Tested to compare performance
  - Validated the CFD model results
  - High quality test results – over 900 data sets
  - Paper published in Journal of Hydraulic Engineering
- Selected the best design for larger prototype fabrication

Closed Molding of Blade Segments

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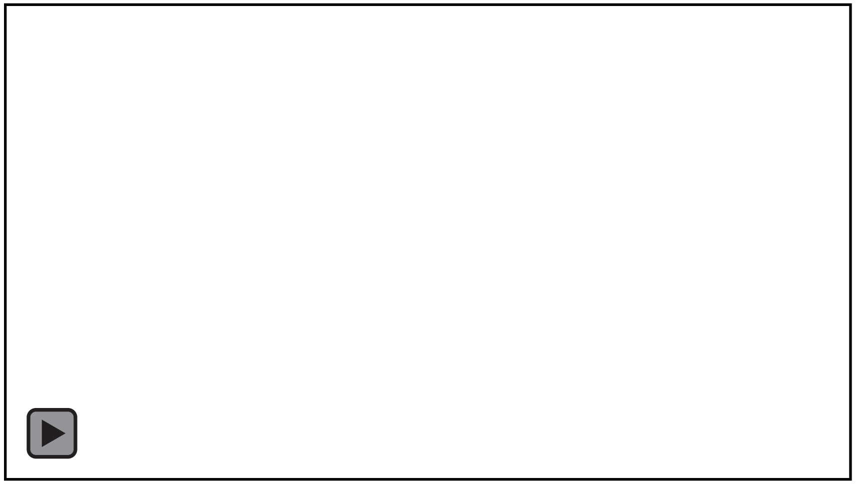
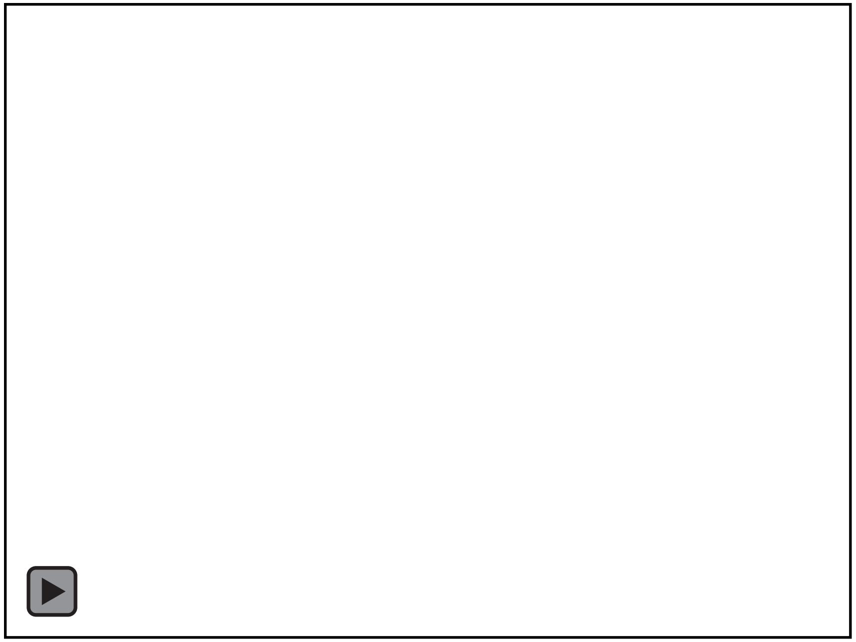
Investigated various Blade Fab Methods – selected LRTM (Light Resin Transfer Molding)

- Greater consistency and repeatability, and better thickness control
- Superior mechanical properties to hand laid parts
- Reduced cycle times
- Higher productivity and lower labor costs
- Reduced waste and emissions and cleaner environment

LRTM Blade Fabrication

Video Clips of “Freshly” De-Molded Blade





Completed Testing at Utah Water Research Laboratory of USU

- More than 70 Water Test Runs Successfully performed
  - Achieved highest measured efficiency of any known Archimedes Screw
- Tested with Flows 0 to 50 cfs and turbine speeds from 10 to 40 rpm
- Ready for permanent field demonstration and power off-take

Project Budget

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Total Project Budget – Award Information		
DOE	Cost-share	Total
$1,111,212	$277,803	$1,389,015

FY17 (Q1 & Q2 Only)	FY18	FY19	Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
$503,558	$420,986	$582,252	$982,796

- Project began in FY16. Therefore, the table above does not reflect funds received prior to FY17. The total funds, including FY16 funds, are $1,389,015.

Management and Technical Approach

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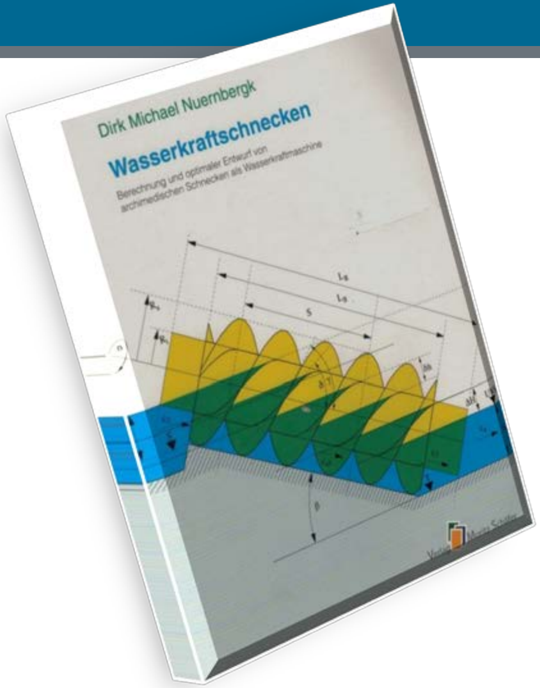
- **Interactive Design Methodology**
- **Share theories, results, observations and videos of models and physical testing with Project Team for best results**
  - Water Testing of Bench Scale Models
  - Mathematical Models and Predictions by Dr.'s Rorres and Nuernbergk
  - PNNL's Computational Fluid Dynamics (CFD) and Finite Element Analyses (FEA) analyses of Percheron's models
  - Select the best turbine design and fab method for full-scale prototype based on all results
  - Perform full-scale water testing of first prototype at Utah Water Research Lab



End-User Engagement and Dissemination Strategy

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- **Percheron worked with canal companies and water user groups to understand issues, concerns and opportunities**
  - Identified low head sites as an untapped opportunity, and the Archimedes Turbine as the best proven technology
  - Personally visited many sites/users and presented the Archimedes Turbine as a successful low head technology used in Europe
  - Received multiple letters of interest and support for a lower cost, composite Archimedes turbine manufactured in the U.S.
    - End-users/stakeholders from 4 different states, representing more than 100 potential sites
- **Included international experts and manufacturers of the steel turbines in the turbine optimization**
- **Shared results in various media including technical journal article, news releases, videos, USU website, NHA webinar**

Technical Accomplishments

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- Successfully developed a new optimized Composite Archimedes Hydrodynamic (CAHS) Turbine
  - Demonstrated the feasibility and advantages of using advanced manufacturing methods to produce the prototype and expected future turbine assemblies
- Patent filed on the design and method of making of the blades and turbine assembly
  - Percheron is believed to be first in the world to manufacture replaceable composite blades for an Archimedes Turbine or pump using Light Resin Transfer Molding (LRTM)
- CAHS prototype turbine provided “best ever” experimentally-measured hydraulic efficiencies over conventional steel turbines

Technical Accomplishments (Cont.)

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- Lighter weight composite blades and turbine assemblies
- LRTM provides extremely reproducible/identical blades
  - The mold can be re- used hundreds of times, providing reduced cost per turbine unit
- Blade segments are gel-coated in the mold as part of the LRTM process
  - No labor-intensive activities such as grinding, prep work, primer paint and corrosion resistant surface coats are needed for the composite turbine
  - Very corrosion resistant (excellent for saltwater and wastewater screw pump applications) and blades have less friction so lower hydraulic losses
- Each blade segment can be installed/replaced in the field

Video Clips of UWRL Testing