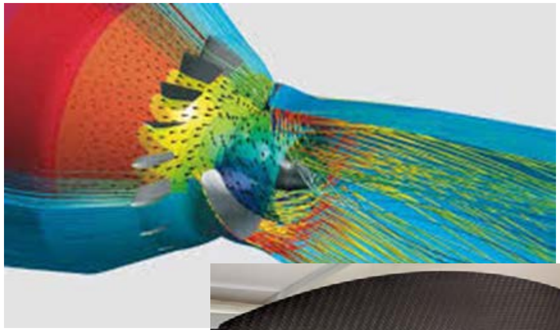
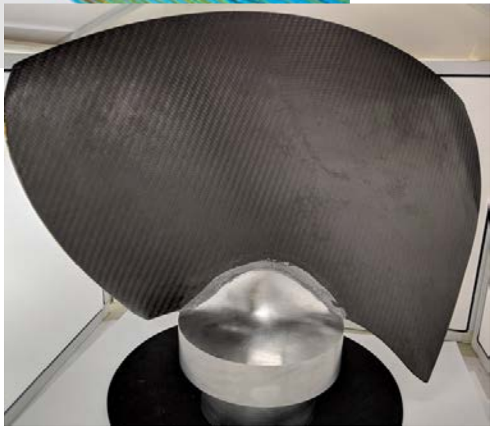
COMPOSITE TECHNOLOGY DEVELOPMENT, INC.

ENGINEERED MATERIAL SOLUTIONS





The Design and Development of a Composite Hydropower Turbine Runner

EE0007248

Hydropower Program

October 9, 2019

Paul E. Fabian

Composite Technology Development, Inc., Lafayette, CO

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

- DOE objective: Design and test new and innovative conventional hydropower powertrain components.
- Project goal: Verify that composite materials are a reliable and economic alternative to traditional metallic runners to reduce costs and increase energy capture.
- Develop cavitation-resistant coatings.
- Prototype and test a composite runner system under real-world hydropower turbine operating conditions.

Project Objective & Impact

- Prototype a weight-efficient, fatigue resistant, low-maintenance turbine runner using composite materials to reduce mass and extend service life.
- Improve runner reliability by developing a high-performance coating system that resists cavitation and sediment erosion.
- Provide performance test data of the composite runner/coating in true hydropower turbine operating conditions.

Project Information

Project Principal Investigator(s)

Mr. Paul E. Fabian
Composite Technology Development, Inc., Lafayette, CO

WPTO Lead

Marisol Bonnet
Erik Mauer

Project Partners/Subs

- Penn State University – Applied Research Lab (PSU-ARL)
- Sandia National Laboratory (SNL)
- Tribologix Inc.
- Voith Hydro, Inc.

Project Duration

- July 1, 2016
- December 31, 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.

- This project was funded through DOE FOA # DE-FOA-0001286, titled "Research and Development of Innovative Technologies for Low Impact Hydropower Development."
- The objectives of this FOA that CTD has sought to address under Topic Area #3 were to design and laboratory test new and innovative conventional hydropower powertrain components such as composite and replaceable blade technologies for turbine runners and/or materials and coatings for powertrain components.
- The use of new composite materials, coatings, and manufacturing methods will support lower cost production.

Project Budget

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Total Project Budget – Award Information		
DOE	Cost-share	Total
$975,905	$371,148	$1,347,053

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
$558,115	$217,973	$201,189	$977,277

- Primary hard and soft coating R&D conducted during FY17.
- Additional $25.9K authorized during FY18 for additional accelerated cavitation erosion testing at PSU-ARL.
- Program moved into third year due to delays in composite blade fabrication efforts and in PSU-ARL water tunnel testing availability.

Management and Technical Approach

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Technical Approach

<u>Phase I:</u>

- Requirements Management/Assessment
- Materials Assessment & Coating Development
- Turbine Runner Design

<u>Phase II</u>

- Blade Prototype Fabrication
- Single Blade Prototype Testing
- Turbine Runner Fabrication
- Turbine Runner Water Tunnel Testing

Success Factors

- Development of cavitation resistant coating
- Fabrication of composite runner
- Matching composite runner performance with FEA predictions
- Successful performance of composite runners & coatings under simulated hydroturbine operating conditions

Management Approach

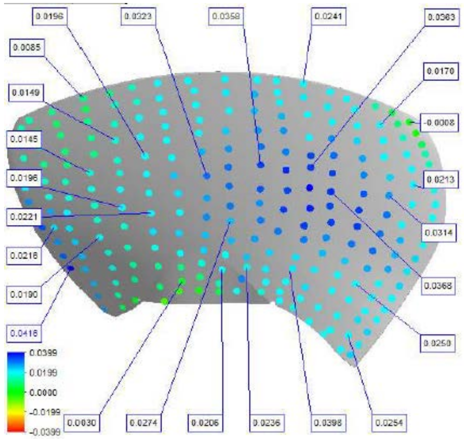
- Project Lead for each team partner
- Bi-weekly team meetings
- Milestones tracked with DOE
- Common file-share repository
- CTD responsible for coating and composite blade development & fabrication
- PSU-ARL responsible for water tunnel design modifications & testing

Challenges/Risks

- Anti-cavitation coatings not compatible with composites
- Design & fabrication of composite runner not achievable
- Composite runner does not perform as designed
- Simulated hydroturbine in water tunnel too difficult/costly

End-User Engagement and Dissemination Strategy

- **Primary End-Users:**
  - Current & future hydropower turbine manufacturers
  - Hydropower turbine operators
- **Commercial Partner – Voith Hydro, Inc.**
  - Worldwide hydropower turbine manufacturer/supplier
  - Actively engaged and helpful team member throughout program
  - Provided baseline metallic runner design and cost-share support
  - Participates in bi-weekly team meetings
  - Eager to commercialize once performance proven
- **Dissemination**
  - Work has been kept proprietary to maintain competitive advantage



Technical Accomplishments

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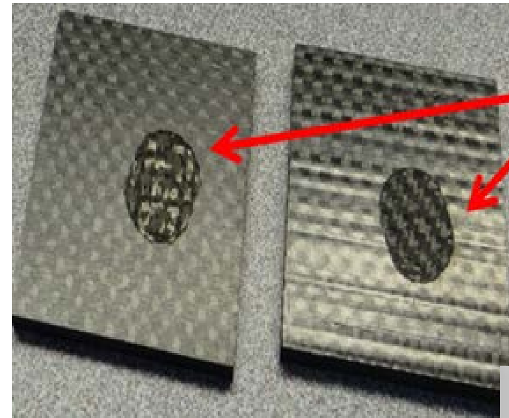
- Phase I
  - Runner polymer resin material selected
  - Soft & hard cavitation resistant coatings evaluated
    - Soft coating selected – CTD-133
  - Accelerated cavitation testing performed at PSU-ARL
  - CFD complete for primary hydropower turbine operating conditions

Operating Condition	Description
Maximum Efficiency	Operating at peak efficiency
Maximum Power	Operating at peak power extraction
Controlled Runaway	Maximum speed, blade angles fixed
Uncontrolled Runaway	Maximum speed, blade angles uncontrolled



Vibratory Horn erosion

Accelerated Cavitation erosion

ESD hard coatings

Technical Accomplishments

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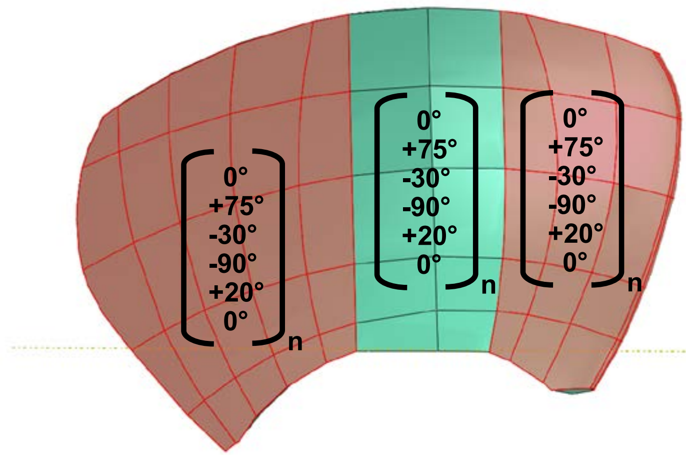
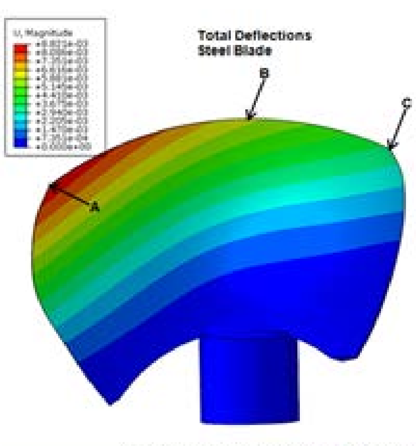
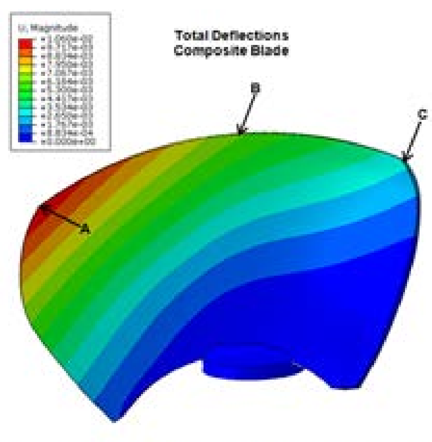
- **Phase I**
  - Detailed composite runner design & analysis completed
    - FEA indicates composite design can sufficiently represent steel design
  - Larger scale manufacturing trial completed with good results
    - VARTM manufacturing method

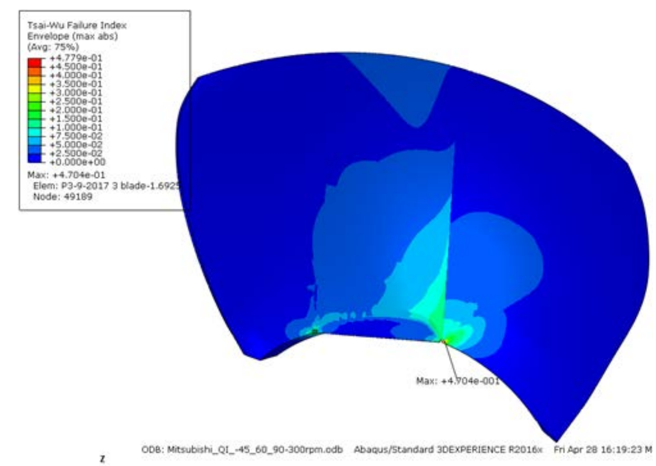
Composite Design



Finite Element Analysis



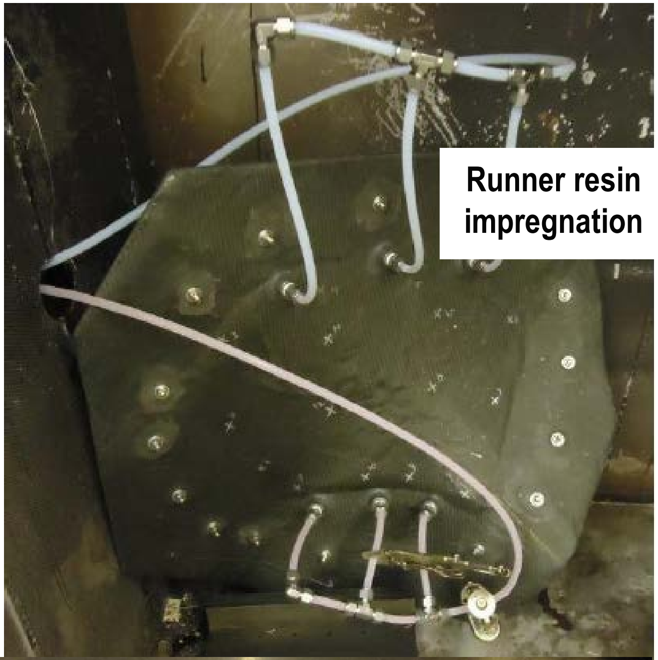




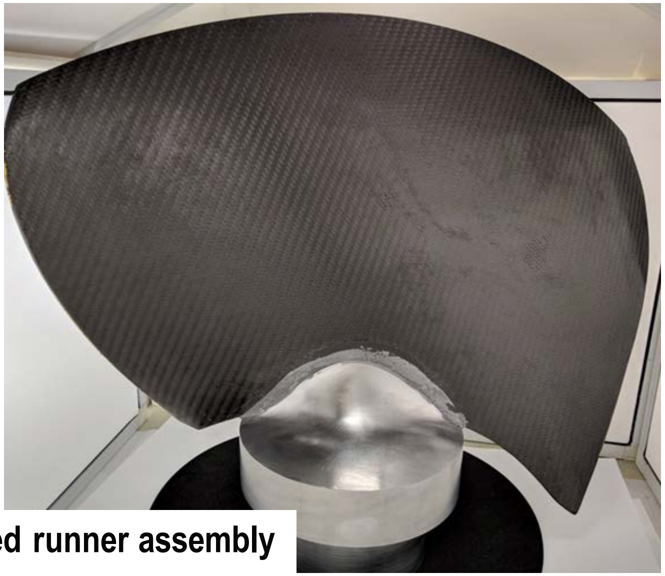
	A	B	C	Allowable Radial Deflection
Composite Blade Total Deflections	0.011"	0.006"	0.003"	
Composite Blade Radial Deflections	0.002"	0.0"	-0.001"	0.018"

Technical Accomplishments

- Phase II
  - Additional accelerated cavitation erosion tests completed at PSU-ARL
  - Composite runners fabricated
    - Closed mold vacuum impregnation method
    - CTD-K08 resin & high modulus carbon fiber



Runner resin impregnation

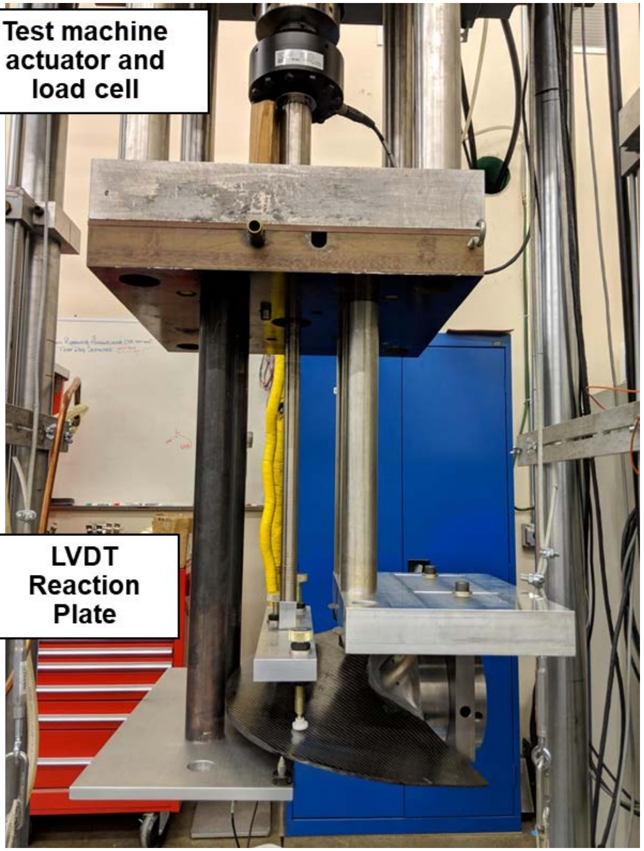


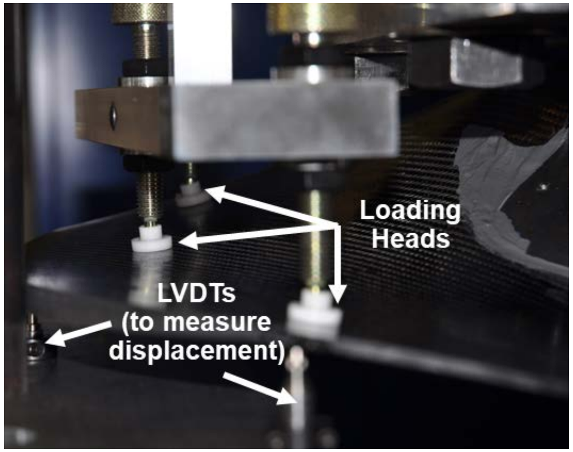
Completed runner assembly

Machined runner

Technical Accomplishments

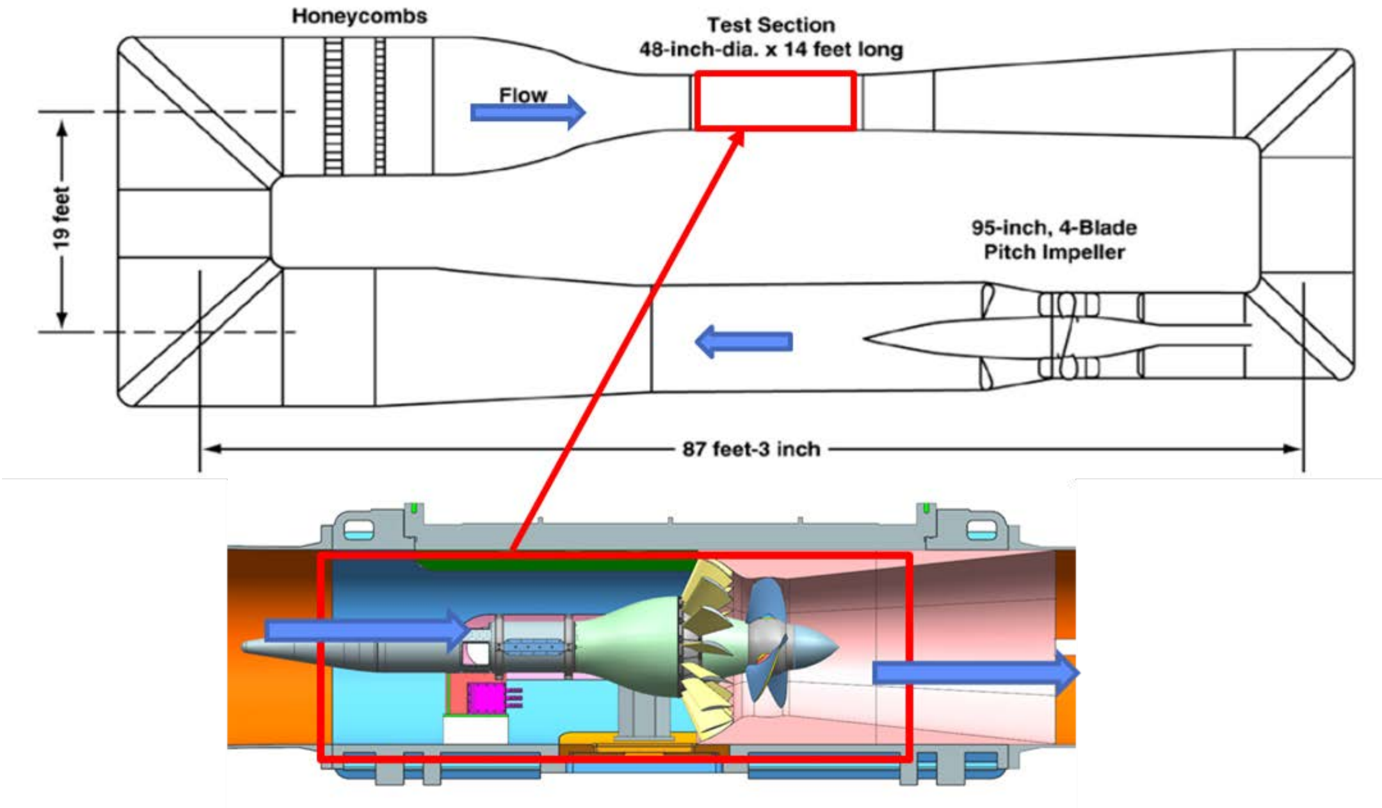
- Phase II
  - Single blade (runner) bend tests completed
    - Deflection under load performance matched FEA predicted values
    - Fatigue loading completed to 10^6 cycles
      - 1.25x Maximum Efficiency loading condition
      - Stiffness unchanged
      - No apparent damage





CASE	A	B	C
TEST: Raw LVDT Measurement	0.096	0.102	0.104
TEST: Compensated for Fixture Rotation	0.025	0.031	0.033
FEM: E1=52MSI	0.028	0.025	0.029

- **Phase II**
  - **PSU-ARL Scaled Voith Bulb Hydropower Turbine System**
    - **Designed and integrated scaled (76%) hydropower turbine system with existing 48 in. water tunnel dynamometer**



48" Diameter Garfield Thomas Water Tunnel Operating Specifications:

- **Powered by 2000 hP variable speed electric motor with variable pitch impeller**
- **Maximum tunnel velocity = 17 m/s (Q = 19.85 $\frac{m^3}{s}$)**
- **Static pressure range = 3-60 psia**

Technical Accomplishments (Cont.)

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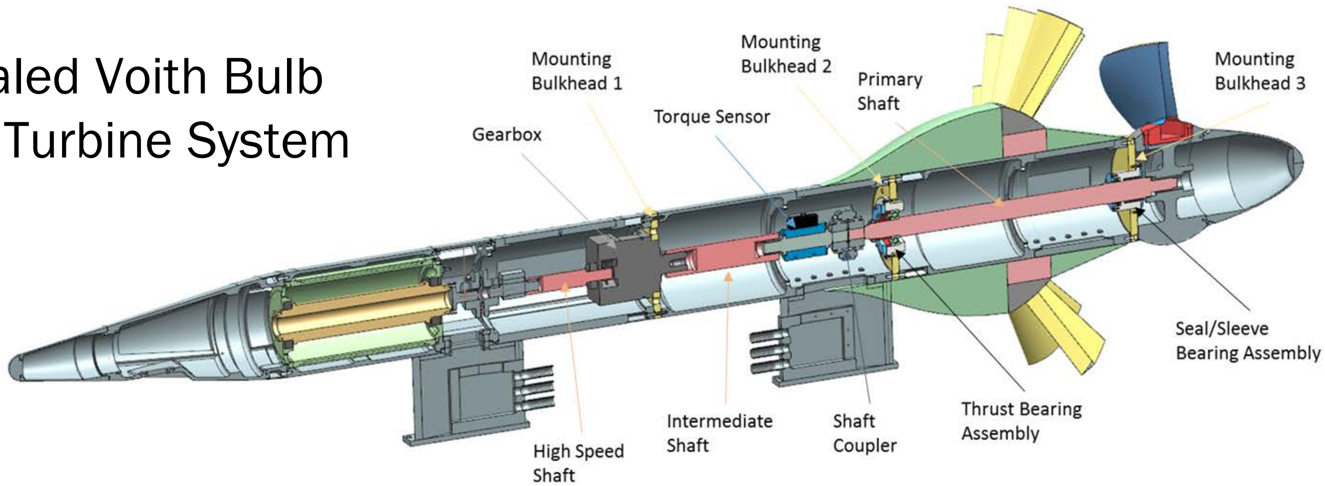
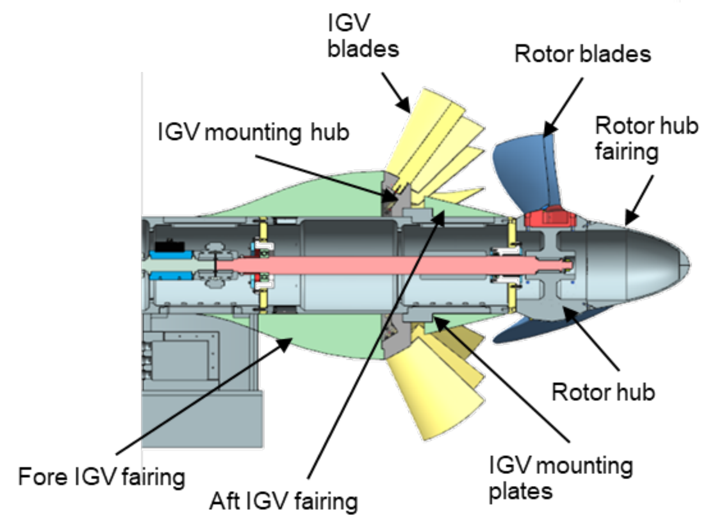
- **Phase II**

  PSU-ARL Scaled Voith Bulb Hydropower Turbine System



- Currently testing stability and controllability of tunnel main motor
  - Low flow rates
  - Range of RPM and impeller blade pitch angles
  - To ensure testing with turbine does not lead to accidents or transients
- Preparing for Runner system testing later in 2019



Progress Since Project Summary Submittal

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- **Assembly of runner blades and metallic hub inserts to start in September**
  - Bond and pin runner blades to hub insert
  - Apply CTD-133 soft coating to all outside blade surfaces
- **PSU-ARL completing testing on water tunnel - scaled hydropower turbine system**
- **Testing in water tunnel in Fall of 2019**