U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Oil-Less Compressor/Rapid-Cast, High-Speed Centrifugal Compressor Impeller

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Project Summary

Timeline:

Start date: 10/1/2018

Planned end date: 9/30/2020

Key Milestones

1. M9–20% cost savings
2. M15–Success of internal channel build

Key Partners:

PennState

University of Northern Iowa

Budget:

Total Project $ to Date:

- DOE: $193K
- Cost share: N/A

Total Project $:

- DOE: $450K
- Cost share: N/A

Project Outcome:

A new rapid casting approach to impeller manufacturing that removes many of the postcasting processes such as machining and brazing and introduces active flow control (AFC) to prevent the surge/stall phenomenon that can destroy a high-speed centrifugal compressor impeller.

Team

Patrick Geoghegan, PhD
Principal Investigator

Amy Elliot, PhD
Manufacturing Demonstration Facility

ORNL

Jerry Thiel
Director of Additive Manufacturing Center and Metal Casting Center

University of Northern Iowa

Pennsylvania State University

Steve Lynch
Shuman Family Early Career Assistant Professor, Department of Mechanical Engineering

Alexander J. Rusted
PhD Student

Challenge

- According to the 2016 Annual Energy Outlook, the United States consumed 2.15 Quads in delivered energy in cooling, refrigeration, and freezing across the residential and commercial sectors
- Oil provides lubrication, cooling, and leak tightness
- Heat exchangers fouled by compressor oil leads to 10–15% loss in performance over time
- Alternative refrigerants could require larger flow rates not possible by scroll compressors

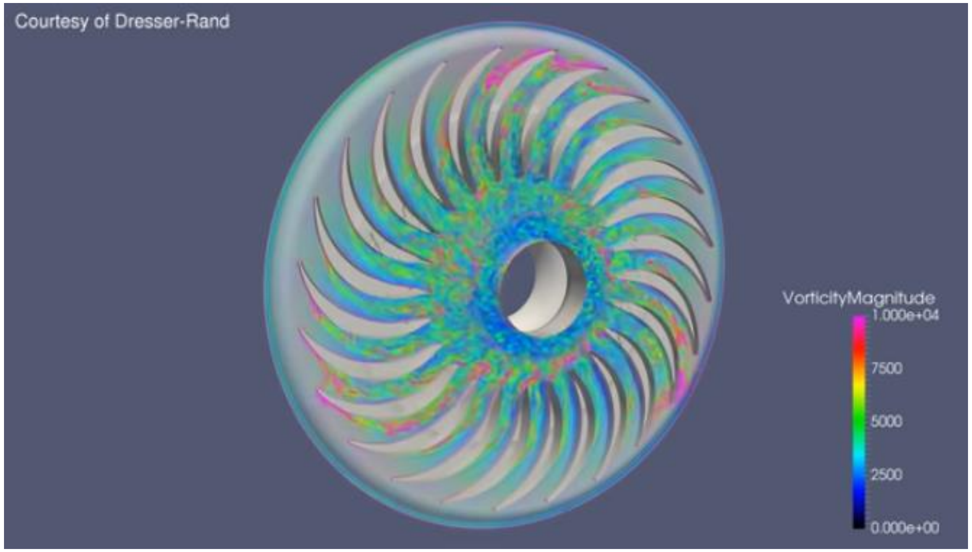
Emerging Technologies Multi-Year Program Plan

- By 2030, develop cost-effective technologies capable of reducing a building's energy use per square foot by 45%, relative to 2010
- Fund early-stage R&D

Approach — Small-Scale Centrifugal Compressors

Characteristics:

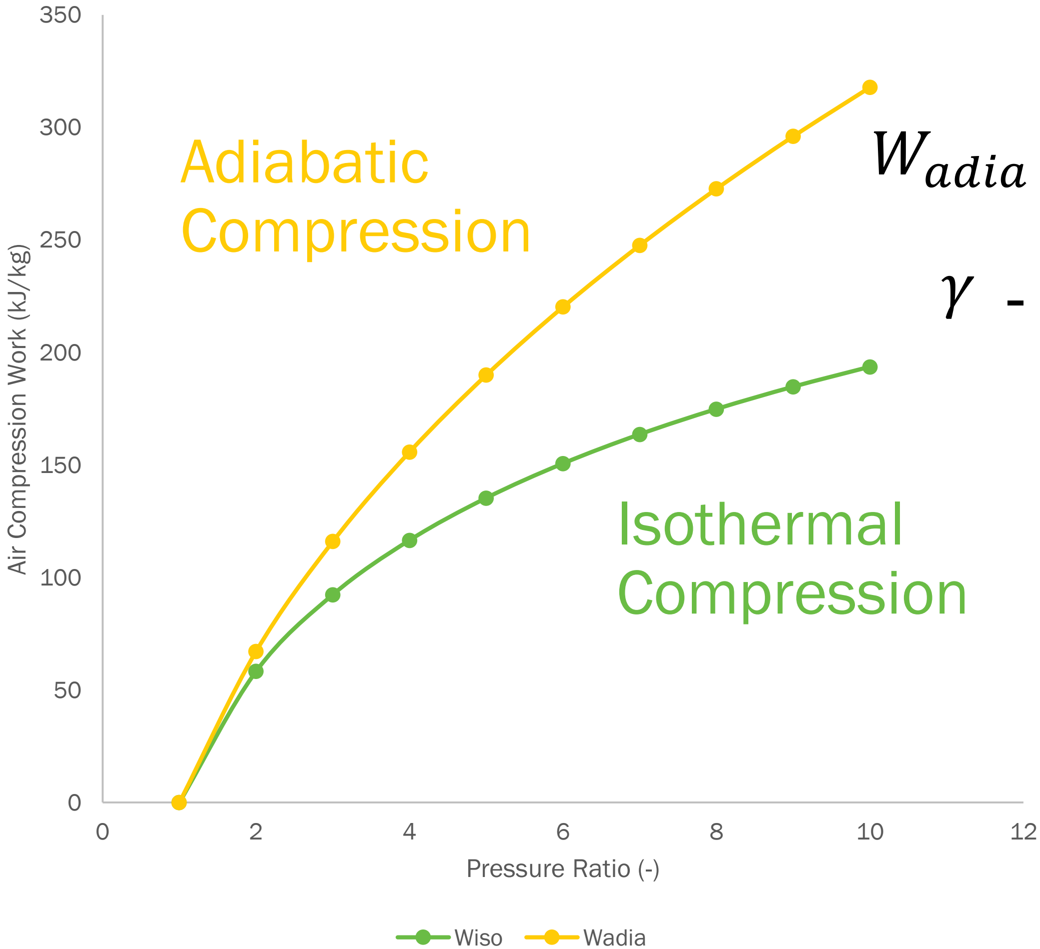
- Oil-free
- Surge/stall, mitigated through AFC
- Towards isothermal compression



- Onset of rotating stall in a turbomachinery diffuser/return channel.
- FINE/Open unsteady DES solved on the OLCF Titan supercomputer
- Numeca–Dresser Rand Rotating Stall Animation (https://youtu.be/emCgbNc4ZLQ)

Approach — Internal Flow/Cooling Channels

Through shroud and impeller base



$$W_{adia} = \frac{nRT_0}{\gamma - 1}\left[\left(\frac{V_0}{V}\right)^{\gamma-1} - 1\right]$$

γ - ratio of specific heats

$$W_{iso} = nRT_0 \ln\frac{V_0}{V}$$

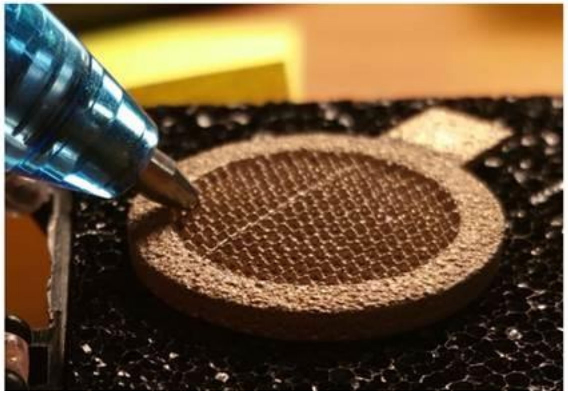
Approach — Manufacturing Approaches

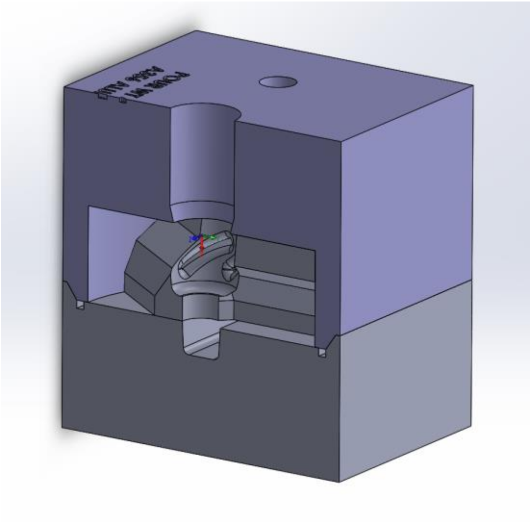
- **Impellers are traditionally sand investment casted**

Investment casting of parts → CNC machining of brazing surfaces → Brazing of parts

- 3D printing of impellers is possible but there might be issues with
  - Porosity
  - Surface finish
  - Cost

Approach — Rapid Casting



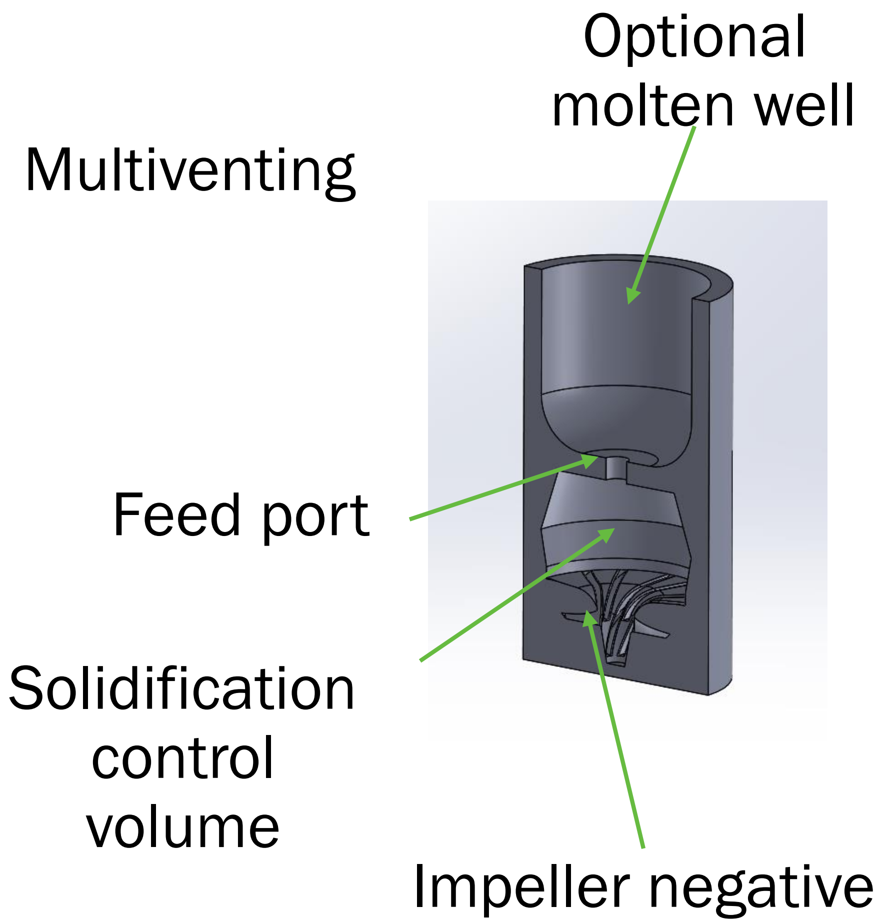


ExOne Binder Jetting 3D printer

Printing sand

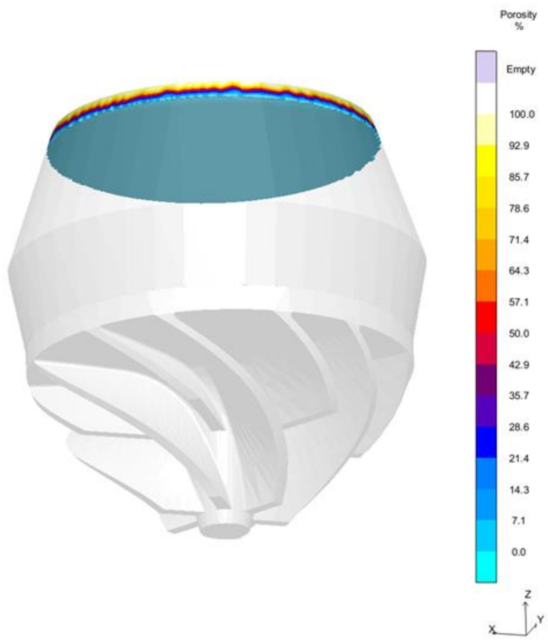
Characteristics

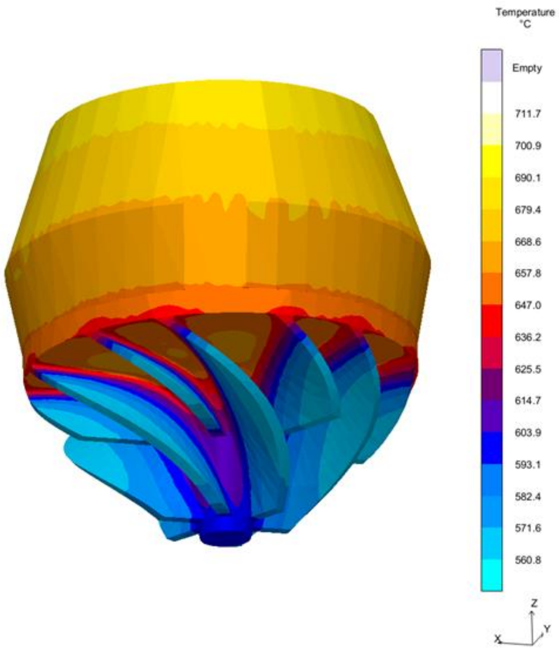
- Casting into a 3D-printed mold
  - Avoids porosity issues
  - Enables complexity (impeller and shroud)
  - Surface finish (Ra 3 to 6 μm)
  - Cost per part and productivity
  - AFC
  - Castable aluminum cerium alloy



Approach — Modeling of the Casting Process

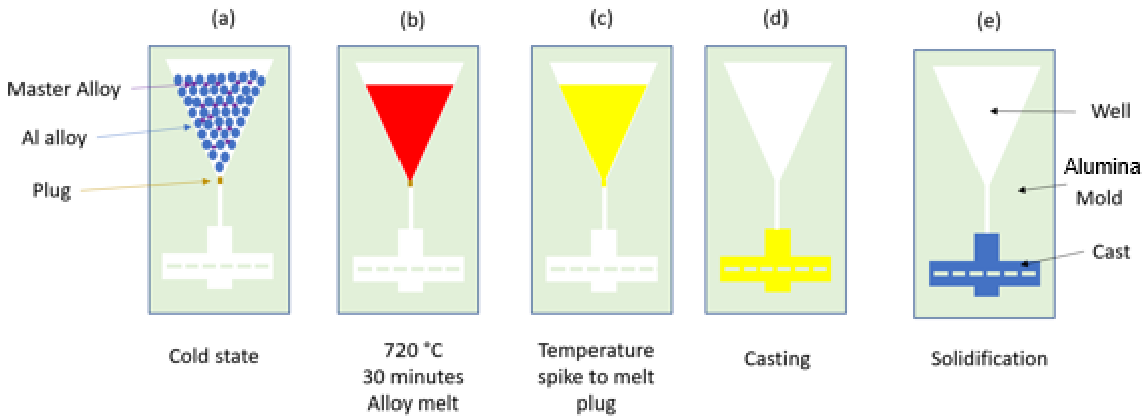
- Commercial codes
- Open source (OpenFOAM)
- Multiventing analysis

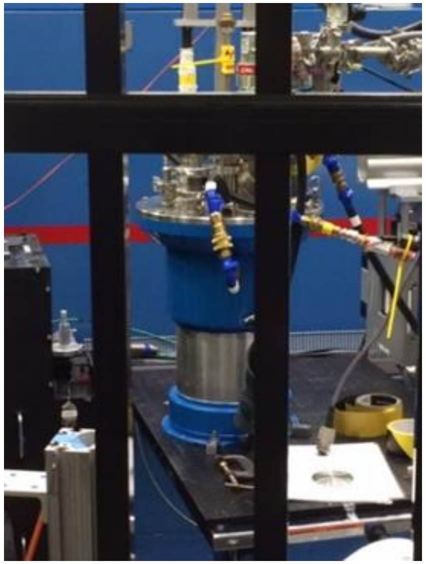




Approach — Validation Through Neutron Imaging

Non-invasive





Boron-containing master alloy

Impact

- 20% cost savings on impeller manufacturing by combining shroud and impeller
- Adaptable to alternative refrigerants
- Potential for 36% energy savings in conversion from isentropic to isothermal compression
- 0.24 Quads of energy savings through oil-less compression

Project Plan

Milestone Name/Description	Criteria	Planned End Date	Milestone type (Annual Regular, Quarterly progress)
Report on the manufacturing of a shrouded impeller	Benefits outweigh limitations	3/31/2019	Regular
AFC channel design	Complete AFC design	9/30/2019	Regular
Report on success of AFC channel fabrication	Channels must be clear, and pressure drop reasonable	12/31/2019	Regular
Report on rapid casting of full scale AFC shrouded impellers	Confidence in scale-up	9/30/2020	Regular

Go/No-Go Decision	Description	Criteria	Date	Actions Go: No-Go:
Define the cost savings versus investment casting, CNC machining and brazing	Report on Cost Comparison of traditional manufacturing to rapid casting	Must provide a 20% cost savings over traditional manufacturing	6/30/2019	
Design Scale-up	Define size limitations, surface finish, balance, etc.	No bottleneck issues in scale-up	3/31/2020	

Progress

- Go! @ ORNL memorandum of understanding signed with Penn State
- Contract in place
- Costing analysis under way
- Casting into the AccuCast 3D-printed mold, unshrouded part scheduled to be neutron imaged
- Sample environment design is progressing

Stakeholder Engagement

Danfoss

Ingersoll Rand
Inspiring Progress™

Remaining Project Work

- **New project**
- **Immediate future**
  - Examine rapid-casted shrouded impeller
  - Print sand molds with annular passages of varying diameter to test for channel stability
- **Distant future**
  - Neutron Imaging of in situ rapid casting integrated impeller design and build

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: DOE Total $450K
Variances: Project delayed until 3/1/2019 due to contract negotiations
Cost to Date: $115K
Additional Funding: None

Budget History					
FY 2016-2018 (past)		FY 2019 (current)		FY 2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$85k	$0	$140	$0	$225	$0

Project Plan and Schedule

Project Schedule

Project Beginning: 10/1/2018		Completed Work
Projected End: 9/30/2020		Active Task (in progress work)
	◆	Milestone/Deliverable
	◆	Milestone/Deliverable (Actual)

	FY2019				FY2020			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work								
1.1 Report on the manufacturing of a shrouded impeller		◆						
Current/Future Work								
1.2 Go/No-Go Cost comparison of traditional manufacturing to rapid casting			◆					
2.1 Channel fabrication				◆				
3.1 Go/No-Go Design scale-up					◆			
3.2 Rapid casting of full scale AFC shrouded impeller								◆