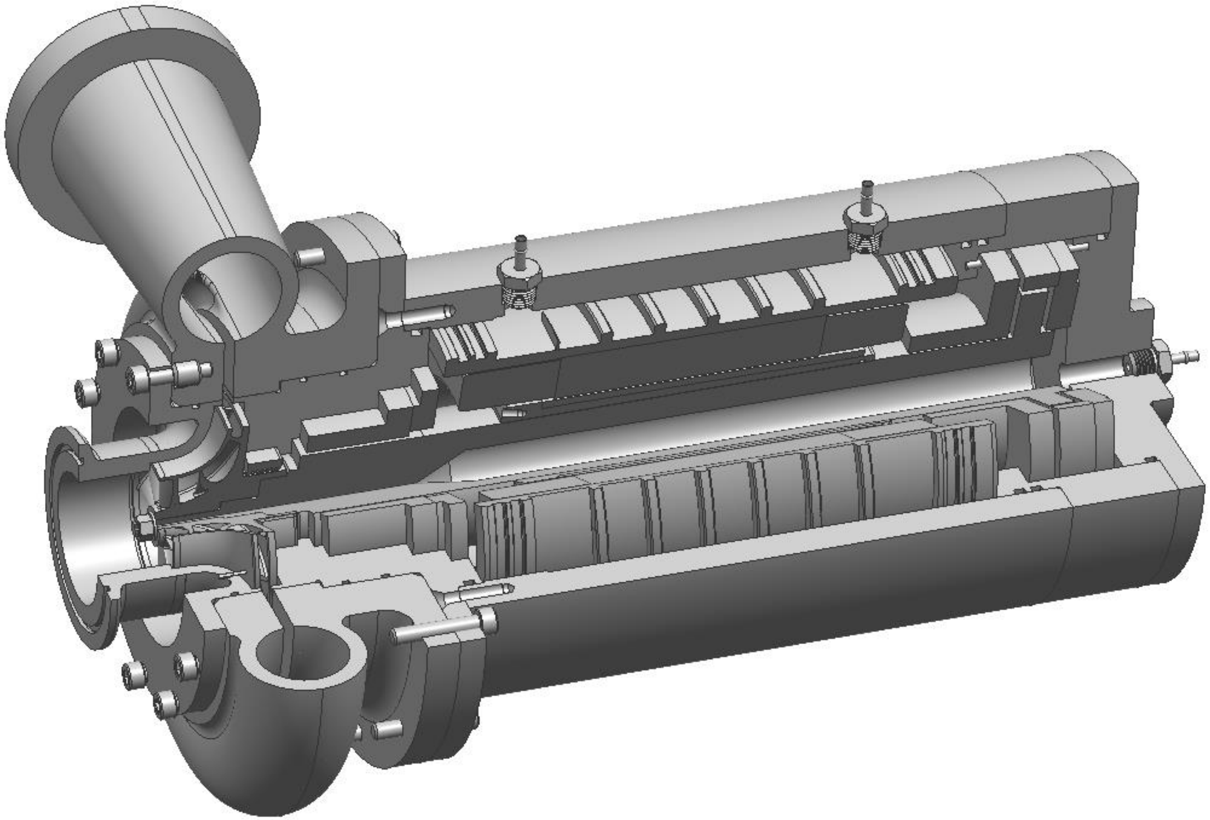
LOW-GWP HVAC SYSTEM WITH ULTRA-SMALL CENTRIFUGAL COMPRESSION

2016 Building Technologies Office Peer Review



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

Project Summary

Timeline:

Start date: 10/2015

Planned end date: 6/2017

Key Milestones

1. Milestone 3.3.1; 1/29/16
2. Milestone 2.1.1 ~40% complete; 1/29/16

Budget:

Total Project $ to Date:

- DOE: $134,406 + $56,776 (fy: 2016)
- Cost Share: $52,867

Total Project $:

- DOE: $999,921 ($362,794 Approved Budget)
- Cost Share: $251,525 ($125,886 Approved Budget)

Key Partners:

Lennox International, Inc.	
TURBOCAM International, Inc.	

Project Outcome:

Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.

Purpose and Objectives

Problem Statement: Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.

Target Market and Audience: This project is targeted toward residential and commercial air conditioning. The market is approximately 3 quads of cooling for both residential and commercial. The audience is new units selected for low-GWP refrigerant capability.

Impact of Project:

- Project Output – Technical performance goals met, technical and manufacturing pathway established, and prototype for efficient use of low-GWP refrigerants in HVAC applications
- Near-term outcomes: Private sector aware of technology through investment/ collaboration, begin additional investment to refine technology/reduce cost
- Intermediate outcomes: Continued partnership with private sector system and component manufacturers to refine technology and reduce cost, introduce to market
- Long-term outcomes: Enable cost effective and energy efficient shift to low-GWP refrigerants in HVAC industry

Approach

Approach: Develop conceptual model in collaboration with system vendor to determine efficiencies, system design and manufactured cost. Refine design and build/test prototype to validate solution.

Key Issues:

1. Efficiency – Low-GWP refrigerants are new and untested in this application. Early compressor studies are based on isentropic efficiency, but system efficiency results required.
2. System integration – Small centrifugal is a departure from current HVAC applications in this size range. Need good integration into system, including operating methodology, materials compatibility, etc. Heat exchanger is an integral component.
3. Cost – Technology will need to be cost effective to be adopted by industry and subsequently consumers.

Distinctive Characteristics: Determine system efficiency and cost estimates early in program

Progress and Accomplishments

Accomplishments:
- Study of various low-GWP refrigerants performed and downselected
- Conceptual aero design completed
- Preliminary heat exchanger design completed, parts being sourced
- Conceptual bearing and motor design completed

Market Impact:
- Presenting findings to date at Purdue Compressor Conference Aug 2016
- Still early in project (Budget Period 1)

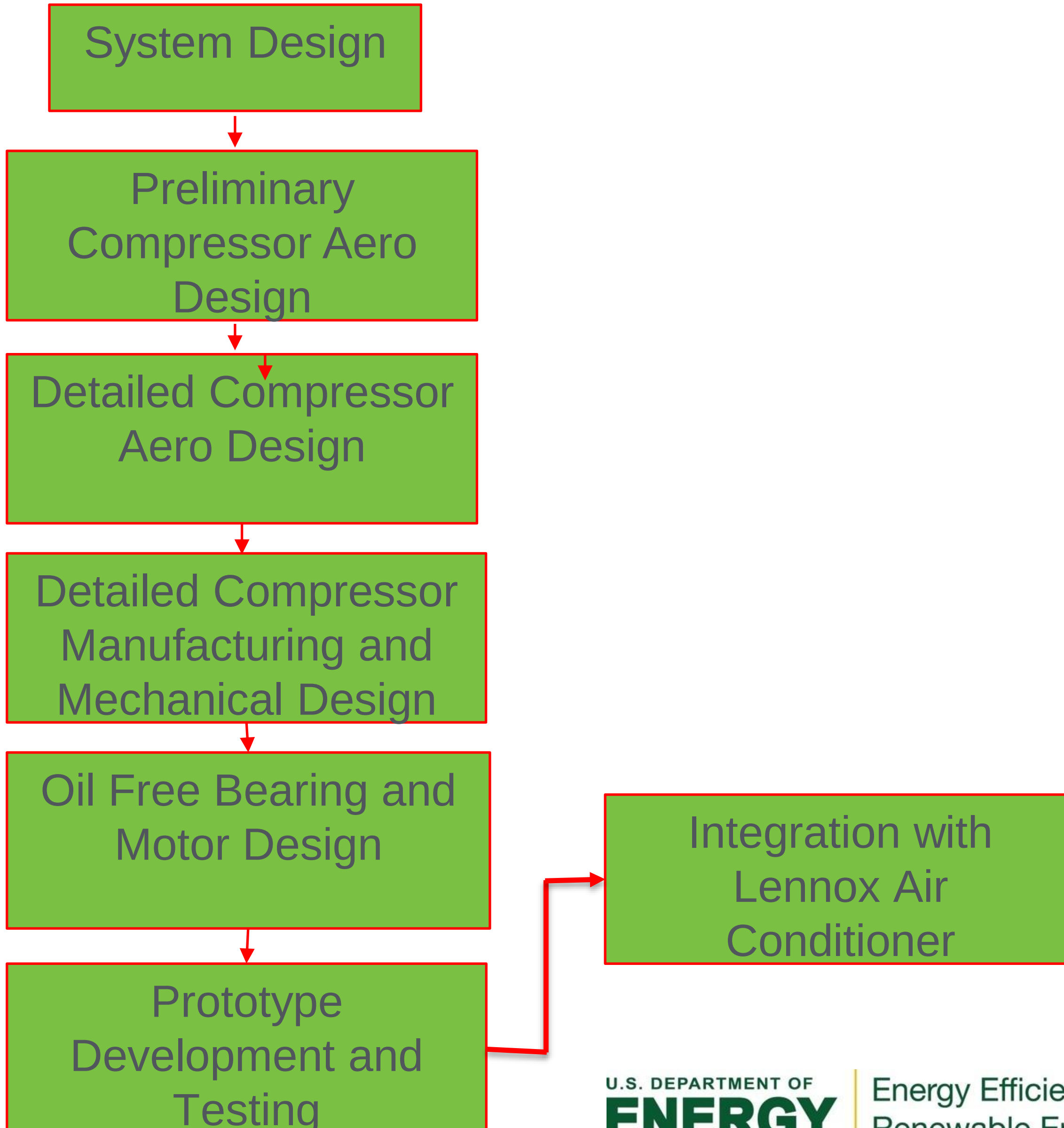
Awards/Recognition:
- None to date

Lessons Learned:
- Business Development negotiations with partners can be very time consuming

Project Objectives

- Design and development of an ultra-small, efficient, maintenance-free, oil-free, inexpensive centrifugal compressor, including aero components, rotor-bearing system, inverter and motor for a 5-ton air conditioning system
- Optimization for partial load efficiency, without sacrificing peak load performance
- Design for manufacturability and cost
- Validation and system integration of a high effectiveness heat transfer system, engineered for a very low-GWP refrigerant, e.g., microchannel heat exchanger
- Analysis of:
  - very low-GWP refrigerant compatibility with system materials
  - throughput benefits of centrifugal compression of lower density, very low-GWP's
- Quantification of beneficial lifecycle impacts of centrifugal technology, including installation, diagnosing, and servicing of systems
- Optimization for unitary "drop in" replacement, including flammability and safety risks, suction line pressure drop, and performance relative to outdoor temperature
- Testing of prototype system

Design and Prototype Development Flowchart



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System Design

- Conducted by Lennox
  - System design consisting of all components(Compressor, heat exchanger, etc.), using Cycle_D code
- Multiple refrigerants examined
  - Several HFO blends were evaluated

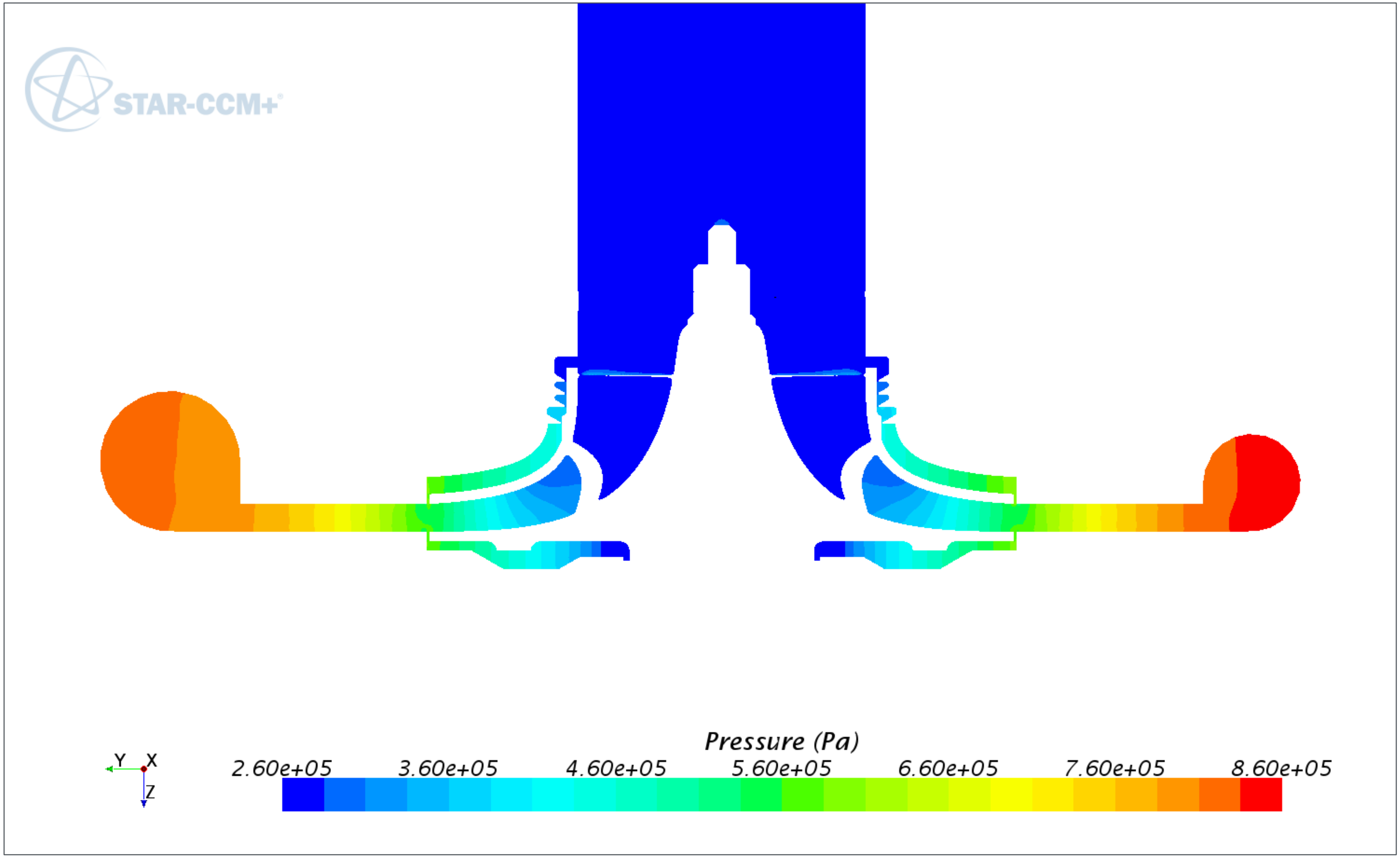
Preliminary Aero Design

- Conducted using PCA Vista Design Code and CFturbo
- Both codes employed modified Redlich Kwong and Peng Robinson Equation of State(EOS) to simulate Refrigerant PVT behavior

Detailed Aero Design

- Upon Completion of the preliminary design, a detailed 3-dimensional geometry of the centrifugal compressor was made using specific turbomachinery design software(ANSYS and CFturbo)
- The flowpath was analyzed using the real gas CFD code, STAR-CCM+
- A secondary flowpath was added to the system using the NX and Pro-Engineer CAD products to add fidelity to the analyses
- Complete analyses were conducted for subject refrigerants
- The analyses were completed at the rated condition, as well as a appropriate turndown condition to ensure proper off-design performance
- The effect of the foil bearings were considered in these analyses. A supply flow was taken from the impeller. This flow will feed the bearings, and provide motor cooling flow.

Compressor Coupled CFD Analysis



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Project Integration and Collaboration

Project Integration:
MSI and Lennox are coordinating system design parameters to guide development. Lennox participates in requirements definition, design reviews, and parallel development.

Partners, Subcontractors, and Collaborators:
Project partner – Lennox International, Inc.

Communications:
Presenting findings to date at Purdue Compressor Conference Aug 2016

Project Plan and Schedule

Major Task Schedule									
Phase	SOPO Task #	Item: Task = T Milestone = M Deliverable = D	Task Title or Milestone/Deliverable Description	Performer (if different from recipient)	Task Completion Date				Progress Notes
					Original Planned	Revised Planned	Actual	% Com-plete	
1	1	T	Program Management - Ongoing	Principal Engineer I	9/30/2017	10/12/2017		20%	Project Schedule has been shifted by 2 months due to late kickoff meeting
1	2	T	Requirements Definition	Vice President	6/31/17			60%	
1	2	M	First version of Requirements Document complete	Vice President	1/29/2016	2/28/2016		40%	First Version Of Requirements Document To Be Finalized At Concept Design Review
1	3	T	Materials Comaptibility Investigation	Lennox	4/30/2016			70%	
1	3	M	Preliminary materials selection complete	Lennox	1/29/2016			100%	Refrigerant Selected
1	3	M	Final materials selection	Lennox	7/30/2016			20%	
1	4	T	Market Transformation		6/30/2016			10%	Subtask 4.2 (Identified TURBOCAM) Conducting In Concert With Production Cost Estimate Effort
1	4	M	Obtain letter of interest from potential manufacturing partners		4/30/2016				
1	5	T	Conceptual Design	Vice President	2/28/2016			60%	
1	5	M	Aerodynamic Design		1/15/2016			100%	Per DOE/MSI Aerodynamic Design Review (1/19/2016)
1	5	M	Motor Type Selected		3/1/2016			5%	
1	5	M	Economical bearing solution identified		2/28/2016			10%	
1	6	T	Preliminary & Critical Design	Vice President	8/30/2016				
1	6	M	Final integrated compressor/motor design efficiency meets 78%		8/30/2016				
1	6	M	Refrigerant selection complete		8/30/2016				
1		M	Go/No-Go Decision Point (Continuation Report)		6/30/2016				
1	7	T	Prototype Procurement and Assembly	Principal Engineer I	3/31/2017				
1	7	M	LCCP improvement of at least 38% over typical A/C unit		9/30/2016				
1	7	M	Checkout test successful		3/31/2017				
1	8	T	Heat Exchanger Design	Lennox	12/31/2016				
1	8	M	Heat exchanger types for evaluation selected	Lennox	11/30/2015				
1	8	M	Achieve condenser HX cost parity vs. baseline R-410A condenser	Lennox	12/31/2016				
1	9	T	Procure Heat Exchanger Prototype	Lennox	1/30/2017				
1	10	T	Integrated compressor/motor and a/c system tests	Principal Engineer I	4/30/2017				
1	10	M	100% speed test for compressor		4/30/2017				
1	11	T	Final Design	Vice President	6/31/17				
1	11	M	Final manufactured component cost still below $275 per unit (Go/No-Go Meeting)		6/31/17				

Project Dates:

- Start: 10/2015
- End: 6/2017

Current and Future Work

- See Schedule

Project Budget

Project Budget:
- DOE: $999,921 ($362,794 Approved Budget)
- Cost Share: $251,525 ($125,886 Approved Budget) - Lennox International, Inc

Variances:
- Currently no variances specific to project

Cost to Date:
- DOE: $134,406 (CY 2015) + $56,776 (Q1 CY 2016 – End Of Q1 CY 2016)
- Cost Share: $52,867 (CY 2015)

Additional Funding:
- Strategic Partner (Lennox International, Inc.) To Dedicate $251K Cost Share

Budget History					
10/2015– CY 2015 (past)		FY 2016 (Q1 CY 2016– through end of FY 2016)		FY 2017 – 6/2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$134,406	$52,867	$240,375	$71,517	$625,140	$127,141

Next Steps and Future Plans

Next Steps and Future Plans:

- Consider 2-stage compressor
  - Longer lifecycle
  - More refrigerant options
  - Applicable to heat pumps, including cold climate
- Need to investigate higher resolution 3-d printing for various materials