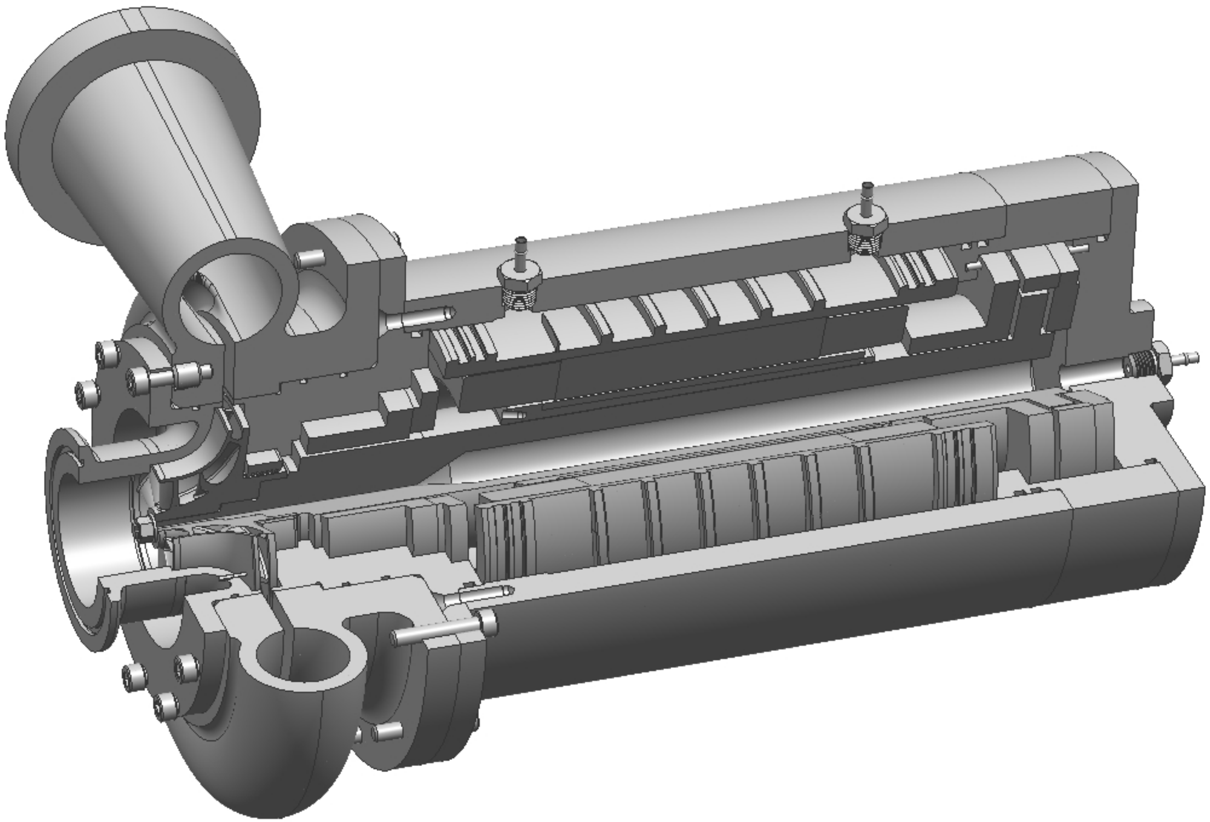
LOW-GWP HVAC SYSTEM WITH ULTRA-SMALL CENTRIFUGAL COMPRESSION

2017 Building Technologies Office Peer Review



Dr. Edward Bennett
Vice President of Fluids Engineering
Mechanical Solutions, Inc.
e-mail: emb@mechsol.com

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 7.5.1 (M21) Checkout test successful
2. Milestone 10.2.1 (M22) 100% speed test for compressor

Budget:

Total Project $ to Date:

- DOE: $502,500
- Cost Share: $129,957 (through 12/31)

Total Project $:

- DOE: $999,921

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:

- The MSI/Lennox team conducted a preliminary and critical design review meeting with the DOE, August 2016
  - Obtained approval for subsequent phase (go/no go)
- Final integrated compressor/motor design efficiency goal meets target objective analytically
- Critical design completed (currently procuring prototype hardware)

Market Impact:

- Initial analytical results demonstrate commercially viable technology
- Commercial partner is interested in pursuing technology beyond current project
- Additional commercial interest in technology

Awards/Recognition:

- None to date

Lessons Learned:

- Business Development negotiations with partners can be very time consuming

Project Objectives

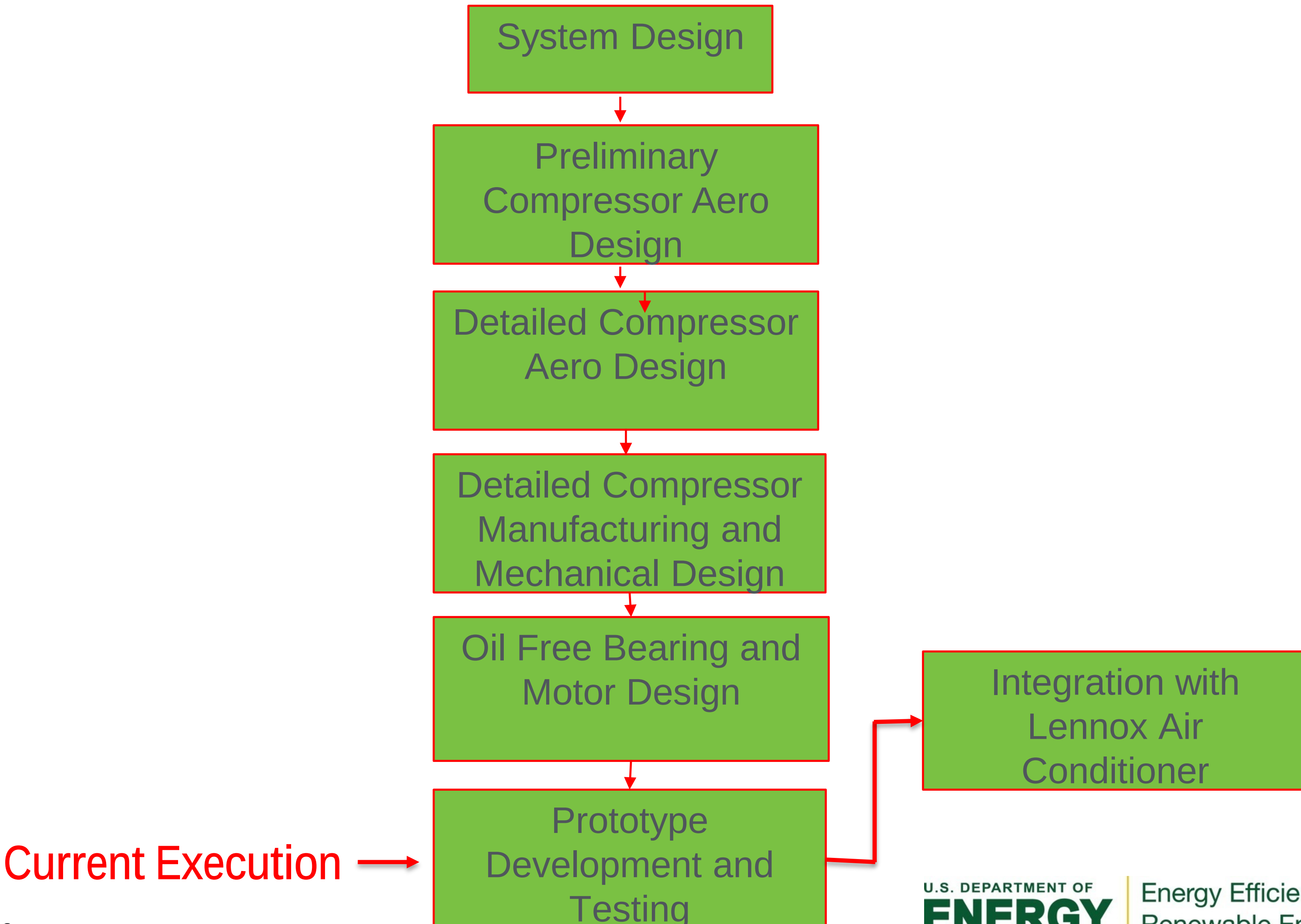
- Design and development of an ultra-small, efficient, maintenance-free, oil-free, inexpensive centrifugal compressor, including aero components, rotor-bearing system, inverter and motor for a 5-ton air conditioning system
- Optimization for partial load efficiency, without sacrificing peak load performance
- 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

Project Integration and Collaboration

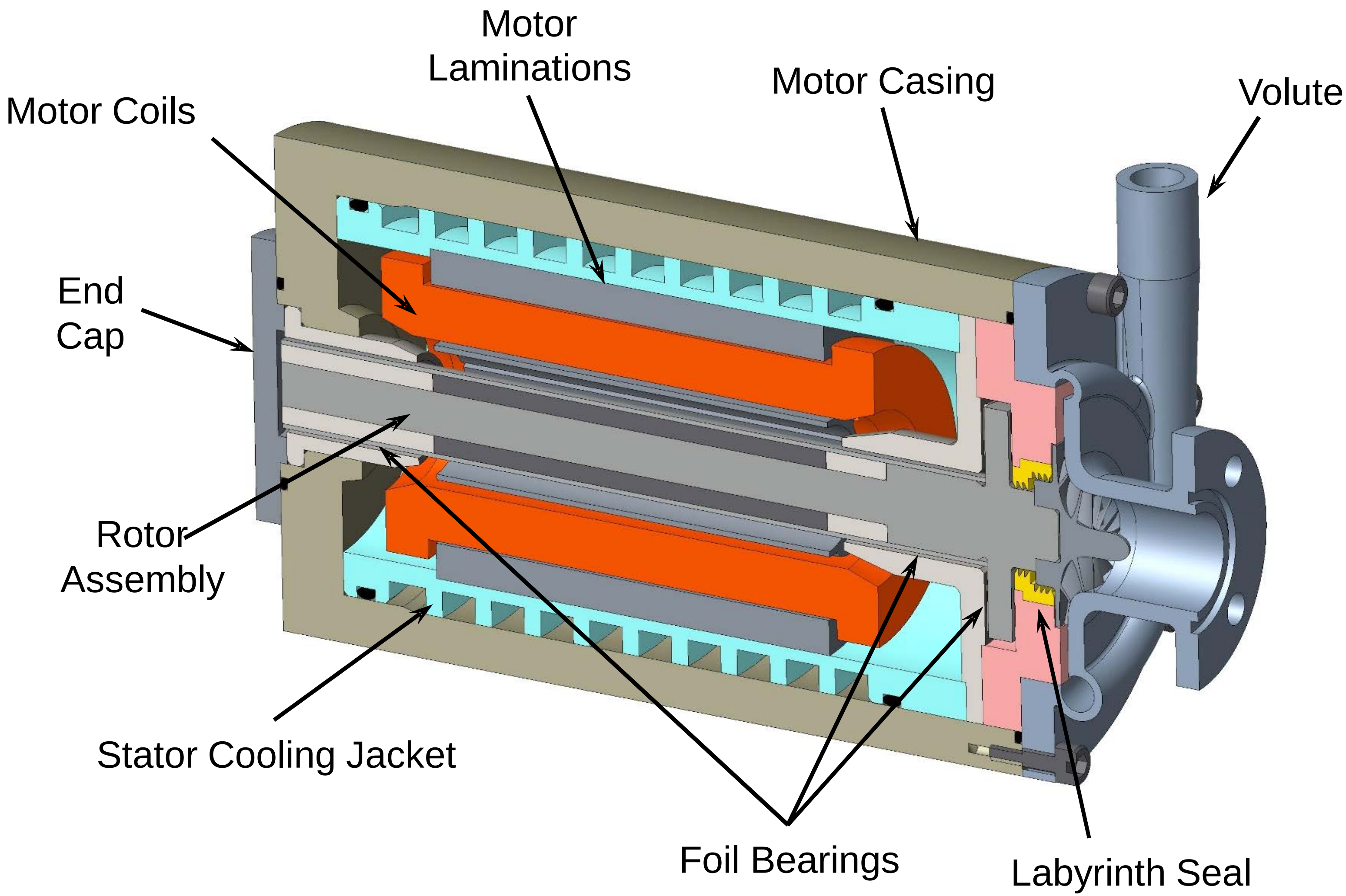
Project Integration:
MSI and Lennox are coordinating system design parameters to guide development. Lennox participates in requirements definition, design reviews, and parallel development.

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

Design and Prototype Development Flowchart



Motor/Compressor Assembly



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

Design Summary

- The MSI/Lennox team has made significant progress since initial Peer Review
- Tasks initiated early focused on establishing preliminary requirements to initiate the design effort for the compressor subsystem (integrated motor/compressor)
  - To establish requirements for the compressor subsystem, Lennox and MSI performed system level cycle studies included the condenser, expansion device, evaporator, and compressor/motor subsystem
- Multiple low GWP refrigerants were considered as part of the system level cycle study
  - MSI conducted component level trade studies for the compressor for all refrigerants in concert with the system level cycle studies to adequately downselect to a single refrigerant.

Design Summary – cont'd

- Detailed aerodynamic designs were undertaken that considered performance of the compressor, material selection, structural limitations, associated deflections, life, manufacturability, and associated cost to procure the compressor
  - Consideration to these parameters resulted in a rigorous iterative process
- Finite element analysis (FEA) using ANSYS Workbench was conducted on the compressor to determine centrifugal as well as pressure/temperature loading on the geometry
- Several materials were tested and evaluated under identical loads and boundary conditions
- MSI generated conceptual level drawings to convey tolerance needs for select manufacturing vendors to assess the ease (or challenges) of producibility and its associated cost
- While multiple manufacturing vendors and machining processes were considered, MSI ultimately coordinated with TURBOCAM for all hardware within the compressor subsystem including housings, foil bearings, seals, etc.

Design Summary – cont’d

- Tasks associated with the design of the high speed electric motor and gas foil bearings were subsequently conducted after the compressor design was established
  - The completion of the compressor design was considered paramount to define requirements for the motor and rotor support system
- To achieve the system level efficiency targets, a complex motor and rotor support system would need to be developed
- During discussion with the vendors, it was discovered that the motor has inherent challenges in obtaining high efficiency
  - High speed motors have high heat and windage losses due to speed of rotation as compared to the losses associated with low speed motors
- MSI conducted trade studies and associated analyses relating to the motor and rotor support subsystem losses
- Given these losses dramatically increase as a function of speed, MSI has expended an extensive amount of time in an attempt to reduce previously referred to losses as much as feasible
  - Trades included reducing the speed of the compressor/motor subsystem, increasing axial length while reducing shaft diameter, types of media utilized to maintain thermal equilibrium within the motor, and type of bearings for the rotor support system

Recent Accomplishments

- Integrated motor compressor efficiency meets/exceeds go/no go criteria
- Team continues to successfully meet Statement of Project Objectives
- Study of various low-GWP refrigerants performed and downselect
- Aero/mechanical design of integrated compressor/motor/bearings completed
- 3-dimensional CAD model generated
- Material compatibility for compressor substantially completed
- Heat exchanger types for evaluation selected
- Downselect design complete and ready for fabrication
- Drawing generation complete for prototype system
- Hardware procurement in-process

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			
					Original Planned	Revised Planned	Actual	% Com-plete
1	1	T	Program Management - Ongoing	Principal Engineer I	9/30/2017	10/12/2017		70%
1	2	T	Requirements Definition	Vice President	6/31/17			90%
1	2	M	First version of Requirements Document complete	Vice President	1/29/2016	2/28/2016		100%
1	3	T	Materials Comaptibility Investigation	Lennox	4/30/2016			97%
1	3	M	Preliminary materials selection complete	Lennox	1/29/2016			100%
1	3	M	Final materials selection	Lennox	7/30/2016			97%
1	4	T	Market Transformation		6/30/2016			95%
1	4	M	Obtain letter of interest from potential manufacturing partners		4/30/2016			100%
1	5	T	Conceptual Design	Vice President	2/28/2016	5/11/2016		100%
1	5	M	Aerodynamic Design		1/15/2016			100%
1	5	M	Motor Type Selected		3/1/2016	5/1/2016		100%
1	5	M	Economical bearing solution identified		2/28/2016	4/28/2016		100%
1	6	T	Preliminary & Critical Design	Vice President	8/30/2016			100%
1	6	M	Final integrated compressor/motor design efficiency meets x%		8/30/2016			100%
1	6	M	Refrigerant selection complete		8/30/2016			100%
1	6	M	Go/No-Go Decision Point (Continuation Report)		6/30/2016			100%
2	7	T	Prototype Procurement and Assembly	Principal Engineer I	3/31/2017			
2	7	M	LCCP improvement of at least 38% over typical A/C unit		9/30/2016			75%
2	7	M	Checkout test successful		3/31/2017			
2	8	T	Heat Exchanger Design	Lennox	12/31/2016			100%
2	8	M	Heat exchanger types for evaluation selected	Lennox	11/30/2015			100%
2	8	M	Achieve condenser HX cost parity vs. baseline R-410A condenser	Lennox	12/31/2016			90%
2	9	T	Procure Heat Exchanger Prototype	Lennox	1/30/2017	2/1/2017		65%
2	10	T	Integrated compressor/motor and a/c system tests	Principal Engineer I	4/30/2017			
2	10	M	100% speed test for compressor		4/30/2017			
2	11	T	Final Design	Vice President	6/31/17			
2	11	M	Final manufactured component cost still below $x 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
- Cost Share: $251,525 - Lennox International, Inc.

Variances:
- Currently no variances specific to project

Cost to Date:
- DOE: $502,500
- Cost Share: $129,957 (12/2016)

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

Next Steps and Future Plans

- Drawing generation complete for prototype system
    - Hardware procurement in-process
- Procure Compressor Hardware Through March/Early April 2017
- Initiate Checkout Sub-system Test Loop At MSI For Short Duration Checkout Testing
- Support Lennox In Integrated Test Loop Design (To Be Conducted In Texas)