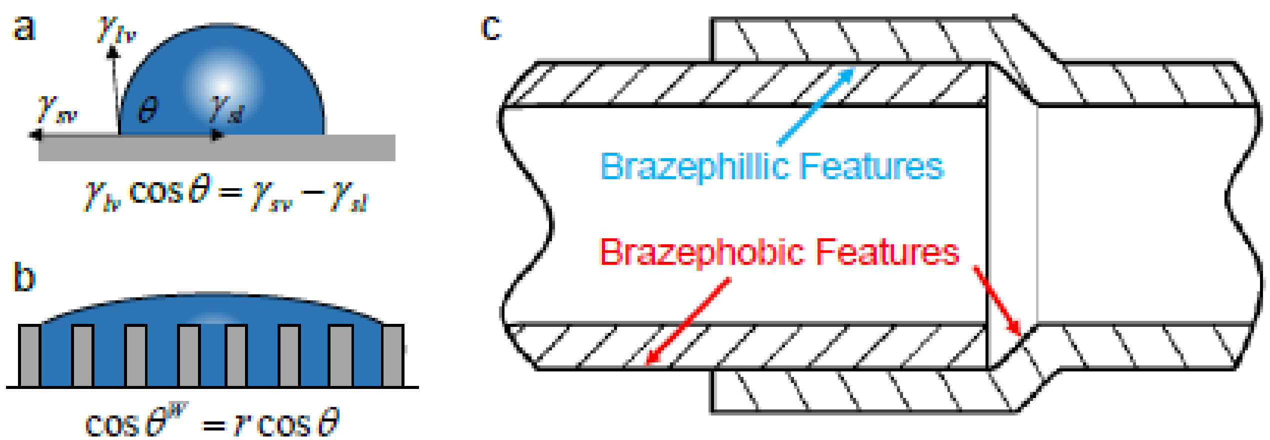
Improved Braze Joint Quality Through use of Enhanced Surface Technologies



Trane US Inc., a company of Ingersoll Rand
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Project Summary

Timeline:

Start date: 10/3/2016

Planned end date: 10/1/2019

Key Milestones

1. Milestone 1; 1/27/17 – Rationale for selection
2. Milestone 2; 2/21/17 – Potential landscape geometries
3. Milestone 3; 5/31/19 - Candidate for maturation and manufacturability assessment
4. Milestone 4; 10/3/19 - Manufacturing and proof of concept verification

Budget:

Total Project $ to Date:

- DOE: $208,522
- Cost Share: $54,431

Total Project $:

- DOE: $222,621
- Cost Share: $57,956

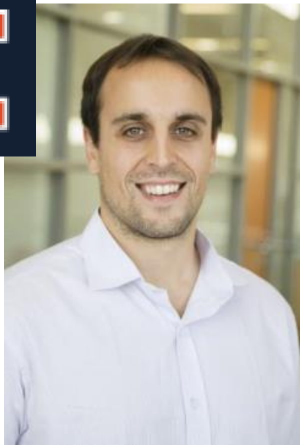
Key Partners:

University of Illinois at Champaign/Urbana

Project Outcome:

Maintenance of life cycle HVAC equipment efficiency by refrigerant retention through use of enhanced surface braze joints to reduce refrigerant leakage. Ultimate goal of reduction in refrigerant leaks by 25% and reduction in braze materials by 10%.

Team



Nenad Miljkovic – UIUC lead investigator

Kalyan Boyina – UIUC primary grad student researcher

Brian Westfall – PI - VP Advanced Manufacturing Engineering

Melanie Rowe – AME braze engineer

Laura Murry – Materials Engineer

Ron Cosby – NA Commercial HVAC Technology Leader

Challenge

Problem Statement: One of the causes of reduced efficiency during the life cycle of commercial and residential HVAC products is loss of refrigerant charge

- Systems leave manufacturing facilities having been proofed and leak checked
- Over time charge is lost through tiny joint leakage due to vibration, structure movement, etc.
- Loss of charge from an optimized system can result in dramatic efficiency reductions dependent upon the type of system and components used

Target Market and Audience: Commercial and residential HVAC industries and their customers will benefit from the technology development to reduce refrigerant leaks. This $50+B market's energy consumption increase due to refrigerant leakage can be as high as 30 TBtu over a 10 year span for a single market segment.

- Reduced customer life cycle energy consumption and cost
- Reduced direct and indirect GHG emissions

Approach

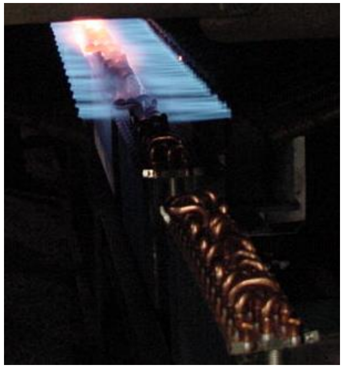
Approach: Engineered surface structures will be used to wick braze alloy and flux to brazing joint areas to create stronger and more robust braze joints. These surfaces for brazing would be braze alloy/flux phobic or philic to help direct the brazing materials.

Key Issues:

1. Surface topology identification through wicking capability and strength improvements
2. Cost of Surface Application
3. Ease of Manufacturability

Distinctive Characteristics: Attacks issues within a mature manufacturing process methodology through use of new surface topologies

Impact



Project Output: Life cycle improvements in HVAC&R equipment energy consumption through reduction in braze joint refrigerant leaks.

Near-term outcomes: Surface enhancement identification that enhances braze joint strength and ability of components to withstand thermal/pressure cycling capability. Investigation and validation of manufacturing processes.

Intermediate outcomes: Implementation of use in round tube plate fin coil manufacturing processes

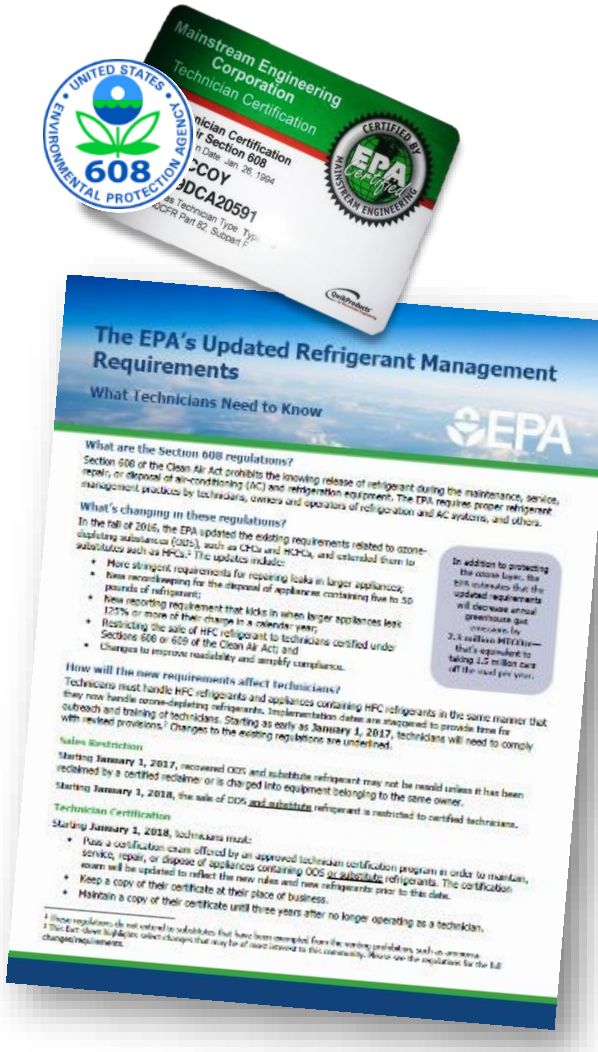
Long-term outcomes: Use of surface enhancements throughout commercial, residential HVAC, transport refrigeration and other industry brazing processes on all types of braze joints to minimize refrigerant leakage.

Impact

Reduced customer lifecycle costs: Reduction of leaks in HVAC/R systems will help eliminate the quantity of leak inspections required by EPA 608

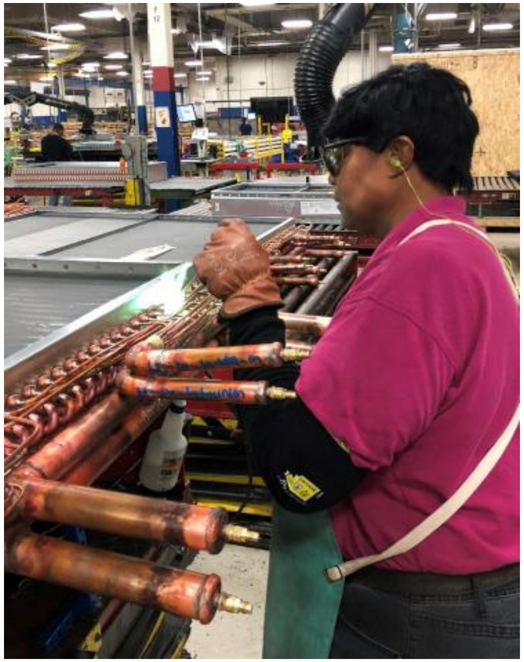
EPA 608 Refrigerant Management Regulation

Covered	CFCs, HCFCs, HFCs & HFOs *(including all blends)*	
Recordkeeping	> 5 lbs. for disposal > 50 lbs. for service/repair	Jan 1 2018
Allowable Leak Rates (systems >50 lbs.)	Industrial Process Ref: 30% Commercial Ref: 20% Comfort Cooling: 10%	Jan 1 2019
Leak Inspections	If allowable leak rate is exceeded, then 50-500 lbs. – annual inspections > 500 lbs. – quarterly inspections	Jan 1 2019
Chronic Leaks	≥ 125% charge loss (in a calendar year), detailed reports must be filed (find & repair equipment)	Jan 1 2019



https://www.epa.gov/section608/revised-section-608-refrigerant-management-regulations

Impact



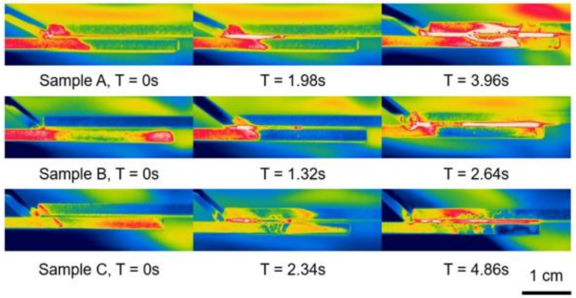
Technology Differentiation:

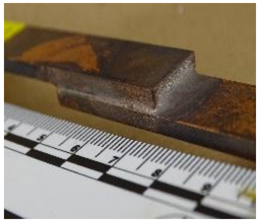
- Project attacks a very mature manufacturing process to improve robustness of braze joints to garner energy savings
  - Reduce energy consumption through small changes on billions of U.S. braze joints to garner life cycle energy consumption improvements
  - 10-50 TBtu of savings with improvements in annual refrigerant loss reduction
- Final year of project examines manufacturability to ensure that additional manufacturing tasks do not negatively impact manufacturing and/or design cost
  - Cost of surface enhancement
  - Brazing takt time changes
  - Braze alloy cost improvements

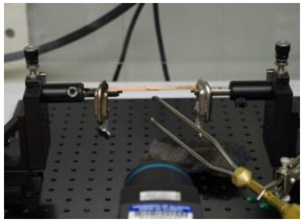
Progress

Overview of Accomplishments:

- Landscaping of existing technologies and information on microstructures
- Experimental test rig designed and built to observe the interaction between the braze material and modified copper surface and ensure repeatability of measurements
- Microstructure surface assessment on flat plate geometries
- Braze alloy propagation on flat plate geometries
- Initiation of microstructure surface assessment on real tube geometries and braze joints
  - Microstructure surface assessment
  - Microstructure coupled w/ macrosurface geometries
- Examination of braze alloy savings

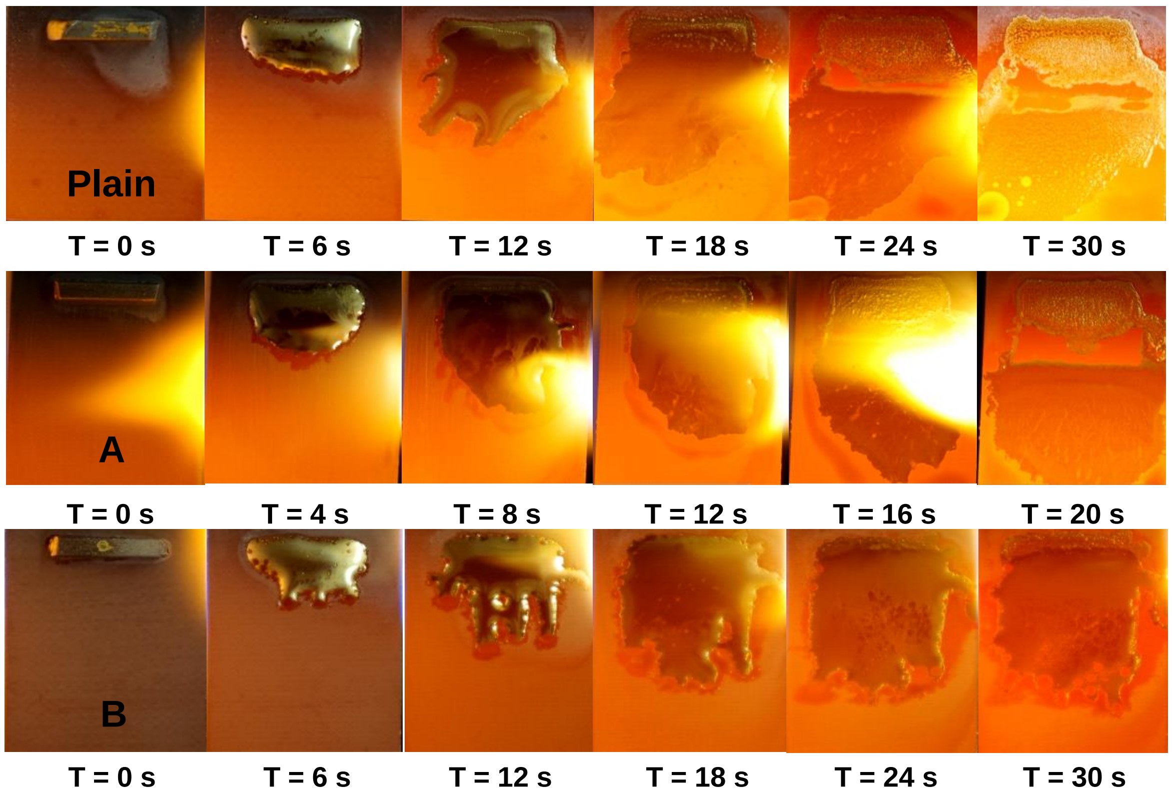






Progress

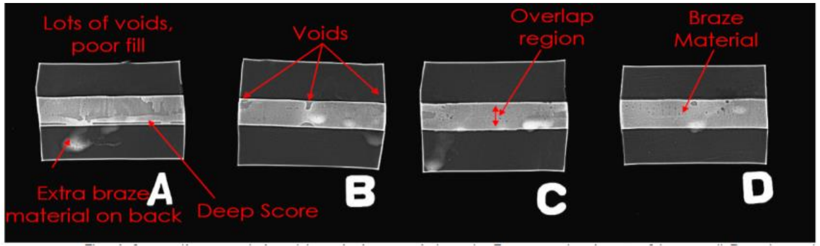
- UIUC examined flow spreading properties of braze alloys both with and without surface modification
- Flow visualization utilized to indicate differences between surfaces and braze alloy propagation with differing torch size, flame location and temperature distribution



Stationary Flame, single alloy piece

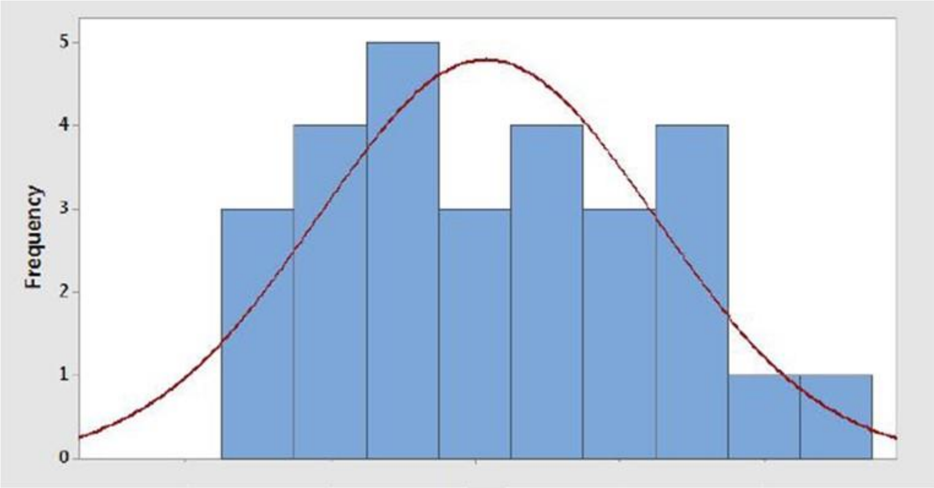
Progress

- Moved from from flat plate braze samples to tube braze samples with different surface enhancements after seeing ability to change brazing characteristics on flat plate
  - Manual brazing
- Conducting burst strength tests to determine initial braze joint strength assessment for enhanced vs. unenhanced surfaces
  - Comparison of different enhanced surfaces against each other on realistic HVAC braze joints
- Sectioning of tube braze joints to determine if braze voids and porosity issues exist
- Voids and porosity examination inconclusive between plain and modified surfaces, i.e., no discernable differences in the small sample sizes

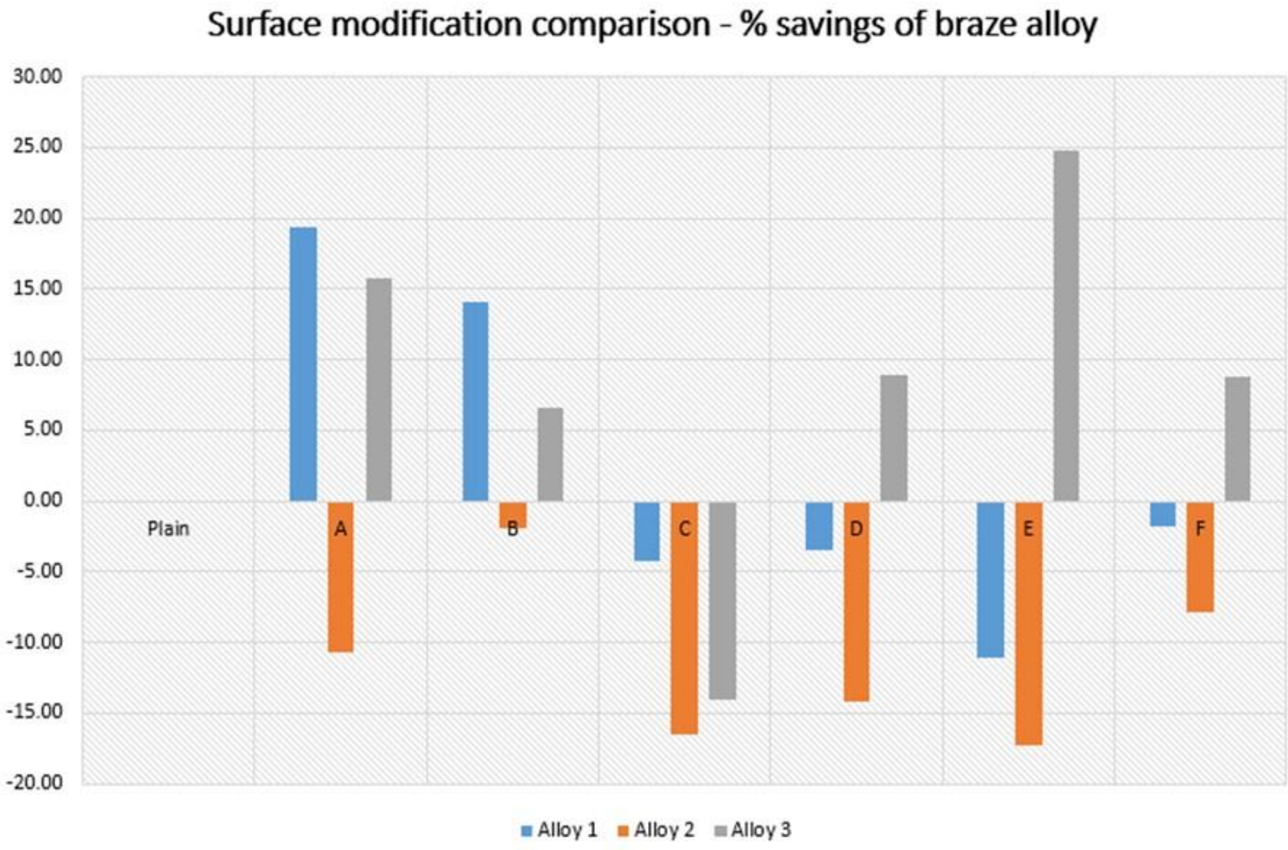


Progress

- Burst strength tests did not indicate any differences between plain and enhanced surfaces
- All joints failing in base metal, not in braze joint
- Attempted to shorten braze length below standard length to move failure mechanism into braze joint
- Unfortunately, joint depth insertion varied from 1X - 3X desired joint thickness – did not adjust bell depth but attempted to control insertion depth
- Inconsistency on insertion depth resulted in inconclusive results for both burst strength and braze joint void and porosity



Progress

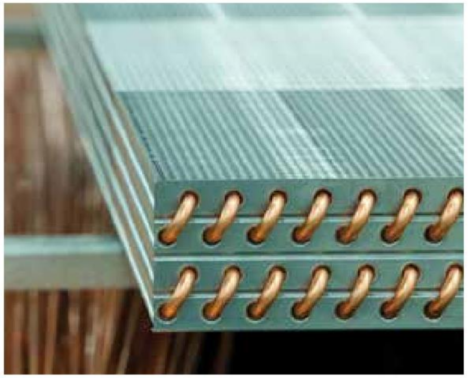


- Braze joint alloy usage was examined to determine potential cost savings with use of microsurfaces
- Inconsistent results across surfaces, braze alloys and tube OD

Remaining Project Work

Work remaining:

- Examination/comparison of plain geometry coil vs. enhanced microsurface geometry coil – coils autobrazed to remove manual brazing variation– 2Q19



- Larger scale braze joint creation and brazing – 3Q19
  - Utilization in a near manufacturing based representation
  - Actual brazers – no automation
  - Larger number of joints
  - Strength and sectioning analyses
- Initial assessment of manufacturability – 3Q19
- Reliability testing analysis versus current brazing techniques – 3Q19
- Cost analysis of technology – 3Q19
- Commercialization plan – 4Q19

Stakeholder Engagement

Downstream implementation:

- Pending technical viability for surface strength, joint integrity and manufacturing cost justification, the PI and Trane team will move to implement within Trane manufacturing facilities
- Initiate with copper round tube plate fin coil manufacturing locations
  - Multiple facilities for coil manufacturing for commercial HVAC equipment globally (unitary rooftops, WSHP, chillers, etc.)
- Assuming acceptable implementation and improved lifecycle benefits would move to pursue in adjacent areas
  - Aluminum round tube plate fin coil manufacturing locations (residential HVAC)
  - Larger interconnecting piping braze joints (unitary rooftops, WSHP, chillers, transport refrigeration)
  - Dissimilar metal braze joints (unitary rooftops, chillers, transport refrigeration, residential HVAC) utilizing microchannel heat exchangers
- Determine applicability for cost savings and/or strength improvements on non-refrigerant bearing braze joints

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Thank You

Trane U.S. Inc. and University of Illinois
Brian Westfall – VP Advanced Manufacturing Engineering
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REFERENCE SLIDES

Project Budget

Project Budget: Chart Below
Variances: Project ending prior to soft tooling expense ordering
Cost to Date: 93%
Additional Funding: None

Budget History					
3/20/2017 – FY 2018 (past)		FY 2019		End date June, 30, 2019 (total)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$208,122	$54,331	$14499	$3625	$0.00	$0.00

Project Plan and Schedule

Project Schedule		
Project Start: 10/3/2016		Completed Work
Projected End: 6/30/2019		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	FY2017				FY2018				FY2019			
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)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Rationale for selection												
Q2 Milestone: Review of landscaping candidates												
Q2 Milestone: Review of generated surfaces and initial manually brazed joint analysis												
Q3 Milestone: Initial assessment of braze joint improvements												
Q4-Q8 Milestone: Initial Assessment of microstructure enhancement candidates for further maturation												
Q4-Q8 Milestone: Initial Assessment of microstructure enhancement candidates for further maturation												
Current/Future Work												
Q9-Q10 Milestone: Automated braze microstructure coil build												
Q10 Milestone: Microstructure autobrazed coil analysis												
Q10 Milestone: Project final documentation												

Project Plan and Schedule

Schedule slips:

- Assessment of microstructure enhancement candidates continued to slip as inconsistencies were seen with brazing
    - Results inconsistency with tube OD
    - Lack of burst in braze material necessitated further work moving to shorter braze joint lengths
- Braze alloy usage results were inconsistent and required additional trials

Future Work:

- Autobrazed coils with and without enhanced microsurface
- Comparison of braze joints on autobrazed coils