Freezing Damage to Coolers at the NASA-GRC 10x10 Supersonic Wind Tunnel

Prepared by: Jim Roeder, 10x10 SWT Facility Engineer
Jonathan Kubiak, 10x10 SWT Facility Manager

For the 130th Semi-Annual Meeting of the Supersonic Tunnel Association, International (October 7-10, 2018)

Overview of the 10x10 Supersonic Wind Tunnel

The 10x10-foot supersonic wind-tunnel tests supersonic propulsion components such as inlets and nozzles, and propulsion system integration and full-scale jet and rocket engines. Aerodynamic force and moment, sonic boom mitigation and advanced aircraft models have been successfully tested in the 10x10 SWT.

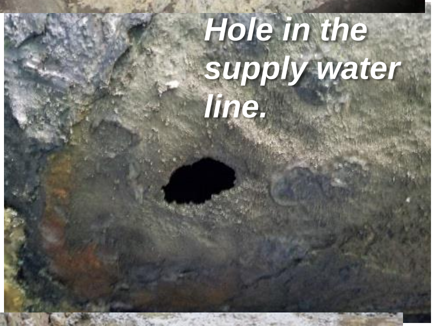
Test section:	10 ft high by 10 ft wide by 40 ft long
Mach number:	0 – 0.36 and 2.0 – 3.5
Altitude (supersonic operation):	50,000 – 154,000 ft (aerodynamic cycle) 57,000 – 77,000 ft (propulsion cycle)
Reynolds no./ft (supersonic operation):	0.1 to 3.4 x 10^6 (aerodynamic cycle) 2.2 to 2.7 x 10^6 (propulsion cycle)
Dynamic pressure:	20-720 psf (aerodynamic cycle) 500-600 psf (propulsion cycle)
Total temperature:	540°R-750°R (aerodynamic cycle) 520°R-1140°R (propulsion cycle)

Description of Freezing Event

What happened?

- On January 2nd, 2018 a large underground leak occurred in the cooling tower water (CTW) supply pipe located in the 10x10-Foot SWT complex. The water supply was shut off quickly to minimize discharge into a local storm drain, and to prevent undermining of the nearby foundation and retaining wall.
- Outside air temperatures were continuously between 3°F and 20°F for several days before, during and after the CTW shutdown (13°F /3°F on Jan. 1st,15°F/7°F on Jan 2nd).
- Cooler 2, Ross cooler, and Cooler 1 (lesser extent) are located in sections of the wind tunnel or exhaust piping that are exposed to outside air temperature. CTW flow is normally maintained through these coolers for freeze protection.
- Facility personnel took immediate emergency action to drain all three coolers (Cooler 1, Cooler 2, and the Ross cooler) in order to protect these critical components.
- Upon inspection, it was discovered that before everything could be drained completely water froze in tubes of Cooler 2 and the Exhauster (Ross) Cooler causing damage. Cooler 1 did not sustain any damage (likely due to greater % in enclosed conditioned space).

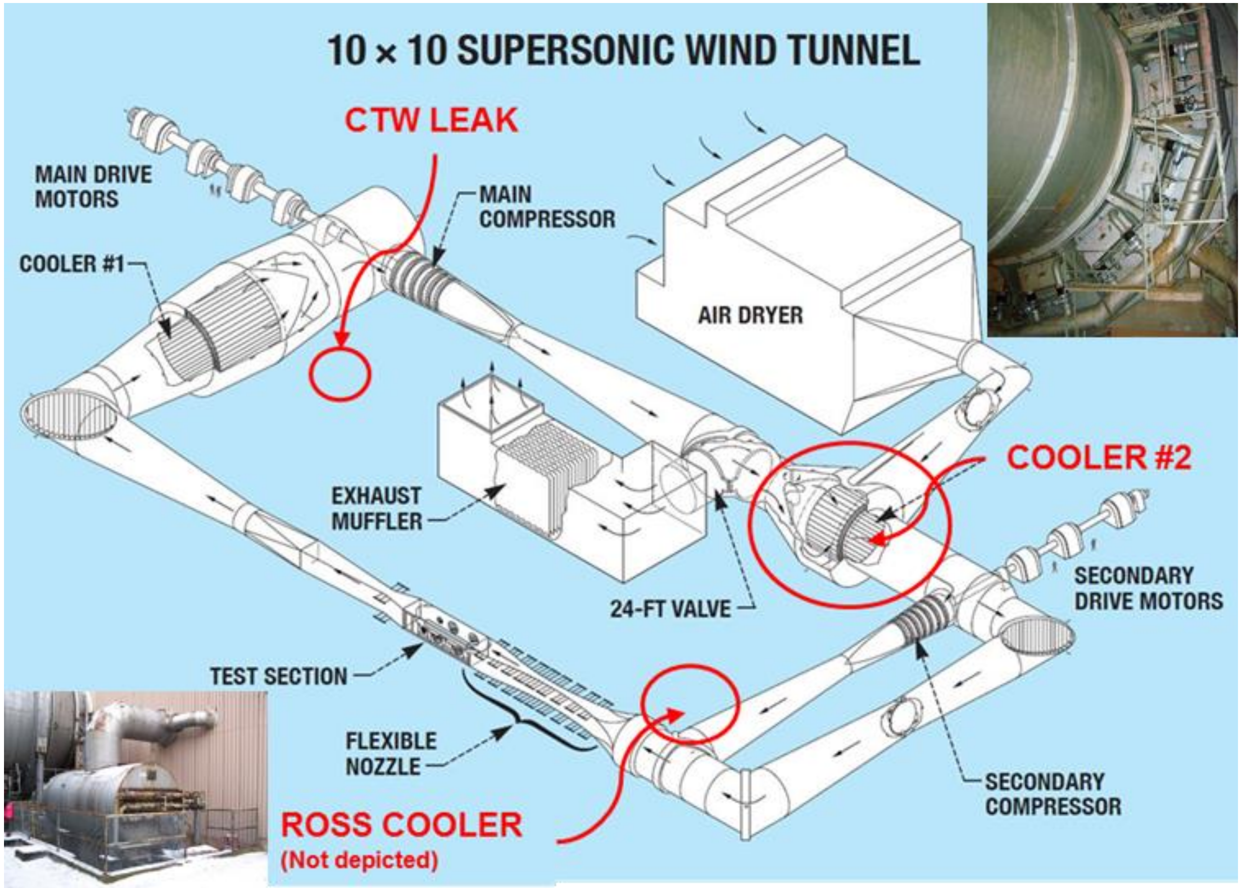
Excavation of the CTW supply line.



Hole in the supply water line.

Welding repairs of the CTW pipe.

Cooler Size and Description



Cooler 2

- Circular arrangement of 14 tube bundles each containing 312 finned copper tubes and weighing ~17,000 lbs each.
- Reduces air temperature prior to entering secondary compressor.
- Cooling tower water (CTW) flowing through tubes cools up to 2680 lbm/s of tunnel circuit air flow from 310°F to 100°F.

Ross Cooler

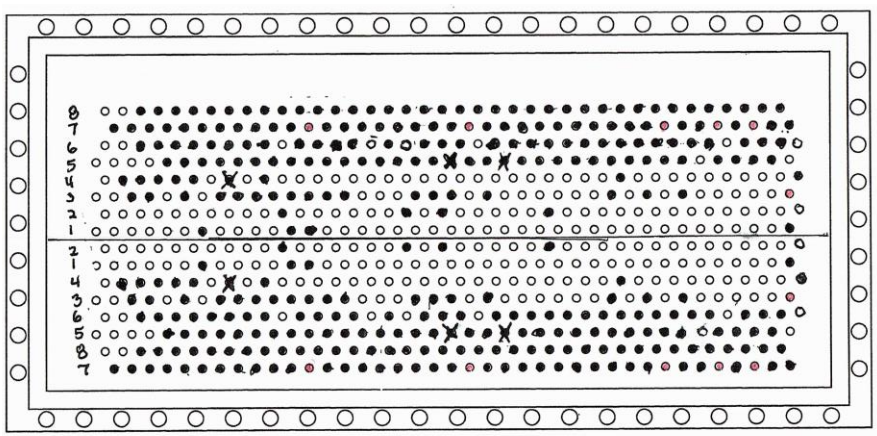
- Reduces temperature of air prior to entering exhaust equipment.
- CTW flowing through finned copper tubes (3 tube bundles) cools up to 130 lbm/s of tunnel exhaust air flow from 290°F to 100°F.

Damage Found

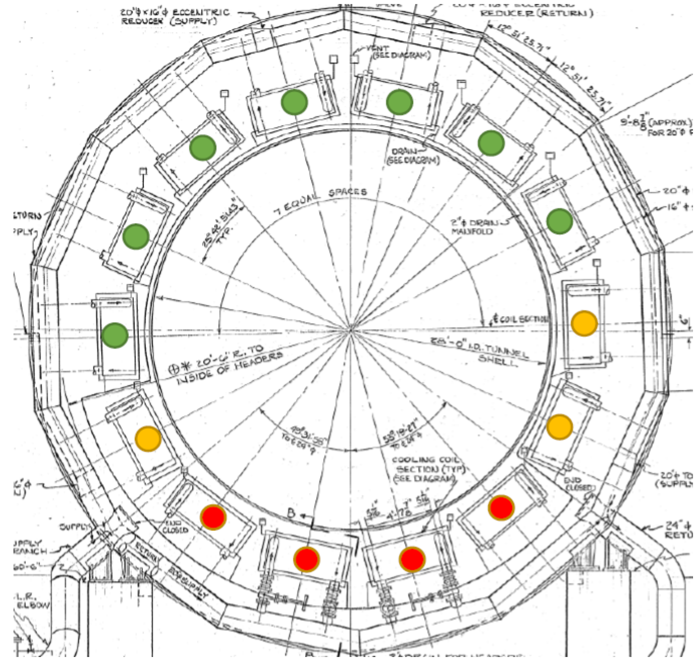
- Visual inspection of Cooler 2 found multiple signs that freezing damage had occurred (icicles, split tubes).
- A water level sensor in the air-side of the Ross cooler indicated that it too sustained damage.

Damage Evaluation

An assessment of the coolers was contracted. All waterboxes were removed from Cooler 2 and the Ross Cooler and all U-tubes were pressure-checked. Hundreds of tubes found damaged.



Typical tube sheet map showing failed tubes



Extensive damage occurred to 7 of 14 cooler 2 tube bundles and all 3 Ross cooler tube bundles. (Acceptable loss was determined to be 5% per bundle.)

Causes and Contributing Factors

- Underground water leak & resulting shutdown of cooling tower caused loss of freeze protection flow through 10x10 coolers.
- Cooler 2 and Ross Cooler were not drained sufficiently before freezing occurred.
- Contributing factors…
  - CTW system supply and return valves leaked, which prevented the coolers from being isolated from the cooling tower and slowed the draining process.
  - The pitch of some (possibly all) cooler tube bundles is slightly away from the waterboxes. It is likely the tubes do not fully drain.
  - Unusually cold air & water temperatures at cooler tube bundles at the time of cooling tower shutdown, caused by two conditions: extreme weather cold spell; CTW supply temperature much colder than usual.

Causes and Contributing Factors

- Contributing factors…
  - Underground cooling tower water piping on the lab is 63 years old and degrading in condition. Thin walls on the piping at the location of the leak may have contributed to the failure during the cold weather conditions.
  - Institutional (HVAC) loads were moved to smaller chilled water plants to save energy. It is suspected that this has created a problem unique to the 10x10 cooling tower. Historically, the CTW supply has run around 75°F in the winter. Without the institutional load it is around 45°F. Other cooling towers on the lab still have a heat load from continuously running service air compressors to help keep the water temperature warm. With a lower water supply temperature it may have taken a shorter amount of time for the water in the tubes to reach freezing.
  - Ramification of release of water into storm sewers was not well understood and thus never considered as an emergency action. Emergency plans and procedures to be revisited.

Recovery and Impact

- Seven (of 14) tube bundles from cooler 2 and all three Ross cooler tube bundles have been removed from service and sent off-site for repairs.
- Replaced all supply and return valves on Cooler 2 and the Ross Cooler.
- Bundles are being completely re-tubed (copper tubes with embedded aluminum fins)
- Impact to wind tunnel test schedule: ~14 months.
- Current schedule anticipates completion of cooler repairs by end of February 2019, including one month of checkout and tunnel reactivation.

Freeze Protection Plans

- Additional low temperature monitoring (24/7) being implemented around coolers.
- Evaluate existing pitch of cooler tube bundles (Lidar survey in process) and (if possible) correct to allow proper drainage.
- Implementing preventative maintenance tasks to check for CTW valve leakage.
- Engineering study needed to evaluate alternatives (air purge, vacuum, backup circulation, heat, etc.), followed by implementation.

Lessons Learned

- Backup (or alternative) to cooling tower water flow is needed for cooler freeze protection.
- Improved low temperature monitoring needed around cooler tube bundles.
- Coolers will not fully drain unless pitch is corrected.
- CTW isolation valves are important for cooler protection, and should be checked for leakage regularly.
- Emergency plans and procedures to be revisited.