STUDY OF SONIC BURNER, CARLIN BURNER AND INNOVATIVE MAPPING TECHNIQUES FOR POWERPLANT FIRE TESTING

2019-05-14

PRESENTED BY: DR MARY KELLY (RESONATE)





BATTLE OF THE BURNERS – PART 2

Resonate TESTING LIMITED

www.resonatetesting.com

T: +44 28 9073 6390 Company No: NI634844

Premise – why are we doing this study?
Presentation overview

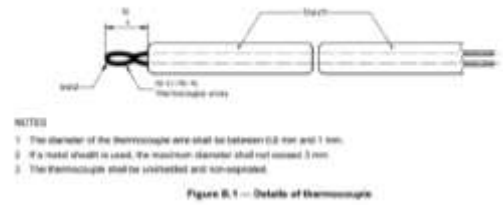
Premise

Comparison of new sonic burner, with existing burners carried out to add to the body of knowledge and increase consistency between labs for powerplant/systems testing aiding in providing direction for future trials.

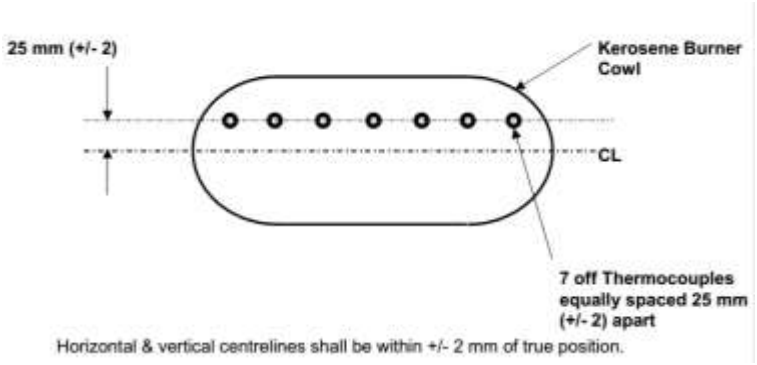
Presentation overview

- Equipment used
- Modifications to Sonic
- Calibration comparison of Carlin and existing Sonic configuration
- Calibration comparison of Carlin and Newly modified Sonic Configuration
- Novel mapping techniques to compare the burner flames
- Conclusions and future work

TC Rake – Temperature Calibration



Brand New TC's Used in Round 1 – Existing in Round 2



- 7 type K thermocouples
- 1-inch apart (25mm)
- 1-inch above centreline
- 4-inches away from cone
- 3mm external sheath
- 4-6mm exposed tip
- 24 AWG (0.5mm) wire

Compliant with BS EN 60584.1 Pt4 Class 1

375°C to 1000°C ±0.004 . |t| → ± 40°C

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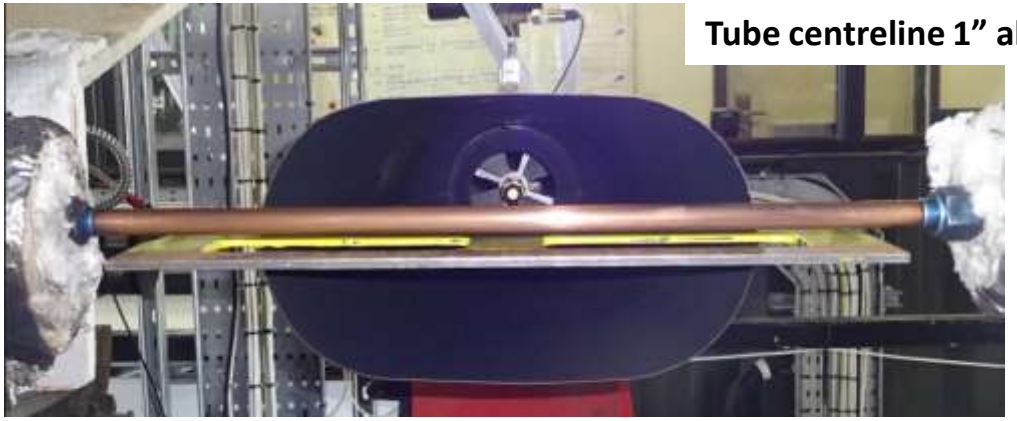
Copper Tube – Heat flux Calibration



Tube centreline 1” above burner cone centreline

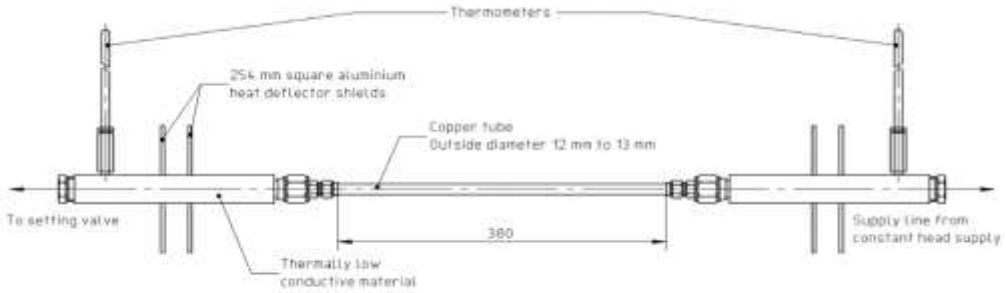
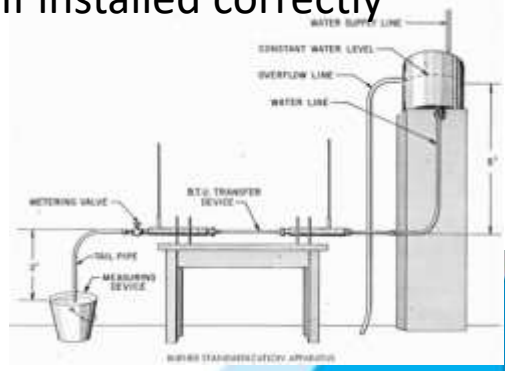


Figure B.4 — Overall view of the mounting of the standard heat flux density measuring tube

RTD’s for temp measurement offer a better solution than Glass bulb thermometers if installed correctly



- 500 lb/hr, 1 US gallon, 3.8 litre per minute flow water
- 50-71˚F input temp,
- minimum of 9˚F temperature increase required

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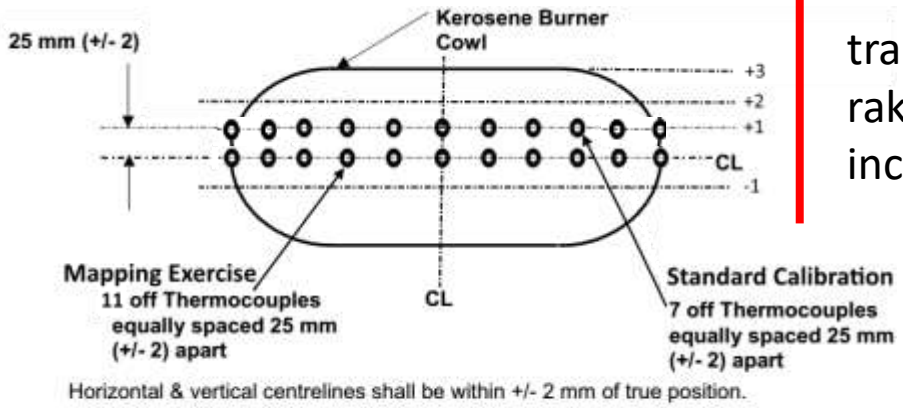
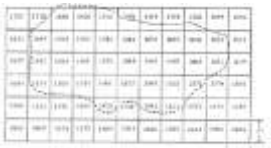
11 TC Map – 1” vertical Increments & 1” TC spacing



transitioning rake with 1” increments.

FIGURE 2 - FLAME TEMPERATURE MEASUREMENT POSITIONS FOR KEROSENE BURNER

Flame temperature mapping
- Engineering Report 3A CARLIN 200 CRD

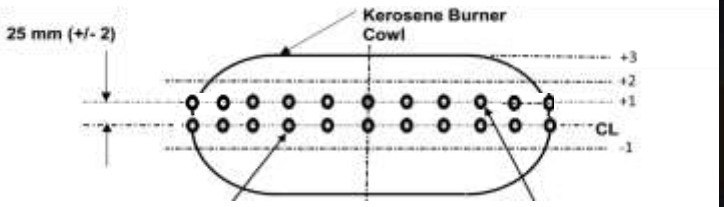


Burner Map looking into the Burner [°F] - Max Values

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	Average Central 7 TC's
Level 6	1420.0	1738.0	1850.0	1908.0	1912.0	1798.0	1777.0	1725.0	1686.0	1579.0	1204.0	1808.0
Level 5	1671.0	1869.0	1947.0	1983.0	1981.0	1881.0	1894.0	1859.0	1848.0	1823.0	1611.0	1910.4
Level 4	1697.0	1843.0	1919.0	1942.0	1972.0	1885.0	1942.0	1908.0	1886.0	1852.0	1679.0	1922.0
Level 3	1634.0	1874.0	1904.0	1936.0	1961.0	1877.0	1947.0	1915.0	1871.0	1794.0	1573.0	1915.9
Level 2	968.0	1323.0	1490.0	1609.0	1825.0	1766.0	1882.0	1813.0	1707.0	1474.0	1159.0	1724.6
Level 1	602.0	805.0	1034.0	1175.0	1389.0	1363.0	1536.0	1389.0	1214.0	964.0	684.0	1300.0

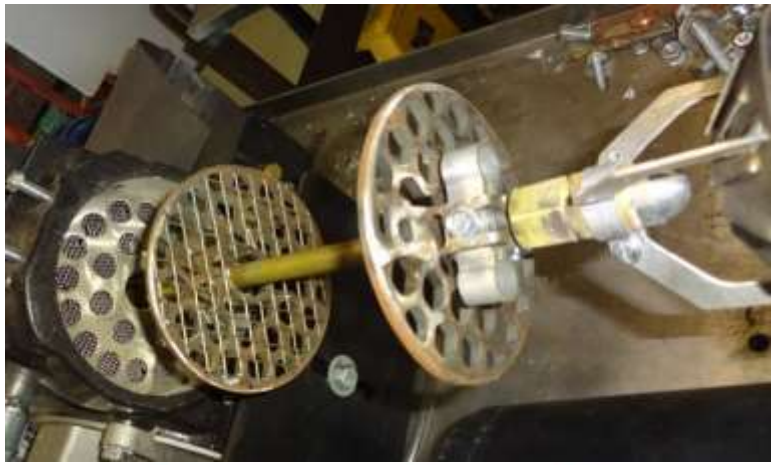
11 TC Map – 1” vertical Increments & 1” TC spacing- fire board/firewool

Transitioning rake with 1” increments.



Carlin 200 CRD

Engineering report 3A



Acceptable Modified Burners:

CARLIN 200 CRD, manufactured by the Carlin Company, 912 Silas Deane Highway, Wethersfield, Connecticut 06109, shown in figures 5 and 6, was modified in the following manner to produce a diffused 6-inch (vertical) by 11-inch (horizontal) sized flame with homogeneous temperature gradiant. Note: Carlin 200 CRD AS 1055 incorporates these following modifications and may be purchased directly.

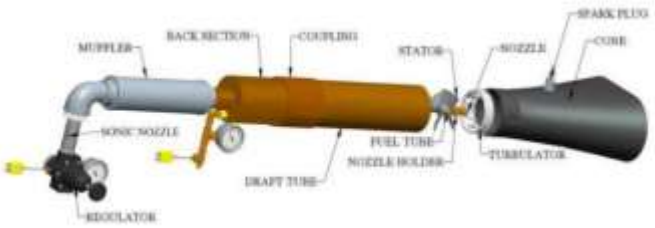
1. An 80 fuel nozzle rated at 2.25 gal/hr. and pressure adjusted to deliver 2.04 gal/hr. at 97 psig was installed.

2. The retention and throttle rings plus the support and forward extension were removed.

3. A flat-plate disc, approximately 4 inches in diameter and randomly punched with ten 1/2-inch holes, was installed 4 inches aft of the fuel nozzle tip. This provided support and centering of the oil delivery tube.

Sonic – Existing configuration

Supplier : Marlin Engineering



Fuel Nozzle
FAATC data from presentations (as late as 2017):
2.0 gph 80°B Delevan nozzle, 100 psi fuel, 40/50 psi air
FAATC config Resonate used for this test:
2.0 gph <u>80°W</u> nozzle, 100 psi fuel, 50 psi air

Ignitorless stator
Muffler foam retained with wire
Turbulator – no flame retention head

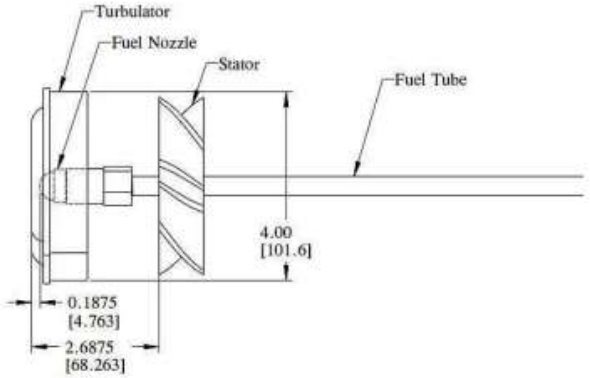


Figure 7-S-17. Typical Configuration of the Stator and Turbulator

supplied by Marlin Engineering, part number ME1512-1.

Figure 7-S-13. Stator

Figure 7-S-14. Turbulator, Front View and Back View

12. Safety Wire Affixed to inside of the Muffler for Restrainin

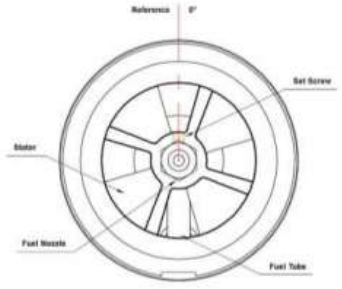
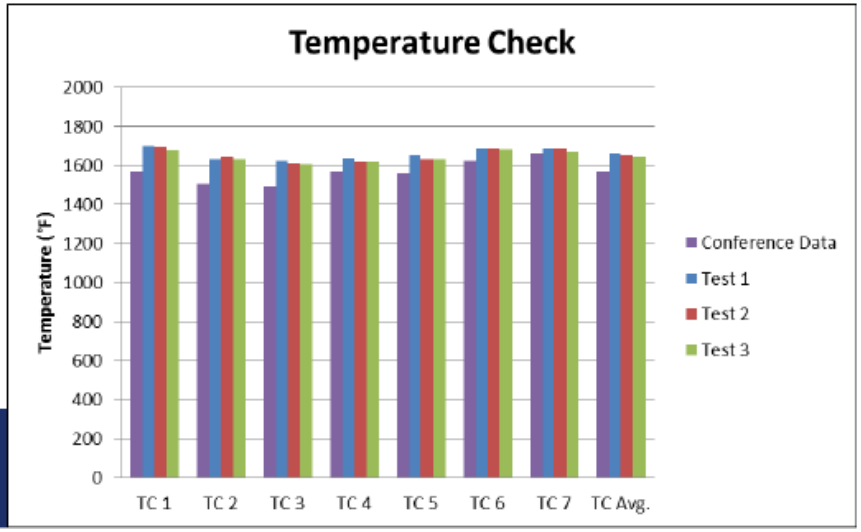


Figure 7-S-29 Stator Axial Position (looking into draft tube)

Next Generation Fire Test Burner For Powerplant Fire Testing Applications – Summer, Rehn, Nov17

Burner Settings

- Nozzle: 80° B 2.0 gph
- Flow-checked 2.00 gph @ 102 psi
- Air Pressure: 50 psi
- Copper Tube Heat Flux (3 test average): 5111.3 Btu/hr
- Temperature check (first 3 tests with brand new 1/8" exposed-bead thermocouples



Powerplants Fire Test Development
November 1, 2017

Innovative R&D – Sonic Burner Modification – Round 1

Objective: Produce temperature and heat flux output data which demonstrate the modified Sonic burner can replicate Carlin conditions - i.e. Sonic can be calibrated according to AC20-135 guidance using the same equipment to produce similar results to a traditional oil burner.

Danfoss 80°H 2.0 GPH

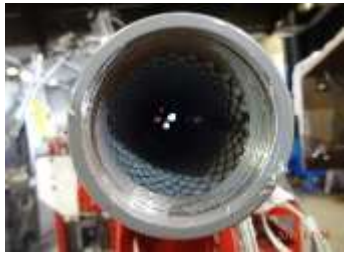
Muffler foam was removed

Added Carlin type turbulator on fuel nozzle fitting

Innovative R&D – Sonic Burner Modification – Round 2

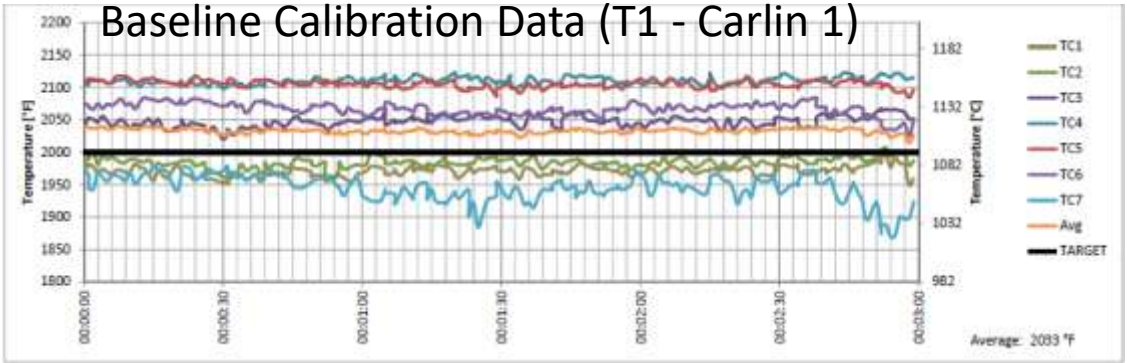
Monarch 80°PLP 2.25 GPH

Muffler foam was removed



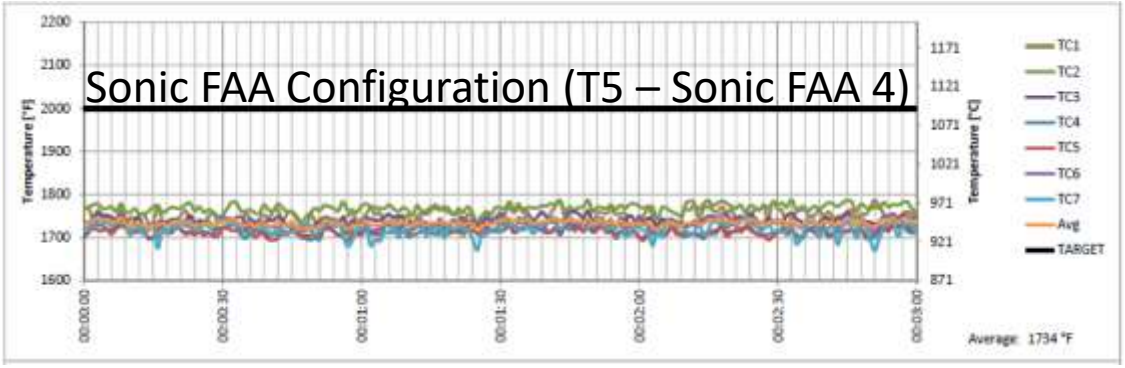
Added Carlin type turbulator on fuel nozzle fitting

Baseline Calibration Data (T1 - Carlin 1)



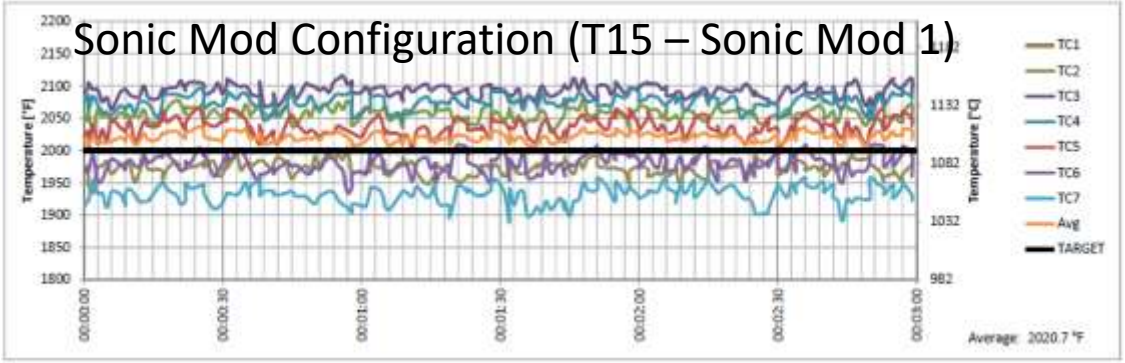
	Temp (°F)	Heat Flux (BTU/hr)
Avg	2033	4836
Min	1869	4509
Max	2123	4938

Sonic FAA Configuration (T5 – Sonic FAA 4)



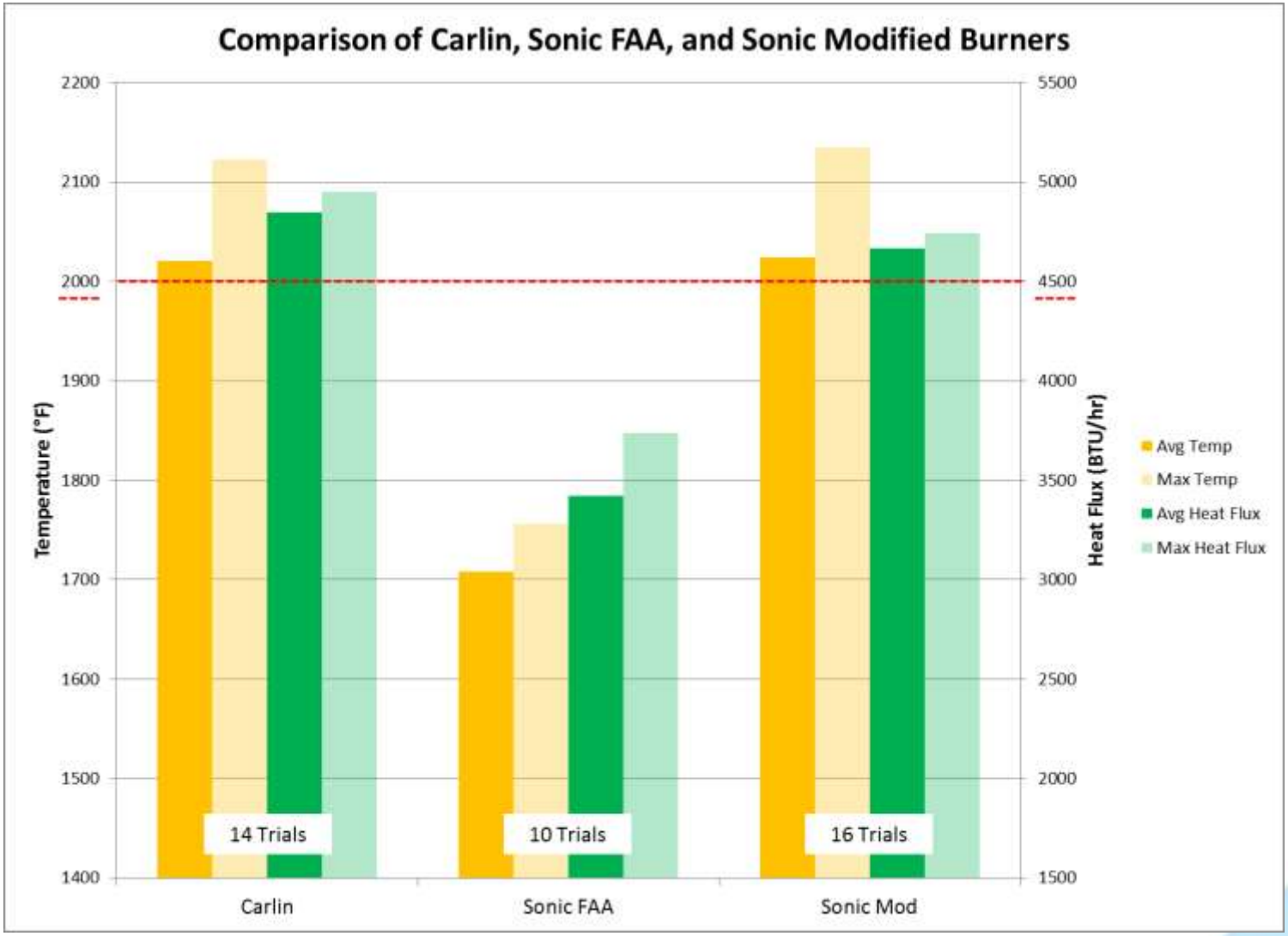
	Temp (°F)	Heat Flux (BTU/hr)
Avg	1734	3531
Min	1670	2342
Max	1788	3832

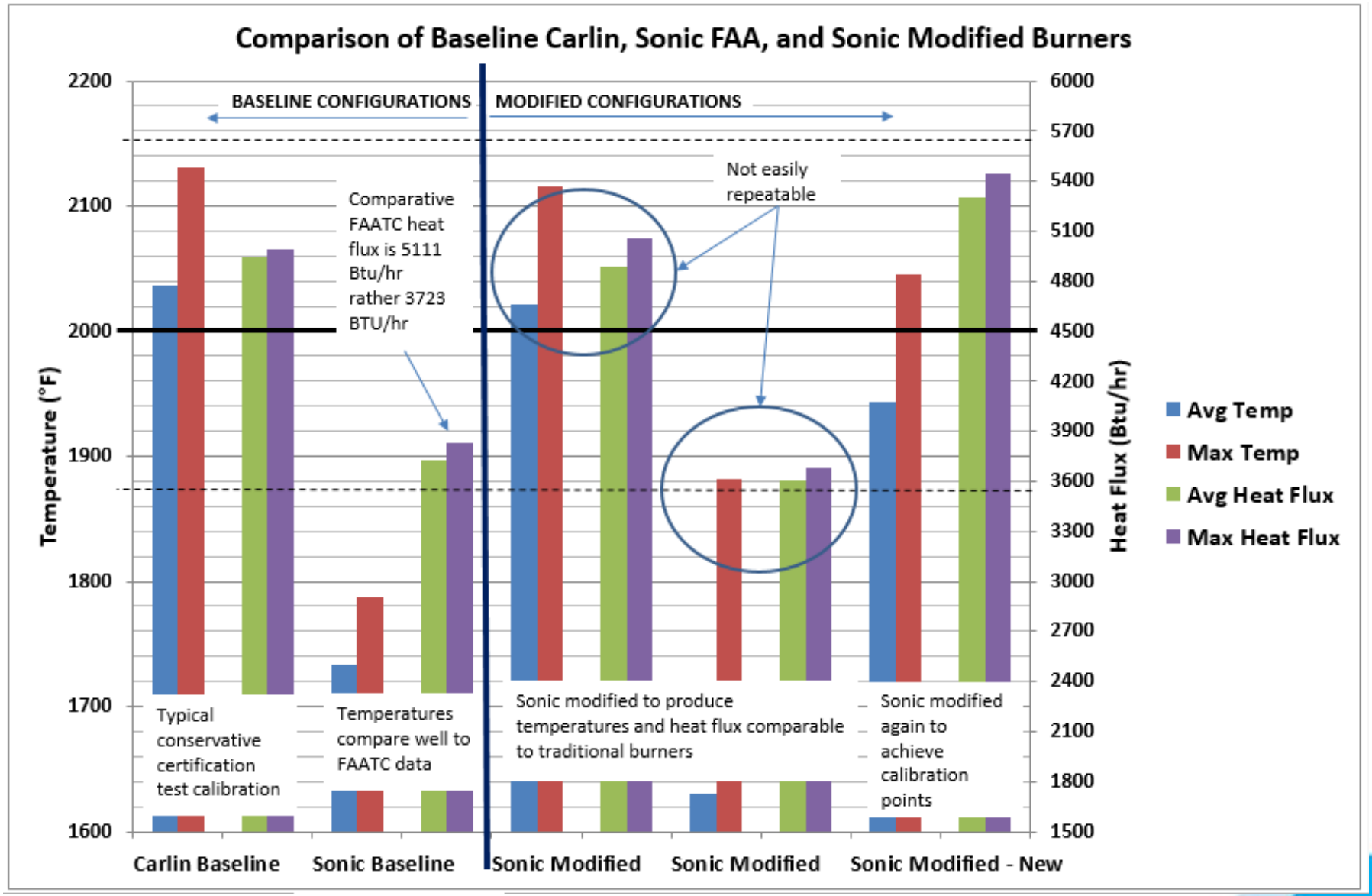
Sonic Mod Configuration (T15 – Sonic Mod 1)



	Temp (°F)	Heat Flux (BTU/hr)
Avg	2021	4888
Min	1889	4501
Max	2116	5061

Summary of Burner Calibration Data – Round 1




Comparison of Baseline Carlin, Sonic FAA, and Sonic Modified Burners
BASELINE CONFIGURATIONS
MODIFIED CONFIGURATIONS
Temperature (°F)
Heat Flux (Btu/hr)
2200
2100
2000
1900
1800
1700
1600
6000
5700
5400
5100
4800
4500
4200
3900
3600
3300
3000
2700
2400
2100
1800
1500
Comparative FAATC heat flux is 5111 Btu/hr rather 3723 BTU/hr
Not easily repeatable
Typical conservative certification test calibration
Temperatures compare well to FAATC data
Sonic modified to produce temperatures and heat flux comparable to traditional burners
Sonic modified again to achieve calibration points
Avg Temp
Max Temp
Avg Heat Flux
Max Heat Flux
Carlin Baseline
Sonic Baseline
Sonic Modified
Sonic Modified
Sonic Modified - New

Sonic – with new modifications

Different fuel and air parameters

150psi 0.13l/m fuel -- 65psi air

Burner Map looking into the Burner [°F] - Max Values — No Board

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1822.9	1907.3	2039.6	2138.7	2131.1	2146.6	2168.3	2131.2	1983.7	1899.5	1726.9	2105.6
Level 6	1799.2	1920.0	2051.0	2131.5	2123.9	2152.5	2174.2	2135.0	2009.2	1912.4	1763.9	2111.1
Level 5	1907.0	1972.0	2080.2	2132.6	2113.6	2161.7	2201.8	2163.3	2049.3	1952.4	1838.9	2128.9
Level 4	1923.8	1943.0	1908.4	1959.6	1993.0	2037.5	2089.7	2001.7	1942.9	1881.5	1800.6	1990.4
Level 3	1725.8	1740.0	1560.6	1496.3	1522.2	1586.1	1541.6	1518.4	1598.8	1659.8	1574.8	1546.3
Level 2	1203.3	1302.7	1146.5	1080.9	986.4	1035.3	1035.0	1046.6	1212.9	1312.6	1197.6	1077.7
Level 1	906.0	958.6	929.5	860.9	853.1	859.2	874.9	893.8	934.7	936.8	900.4	886.6

Burner Map looking into the Burner [°F] - Max Values — Ceramic Fireboard

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1940.7	1945.4	2032.1	2013.3	1942.5	1962.4	2038.3	2010.7	1938.5	1917.1	1890.5	1991.1
Level 6	1959.6	1976.2	2061.9	2046.8	1966.4	1993.8	2040.9	2018.8	1961.7	1955.3	1901.9	2012.9
Level 5	1975.7	1997.9	2099.2	2108.7	2060.8	2059.4	2118.9	2095.8	2029.3	1996.1	1952.0	2081.7
Level 4	1948.5	1985.1	2066.1	2106.1	2092.3	2102.1	2128.9	2119.9	2036.3	1992.7	1934.9	2093.1
Level 3	1894.6	1931.1	2003.3	2066.5	2095.3	2145.3	2169.1	2145.2	2047.3	1961.6	1870.5	2096.0
Level 2	1853.5	1869.4	1935.3	2011.3	2077.4	2122.0	2147.3	2072.4	1971.3	1842.9	1720.2	2048.2
Level 1	1623.7	1667.0	1748.4	1845.7	1912.2	1958.6	1939.8	1874.8	1798.7	1632.3	1543.7	1868.3

Burner Map looking into the Burner [°F] - Max Values — Ceramic Firewool

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1713.3	1885.4	1966.4	1975.4	1921.0	1979.0	2021.7	1979.4	1851.6	1747.8	1625.4	1956.4
Level 6	1707.8	1895.1	1989.5	2000.1	1946.1	1993.9	2022.9	1963.2	1836.8	1730.4	1610.4	1964.7
Level 5	1717.3	1909.6	2002.5	2032.9	1976.4	2028.0	2071.5	1991.8	1849.6	1736.3	1597.4	1993.3
Level 4	1741.7	1948.1	2058.8	2084.9	2048.9	2084.1	2107.0	2040.6	1916.4	1773.4	1598.0	2048.7
Level 3	1726.8	1906.7	2013.5	2076.4	2075.3	2122.1	2141.3	2060.7	1899.7	1745.5	1562.4	2055.6
Level 2	1708.5	1851.8	1927.5	1999.2	2076.5	2127.7	2139.6	2021.3	1912.1	1698.9	1523.8	2029.1
Level 1	1638.0	1714.1	1747.6	1859.7	1991.7	2055.0	2019.1	1917.0	1790.3	1587.9	1458.5	1911.5

125psi 0.13l/m fuel -- 60 psi air

Burner Map looking into the Burner [°F] - Max Values — No Board

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1701.2	1846.0	1980.0	2071.1	2066.5	2107.0	2133.4	2072.0	1949.8	1855.4	1719.7	2054.2
Level 6	1726.9	1865.2	1991.9	2069.5	2068.3	2091.1	2124.6	2079.2	1954.9	1876.8	1773.2	2054.2
Level 5	1867.2	1905.6	1977.4	2033.0	2033.9	2083.5	2102.6	2044.8	1971.6	1895.9	1809.7	2035.3
Level 4	1839.1	1802.5	1745.1	1725.6	1763.0	1828.2	1792.1	1716.7	1766.8	1819.1	1751.3	1762.5
Level 3	1585.1	1637.1	1476.3	1393.8	1363.2	1486.1	1424.7	1399.9	1566.4	1600.5	1467.0	1444.3
Level 2	1073.9	1164.2	1083.8	857.5	846.3	913.5	818.5	821.9	1039.0	1164.5	1085.5	911.5
Level 1	534.9	601.4	569.8	459.7	414.1	405.1	428.6	414.0	554.0	627.8	558.7	463.6

Burner Map looking into the Burner [°F] - Max Values — Ceramic Fireboard

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1917.5	1929.2	2023.1	2028.2	1955.6	1972.4	2008.2	1979.2	1919.7	1900.0	1872.7	1983.8
Level 6	1930.0	1935.3	2026.5	2016.0	1947.6	1963.8	2007.6	1985.2	1921.2	1902.2	1863.4	1981.1
Level 5	1953.6	1982.4	2056.1	2082.3	2035.3	2037.6	2079.7	2050.7	1981.0	1937.7	1885.3	2046.1
Level 4	1929.4	1964.5	2044.1	2088.7	2071.6	2102.3	2127.3	2091.6	1987.8	1913.0	1845.1	2073.3
Level 3	1887.0	1918.5	1983.7	2053.5	2082.9	2122.0	2144.4	2072.1	1975.9	1864.6	1758.4	2062.1
Level 2	1783.5	1798.1	1860.0	1937.0	2020.2	2065.1	2072.5	1993.7	1922.0	1783.0	1673.0	1981.5
Level 1	1561.7	1587.9	1645.2	1751.1	1818.1	1854.0	1841.1	1742.9	1657.5	1526.4	1461.2	1758.6

Burner Map looking into the Burner [°F] - Max Values — Ceramic Firewool

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1684.1	1820.1	1884.5	1928.9	1874.4	1912.5	1980.3	1946.4	1827.7	1737.8	1655.9	1907.8
Level 6	1692.6	1856.3	1932.3	1957.7	1888.2	1940.1	1989.7	1946.4	1831.3	1738.9	1643.1	1926.5
Level 5	1690.4	1888.5	2000.2	2037.6	1988.1	2003.6	2042.9	2006.0	1891.9	1797.0	1656.0	1995.8
Level 4	1693.5	1884.6	2004.2	2041.2	2018.7	2041.1	2065.5	2026.6	1906.5	1772.1	1602.9	2014.8
Level 3	1665.5	1851.2	1963.4	2011.1	2035.4	2077.3	2108.3	2053.0	1923.5	1764.3	1583.0	2024.6
Level 2	1678.5	1798.1	1890.7	1961.8	2043.0	2102.3	2116.0	2032.7	1914.7	1732.9	1565.7	2008.7
Level 1	1650.0	1727.5	1770.1	1866.5	1969.5	2010.0	2005.7	1898.9	1813.5	1631.4	1506.2	1904.9

Carlin vs Sonic – with new modifications

- the same nozzle and similar turbulator

125psi -- 1960 fpm air

Burner Map looking into the Burner [°F] - Max Values — **No Board**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 6	1336.7	1787.0	2058.4	2084.1	2027.6	2104.0	2105.1	2059.6	1907.7	1949.1	1883.7	2049.5
Level 5	1537.0	1930.4	2161.4	2146.0	2110.0	2192.0	2259.5	2236.9	2131.2	2113.1	1942.3	2176.7
Level 4	1389.1	1825.8	2074.2	2156.2	2089.8	2091.7	2089.5	2065.1	2042.4	2009.7	1797.7	2087.0
Level 3	890.0	1321.3	1627.0	1738.8	1523.4	1508.5	1502.5	1496.0	1539.2	1594.6	1395.4	1562.2
Level 2	494.3	707.8	941.0	1039.3	899.6	856.5	965.1	995.0	1057.8	1043.2	880.2	964.9
Level 1	462.7	523.0	565.2	595.5	558.1	553.4	577.2	574.8	595.8	587.0	493.8	574.3

Burner Map looking into the Burner [°F] - Max Values — **Ceramic Fireboard**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	2078.3	2130.4	2150.8	2156.5	2133.5	2095.6	2182.1	2192.1	2131.5	2123.6	2058.3	2148.9
Level 6	2039.7	2052.5	2104.4	2142.2	2110.0	2076.4	2141.9	2144.5	2098.3	2113.9	2061.8	2116.8
Level 5	2061.6	2077.0	2117.2	2159.1	2131.0	2086.1	2153.6	2169.2	2118.0	2130.9	2074.3	2133.5
Level 4	2059.7	2101.3	2132.2	2149.4	2137.2	2105.6	2195.1	2219.9	2161.4	2148.5	2090.8	2157.3
Level 3	2063.0	2097.5	2135.8	2128.5	2105.8	2067.2	2082.9	2130.8	2119.2	2088.0	2043.4	2110.0
Level 2	2034.2	2079.2	2081.4	2083.8	2082.4	2056.3	2027.6	2039.4	2032.9	2002.4	1979.9	2057.7
Level 1	1911.0	1978.9	1968.8	1998.0	2002.5	1987.1	1938.0	1914.3	1901.9	1822.5	1809.1	1958.7

Burner Map looking into the Burner [°F] - Max Values — **Ceramic Fireboard - 100psi fuel**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1829.8	1899.5	2013.0	2043.9	2013.4	1981.6	2040.7	2055.8	2025.2	2027.3	1985.4	2024.8
Level 6	1855.8	1920.1	2001.7	2028.2	2001.5	1956.7	1901.7	1943.7	1983.6	1986.5	1971.6	1973.9
Level 5	1816.0	1903.4	2019.0	2046.2	1979.4	1984.3	2070.5	2084.0	2037.7	2049.9	1994.6	2031.6
Level 4	1767.0	1837.9	2012.5	2068.6	2033.0	1996.6	2080.7	2095.6	2030.2	1986.4	1970.2	2045.3
Level 3	1699.6	1764.9	1937.4	2017.9	2038.4	2041.6	2121.9	2075.6	1938.5	1928.3	1938.6	2024.5
Level 2	1590.7	1666.3	1820.8	1965.0	2018.6	2055.3	2073.1	1985.8	1884.0	1849.9	1886.6	1971.8
Level 1	1473.4	1576.9	1698.5	1860.2	1955.7	2004.6	1945.5	1862.3	1799.0	1704.5	1707.9	1875.1

125psi 0.13l/m fuel -- 60 psi air

Burner Map looking into the Burner [°F] - Max Values — **No Board**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1701.2	1846.0	1980.0	2071.1	2066.5	2107.0	2133.4	2072.0	1949.8	1855.4	1719.7	2054.2
Level 6	1726.9	1865.2	1991.9	2069.5	2068.3	2091.1	2124.6	2079.2	1954.9	1876.8	1773.2	2054.2
Level 5	1867.2	1905.6	1977.4	2033.0	2033.9	2083.5	2102.6	2044.8	1971.6	1895.9	1809.7	2035.3
Level 4	1839.1	1802.5	1745.1	1725.6	1763.0	1828.2	1792.1	1716.7	1766.8	1819.1	1751.3	1762.5
Level 3	1585.1	1637.1	1476.3	1393.8	1363.2	1486.1	1424.7	1399.9	1566.4	1600.5	1467.0	1444.3
Level 2	1073.9	1164.2	1083.8	857.5	846.3	913.5	818.5	821.9	1039.0	1164.5	1085.5	911.5
Level 1	534.9	601.4	569.8	459.7	414.1	405.1	428.6	414.0	554.0	627.8	558.7	463.6

Burner Map looking into the Burner [°F] - Max Values — **Ceramic Fireboard**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1917.5	1929.2	2023.1	2028.2	1955.6	1972.4	2008.2	1979.2	1919.7	1900.0	1872.7	1983.8
Level 6	1930.0	1935.3	2026.5	2016.0	1947.6	1963.8	2007.6	1985.2	1921.2	1902.2	1863.4	1981.1
Level 5	1953.6	1982.4	2056.1	2082.3	2035.3	2037.6	2079.7	2050.7	1981.0	1937.7	1885.3	2046.1
Level 4	1929.4	1964.5	2044.1	2088.7	2071.6	2102.3	2127.3	2091.6	1987.8	1913.0	1845.1	2073.3
Level 3	1887.0	1918.5	1983.7	2053.5	2082.9	2122.0	2144.4	2072.1	1975.9	1864.6	1758.4	2062.1
Level 2	1783.5	1798.1	1860.0	1937.0	2020.2	2065.1	2072.5	1993.7	1922.0	1783.0	1673.0	1981.5
Level 1	1561.7	1587.9	1645.2	1751.1	1818.1	1854.0	1841.1	1742.9	1657.5	1526.4	1461.2	1758.6

Burner Map looking into the Burner [°F] - Max Values — **Ceramic Firewool**

	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1684.1	1820.1	1884.5	1928.9	1874.4	1912.5	1980.3	1946.4	1827.7	1737.8	1655.9	1907.8
Level 6	1692.6	1856.3	1932.3	1957.7	1888.2	1940.1	1989.7	1946.4	1831.3	1738.9	1643.1	1926.5
Level 5	1690.4	1888.5	2000.2	2037.6	1988.1	2003.6	2042.9	2006.0	1891.9	1797.0	1656.0	1995.8
Level 4	1693.5	1884.6	2004.2	2041.2	2018.7	2041.1	2065.5	2026.6	1906.5	1772.1	1602.9	2014.8
Level 3	1665.5	1851.2	1963.4	2011.1	2035.4	2077.3	2108.3	2053.0	1923.5	1764.3	1583.0	2024.6
Level 2	1678.5	1798.1	1890.7	1961.8	2043.0	2102.3	2116.0	2032.7	1914.7	1732.9	1565.7	2008.7
Level 1	1650.0	1727.5	1770.1	1866.5	1969.5	2010.0	2005.7	1898.9	1813.5	1631.4	1506.2	1904.9

Previous work with different fuel nozzles
Baseline Assessment – 1” Map

T8 – Carlin 2

- Standard TC calibration average = 2033°F

Burner Map looking into the Burner [°F] - Max Values	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 7	1845.3	1923.1	1951.1	1922.5	1970.7	1971.0	1901.7	1871.4	1695.3	1434.4	1108.6	1897.7
Level 6	1862.8	1937.7	1959.4	1926.6	1987.4	1994.2	1943.9	1884.7	1720.1	1500.0	1150.3	1916.6
Level 5	1917.5	1993.2	2008.6	2004.6	2077.6	2121.8	2111.6	2074.3	1958.9	1828.4	1380.9	2051.1
Level 4	1767.2	1907.1	1890.2	1866.8	2017.0	2110.0	2111.6	2035.8	1894.4	1657.1	1304.3	1989.4
Level 3	1261.9	1535.7	1612.3	1439.7	1671.5	1881.9	1921.0	1846.3	1627.8	1419.6	1027.7	1714.3
Level 2	670.6	1004.1	1172.4	960.0	1101.2	1351.6	1455.3	1364.6	1157.2	905.6	588.2	1223.2
Level 1	380.9	547.1	688.2	561.1	625.8	750.0	863.2	811.1	643.7	461.7	381.9	706.1

T5 – Sonic FAA 4

- Standard TC calibration average = 1734°F

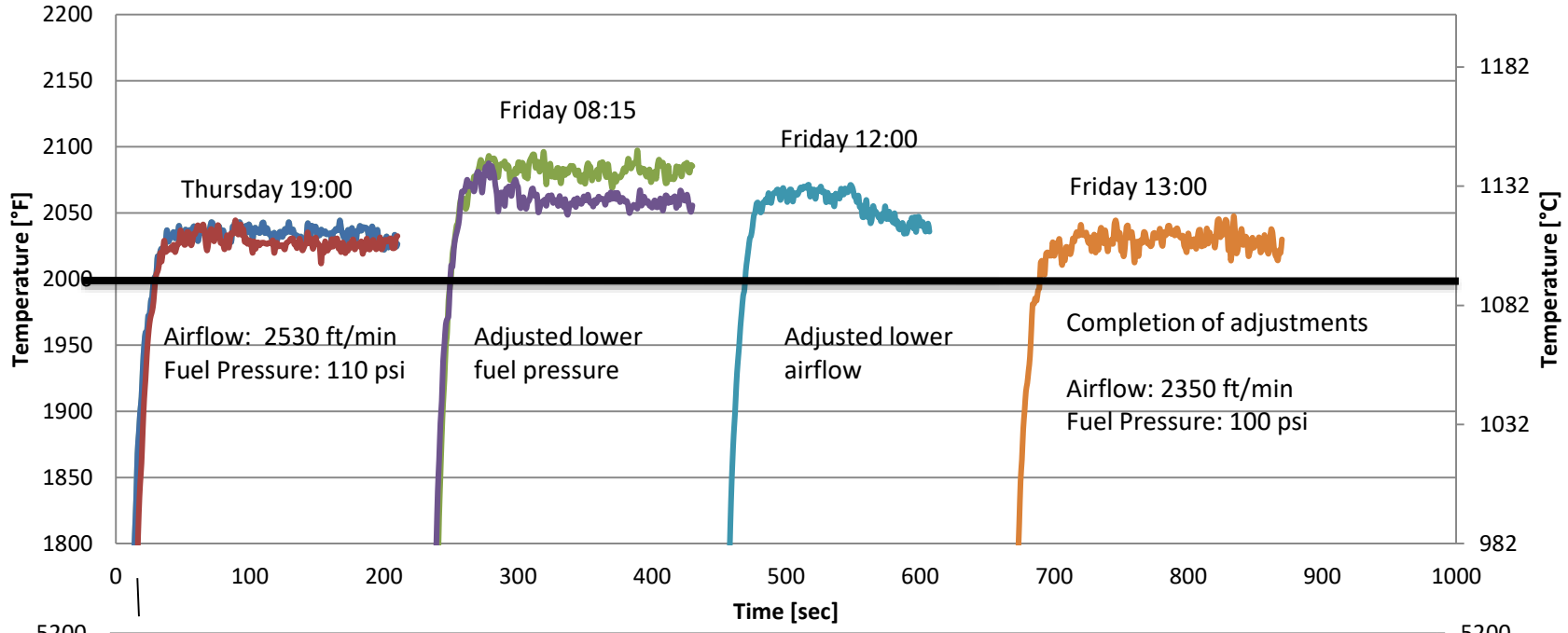
Level 7	1542.6	1798.6	1849.3	1855.9	1848.9	1828.1	1841.5	1840.1	1807.4	1728.7	1456.7	1838.8
Level 6	1576.9	1800.3	1848.5	1860.8	1853.1	1831.9	1839.5	1843.0	1812.9	1774.7	1519.1	1841.4
Level 5	1367.9	1664.9	1770.4	1805.5	1797.3	1775.8	1793.2	1813.4	1775.1	1733.2	1554.6	1790.1
Level 4	1224.9	1593.6	1720.5	1753.7	1745.3	1717.2	1729.4	1736.0	1708.3	1656.3	1414.7	1730.1
Level 3	908.2	1271.5	1525.8	1660.4	1692.7	1673.5	1661.9	1635.6	1558.7	1420.8	1176.0	1629.8
Level 2	673.3	947.7	1206.3	1339.6	1459.4	1443.6	1454.3	1361.2	1202.2	1000.6	769.7	1352.4
Level 1	509.2	662.8	858.3	1002.5	1059.0	1058.4	1091.3	948.0	787.6	641.8	544.6	972.1

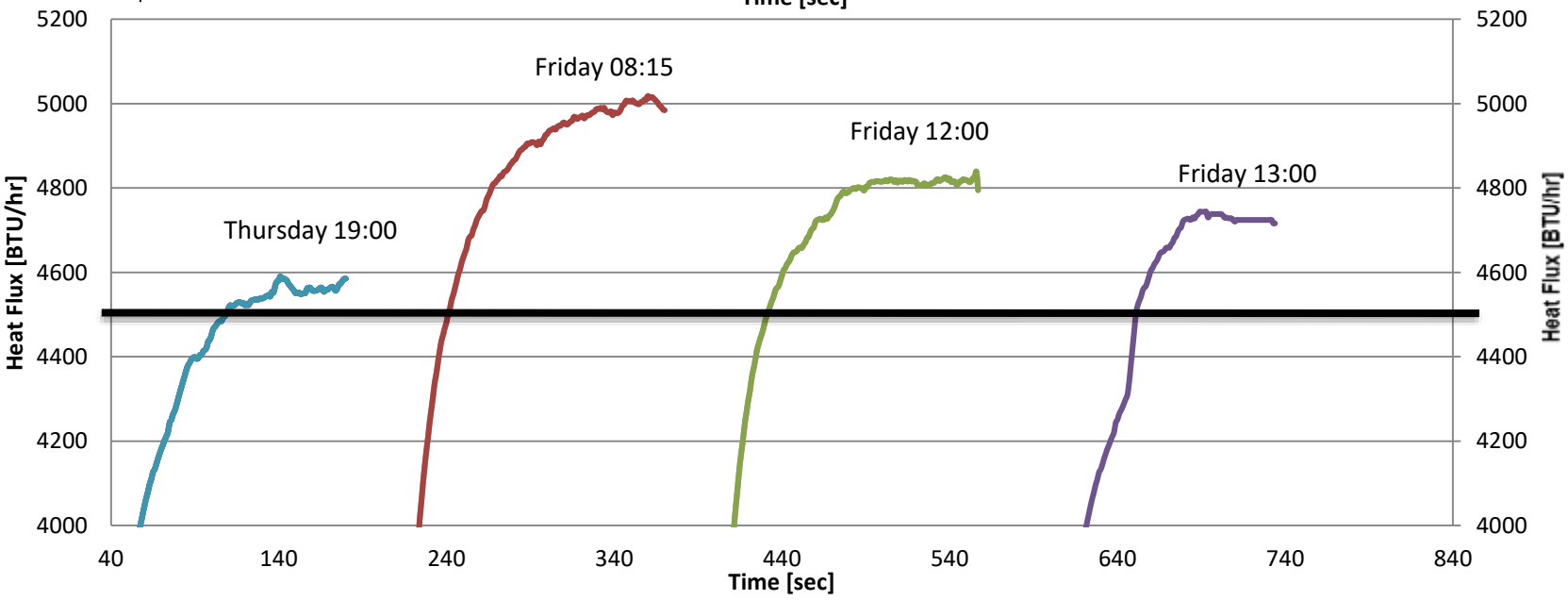
T17 – Sonic Mod 3

- Standard TC calibration average = 2021°F

Level 7	1683.8	1862.8	1978.6	2081.6	2133.9	2109.8	2095.5	2035.7	1944.0	1863.1	1440.5	2054.1
Level 6	1700.1	1877.5	2000.2	2102.2	2155.9	2117.2	2102.5	2037.8	1952.8	1877.0	1483.3	2067.0
Level 5	1712.1	1891.9	2017.1	2130.0	2165.6	2119.8	2100.2	2013.8	1959.8	1900.7	1547.1	2072.3
Level 4	1538.4	1812.3	1959.0	2048.1	2097.2	2039.2	1993.1	1919.9	1900.3	1895.3	1528.7	1993.8
Level 3	1334.5	1710.1	1829.8	1842.4	1803.3	1768.5	1745.8	1719.7	1764.5	1804.1	1411.7	1782.0
Level 2	1013.8	1502.0	1579.5	1393.4	1269.1	1288.7	1317.0	1326.3	1421.0	1476.2	1087.0	1370.7
Level 1	584.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Difficulty with Carlin - factors: air P, density, temp?





Summary of Main Observations

- Sonic can be modified from current configuration to achieve traditional burner like output
  - Similar to work FAATC conducted with flame retention head change the fuel nozzle and varying fuel and air pressures)
  - Calibration to AC20-135 can be achieved with the sonic – but not with set inputs
  - Potentially simplifies any guidance appendix (AC20-135) for use of Sonic burner – upcoming SAE A22/FAA task
  - Does not take advantage of the expected Sonic burner repeatability – but have we seen this?
  - A major unknow would be pressure and air speed at burner cone exit
- Tools have been developed to achieve greater understanding of burner outputs
  - 2D HD temperature maps
    - with and without impingement surface
  - BTU mapping – round 1
  - All to better qualify burner flames for comparison during any research effort
    - Ensure that we know where the hottest part of the flame is and the highest energy and relate that to calibration sensor location.
- For any given burner setup we might be able to establish useful expectations in terms of time to 4500 BTU/hr and peak value – will likely rely on more data than simply average.
- Do not draw major conclusions from shallow data sets. This is particularly important when talking about repeatability or reliability.

Future Work:

- Alu strip idea – electrical cond. – takes out difficult burnthrough assessment and is cheaper
- Composite panels?
- Other labs involvement – to assess variability
- Consider fuel types
- Consider application of other tools
- Repeatability data/statistical analysis
- Numerical tools to predict flame dynamics
- Understanding individual burner limitations and sources of variability
- Sensitivity study of burner parameters – could potentially further simplify set up
- Studying the modified Sonic Burner with off-the-shelf parts

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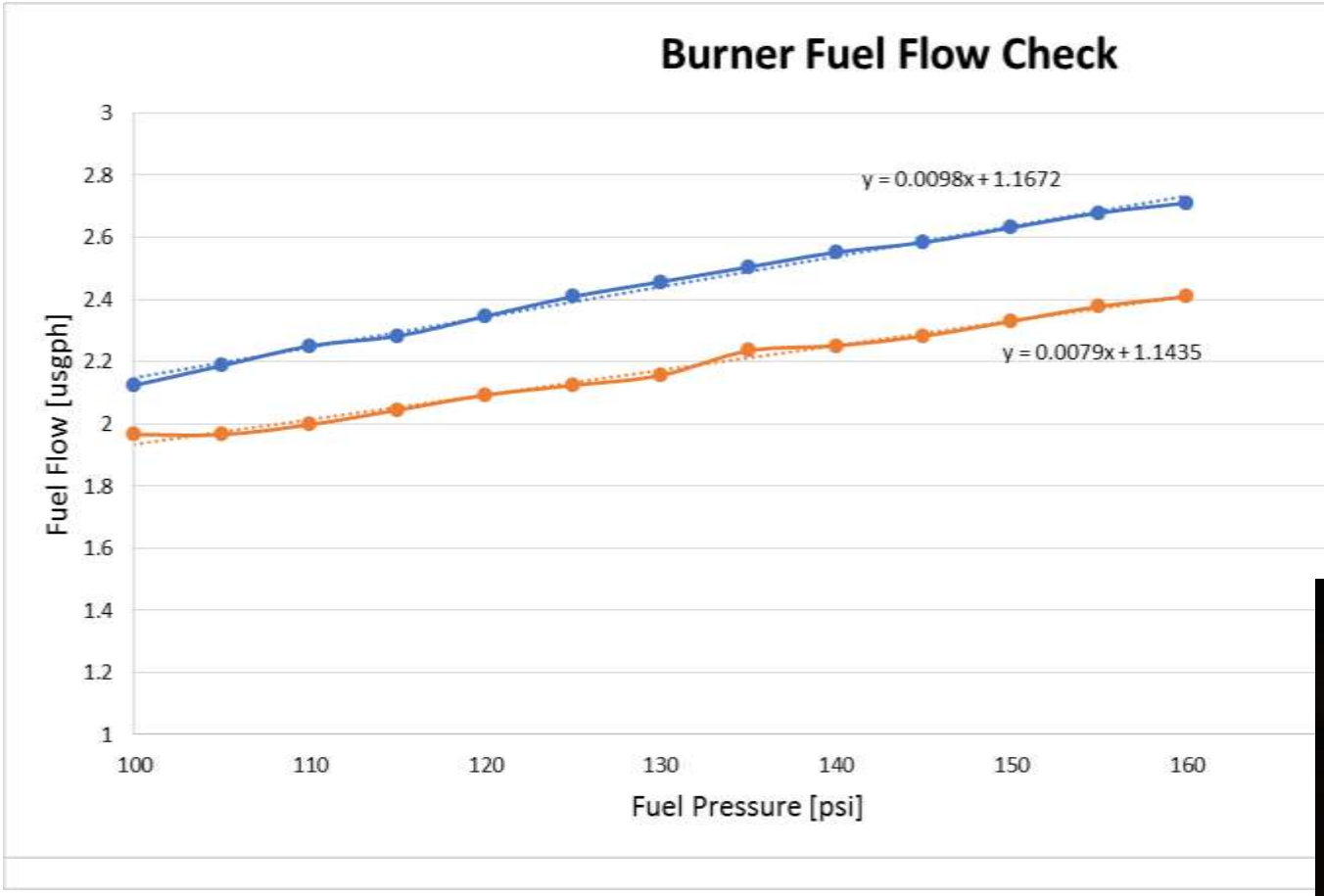
Fuel Flow Check – Based on FAA Procedure



Carlin 2.25 80°PLP
Sonic 2.0 80°H
Linear (Carlin 2.25 80°PLP)
Linear (Sonic 2.0 80°H)