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STUDY OF MODIFIED SONIC BURNER FOR POWERPLANT FIRE TESTING WITH INNOVATIVE MAPPING TECHNIQUES

2019-10-29

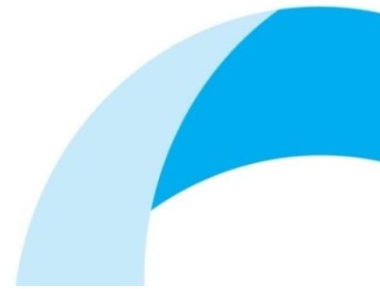
PRESENTED BY: DR. MARY KELLY (RESONATE)



BATTLE OF THE BURNERS



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Premise – why are we doing this study?

Presentation overview

Premise

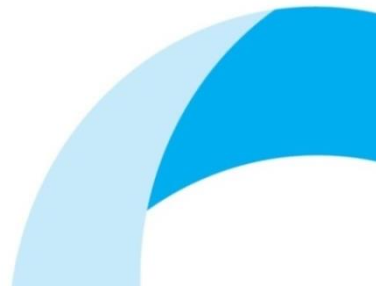
Comparison of existing and new Burners carried out to add to the body of knowledge and increase consistency between labs for powerplant/systems testing aiding in providing direction for future trials.

Presentation overview

- Background and introduction
- Burner set up and configuration
- Comparative calibration data
- Temperature and Heat transfer mapping – Flame Characterisation
- Aluminium strip Burnthrough
- Conclusions and future work



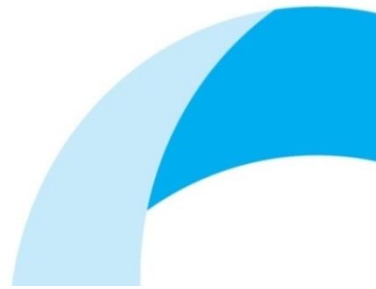
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BACKGROUND AND INTRODUCTION



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What is the Sonic Burner?

- This next-generation (Sonic) burner was developed mainly to provide industry with an alternative to the currently accepted burner apparatus
- The Sonic burner can be considered a direct replacement to the Park-manufactured burner, with several key improvements.
- The Sonic burner is based on the same operating principle as the Park DPL 3400, using the same, or very similar, internal components to avoid drastically changing the overall character of the flame.
- The main difference is the elimination of the electric motor, which provided power to the fuel pump and blower fan in the Park-manufactured burner.
- In the Sonic burner, these functions have been replaced with regulated and conditioned compressed air and a pressurized fuel delivery system.
- Compressed air, when metered with a sonic orifice and conditioned to remove heat and moisture, proves to be more consistent over extended periods of time than to using a shaft-driven blower and laboratory air for the burner, thus increasing the repeatability of the Sonic burner.
- Sonic fuel delivery is provided by applying a head pressure of nitrogen gas on liquid fuel contained in a pressure vessel. This new method eliminates any fluctuations that were previously experienced with the electric motor and shaft-driven fuel pump typical of the Park-manufactured burner.

May 2009 DOT/FAA/AR-TN09/23 Robert. I. Ochs



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What burner options does the powerplant community have, currently?

- **Stewart warner HPR 250** - this burner is no longer available
- **Stewart warner FR-650** - this burner is no longer available
- **Carlin 200 CRD** - this model is no longer available
- **Lennox OB-32** - this is burner is no longer available
- **Park DPL 3400** – this is burner is no longer



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Trial Summary - Set one – July 2018

Date	Trial		
16-Jul-18	T1 - Carlin 1	19-Jul-18	T18 - Sonic Mod 4 Temp Map
16-Jul-18	T2 - Sonic FAA 1	19-Jul-18	T19 - Sonic Mod 5 pre burn
16-Jul-18	T3 - Sonic FAA 2	19-Jul-18	T20 - Sonic Mod 6 post burn
16-Jul-18	T4 - Sonic FAA 3	19-Jul-18	T21 - Sonic Mod 7 Temp Map
16-Jul-18	T5 - Sonic FAA 4 Temp Map	19-Jul-18	T22 - Sonic Mod 8 pre burn
16-Jul-18	T6 - Sonic FAA 5 Temp Map	19-Jul-18	T23 - Sonic Mod 9 post burn
16-Jul-18	T7 - Sonic FAA 6	19-Jul-18	T24 - Sonic Mod 10 Temp Map
		19-Jul-18	T25 - Sonic Mod 11
		19-Jul-18	T26 - Sonic Mod 12
17-Jul-18	T8 - Carlin 2	19-Jul-18	T27 - Sonic Mod 13 pre BTU/hr Map
17-Jul-18	T9 - Carlin Panel 3 pre burn	19-Jul-18	T28 - Sonic Mod 14 post BTU/hr Map
17-Jul-18	T10 - Carlin Panel 4 post burn		
17-Jul-18	T11 - Carlin 5	20-Jul-18	T29 - Sonic Mod 15 Temp Map
17-Jul-18	T12 - Carlin 6	20-Jul-18	T30 - Sonic Mod 16 burn
17-Jul-18	T13 - Carlin 7	20-Jul-18	T31 - Sonic FAA 7 Temp Map
		20-Jul-18	T32 - Sonic FAA 8
18-Jul-18	T14 - Carlin 8	20-Jul-18	T33 - Sonic FAA 9
18-Jul-18	T15 - Sonic Mod 1	20-Jul-18	T34 - Sonic FAA 10
18-Jul-18	T16 - Sonic Mod 2		
18-Jul-18	T17 - Sonic Mod 3 Temp & BTU/hr Map	21-Jul-18	T35 - Carlin 9
		21-Jul-18	T36 - Carlin 10
		21-Jul-18	T37 - Carlin 11
		21-Jul-18	T38 - Carlin 12 pre BTU/hr Map
		21-Jul-18	T39 - Carlin 13 post BTU/hr Map
		21-Jul-18	T40 - Carlin 14

More than 40 trials conducted over 6 days of testing:

- Carlin x 14
- Sonic FAA Config1 x 10
- Sonic Mod. Config2 x 16

Trial Summary - Set two – April/May 2019

Date	Name
02-May-19	T1 - Sonic Mod Config2 - R2
02-May-19	T2 - Sonic Mod Config2 - R2
02-May-19	T4 - Sonic Mod Config3 - R2
03-May-19	T5 - Sonic Mod Config3 - R2
03-May-19	T6 - Sonic Mod Config3 - R2
03-May-19	T4 - Sonic Mod Config3 - R2
02-May-19	T5 - Sonic Mod Config3 - R2
03-May-19	T6 - Sonic Mod Config3 - R2
03-Apr-19	T7 - Carlin - R2
03-Apr-19	T8 - Carlin - R2
03-Apr-19	T9 - Carlin - R2
03-Apr-19	T10 - Carlin - R2
03-Apr-19	T11 - Carlin - R2

More than 12 trials conducted over 3 days of testing:

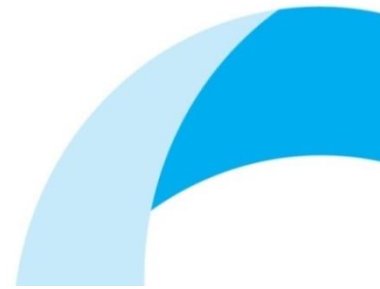
- Carlin x 5
- Sonic FAA Config1 x 0
- Sonic Mod. Config2. x 2
- Sonic Mod. Config3. x 6

Trial Summary - Set three – July/Aug 2019

Date Time	Burner Configuration
25 July 2019	T1 - Carlin - R3
26 July 2019	T2 - Carlin - R3
29 July 2019	T3 - Carlin - R3
29 July 2019	T4 - Carlin - R3
29 July 2019	T5 - Carlin - R3
29 July 2019	T6 - Carlin - R3
29 July 2019	T7 - Carlin - R3
29 July 2019	T7 - Carlin - R3
29 July 2019	T8 - Carlin - R3
29 July 2019	T8 - Carlin - R3
01 August 2019	T9 - Sonic FAA Config1 – R3
02 August 2019	T10 - Sonic FAA Config1 – R3
02 August 2019	T11 - Sonic FAA Config1 – R3
02 August 2019	T12 - Sonic FAA Config1 – R3
02 August 2019	T13 - Sonic FAA Config1 – R3
02 August 2019	T14 - Sonic FAA Config1 – R3
05 August 2019	T15 -Sonic MOD Config2 – R3
05 August 2019	T16 -Sonic MOD Config2 – R3
06 August 2019	T17 -Sonic MOD Config2 – R3
06 August 2019	T18 -Sonic MOD Config2 – R3
06 August 2019	T19 -Sonic MOD Config2 – R3
06 August 2019	T20 -Sonic MOD Config2 – R3
06 August 2019	T21 -Sonic MOD Config2 – R3
06 August 2019	T22 -Sonic MOD Config2 – R3
07 August 2019	T23 - Sonic MOD NEW Config3 – R3
07 August 2019	T24 - Sonic MOD NEW Config3 – R3
07 August 2019	T25 - Sonic MOD NEW Config3 – R3
07 August 2019	T26 - Sonic MOD NEW Config3 – R3
07 August 2019	T27 - Sonic MOD NEW Config3 – R3
07 August 2019	T28 - Sonic MOD NEW Config3 – R3

More than 28 trials conducted over 6 days of testing:

- Carlin x 8
- Sonic FAA Config1 x6
- Sonic Mod. Config2 x 8
- Sonic Mod. Config3 x 8



BURNER SETUP AND CONFIGURATION

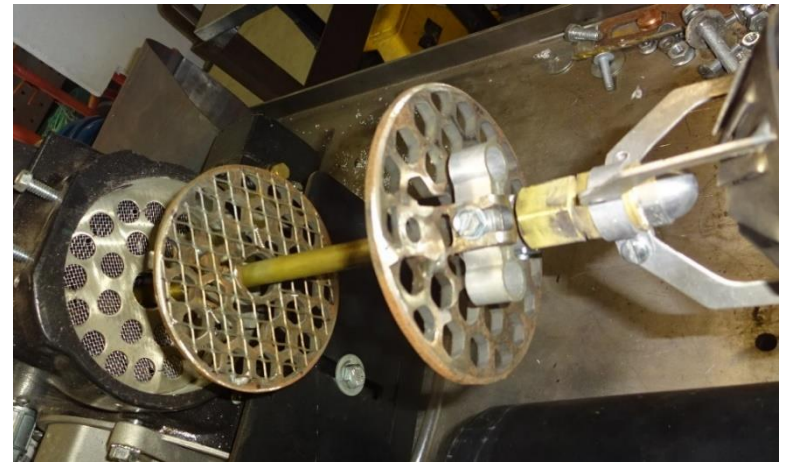


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Carlin 200 CRD

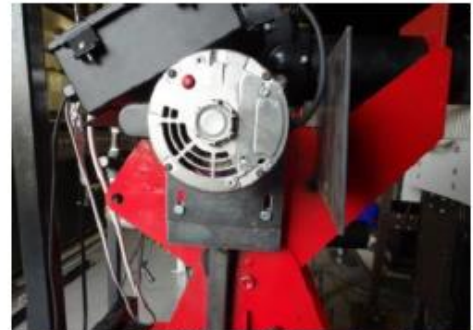
Engineering report 3A



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 gradient. 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 – Configuration 1 [FAA]

FAA FIRE TEST HANDBOOK - Chapter 7 configuration
Supplied by 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 80°W manufacturer nozzle – semi solid pattern,
100 psi fuel, 50 psi air

Ignitorless stator

Muffler foam retained with wire

Turbulator – no flame retention head

supplied by Marlin Engineering, part number ME1513-3.

supplied by Marlin Engineering, part number ME1512-1.



Figure 7-S-13. Stator



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



Semi-solid



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

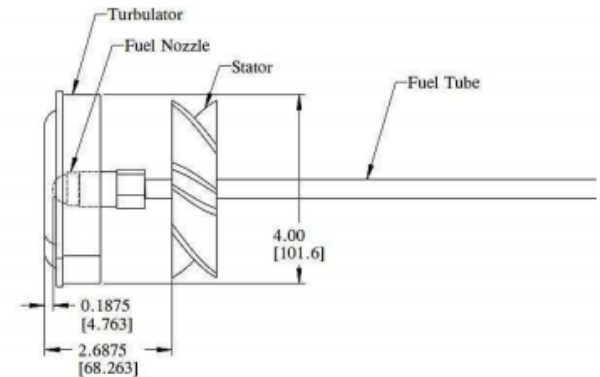
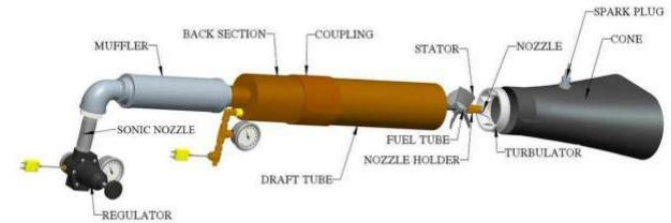


Figure 7-S-17. Typical Configuration of the Stator and Turbulator

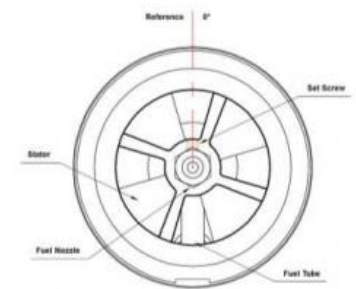


Figure 7-S-29 Stator Axial Position (looking into draft tube)

Sonic Burner Modification – Configuration 2

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.

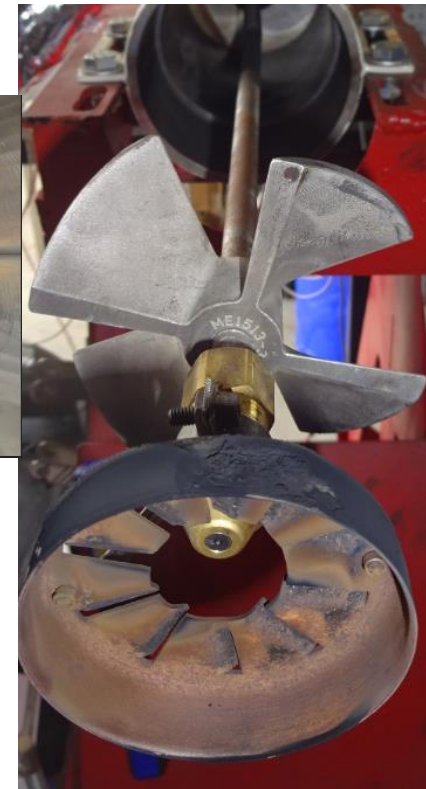
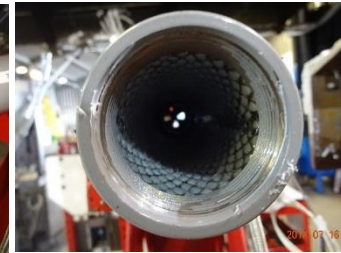
Danfoss 80°H 2.0 GPH – Hollow pattern



Added Carlin type turbulator on fuel nozzle fitting

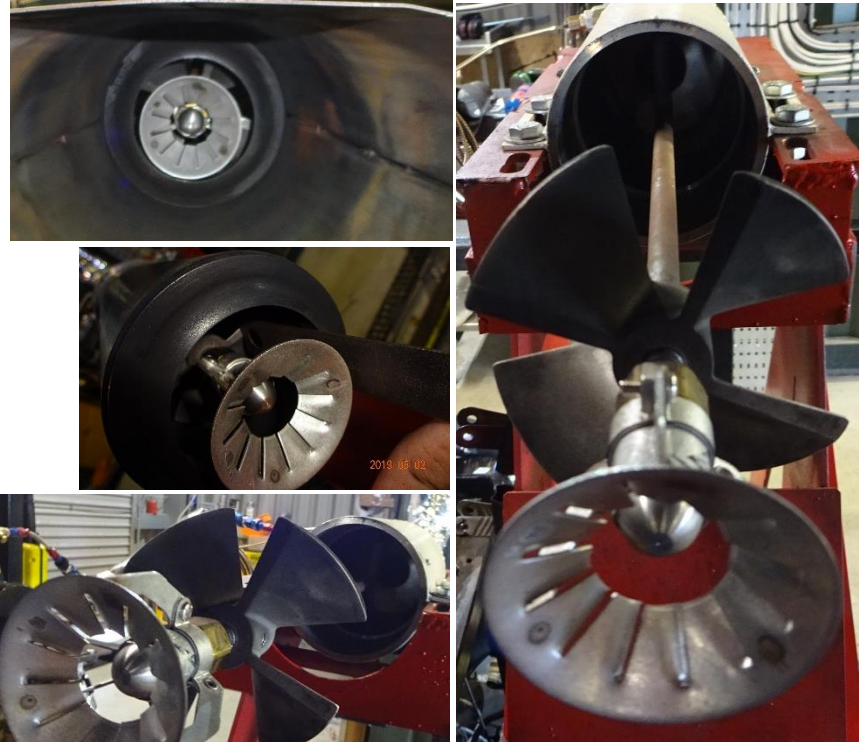


Muffler foam was removed



Sonic Burner Modification – Configuration 3

Monarch 80°PLP 2.25 GPH
– semi solid pattern



Muffler foam was removed



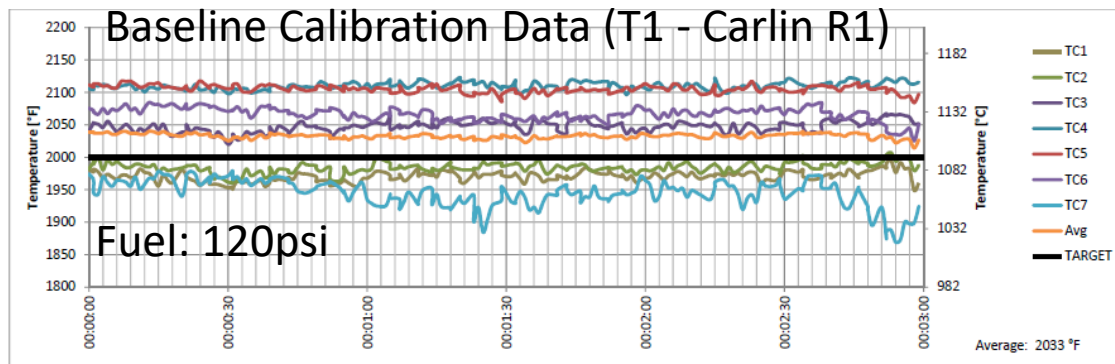
**Added Carlin type turbulator
on fuel nozzle fitting**

COMPARATIVE CALIBRATION DATA

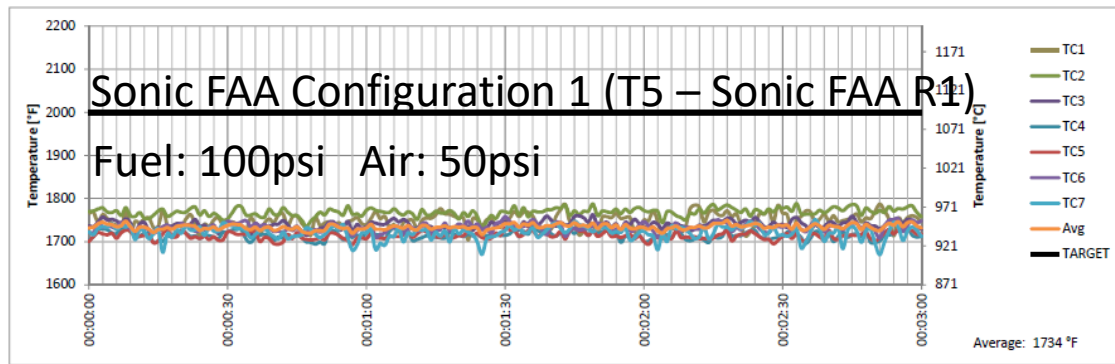


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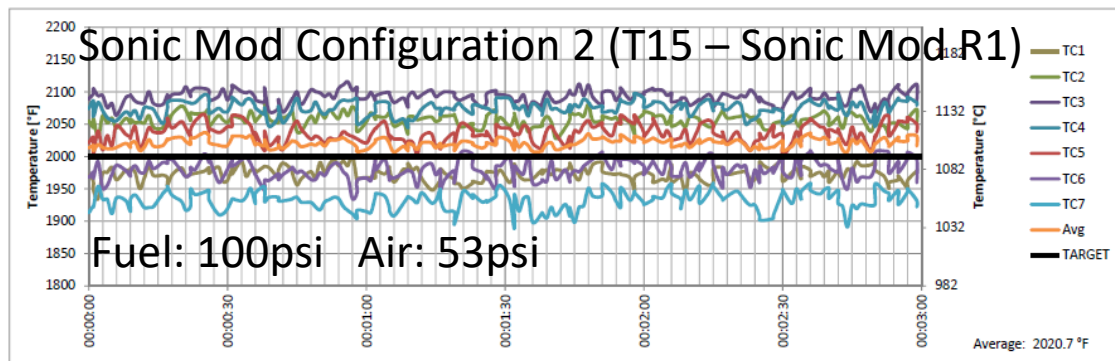




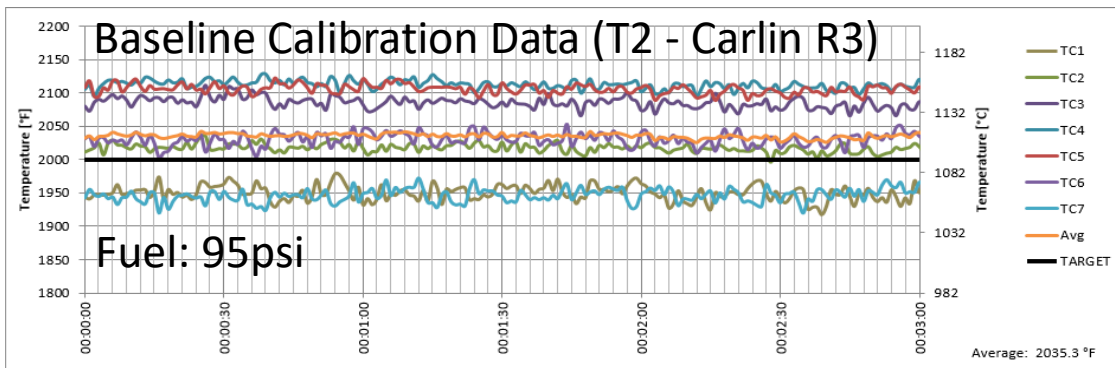
	Temp (°F)	Heat Flux (BTU/hr)
Avg	2033	4836
Min	1869	4509
Max	2123	4938



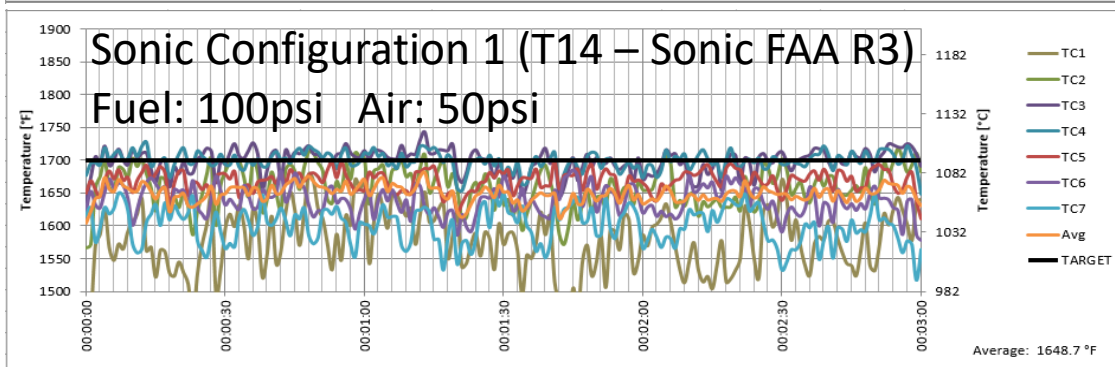
	Temp (°F)	Heat Flux (BTU/hr)
Avg	1734	3531
Min	1670	2342
Max	1788	3832



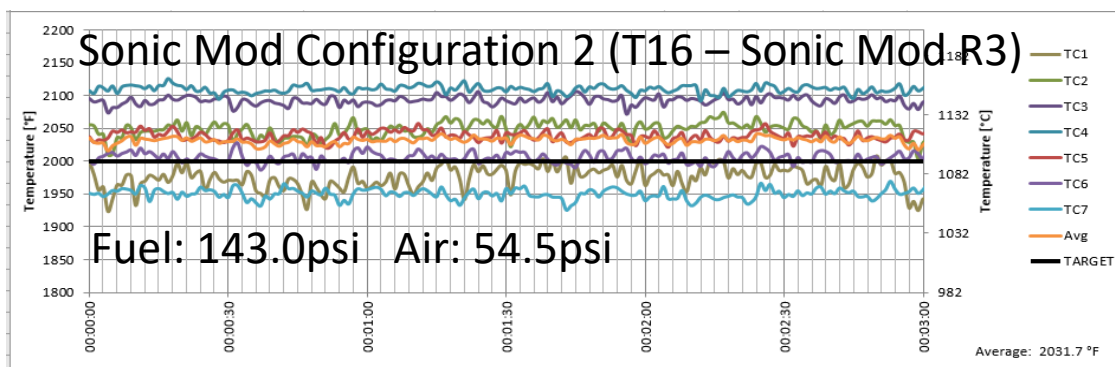
	Temp (°F)	Heat Flux (BTU/hr)
Avg	2021	4888
Min	1889	4501
Max	2116	5061



	Temp (°F)	Heat Flux (BTU/hr)
Avg	2035	4688
Min	1917	4490
Max	2129	4764



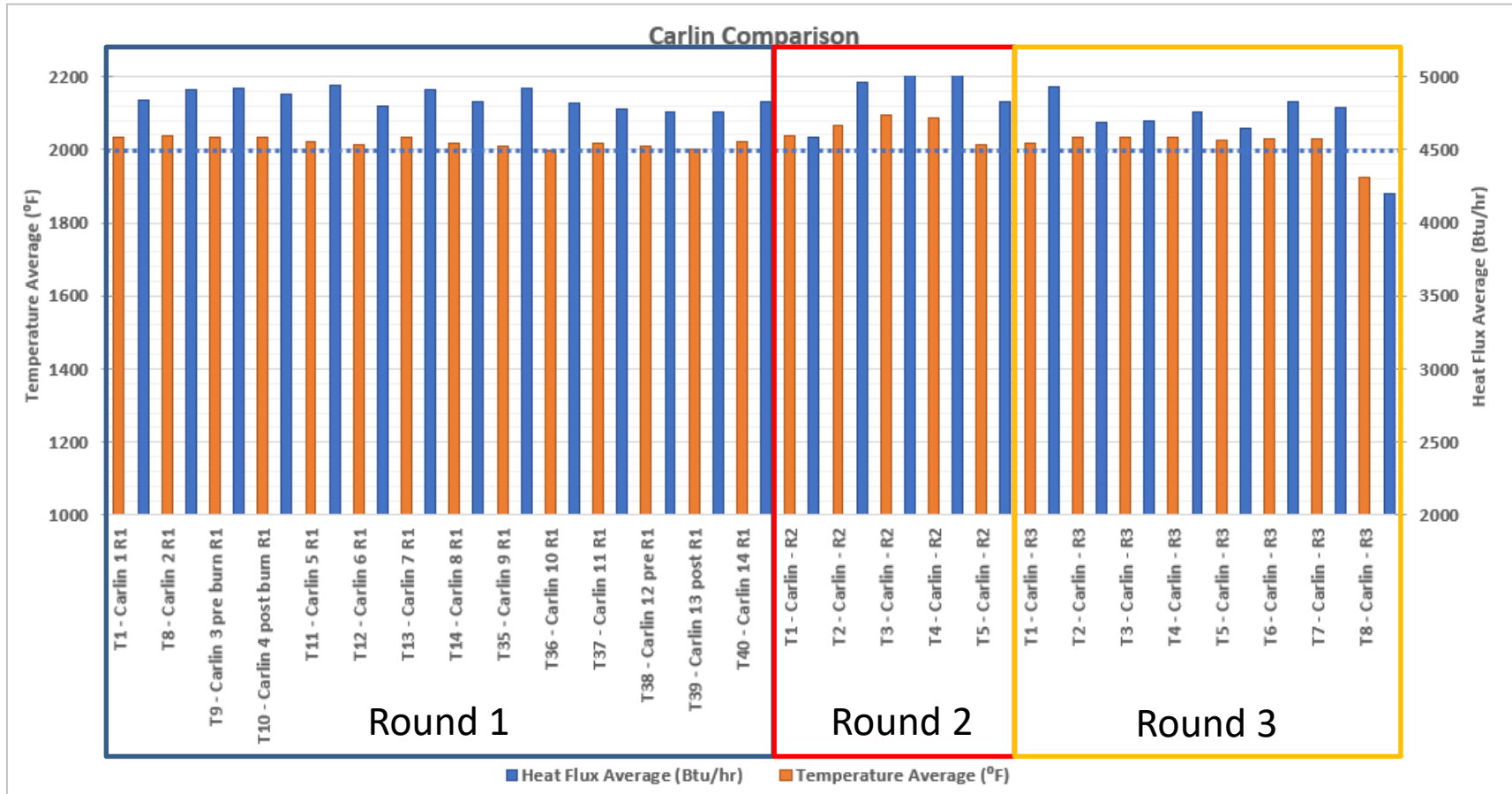
	Temp (°F)	Heat Flux (BTU/hr)
Avg	1649	3458
Min	1445	3180
Max	1742	3536



032	Temp (°F)	Heat Flux (BTU/hr)
Avg	2032	4621
Min	1924	4544
Max	2124	4736

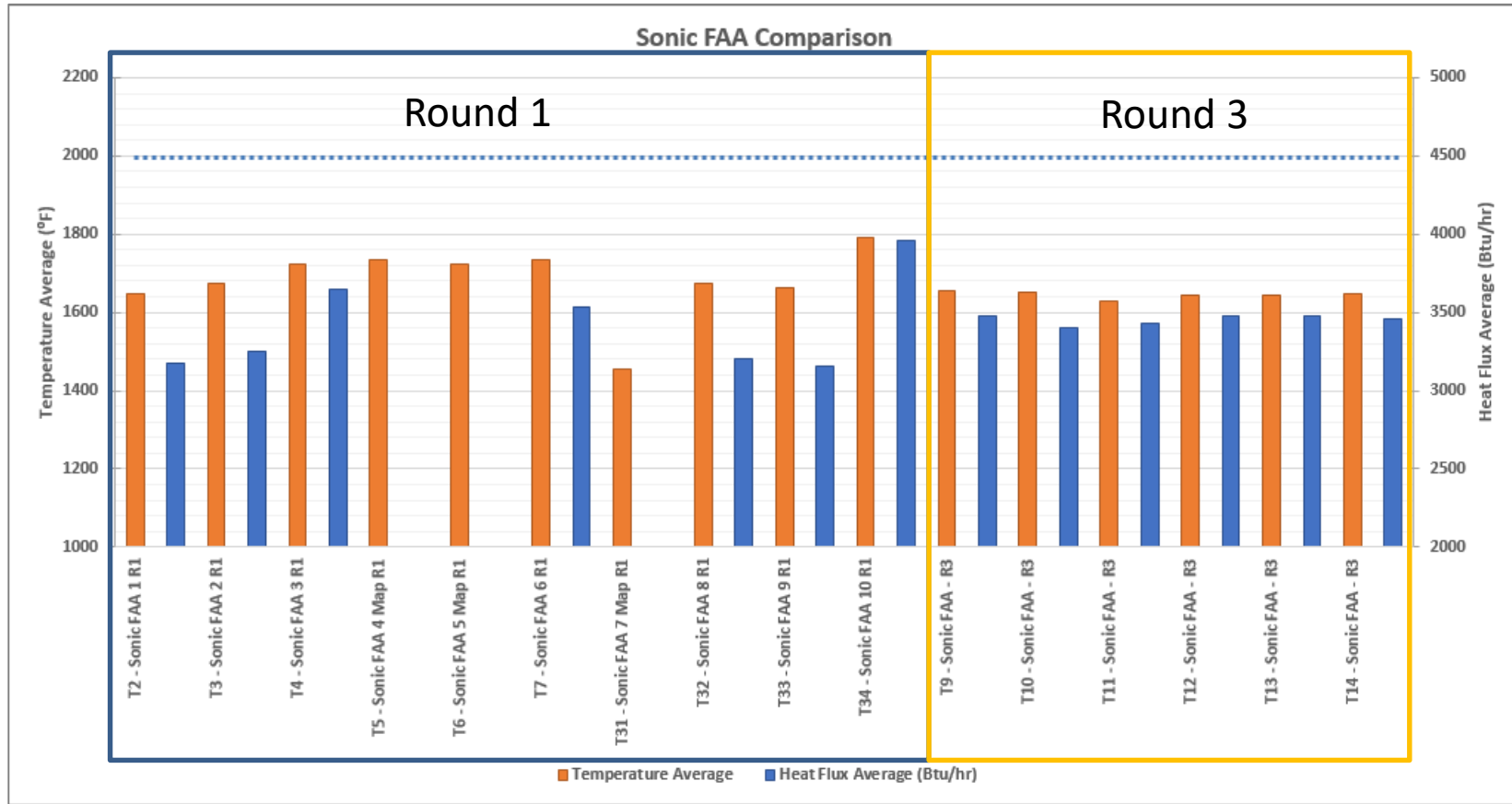
Summary of Carlin Calibration Data

Fuel pressure ranging from 80 psi to 120psi



Summary of Sonic Config 1 [FAA]

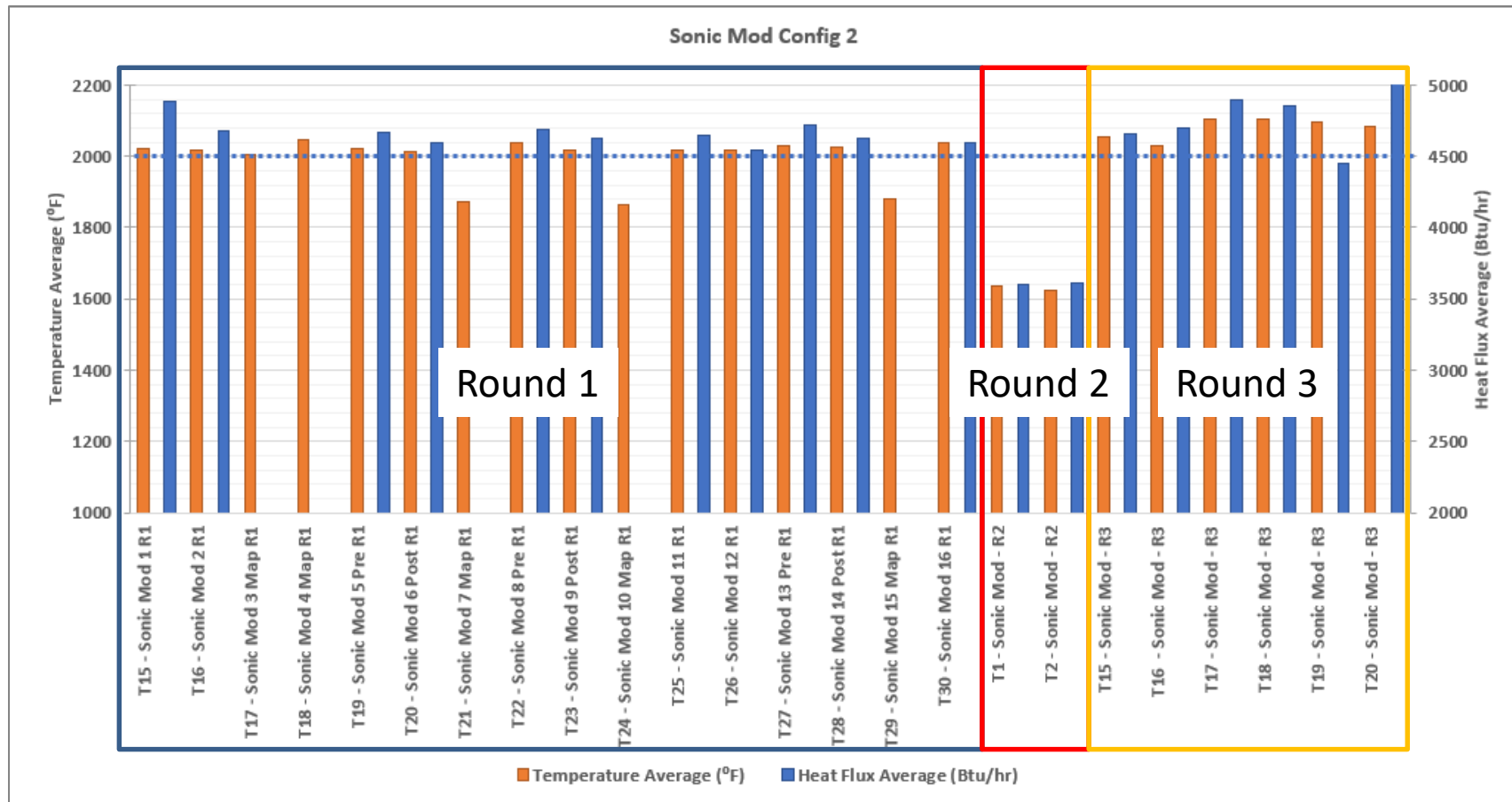
Fuel: 100psi Air: 50psi



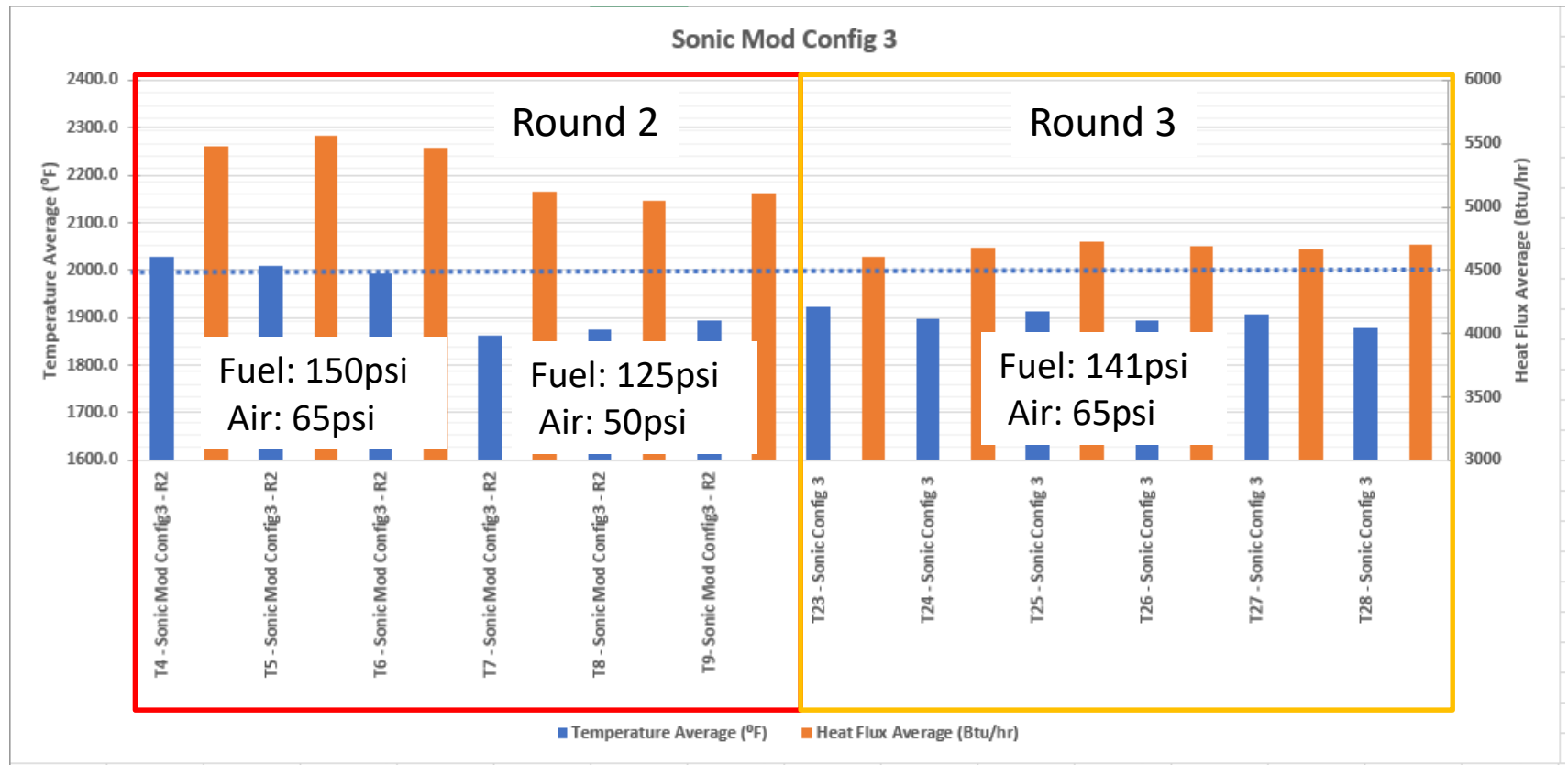
Summary of Sonic Mod Config 2

Fuel: 147psi Air: 62psi

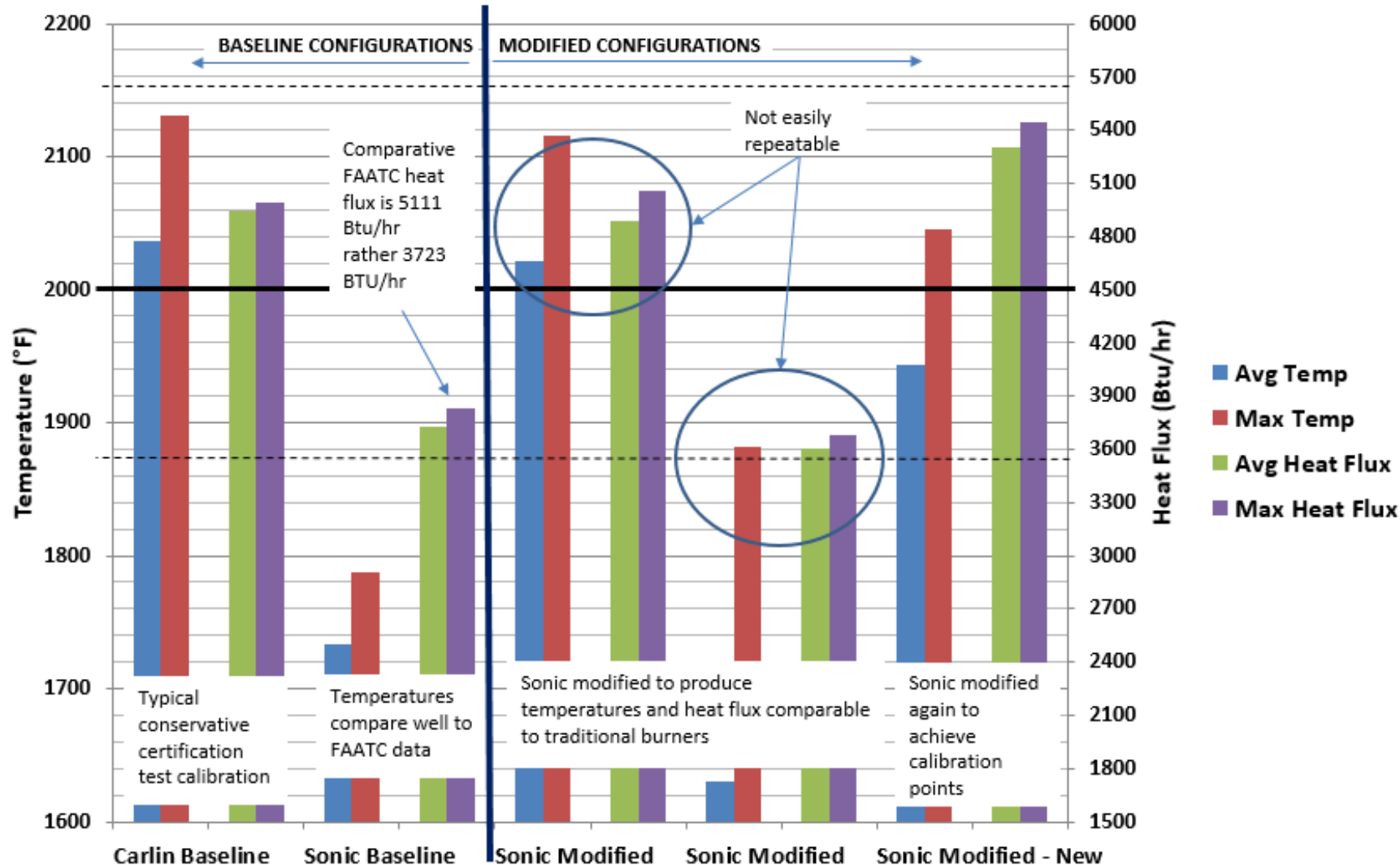
Fuel: 145psi Air: 50psi



Summary of Sonic Mod Config 3



Comparison of Baseline Carlin, Sonic FAA, and Sonic Modified Burners



TEMPERATURE AND HEAT TRANSFER MAPPING – FLAME CHARACTERISATION



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

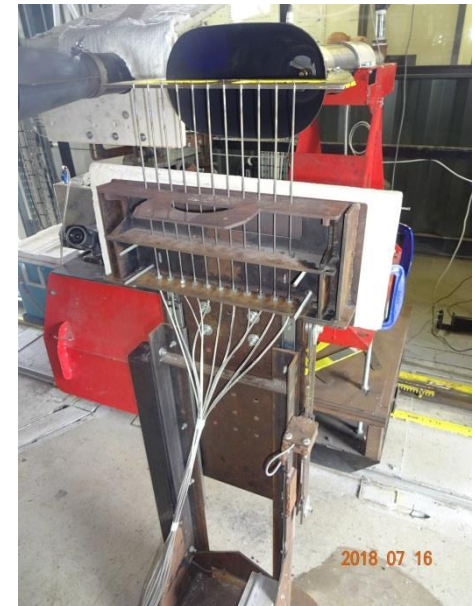
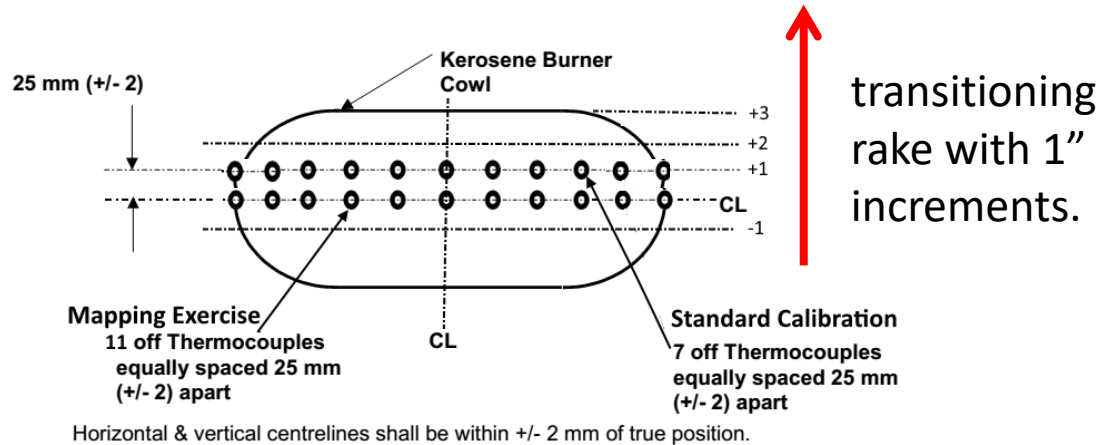


FIGURE 2 - FLAME TEMPERATURE MEASUREMENT POSITIONS FOR KEROSENE BURNER

Flame temperature mapping

- Engineering Report 3A CARLIN 200 CRD

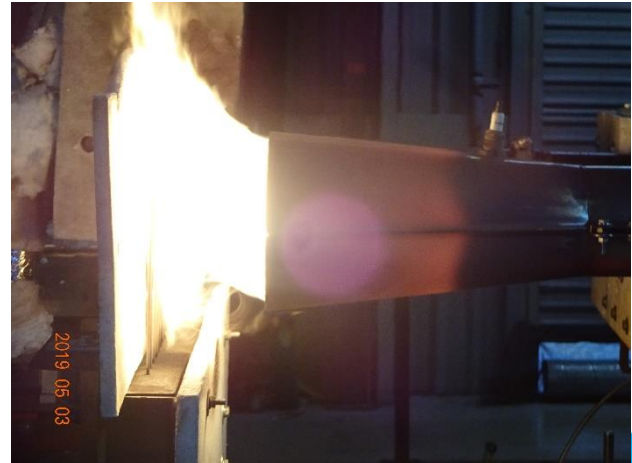
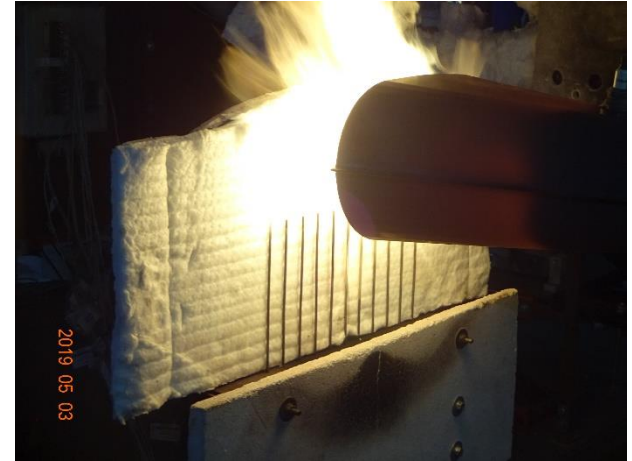
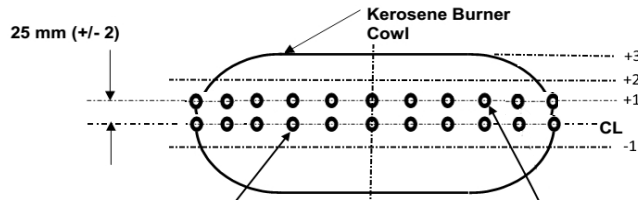
1420	1738	1850	1908	1912	1798	1777	1725	1686	1579	1204	1808
1671	1869	1947	1963	1981	1881	1894	1859	1848	1823	1611	1910
1697	1843	1919	1942	1972	1885	1942	1908	1886	1852	1679	1922
1634	1874	1904	1936	1961	1877	1947	1915	1871	1794	1573	1915
968	1323	1490	1609	1825	1766	1862	1813	1707	1474	1159	1724
602	805	1034	1175	1389	1363	1536	1389	1214	964	684	1300

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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	1963.0	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	1862.0	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.



Sonic – with new modifications – Config 3

Different fuel and air parameters

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

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
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 – Config 3 – Round 2

- the same nozzle and similar turbulator

125psi -- 1960 fpm air

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's	
No Board													
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11		
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												AVERAGE Central 7 TC's	
Ceramic Fireboard													
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11		
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												AVERAGE Central 7 TC's	
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		
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	

Carlin



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

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's	
No Board													
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11		
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												AVERAGE Central 7 TC's	
Ceramic Fireboard													
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11		
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												AVERAGE Central 7 TC's	
Ceramic Firewool													
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11		
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	

Sonic MOD Configuration 3

Carlin vs Sonic – Config 3 – Round 3

- the same nozzle and similar turbulator

BURNER AIR PRESSURE: 56PSI FUEL:145PSI

	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	1668.3	1795.1	1869.8	1934.0	1955.0	1985.0	1978.2	1955.0	1928.2	1831.3	1603.1	1943.6
Level 5	1805.9	1875.1	2005.6	2083.2	2096.6	2149.0	2174.2	2128.1	1983.7	1880.4	1769.2	2088.6
Level 4	1630.6	1845.4	1949.1	2025.3	2085.2	2138.0	2187.8	2117.3	1995.8	1890.0	1771.2	2071.2
Level 3	1140.7	1632.8	1730.4	1654.2	1626.4	1704.4	1822.9	1886.4	1878.9	1743.7	1462.3	1757.6
Level 2	660.4	1058.0	1185.5	1082.1	1007.1	1080.2	1255.6	1384.5	1414.8	1129.2	831.5	1201.4
Level 1	416.8	632.4	700.5	668.7	636.2	690.7	795.9	843.8	864.4	675.2	470.8	742.9

	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	1469.1	1499.1	1596.2	1769.9	1951.9	2071.2	2109.1	2102.6	2080.0	1933.2	1782.1	1954.4
Level 5	1186.8	1264.6	1366.8	1646.4	1950.5	2158.8	2241.4	2224.8	2151.8	1964.3	1847.3	1962.9
Level 4	929.5	996.7	1164.3	1410.3	1829.6	2108.4	2253.3	2204.2	2106.6	1873.2	1683.1	1868.1
Level 3	643.4	732.8	876.4	1156.3	1522.6	1797.6	2011.6	1972.0	1836.9	1535.8	1256.3	1596.2
Level 2	535.0	602.0	663.2	821.1	1128.2	1420.2	1611.3	1561.4	1431.1	1112.6	869.0	1233.8
Level 1	455.2	498.2	543.1	576.6	718.5	843.0	933.1	911.5	832.8	637.4	492.3	765.5

	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	1806.4	1820.0	1885.2	1912.0	1980.5	2055.4	2055.8	2011.0	1996.7	1961.7	1934.6	1985.2
Level 5	1765.5	1832.0	1914.4	1953.3	1991.0	2056.1	2128.8	2126.6	2084.9	2058.3	2019.7	2036.5
Level 4	1701.4	1773.6	1899.3	1938.2	1973.4	2015.7	2117.9	2123.2	2086.6	2082.2	2044.4	2022.1
Level 3	1654.9	1708.9	1826.0	1859.5	1876.1	1889.0	1927.3	1964.2	1968.4	1934.1	1906.2	1901.5
Level 2	1566.7	1591.7	1642.9	1685.5	1754.2	1802.1	1793.2	1773.4	1790.2	1757.0	1767.0	1748.8
Level 1	1299.5	1308.3	1359.9	1435.8	1502.7	1594.4	1615.1	1600.6	1616.3	1542.8	1533.0	1532.1

	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	1885.0	1953.6	2042.3	2034.4	2095.1	2170.3	2231.6	2209.7	2187.9	2111.8	2039.7	2138.8
Level 5	1905.9	1980.1	2050.9	2058.1	2101.4	2203.3	2259.3	2229.3	2197.5	2130.8	2071.7	2157.1
Level 4	1909.7	1980.2	2060.3	2077.5	2124.2	2217.3	2279.8	2253.3	2223.2	2142.4	2079.5	2176.5
Level 3	1902.3	1965.5	2036.0	2091.9	2143.5	2242.7	2272.5	2224.5	2194.4	2109.8	2046.4	2172.2
Level 2	1779.2	1846.6	1886.3	1996.9	2091.9	2169.5	2153.4	2104.5	2091.9	2030.1	1981.8	2070.6
Level 1	1566.1	1668.4	1686.4	1774.3	1869.6	1922.7	1909.5	1924.5	1928.1	1866.2	1866.7	1859.3

	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	1622.6	1713.1	1786.0	1857.4	1968.6	2063.4	2061.4	2023.8	2012.7	1987.2	1933.3	1967.6
Level 5	1565.9	1684.6	1783.1	1851.7	1957.5	2067.1	2109.3	2110.7	2109.3	2094.2	2016.9	1998.4
Level 4	1573.0	1646.3	1746.2	1778.6	1842.7	1959.0	2090.4	2107.4	2097.8	2110.2	2078.3	1946.0
Level 3	1575.4	1620.2	1706.1	1725.3	1770.3	1813.1	1867.3	1931.3	1966.1	1950.7	1902.2	1825.6
Level 2	1548.7	1581.5	1610.4	1634.8	1677.7	1752.5	1729.7	1694.6	1717.7	1679.6	1713.2	1688.2
Level 1	1358.8	1398.8	1436.4	1469.1	1537.1	1590.1	1595.6	1564.1	1583.1	1549.0	1589.9	1539.3

	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	1814.9	1895.5	1945.8	2005.2	2095.4	2144.3	2187.2	2153.1	2191.6	2133.7	2086.6	2103.2
Level 5	1820.5	1930.4	1984.5	2015.9	2095.2	2206.8	2216.8	2167.7	2200.9	2149.7	2128.7	2126.8
Level 4	1861.7	1982.2	2067.4	2084.6	2157.1	2243.5	2250.3	2204.2	2218.0	2162.7	2169.5	2175.0
Level 3	1846.0	1986.0	2074.9	2102.7	2185.8	2264.4	2247.5	2200.5	2204.7	2138.9	2171.8	2182.9
Level 2	1768.7	1966.6	2089.1	2114.4	2171.7	2244.8	2221.7	2174.4	2170.8	2116.9	2125.1	2169.6
Level 1	1601.1	1834.1	1937.5	2025.9	2093.7	2125.5	2069.7	2036.1	2039.8	1970.7	1960.8	2046.9

Carlin

Sonic MOD Configuration 3

Sonic Mod Configuration 2

- Effect of fuel and air pressure

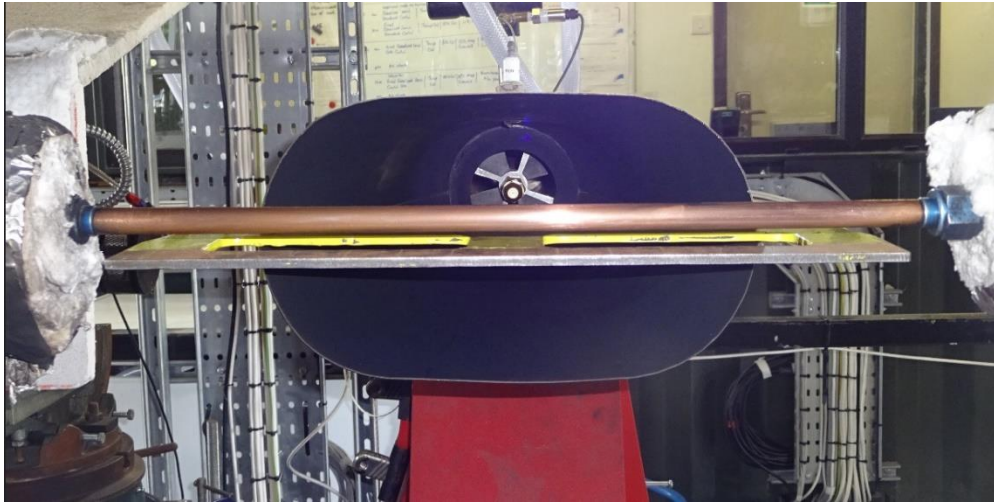
BURNER AIR PRESSURE: 56PSI FUEL:112PSI

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
Level 6	1496.0	1805.3	1959.4	2040.2	2063.9	2091.2	2041.8	1998.1	1952.5	1864.0	1656.8	2021.0
Level 5	1688.0	1909.4	2037.4	2134.4	2147.7	2154.5	2081.3	2019.2	1962.5	1849.2	1565.1	2076.7
Level 4	1772.3	1922.2	2049.0	2139.1	2153.4	2140.9	2048.8	1995.9	1964.4	1824.1	1469.7	2070.2
Level 3	1570.1	1743.4	1878.2	2028.6	2042.4	1990.5	1901.8	1939.6	1953.3	1828.8	1384.3	1962.1
Level 2	1118.7	1311.4	1440.7	1641.0	1699.4	1571.9	1600.8	1791.0	1856.9	1639.7	1022.9	1657.4
Level 1	561.1	708.2	859.6	972.0	1035.0	947.9	1096.8	1356.6	1365.1	1001.9	550.7	1090.4

BURNER AIR PRESSURE: 50PSI FUEL:145PSI

Burner Map looking into the Burner [°F] - Max Values												AVERAGE Central 7 TC's
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	
Level 6	964.1	1383.4	1744.5	1939.5	1934.1	1887.5	1873.1	1897.9	1854.4	1659.2	1296.9	1875.9
Level 5	915.8	1433.7	1860.5	2112.7	2154.4	2186.4	2159.0	2125.2	2039.5	1841.3	1450.0	2091.1
Level 4	949.2	1458.9	1957.4	2199.5	2275.1	2293.8	2256.5	2227.1	2113.5	1822.0	1365.4	2189.0
Level 3	747.7	1205.6	1758.1	2125.0	2264.1	2309.9	2255.2	2240.8	2186.9	1911.3	1354.8	2162.9
Level 2	620.3	1026.0	1511.4	1935.8	2124.2	2208.3	2212.4	2211.1	2152.2	1785.8	1201.1	2050.8
Level 1	437.7	689.1	1080.9	1426.6	1670.3	1797.7	1899.5	1989.1	1834.7	1376.9	824.0	1671.3

Heat Flux (BTU/hr) Map – 1" vertical Increments



Burner BTU Map looking into the Burner [BTU/hr] - Average Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch

3448.3
4452.0
4733.5
3833.7
2211.4
800.6

At each level : 1mins warm up was allowed and 3 mins of data recorded after this

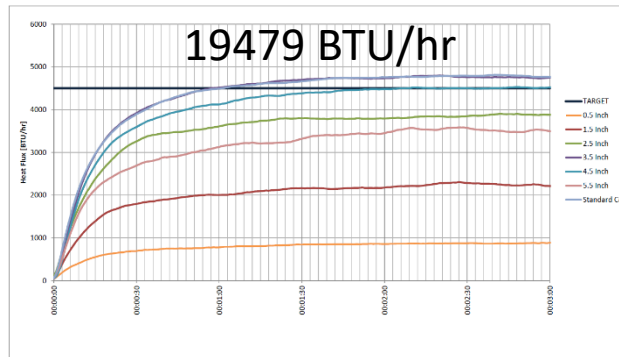


Heat flux Mapping: Copper tube transitioned in 1" increments vertically

Copper tube cleaned between levels

BTU/hr Mapping Summary – Round 1

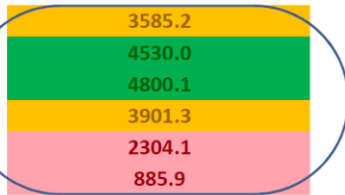
T8 - Carlin 2



Carlin Burn 2b BTU Map

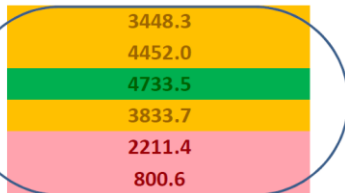
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch

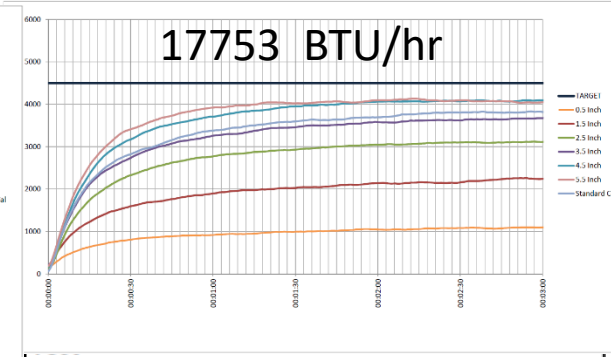


Burner BTU Map looking into the Burner [BTU/hr] - Average Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch



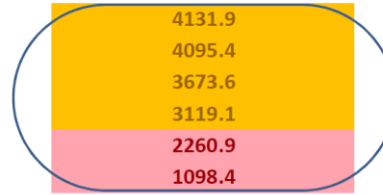
T7 – Sonic FAA 6



Sonic - FAA Burn 5 BTUmap

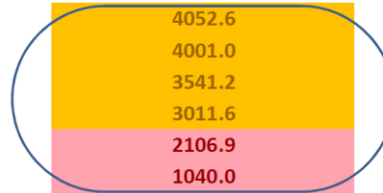
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch

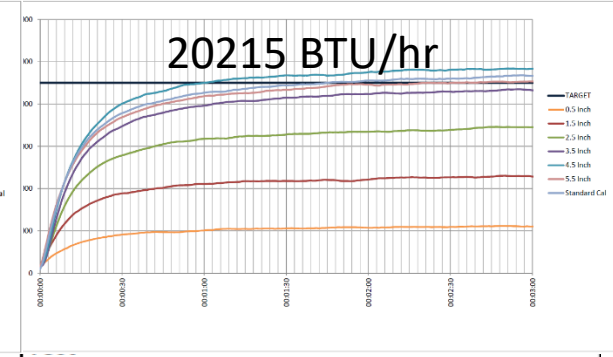


Burner BTU Map looking into the Burner [BTU/hr] - Average Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch



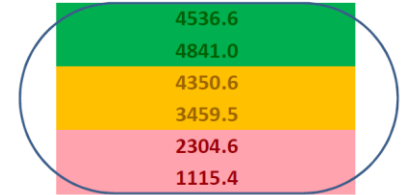
T27 – Sonic Mod 3



Sonic ModV3 Burn4 BTU Map

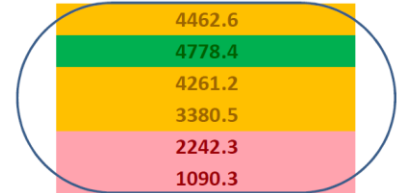
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch



Burner BTU Map looking into the Burner [BTU/hr] - Average Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch

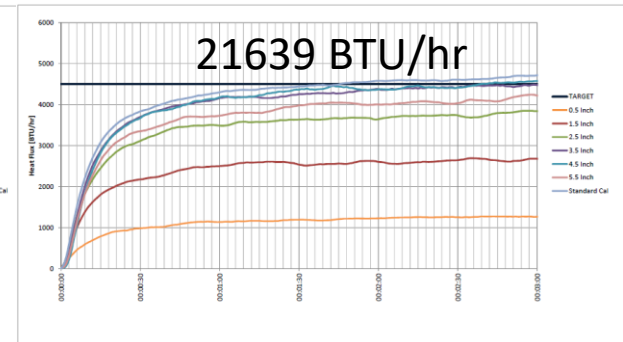
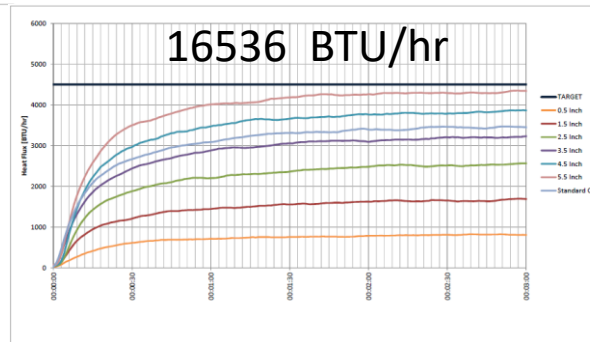
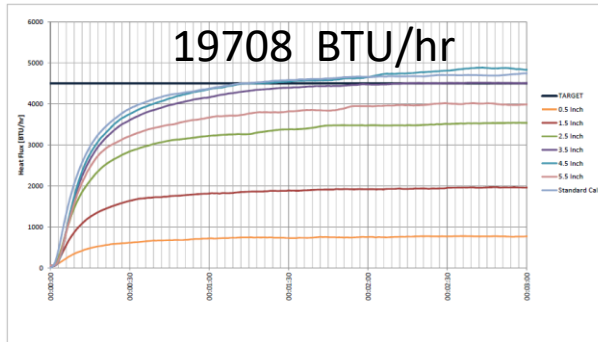


BTU/hr Mapping Summary – Round 2

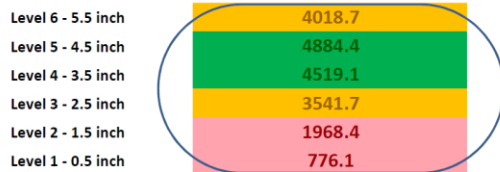
Cal Avg: 4666 BTU/hr
T2 - Carlin

Cal Avg: 3392 BTU/hr
T10 – Sonic FAA

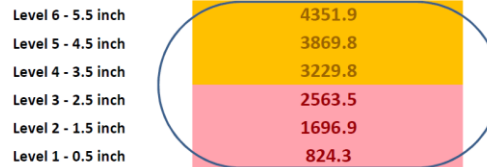
Cal Avg: 4600 BTU/hr
T15 – Sonic Mod 3



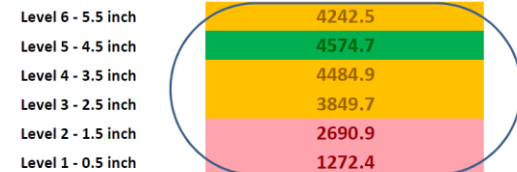
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values



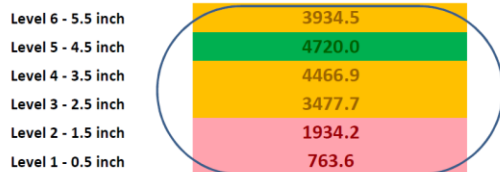
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values



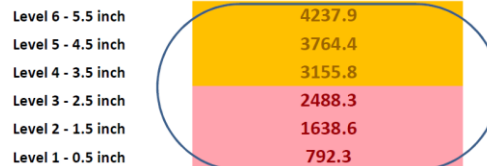
Burner BTU Map looking into the Burner [BTU/hr] - Peak Values



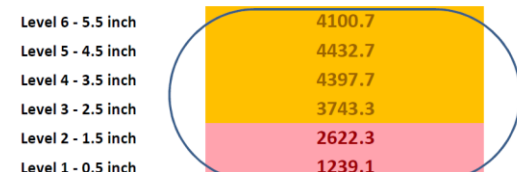
Burner BTU Map looking into the Burner [BTU/hr] - Average Values



Burner BTU Map looking into the Burner [BTU/hr] - Average Values



Burner BTU Map looking into the Burner [BTU/hr] - Average Values

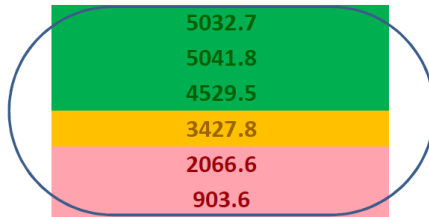


Sonic - Config 3

Cal Avg: 4721 BTU/hr

Burner BTU Map looking into the Burner [BTU/hr] - Peak Values

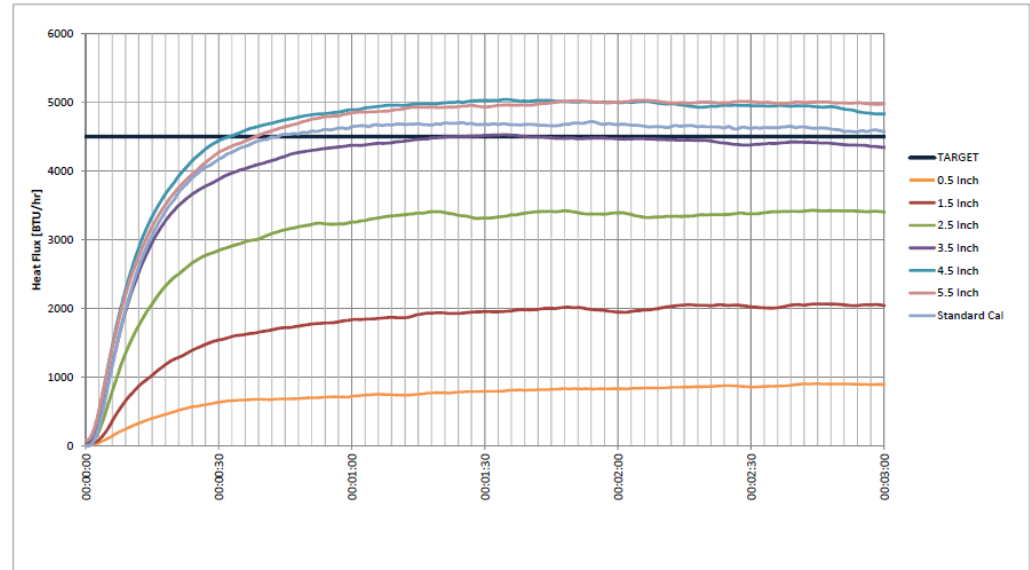
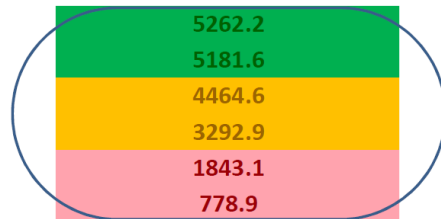
Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch



Cal Avg: 4784 BTU/hr

Burner BTU Map looking into the Burner [BTU/hr] - Peak Values

Level 6 - 5.5 inch
Level 5 - 4.5 inch
Level 4 - 3.5 inch
Level 3 - 2.5 inch
Level 2 - 1.5 inch
Level 1 - 0.5 inch



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	1469.5	1519.4	1603.6	1755.1	1956.9	2057.9	2099.8	2092.2	2101.0	1951.4	1786.7	1952.4
Level 5	1210.4	1261.1	1376.4	1650.2	1943.8	2161.5	2241.3	2219.1	2168.4	1980.2	1863.9	1965.8
Level 4	868.2	996.8	1138.7	1416.5	1831.3	2126.1	2240.0	2214.4	2129.7	1873.1	1705.4	1870.9
Level 3	607.2	679.8	802.6	1024.8	1417.7	1733.6	1975.8	1993.7	1917.4	1611.9	1383.3	1552.2
Level 2	448.2	527.7	593.9	711.8	1024.5	1334.4	1501.0	1478.8	1409.6	1121.3	895.4	1150.6
Level 1	340.6	394.2	435.7	461.7	596.1	741.5	871.0	834.9	742.2	588.5	448.1	669.0

ALUMINIUM STRIP BURNTHROUGH DATA

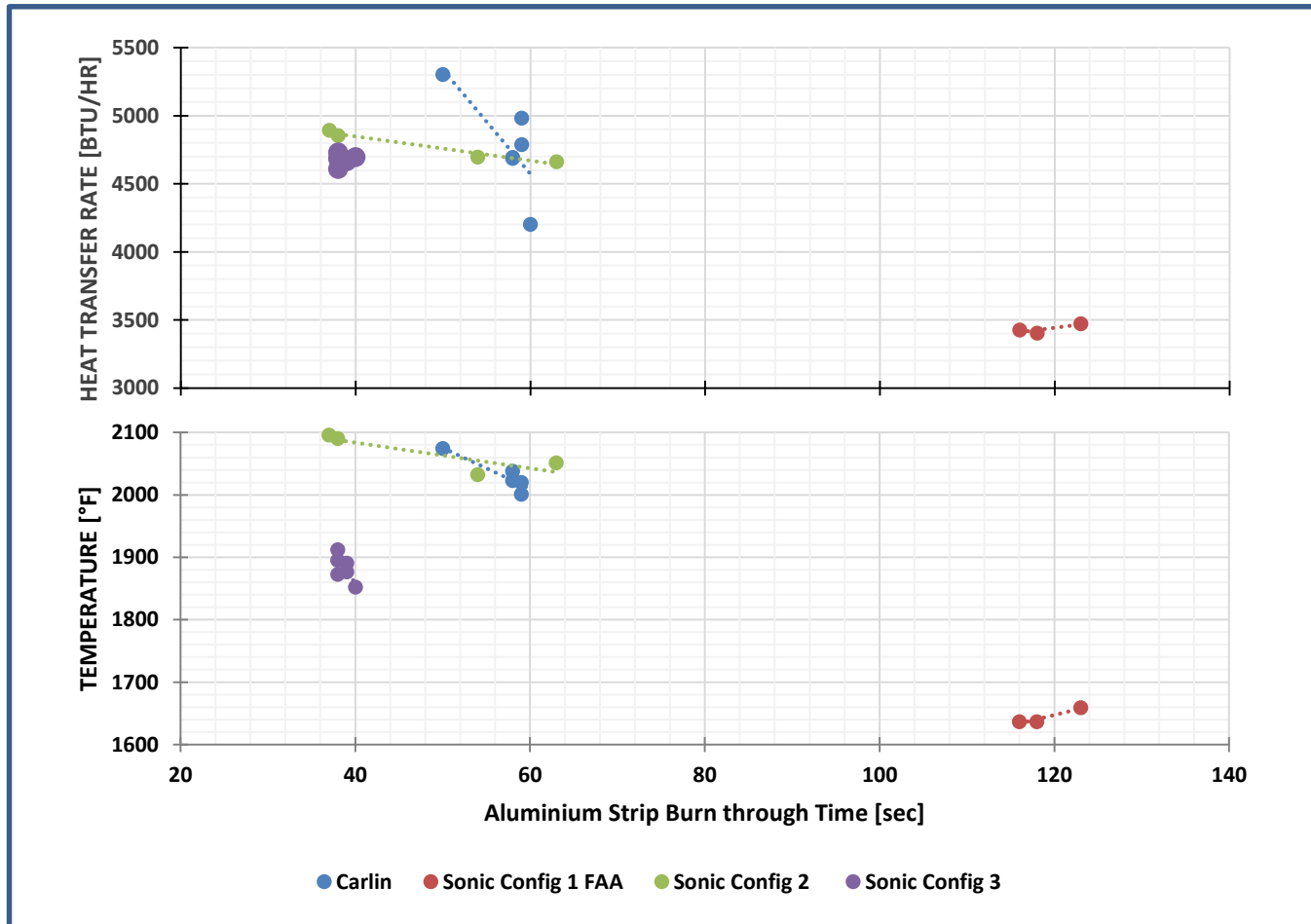


National Research
Council Canada
Conseil national de
recherches Canada



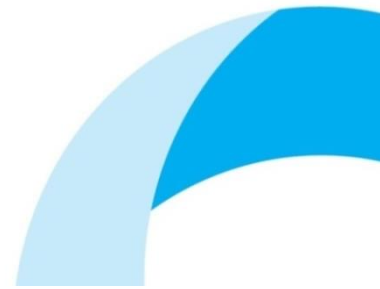
Temperature and heat transfer calibrations

-Effect on Burnthrough time



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
 - Can calibrate sonic burner according to current AC20-135 guidance and equipment
 - Does not take advantage of the expected Sonic burner repeatability – but have we seen this?
- Tools developed to achieve greater understanding of burner outputs
 - 2D HD temperature maps
 - with and without impingement surface
 - BTU mapping
 - 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.
 - We always need to assess the significance of our data. This is particularly important when talking about repeatability or reliability.



Future Work:

- Additional mapping ideas/plate thermocouples/slug calorimeter/
- Composite panels?
- Other labs – variability
- 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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