A NACELLE GROUP COMPANY

Development of FAA Copper Tube Heat Flux Calorimeter and Parametric Study of Burner Calibration

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Presentation overview

- Background – requirements for powerplant fire testing
- Objectives for this work
- Test equipment and burner set up
- Development of a copper tube calorimeter
- Achieving burner calibration – Heat Flux
- Achieving temperature calibrations – comparison of thermocouples
- Burning mapping
- Conclusion and future work

Background
- Fire testing for Powerplant Components

- Certification fire testing is used as a means for determining if a component of an aircraft is fire proof or fire resistant to the regulations

- Criteria has been established to try to define that all components undergoing such a test are subjected to the same severity of flame from a burner which satisfies set requirements, to ensure that the test is comparative and consistent.

- In particular the flame temperature and heat flux produced by the burner have to be calibrated at the given test location both pre and post testing, to qualify the test environment accurately simulates the real world condition.

- Approved instrumentation is used to provide calibration data to show the repeatability and consistency of the results achieved.

Background
- Fire testing for Powerplant Components

Various test methods, advisories and guides are used to provide criteria used in determining the flame characteristics required to test various components used in aircraft engines, their nacelles and their other supporting structures.

These Include:

- **FAA Power Plant Engineering Report No. 3A:** Standard Fire Test Apparatus and Procedure (For Flexible Hose Assemblies), Revised March 1978
- **FAA Aircraft Material Fire Test Handbook:** Chapter 11 Powerplant Hose Assemblies Test and Chapter 12 Powerplant Fire Penetration Test - used to determine the fire resistance componets used in designated fire zones to damage due to flame and vibration for showing compliance with TSO C42, C53A, and C75. April 2000
- **AC 20-135**: Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards and Criteria, Revised 1990
- **SAE AIR 1377A:** Fire Test Equipment for Flexible Hose and Tube Assemblies, Revised January 1980.
- **SAE AS 1055:** Fire Testing of Flexible Hose, Tube Assemblies, Coils, Fittings and Similar System Components, Revised 1978.
- **ISO2685**: Environmental Test Procedures for Airborne Equipment – Resistance to Fire in Designated Fire Zones, International Standards Organisation

Objectives of this work

- Development of FAA Copper Tube Heat Flux Calorimeter
- A parametric study of the factors that affect the accuracy and repeatability of flame calibration
- Provide a fresh and objective look on the guidance that’s available
- Future collaboration with other test facilities to iron out questions and queries found long the way

Background
- Burner Calibration Requirements

Heat Flux

Aircraft Material Fire Test Handbook Chapters 11 & 12 and AC 20.135 : requirement :

> 10.6 W/cm² (9.3 Btu/ft².s) or > 4500 Btu/hr

Heat Flux density is measured by a water-cooled calorimeter Power is measured by the heat transfer device

FAA Power Plant Engineering Report No. 3A : requirement :

> 9.3 Btu/ft².s (10.6 W/cm²) and < 11.8 Btu/ft².s or > 4500 Btu/hr and < 4650 Btu/hr

Parameters are measured by the heat transfer device or calorimeter.

ISO 2685 : requirement :

11.6 W/cm² (+/- 1 W/cm²)

The Heat Flux density is calculated from the heat transfer device (the total heat recorded by the heat transfer device is supposed to come from the surface of the tube in front of the burner exit).

Test equipment and burner set up

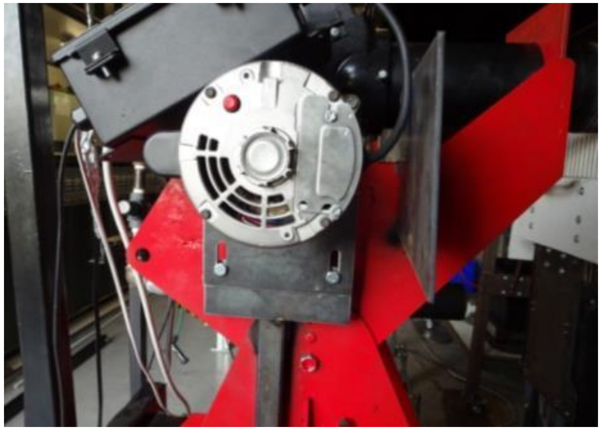
Acceptable Modified Burners:

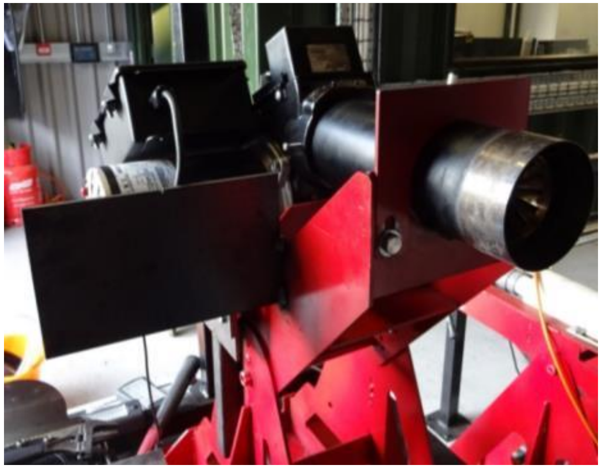
CARLIN 200 CRD, manufactured by the Carlin Company, 912 Silas Deane Highway, Wethersfield, Connecticut 06109, shown in figures 5 and 6, was modified in the following manner to produce a diffused 6-inch (vertical) by 11-inch (horizontal) sized flame with homogeneous temperature gradiant. Note: Carlin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

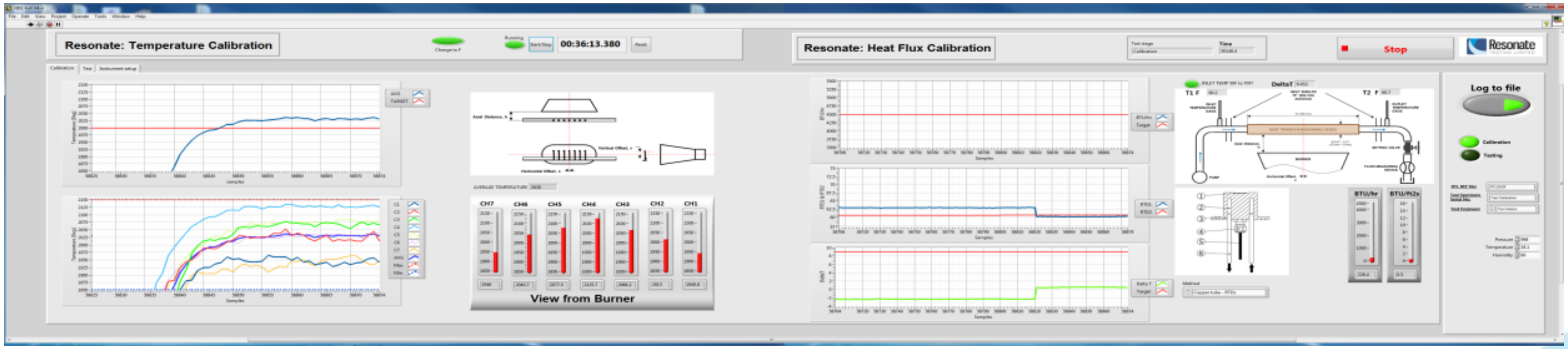




Test equipment and burner set up

- The burner is mounted on a carriage that travels along a 6m rail track. The Carriage is controlled from control room.
- The Track has four separate zones
  - 1. Warm up Area.
  - 2. Flame Temperature Calibration .
  - 3. Heat flux Calibration.
  - 4. Specimen Test area.

The data acquisitions is via National Instruments LabVIEW, giving real time display of heat flux and temperature distribution during calibration stages.



Development of copper tube calorimeter

Engineering report 3A
Chp 11 & 12

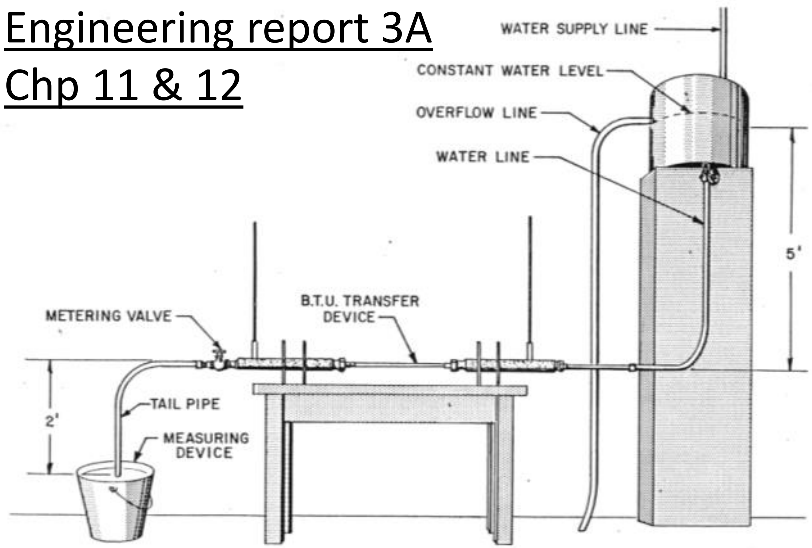
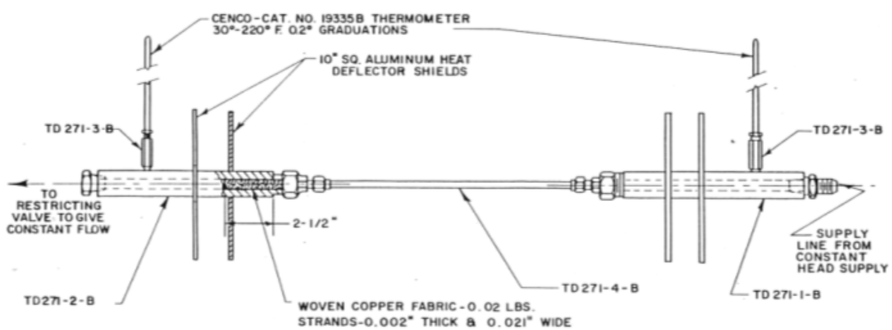


FIGURE 3. BURNER STANDARDIZATION APPARATUS



ASSEMBLY
B.T.U. TRANSFER DEVICE FOR TORCH STANDARDIZATION

ISO 2685

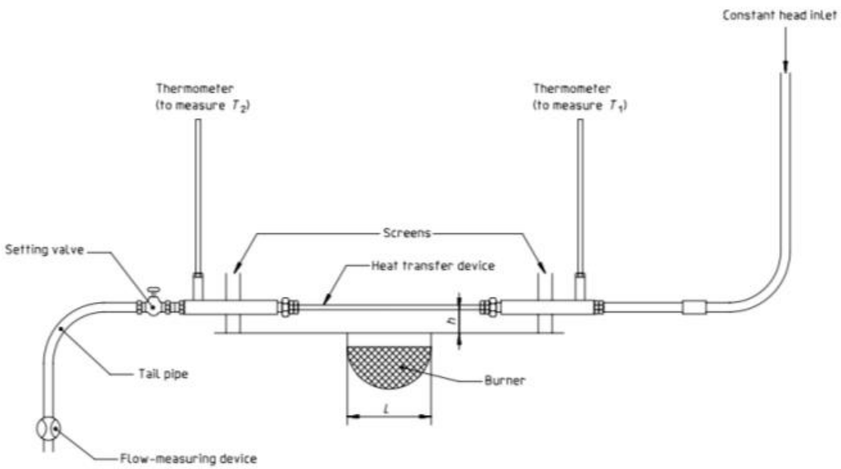


Figure B.3 — Set-up of the standard heat flux density measuring apparatus

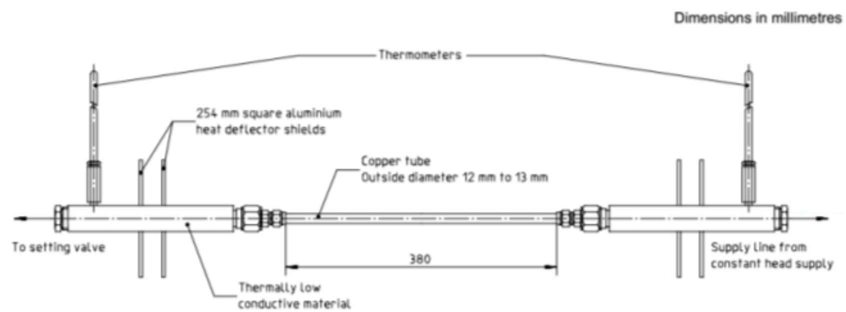
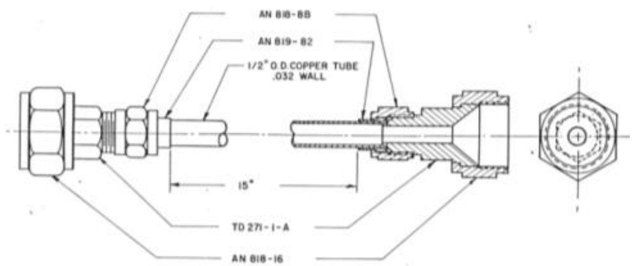


Figure B.4 — Overall view of the mounting of the standard heat flux density measuring tube

Development of copper tube calorimeter

Item	Engineering Report 3A and AC20-135	ISO 2685	FAA Fire Test Handbook – Chapters 11/12	Resonate Testing solution
Thermometer	Cenco-Cat No 19335B 30-220°F 0.20°F Graduations	Small, mercury thermometers capable of reading to within 0.1 °C or immersion thermocouples	Two glass scientific thermometers calibrated in 0.05°C (0.1°F) increments, immersible thermocouples, or equivalent	RTDS - IEC 60751 class I / 10:2008. (±0.03° C).
TD 271-4-B	Copper Tube OD 1/2" Inch 0.032" Wall Length: 15" (381mm)	Copper tube OD 12 to 13mm Thickness: 1mm ±0.1mm Length: 380 mm	Copper Tube OD 1/2" Inch 0.032" Wall Length: 15" (381mm)	Copper Refrigeration tubing 1/2inch OD Nominal wall 0.9 mm Length: 15" (381mm)
TD 271-2-B	Asbestos tubing 1 7/16" OD x 13/16" ID x 12" Long	Thermally low conductive material - Aluminium tube and brass fittings OD 27mm ID 20.6mm 300mm long	Material Transit Asbestos based tubing or material with equivalent thermal conductivity	Steel tubing around copper tube cavity filled with aerogel - a low thermal conductivity insulation material (from 0.014-0.015W/mk)
Copper mesh	Woven copper fabric 0.002in thick / 0.021in wide	No mesh mentioned	Woven copper fabric 0.002in thick / 0.021in wide	Woven copper fabric
Deflector plates	10" sq aluminium heat deflector shields	254 mm sq aluminium deflector shields	10" sq aluminium heat deflector shields	10" sq stainless Steel deflector plates



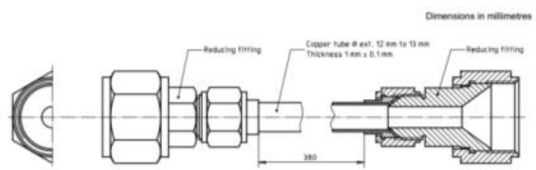
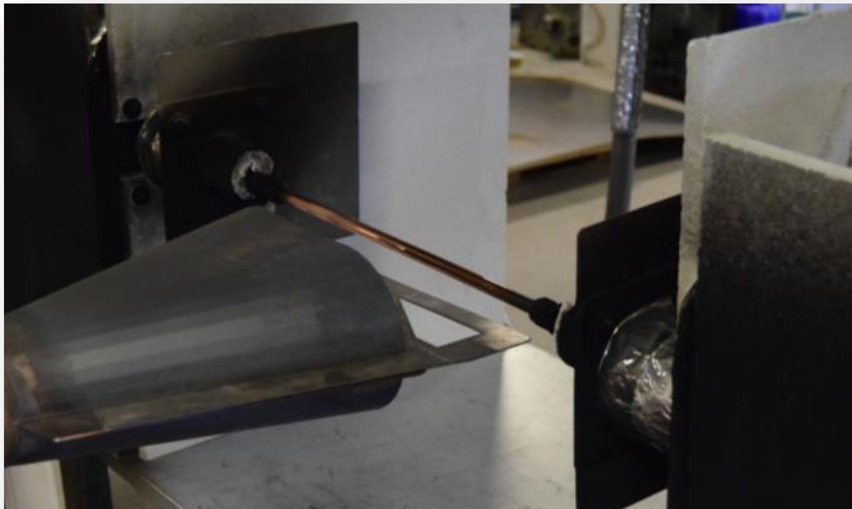
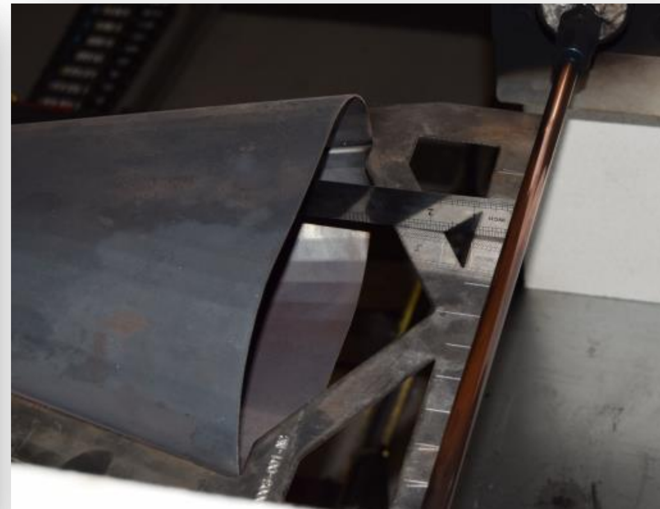


Figure B.9 — Overall view of the standard heat flux density measuring tube

Development of copper tube calorimeter





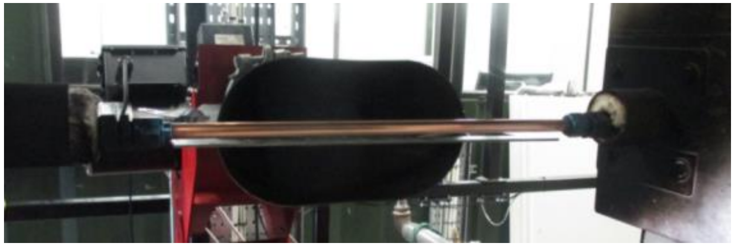
Development of copper tube calorimeter

The copper tube heat flux measurement is reliant upon the accurate measurement of the relatively small temperature rise between the water entering and exiting the bare section of copper tube.

$$Q = \dot{m}C_p(\Delta T)$$
$$Q = 500(\Delta T)$$

The temperature measurement is sensitive to:

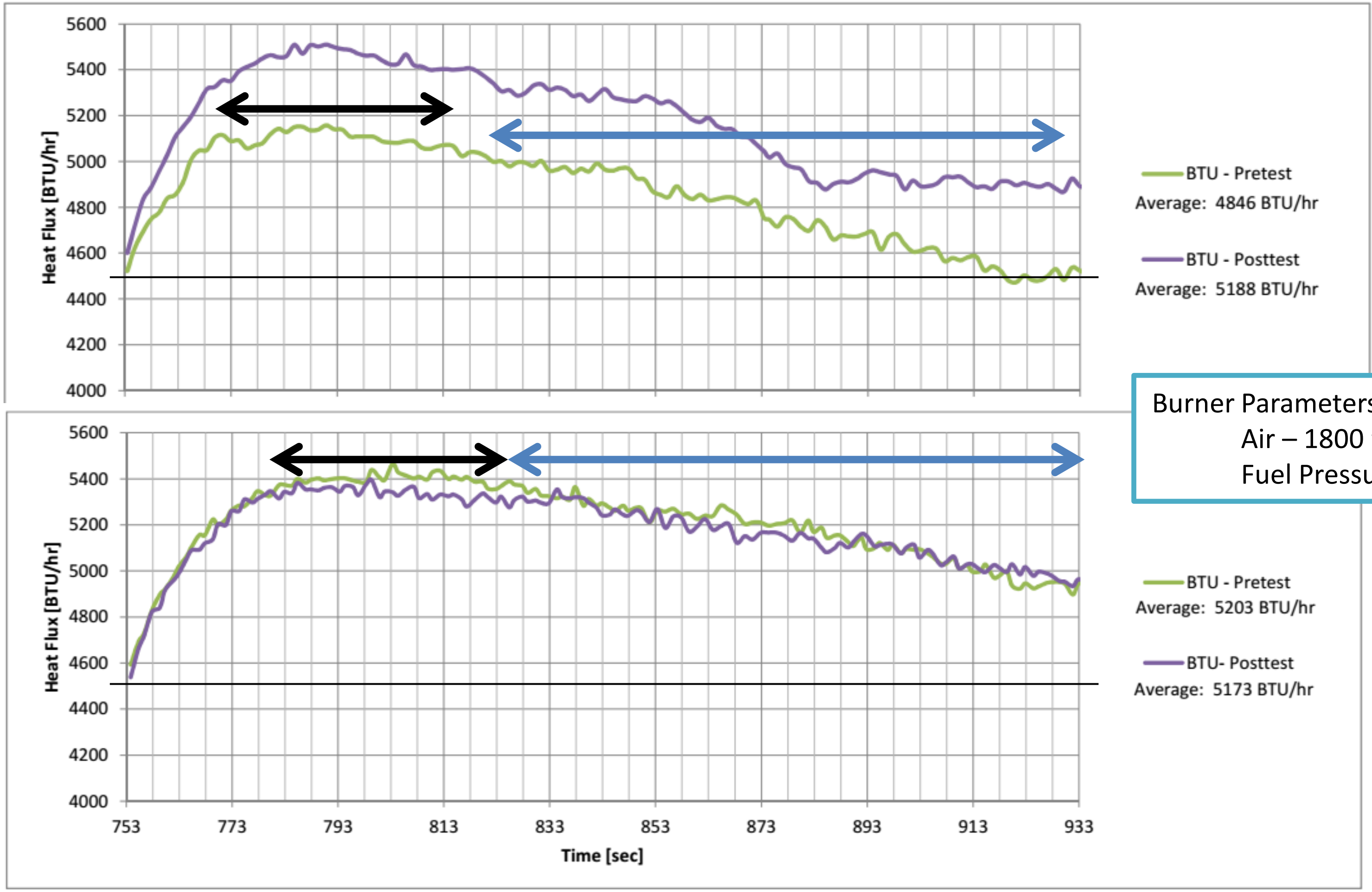
- The flow rate measurement and the tolerances
- The temperature difference measurement – RTD's are required for accuracy instead of thermocouples
- Best practices of using accurate RTDS (four wire) – shielding of cables is essential and common grounding
- Warm up time spent on the copper tube and resulting carbon deposits on the tube
- Changes in the characteristics of the burner and if the flame is 'clean' or sooty



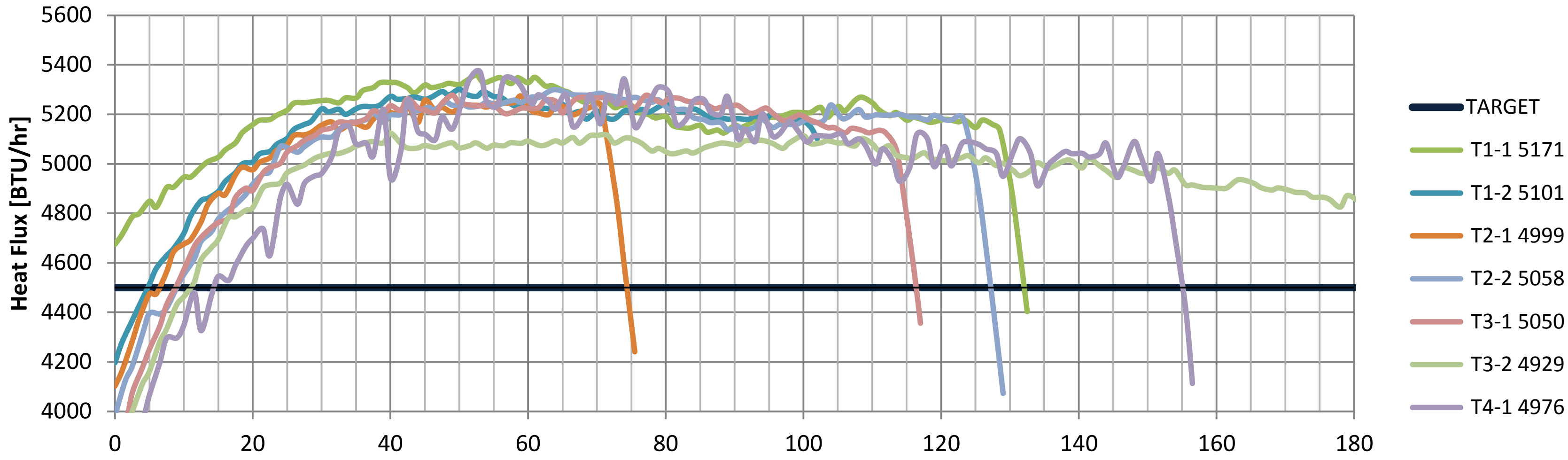
Heat flux Results

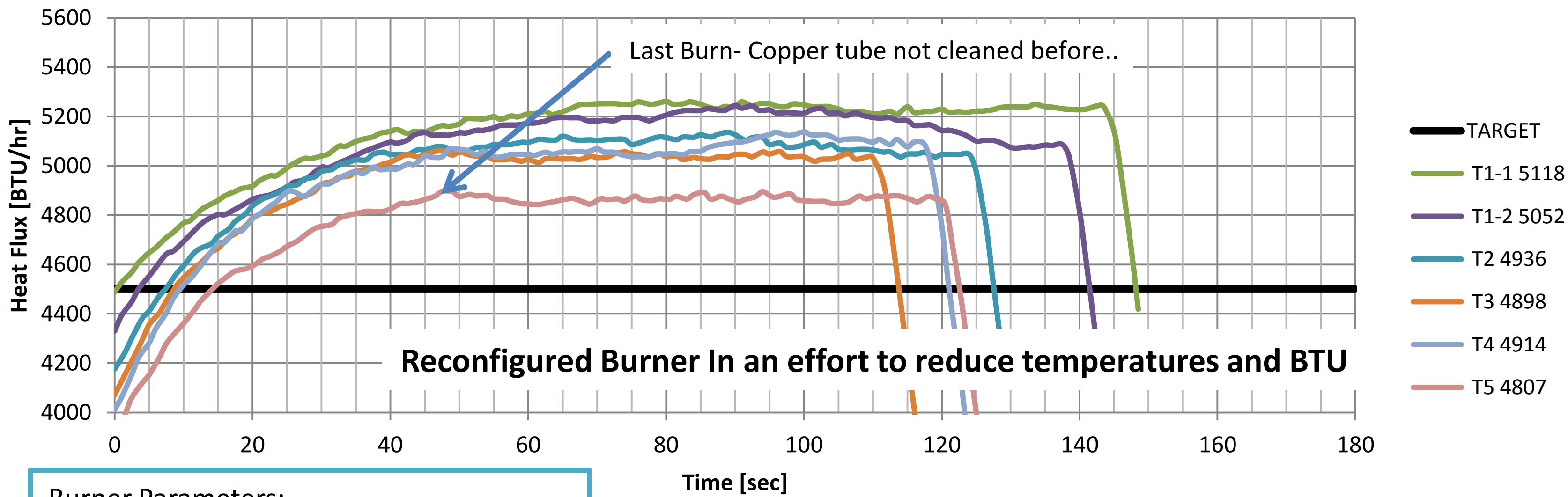
Actual Flame Heat Flux

Decay due to carbon



Burner Parameters:
Air – 1800 ft/min
Fuel Pressure – 120 psi





Burner Parameters:
Air – 2900 ft/min
Fuel Pressure – 86 psi

Summary –
Heat flux Calibration

Differences in the advice documentation have led to different test houses interpreting the following differently:

- The flow rate measurement and the tolerances
- The temperature difference measurement – RTD's are required for accuracy instead of thermocouples
- Warm up time spent on the copper tube and resulting carbon deposits on the tube
- Changes in the characteristics of the burner and if the flame is 'clean' or sooty

$$Q = \dot{m}C_p(\Delta T)$$
$$Q = 500(\Delta T)$$

This leads to inconsistencies in how that calibrations is carried out in different Test facilities

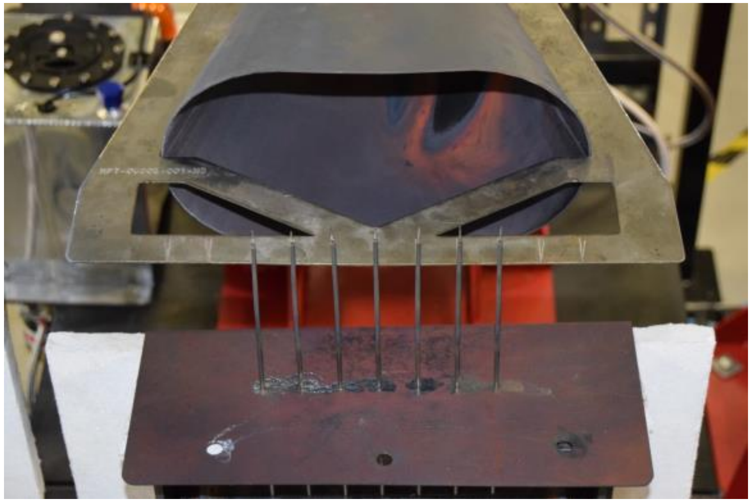
Flame characterisation

Development of the copper tube calorimeter led us to further examine the art of burner heat flux and temperature calibration

Previous work

- James Demaree, Report No. DOT/FAA/RD/76/213, “Re-evaluation of Burner Characteristics for Fire Resistant Tests,” dated January 1977
- Serge Le Neve, “Fire Tests on Components Used in Fire Zones. Comparison of Gas Burner to Oil Burner,” AC20-135/ ISO 2685, Proceedings of the FAA Materials Meeting, Atlantic City, New Jersey, October 21–22, 2008.
- Ochs, R., “Development of the Next Generation Fire Test Burner for Powerplant Fire Testing Applications,” Proceeding of IASFPWG, London, United Kingdom, May 18, 2010.
- Samir Tambe, Yi-Huan Kao, and San-Mou Jeng , “Development of Next Generation Burner Characteristics for Fire Testing of Power Plant Materials and Components”, DOT/FAA/TC-13/38, April 2015

Thermocouple rake and mapping capability



The mobile and remotely controlled data collection system allows a more complete analysis of flame characteristics.

The temperature-indicating system used permitted an II-point or 7-point horizontal survey at I-inch increments across the flame at any selected vertical height.

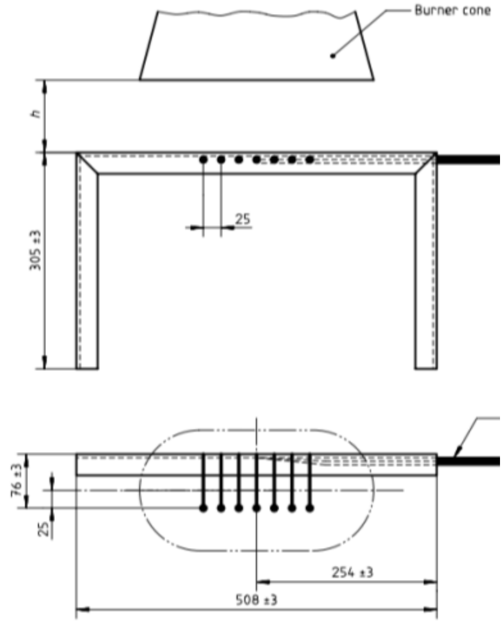
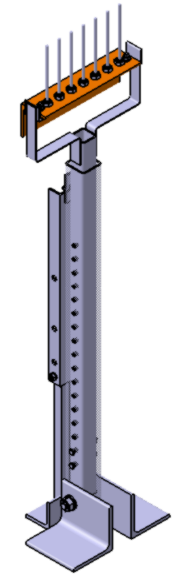
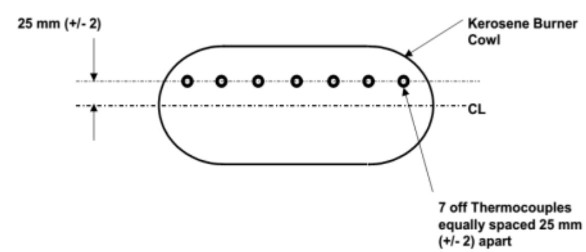


Figure B.2 — Liquid fuel burner — Thermocouple positions



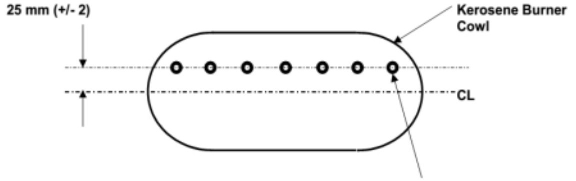


Horizontal & vertical centrelines shall be within +/- 2 mm of true position.

FIGURE 2 - FLAME TEMPERATURE MEASUREMENT POSITIONS FOR KEROSENE BURNER

Thermocouples

	Engineering Report 3A	AC20-135	ISO 2685	FAA Fire Test Handbook – Chapter 11 and 12
Number	Not less than five inches		The seven thermocouple measuring points	at least five
Type		Chromel-Alumel, thermocouples	NI-CR/Ni-AL Thermocouple wires.	Chromel-Alumel (Type K) thermocouples
Sheath		l/16 to l/8-inch metal sheathed, ceramic packed	If a metal sheath is used, the maximum diameter shall not exceed 3 mm	sheathed in 1/16 inch (1.6 mm) stainless steel or inconel tubes or equivalent
Wire thickness		Nominal 22 to 30 AWG (America Wire Gage) size conductors or equivalent.	The diameter of the thermocouple wire shall be between 0.6 mm and 1 mm	ANSI 22-gauge
Junction/tip		Bare junction	Exposed junction is 4-10mm	
Accuracy/error	allowable overall error of +/-1 (one) % at 2000°F.			
Alignment	1 Inch apart		25mm apart	CH 11: aligned in a row 1 ± 0.1 inch (25 ± 3 mm) apart Ch12: aligned in a row, 1.0 ± 0.1 inch (25 ± 2 mm) apart.
Additional information		An air aspirated, shielded, thermocouple should not be used.	The thermocouple shall be unshielded and non-aspirated.	

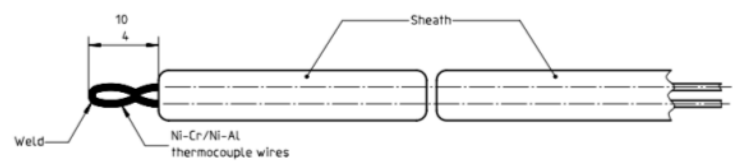


Thermocouples

1/8 inch (3mm) OD
Fully sheathed

**1/8 inch (3mm) OD
Exposed Junction
(10mm)**

**1/16 inch (1.6mm) OD
Fully sheathed**



NOTES

1 The diameter of the thermocouple wire shall be between 0,6 mm and 1 mm.
2 If a metal sheath is used, the maximum diameter shall not exceed 3 mm.
3 The thermocouple shall be unshielded and non-aspirated.

Figure B.1 — Details of thermocouple

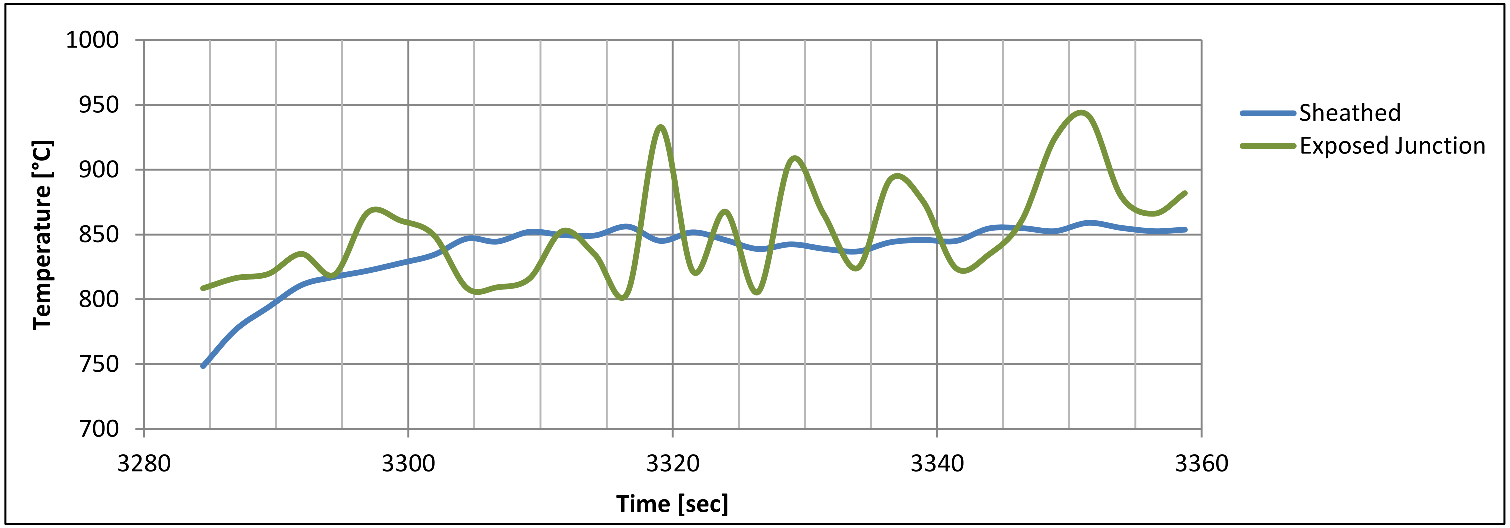
Thermocouple Output Tolerances
IEC 60584.2:1993, (BS EN 60584.2:1993)
Note BS EN 60584.2:1993 replaced BS 4937 Pt 20:1991
see note A below

TYPE	Tolerance Class 1	Tolerance Class 2	Tolerance Class 3
Temperature Range	–40°C to +375°C	–40°C to +333°C	–167°C to +40°C
Tolerance Value	±1.5°C	±2.5°C	±2.5°C
Temperature Range	375°C to 1000°C	333°C to 1200°C	–200°C to –167°C
Tolerance Value	$\pm 0.004 \cdot \lvert t \rvert$	$\pm 0.0075 \cdot \lvert t \rvert$	$\pm 0.015 \cdot \lvert t \rvert$

Type K thermocouples compliant with BS EN 60584.1 Pt4 Class 1

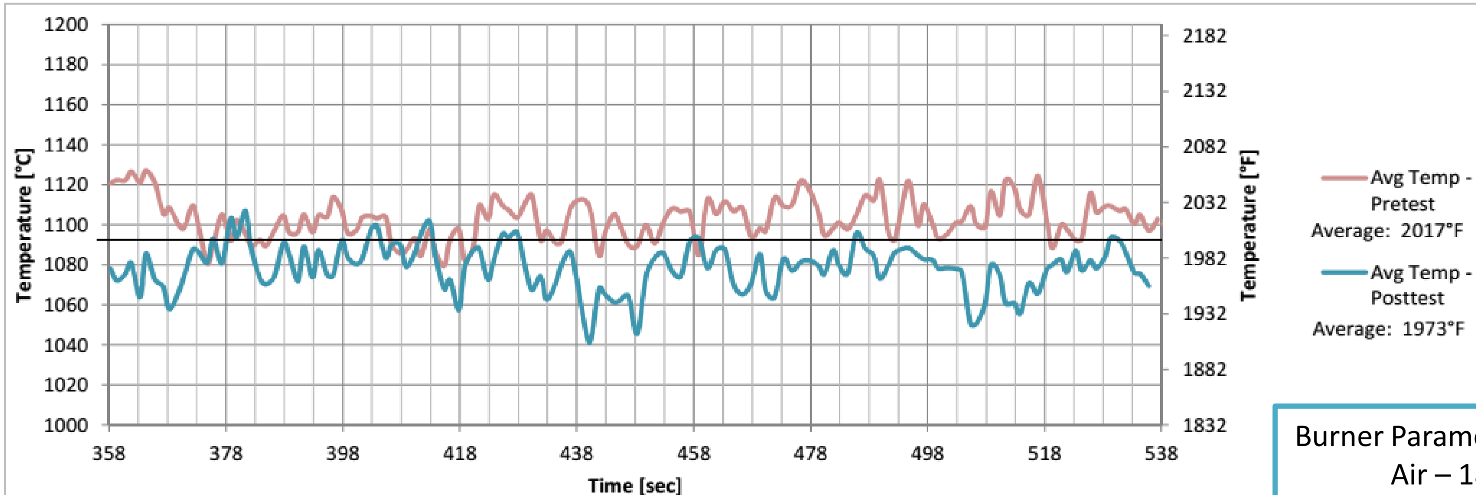
375°C to 1000°C
$\pm 0.004 \, . \, \lvert t \rvert \rightarrow \pm 40$°C

Thermocouple – Exposed junction/sheathed

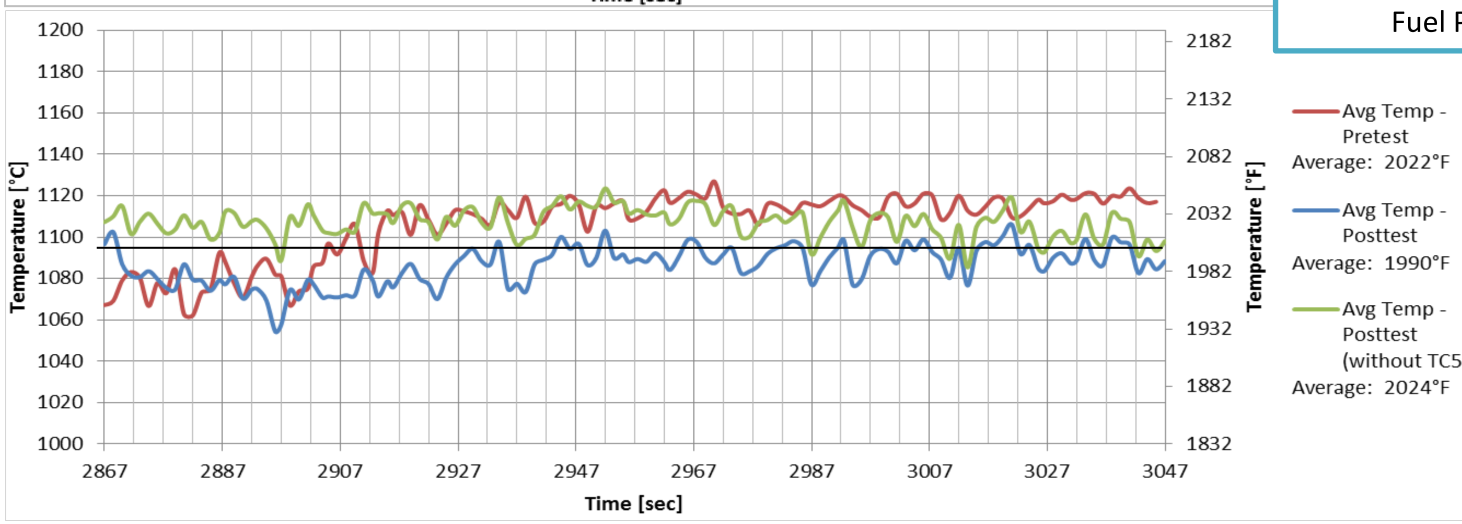


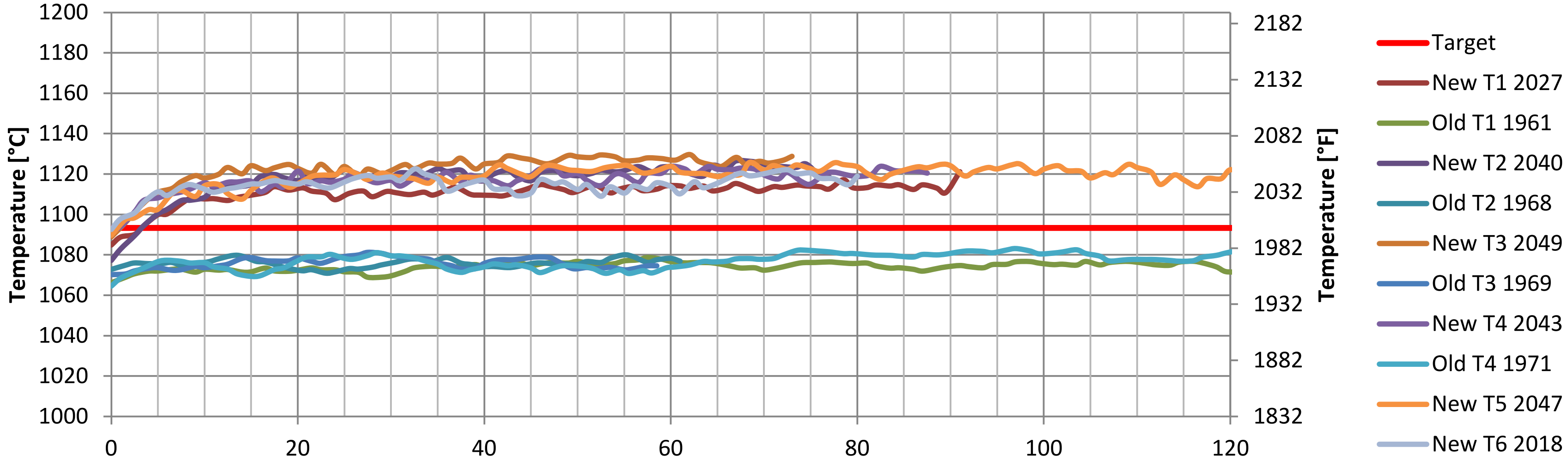
- Provided the type and age of the thermocouples are the same they essentially read the same value.
- The fully sheathed version is slower to respond providing an aliasing effect which results in an averaging of the temperature measured
- This effect is amplified when the thicker sheathed thermocouple is used - the thicker sheathed thermocouples will often read a lower value as the speed at which they react is much slower than the changing dynamic nature of the flame

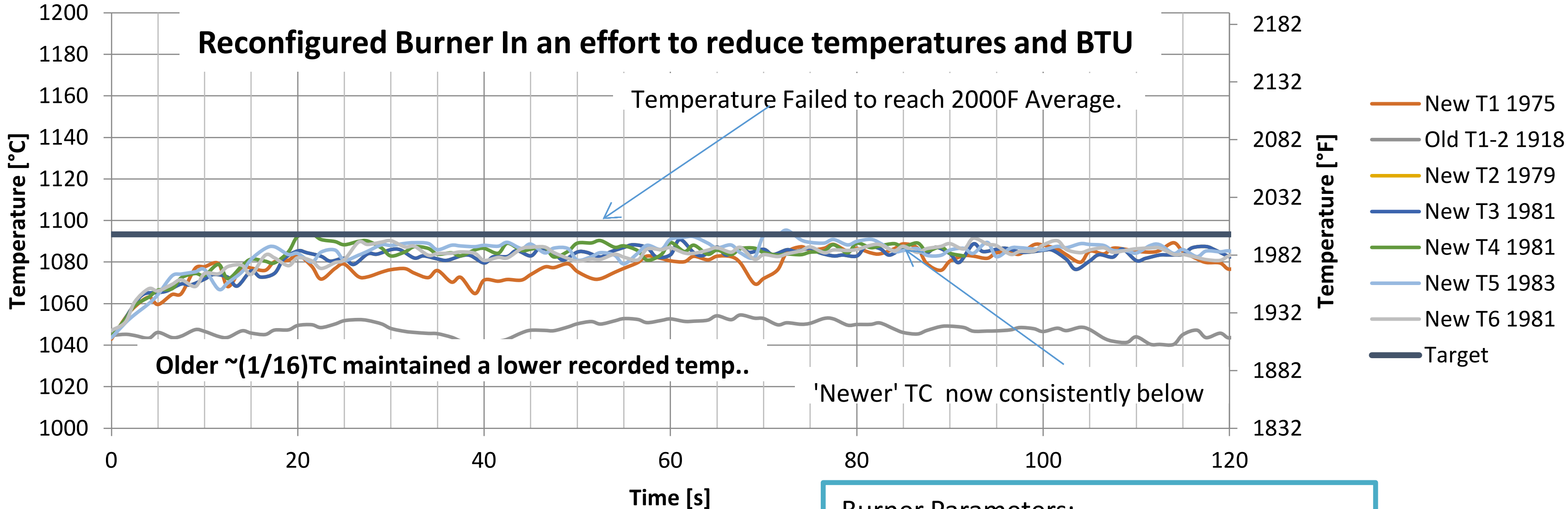
Temperature Results



Burner Parameters:
Air – 1800 ft/min
Fuel Pressure – 120 psi





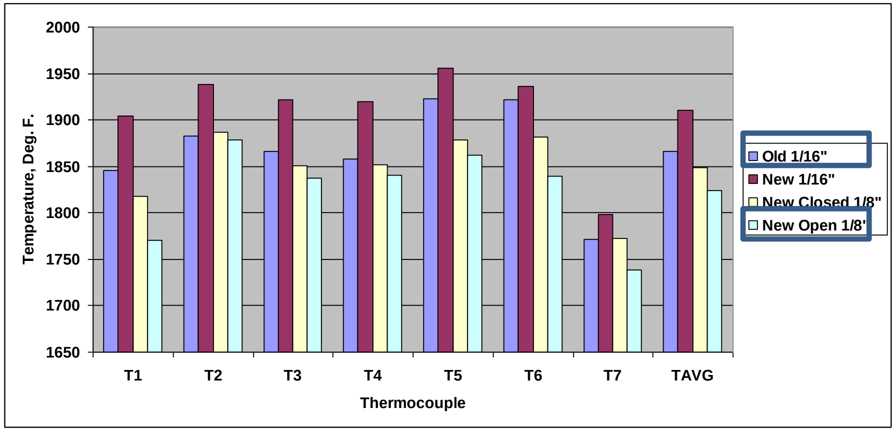


Burner Parameters:

Air – 2900 ft/min

Fuel Pressure – 86 psi

Thermocouple - age



Ref: Development of the Next Generation Fire Test Burner for Powerplant Fire Testing Applications, Robert Ochs

Thermocouple size, construction, and age all have an effect on the measured flame temperature

- 1/16” sheathed TC’s had the highest measured temperature, although their accuracy degrades quickly
- 1/8” sheathed TC’s had a lower temperature measurement than both old and new 1/16” TC’s
- 1/8” exposed junction TC’s had the lowest temperature measurement of all TC’s

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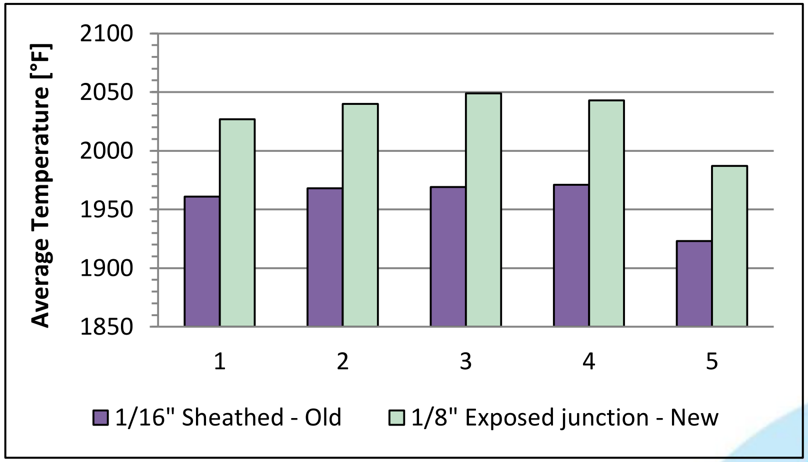
- 1/8” exposed junction and the 1/16” sheathed TC’s had the highest measured temperature, although their accuracy degrades quickly
- 1/8” sheathed TC’s had a lower temperature measurement
- Age has the biggest impact of the temperature measurement – and Heat flux can be used a more accurate indicator that the flame is the same

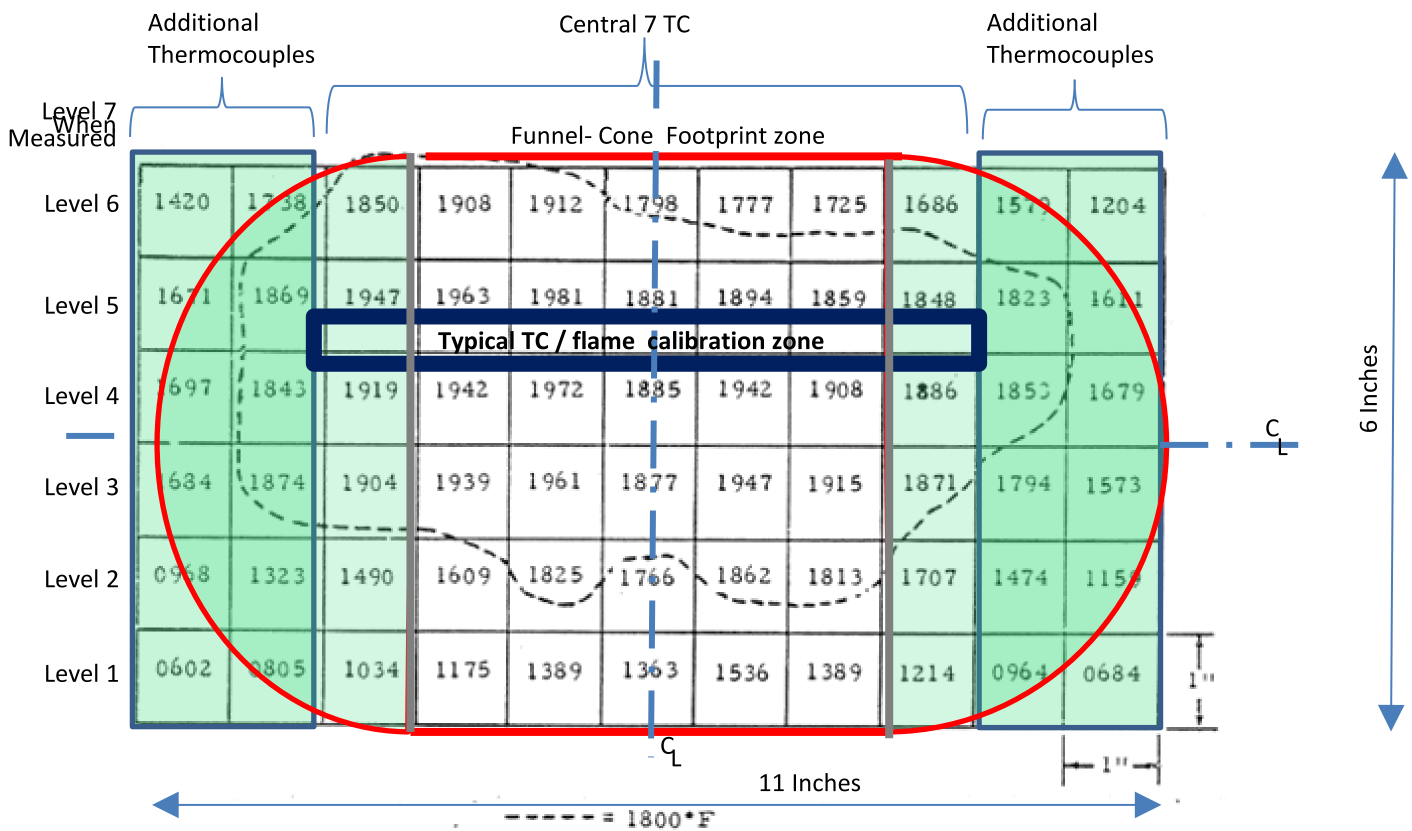


Summary –
Thermocouples and temperature calibration

- Type K thermocouples are being used at the top end of their range
- The actual specified thermocouples are not available and the thermocouple industry has moved away from this definition
- Exposed tip thermocouple, while giving fast response time and therefore a more accurate representation of the flame temperature have a finite life and should be replaced for every burn
- Advice should be sought from thermocouple experts on the most accurate way to measure the flame temperature
- Thermocouples should be specified to meet international standard for their manufacture to ensure consistency and a minimum accuracy
- Age has the biggest impact of the temperature measurement – and heat flux can be used a more accurate indicator that the flame is the same

Again this leads to inconsistencies in how that calibrations is carried out in different Test facilities

Mapping requirements



TC's averaged over 3 minutes per formal calibration procedure. Map is recorded with shortened duration at each Level.

Pre Mapping flame temps 1" above centre line have been included in Map. Note: this was taken several minutes before the map was undertaken. The rationale followed was: Calibrate flame (Temp and BTU) followed by Map.

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	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

1420	1738	1850	1908	1912	1798	1777	1725	1686	1579	1204
1671	1869	1947	1963	1981	1881	1894	1859	1848	1823	1611
1697	1843	1919	1942	1972	1885	1942	1908	1886	1853	1679
1634	1874	1904	1939	1961	1877	1947	1915	1871	1794	1573
0968	1323	1490	1609	1825	1766	1862	1813	1707	1474	1159
0602	0805	1034	1175	1389	1363	1536	1389	1214	0964	0684

1"

1"

----- = 1800°F

An 80° fuel nozzle rated at 2.25 gal/hr and pressure adjusted to deliver 2.04 gal/hr, at 97 psig

Flame temperature mapping

2016-09-20

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

												AVERAGE Central 7 TC's
Level 7	1713.6	1785.1	2075.7	2027.9	1854.5	1815.6	1765.8	1774.2	1701.9	1606.2	1721.6	1859.4
Level 6	1796.8	1875.8	2178.1	2216.2	2191.4	2251.9	2197.7	2115.6	2098.0	1887.3	1986.4	2178.4
Level 5	1764.1	1865.7	2119.3	2160.9	2156.4	2155.1	2145.2	2130.6	2113.1	1911.0	2061.4	2140.1
Level 4	1498.6	1619.5	1786.8	1858.0	1913.1	1922.2	1923.9	1923.9	1916.4	1768.8	1930.2	1892.0
Level 3	1220.3	1329.1	1422.3	1493.7	1565.6	1580.5	1589.7	1554.8	1571.3	1541.6	1587.0	1539.7
Level 2	933.8	1035.3	1004.1	1076.8	1137.4	1155.8	1197.2	1151.2	1161.1	1237.3	1126.0	1126.2
Level 1	718.4	764.4	660.1	733.6	803.5	766.8	806.9	776.9	794.9	872.0	746.1	763.2

Pre test Calibration

Full Average	2040.1	°F
Average reading every 30 sec	2038.1	°F

Full Average	6687.7	BTU/hr	13.8	BTU/ft^2 s
Average reading every 30 sec	6691.5	BTU/hr	13.8	BTU/ft^2 s

Post test Calibration

Full Average	2078.8	°F
Average reading every 30 sec	2072.0	°F

Full Average	6370.6	BTU/hr	13.2	BTU/ft^2 s
Average reading every 30 sec	6213.7	BTU/hr	12.8	BTU/ft^2 s

Flame temperature mapping

2016-09-22

Reconfigured Burner In an effort to reduce temperatures and BTU

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

												AVERAGE Central 7 TC's
Level 6	1415.2	1781.4	2164.5	2133.2	2154.3	2321.1	2214.5	2171.1	1972.4	1636.9	1101.7	2161.6
Level 5	1553.5	1811.6	2065.5	2174.7	2180.0	2301.3	2152.8	2046.4	1928.7	1807.0	1732.6	2121.3
	Calibration		1983.9	1971.4	2102.5	2127.9	2012.2	1967.1	1928.1	Calibration		2013.3
Level 4	1312.9	1562.7	1855.2	2001.6	2091.9	2161.8	2096.6	2001.1	1971.1	1747.1	1438.1	2025.6
Level 3	1062.4	1307.5	1557.9	1670.0	1790.7	1866.8	1931.1	2006.4	1989.5	1796.3	1892.5	1830.3
Level 2	828.4	994.6	1093.9	1160.0	1267.7	1383.5	1434.2	1568.9	1657.5	1491.9	935.8	1366.5
Level 1	714.4	786.2	664.6	726.2	810.2	872.5	928.1	1011.4	1101.1	971.2	749.8	873.4

Pre test Calibration

Full Average	2013.3	°F
Average reading every 30 sec	2013.6	°F

Full Average	4968.2	BTU/hr
Average reading every 30 sec	4874.5	BTU/hr

Post test Calibration

Full Average	1999.8	°F
Average reading every 30 sec	1987.4	°F

Full Average	4893.4	BTU/hr	10.1	BTU/ft^2 s
Average reading every 30 sec	4766.6	BTU/hr	9.9	BTU/ft^2 s

Slight Reduction in Temp , BTU remains strong

Flame temperature mapping

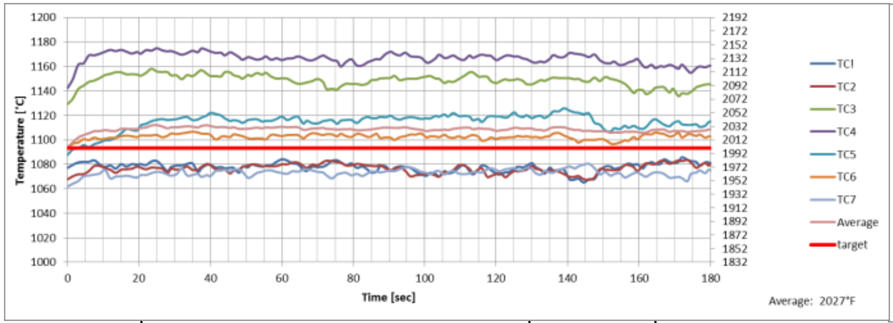
2016-09-**24**

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

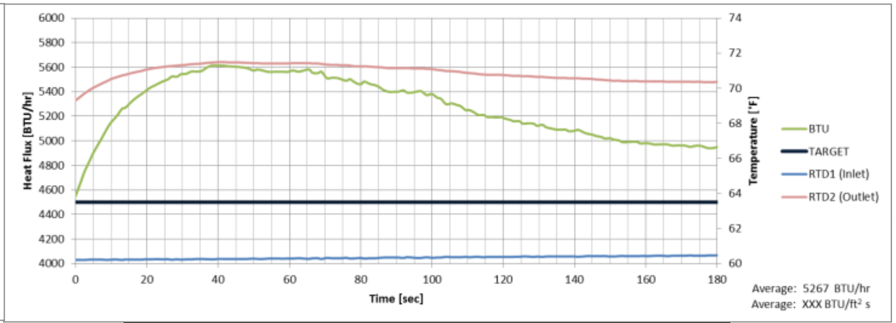
	TC 1	TC 2	TC 3	TC 4	TC 5	TC 6	TC 7	TC 8	TC 9	TC 10	TC 11	AVERAGE Central 7 TC's
Level 6	1632.5	1853.6	2096.3	2045.4	2044.0	2245.9	2037.7	2114.1	1984.2	1640.0		2081.1
Level 5	1663.3	1865.0	2155.8	2144.9	2077.8	2231.5	2092.3	2089.0	1980.8	1797.2		2110.3
	Calibration		1962.7	1958.8	2036.5	2076.2	2012.8	2002.1	1944.0	Calibration		1999.0
Level 4	1299.9	1395.9	1813.6	1928.9	2075.1	2182.6	1358.3	2078.4	2048.9	1857.5		1926.6
Level 3	1038.5	1167.8	1514.9	1597.8	1769.1	1890.9	760.3	2009.4	2023.7	1850.8		1652.3
Level 2	723.6	816.6	1082.4	1104.3	1229.8	1382.2	1147.1	1590.0	1723.5	1673.1		1322.7
Level 1	524.3	572.4	617.4	661.9	740.3	807.3	713.2	935.9	1092.7	1141.4		795.5

TC7 and TC11 of map replaced.

Pre test Calibration



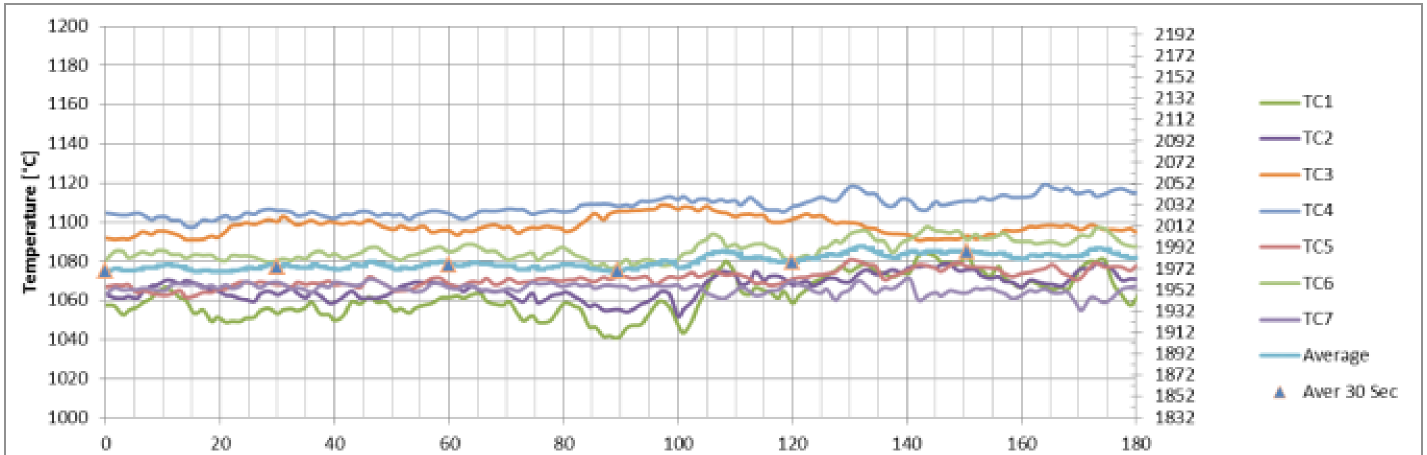
Full Average	2027.3	°F
Average reading every 30 sec	2024.3	°F



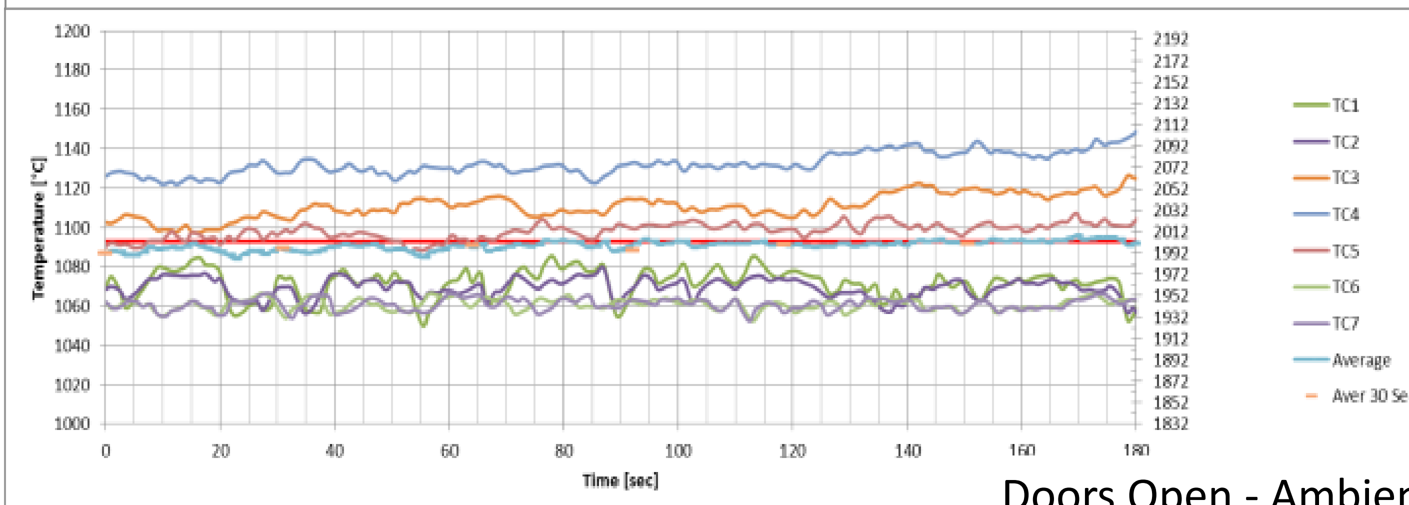
Full Average	5267.0	BTU/hr
Average reading every 30 sec	5323.6	BTU/hr

Post test temperature calibration

2016-09-24



1978.0	°F
1977.0	°F



1999.1	°F
1997.9	°F

Doors Open - Ambient Cooled.

Conclusions and Next Steps

Conclusions

- Temperature and heat flux calibration still has many uncertainties
- Heat flux calibration seems more reliable – but temperature calibration maybe possible which a re-evaluation of the how it is carried out

Further work

- Collaboration with other test houses, to compare setups and data and help fill in the blanks
- Now with the baseline set for the copper tube – the sensitivities of the heat flux to changes in the setup can be investigated
- Comparisons can be made with other burners such as the Nex Gen

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