Liquid Burner Development for Powerplant Fire Test

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Project Objective:

- Develop the operating settings for NexGen burner for powerplant fire tests
  - NexGen burner should simulate previously FAA approved liquid burners
  - NexGen burner should be robust and repeatable

Approach:

- Sensitivities of NexGen burner settings on burner temperature and heat flux ➔ to understand burner behavior and to derive the “accuracy” or “tolerance” for burner settings
- Derive the NexGen burner settings
  - Comparison of fire test results from different burners (Park, NexGen and ISO) *…future work*
  - Comparison of fire test results from NexGen burner with different settings *…future work*

Standard Liquid Burners

from

Power Plant Engineering Report NO. 3 A

Standard Fire Test Apparatus and Procedure (for flexible hose assemblies)

E. P. Burke and T. G. Horeff

March 1978

Individual TC Temperature Requirements: 1850~2150 F

Burner	Rated Fuel Flow Capacity	Motor	Blower Wheel (inches)	Fuel Pump	Tube Extension (inches)	Heat Transfer to 1/2-in. Tube Btu/hr.	Total Thermal Energy ($Btu/ft^2/s$)	Flame Oxygen Concentration (persent)
Lennox OB-32	(Reference) only	1/4 hp 1,725 r/min.	3 5/8 x 6 1/8	Two Stage	4x12	4,574	9.8-10.8	5-11
Carlin 200 CRD	2.0-5.0 gal/hr.	1/4 hp 3,450 r/min.	3 1/2 x 5 1/4	Single Stage	4 1/8x11	4,545	9.3-11.2	6.5-8.5
Stewart Warner HPR-250	1.35-2.50 gal/hr.	1/7 hp 3,450 r/min.	3 9/16 x 5 3/8	Single Stage	4x13 5/32	4,646	9.3-10.1	9.2-9.5
Stewart Warner FR-600	2.0-6.0 gal/hr.	1/3 hp 3,450 r/min.	3 15/16 x 6 1/32	Two Stage	4x12 7/8	4,466	9.9-10.9	8.5-15.2

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Typical Temperature Distribution

1430	1749	1721	1847	1820	1858	1887	1914	1822	1717	1418
1778	1747	1891	1980	1988	1990	1994	1994	1947	1818	1718
1789	1847	1944	1997	1987	1978	1948	1975	1983	1915	1669
1179	1682	1882	1843	1775	1750	1709	1703	1883	1883	1401
0740	1325	1597	1398	1238	1247	1064	1186	1550	1510	0719
0673	0647	0642	0596	0565	0569	0630	0649	0730	0553	0420

1"

1"

----- = 1800°F

Liquid Burner Requirements

Park Burner (FAA Handbook & AC20-135)

	Fuel Rate (GPH)	Air Rate (ft³/min)	A/F ratio (equivalence ratio)	TC size	Temperature	Heat Flux (Btu/ft²-s)
CH. 7 Seat Cushion	2	67	23.0 (0.67)	1/16” (0.010”)	7 TC > 1750 F 5 TC > 1800 F AVE> 1800 F	10
CH. 11 &12 Powerplant	?	?	?	1/16” (0.025”)	AVE> 2000F	9.3
AC20-135 & AC33-17-1	?	?	?	1/16” to 1/8” (0.010”- 0.025”)	1850 F -2150 F TAVE > 2000 F	9.3

NexGen Burner

	Fuel Rate (GPH)	Air Rate (ft³/min)	A/F ratio (equivalence ratio)	TC size	Temperature	Heat Flux (Btu/ft²-s)
Seat Cushion	2 .02	45-53 (35 to 45 psi)	14.4 – 17.3 (1.02 – 0.849)	1/8”	About 100 F less than Park Burner	10
Acoustic Insulation (AC-25.856-2A)	6	63	6.72 (2.16)	1/8”	1900 ±100°F	16.0 ±0.5
Powerplant	?	?	?	?	?	?

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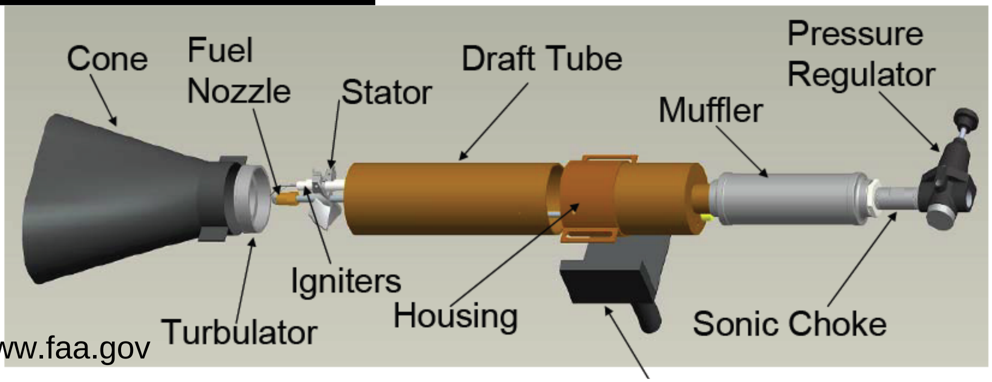
NexGen and Park Burner

NexGen Burner

Both fuel and air rate can be accurately metered and controlled



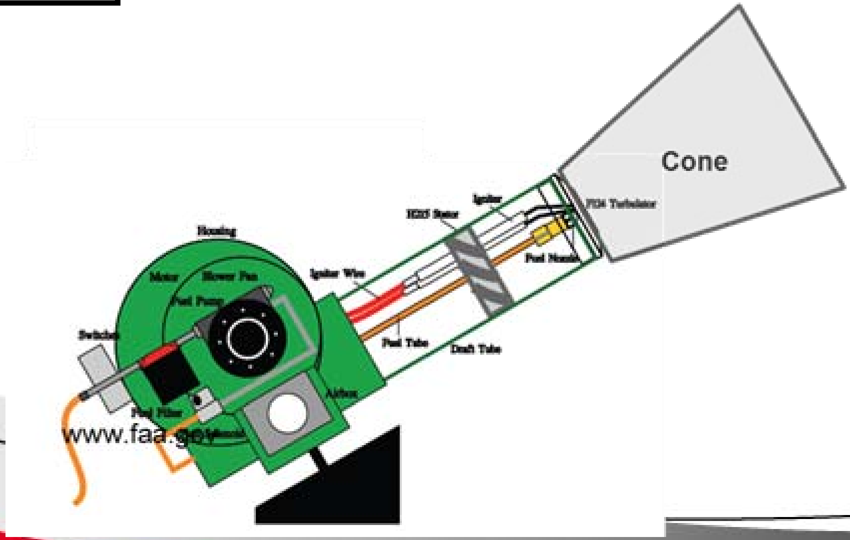
Fuel Nozzle

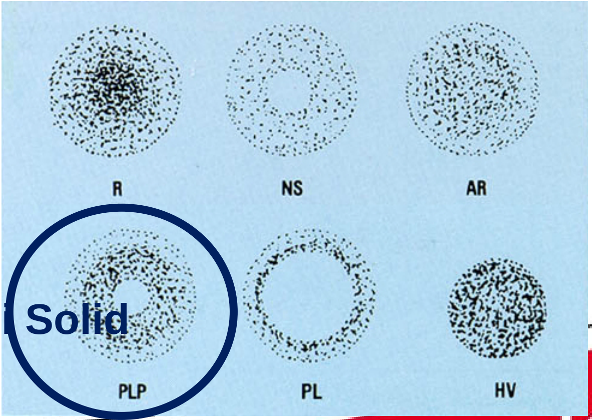
Mornach, 2.25 80º PLP

- ✓<u>2.25</u>: Max Flow Rate=2.25 gph
- ✓<u>80º</u>: Spray Angle=80º
- ✓<u>PLP</u>: Spray Pattern

Park Burner

Only fuel rate can be accurately metered and controlled



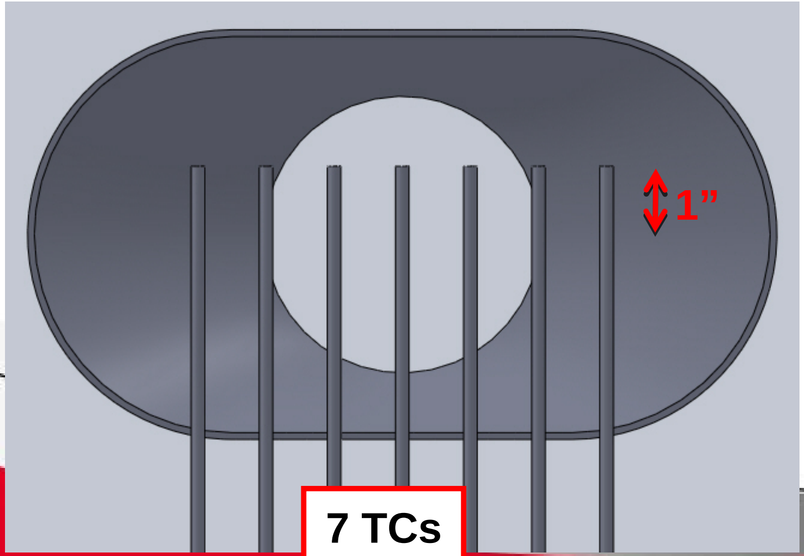


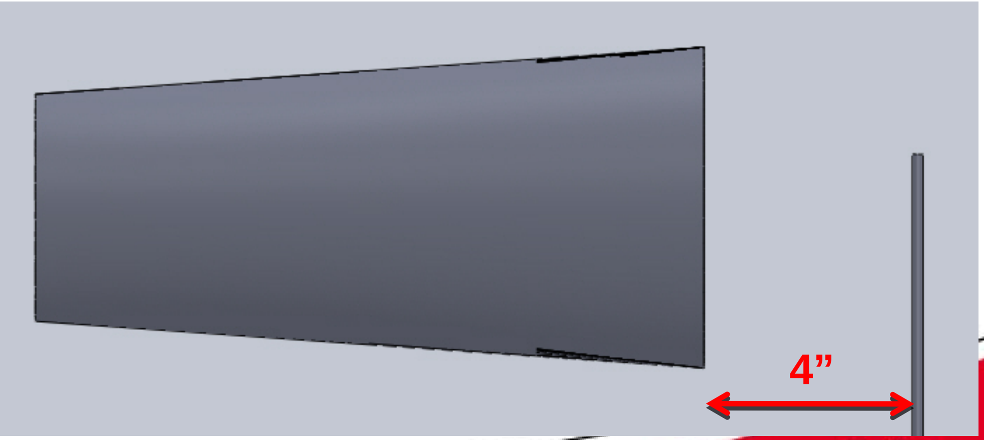
www.mornachnozzles.com

Temperature Calibration

- Thermocouple rack
  - 7 thermocouples
  - K-Type, 1/8 or 1/16 inch stainless steel sheath
  - Exposed bead, 1/4 inch exposed wire
  - Located at target plane (4 inch from burner exit) and 1 inch above burner horizontal center line

- Temp. Min. Avg. =**2000 F**, Individual= **2000±150 F**





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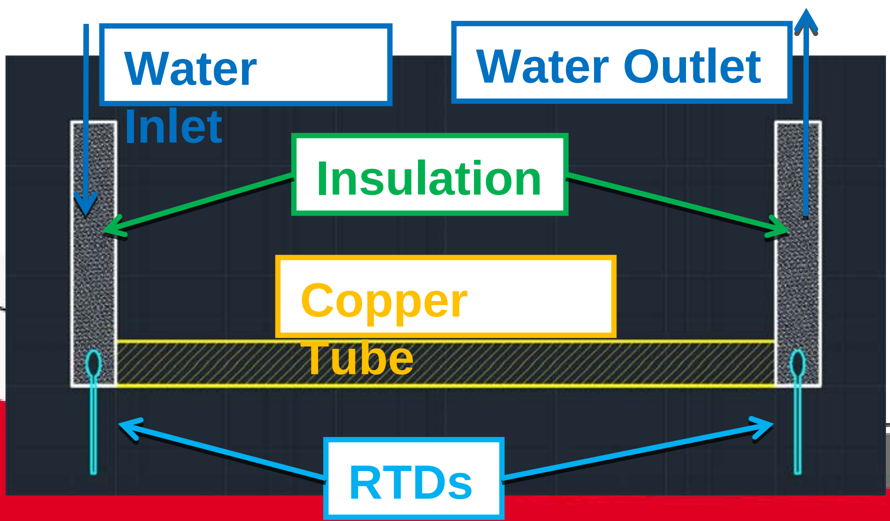
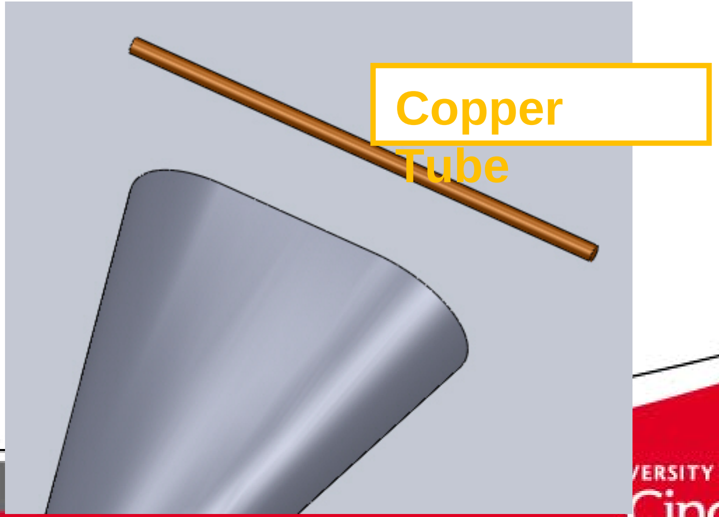
Heat Flux Calibration

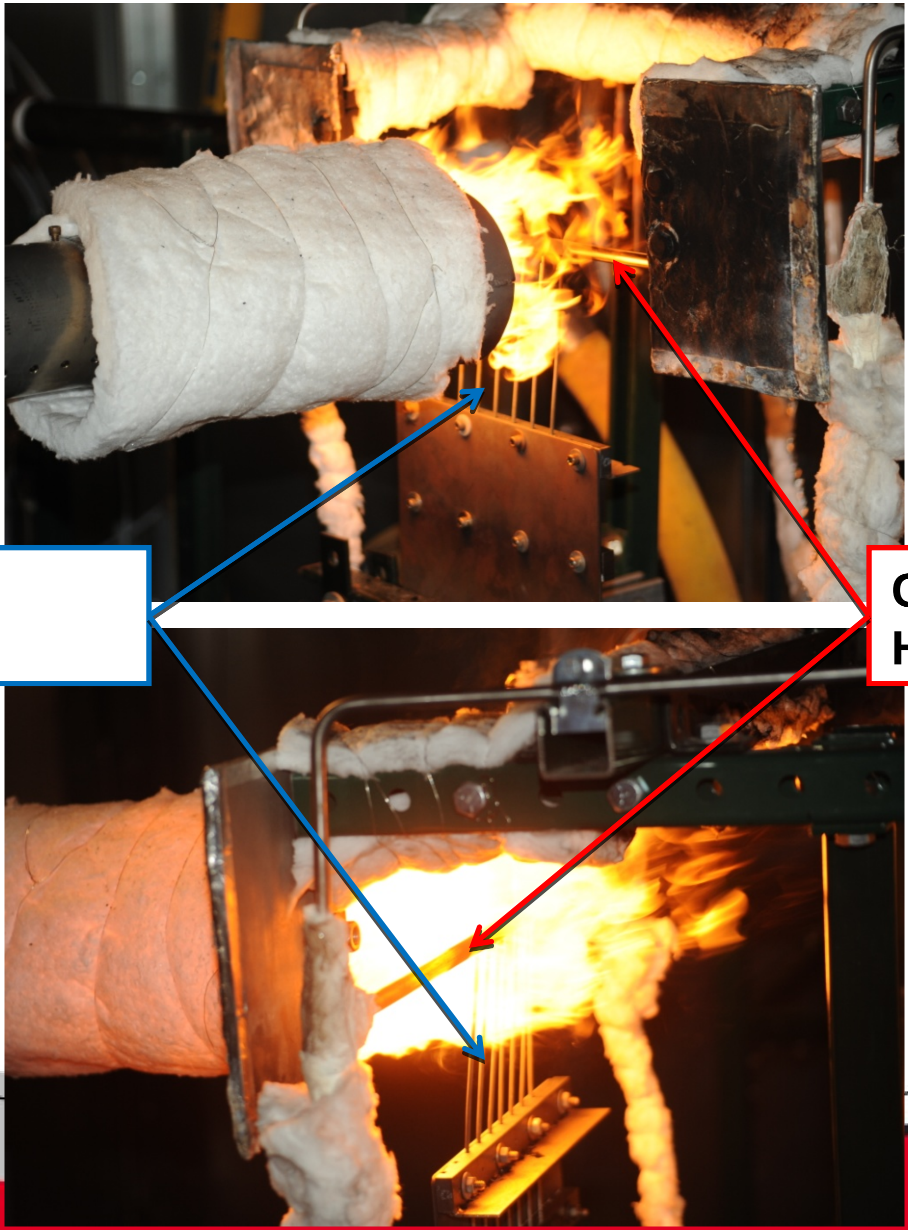
- Copper tube used as heat transfer device
  - ➢1/2 inch outer diameter, 15 inch un-insulated length
  - ➢Water flow rate maintained a 3.8 liter/ min
  - ➢Center of copper tube located at target plane (4 inch from burner exit)

- Heat flux calculated from water flow rate and temperature rise across the tube
  - ➢Exposed tube length for heat flux calculation is equal to burner horizontal size (11 inch)
  - ➢ Min. **9.3 Btu/ft^2-s**

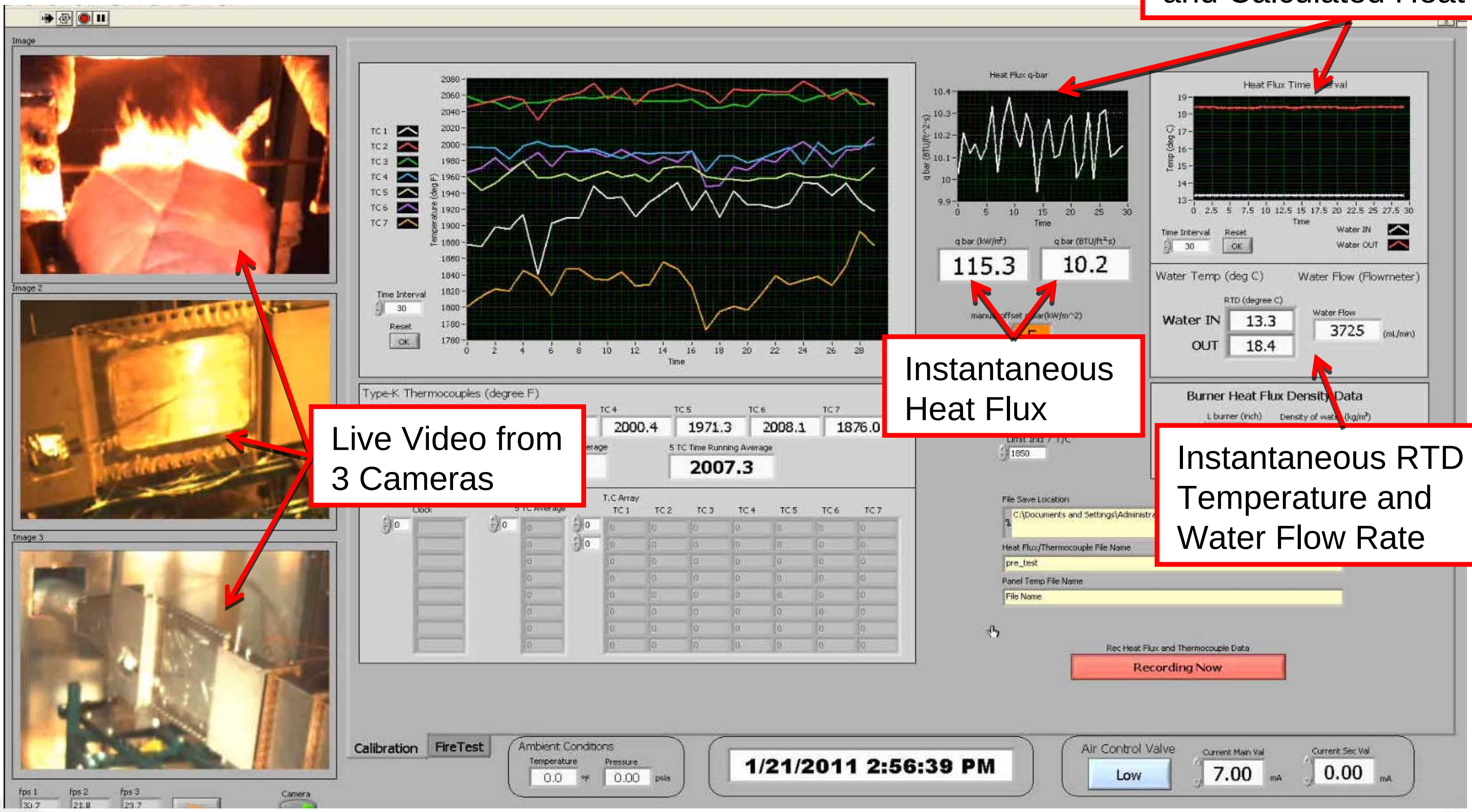




Temperature/ Heat Flux Calibration Rigs

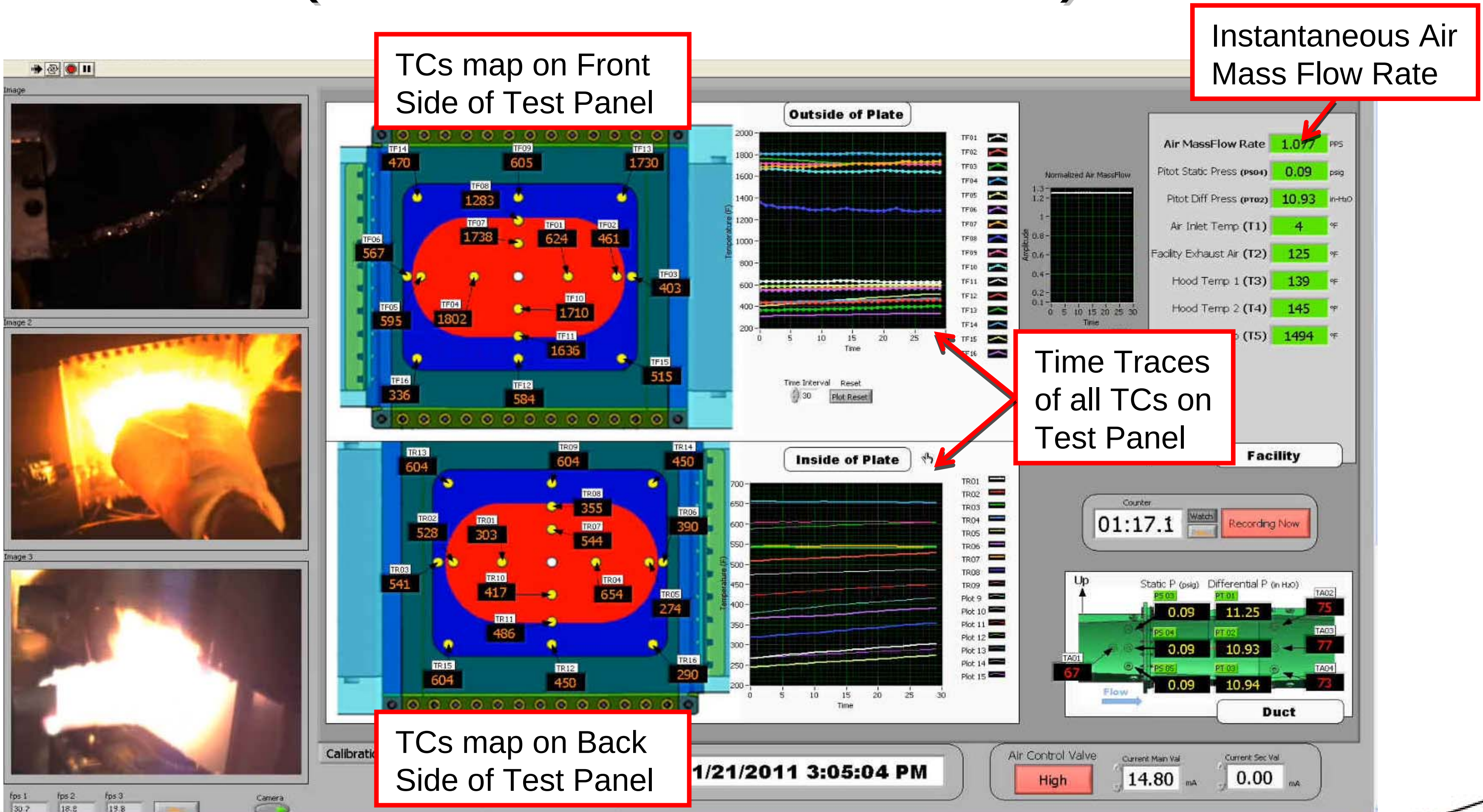


Powerplant Calibration Requirements



Courtesy by HONDA R&D

Powerplant Fire Wall (engineering) Fire Test (with back side air flows)



Courtesy by HONDA R&D

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Burner Configurations

Turbulator Modifications

Back Side

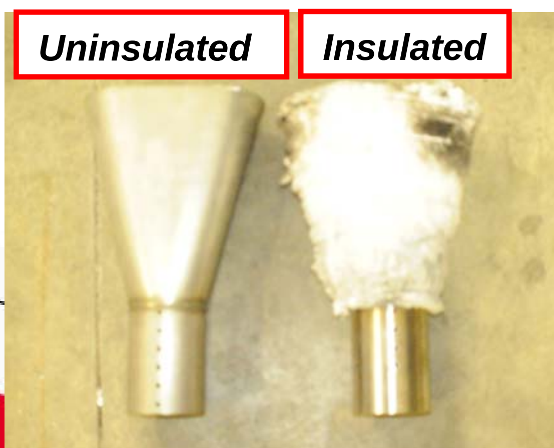
Front Side

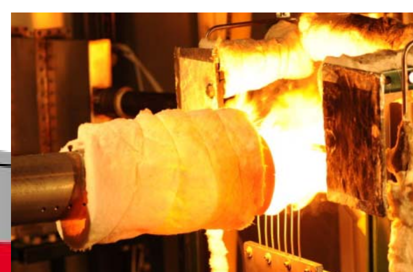
Original w/o tab

Short Tabs (1”x3/4”)

Long Tabs (1 1/8”x3/4”)

Insulation on Expansion Cone

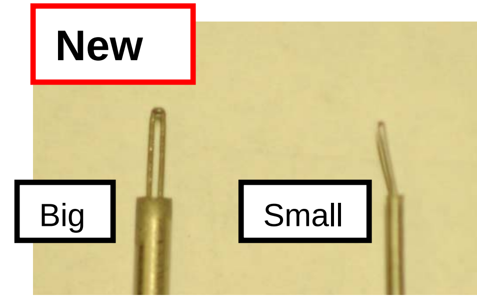


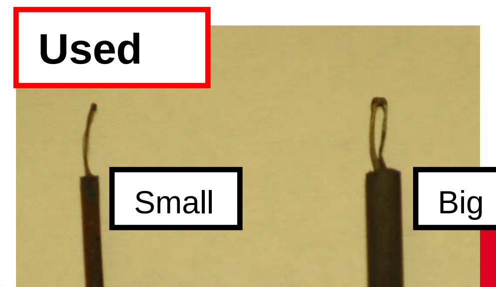


TC Wire and Bead size

K-type TC-Big	
bead size	0.033 inch
wire size	0.020 inch

K-type TC-Small	
bead size	0.020 inch
wire size	0.012 inch





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NexGen Burner w/o cone
Original v.s. Modified Turbulator

Record: 3000 fps/ Playback: 15 fps

Park Burner Performance

$$\theta = \frac{T_{max} - T_{min}}{T_{avg}}$$

	Insulation	TAB	TC	Fuel rate (GPH)	T_avg (F)	T_max (F) / T_min (F)	Heat Flux (BTU/ft^2-s)	θ
Park Burner	N	N	Big	3.70	1996	2157 / 1813	12.95	17.23%
	Y	N	Big	3.65	2025	2147 / 1865	14.45	13.93%
	N	Short	Big	3.22	2013	2095 / 1867	11.10	11.30%
	Y	Short	Big	2.86	2009	2098 / 1885	12.07	10.59%

- ✓Original (unmodified):
  - ✓Extremely hard to reach ave.2000 F temperature
  - ✓Highly non-uniform temperature distribution
- ✓ With Tabs to improve aerodynamics and air/fuel mixing:
  - ✓Reduce the required fuel rate to meet 2000 F Ave. temperature requirements
  - ✓Reduce heat flux by about 20%
  - ✓improve temperature distribution
- ✓ With Thermal Insulation to reduce heat loss from expansion cone:
  - ✓Reduce the required fuel rate to meet 2000 F Ave. temperature requirements
  - ✓Increase heat flux by about 12%
  - ✓improve temperature distribution

NexGen Burner Performance

$$\theta = \frac{T_{max} - T_{min}}{T_{avg}}$$

	Insulation	TAB	TC	Jet-A (GPH)	Air (SCFM)	A/F	ϕ	T_adia(F)	T_avg (F)	T_max (F) / T_min (F)	Heat Flux (BTU/ft^2-s)	θ
NexGen Burner	N	Short	TC1	2.86	61.09	14.02	1.05	3647	2008	2095 / 1884	10.51	10.53%
	Y	Short	TC1	2.38	59.12	16.33	0.90	3469	2038	2092 / 1988	11.40	5.11%
	N	Long	TC1	2.44	55.18	14.86	0.99	3615	2007	2063 / 1916	9.70	7.33%
	Y	Long	TC1	2.26	55.18	16.05	0.91	3491	2002	2059 / 1927	11.07	6.62%

✓ Will use less fuel rate, compared to Park burner, to meet temperature requirements

✓ More uniform temperature distribution compared to Park Burner

✓ “Long Tabs” has lower heat flux and more uniform temperature

✓ Burner behavior is sensitive to details of TAB’s “geometry and configuration”

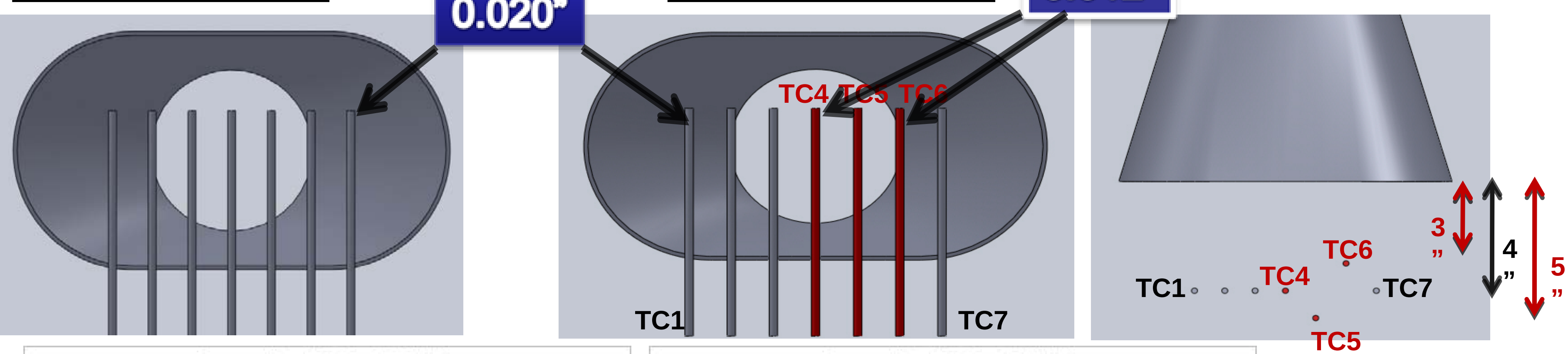
✓ Insulation on expansion cone reduces the fuel rate requirements and has more uniform temperature but increase the heat flux about 10%

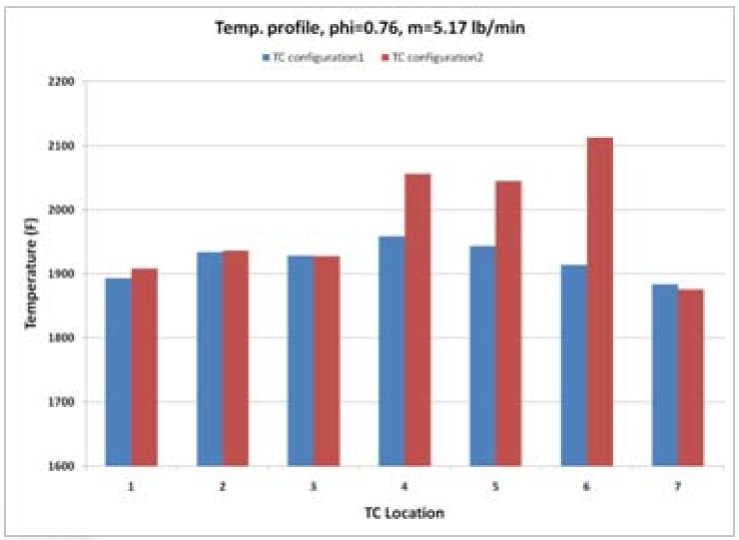
✓A/F ratio (equivalence ratio: 0.90 -1.05) is near stoichiometric and will generate the “highest” temperature fire (around 3500 F theoretical gas temperature)

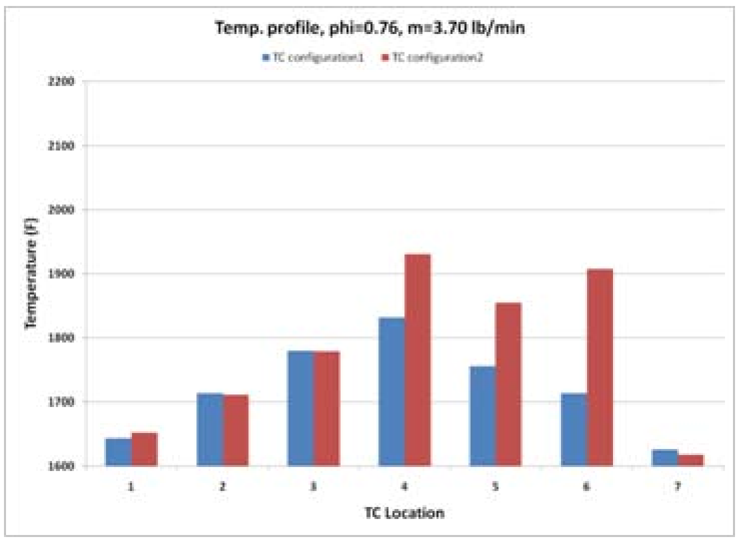
Different TC Configurations

Configuration 1

Configuration 2:







✓Small TCs provide around 100 F higher temperature readings
✓Distance from burner exit impacts on measured temperatures

Effects of TC Wire and Bead Size

	Insulation	TAB	TC	Jet-A (GPU)	Air (SCFM)	A/F	ϕ	T_adia(F)	T_avg (F)	T_max (F) T_min (F)	Heat Flux (BTU/ft^2-s)	θ
NexGen Burner	N	Long	Big	2.44	55.18	14.86	0.99	3615	2007	2063 1916	9.70	7.33%
	N	Long	Small	2.35	55.18	15.43	0.95	3563	2021	2101 1889	9.40	10.48%
	Y	Long	Big	2.26	55.18	16.05	0.91	3491	2002	2059 1927	11.07	6.62%
	Y	Long	Small	2.20	55.18	16.50	0.89	3448	2008	2106 1933	10.74	8.60%

✓ Thermocouple wire size (bead size) can affect burner settings and heat flux
✓With smaller thermocouple bead (wire size) the fuel rate can be reduced by about 3 % and heat flux is also reduce by about 3 %

Fuel Sensitivity, Air Sensitivity for NexGen Burner

Burner Arrangements: ***Inculated Cone, TAB- small, TC- small***

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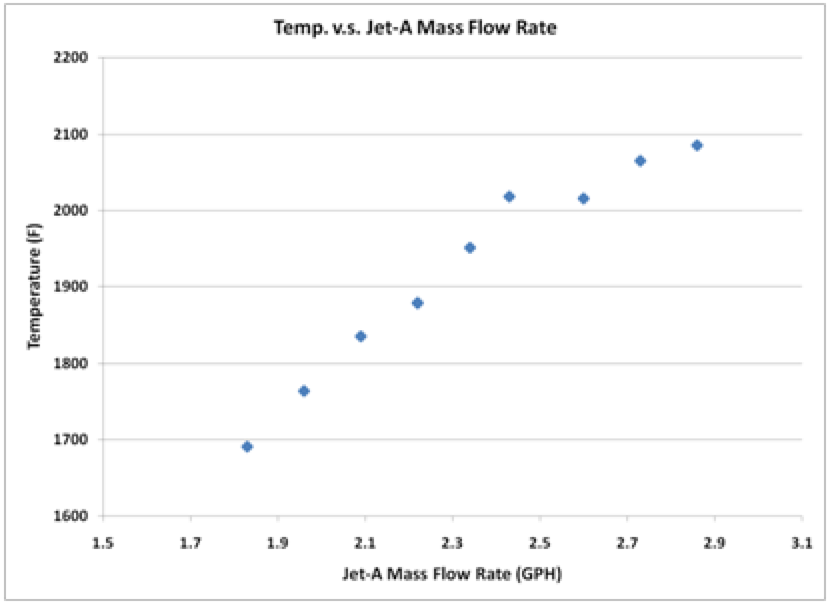
Fuel Sensitivity, NexGen Burner

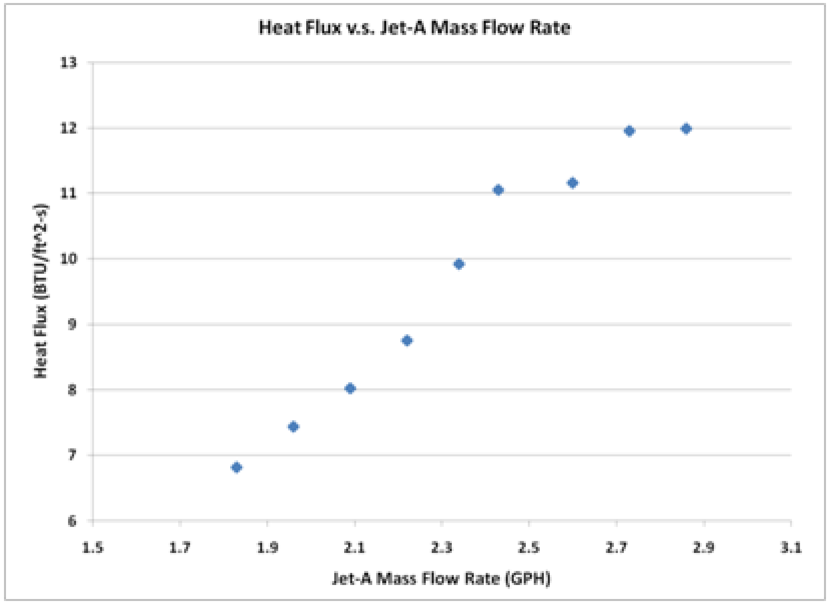
Jet-A (GPU)		Air (SCFM)	A/F	ϕ	T_adia(F)	T_avg (F)	T_max (F) / T_min (F)	Heat Flux (BTU/ft^2-s)
1.83	75.5%	63.9	22.89	0.64	2735	1690	1809 / 1392	6.82
1.96	80.7%	63.9	21.41	0.69	2895	1763	1870 / 1525	7.44
2.09	86.2%	63.9	20.05	0.73	3019	1835	1934 / 1674	8.03
2.22	91.4%	63.9	18.91	0.78	3167	1878	1982 / 1700	8.76
2.34	96.6%	63.9	17.89	0.82	3277	1951	2049 / 1808	9.92
2.43	100.0%	63.9	17.28	0.85	3354	2018	2102 / 1868	11.06
2.6	107.3%	63.9	16.11	0.91	3491	2015	2135 / 1824	11.17
2.73	112.5%	63.9	15.36	0.96	3579	2065	2189 / 1864	11.96
2.86	117.7%	63.9	14.68	1.00	3626	2085	2215 / 1860	11.99

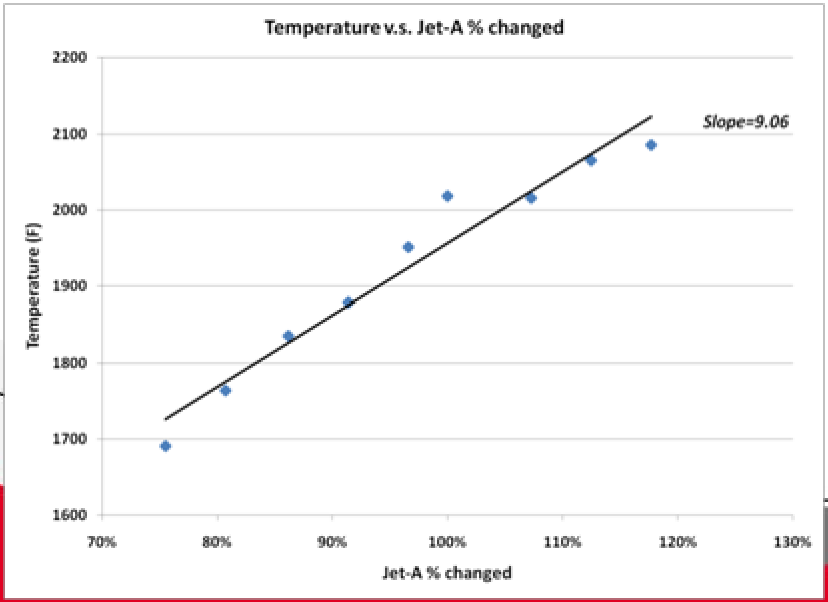
:baseline point

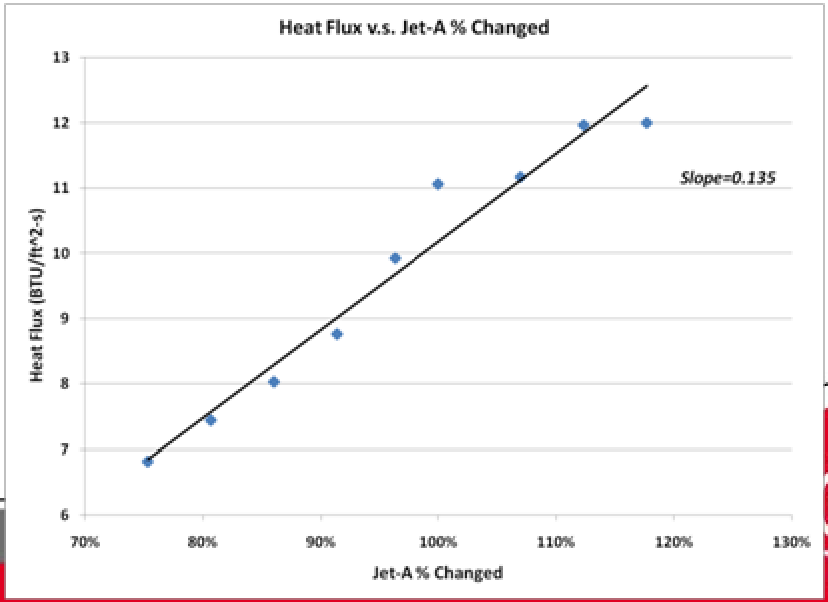
- ✓Air mass flow rate is fixed around 63.9 SCFM.
- ✓Jet-A mass flow rate is changed from 1.83~2.86GPH, and φ is also changed from 0.64 to 1.

Fuel Sensitivity, NexGen Burner …con't









Air Sensitivity, NexGen Burner

Jet-A (GPH)	Air (SCFM)		A/F	ϕ	T_adia(F)	T_avg (F)	Temp. Diff. %	T_max(F) / T_min(F)	Heat Flux (BTU/ft^2-s)	Heat Flux Diff. %
2.34	55.3	86.5%	15.48	0.95	3563	1892	-1.38%	2085 / 1463	9.93	4.73%
2.34	58	90.6%	16.20	0.91	3491	1938	1.00%	2096 / 1605	9.29	-2.04%
2.34	61	95.5%	17.09	0.86	3379	1948	1.55%	2071 / 1704	9.08	-4.25%
2.34	63.9	100.0%	17.89	0.82	3277	1943	1.29%	2055 / 1719	9.28	-2.17%
2.34	66.8	104.4%	18.68	0.79	3196	1909	-0.50%	2027 / 1659	9.75	2.83%
2.34	69.6	108.9%	19.48	0.75	3079	1881	-1.96%	2002 / 1629	9.57	0.89%

:baseline point

$$Temp.Diff.\% = \frac{T_{indi\ case} - T_{mean,6\ cases}}{T_{mean,6\ cases}}$$

$$Heat\ Flux\ Diff.\% = \frac{\dot{Q}_{avg,indi} - \dot{Q}_{avg,6\ cases}}{\dot{Q}_{avg,6\ cases}}$$

✓Jet-A mass flow rate is fixed around 2.34 GPH

✓Air mass flow rate is changed from 55.3~69.6 SCFM, and φ is changed from 1 to 0.75 as well.

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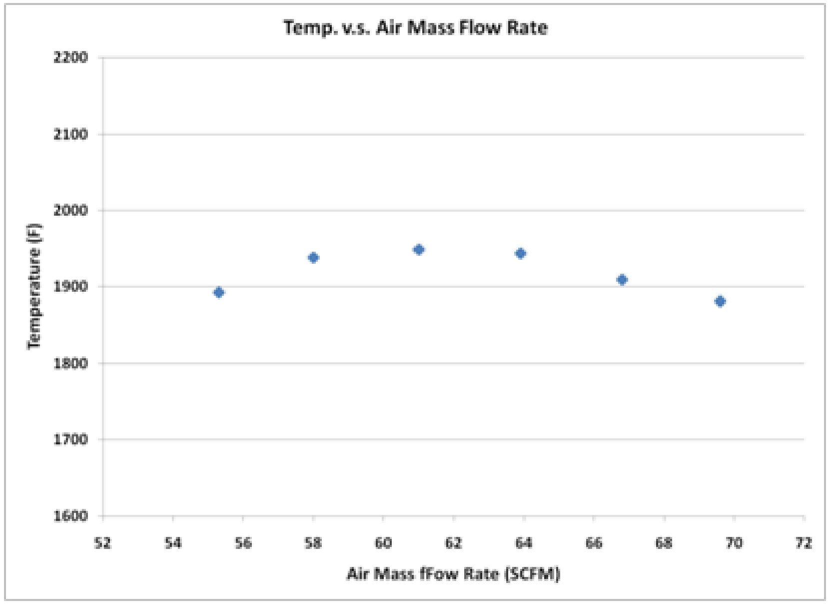
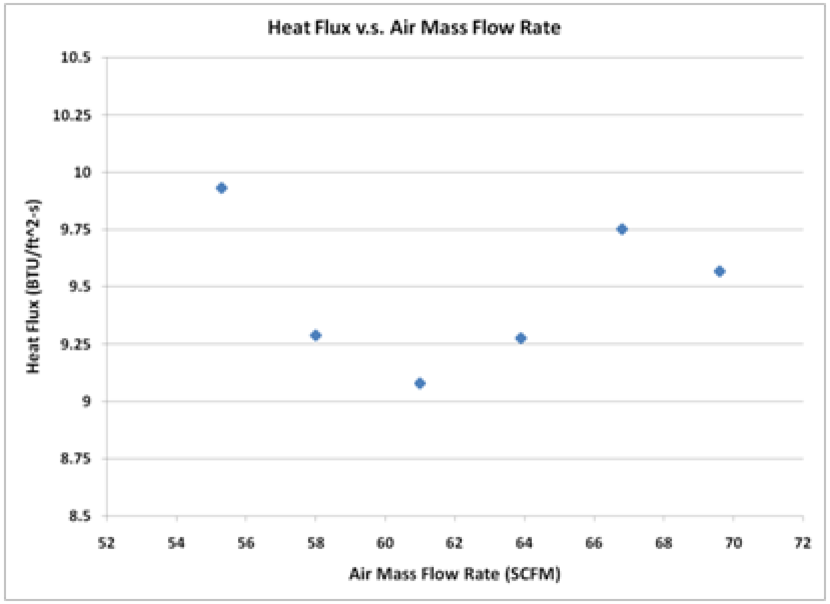
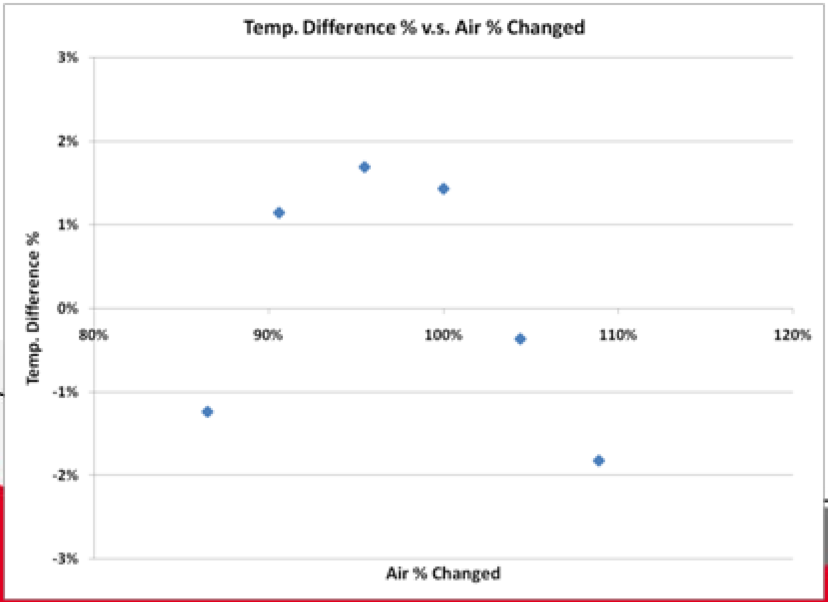
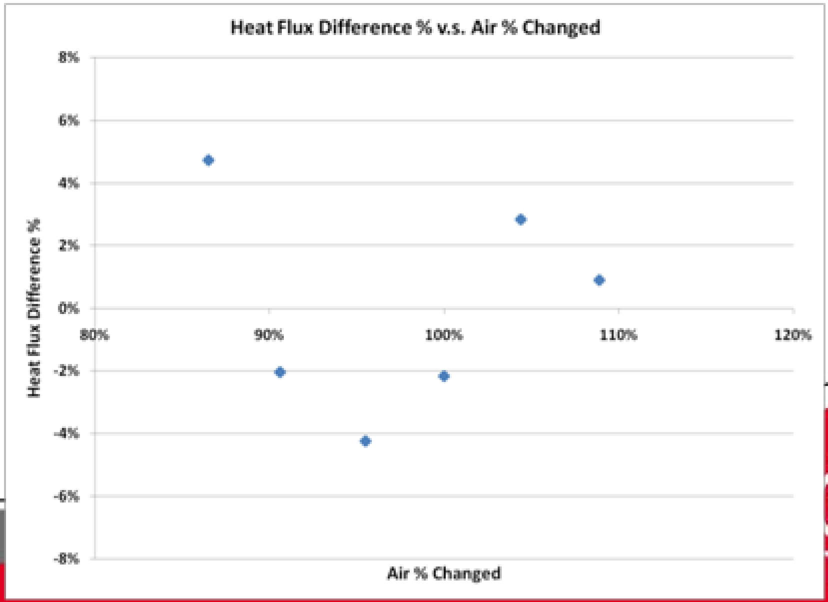
Air Sensitivity, NexGen Burner …con't





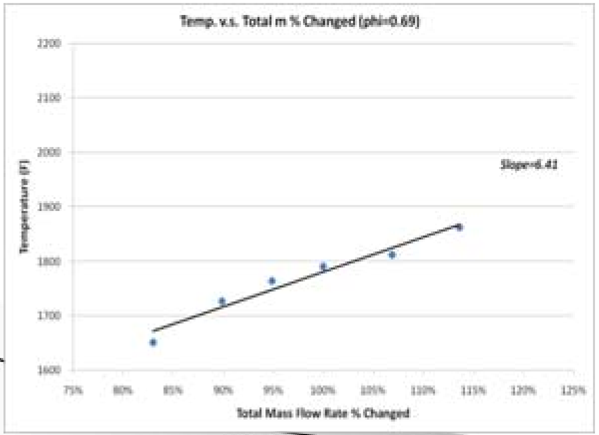


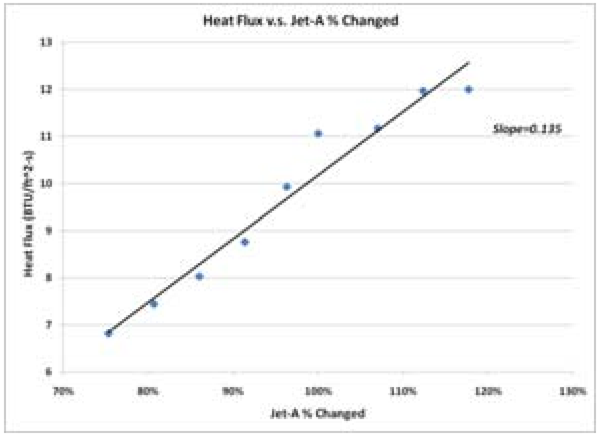


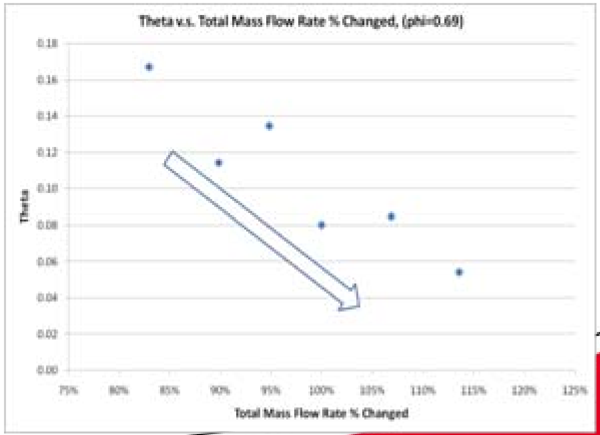
Mass Flow Rate Effect, NexGen Burner

Jet-A (GPH)	Air (SCFM)	Total Mass (lb/min)		A/F	ϕ	T_adia(F)	T_avg (F)	T_max(F) T_min(F)	Heat Flux (BTU/ft^2-s)	θ
1.47	47.6	3.68	82.99%	21.23	0.69	2895	1651	1744 1468	6.74	0.17
1.6	51.6	3.99	89.86%	21.24	0.69	2895	1727	1806 1609	7.53	0.11
1.68	54.4	4.21	94.85%	21.22	0.69	2895	1764	1851 1613	7.91	0.13
1.77	57.3	4.44	100.00%	21.23	0.69	2895	1791	1857 1714	8.39	0.08
1.89	61.2	4.74	106.87%	21.24	0.69	2895	1812	1876 1722	8.74	0.08
2.00	65.2	5.04	113.58%	21.22	0.69	2895	1863	1914 1813	9.48	0.05

:baseline point







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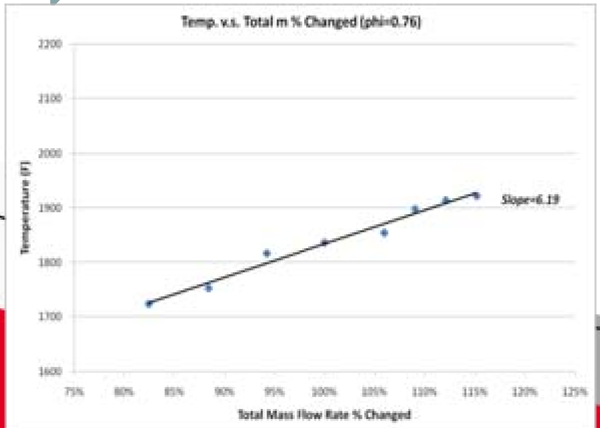
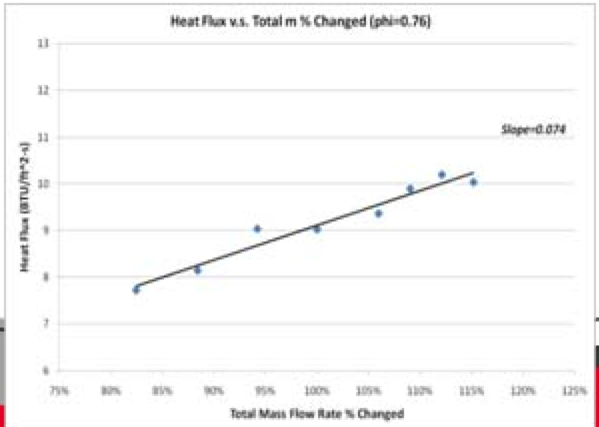
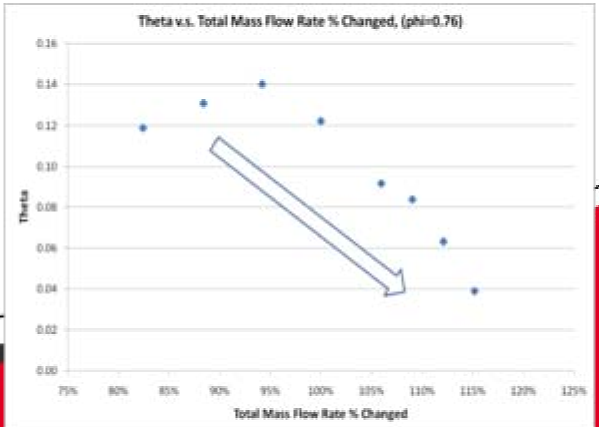
Mass Flow Rate Effect, NexGen Burner …cont'd

Jet-A (GPH)	Air (SCFM)	Total Mass (lb/min)		A/F	ϕ	T_adia(F)	T_avg (F)	T_max(F)	T_min(F)	Heat Flux (BTU/ft^2-s)	θ
1.62	47.6	3.71	82.45%	19.37	0.76	3109	1723	1831	1626	7.72	0.12
1.73	51.2	3.97	88.41%	19.39	0.76	3109	1752	1854	1625	8.14	0.13
1.84	54.4	4.23	94.21%	19.38	0.76	3109	1816	1909	1654	9.04	0.14
1.96	57.8	4.50	100.00%	19.37	0.76	3109	1836	1933	1708	9.03	0.12
2.08	61.2	4.76	105.96%	19.39	0.76	3109	1854	1925	1755	9.37	0.09
2.14	63	4.90	109.02%	19.38	0.76	3109	1897	1962	1803	9.90	0.08
2.2	64.8	5.04	112.09%	19.38	0.76	3109	1914	1972	1851	10.20	0.06
2.25	66.6	5.18	115.16%	19.38	0.76	3109	1922	1958	1883	10.04	0.04

:baseline point



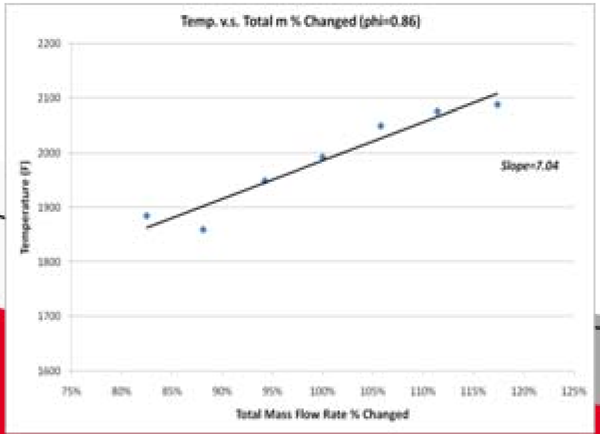


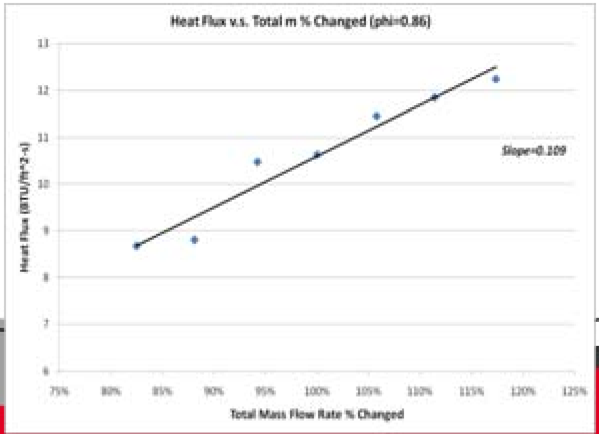


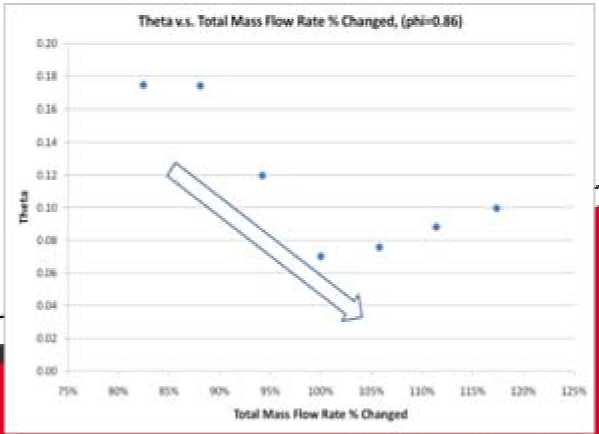
Mass Flow Rate Effect, NexGen Burner …cont'd

Jet-A (GPH)	Air (SCFM)	Total Mass (lb/min)		A/F	ϕ	T_adia(F)	T_avg (F)	T_max(F) T_min(F)	Heat Flux (BTU/ft^2-s)	θ
1.83	47.8	3.74	82.49%	17.11	0.86	3379	1884	1990 1661	98.54	0.17
1.96	51	3.99	88.11%	17.09	0.86	3379	1859	1957 1633	100.01	0.17
2.09	54.6	4.27	94.22%	17.12	0.86	3379	1948	2035 1802	119.06	0.12
2.22	58	4.53	100.00%	17.13	0.86	3379	1992	2047 1908	120.82	0.07
2.35	61.2	4.79	105.78%	17.14	0.86	3379	2049	2105 1950	130.19	0.08
2.48	64.6	5.05	111.40%	17.13	0.86	3379	2075	2134 1951	134.66	0.09
2.61	68	5.32	117.35%	17.12	0.86	3379	2088	2168 1960	139.12	0.10

:baseline point



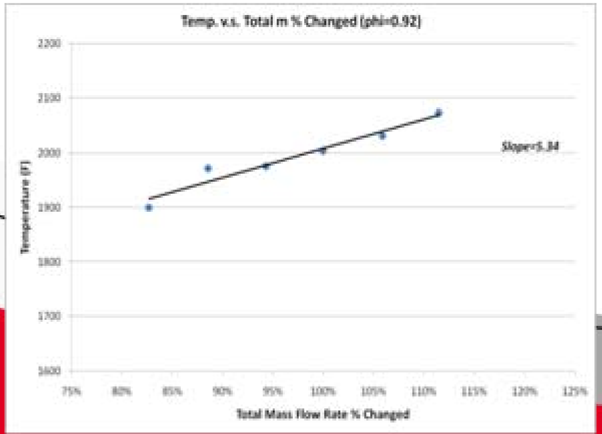


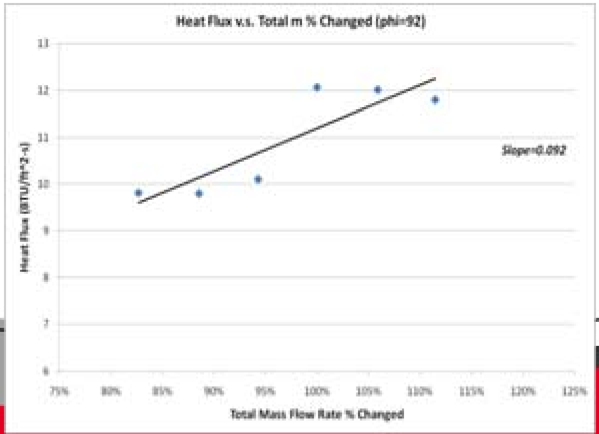


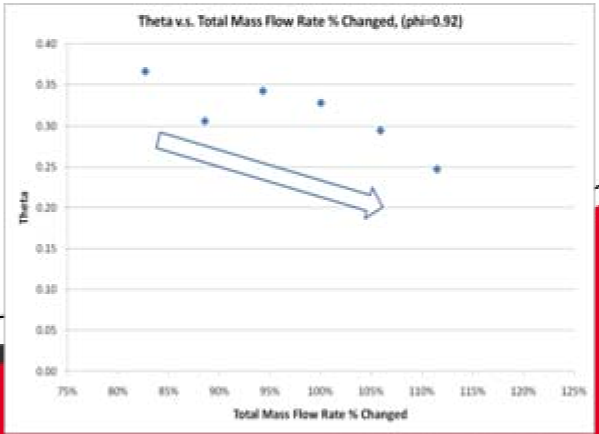
Mass Flow Rate Effect, NexGen Burner …cont'd

Jet-A (GPH)	Air (SCFM)	Total Mass (lb/min)		A/F	ϕ	T_adia(F)	T_avg (F)	T_max(F) / T_min(F)	Heat Flux (BTU/ft^2-s)	θ
2.05	49.9	3.92	82.68%	15.94	0.92	3511	1899	2094 / 1398	111.49	0.37
2.2	53.5	4.20	88.55%	15.94	0.92	3511	1972	2142 / 1539	111.32	0.31
2.35	56.9	4.47	94.28%	15.93	0.92	3511	1975	2182 / 1507	114.79	0.34
2.49	60.3	4.74	100.00%	15.95	0.92	3511	2004	2209 / 1553	137.10	0.33
2.63	63.9	5.02	105.88%	15.92	0.92	3511	2031	2225 / 1627	136.49	0.29
2.77	67.3	5.29	111.46%	15.92	0.92	3511	2073	2244 / 1731	134.06	0.25

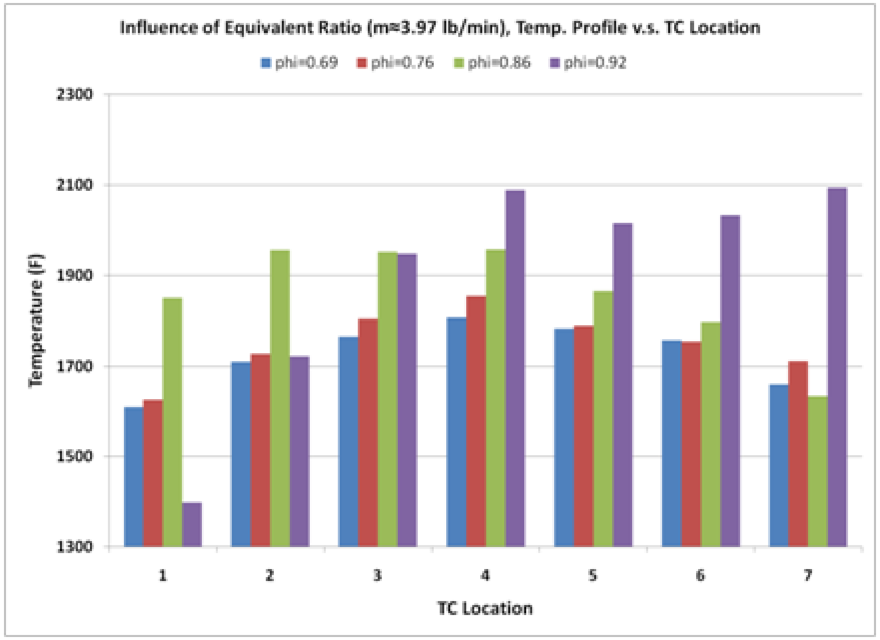
➡ *:baseline point*

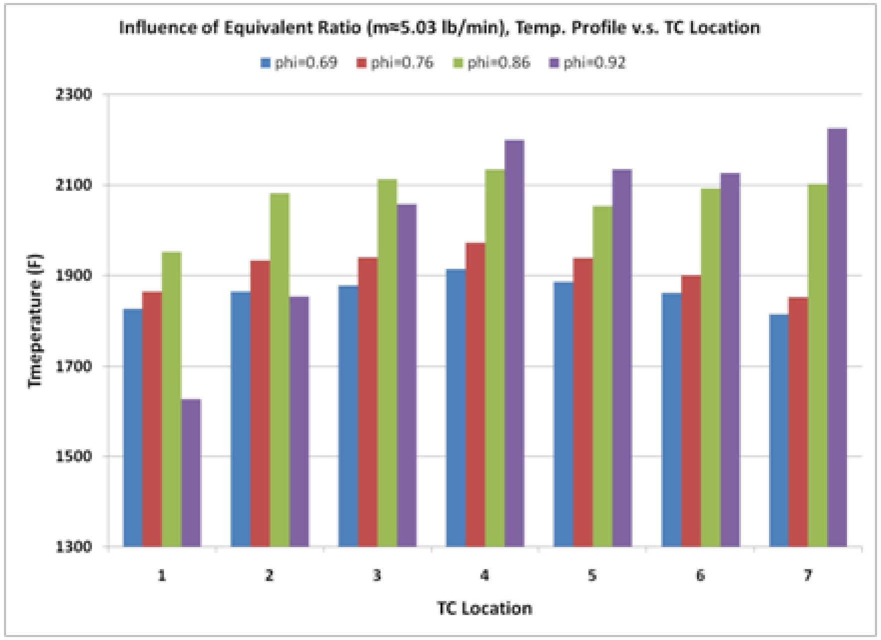






Influence of Equivalent Ratio, φ, NexGen Burner





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NexGen Burner

- Nexgen burner is more sensitive to fuel flow rate change than air flow rate change.

- TC bead size impacts on the measured “TC temperature” under the same flame.

- TC temperature is significantly lower than true flame temperature.

- Higher total mass flow rate can produce higher temperature and higher heat flux at the same A/F (equivalent ratio) conditions.

- Higher total mass flow rate can produce more uniform flame temperature.

- At the similar total mass flow rate conditions, fuel leaner operating (higher A/F ratio) provide more uniform temperature distribution.

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