Burnthrough Test Method for Aircraft Thermal/Acoustic Insulation

NexGen Burner Update

Presented to: Materials Working Group, Cuyahoga Falls, OH

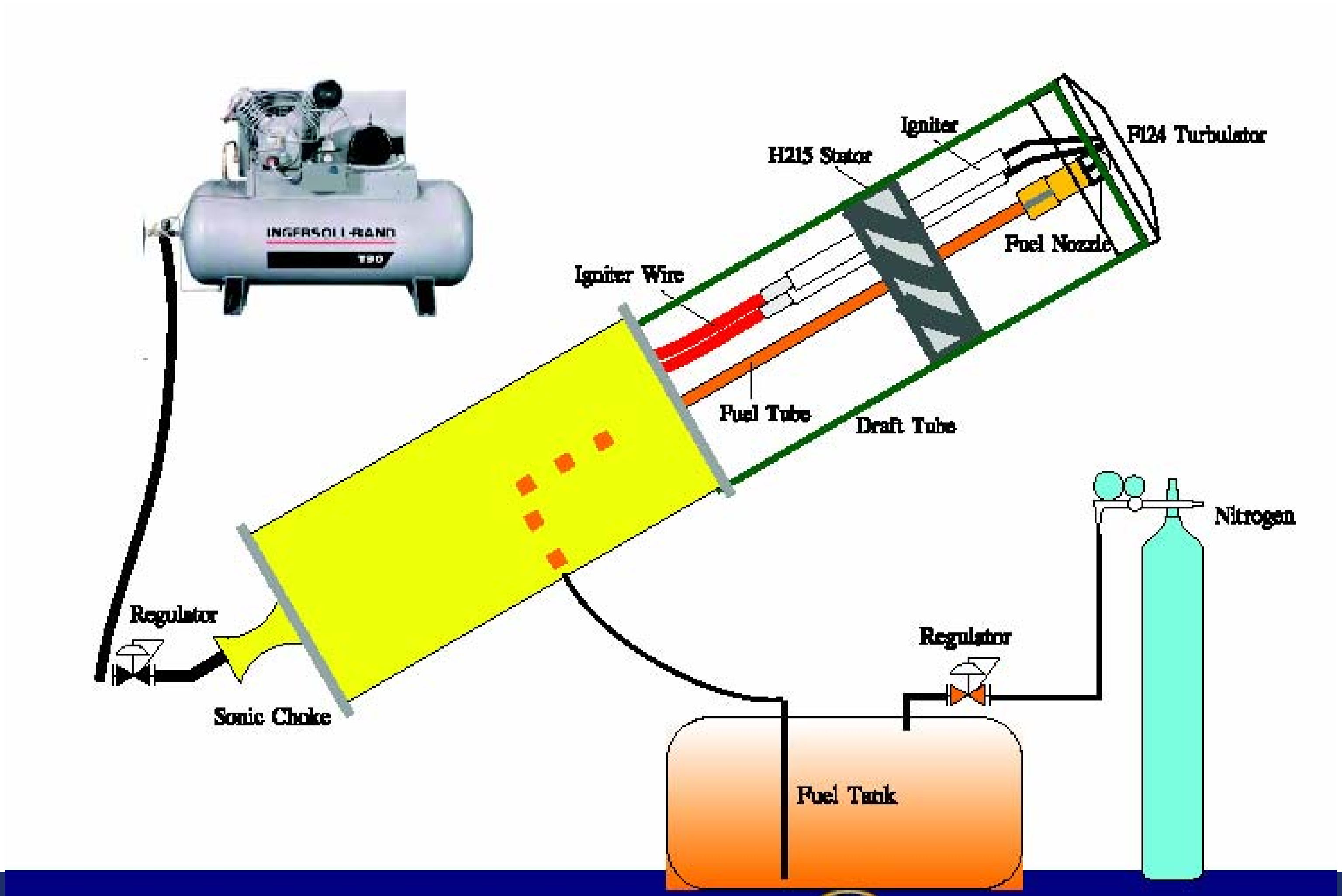
By: Robert I. Ochs

Date: Tuesday, March 6, 2007

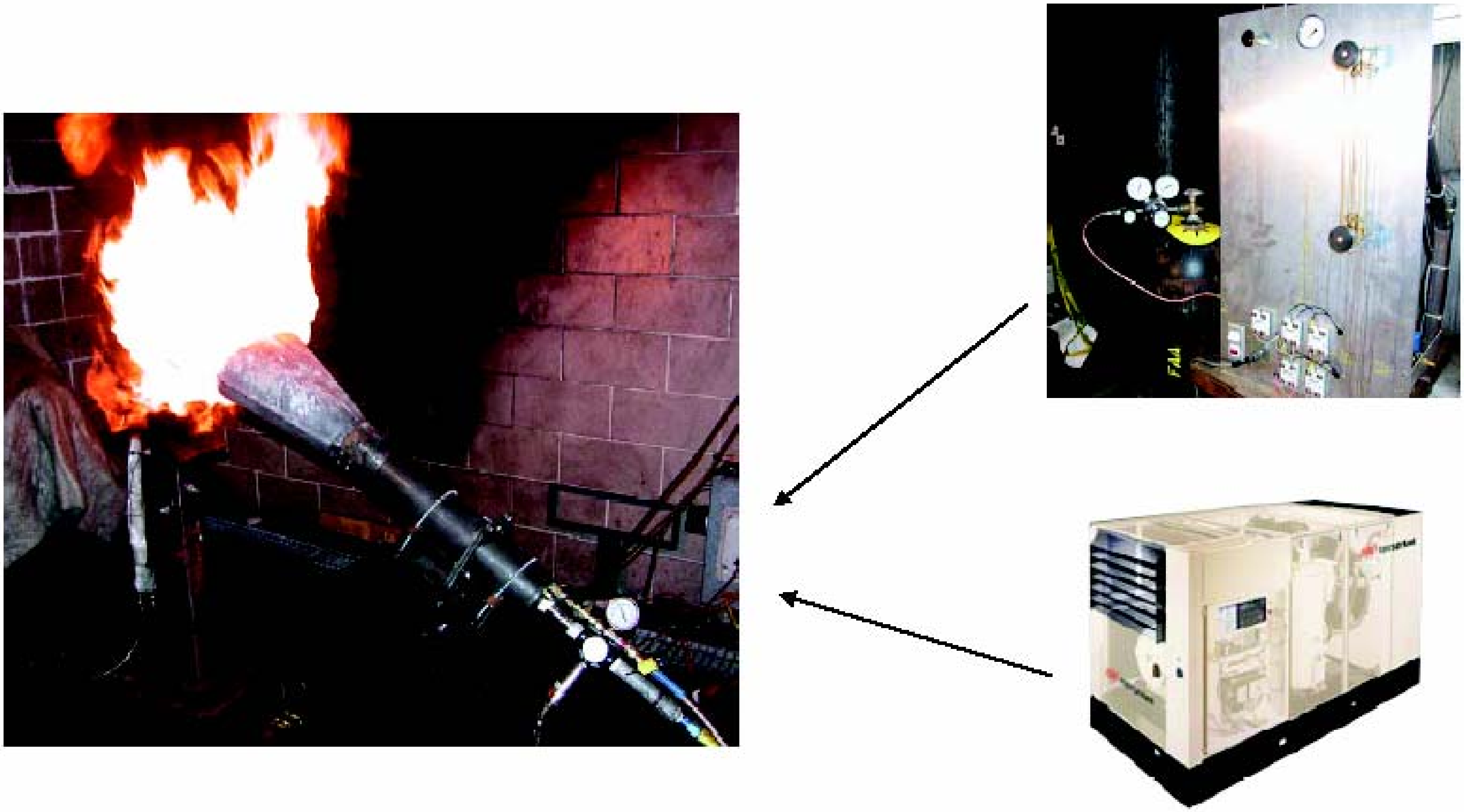
Outline

- **Review of Proof of Concept Phase**
- **Construction and Calibration of Multiple Burners**
  - Results from inter-laboratory tests with NG burners
  - Work completed at FAATC
- **Work to be completed in the near-term**
- **Work to be completed in the future**

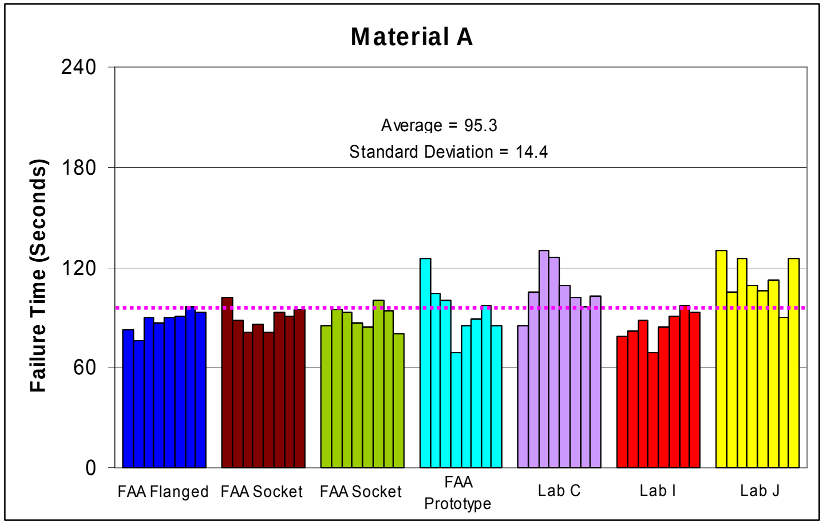
Concept

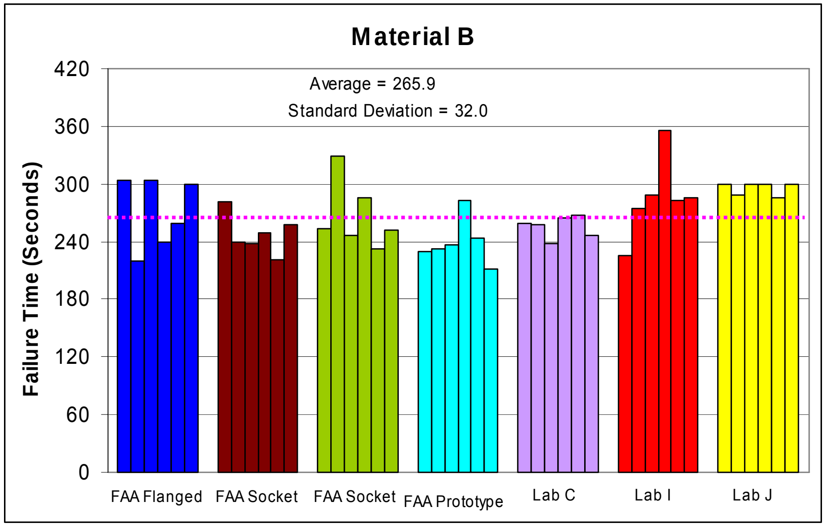

INGERSOLL-RAND
Igniter
H215 Stator
F124 Turbulator
Fuel Nozzle
Igniter Wire
Fuel Tube
Draft Tube
Nitrogen
Regulator
Sonic Choke
Regulator
Fuel Tank

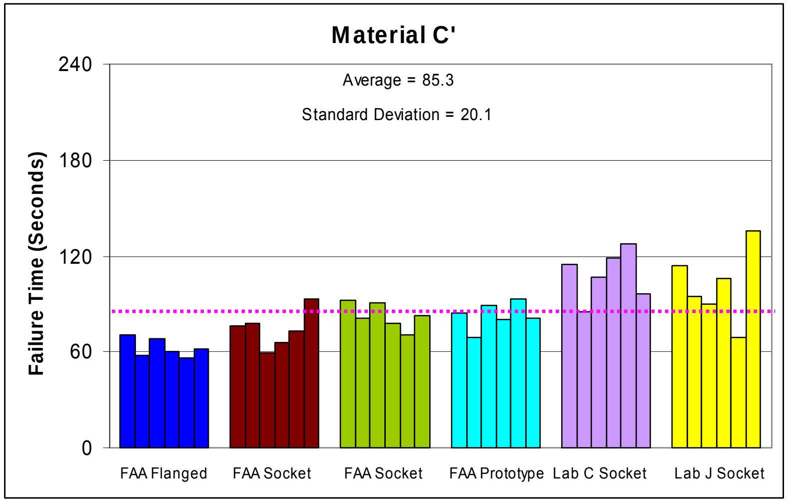
Proof of Concept



Performance Comparison: RRVIII







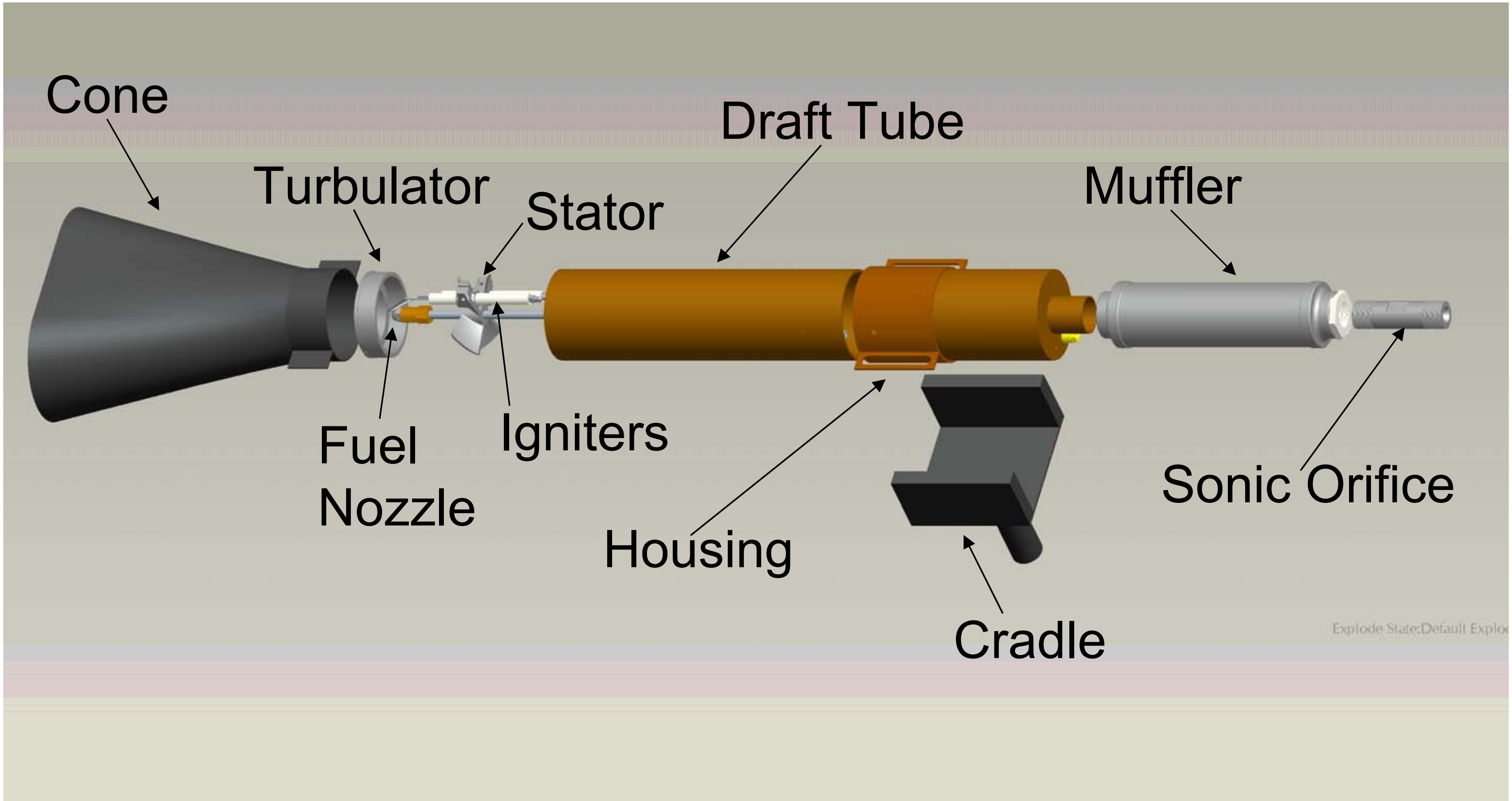
Summary of Concept Phase

- **A burner can be fabricated from easily obtainable parts and materials**
- **By simulating the input/output parameters of the Park oil burner, the concept burner could deliver a flame similar in character to that of the Park**
- **The concept burner’s burnthrough performance was shown to be similar to the FAA Park oil burner, as well as several other “socket” type Park oil burners**

Construction and Calibration of Multiple Burners

- **Objective**
  - Construct 10 identical burners
  - Show reliability of performance from test to test (one burner)
  - Show repeatability of burner performance from burner to burner
  - Show reproducibility of burner performance at various locations
- **Procedure**
  - Assemble and designate a burner (i.e., NG1, NG2, etc.)
  - Burner components are unique to each designated burner (stator, turbulator, cone, fuel rail, fuel nozzle, pressure regulator, muffler, sonic orifice)
  - Measure burner performance at FAATC lab (fuel flow, air flow, flame temperature, burnthrough times)
  - Package burner, ship to participating laboratory
  - Lab will perform same tests and compare results
  - If results are similar to those obtained at the FAATC, then burner is performing properly

NexGen Burners



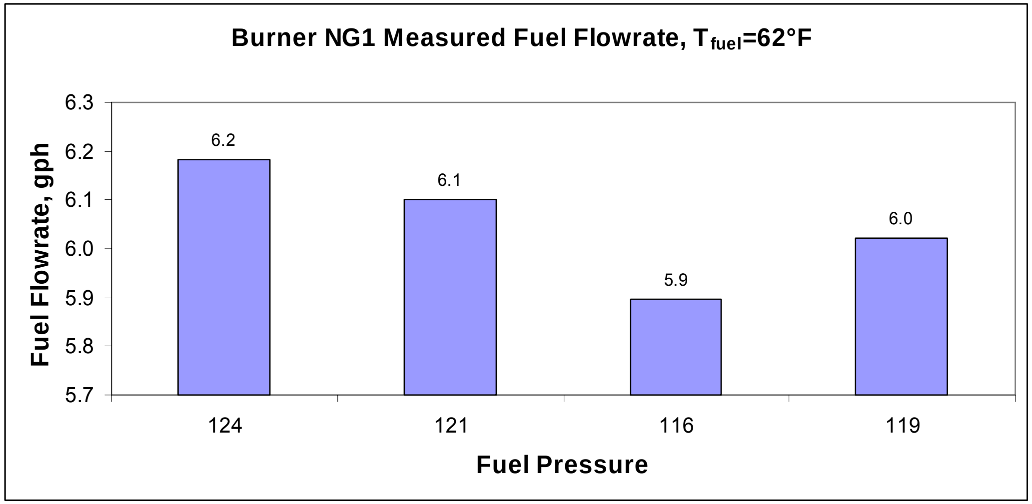
NexGen Burner Components

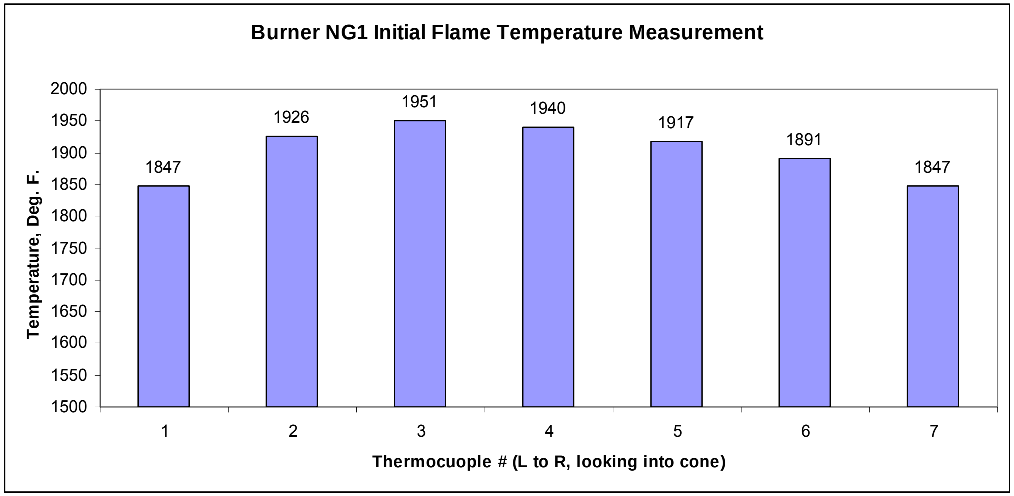
- Cone – custom fabricated burner cone built to dimensions specified in the rule
- Turbulator – Monarch F-124
- Fuel Nozzle – Monarch 5.5 gph 80° PL F-80 hollow cone spray
- Igniters – standard oil burner igniters
- Fuel Rail – custom fabricated fuel rail
- Stator – Monarch H215 replicate, modified with “liquid steel” and turned down on a lathe to increase diameter
- Draft Tube and Housing – removable draft tube allows easy access to internal components; housing “wings” allow for easy adjustment of burner position
- Muffler – drastically reduces high frequency noise from expansion of air
- Sonic Choke – regulates mass flow of air through the burner
- Pressure regulator – precision heavy-duty pressure regulator controls the sonic orifice inlet air pressure

NexGen 1 Burner Performance @ FAATC

- **NG1 was the first assembled and designated burner – November 2006**
  - Intention was to test NG1 at FAATC, then ship to Boeing burnthrough lab
  - Fuel flow was measured; 119-120 psig fuel pressure was found to provide 6.0 gph
  - Flame temperatures were within specification, although in some tests soot was found on T/C 1 after the test
  - Heat Flux measured approx. 14.2 BTU/ft²*s

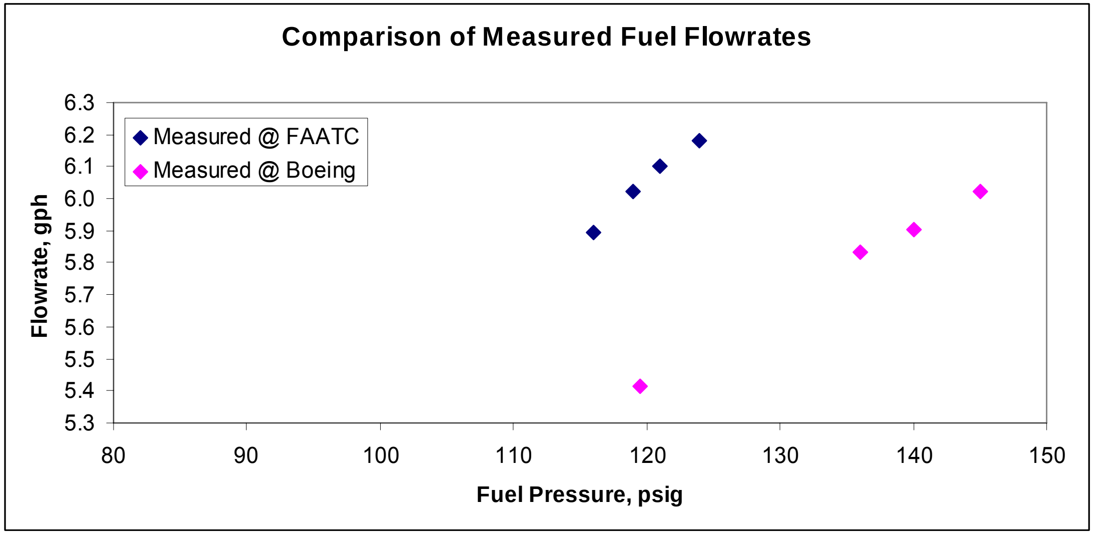
- **Material B.T. Times:**
  - 8579: 183, 190
  - 8611: 220, 214
- **Burner was then shipped out to Boeing**

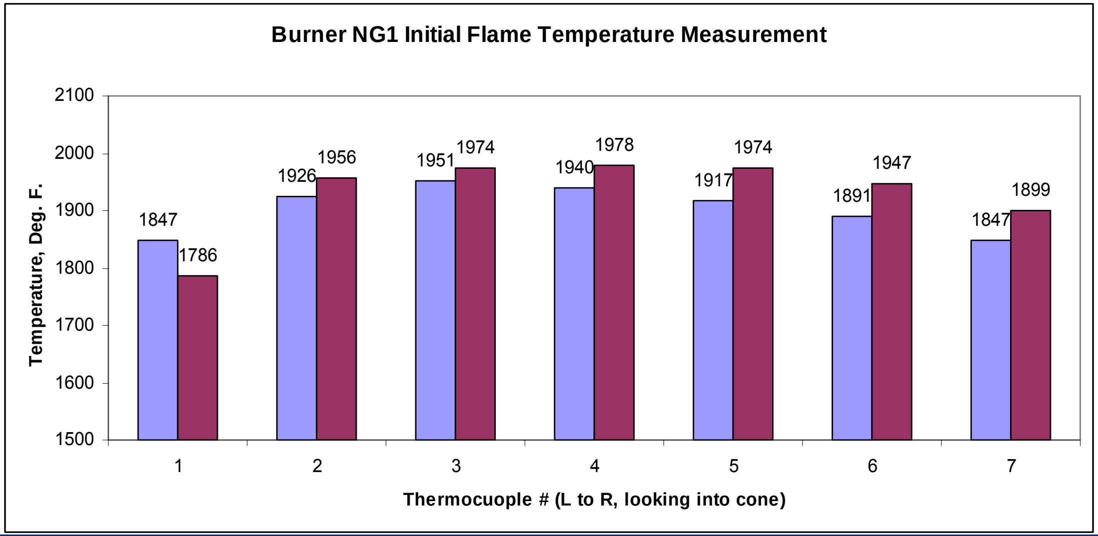




NexGen 1 Burner Performance @ Boeing

- **Fuel flowrate measured considerably less at Boeing for given pressures**
  - At 120 psig, Boeing measured 5.4 gph, whereas at FAATC, flow was 6.0 gph
  - A fuel pressure of 145 psig was required to deliver 6.0 gph
- **Flame temperature profile obtained at Boeing was similar to that obtained at FAATC, although sooting was again found on #1 T/C**
- **Burnthrough times were consistently quicker than those obtained at the FAATC**





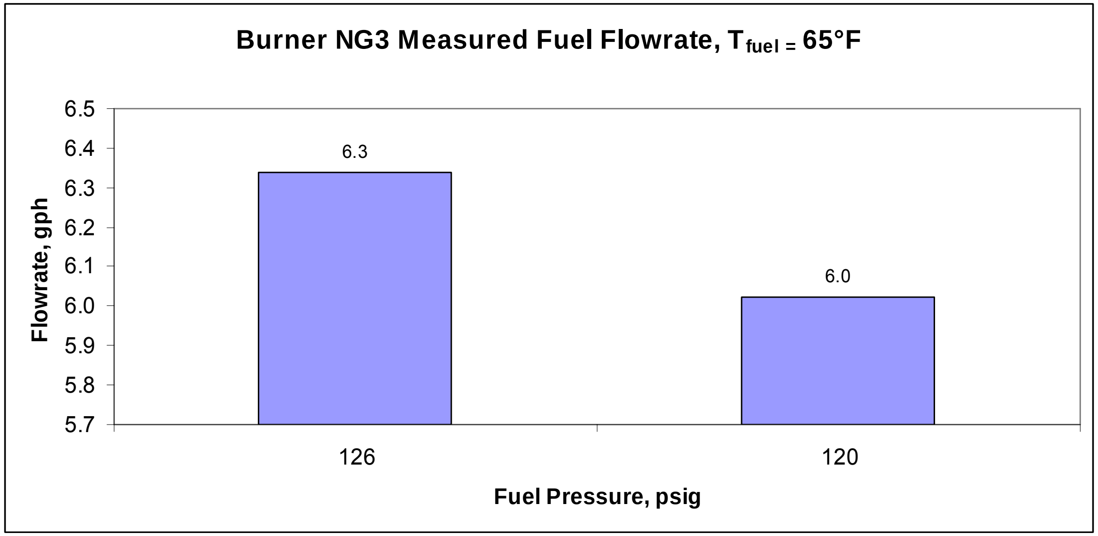
	FAATC	*Boeing*
8579	187	166
8611	217	205

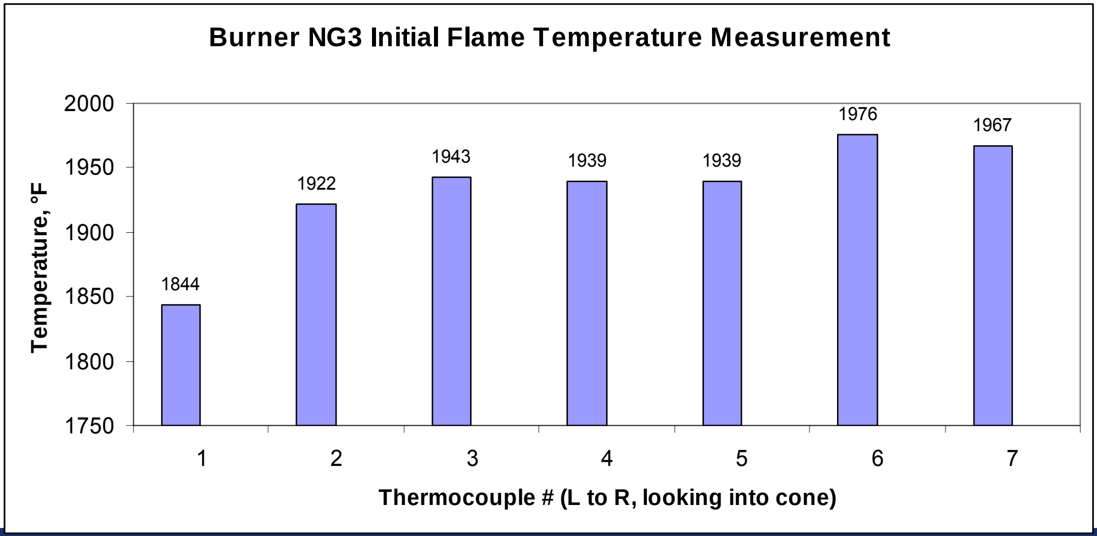
Observations from Boeing – FAATC Comparison

- **Fuel system differences:**
  - Boeing lab used a fuel pump from a commercial oil burner, FAATC uses pressurized fuel vessel
  - Boeing lab required a greater fuel pressure to achieve 6.0 gph fuel flow (145 vs. 120)
  - Boeing lab uses Jet-A fuel, FAATC uses JP8
  - Fuel temperature was not measured at Boeing
- **Air system differences:**
  - Boeing lab uses shop air, no cooling method; FAATC uses compressed air and in-line heat exchanger to maintain air temperature
  - Air temperature was found to fluctuate at Boeing lab
- **Burnthrough time differences:**
  - Boeing lab was consistently quicker to burnthrough
- **Recommendations:**
  - Check fuel pressure gauge for accuracy; replace if inaccurate
  - Monitor fuel and air temperature
  - Install in-line heat exchanger
  - Shield air and fuel lines from flame radiation

NexGen 3 Burner Performance @ FAATC

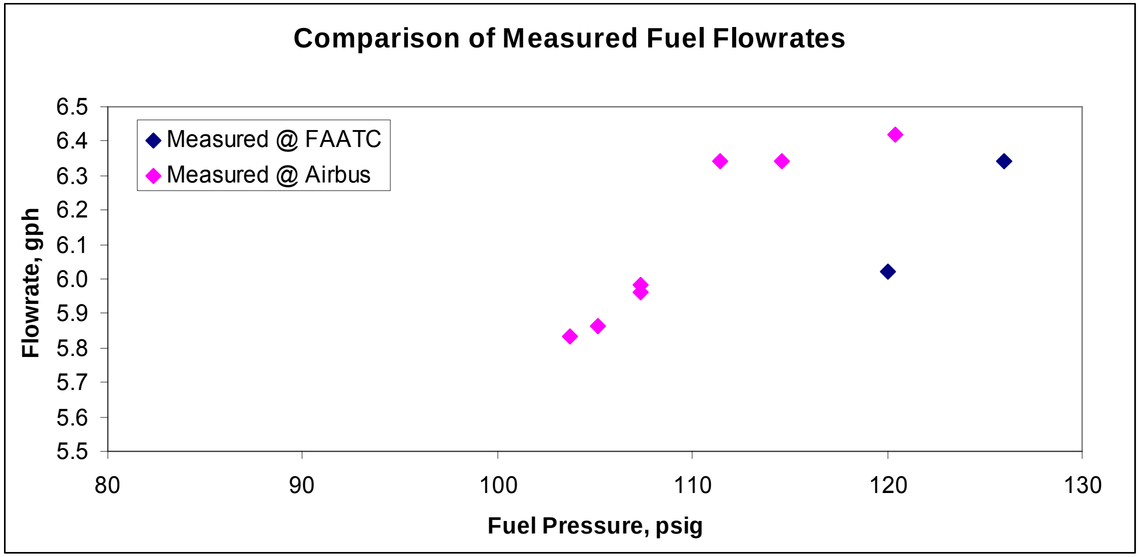
- **NG3 was the next assembled burner, and was to be checked out at FAATC, then shipped to Airbus, December 2006**
  - Fuel flow was measured, 120 psig gave 6.0 gph flowrate
  - Flame temperatures were within specification, although sooting was found on the #1 T/C
  - Heat flux measured approximately 14.7 BTU/ft^2*s
- **Material B.T. Times:**
  - 8579: 187, 182
  - 8611: 239, 235
- **Burner was then shipped to Airbus Germany**





NexGen 3 Burner Performance @ Airbus

- **Fuel flowrate measured considerably more at Airbus for a given fuel pressure**
  - At 120 psig, Airbus measured 6.4 gph
  - A fuel pressure of 108 psig was required to deliver 6.0 gph
- **Flame temperatures were similar, and sooting was again found on T/C #1**
- **Heat flux was measured as around 14.3 BTU/ft²*s**
- **Airbus B.T. Times were consistently longer than those observed at FAATC**



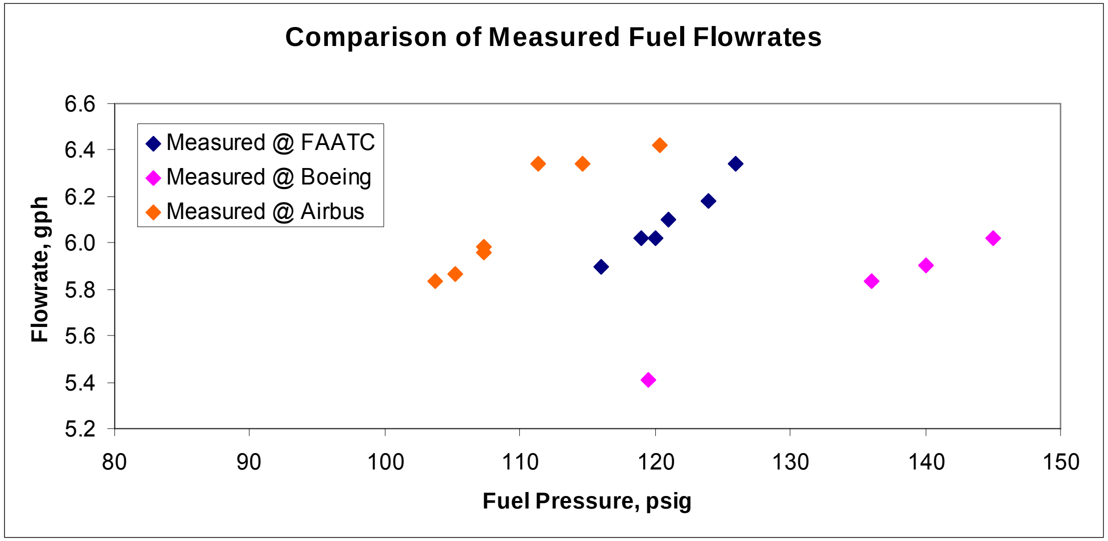
	FAATC	***Airbus***
8579	184	222
8611	236	244

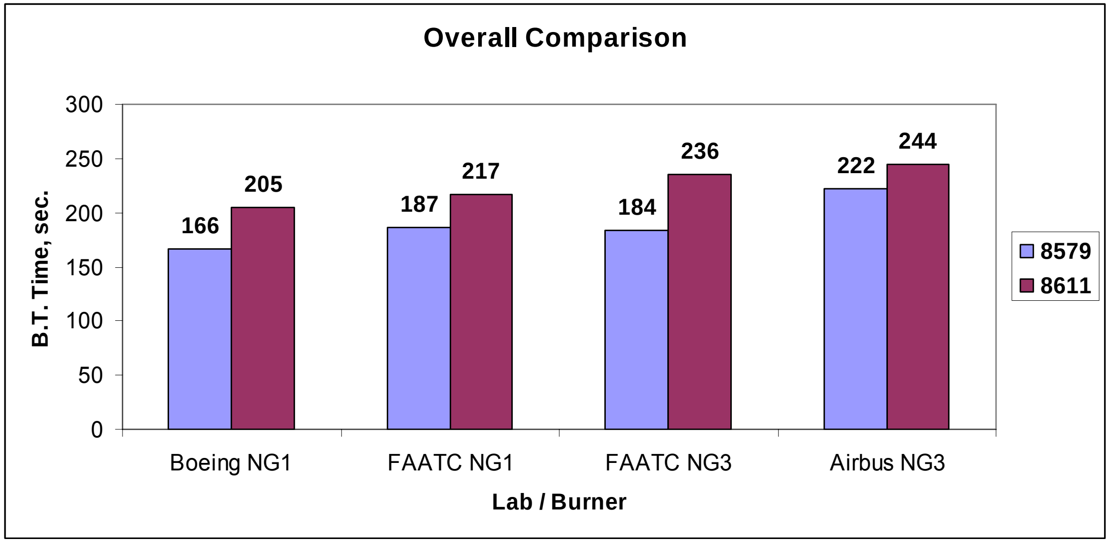
Observations from Airbus – FAATC Comparison

- **Fuel System**
  - Airbus used a pressurized fuel vessel, but pressure was measured in the vessel headspace only, and not near the burner
  - Airbus used JP8 fuel
  - Airbus required less pressure to achieve 6.0 gph
  - Fuel lines were left exposed to flame radiation and possible fuel heating; fuel temperature was not measured
- **Air System**
  - Airbus used unconditioned shop air
  - Air lines were left exposed to flame radiation and possible air heating; air temperature was not measured
- **Burnthrough time differences**
  - Airbus was consistently longer to burnthrough
- **Recommendations**
  - Measure air and fuel temperature and fuel pressure near the burner inlet, check for fluctuations during testing
  - Shield air and fuel lines from flame radiation
  - Install in-line heat exchanger for inlet air

General Observations

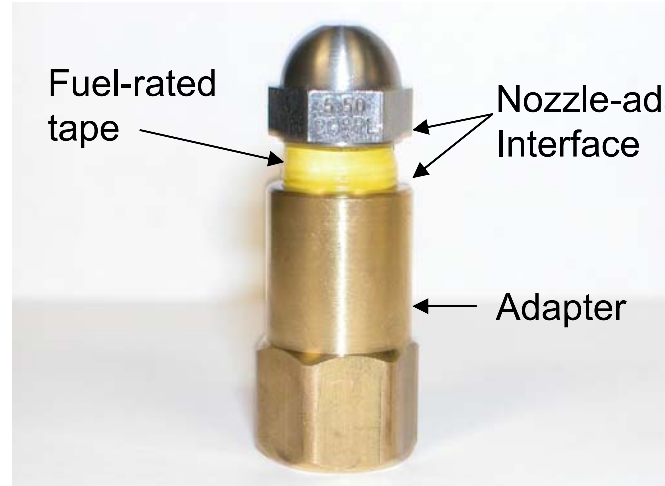
- **All labs required a different pressure to achieve the same fuel flowrate**
  - Possible causes?
    - Method of fuel pressurization
    - Fuel types
    - Fuel temperature
    - Fuel pressure measurement location and accuracy
- **Fuel pressure effect on B.T. times?**
  - Boeing: higher fuel pressure, quicker b.t. times
  - Airbus: lower fuel pressure, longer b.t. times
  - Does fuel pressure have more of an effect on b.t. times than the fuel flowrate?





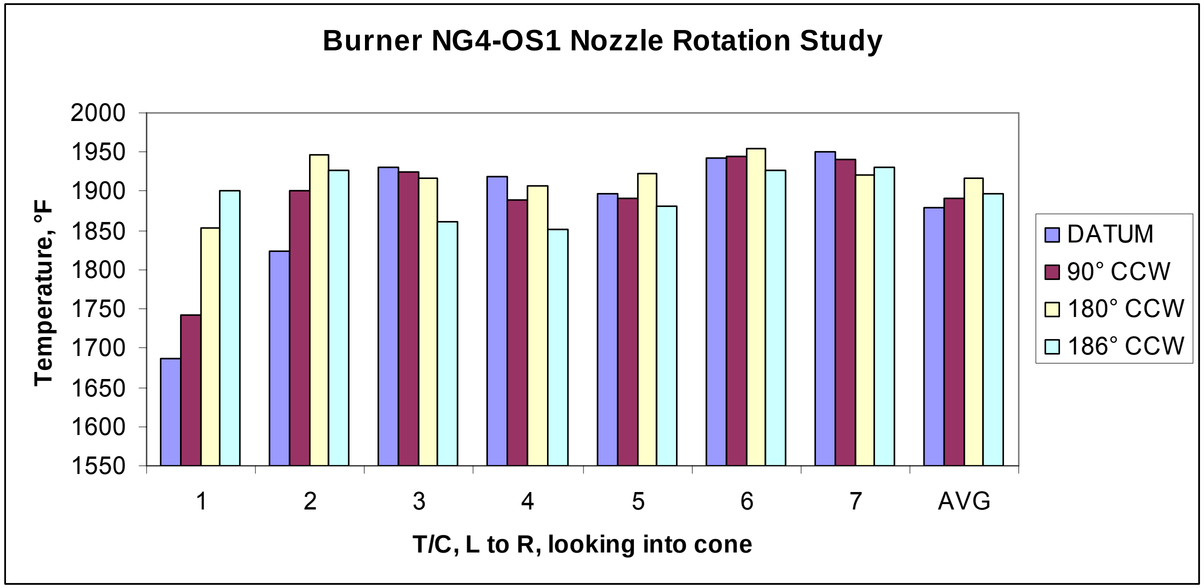
While we were gone…

- **Back at FAATC during December meeting and Airbus lab visit:**
  - Engineering technician Paul S. was hard at work setting up more burners. He found that:
    - Fuel rails require an exact bend in order to fit properly in burners; several fuel rails were not bent properly, and caused misalignment of fuel rail
    - Threading of fuel rails was not exact, and therefore some fuel nozzle adapters may be misaligned
    - Fuel nozzle – adapter interface may leak, causing fuel “spitting” during burner operation. Fuel-rated Teflon tape can be used on nozzle threads to fix leakage
    - He was asked to determine why sooting was occurring on T/C #1. Tim M. recommended to him that rotating the nozzle can make a difference in the spray pattern. He developed a method of indexing the nozzle orientation for each burner, in order to optimize the spray and therefore the flame temperature distribution



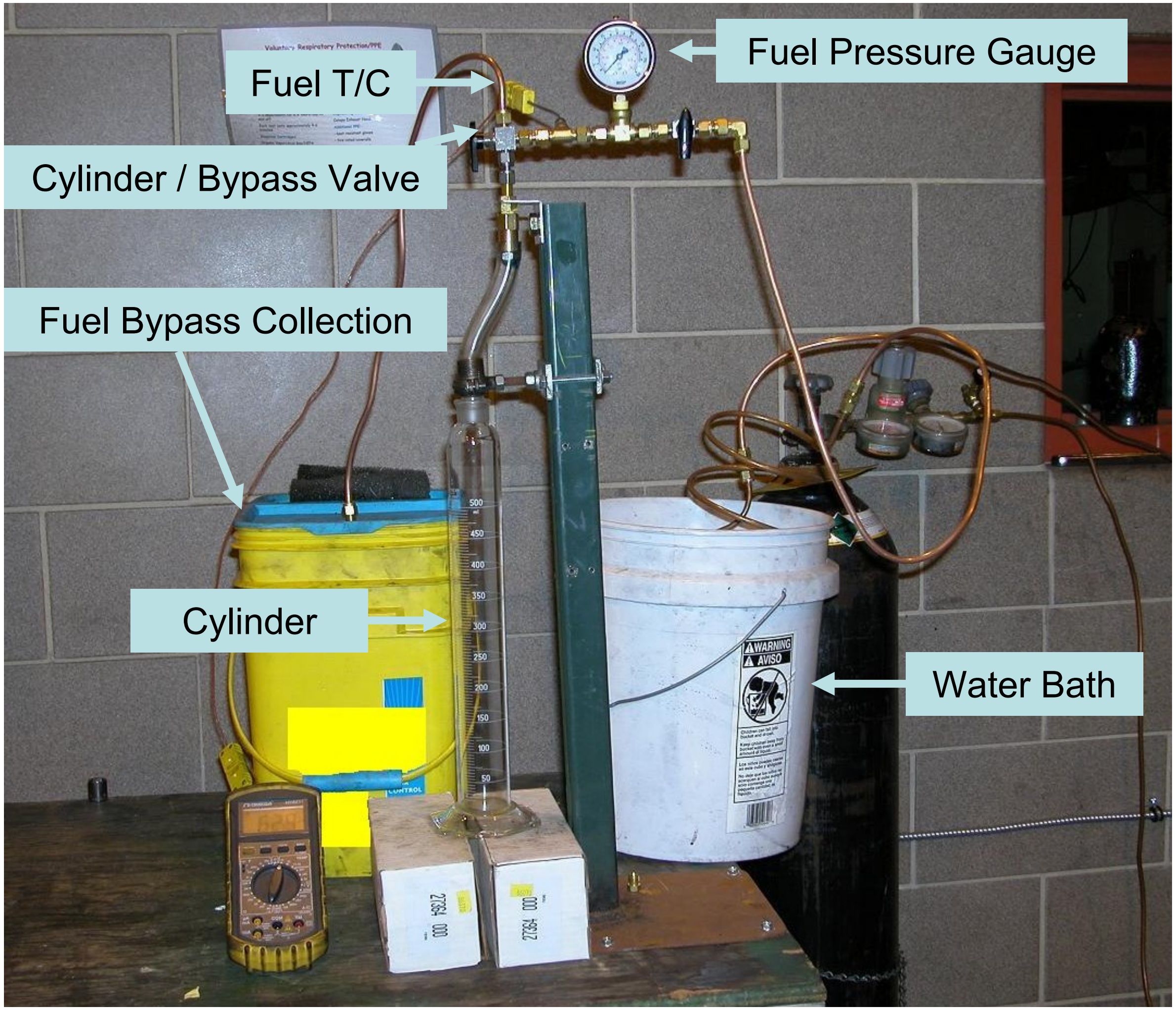
Nozzle Indexing

- **Indexing the nozzle was found to have a significant effect on the flame temperature distribution**
- **Large increments of 90° were initially attempted in order to determine the effect**
- **The main goal was to eliminate the sooting on the #1 T/C and to even out the temperature profile to have an average near 1900°F**
- **In this case, an optimal setting of 180° from the arbitrary datum was found to provide the best flame temperature distribution**
- **This process implies that fuel nozzle spray distribution is not necessarily symmetric about the circumference of the hollow cone spray**
- **Further investigation is required**



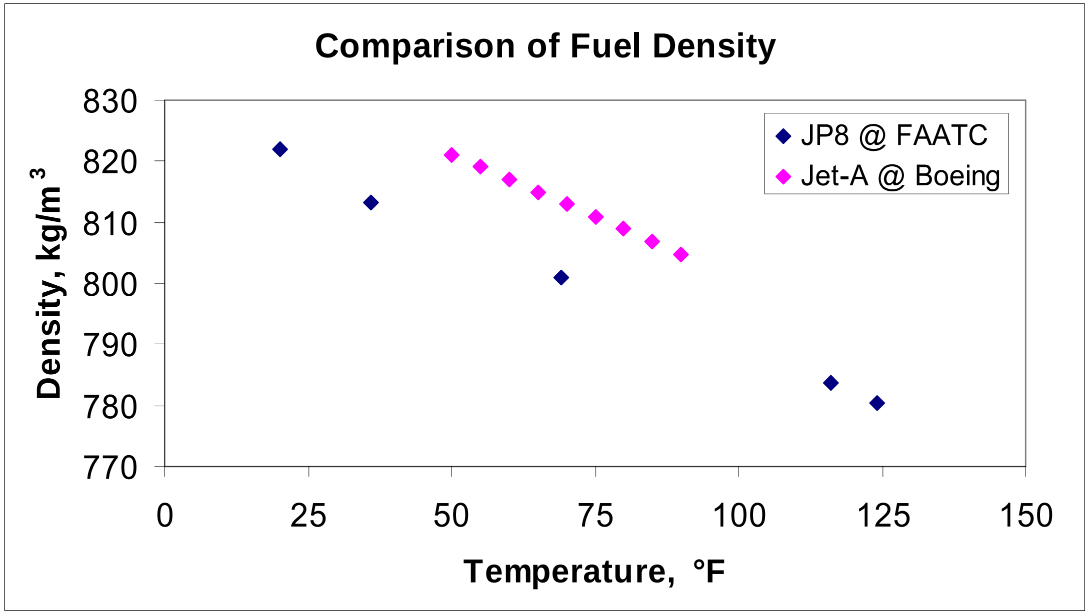
Fuel Nozzle Flowrate Bench Test Apparatus

- A bench test apparatus was developed to easily and quickly test multiple nozzles for flowrate
- Fuel temperature and pressure can be carefully monitored close to the nozzle
- Fuel pressure is supplied by the pressurized fuel vessel
- Fuel temperature can be regulated by means of fuel lines coiled through a water bath
- A calibrated graduated cylinder (500 mL, 5 mL graduations) was used to collect the fuel
- A scale was initially implemented in order to determine mass flow rate as well as volumetric flow rate, and to calculate the fuel density as a function of fuel temperature



Fuel Density Study

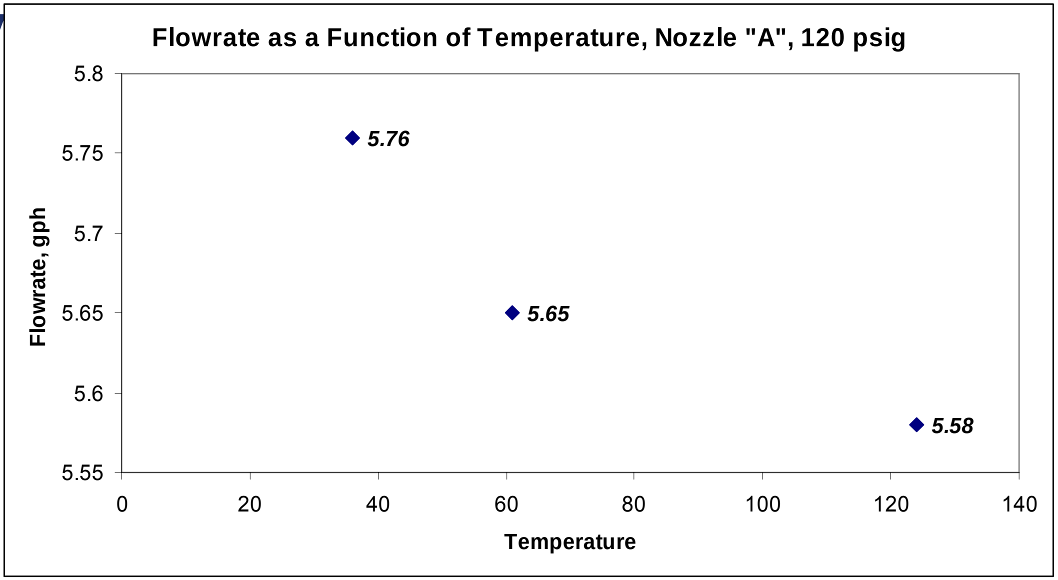
- **Fuel density was measured at FAATC and at Boeing**
  - At a given temperature, the Boeing Jet-A was more dense than the FAATC JP8
  - For example, at 70°F, ρ_{Boeing}=813 kg/m^3; ρ_{FAATC}=801 kg/m^3
  - Results in a % difference of ≈ 1.5%

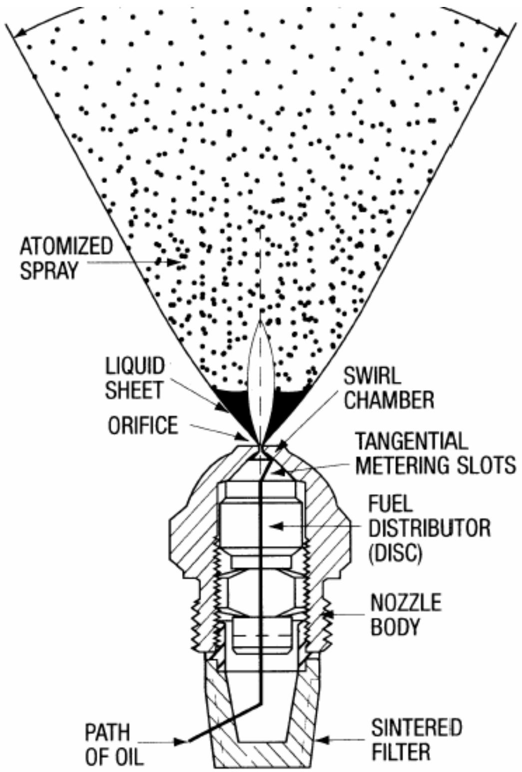


Fuel Nozzle Study

- **For a given nozzle at a standard pressure,**
  - Increasing the fuel temperature results in a decreased fuel flowrate
  - Decreasing the fuel temperature results in an increased fuel flowrate
  - For a temperature interval of ≈90°F, there can be a change in flowrate of ≈3.1%
  - Fuel that is colder (more viscous) flows more through a given nozzle than fuel that is warmer (less viscous)
  - Can be explained by the theory behind spray nozzle operation*
    - With colder, more viscous fuel, the thickness of the liquid sheet is greater as it exits the orifice
    - This reduces the diameter of the air core
    - Therefore, in the same volume, there will be more fuel than air with fuel that is more viscous

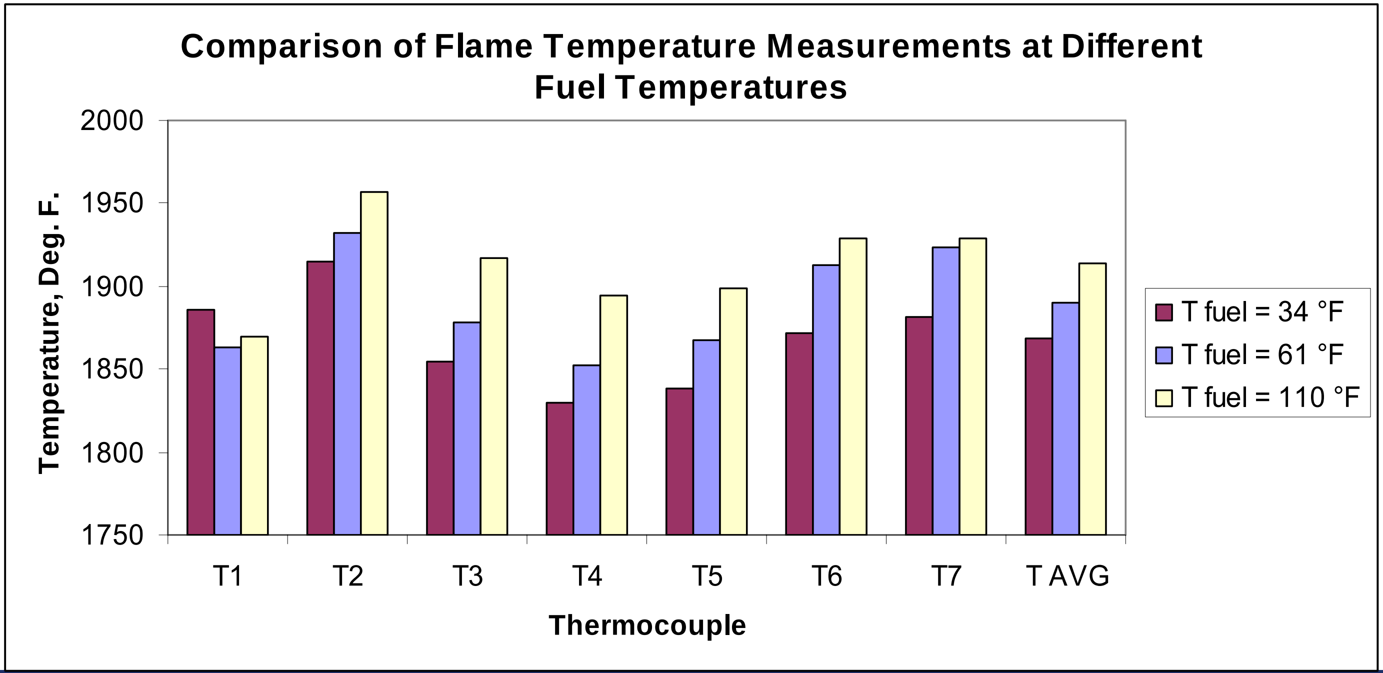
**From "A Technicians Guide To Oil Burner Nozzles", Hago Precision Nozzles, www.hagonozzles.com*



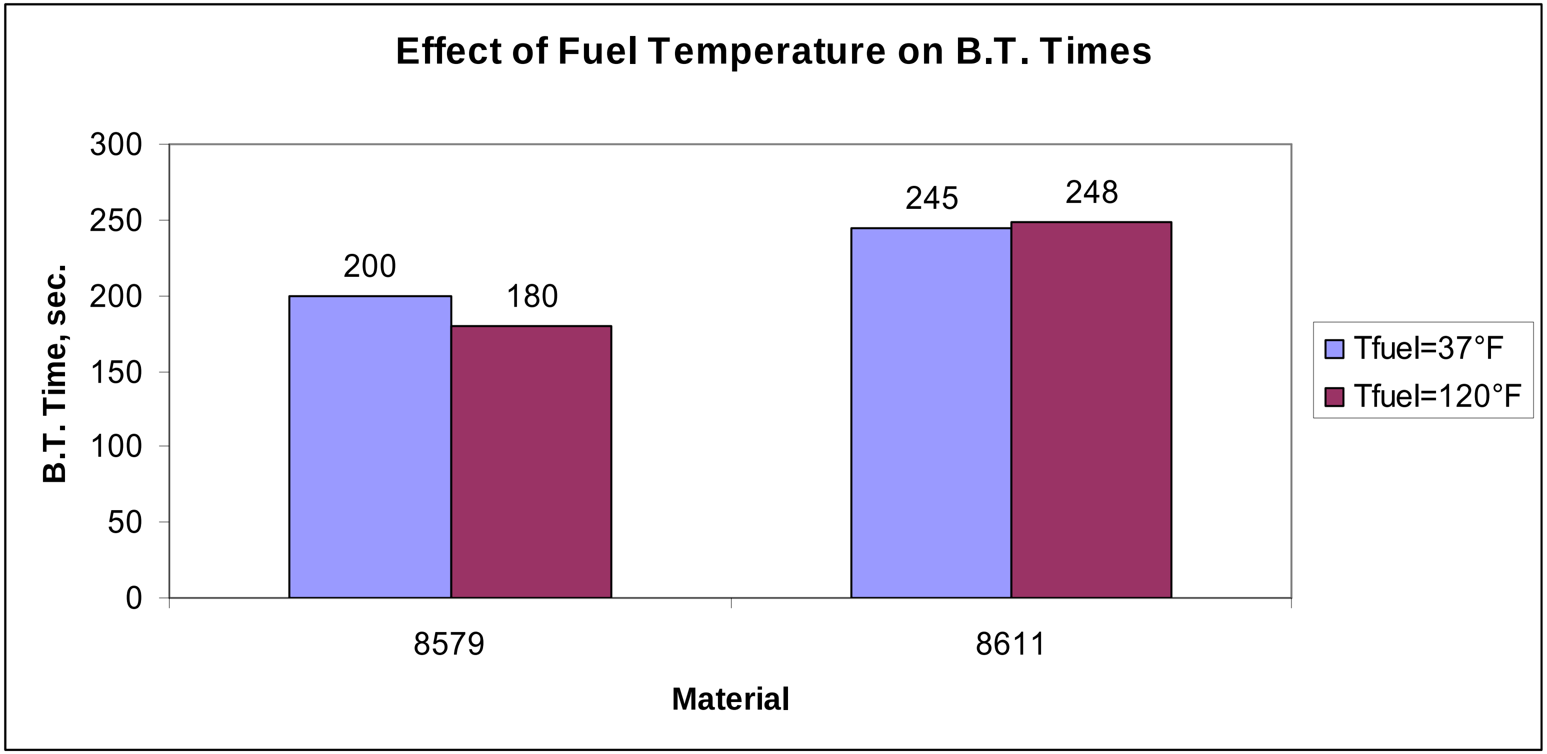


Quantification of Fuel Temperature Effects

- **In general, increasing the fuel temperature results in a higher flame temperature**
  - The combined effect of increased fuel temperature and less fuel flowrate results in higher flame temperatures
  - Does this have an effect on burnthrough times?



Effect of Fuel Temperature on B.T. Times



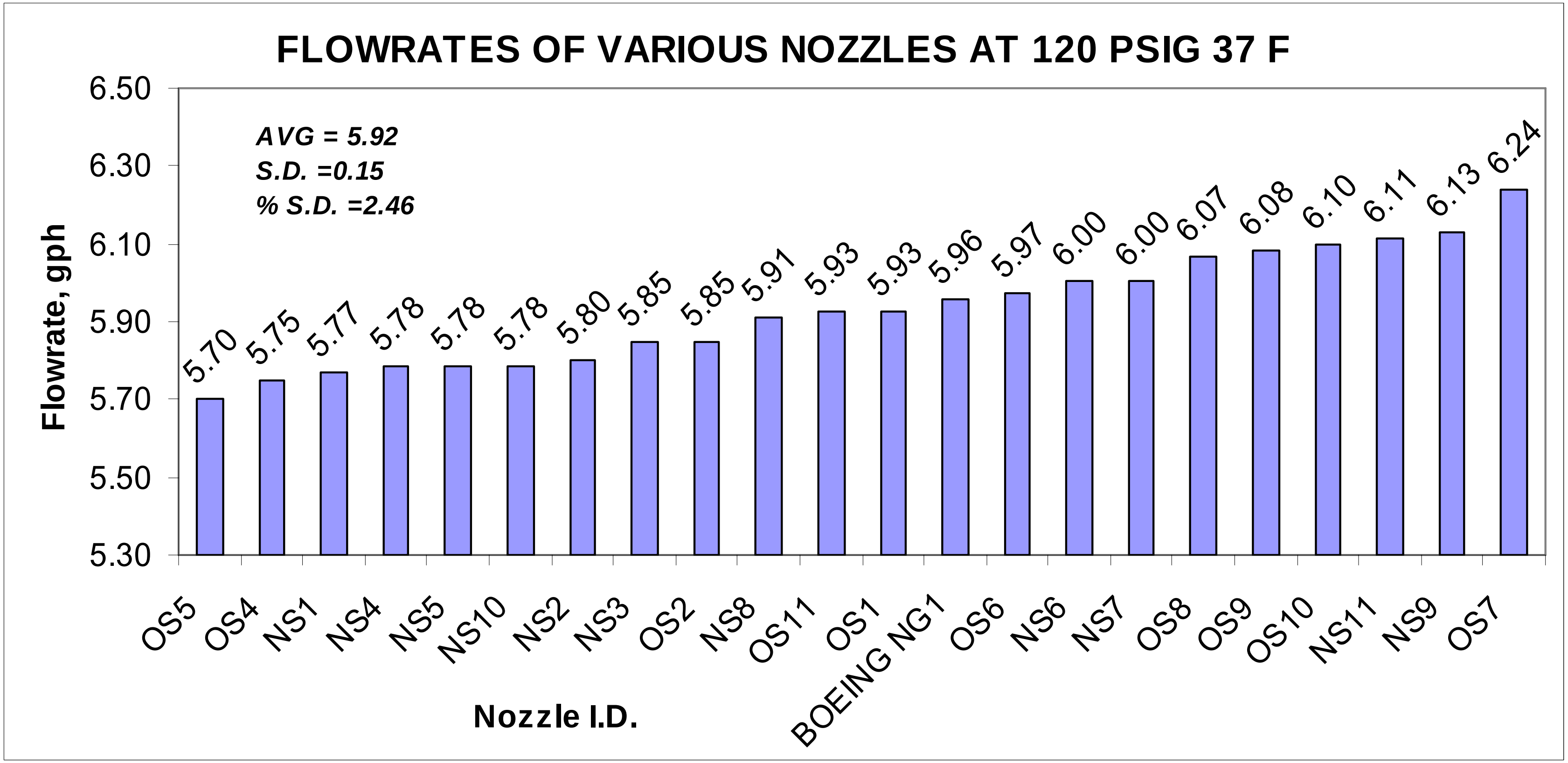
- **Material 8611 seems to be unaffected by changes in fuel temperature**
- **Material 8579 shows a significant change in b.t. time for varying fuel temperatures**
- **Material 8611 seems to be insensitive to minor changes, and will be useful for calibrating burners if an "absolute" b.t. time can be determined**
- **Material 8579 seems to be the more sensitive material to minor changes, will be useful as a diagnostic tool**

Fuel Temperature Summary

	Density	*Viscosity*	*Droplet Size*	*Flowrate*	*Flame Temperature*	*8579 B.T.*	*8611 B.T.*
Cold Fuel	+	+	+	+	-	+	unaffected
Warm Fuel	-	-	-	-	+	-	unaffected

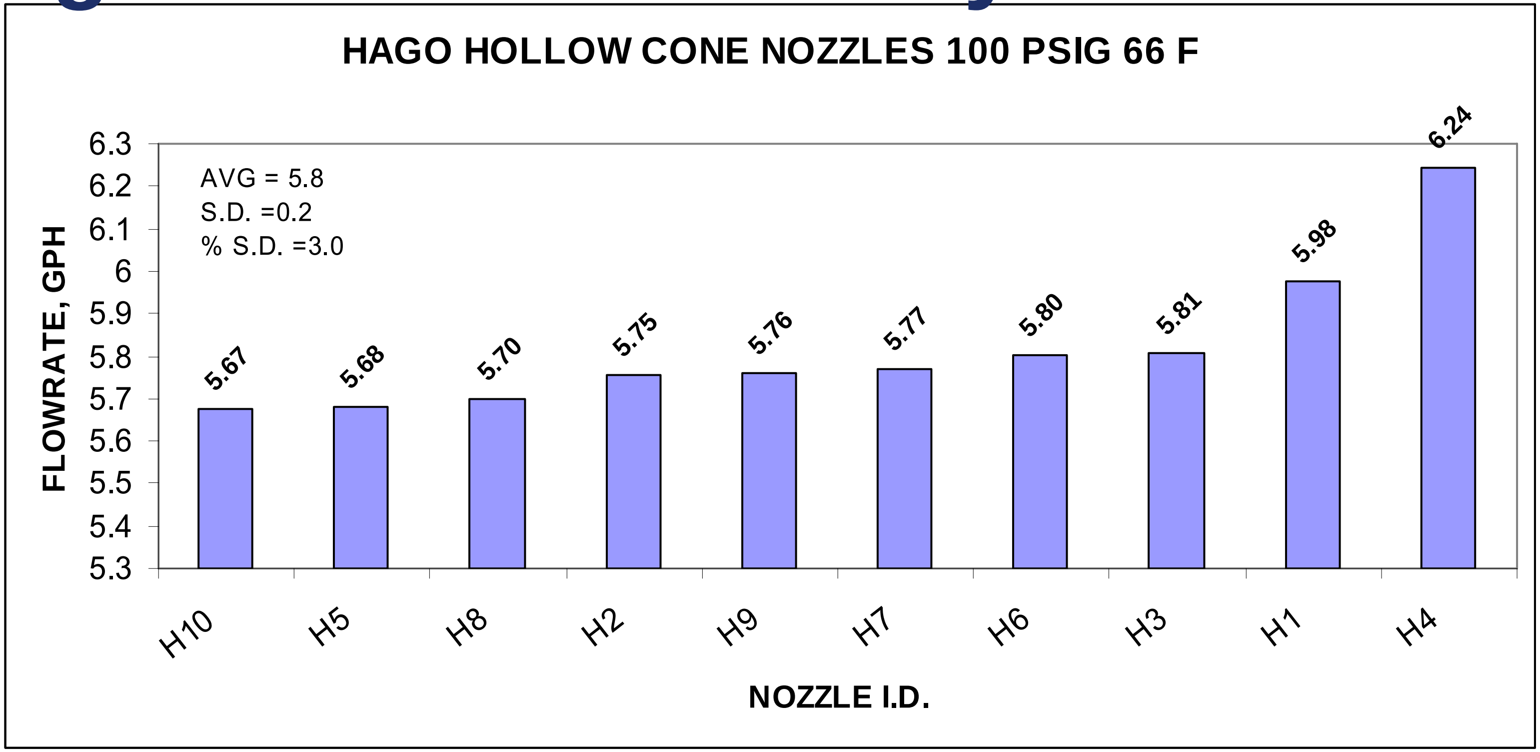
- **Fuel temperature has an effect on several factors, resulting in an effect on the b.t. time of certain materials**
- **The fuel temperature needs to be standardized**
- **The simplest way of achieving a standard fuel temperature is for all labs to use an ice bath to chill the fuel before reaching the burner**
- **Copper tubing can be coiled and immersed in a bucket filled with an ice-water mixture; this will cool the fuel to approximately 32-40°F.**

Monarch Fuel Nozzle Study



- **The intention here is to determine the flow properties of every nozzle in our inventory**
  - 10 “old style” (designated as OS) 5.5 gph F-80 nozzles
  - 11 “new style” (designated as NS) 5.5 gph F-80 nozzles
- **Nozzles were tested on the bench test apparatus, at a constant fuel temperature and pressure**

Hago Fuel Nozzle Study



- Hago Nozzle corp. agreed to work with the FAATC to determine if their production nozzles will work better for our application
- They graciously provided 20 sample nozzles, 10 6.0gph 80° hollow cone, and 10 6.0 gph 80° solid cone
- The hollow cone nozzles were tested on the nozzle bench test apparatus
- The spread in flowrates at a given temperature and pressure was similar to that obtained with Monarch nozzles
- Future work with Hago nozzle will take place, in order to find an optimal nozzle configuration for our application

Warpage of Center Former

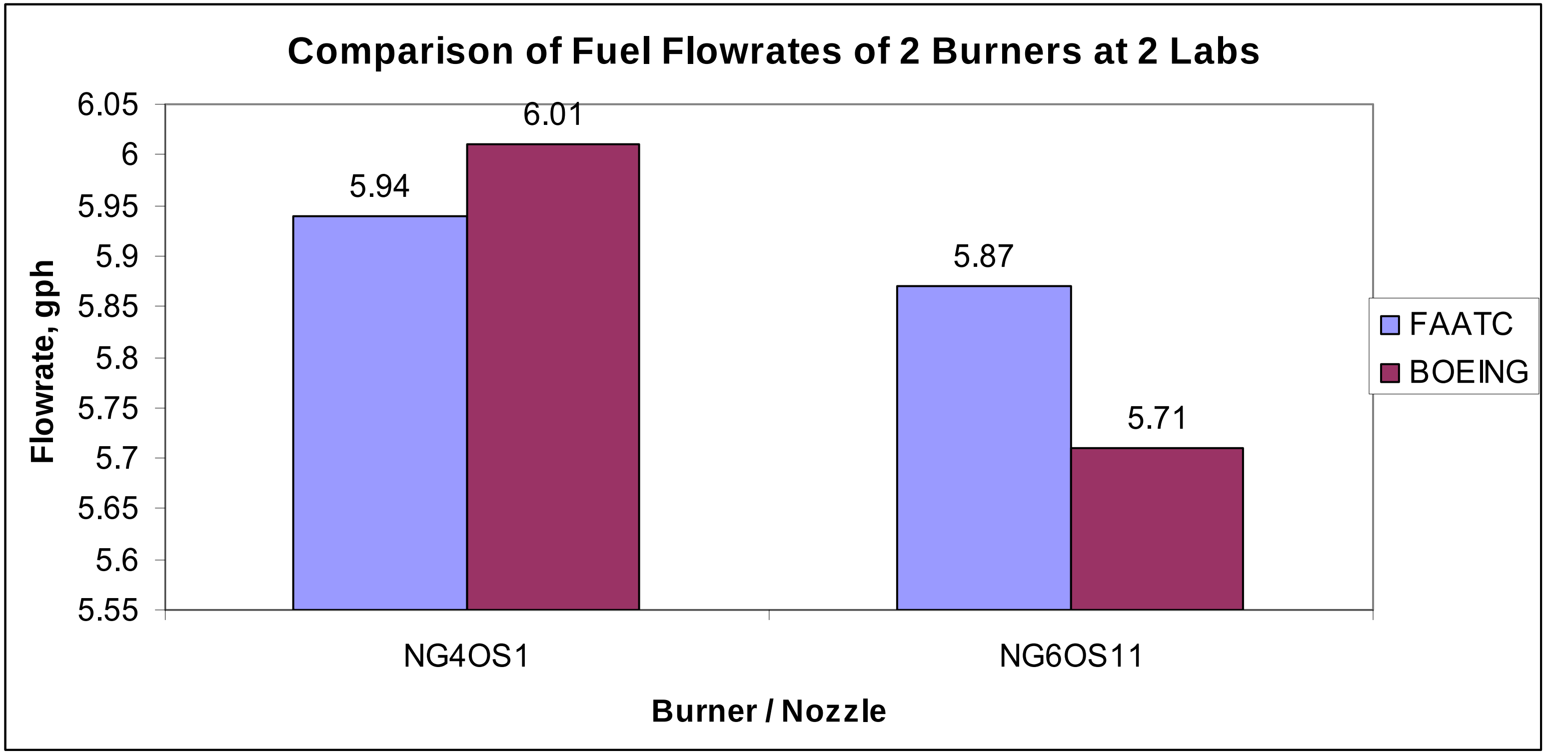
	Warped Center Former	*New Center Former*
8611	236	252

- **During set-up and testing of NexGen burners, the center former on the test rig became noticeably warped**
- **Warping of the center former moves the point at which the burner should be aligned with the test rig**
- **Warping also causes more area of the flame to be covered by the center former, and shields the material from the flame**
- **Significant differences in b.t. times were noticed for back to back comparison testing of warped and new center former**
- **Shows the need for a method of testing materials without the influence of the test rig, in order to determine if the NexGen burners are operating properly**

Comparison of Boeing and FAATC… Take 2 – January 2007

- **In a telephone conference with FAA and Boeing personnel and management, it was decided that Boeing would ship burner NG1 back to the Tech Center, as it was not working properly**
- **The Tech Center would set up, test, and ship out 2 burners to Boeing**
  - Burners NG4OS1 and NG6OS11 were designated to go to Boeing (note the new designation of burners – NG# for burner number, and OS# for nozzle type and number)
  - These burners have been adjusted as per our recent findings:
    - Properly aligned fuel rail
    - Fuel rated Teflon tape on nozzle threads
    - Nozzle orientation was optimized, and sooting on T/C 1 was no longer an issue
  - Both burners would be tested at Boeing, and the plan was for Boeing to ship one burner to their material supplier Mexmil
- **Now, Boeing had installed an ice bath to chill the fuel, as well as measure the fuel temperature and pressure nearer to the back of the burner**
- **Fuel and air lines were also properly shielded, and the fuel temperature stayed constant during the length of a test**
- **No method of cooling the inlet air was established at this point, and air temperatures of anywhere between 60-90°F were observed**

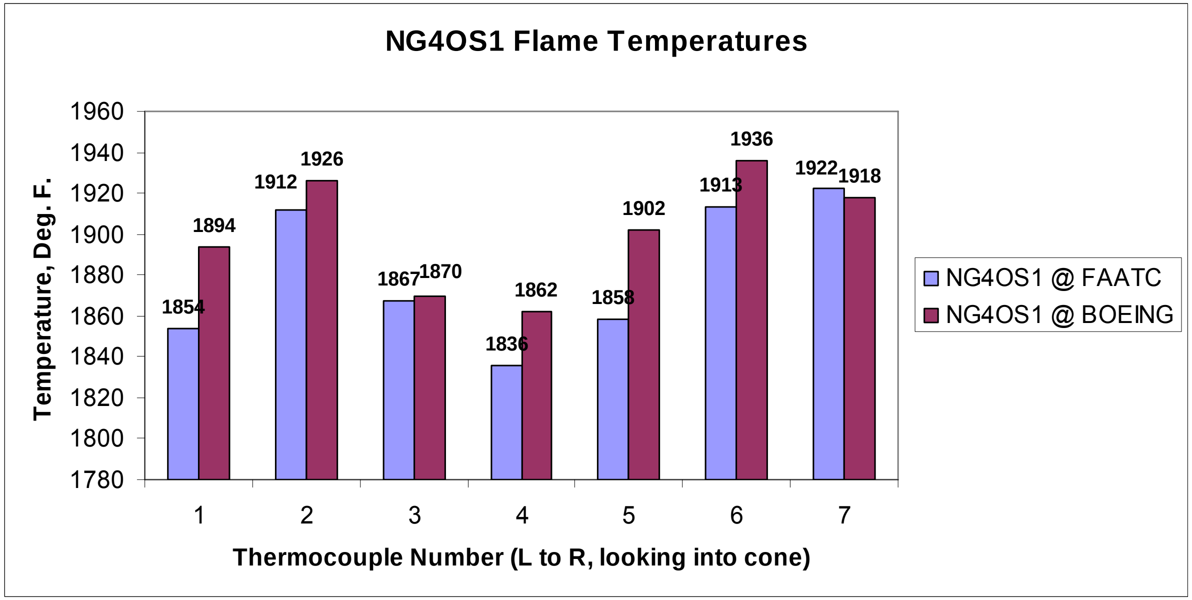
Fuel Flowrate Comparison

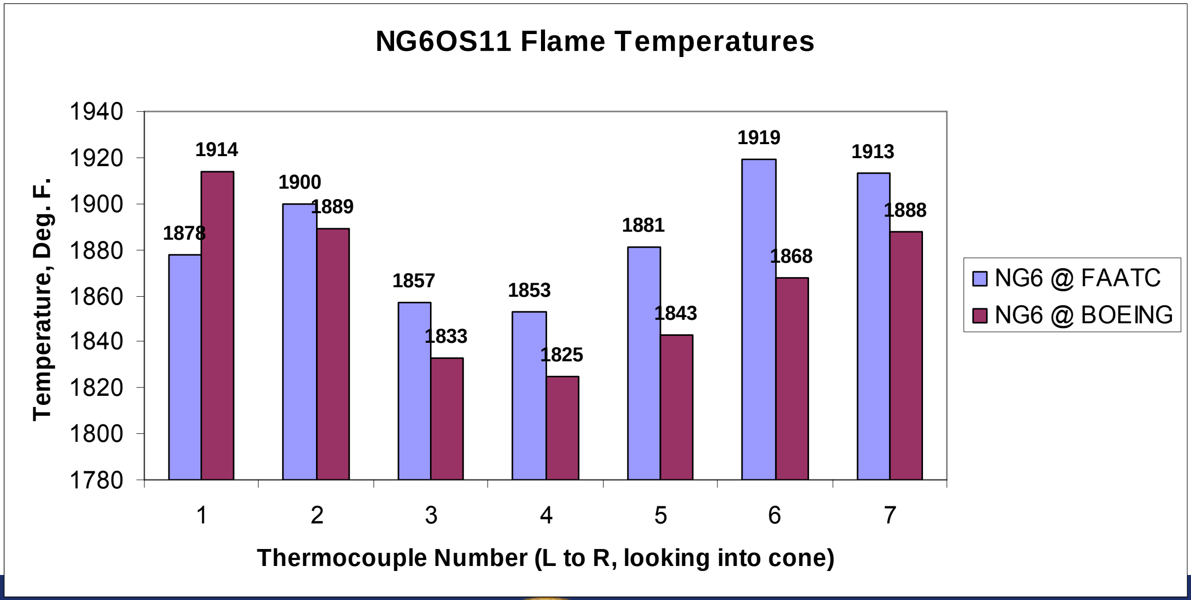


- **Fuel flowrates did not exactly match from FAATC to Boeing labs**
- **No trend was apparent; NG4 measured more flow at Boeing, while NG6 measured less flow**
- **Discrepancy caused by method of fuel pressurization?**

Flame Temperature Comparison

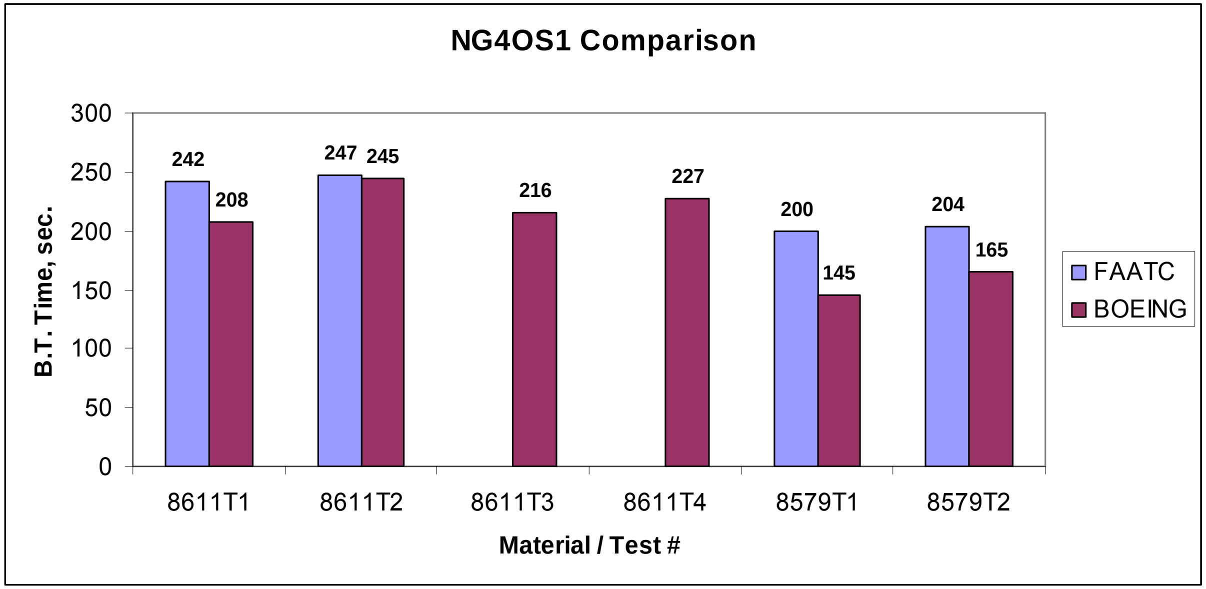
- **Flame temperature profiles were similar at Boeing**
- **NG4 @ Boeing measured slightly higher temperatures; and also measured a higher fuel flowrate**
- **NG6 @ Boeing measured slightly lower temperatures; and also measured a lower fuel flowrate**
- **Correlation?**

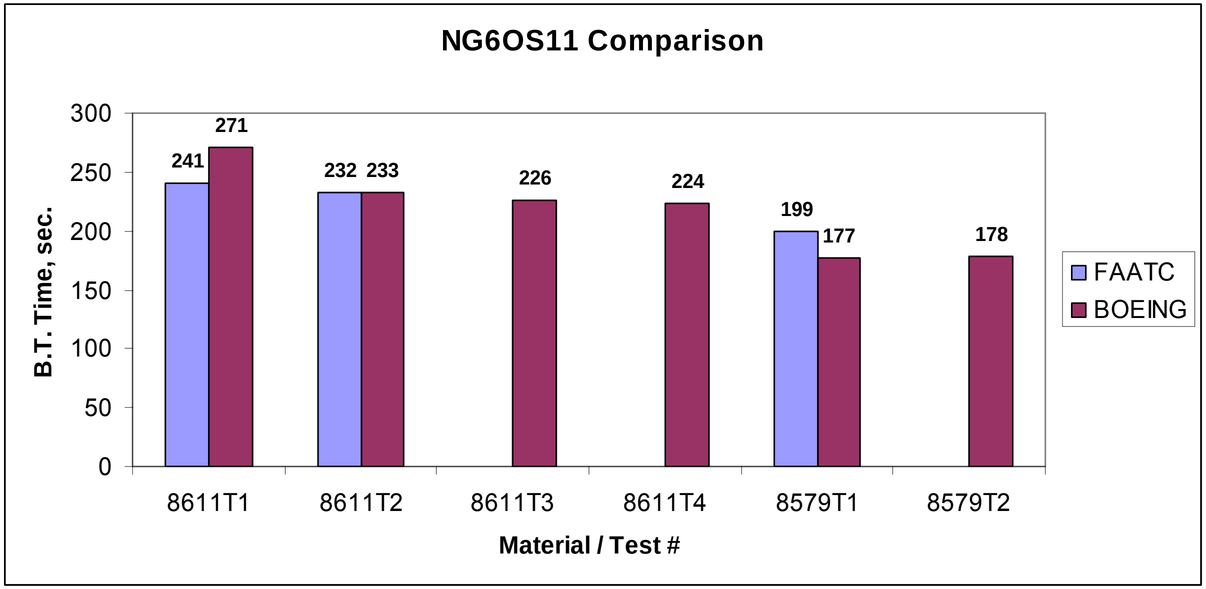




B.T. Comparison

- Again, for both burners, the Boeing lab was burning through quicker than at FAATC
- Fluctuations in b.t. times were noticed at Boeing; burners seemed less consistent than at FAATC
- On the last day of testing with NG6, significant warpage of the center former was noticed; looking at the backside of the sample during a test, less area of blankets were orange when compared to initial testing
- Possible causes of discrepancy:
  - Air temperature not regulated
  - Method of fuel pressurization
  - Fuel type
  - Test rig construction, alignment



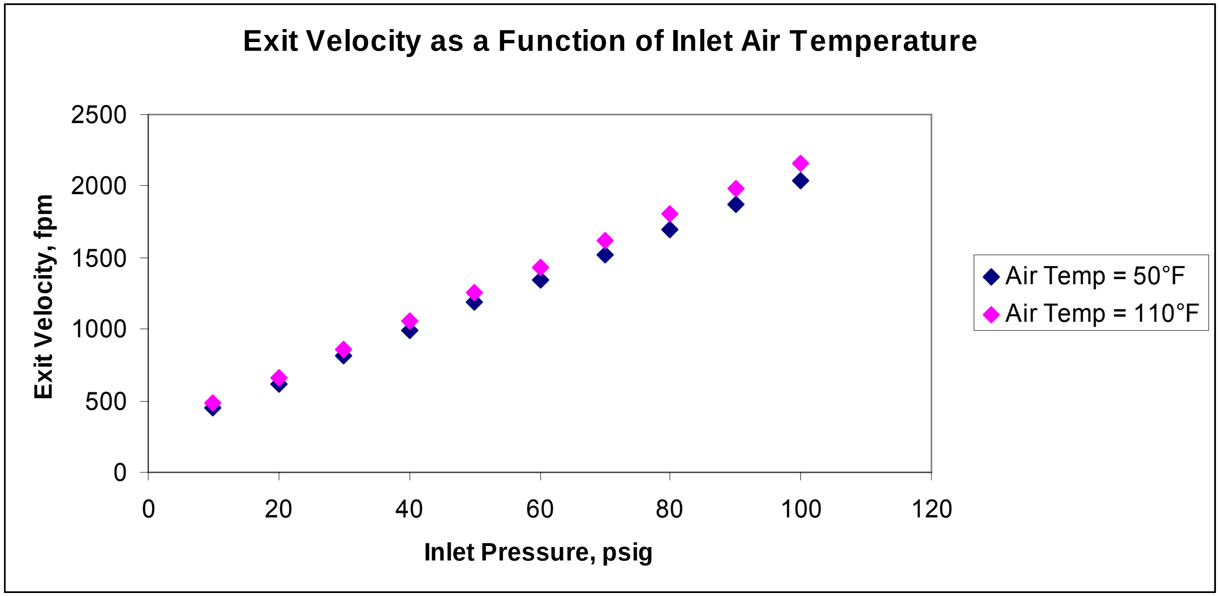


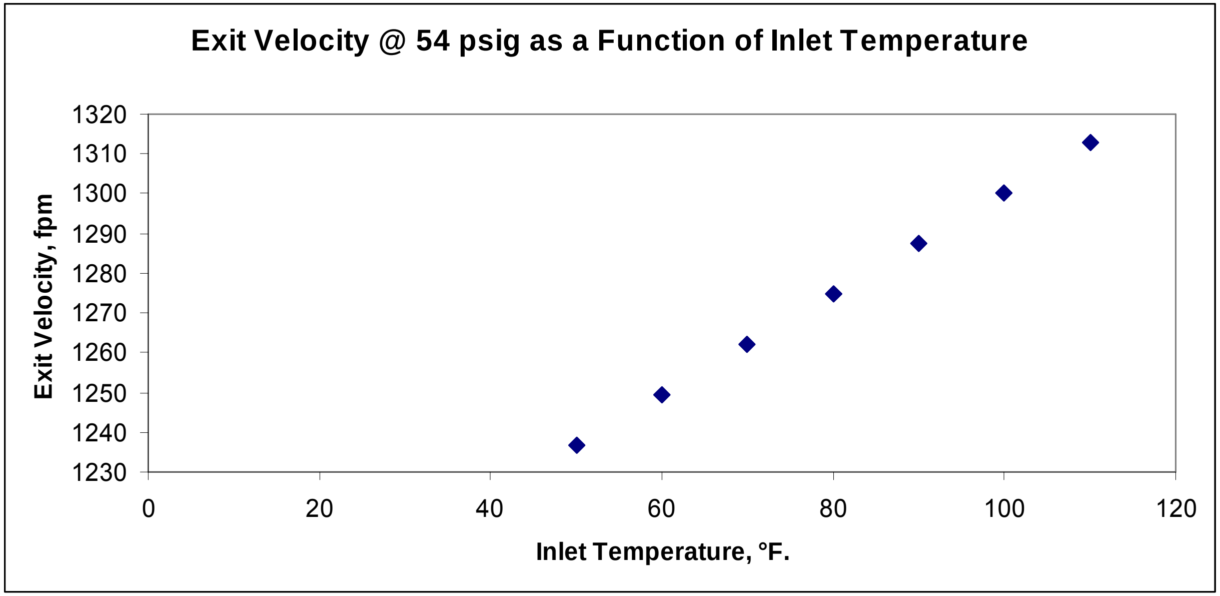
Observations from Boeing – FAATC Comparison, Take 2

- **Overall summary**
  - This time around, burners performed better than initial comparisons in November 2006
  - Proper adjustment of burners critical to operation
  - Boeing lab needs:
    - In line heat exchanger for air
    - New test frame
  - Is the cause of the discrepancy in b.t. times due to burners, materials, or test frame?
    - This comparison again implies the need for a method to determine if burners are operating properly
    - A method is desired that can:
      - Indicate an "absolute" b.t. time of a material, that is independent of the test frame, attachment method, alignment, etc.
      - Show the consistency or inconsistency of a burner or a material
    - Tim M. agreed to develop a sample holder that can hold a material in front of a flame, without stressing the material and causing it to fail
    - More material is required
      - These comparisons were for materials at different ends of the same roll, does this have an effect?
      - More material was ordered, and shuffled in a manner such that each "pile" has an the same distribution of materials from throughout the entire roll

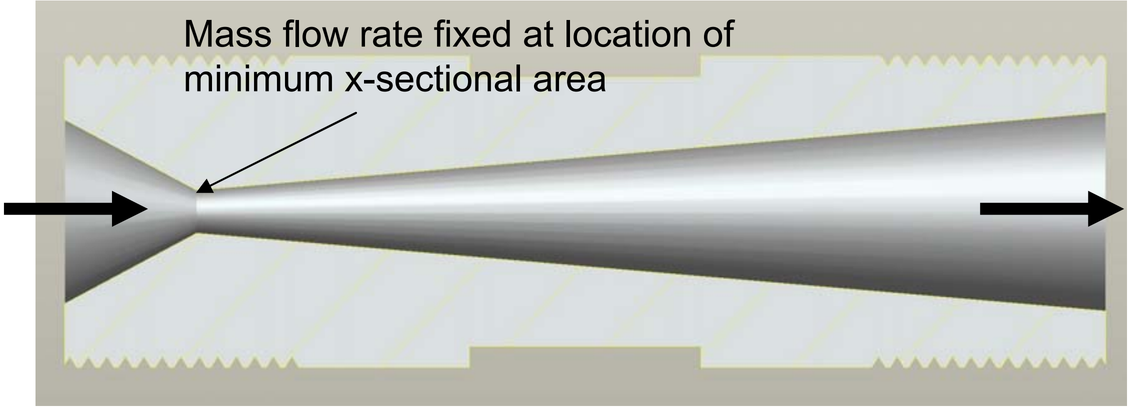
Back to the laboratory…

- Since Boeing did not have an in-line heat exchanger, it was still unknown how much of an effect the air temperature may have on burner performance
- Air temperature was controlled by using heated or chilled water as the heat exchange medium for the in-line heat exchanger
- Burner exit velocity was measured with the Omega HH30 vane type anemometer
- With constant inlet air temperature, the sonic orifice inlet pressure was step increased in intervals of 10 psig, from 0-100
- Results indicate that it is critical for all labs to run at a standard inlet air temperature
- An in-line heat exchanger and an ice bath can be properly set up to give 50°F





Effect of Air Temperature on Exit Velocity



Density is inversely proportional to the inlet air temperature – increasing the inlet air temperature decreases the air density

Mass flow rate = ρ*U*A = mass/time

where:

ρ=inlet air density, mass/length^3

U=inlet air velocity, length/time

A=x-sectional area, length^2

↑T results in ↓ρ

At the throat, the mass flow rate is fixed

ρ*U*A =constant

If the inlet air temperature increases, the density will decrease. In order for the mass flow rate to remain constant at the throat, the product of the velocity and the area must increase accordingly. The x-sectional area can not increase because it is fixed. Therefore, the velocity at the throat must increase, resulting in an overall increase in the velocity from the throat out towards the burner exit

This is demonstrated in the experimental measurements – increases in inlet air temperature resulted in an increase in the measured burner exit velocity.

Initial Picture Frame Testing

15948B-8611R BLKT 41-46 HALVES				
sample	**NG1 DAY 1**	**NG1 DAY 2**	**FAA PARK**	**NG1 @ 1350 fpm exit velocity**
1	247	245	227	227
2	242	231	229	236
3	252	241	231	222
4	240	245	228	231
				220
AVG	**245.3**	**240.5**	**228.8**	**229.0**
STD DEV	**5.4**	**6.6**	**1.7**	**5.9**
% SD	**2.2**	**2.7**	**0.7**	**2.6**

- **The “picture frame” test sample holder was developed**
- **Once a final design was agreed upon, testing commenced with the newly adjusted burner NG1.**
- **Material 8611 was tested first**
  - One blanket could be used for two tests, thanks to the new design of the picture frame holder
  - Results indicated that the Park had a significantly quicker b.t. time
  - Re-evaluation of NexGen burner inlet pressure and exit velocity
- **Material 8579 was tested as well (only 2 blankets left)**
  - FAA Park avg: 160 s
  - NG1 @ 1350 fpm exit velocity avg: 165 s
  - More tests need to be conducted
    - FAA Park exit velocity needs to be re-measured

To be completed in the near-term:

- **A new order of Tex-Tech material has been received by FAATC (purchased by Boeing)**
  - 200 blankets of 8611
  - 100 blankets of 8579
- **Blankets were sorted into 4 piles (see example to right)**
- **Sorting the material in this manner allows simultaneous testing of blankets from the same part of the roll at different labs with different burners**
  - Boeing pile 2 is bracketed by FAA piles, allows for good comparison
- **Pile 1 will be tested on the FAA Park in order to set the standard b.t. times**
  - Orange cells will be tested on test rig
  - Blue cells will be tested on picture frame
- **Boeing will test pile 2, in the same manner, on their NG6 burner**
- **FAATC will test pile 3 with NG1 or NG4 burner**

Blanket Numbers of Each Material in Each Pile				
19394 - 8611R				
1	***2***	***3***	***4***	
1,2	3,4	5,6	7,8	
9,10	11,12	13,14	15,16	
17,18	19,20	21,22	23,24	
25,26	27,28	29,30	31,32	
33,38	40,41	42,43	44,45	
46,48	49,50	53,54	55,56	
57,58	59,60	61,62	63,64	
65,66	67,68	69,70	71	
16	16	16	15	TOTALS

Pile #:	Location / Burner:
1	FAA Park
2	Boeing NG6
3	FAA NG1
4	Currently Unassigned

To be completed…eventually

- Work with Hago Nozzle corp. to develop a nozzle with tighter specifications that can be used for our application
- Develop a nozzle spray pattern measurement device that can quantify the circumferential symmetry of the nozzle spray
- Continue to set up and test the remaining NG burners, work with participating labs to get them up an running
- Use CAD models of H215 stators to develop a stator for our application
- Phase III “fully independent” burner

Questions, Comments, Suggestions, Input?