Heat Flux Sensor Testing

TFAWS 2001 Conference
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Objectives

Develop secondary calibration capabilities for MSFC's Hot Gas Facility (HGF), a Mach 4 Aerothermal Wind Tunnel.

- Evaluate ASTM slug/ thinskin calorimeters against current HGF heat flux sensors
- Provide verification of baselined AEDC/ Medtherm gage calibrations
- Address future calibration issues involving NIST certified radiant gages

Why Are NIST Calibration Standards Valuable?

- Shuttle Safety
  - Thermal Protection Systems are developed, characterized, and qualified for flight using NIST radiant calibration standards at HGF
- Shuttle Performance
  - 26% of the Space Shuttle's weight is TPS
  - On the External Tank alone, a 15% reduction in TPS increases Shuttle payload capacity by 600 pounds, representing $6,000,000 in potential payload cost savings per Shuttle flight

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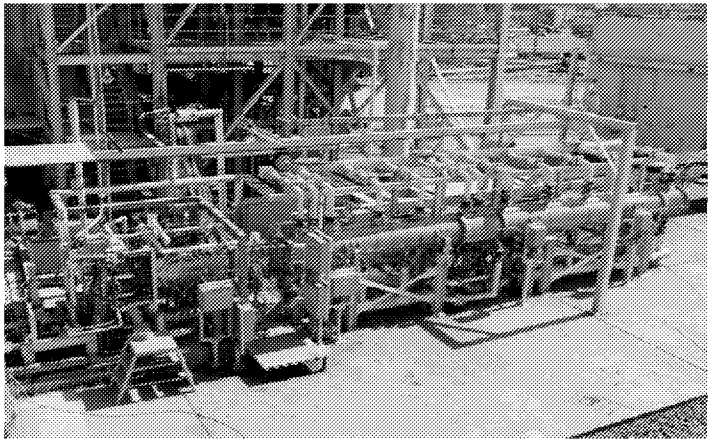
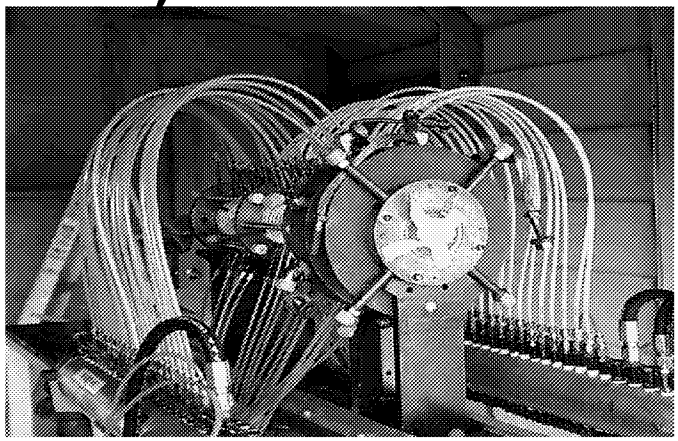
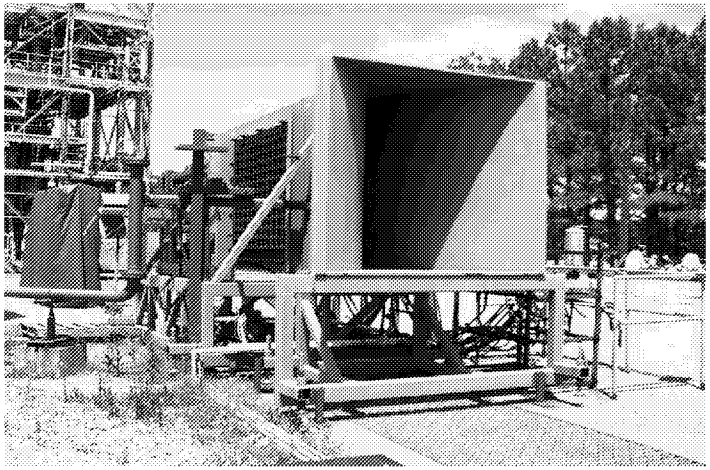
MATERIALS ENVIRONMENT TEST COMPLEX (METCO)



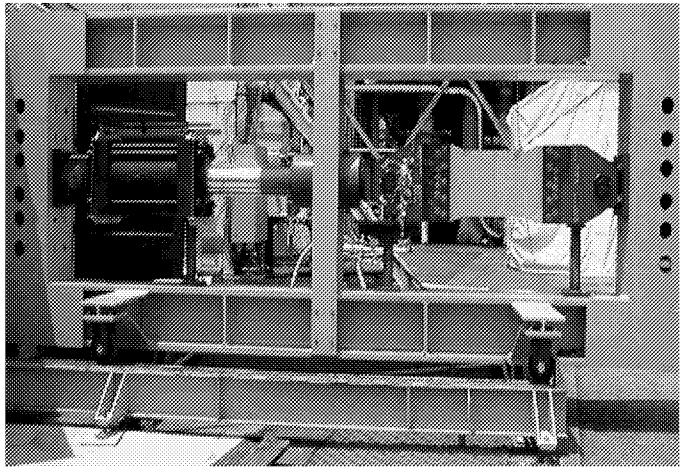
Improved Hot Gas Facility



Hyperthermal Tester



Thermal Acoustics Facility



Large Scale Tensile Tester

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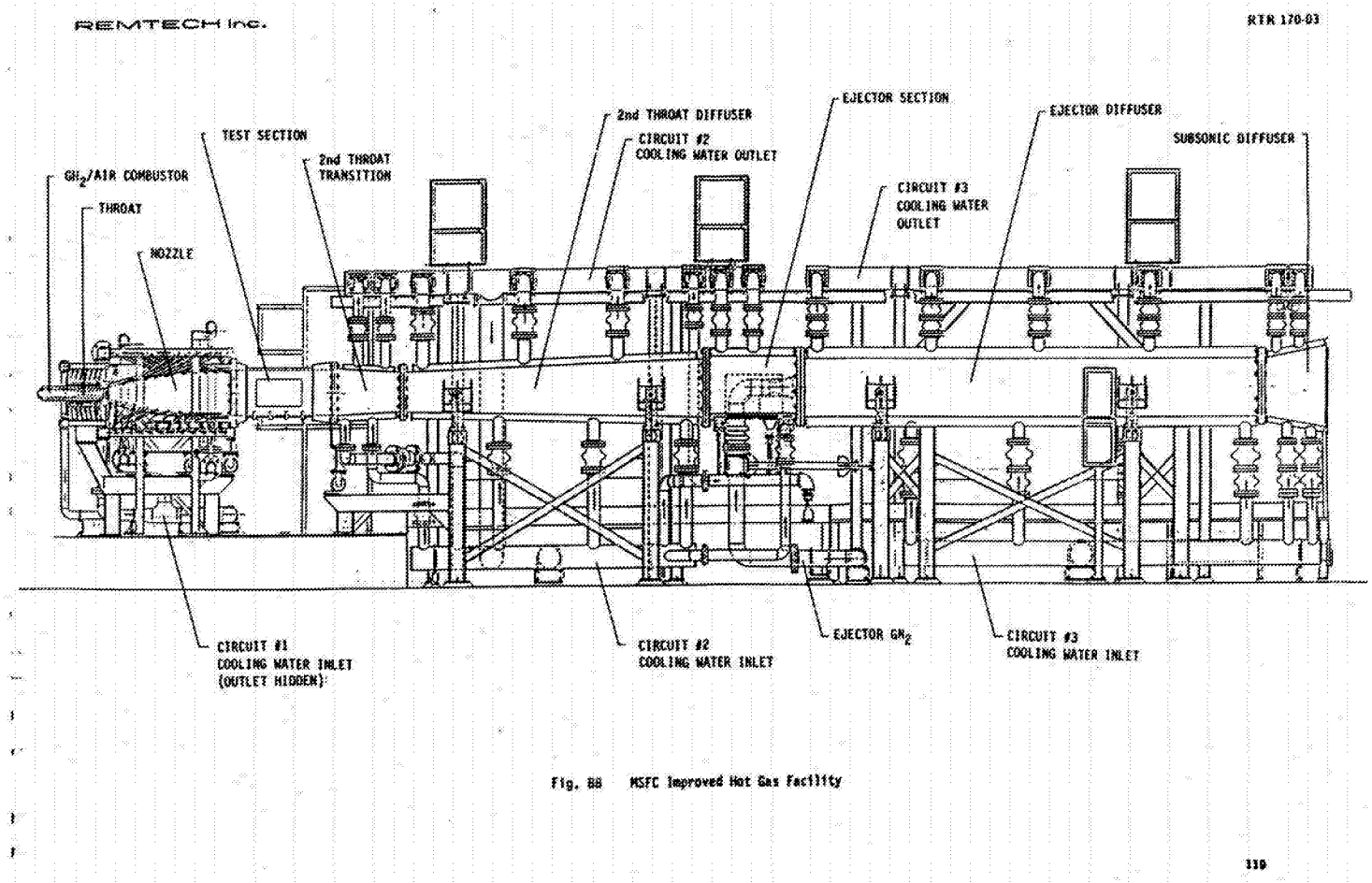
HGF Layout



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HGF Facility Description

- The Marshall Space Flight Center's Improved Hot Gas Facility (IHGF) is an aerothermodynamic testing facility ideal for Thermal Protection System materials characterization and qualification.
  - A combustion driven, Mach 4 wind tunnel, with a 16 x 16 inch test section.
  - Burns a lean mixture of gaseous hydrogen (GH_2) and missile grade air producing total temperatures of 1440 - 2400 ^oF with total pressures of 100 - 220 psia.
  - A 300 kW radiant lamp system is available for plume environment simulation.
  - Infrared (IR) thermal imaging/ video capabilities used for collecting real-time surface temperature measurements
- The IHGF is reasonably small, inexpensive in operation, very flexible and efficient, and is operated with a small, highly experienced crew.
- Run times up to 300 seconds and up to 10 tests per day.
  - Variable wedge angle (up to 20 degrees) model insertion system for panels up to 12" x 19".
  - Can accommodate protuberance testing up to 7" x 12".
- The IHGF provides the opportunities for inexpensive screening, preliminary study, and technique development work.
  - It continues to provide MSFC and Industry with quick response capability during conceptual design phases as well as during flight vehicle problem resolution.
  - It is used for development and flight qualification of Space Shuttle External Tank and SRB TPS

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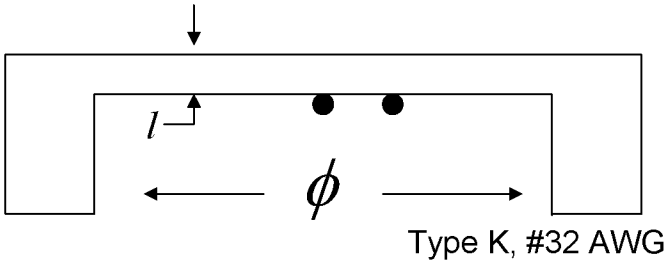
Calorimeter Illustration

METCO Thin Skin:

Dia = 1.5”

L =0.065 & 0.095”

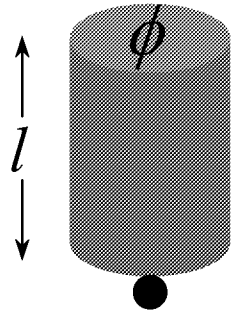


Section View of Thin Skin

Ames Slug:

Dia = 0.302”

L =0.35”



Slug Calorimeter

304 Stainless properties:

Density: 0.29 lbm/in3

Specific Heat: 0.12 Btu/lbm/F

Copper properties:

Density: 0.323 lbm/in3

Specific Heat: 0.092 Btu/ lbm/F

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Schmidt-Boelter Gage Design

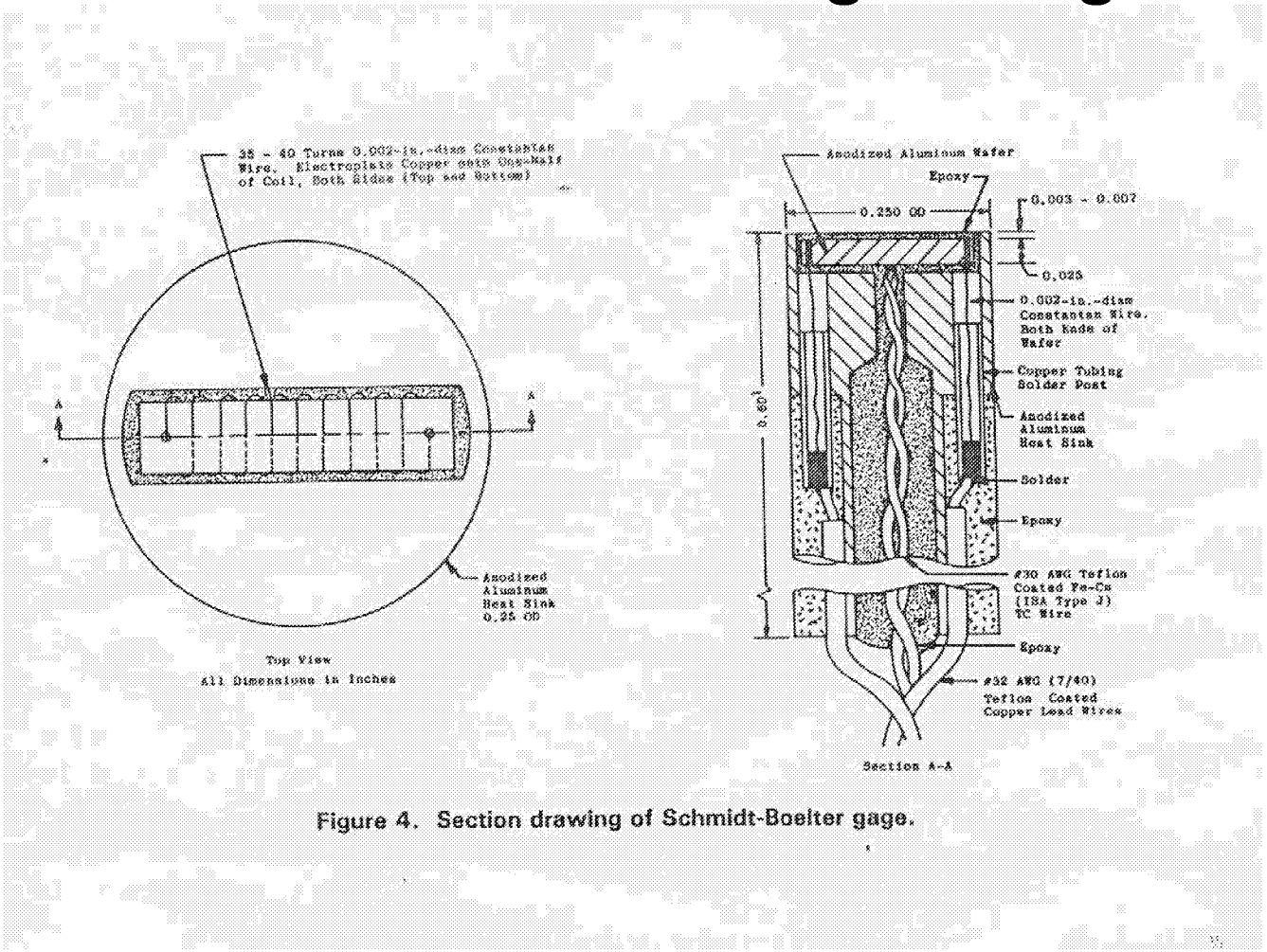
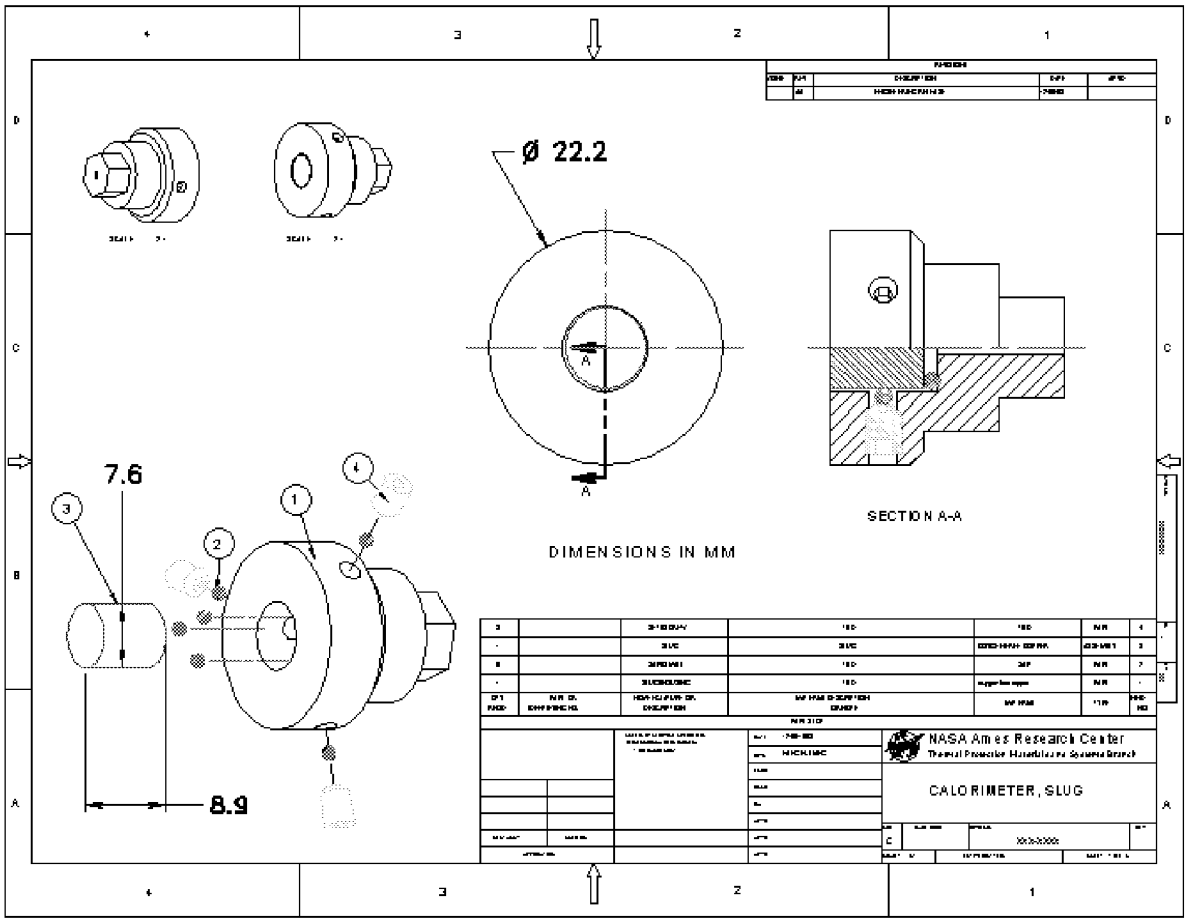


Figure 4. Section drawing of Schmidt-Boelter gage.

Slug Assembly Drawing



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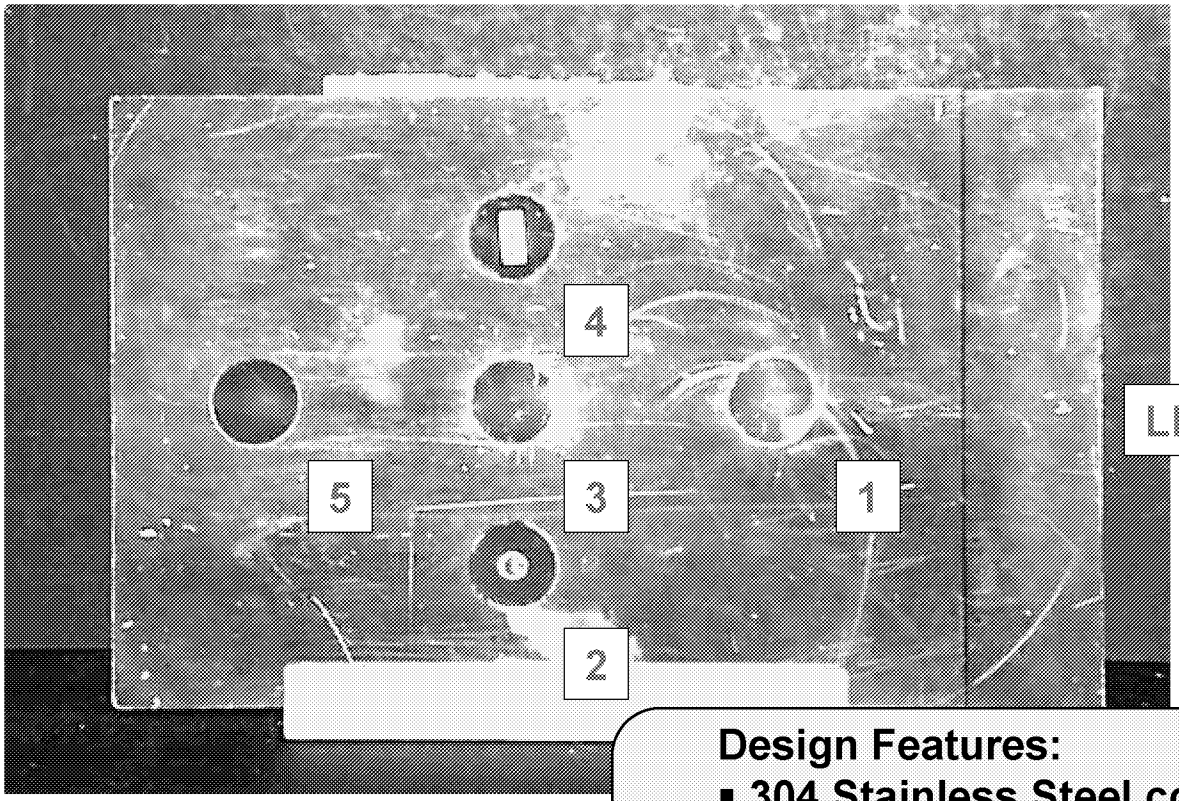
Calibration Plate



Design Features:

- **304 Stainless Steel construction**
- **Multiple mounting ports for simultaneous calorimeter/gage calibrations**

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Calorimetry Study Test Matrix And Chronology

Position > Test	1	2	3	4	5	Tunnel Condition
1 2 3	MT	0.095	3 HF	0.065	SLUG	125 psia / 1600°F / 0°
4 5 6	MT	0.095	3 HF	0.065	SLUG	125 psia / 1600°F / 15°
7 8	MT	0.065	SLUG	0.095	3 HF	125 psia / 1600°F / 0°
9 10	MT	0.065	SLUG	0.095	3 HF	125 psia / 1600°F / 15°
11 12	MT	3 HF	0.065	SLUG	0.095	125 psia / 1600°F / 0°
13 14	MT	3 HF	0.065	SLUG	0.095	125 psia / 1600°F / 15°
15 16	MT	SLUG	0.095	3 HF	0.065	125 psia / 1600°F / 0°
17 18	MT	SLUG	0.095	3 HF	0.065	125 psia / 1600°F / 15°

Calorimeter Legend
MT = 1/2" Medtherm S/N 107641
(Gage "MT" is always in Position 1)
0.065 = Thin Thin Skin Gage
0.095 = Thick Thin Skin Gage
SLUG = Ames Furnished Slug S/N TBD
3 HF #1 = 1/4" Medtherm S/N 667121
3 HF #2 = 3/16" Medtherm S/N 79455
3 HF #3 = AEDC S/N 2679

Test	First Runs HGF No.	First Runs Date	Repeat Runs HGF No.	Repeat Runs Date		Tunnel Condition
1	337	14-Jun	552	30-Jul		125 psia / 1600°F / 0°
2	338	14-Jun	550	30-Jul		125 psia / 1600°F / 0°
3	341	14-Jun	549	30-Jul		125 psia / 1600°F / 0°
4	342	14-Jun	546	30-Jul		125 psia / 1600°F / 15°
5	343	14-Jun	544	30-Jul		125 psia / 1600°F / 15°
6	344	14-Jun	543	30-Jul		125 psia / 1600°F / 15°
7	345	14-Jun	542	26-Jul		125 psia / 1600°F / 0°
8	346	14-Jun	541	26-Jul		125 psia / 1600°F / 0°
9	348	14-Jun	540	26-Jul		125 psia / 1600°F / 15°
10	349	14-Jun	539	26-Jul		125 psia / 1600°F / 15°
11	350	15-Jun	449	12-Jul		125 psia / 1600°F / 0°
12	351	15-Jun	450	12-Jul		125 psia / 1600°F / 0°
13	352	15-Jun	451	12-Jul		125 psia / 1600°F / 15°
14	353	15-Jun	453	12-Jul		125 psia / 1600°F / 15°
15	354	15-Jun	388	25-Jun		125 psia / 1600°F / 0°
16	355	15-Jun	391	25-Jun		125 psia / 1600°F / 0°
17	356	15-Jun	389	25-Jun		125 psia / 1600°F / 15°
18	357	15-Jun	390	25-Jun		125 psia / 1600°F / 15°

Miscellaneous Notes
Gage "MT" is always in Position 1
Tests 1 2 3 and 4 5 6 are intended to check for data repeatability.

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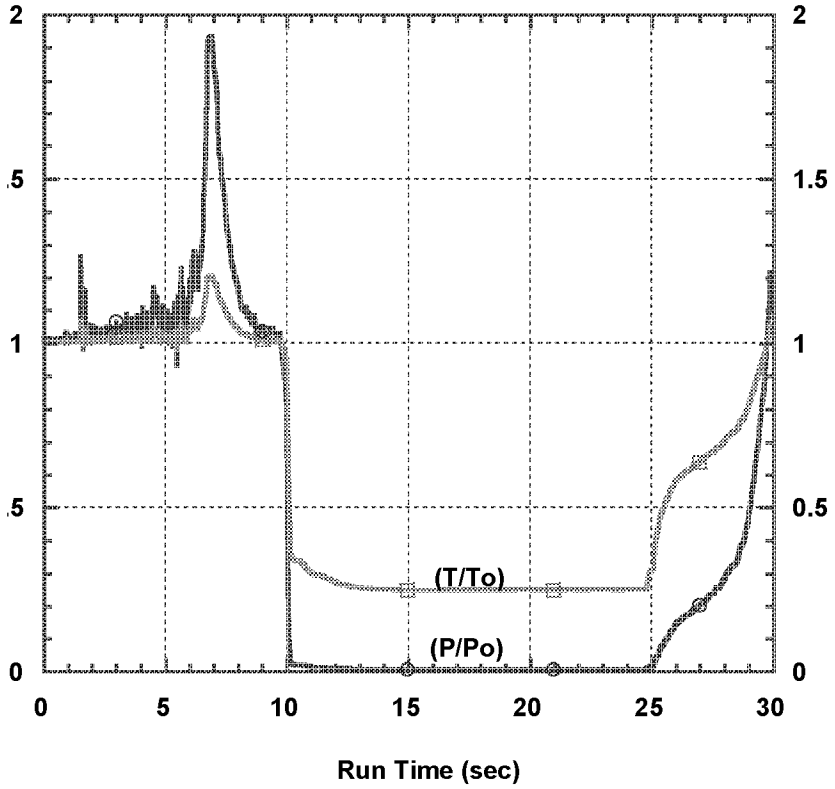
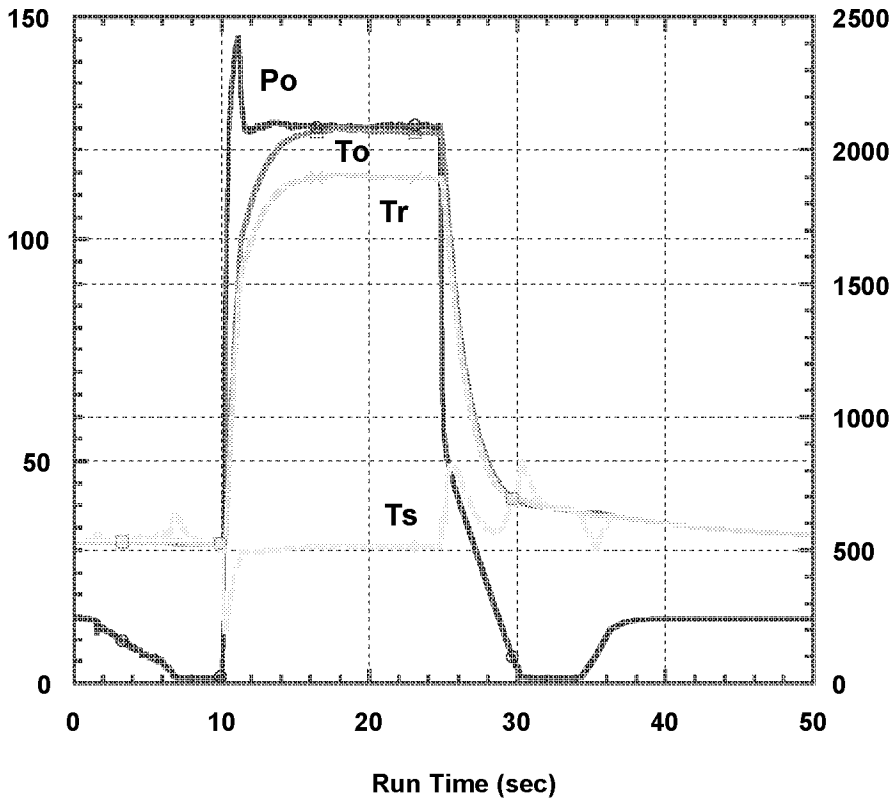
Test Conditions



Tunnel Performance



Tunnel Environments

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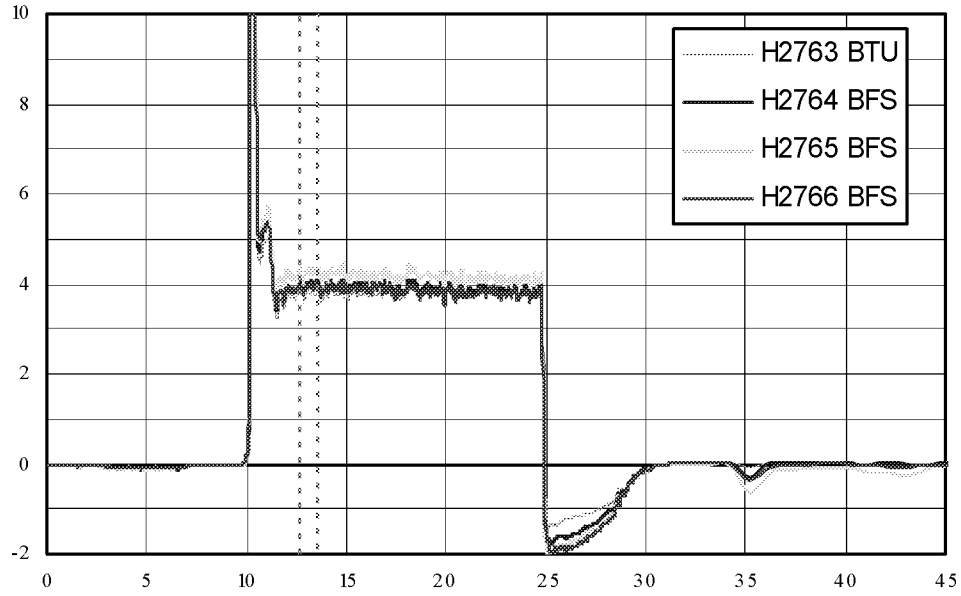
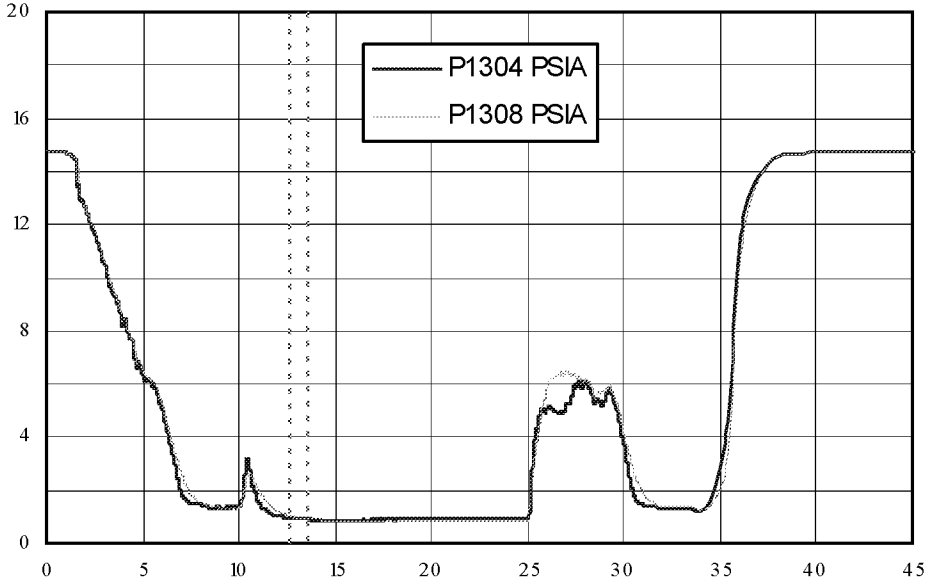
Data Reduction Timeline

SB Gage Output (BFS)



Test Section Static Pressures (psia)



Calorimeter data evaluated when test section reaches steady flow. (~13 sec). Corresponding calorimeter/ gage comparisons made over one second time interval.

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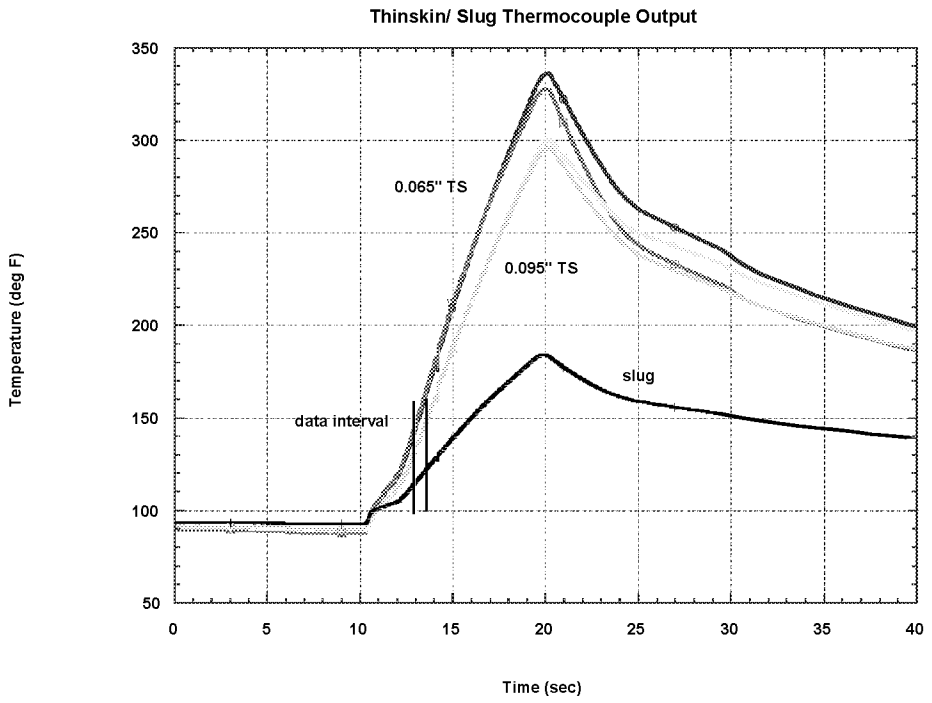
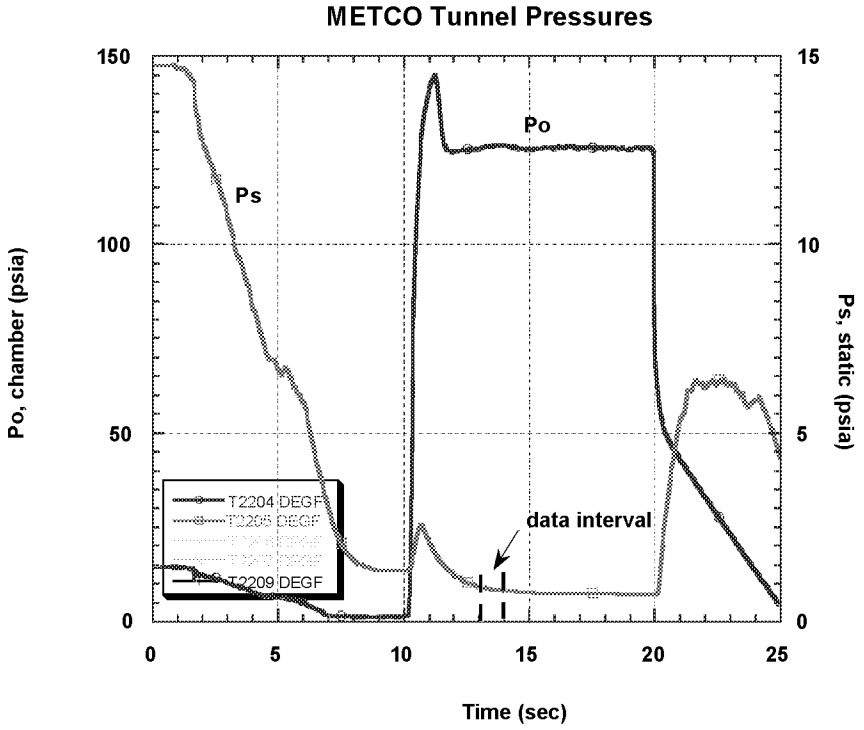
Calorimeter Data



Calorimeter Temperatures



Static Pressures

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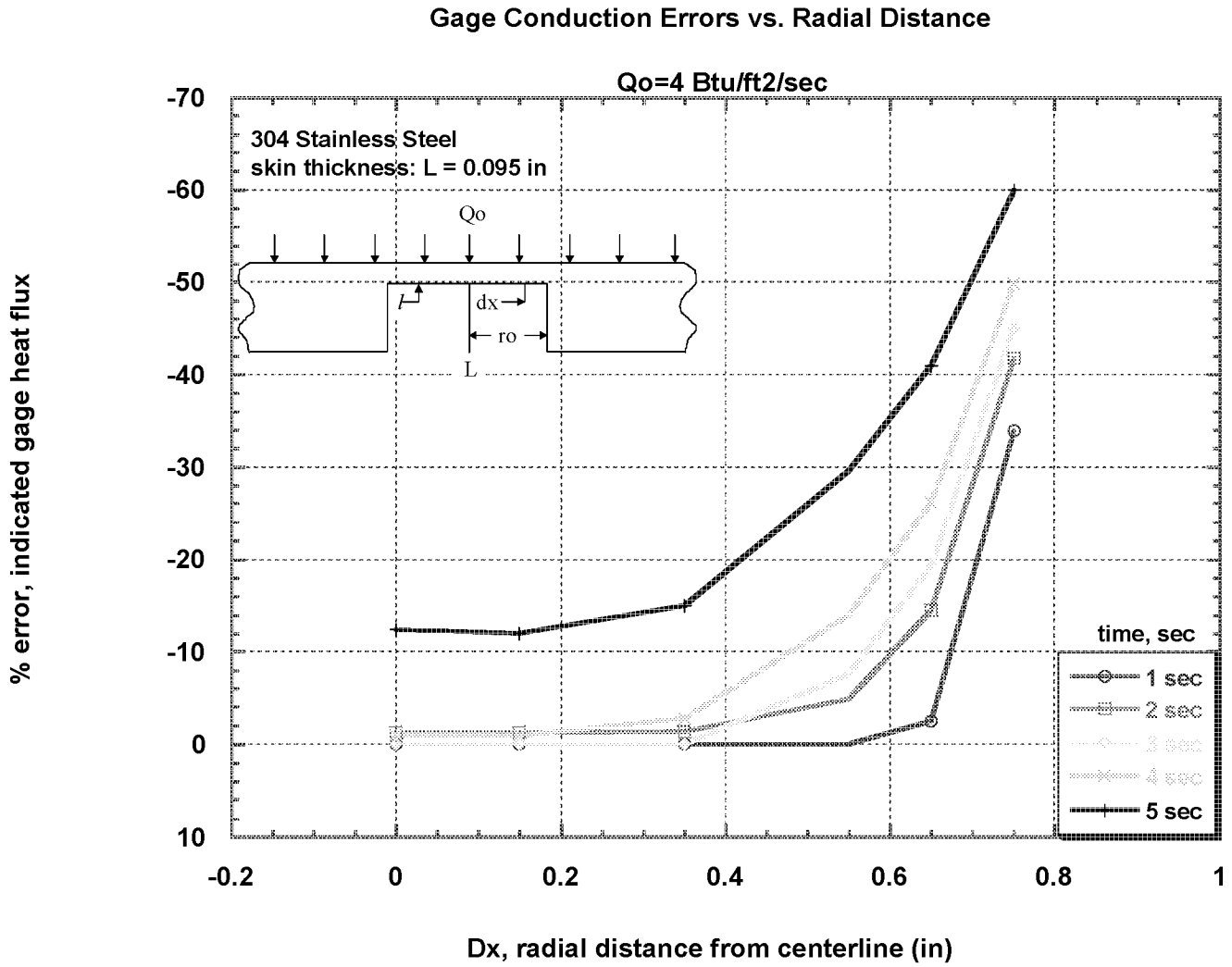
Thin Skin Radial Conduction Errors



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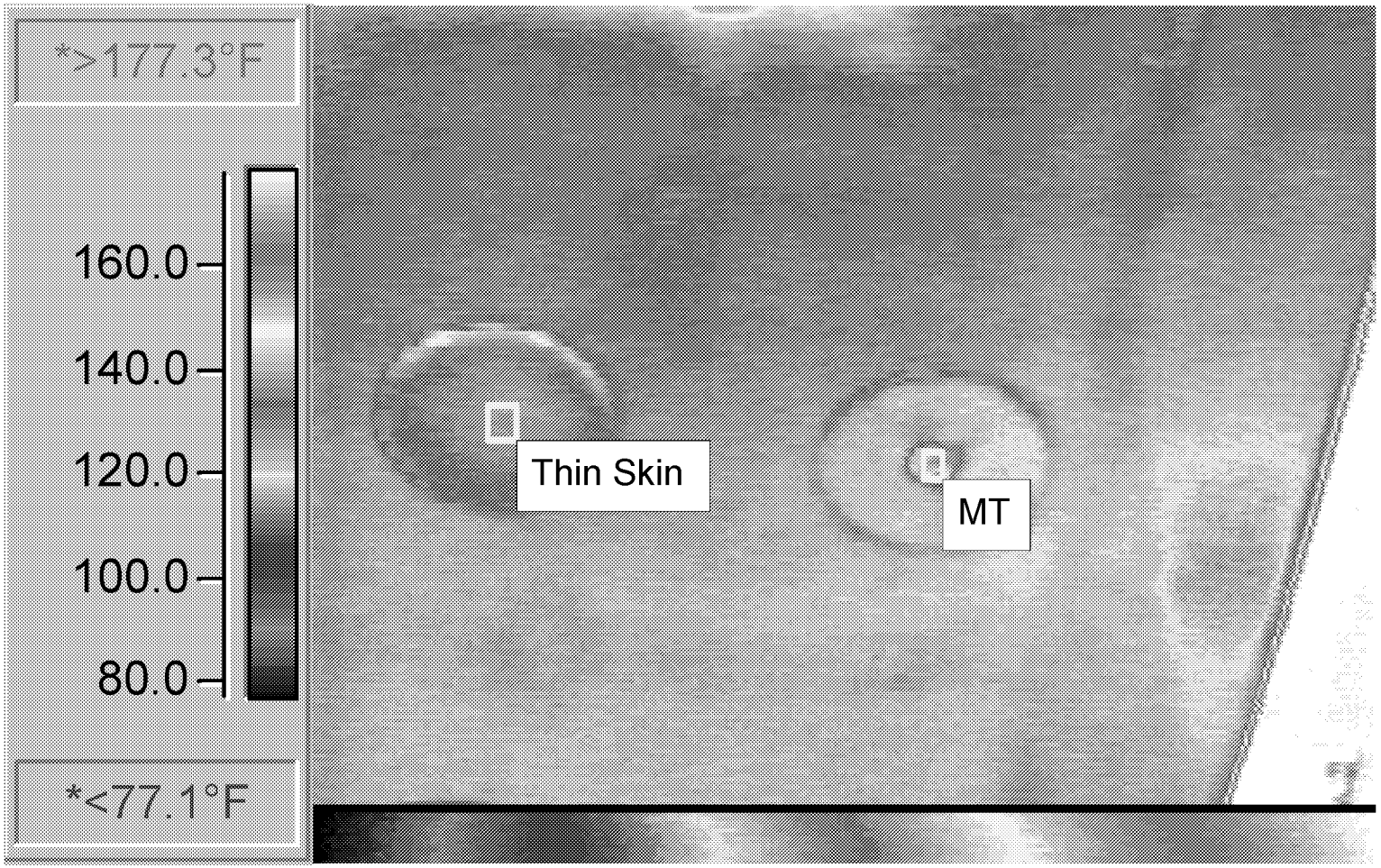
Thin Skin Temperatures



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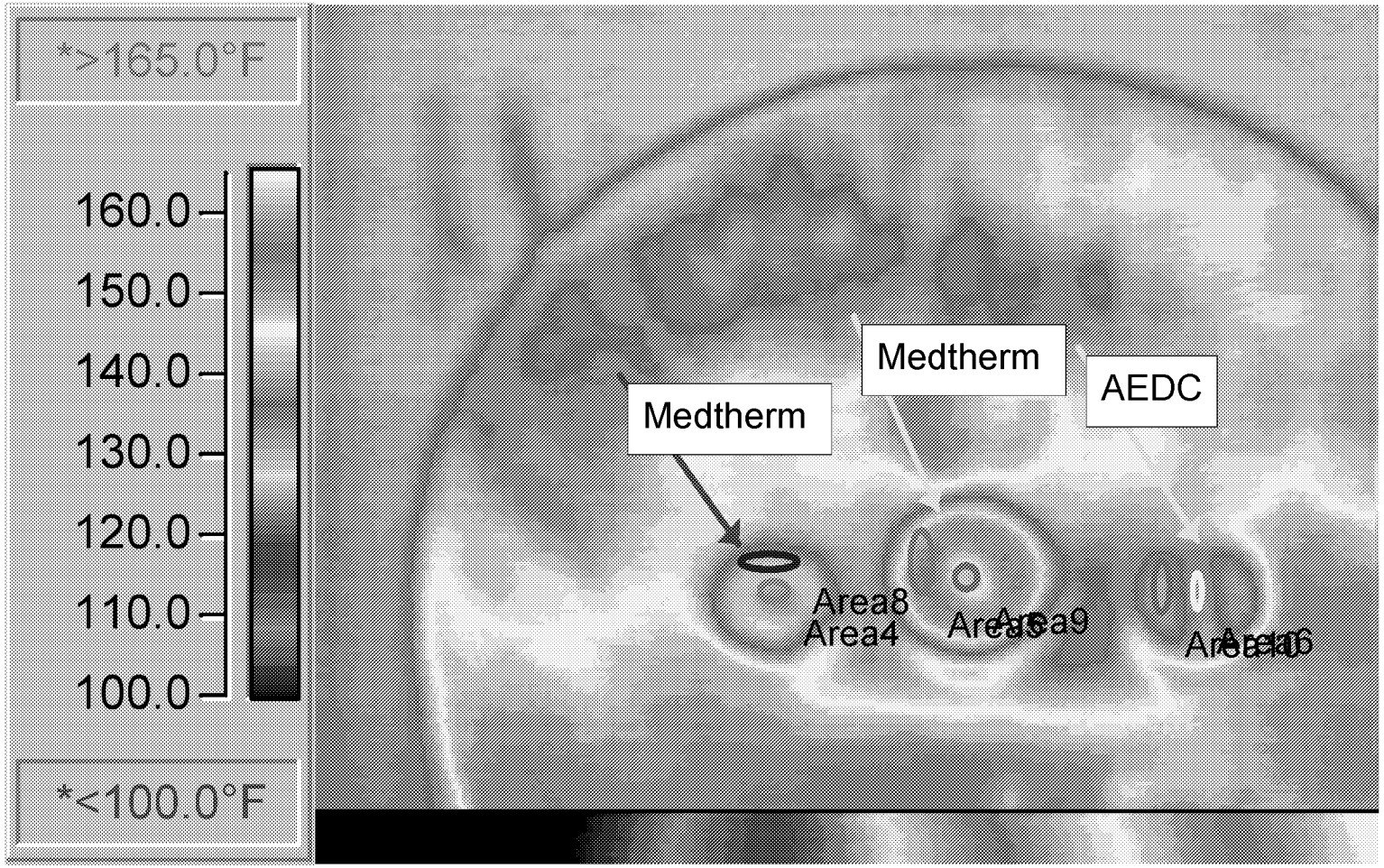
S-B Gage Temperatures



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Calorimeter Heat Transfer

- Hot Wall Rates:

$$\dot{q} = \rho C_p l \frac{dT_c}{dt}$$

- Compressible Flow:

$$\frac{T}{T_o} = \left(\frac{P}{P_o}\right)^{\left(\frac{\kappa-1}{\kappa}\right)} \qquad \text{(temperature ratio)}$$

$$T_r = \Pr^{1/3}\left(T_o - T\right) + T \qquad \text{(recovery temperature)}$$

- Cold Wall Rates:

$$\dot{q}_{cw} = \dot{q}\frac{\left(T_r - 460.\right)}{\left(T_r - T_w\right)}$$

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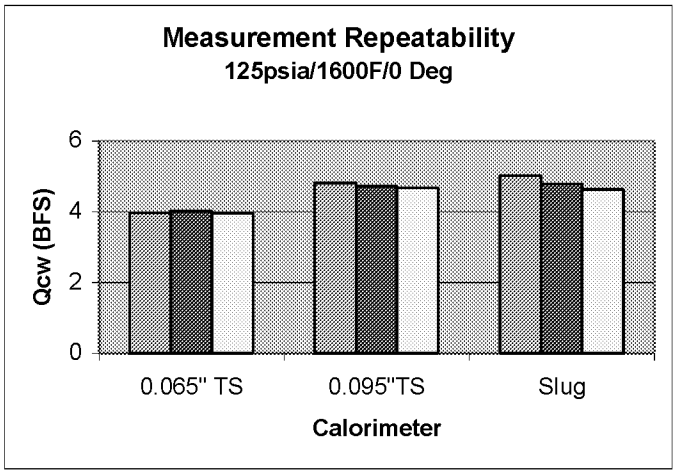
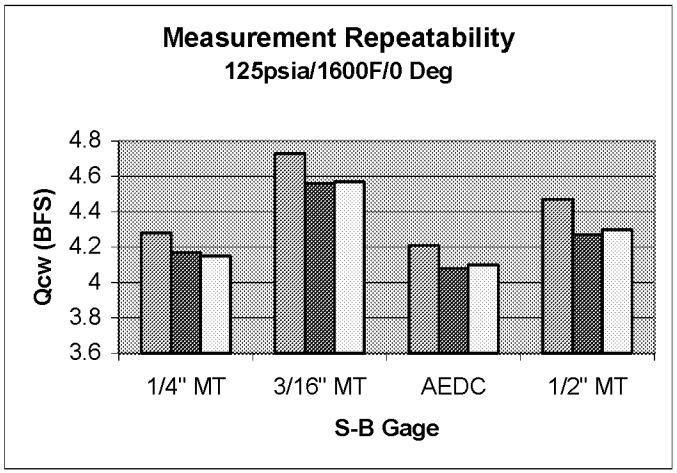
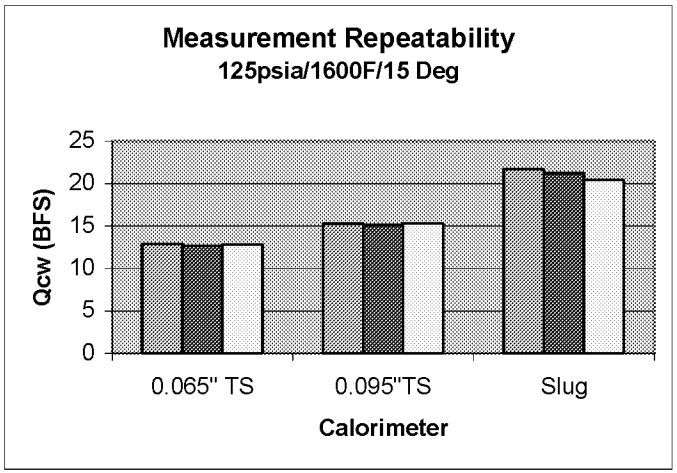
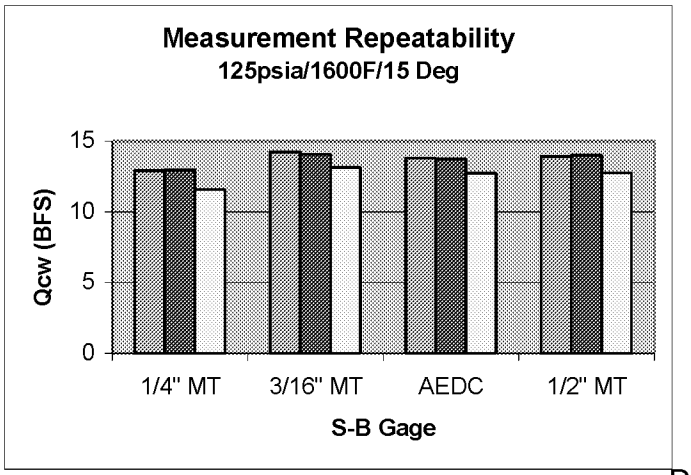
Measurement Repeatability









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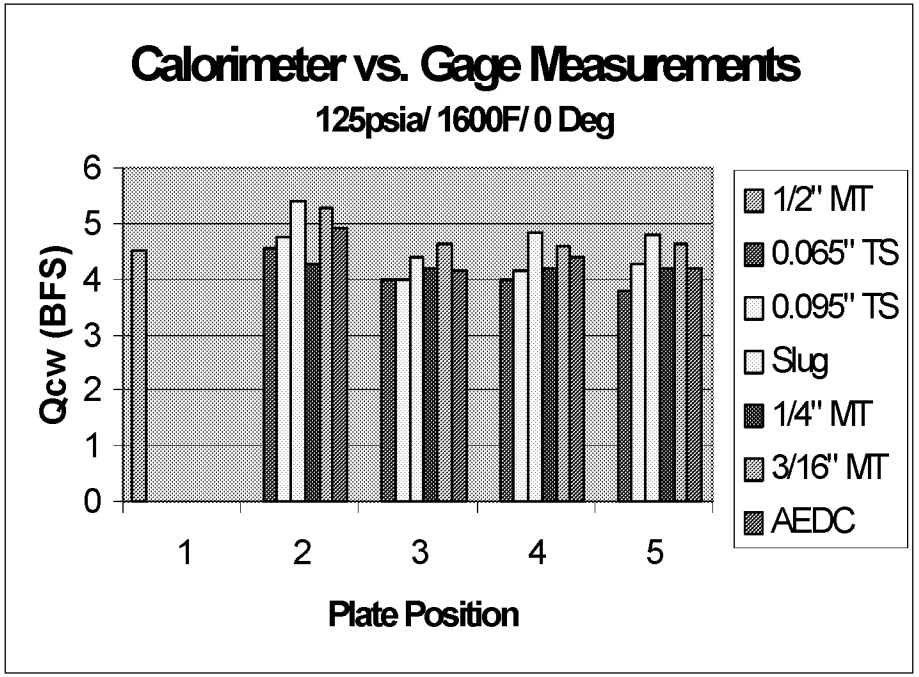
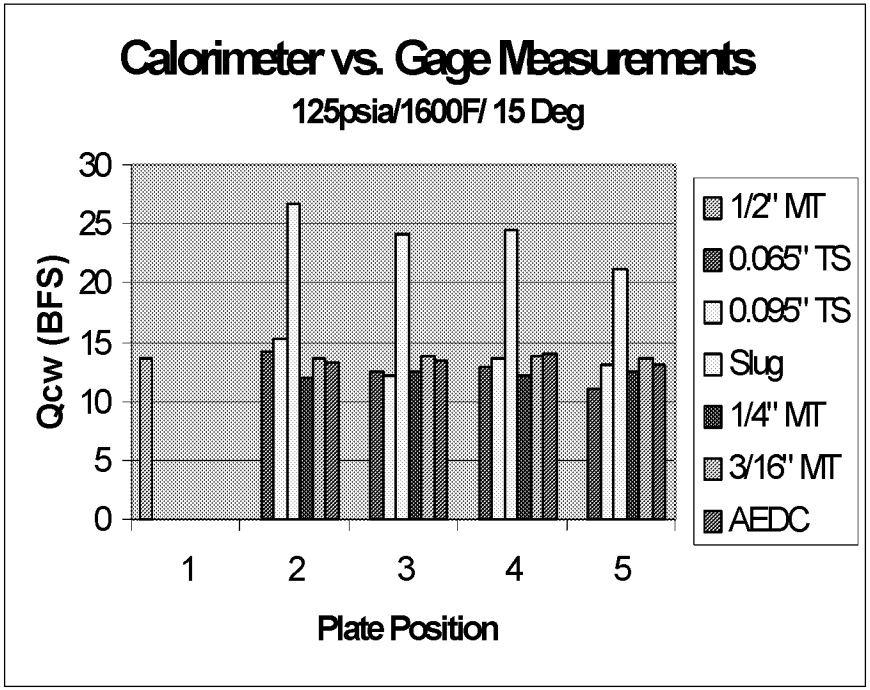
Measurement Comparisons





Test Condition: 125psia/ 1600F/ 0 & 15 Deg

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Future Work Planned At MSFC HGF

- Continue to develop calorimeter database
- Study combined effects of supersonic convection and radiant heating on material response
- Calibrate In-flight measurements of heat fluxes with dissimilar material induced thermal mismatches between gage and surrounding TPS material
- Study radiant heat measurement in the presence of convective cooling

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