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KSC Launch Pad Flame Trench Environment Assessment

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December 2010

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ABBREVIATIONS AND ACRONYMS

ASM	American Society for Metals
CxP GO	Constellation Program Ground Operations
COTS	Commercial off the Shelf
ETDP	Exploration Technology Development Program
FF	Fondu Fyre
FOD	Foreign Objects and Debris
GSE	ground support equipment
Hz	hertz
KSC	John F. Kennedy Space Center
LC-39	Launch Complex 39
MFD	Main Flame Deflector
NASA	National Aeronautics and Space Administration
s	second
SFD	Side Flame Deflector
SMM	Structures, Mechanisms, and Materials
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine

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ABSTRACT

This report summarizes conditions in the Launch Complex 39 (LC-39) flame trenches during a Space Shuttle Launch, as they have been measured to date. Instrumentation of the flame trench has been carried out by NASA and United Space Alliance for four Shuttle launches. Measurements in the flame trench are planned to continue for the duration of the Shuttle Program. The assessment of the launch environment is intended to provide guidance in selecting appropriate test methods for refractory materials used in the flame trench and to provide data used to improve models of the launch environment in the flame trench.

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KSC LAUNCH PAD FLAME TRENCH ENVIRONMENT ASSESSMENT

1 INTRODUCTION

1.1 Background

Corrosion is the environmentally-induced degradation of materials. The natural marine environment at the Kennedy Space Center (KSC) has been documented by Coburn in the American Society for Metals (ASM) as having the highest corrosion rate of any site in the continental United States. As a result, launch structures and ground support equipment (GSE) at KSC degrade faster than similar assets at other locations. With the introduction of the Space Shuttle in 1981, the already highly corrosive natural conditions at the launch pads were rendered even more severe by the acidic exhaust from the solid rocket boosters. As a consequence, corrosion-related costs are significant for all launch structures. These costs were estimated in January 2009 to be approximately $336M over the previous 20 years of the Space Shuttle Program. The estimate included the costs associated with inspection and maintenance of the launch pads, medium-scale and large-scale blasting and repainting activities, the repair and replacement of failed refractory materials, and the replacement of badly corroded structural metal elements. Technologies for the prevention, detection, and mitigation of materials degradation in launch facilities and ground support equipment were identified by the Constellation Program Ground Operations (CxP GO) as a critical need for the safety, efficiency, affordability, and sustainability of future launch operations at KSC. Subsequently, CxP GO established an agreement with the Exploration Technology Development Program (ETDP) Structures, Mechanisms, and Materials (SMM) project to identify alternate refractory material for the protection of the launch pad flame deflectors at KSC. This report, prepared as one of the deliverables for the project, provides testing requirements for refractory materials to be used in launch pad applications as well as the available information from all previous testing of refractory materials for launch pad flame trench protection that was gathered in the process of identifying the testing requirements.

1.2 Flame Deflector System

The launch complexes at KSC are critical support facilities required for the safe and successful launch of vehicles into space. Most of these facilities are over 30 years old and are experiencing deterioration. With constant deterioration from launch heat/blast effects and environmental exposure, the refractory materials currently used in the NASA launch pad flame deflectors have become very susceptible to failure, resulting in large pieces of refractory materials breaking away from the steel base structure and being projected at high speeds during launches. Repair of these failures is a costly and time-consuming process. Improved materials and systems for use in launch pad flame deflectors will improve supportability in KSC launch facilities by reducing operational life cycles.

The flame deflector systems at LC-39A and LC-39B are critical to protect NASA's assets, which include the Space Shuttle and GSE, and personnel. As the name implies, the system diverts rocket exhaust away from critical structures through its geometric design. Further benefits are provided by a water deluge system that dampens acoustic vibrations and high temperatures associated with launches.

Flame deflectors are typically covered with a heat resistant material that protects the flame deflector from erosion, ablation, and extreme temperatures that are produced by the rocket propulsion systems. If this refractory layer is compromised, deterioration to the flame deflector and other load-bearing structures may result. Once compromised, the refractory material and flame deflector substructures can turn into unwanted projectiles known as foreign-object-debris (FOD) that can cause consequent damage.

LC-39A and LC-39B were originally designed to support the Apollo program. With the advent of the shuttle program, the Saturn era flame deflectors were replaced. Figure 1 shows a schematic cross section of the flame deflector at launch complex 39A. The flame deflector system consists of a flame trench, a main flame deflector (MFD), and a pair of side flame deflectors (SFDs). The main flame deflector is designed in an in inverted, V-shaped configuration, is constructed from structural steel, and is covered with refractory concrete material. One side of the inverted "V" deflects the flames and exhaust from the Space Shuttle Main Engine (SSME) and the opposite side deflects the flames and exhaust from the solid rocket boosters (SRBs). Additional protection is provided by the two movable side deflectors at the top of the trench (not shown in the figure). The SFD direct the SRB exhaust and is needed because the SRBs are very close to the side walls of the flame trench. The orbiter side of the flame deflectors is 38 feet high, 72 feet long, and 57 feet wide. The SRB side of the flame deflector is 42 feet high, 42 feet long and 57 feet wide. The total mass of the asset is over 1 million pounds.

The flames from the SSMEs and the SRBs are channeled down opposite sides of the flame deflector. The deflector is constructed of steel on a structural steel I-beam framework. To protect the structure from serious degradation during launch, the faces of the flame deflector are lined with refractory concrete. This product is known as Fondu Fyre WA-1G (supplied by the Pryor Giggey Co.). The thickness of the refractory concrete is 6 inches on the SRB side, 4.5 inches on the SSME side, and 4 inches on the side deflectors.

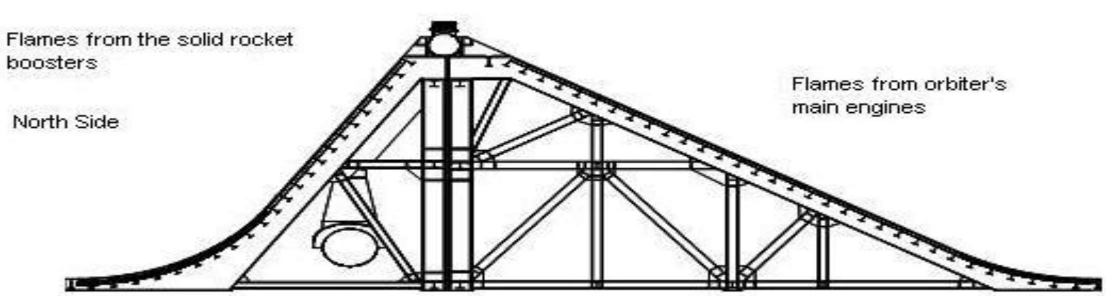


Figure 1. Cross Section of Flame Deflector at Launch Complex 39A

Figure 2 shows the configuration of the Shuttle viewed upward from the flame trench. The openings for the SSME exhaust and the flame deflector used to divert the rocket plume from the SRBs are labeled. The other side of the flame deflector, which is not visible in the picture, diverts the exhaust from the main engines. The SRBs burn at a much higher temperature than the SSME. Consequently, the higher temperatures of the SRB exhaust lead to more severe exposure conditions and result in damage that is more significant to the deflector.

Figure 3 shows a view of the flame deflector underneath the SRBs. The image shows the structural steel at the bottom of the deflector, which is protected with Fondu Fyre. Figure 4 shows the SSME flame trench and deflector.

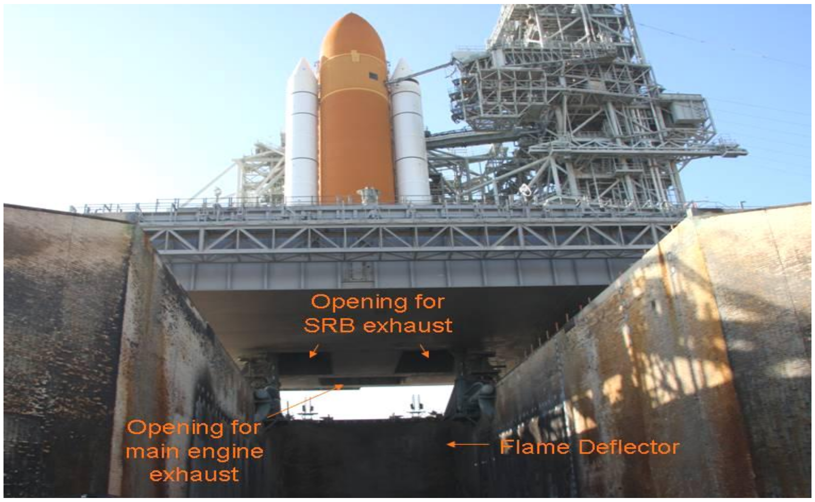


Figure 2. Openings for Flames From the Main Engine and SRBs

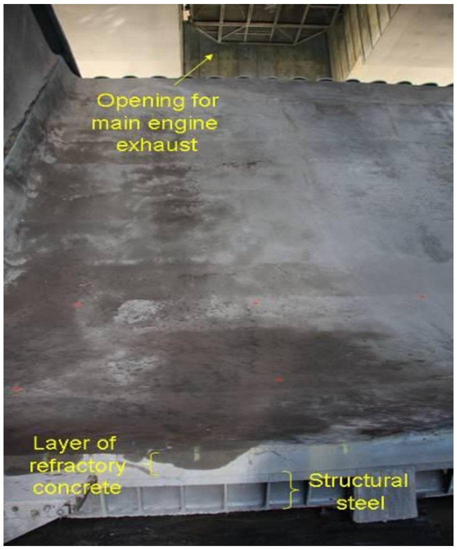


Figure 3. Magnified View of LC-39A Flame Deflector

Figure 4. SSME Flame Trench and Deflector

Safely meeting the flame deflector requirements of diverting the flame, exhaust, and small items that are dislodged during launch is dependent on the integrity and performance of the materials used to construct the flame deflectors. The use of refractory products that have superior material characteristics (under launch conditions) is necessary to protect the flame deflector, Space Shuttle, GSE, and launch personnel.

1.3 Launch Environment

The launch environment is different in the SRB and SSME flame trenches. The SRB side has historically seen more damage than the SSME side because of the harsher conditions found there. This section gives a general overview of the launch environment.

The Space Shuttle has two SRBs, which exhaust in the north flame trench, and three SSMEs, which exhaust towards the south. The SRBs have considerably more thrust, 3,300,000 pounds each, compared to the thrust of the SSMEs, 375,000 pounds each. The SRBs also burn hotter than the SSMEs and produce aluminum oxide particles that can act as abrasives, or, if they are near or above melting point, they may react with the refractory material. The SRBs produce hydrochloric acid that can attack the refractory concrete. The pH is less than 0.5. Samples collected at the pad perimeter measured a pH of 0.5 (STS-2) and 0.36 (STS-4). The pH paper on aircraft foil impactor confirmed a pH of approximately 0.5 (STS-3). SRBs impinge in two locations on the top of the flame deflector, underneath the MLP exhaust holes as seen in Figure 5. The areas that receive direct impingement appear lighter, due to the presence of aluminum oxide particles in these locations. There are two side flame deflectors above the flame trench, shown in Figure 6. The SRBs impinge on the side deflectors before entering the main flame deflector. Examination of the impingement area shows that the material experiences very different conditions than outside the impingement area. These differing conditions may even cause different failure mechanisms for the refractory material. For example, the bottom lip of the deflector appears to undergo more erosion than those areas farther up the deflector towards its apex.

The launch sequence itself affects the environment. Prior to launch, water is continuously flowed onto the refractory material. This procedural requirement ensures that the sound suppression system is operational and results in the refractory material being thoroughly saturated with water during launch. The sound suppression system releases approximately 300,000 gallons of water during launch, with a peak flow rate of 900,000 gallons per minute 9 seconds after launch. The launch timeline is as follows:

- The sound suppression water flow starts just before SSME ignition at T – 6.6 s.
- SSME ignition occurs at T - 6.6 s.
- SRB ignition occurs at T – 0 s.
- The Shuttle clears the tower about 6 seconds after launch.

Figure 5. SRB Main Flame Deflector

Figure 6. Side Flame Deflectors

1.4 Sensor Background

During the launch of STS-124 (Discovery, May 31, 2008) from LC-39A, approximately 3500 bricks were separated from the SRB flame trench east wall, shown in Figure 7. As a result, it was decided to instrument the flame trench to improve the knowledge of the launch environment in the flame trench. There had been no previous measurements within the flame trench, although there had been pressure measurements under the MLP exhaust holes and side flame deflector. The instrumentation effort has been especially important, since the opportunities to get data are limited to the remaining four Shuttle flights. The data collected in this effort has two main purposes: (1) provide information that can be used for testing of new refractory materials in the flame trench and (2) provide real data to validate models that could be used to estimate the launch environment for new vehicles. The information will be used to develop new test methods, which will be reported in a future deliverable. Currently, there have been minimal efforts to improve flame trench environmental prediction models in addition to the modeling done to validate the wall repairs performed post STS-124. Instrumentation efforts have been made on four Shuttle launches, and it is planned to continue on the remaining Shuttle launches.

Figure 7. Brick Damage on the SRB Flame Trench East Wall After the Launch of STS-124

2 INSTRUMENTATION

2.1 Sensor Description and Locations

The launch environment was measured in the flame trench during the launches of STS-126 (Endeavour, November 14, 2008), 119 (Discovery, March 15, 2009), 125 (Atlantis, May 11, 2009), and 127 (Endeavour, July 15, 2009). Temperature, pressure, acoustic pressure, acceleration, total heat flux (calorimeter), and radiative heat flux (radiometer) were measured. The sensors used for each measurement and locations are given in Table 1. The locations of the sensors are shown in Figure 8 thru Figure 11. Sensors were located on both the east and west flame trench walls for locations 1 – 7. The specific location will be denoted with an “E” or “W” after the number denoting the east or west wall as shown in the figures. Sensors at locations 1 – 4 were exposed to the exhaust environment. Locations 4E and 4W were at the bottom of the deflector near the walls as shown in Figure 12. Sensors are facing towards the center of the trench as shown by the arrow. Locations 2 and 3 were old flushing nozzles. The installed sensors are shown in Figure 13. Location 1 was an old junction box, shown in Figure 14. The sensors for accelerometer measurements made at locations 5 – 7 were placed on the cold face of the flame trench wall, in the catacombs. These sensors were not directly exposed to the heat of the launch environment but used to analyze the acoustical response of the reinforced concrete structure. Locations 8W and 9W were located on the west side flame deflector and underneath the MLP as shown in Figure 10. These locations did not have equivalent measurements on the east side. Accelerometer and strain gauge measurements were made on the SRB and SSME flame deflectors, with locations as shown in Figure 11. These locations are the only measurements taken on the deflector structure at the time of this writing. Each strain measurement consisted of a three-gauge rosette, shown in Figure 15. Product data sheets for the sensors are given in section 6.

Currently an effort is under way to install sensors directly on the hot face of the SRB side of the main flame deflector. The current plan is to install a combination of similar sensors, witness rods, and a specially designed slug-type calorimeter. These sensors will measure the temperature, pressure, and heat rate at the locations shown in Figure 16.

Table 1. Sensors Used During Launch Environment Assessment

Measurement	Sensor Model Name/No.	Locations
Temperature	NANMAC 9300 Erodable Thermocouple	1, 2, 3, 4
Pressure	Stellar Technology ST 150	1, 2, 3, 4, 8W, 9W
Acoustic Pressure	Kistler 6013C	4
Accelerometer	Wilcoxon 797L	5, 6, 7, SRB, SSME
Calorimeter	Medtherm 64-2000-600-19-20054AT	1, 2, 3, 4
Radiometer	Medtherm 4TP-2000-600-23-200264AT	1, 4
Strain	CEA-06-125UR-350	SRB, SSME

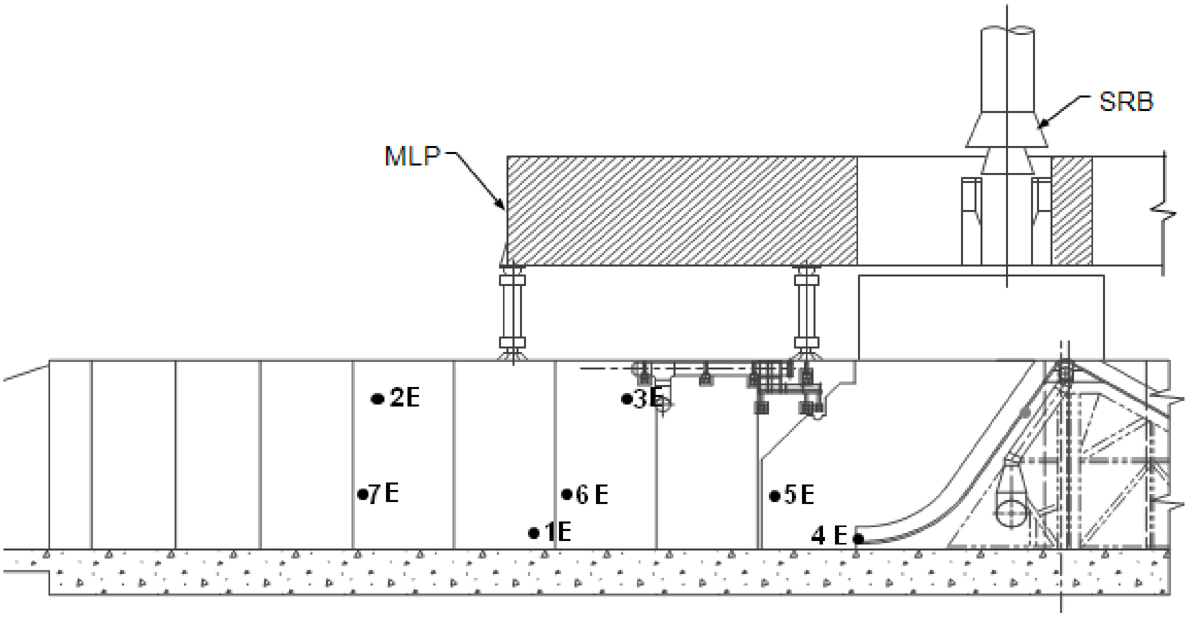


Figure 8. Sensor Locations on the East Wall of the SRB Flame Trench

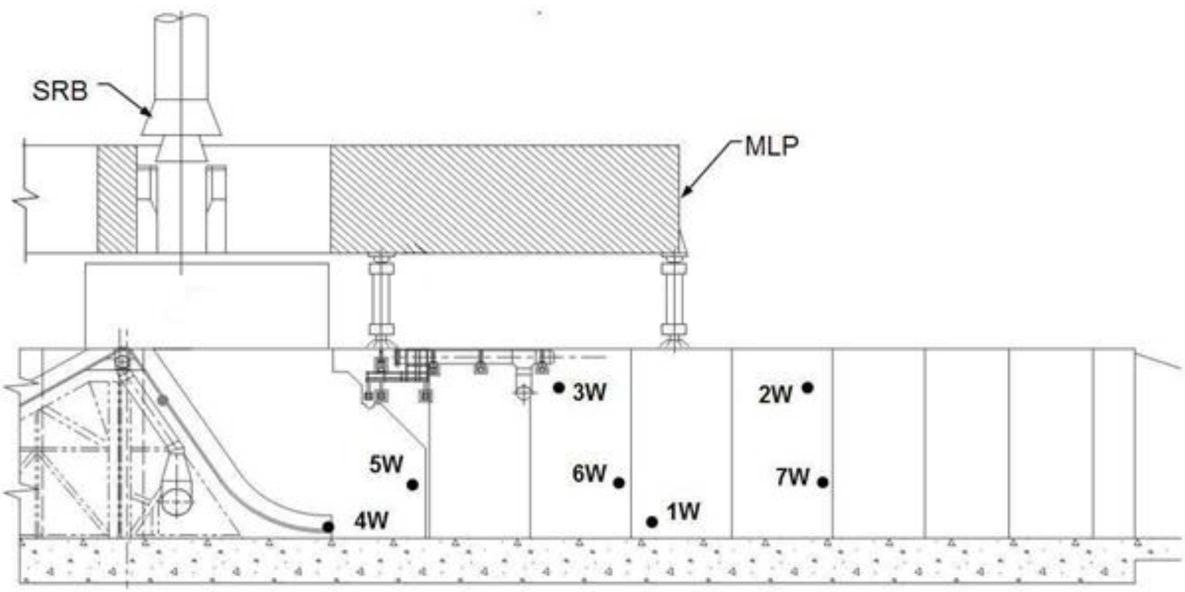


Figure 9. Sensor Locations on the West Wall of the SRB Flame Trench

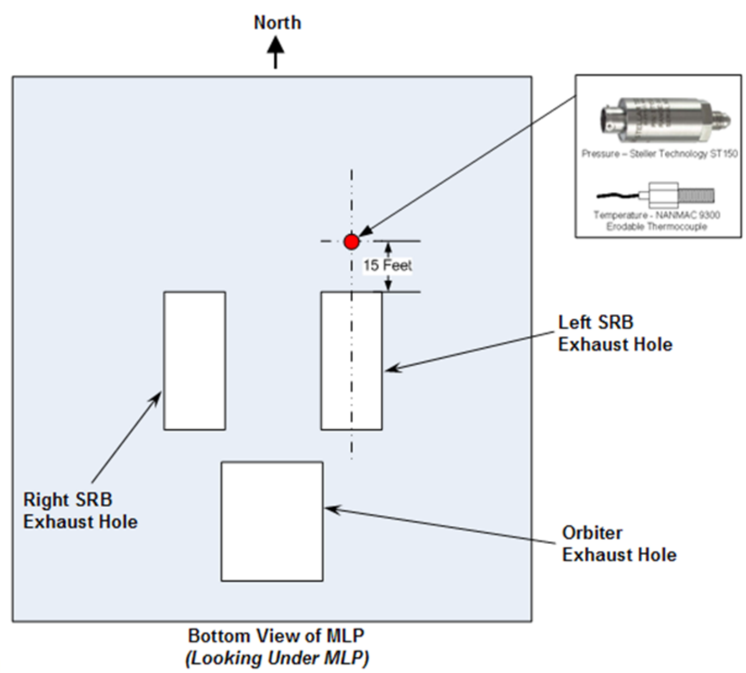


Figure 10. Location of Pressure Sensor 9W Underneath the MLP

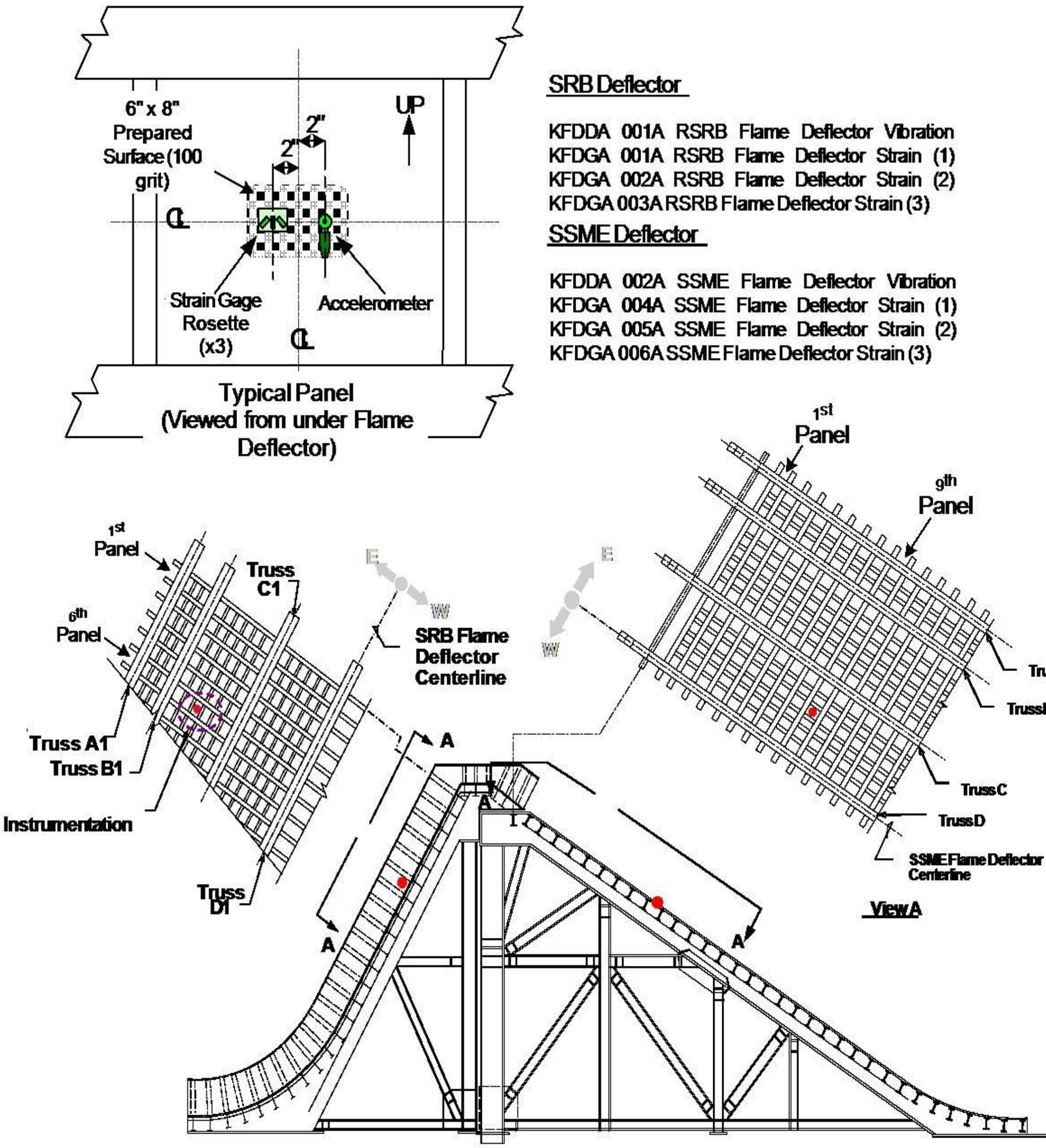


Figure 11. Sensor Locations on the SRB and SSME Flame Deflectors

Figure 12. Location 4E Highlighted in the Circle

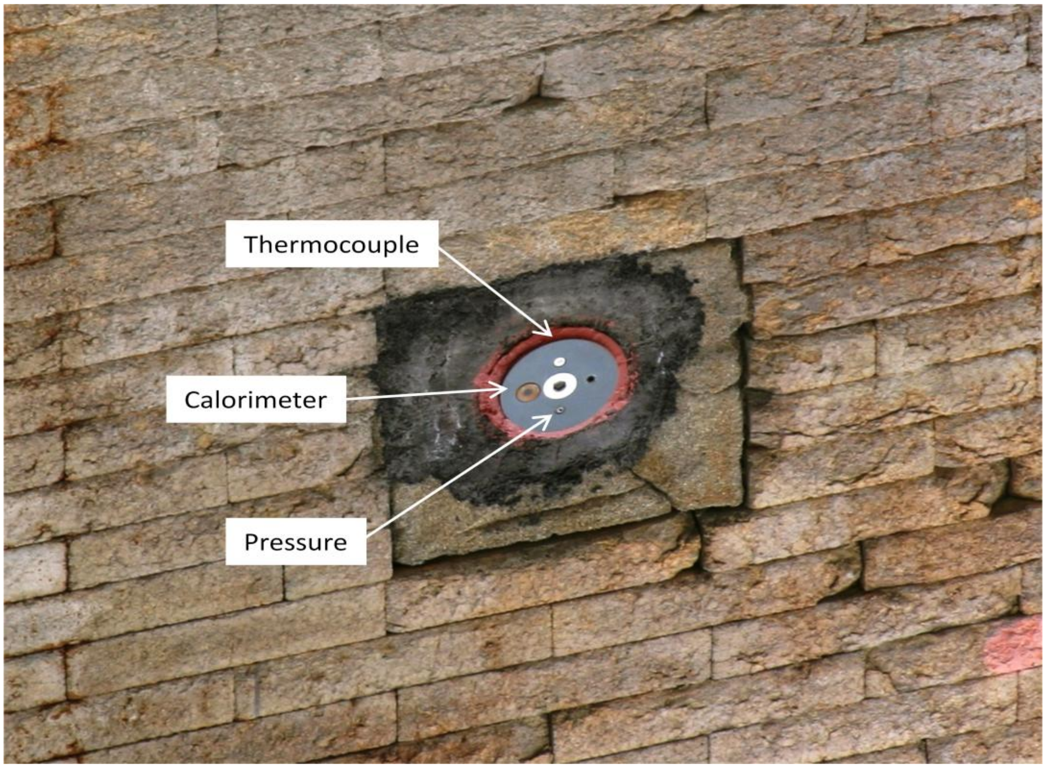


Figure 13. Typical Sensor Installation at Locations 2 and 3

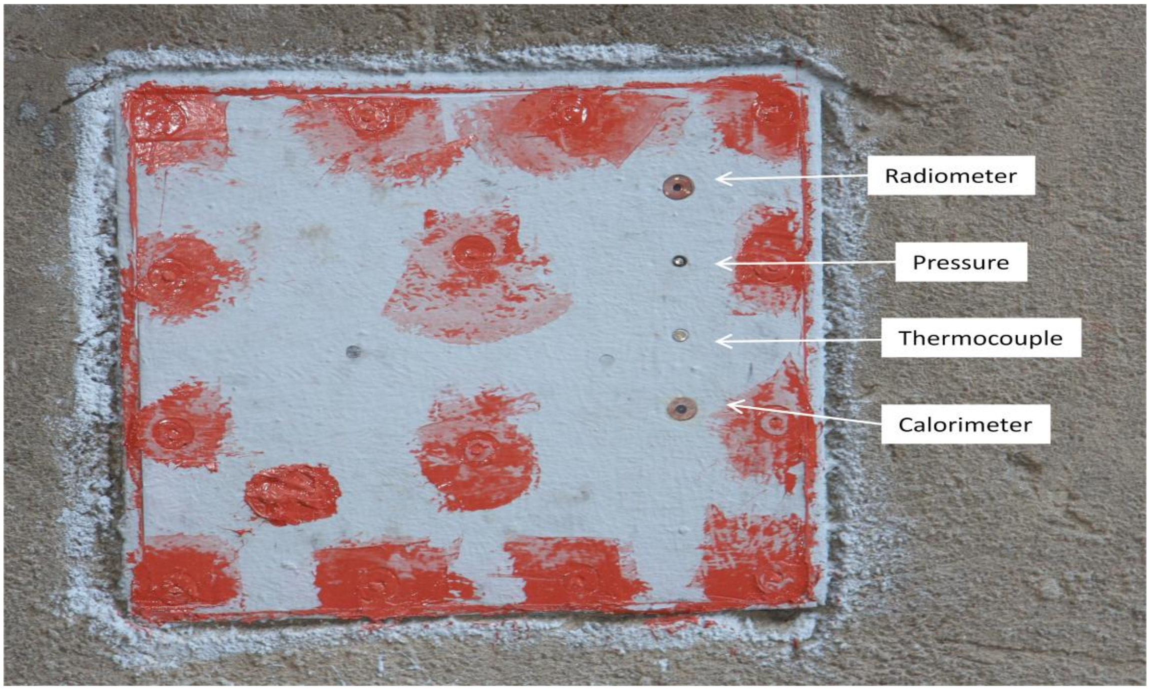


Figure 14. Typical Configuration at Location 1E and 1W

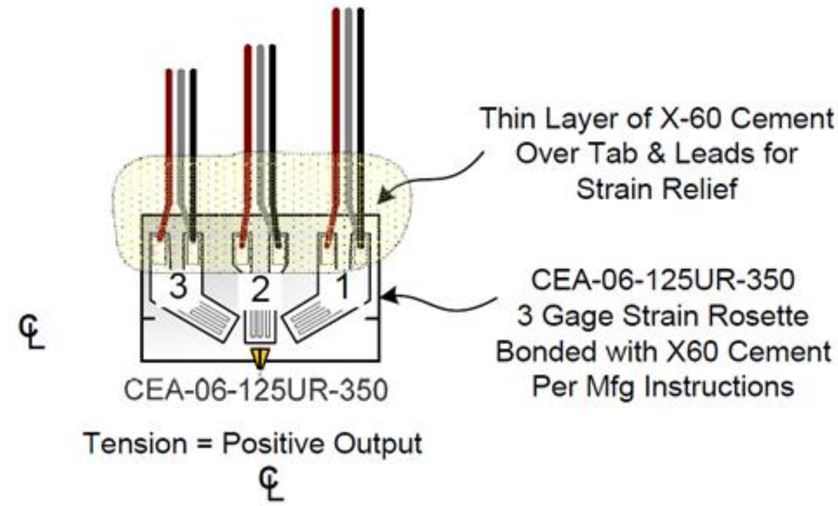


Figure 15. Details of Strain Gauge Installation

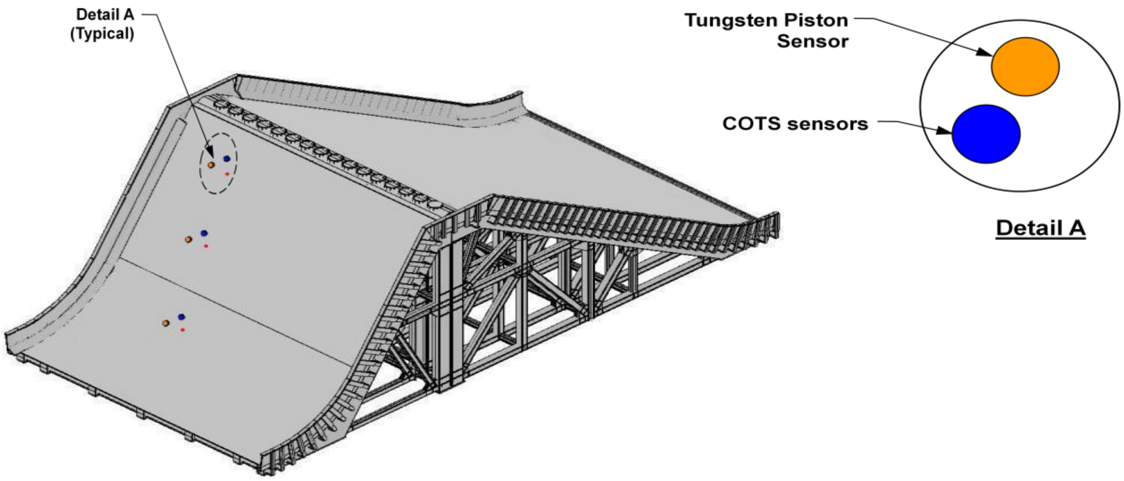


Figure 16. Conceptual Design of New Sensors

2.2 Sensor Problems

Not all sensors functioned properly during all launches. The biggest problem was the deposition of slag (aluminum oxide from the SRB and/or eroded refractory material) on the sensors. Thermocouples at all locations failed during the STS-126, the first launch that was instrumented. The acoustic pressure sensor did not work for any of the launches. This sensor failed very shortly after launch. Pressure sensors did not return to ambient pressure after launch because of the presence of SRB slag. Figure 17 shows the sensors at location 4E before and after a launch. The grey material in the after image is SRB slag. The slag was present at all locations exposed to the rocket plume, but it was not as severe at locations 2 and 3. The effects of the slag on the sensor data are being documented by the United Space Alliance instrumentation group, which is based on post launch inspections of the sensors. A list of these observations was not available at the time of this writing.

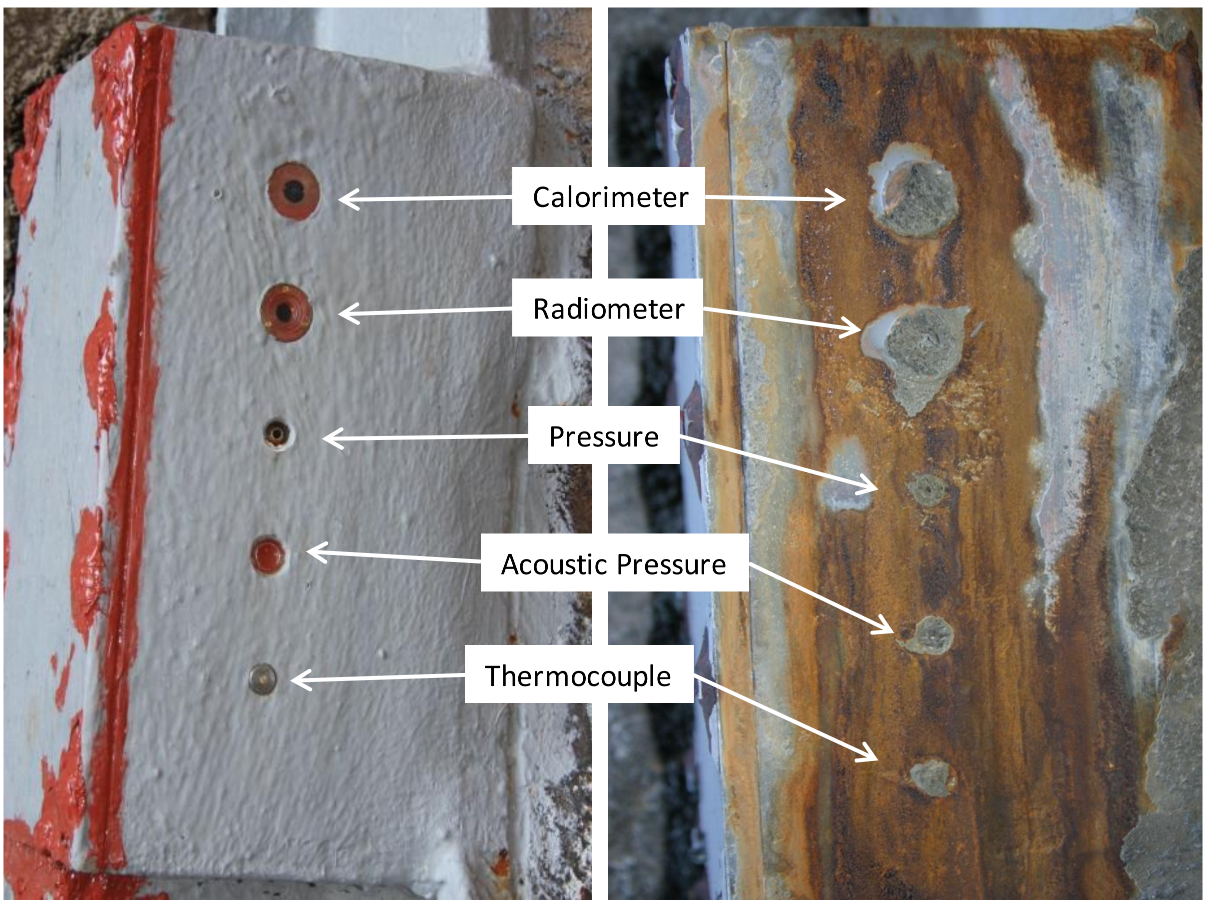


Figure 17. Sensors at Location 4E Before (Left Image) and After (Right Image) Launch

2.3 Sensor Results

2.3.1 Pressure

Pressure measurements were taken at all locations in the flame trench. Table 2 gives the maximum and minimum pressures at each location for each launch. The average over all launches for each location is also given. As would be expected, the highest pressures were found on the side flame deflector, location 8W. At locations 4 and 8, the pressure initially spikes for 0.2 to 0.4 second. After this, the reading is elevated and is consistent with the profile from other launches. At locations 1, 2, and 3, there is an initial increase in pressure, followed by a period of negative pressure, before returning to ambient atmospheric pressure. Figure 18 shows pressure data taken during STS-126 for location 8W and 1- 4E. Plots of pressure data for all locations and launches are given in section 5.1.

Table 2. Maximum and Minimum Pressures (psig) Measured During Three Launches

	STS-126		STS-119		STS-125		All Launches	
Sensor location	Max	Min	Max	Min	Max	Min	Max	Min
8W	91.5	-2.3	99.4	-2.1	56.4	-2.1	99.4	-2.3
9W	5.8	-4.6	6.3	-3.1			6.3	-4.6
1E	8.3	-6.8	7.2	-6.6	9.1	-6.8	9.1	-6.8
2E	5.6	-4.7	3.7	-4.8			5.6	-4.8
3E	7.9	-6.5	6.1	-5.4			7.9	-6.5
4E	45.6	-2.9	36.8	-22.9	61.1	-0.6	61.1	-22.9
1W	7.4	-5.9	7.1	-6.0	7.2	-4.6	7.4	-6.0
2W	5.8	-5.2	4.5	-4.8			5.8	-5.2
3W	6.3	-5.6	7.7	-5.9			7.7	-5.9
4W	45.1	-2.4	45.6	-3.1	42.1	-0.1	45.6	-3.1

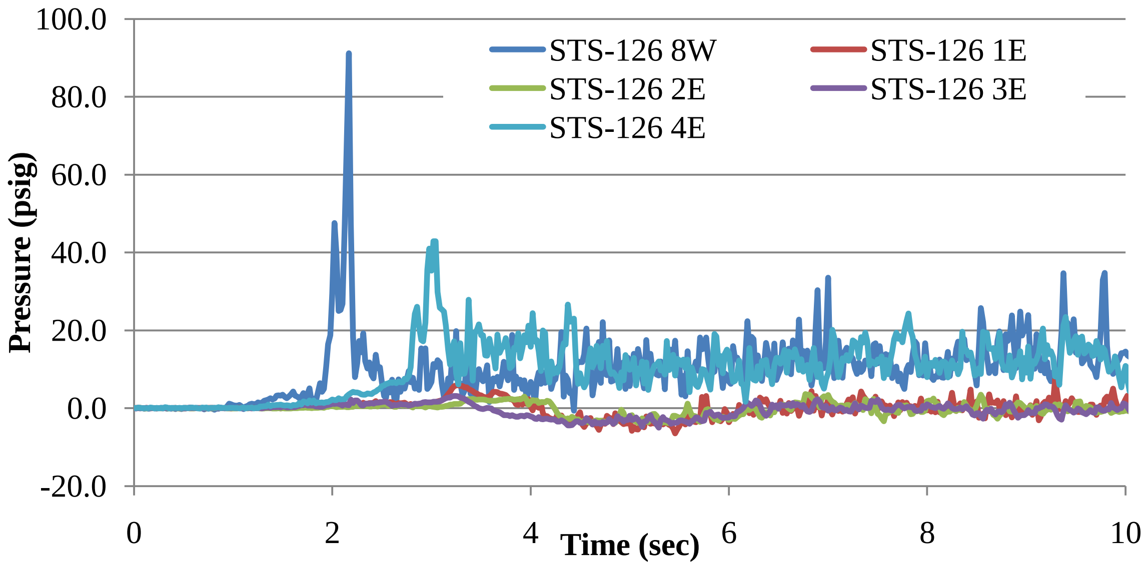


Figure 18. Selected Pressure Measurements During STS-126

2.3.2 Calorimeter and Radiometer

Total heat flux and radiative heat flux were measured with a calorimeter and radiometer during two launches. Total heat flux was taken at locations 1 - 4 on both walls, while radiative flux was taken only at locations 1 and 4. The convective heat flux can be inferred by taking the difference between the two values.

Table 3 and Table 4 list the maximum total heat flux measurements for each location. The total heat flux was highest at location 4W. At this location, the flux has two broad maxima near 2 and 5 seconds after initial heating begins. This is the only location to exhibit this behavior. At all locations, the heat flux spikes to large values for short periods, ranging from 10 to 100 milliseconds, during the launch. Radiative heat flux is also highest at location 4W, and has the double maxima similar to total heat flux. Radiative heat flux does not exhibit the spiking behavior that total heat flux does. Figure 19 and Figure 20 show selected calorimeter measurements, while section 5.2 has complete data for both calorimeter and radiometer measurements.

Table 3. Maximum Calorimeter Measurements (btu/ft^2·sec) Obtained During Two Launches

Sensor location	STS-126	STS-119	All Launches Max
1E	95.0	109.7	109.7
2E	81.1	66.0	81.1
3E	111.5	86.4	111.5
4E	306.8	155.0	306.8
1W	104.1	107.1	107.1
2W	53.1	31.6	53.1
3W	90.3	45.5	90.3
4W	652.2	2492.5	2492.5

Table 4. Maximum Radiometer Measurements (btu/ft^2·sec) Measured During Two Launches

Sensor location	STS-126	STS-119	All Launches Max
1E	25.8	45.3	45.3
4E	13.8	24.3	24.3
1W	10.2	21.5	21.5
4W	72.1	42.0	72.1

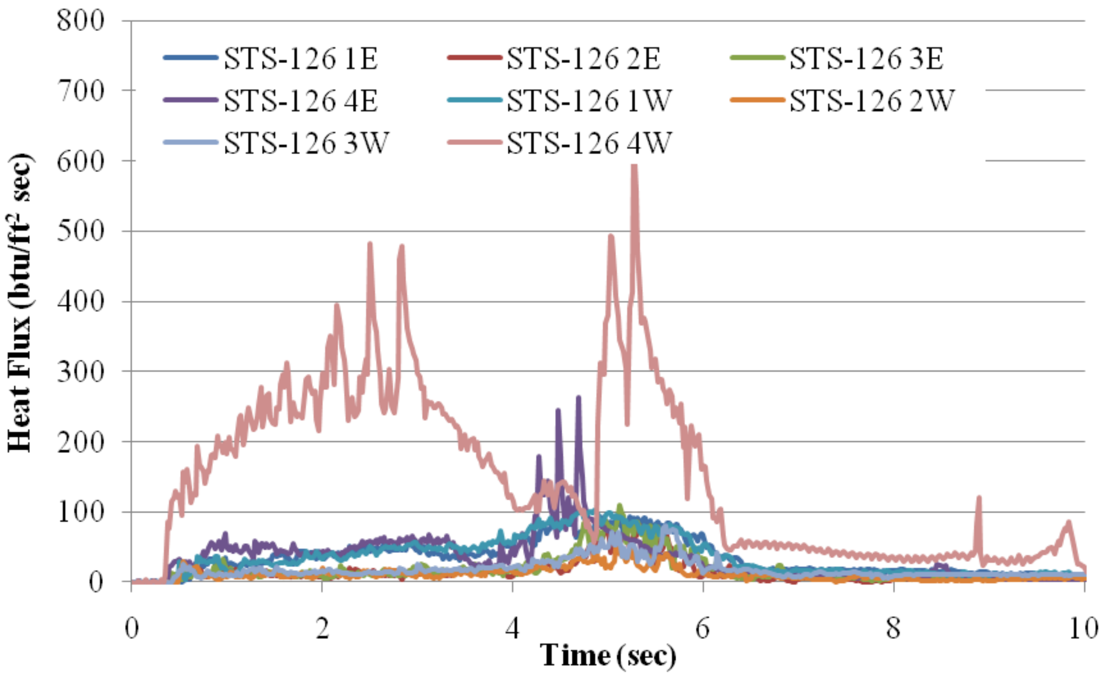


Figure 19. Selected Calorimeter Measurements During STS-126

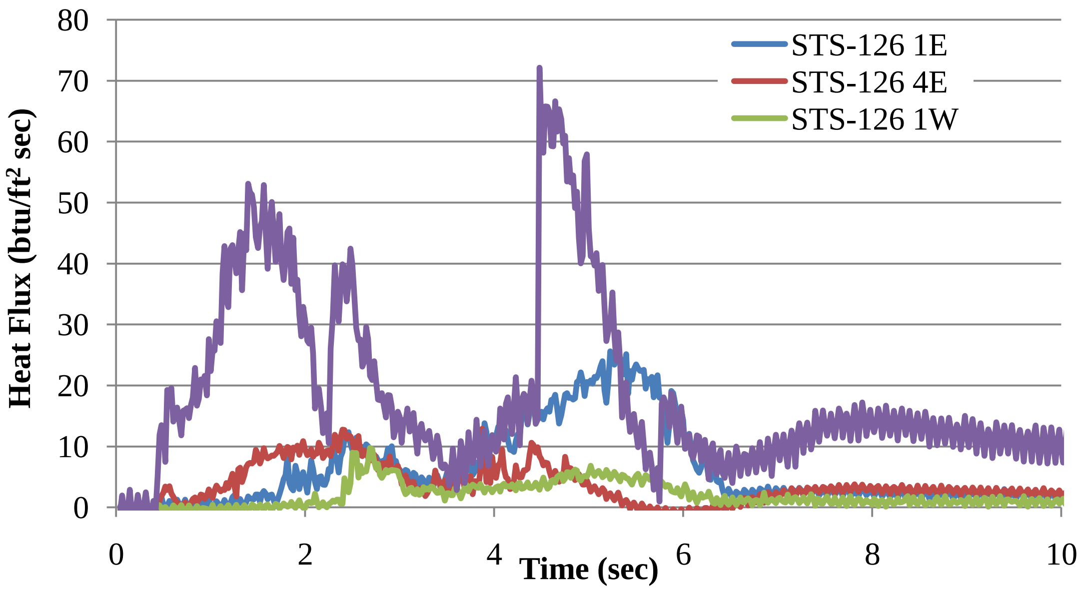


Figure 20. Selected Radiometer Measurements During STS-126

2.3.3 Temperature

The maximum temperatures measured at locations 1 through 4 are presented in Table 5. The measured temperatures are higher on the east wall than on the west wall. Location 4 is the hottest measured point on both walls, reaching maximum temperature of 2165 °F and 1422 °F on the east and west sides, respectively.

Figure 21 shows the temperatures on the east wall during the launch of STS-119. At location 4E, the temperature exhibits a double maximum. The maxima occur about 2 and 5 seconds after initial heating. This behavior is consistent with the measurements at 4E and 4W during all launches. At the other locations, a single temperature maximum is reached at about the same time as the second maximum at location 4. This behavior was consistent during the different launches. Complete data from all measurements is given in section 5.3.

Table 5. Maximum Temperatures (°F) Measured During Three Launches

Sensor location	STS-119	STS-125	STS-127	All Launches Max
1E	605	892	741	892
2E	229	263	260	263
3E	358	384	386	386
4E	1936	2165		2165
1W	492	627		627
2W	201	237	210	237
3W	202	300	284	300
4W	1654	1806	1922	1922

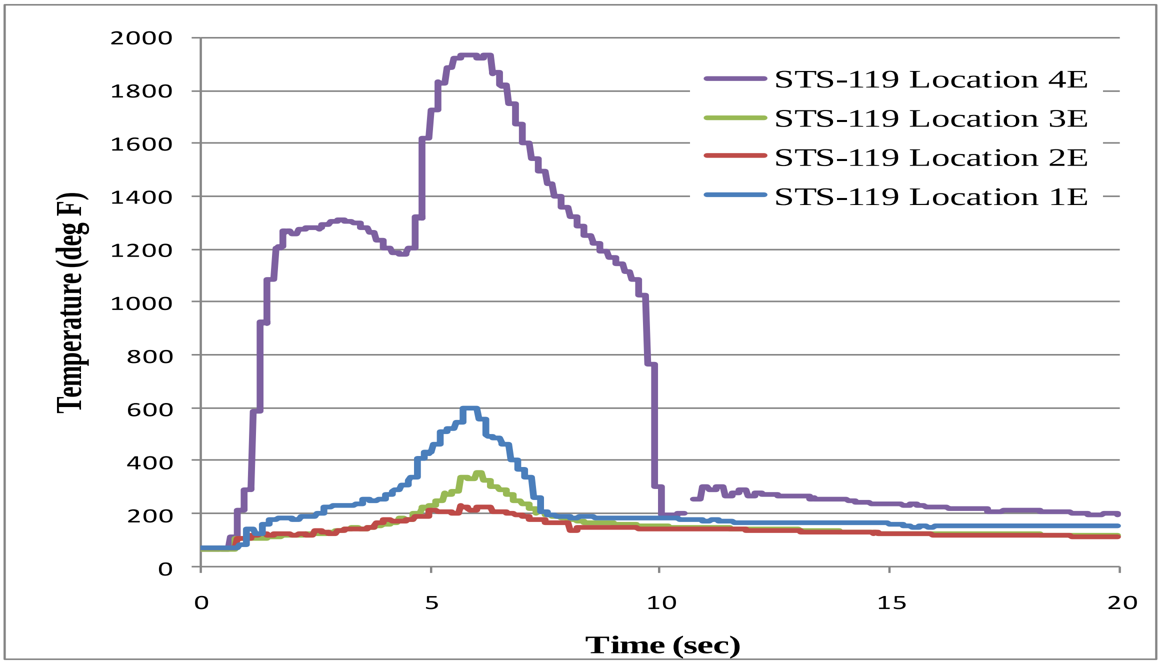


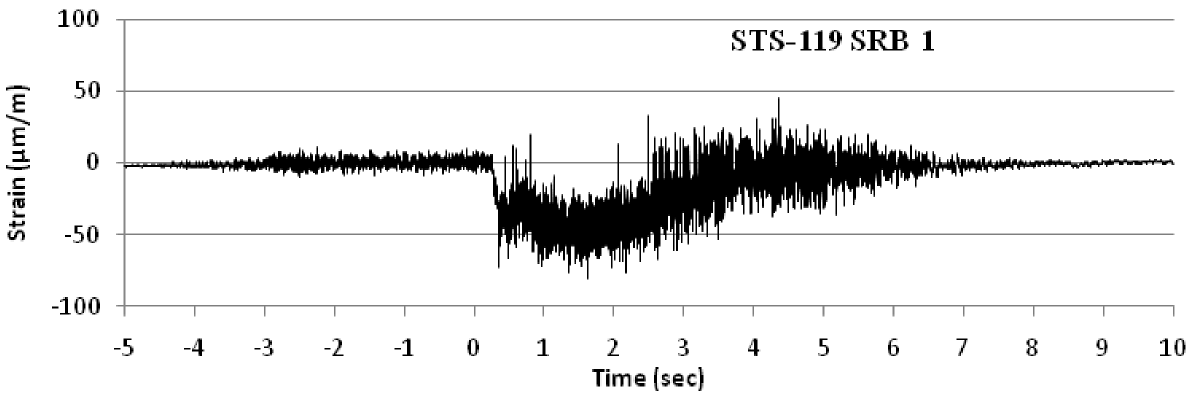
Figure 21. Selected Temperature Measurements During the Launch of STS-119

2.3.4 Strain

Maximum and minimum strain values (μm/m) are reported in Table 6. The strain values show that the refractory material is put into tension on both main flame deflectors. The strain has a broad frequency component from about 0 to 400 hertz (Hz). Graphs of strain during launch are given in Section 5.4. Figure 22 shows selected strain measurements taken during STS-119. Strain values on the SSME deflector begin to increase at about T – 4 seconds, shortly after the SSMEs are started. There is a spike shortly after T – 0. The strain values before and after launch are very close to each other on the SSME deflector. Strain on the SRB deflector also begins to increase at about T – 4 s, but it is considerably larger after SRB ignition at T – 0 s. The maximum and minimum strain values on the SRB deflector are larger than on the SSME deflector, as would be expected because of the more powerful SRB thrust.

Table 6. Maximum and Minimum Strain (µm/m) at the SRB and SSME Locations During the Launches of STS-119 and STS-125

Sensor Location	STS-119		STS-125		All Launches	
	Max	Min	Max	Min	Max	Min
SRB 1	45.01	-80.80	44.99	-89.74	45.01	-89.74
SRB 2	64.70	-75.81	103.59	-75.19	103.59	-75.81
SRB 3	72.77	-68.56	102.33	-65.86	102.33	-68.56
SSME 1	44.27	-24.93	40.36	-32.61	44.27	-32.61
SSME 2	24.81	-44.14	22.38	-50.13	24.81	-50.13
SSME 3	37.00	-43.90	42.28	-38.90	42.28	-43.90



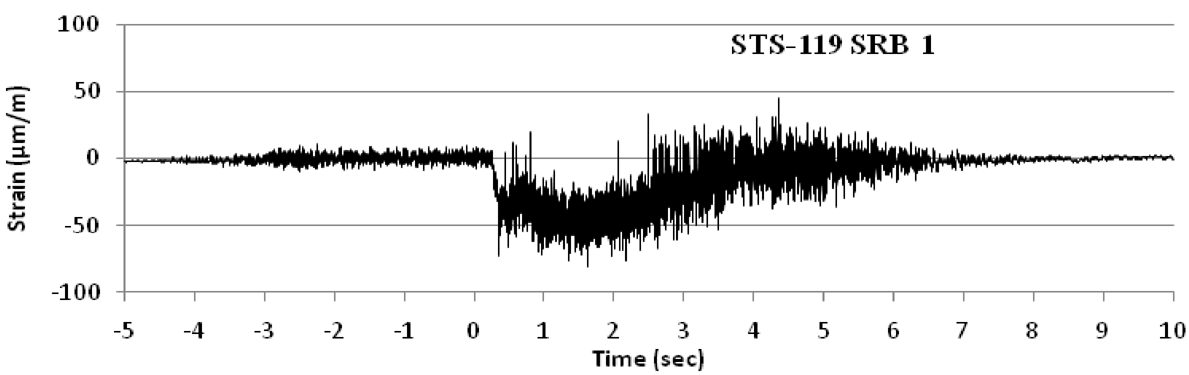


Figure 22. Selected Strain Measurements Taken During STS-119

2.3.5 Acceleration

Maximum and minimum acceleration values are given in Table 7. Selected measurements are given in Figure 23. Locations 5, 6 and 7 begin to see accelerations shortly after ignition of the SRBs at T – 0 s. The acceleration values on the SRB and SSME flame deflectors are considerably higher than those at locations 5 -7, with the SRB deflector seeing the highest values. The SSME deflector sees significant acceleration starting at about T – 3 s. Like the strain values, acceleration spikes shortly after T – 0 s. The SRB acceleration values rapidly increase after T – 0 s. Graphical acceleration data for each measurement is given in section 5.5.

Table 7. Maximum and Minimum Acceleration Values (g) Measured During Four Launches

Sensor Location	STS-126		STS-119		STS-125		STS-127		All Launches	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
SRB			142.9	-169.1	200.1	-179.2			200.1	-179.2
SSME			120.0	-104.8	96.8	-69.2			120.0	-104.8
5E	1.2	-3.8	1.5	-1.3	1.3	-2.0	1.5	-1.7	1.5	-3.8
6E	1.7	-2.0	2.6	-2.4	2.0	-2.5	2.0	-2.1	2.6	-2.5
7E	3.8	-3.7	3.6	-4.1	4.2	-3.9	3.5	-3.4	4.2	-4.1
5W	1.5	-1.6	1.3	-1.3	1.6	-1.3	1.3	-1.5	1.6	-1.6
6W	2.0	-4.4	2.4	-2.5	2.5	-2.6	2.8	-3.3	2.8	-4.4
7W	3.2	-3.1	3.4	-3.4	3.6	-3.8	3.5	-3.3	3.6	-3.8

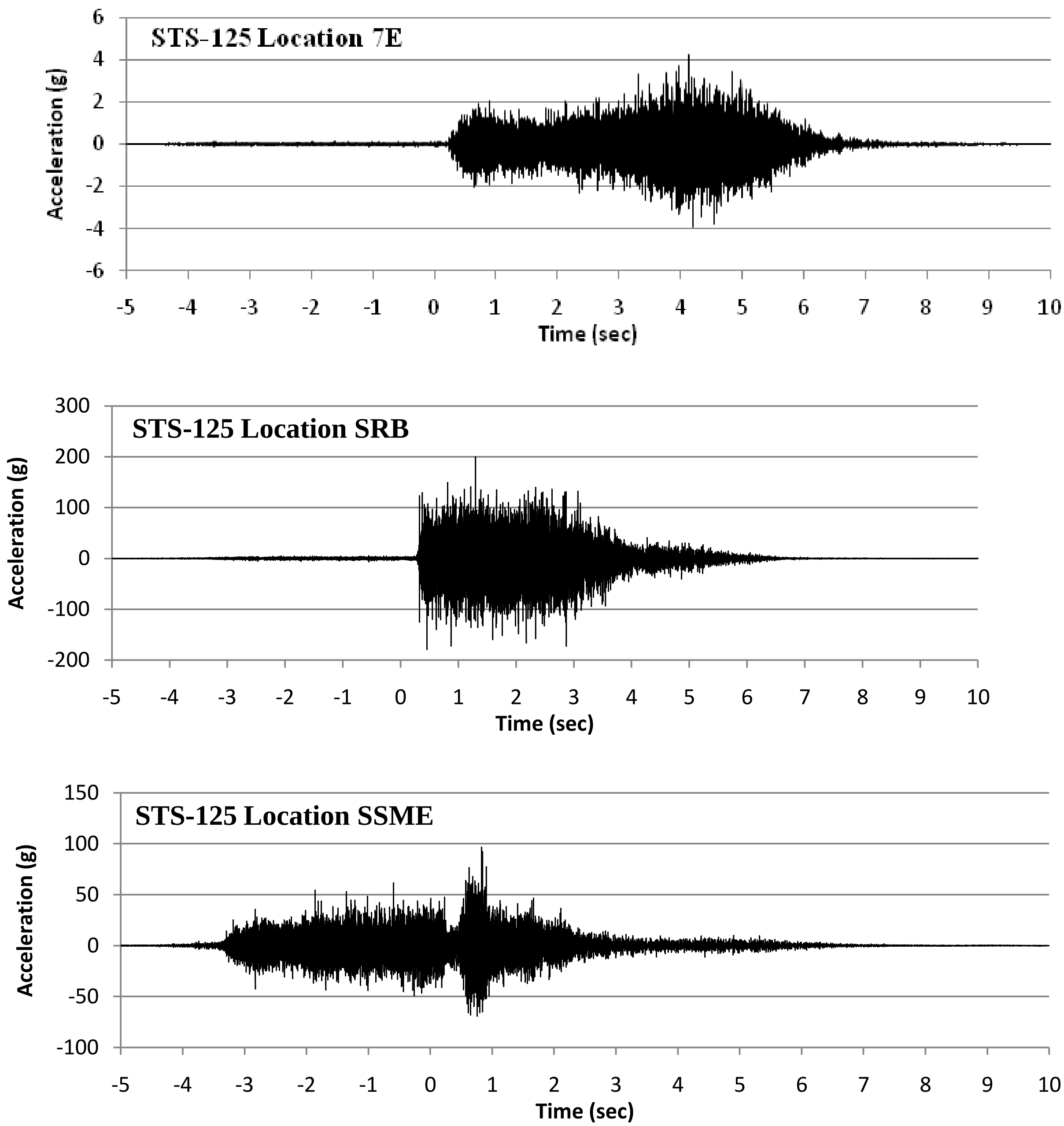


Figure 23. Selected Acceleration Measurements Taken During STS-125

3 CONCLUSIONS

Measurements of temperature, pressure, heat flux, acceleration, and strain have been made at different locations throughout the flame trench. These values can be used to identify appropriate test conditions for new refractory materials. Currently, new materials are qualified by placing the materials in the flame trench during a Shuttle launch. Since there are limited launches left in the program, new test methods must be developed. In addition, this data can be used to validate models of the exhaust plume for Shuttle and new vehicles in the future.

The conditions experienced in the trench vary with location. As would be expected, the closer to the direct impingement zone the harsher the conditions. The refractory material on the flame deflector sees different conditions than the material on the wall, not only because it is closer to the heat source, but also because the deflectors are a free standing steel structure. The steel structure flexes, as shown by the strain measurements, putting the refractory material in tension.

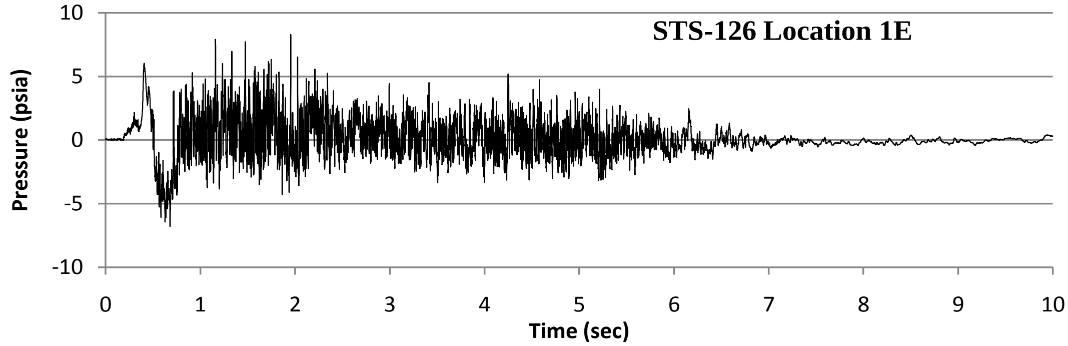
These measurements were the first to be made in the flame trench during the Shuttle Program. Although they have provided considerable information, there is still a desire for more measurements. Specifically, measurements are desired at the impingement area of both the SRB and SSME flame deflectors. This would be the harshest thermal environment to which the refractory material would be exposed. Discussions on the possibility of installing sensors at these locations are ongoing.

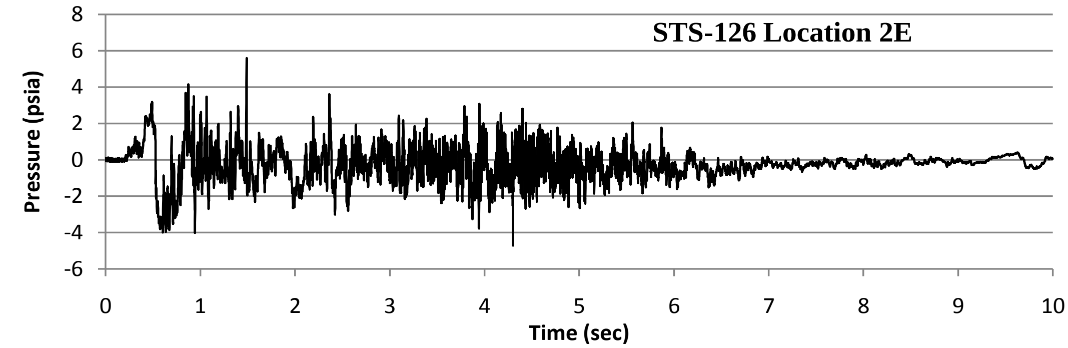
4 DISCLAIMER

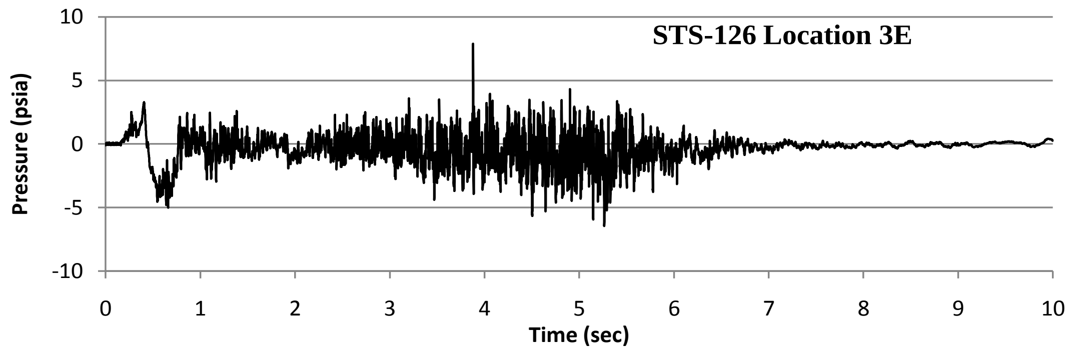
The use of the environmental data collected during the Space Shuttle Program for the selection of a refractory material is based on NASA engineering methods documented in KSC-DE-512-SM, Facility, System, and Equipment General Design Requirements, and referencing documents. Because the launch environment is a transient event, these methods do not simply compare the environmental data to a refractory product technical data sheet. The calculations are summarized to outline methodologies that are more appropriate. As an example, one option for calculating the thermal loading utilizes the applied heating rates captured by the calorimeters. Another method uses the applied convection and radiation thermal load along with other known values. In addition, the pressure, acceleration, and strain measurements contain frequency content between 10 and 400 Hz. This data property demonstrates the importance of including an acoustical analysis as well as the standard static analysis to ensure that the proper loading conditions are considered for the reliable design of the structure.

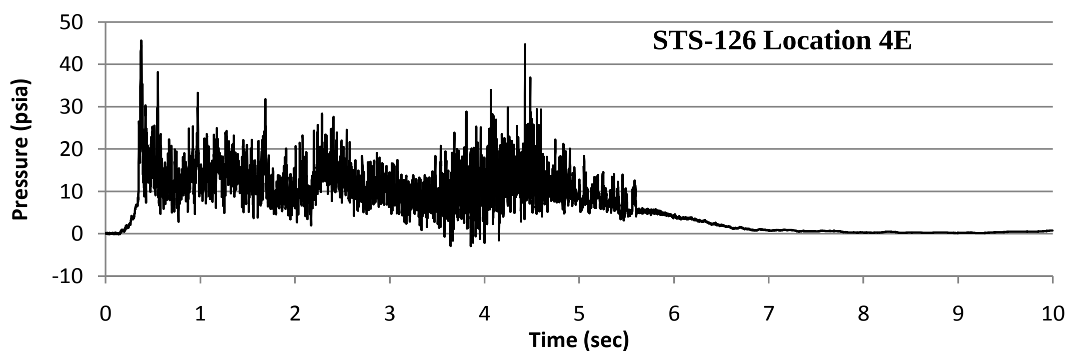
5 GRAPHICAL RESULTS

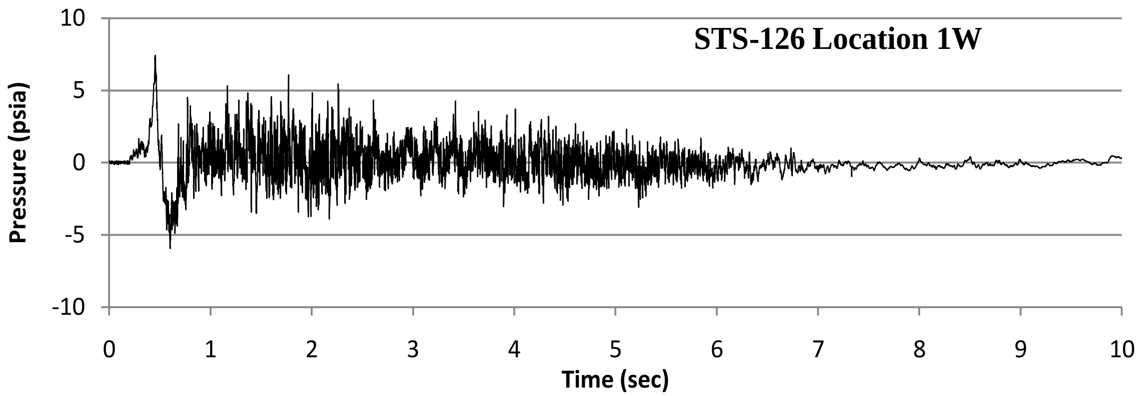
5.1 Charts of Pressure Data







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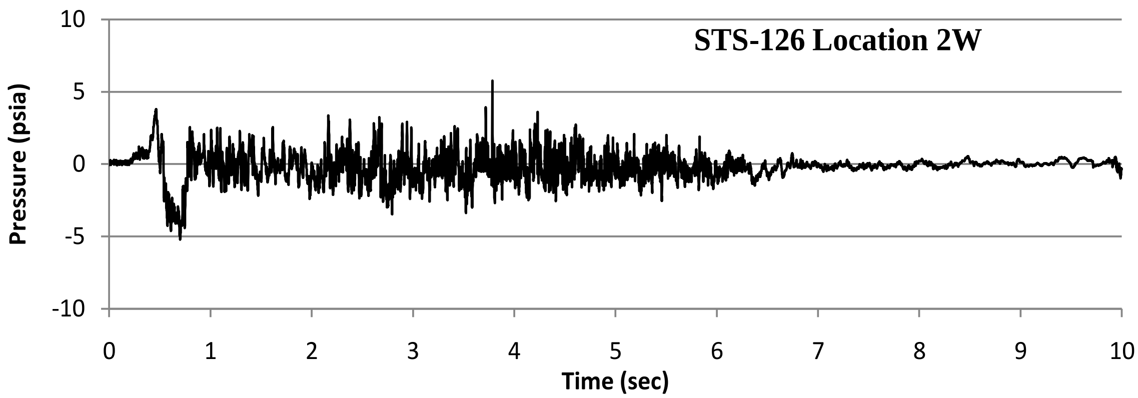
Pressure (psia)
Time (sec)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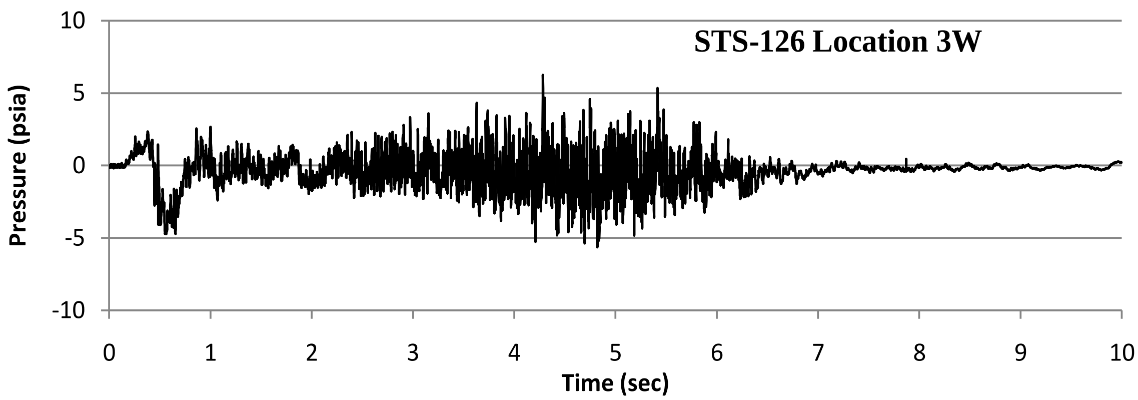
Time (sec)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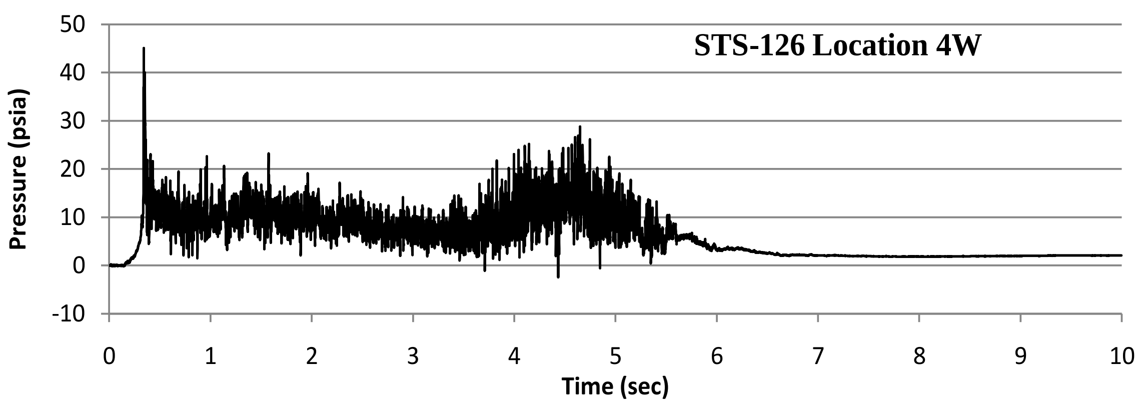
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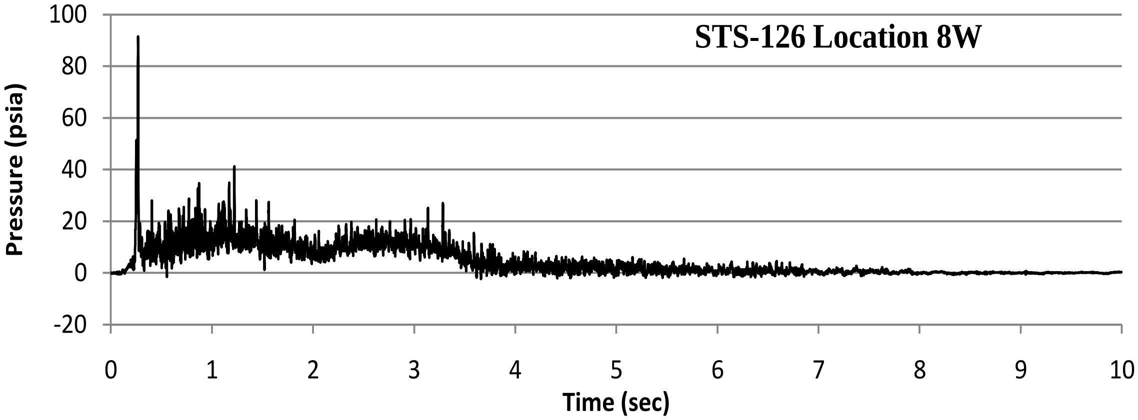
Pressure (psia)
Time (sec)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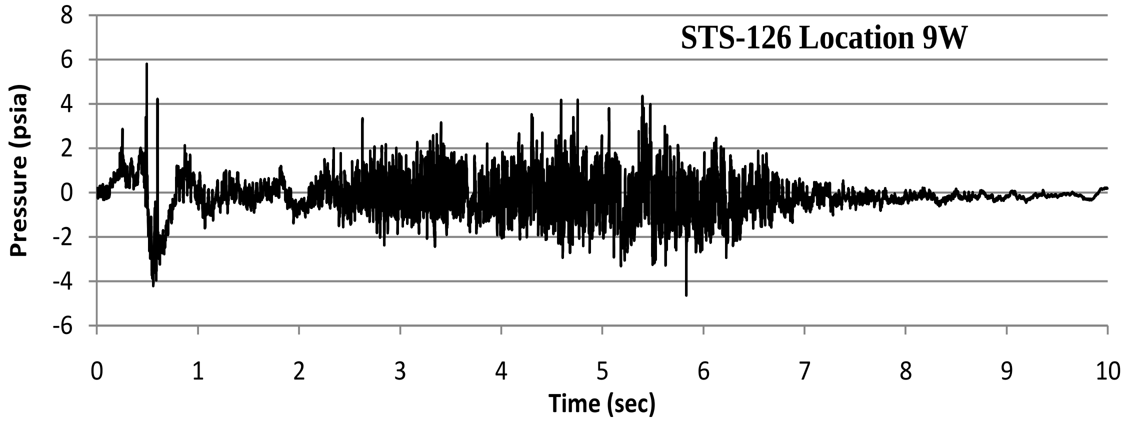
8
9
10
Time (sec)


STS-126 Location 9W
Pressure (psia)
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2
3
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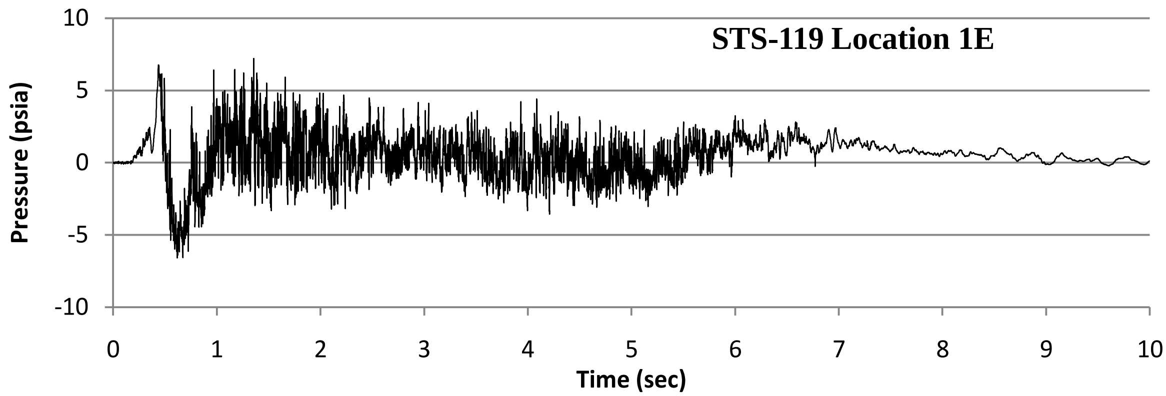
8
9
10
Time (sec)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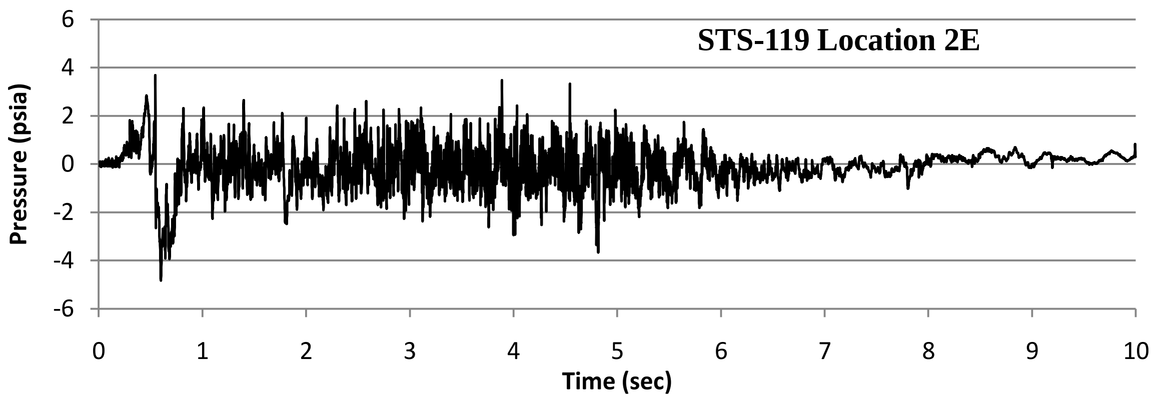
Time (sec)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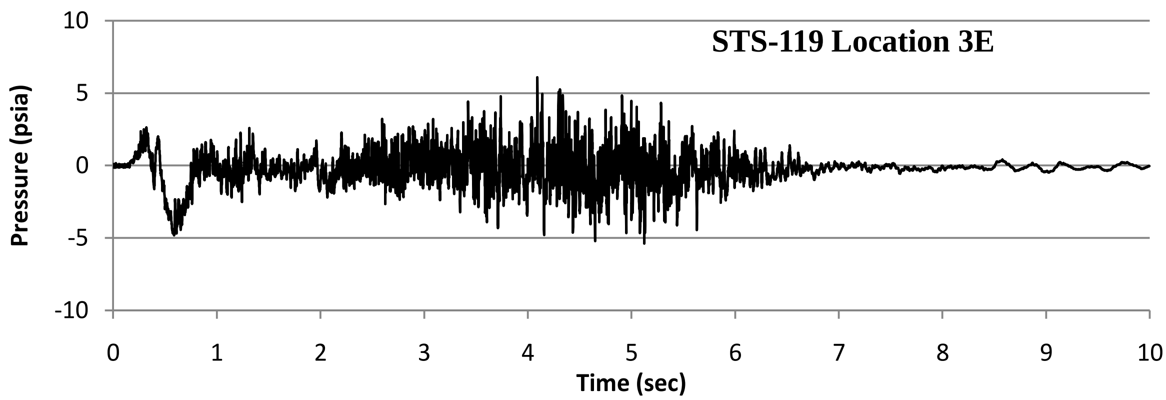
Time (sec)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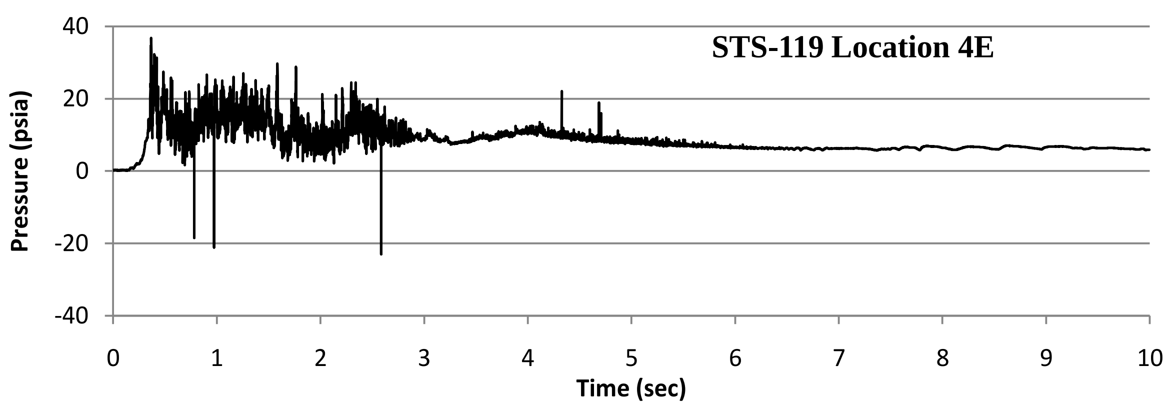
Time (sec)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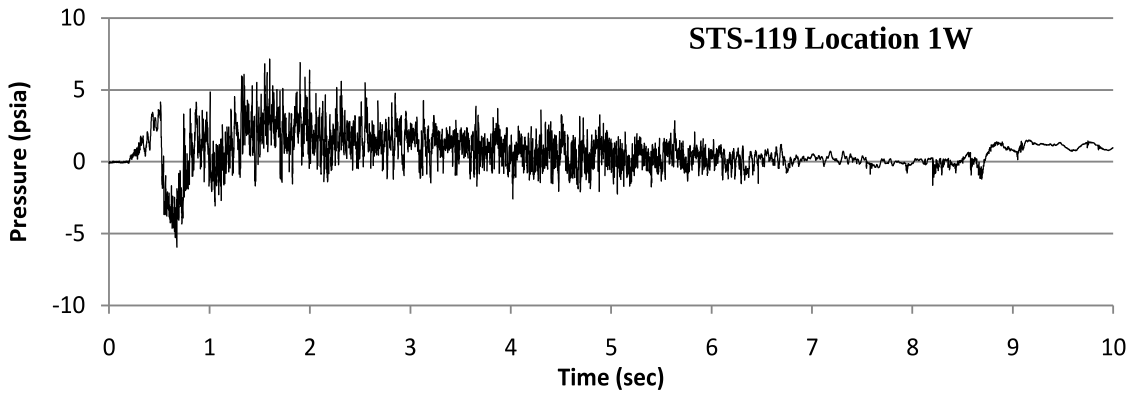
Time (sec)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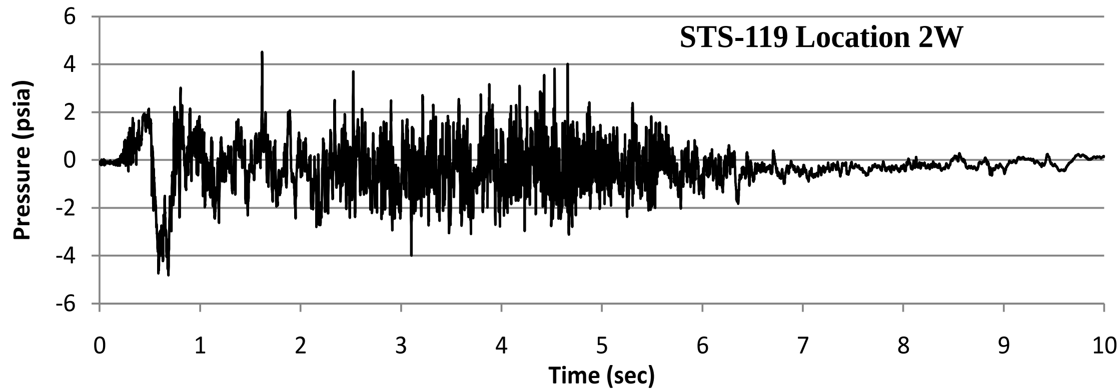
-10
0 1 2 3 4 5 6 7 8 9 10
Time (sec)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Pressure (psia)
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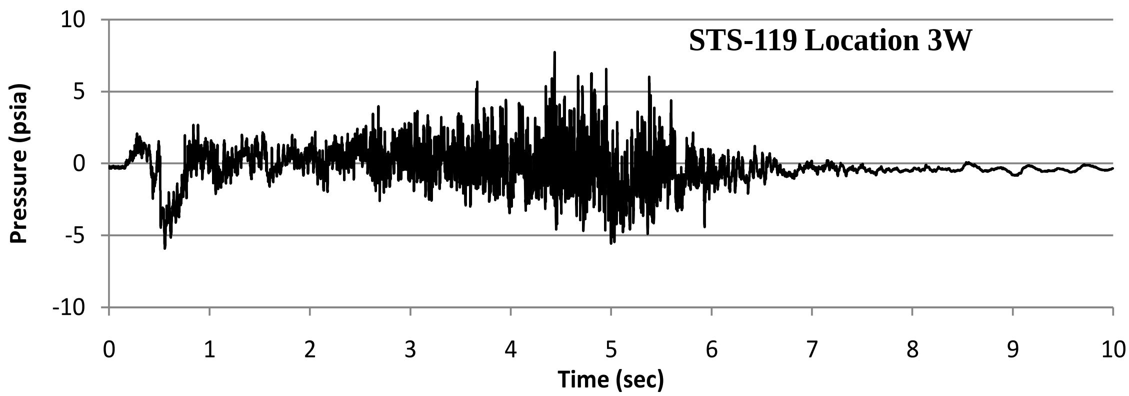
Time (sec)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Pressure (psia)
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-5
-10
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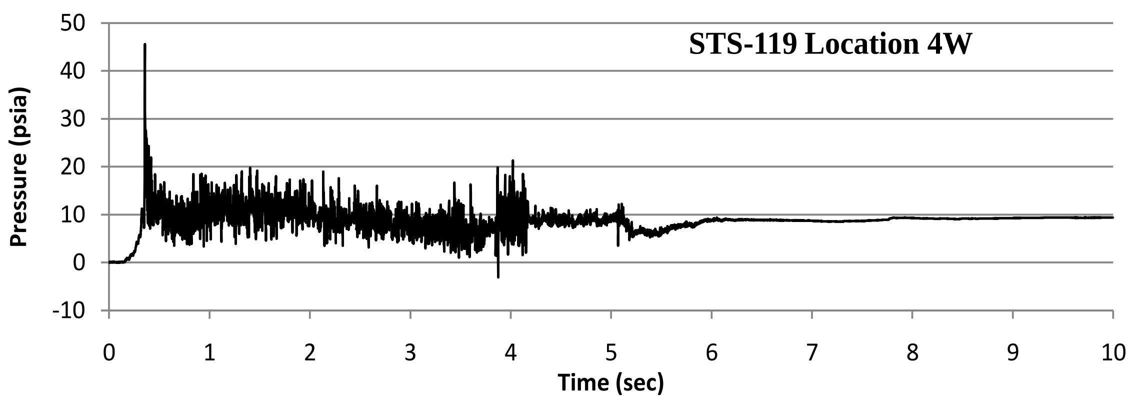
Time (sec)


STS-119 Location 4W
Pressure (psia)
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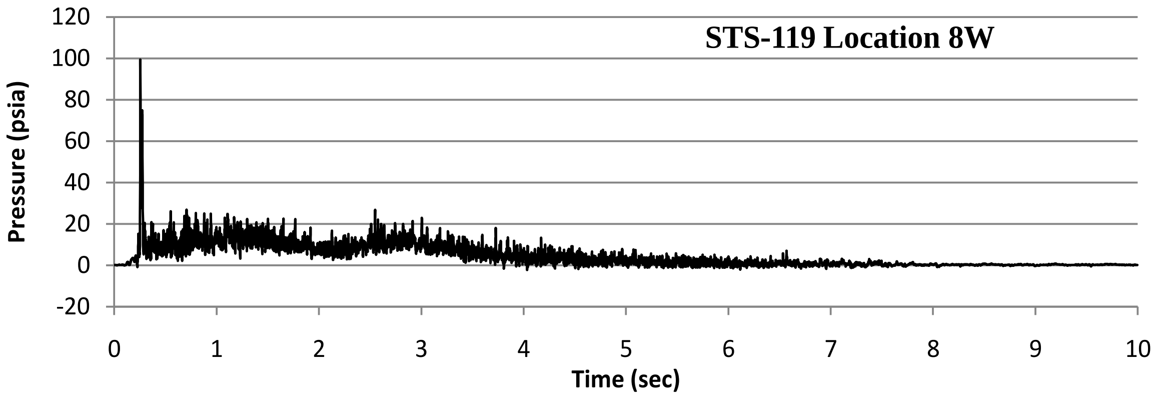
40
30
20
10
0
-10
0 1 2 3 4 5 6 7 8 9 10
Time (sec)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Pressure (psia)
Time (sec)
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60
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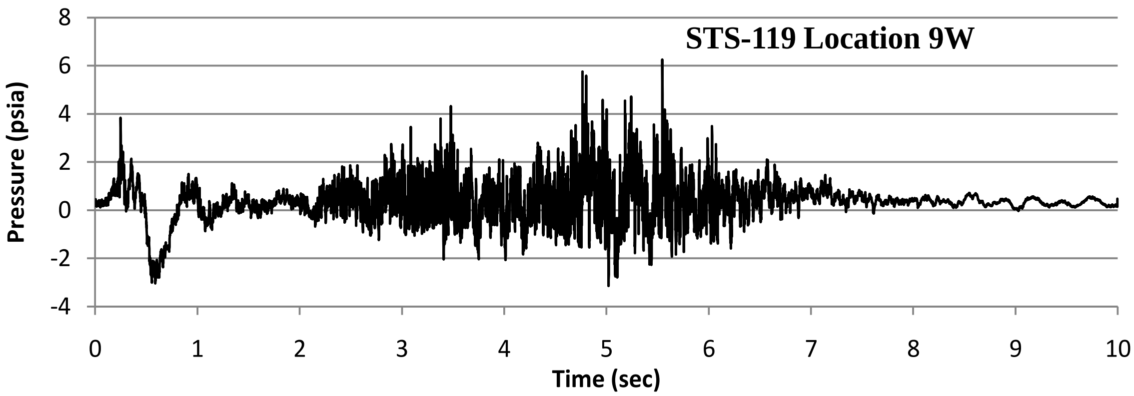
20
0
-20
0 1 2 3 4 5 6 7 8 9 10


STS-119 Location 9W
Pressure (psia)
Time (sec)
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-2
-4
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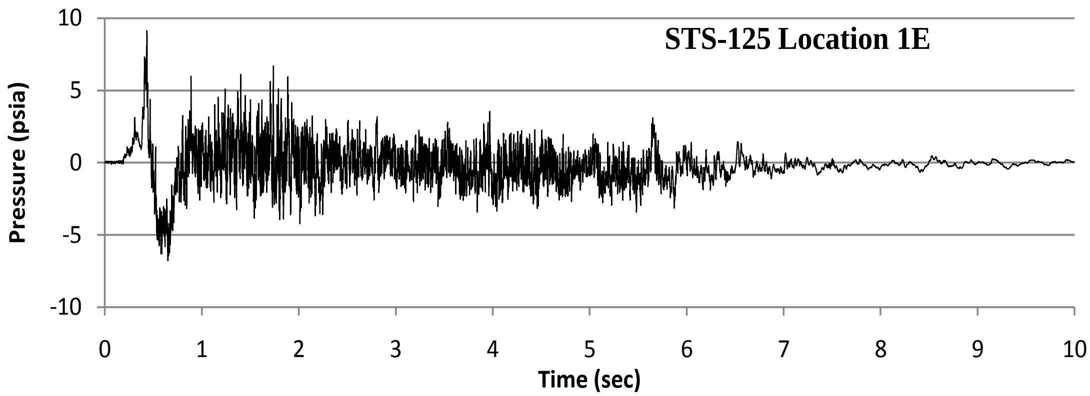
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Pressure (psia)
Time (sec)
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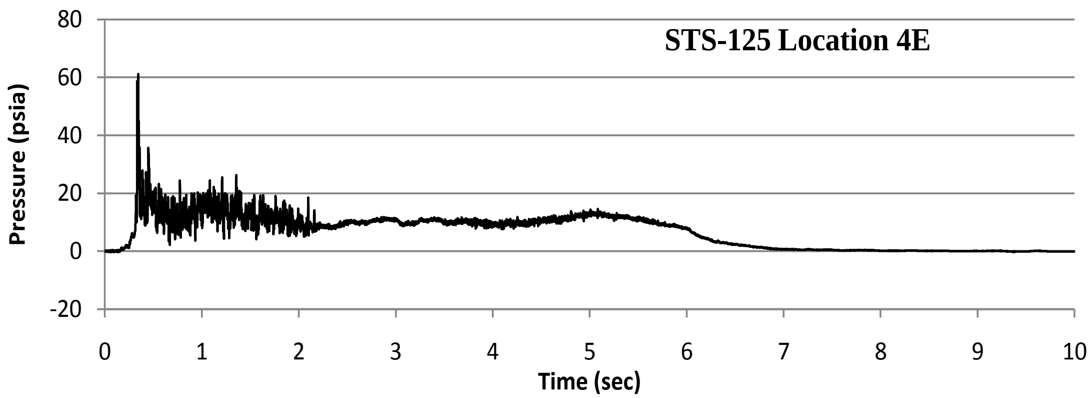
-5
-10
0 1 2 3 4 5 6 7 8 9 10


STS-125 Location 4E
Pressure (psia)
Time (sec)
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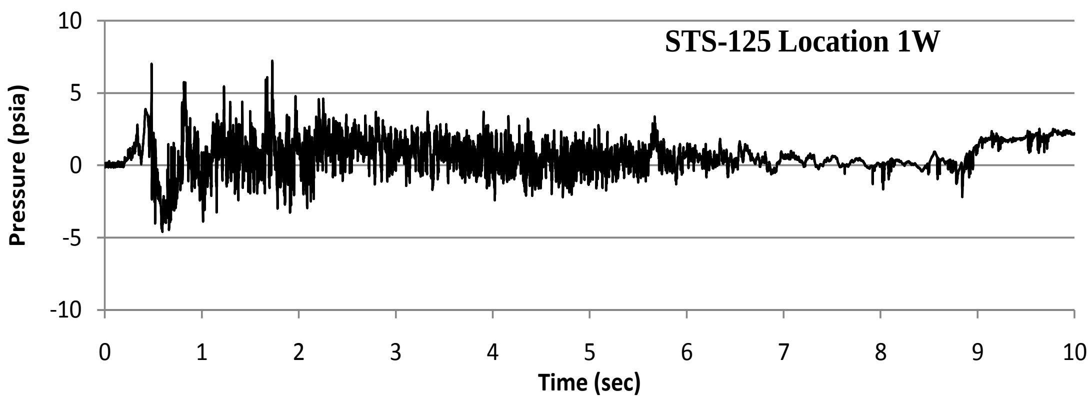
60
40
20
0
-20
0 1 2 3 4 5 6 7 8 9 10


STS-125 Location 1W
Pressure (psia)
Time (sec)
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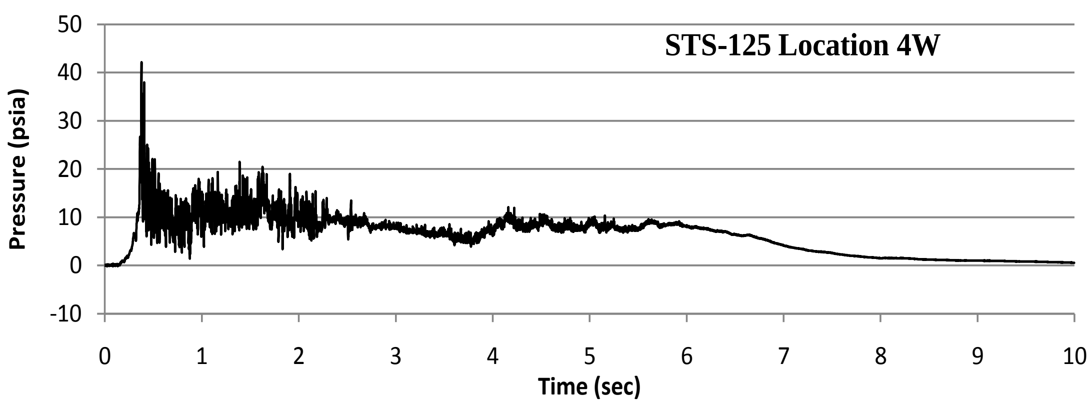
-5
-10
0 1 2 3 4 5 6 7 8 9 10


STS-125 Location 4W
Pressure (psia)
Time (sec)
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10
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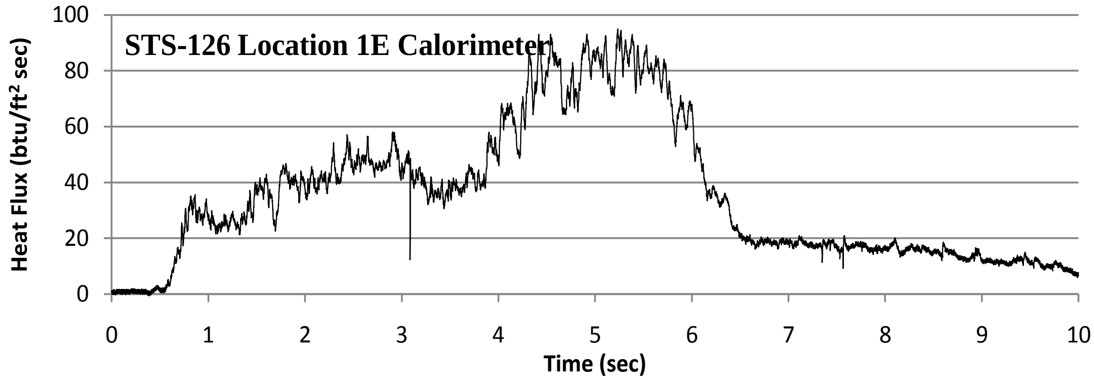
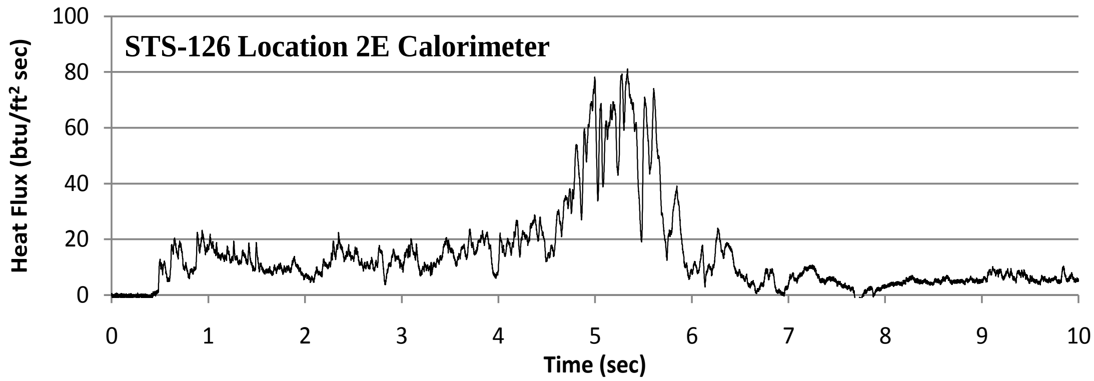
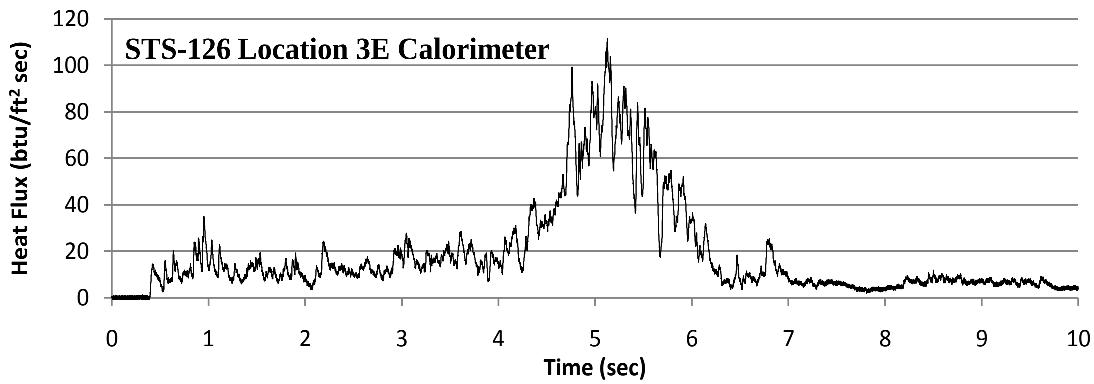
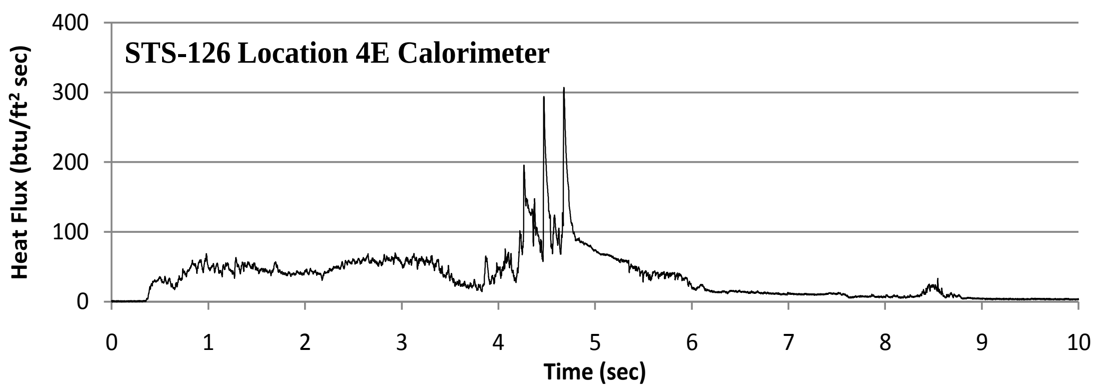
-10
0 1 2 3 4 5 6 7 8 9 10

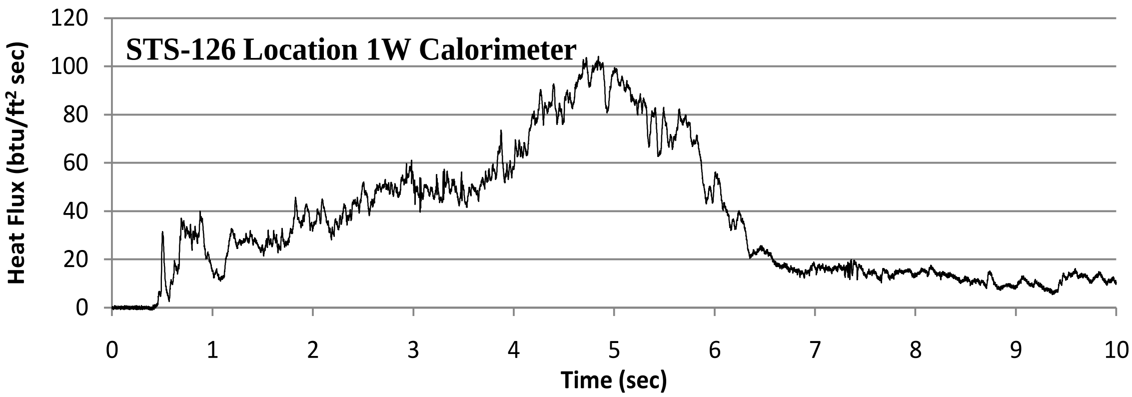
5.2 Charts of Calorimeter and Radiometer Data










STS-126 Location 1W Calorimeter
Heat Flux (btu/ft² sec)
120
100
80
60
40
20
0
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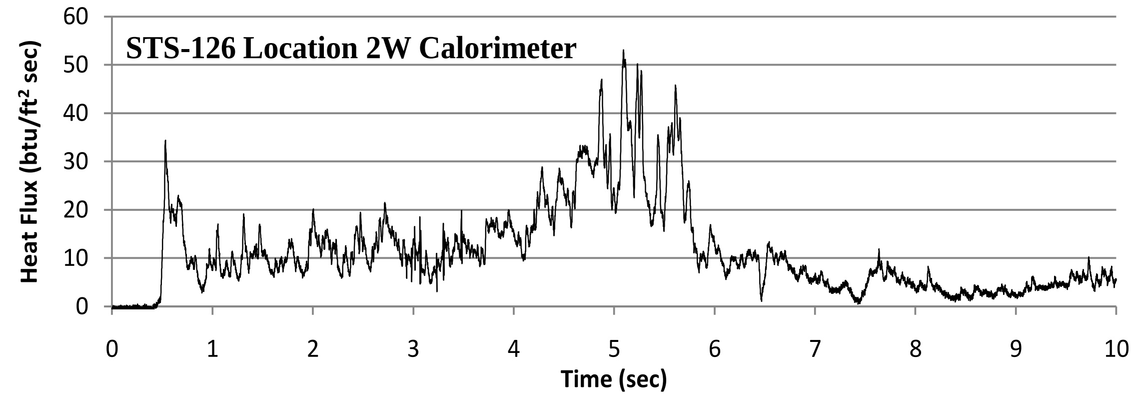
Time (sec)


STS-126 Location 2W Calorimeter
Heat Flux (btu/ft² sec)
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50
40
30
20
10
0
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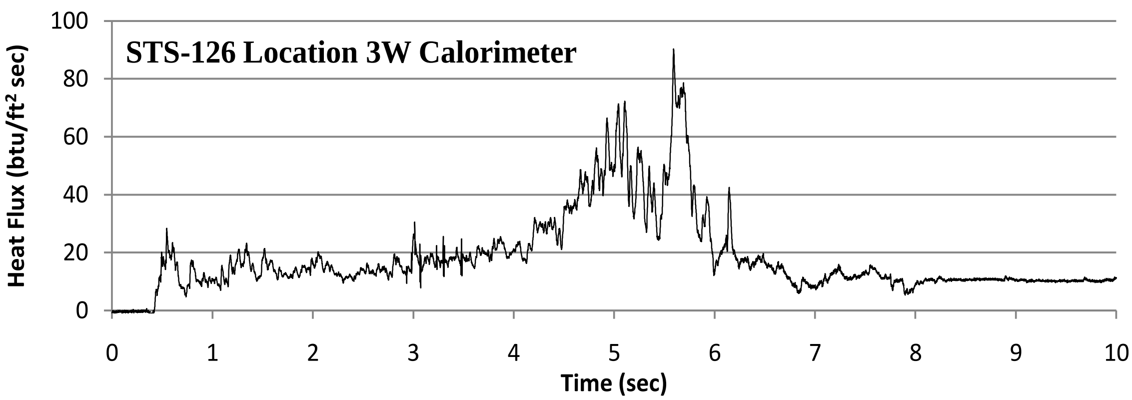
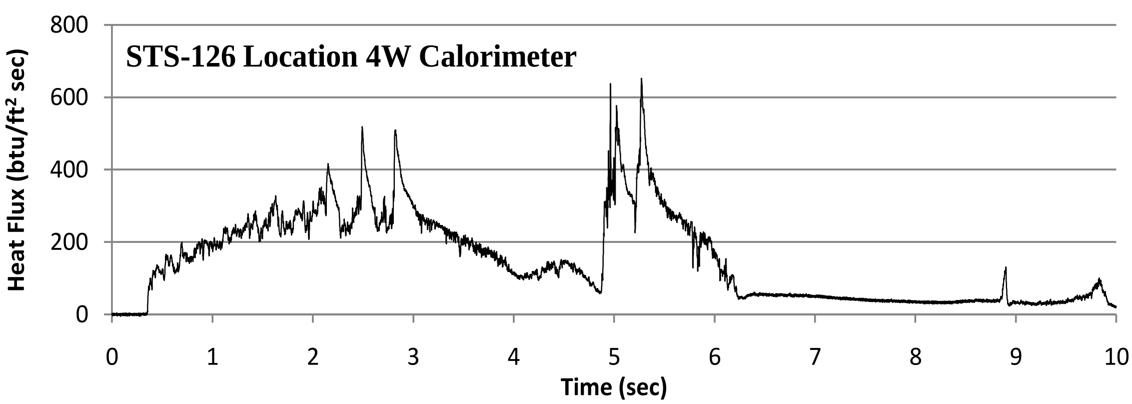
Time (sec)


STS-126 Location 3W Calorimeter
Heat Flux (btu/ft² sec)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec)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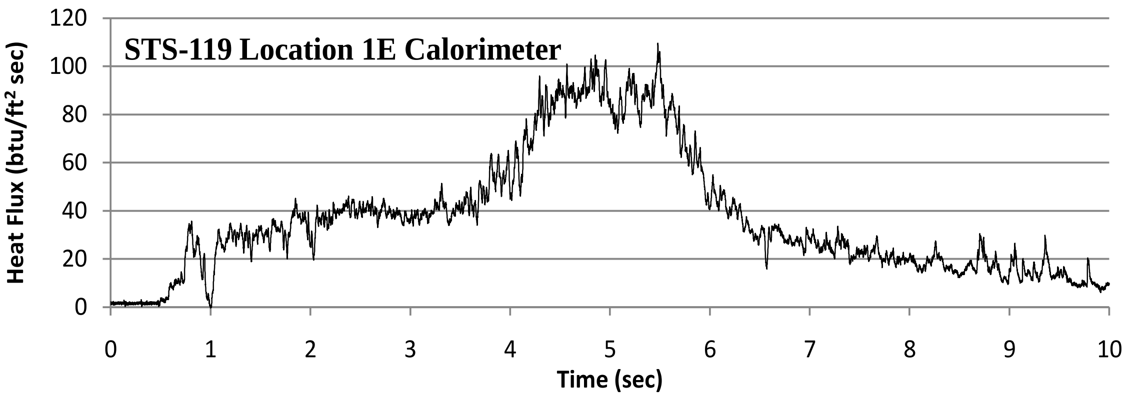
Heat Flux (btu/ft² sec)
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-119 Location 1E Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)
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40
60
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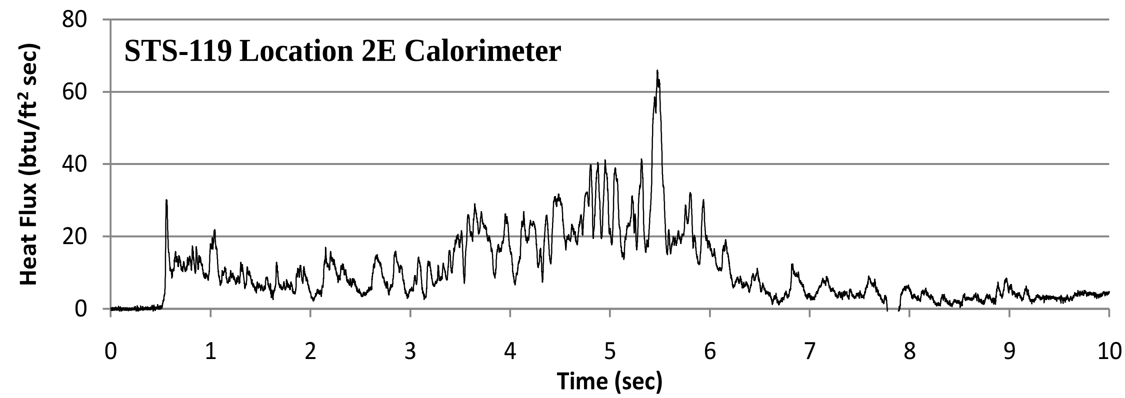
6
7
8
9
10


STS-119 Location 2E Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)
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60
80
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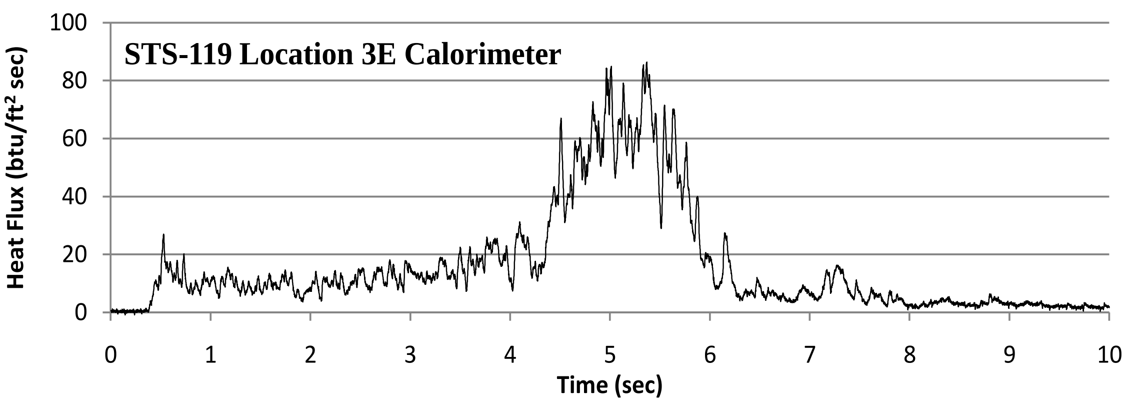
6
7
8
9
10


STS-119 Location 3E Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)
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1
2
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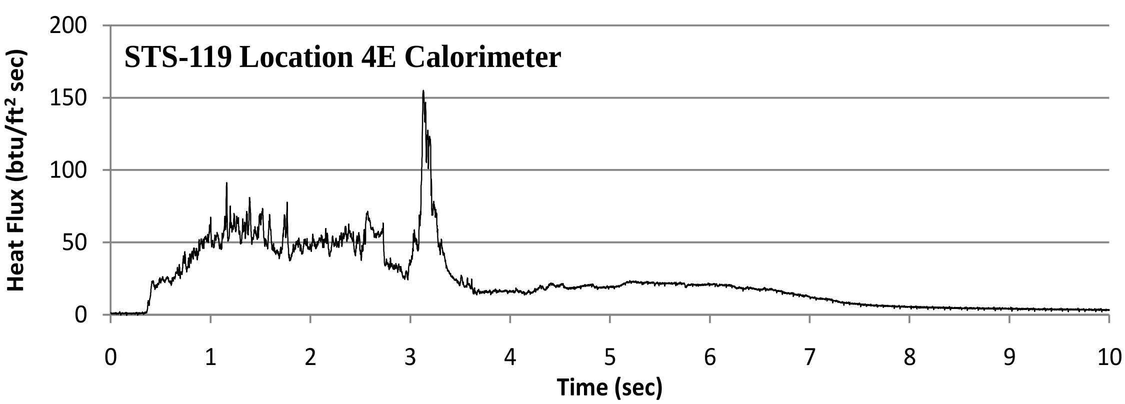
6
7
8
9
10


STS-119 Location 4E Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)
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50
100
150
200
0
1
2
3
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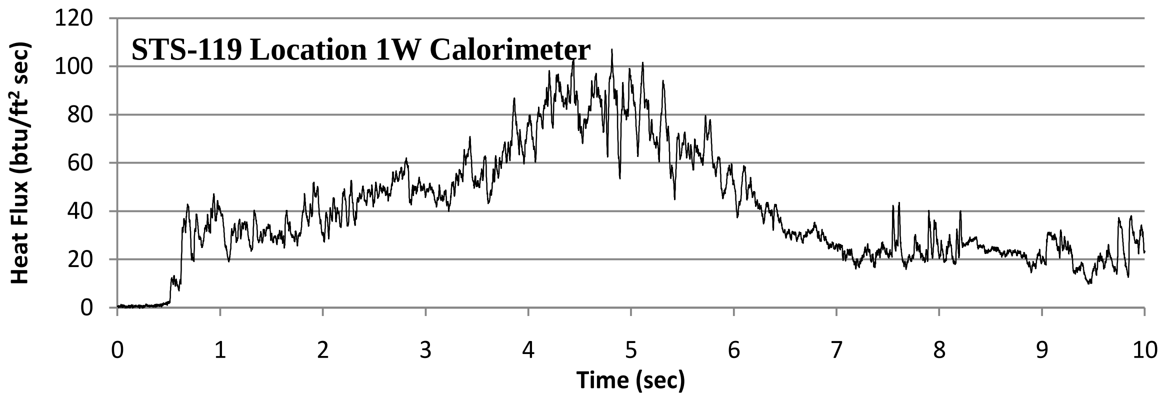
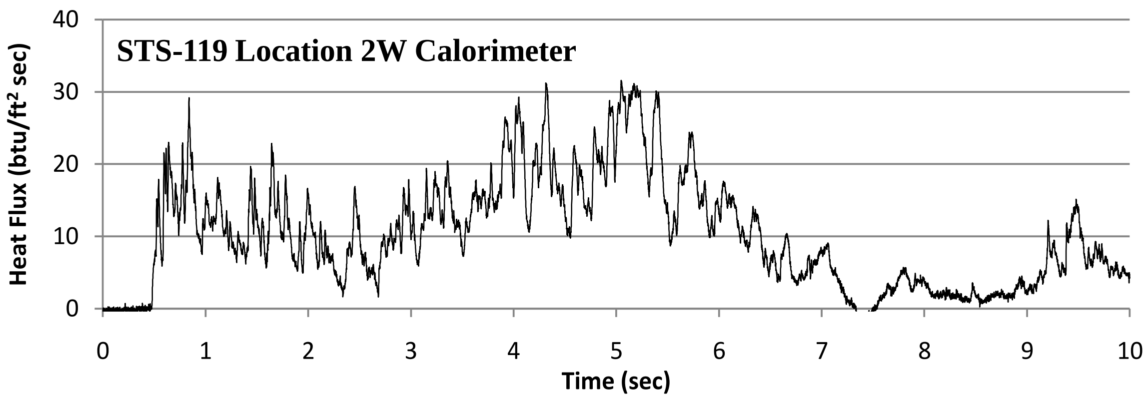
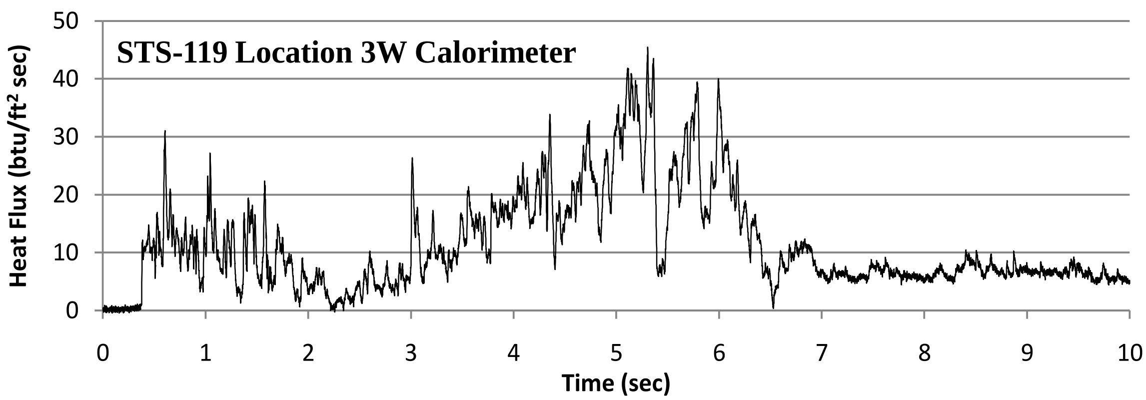
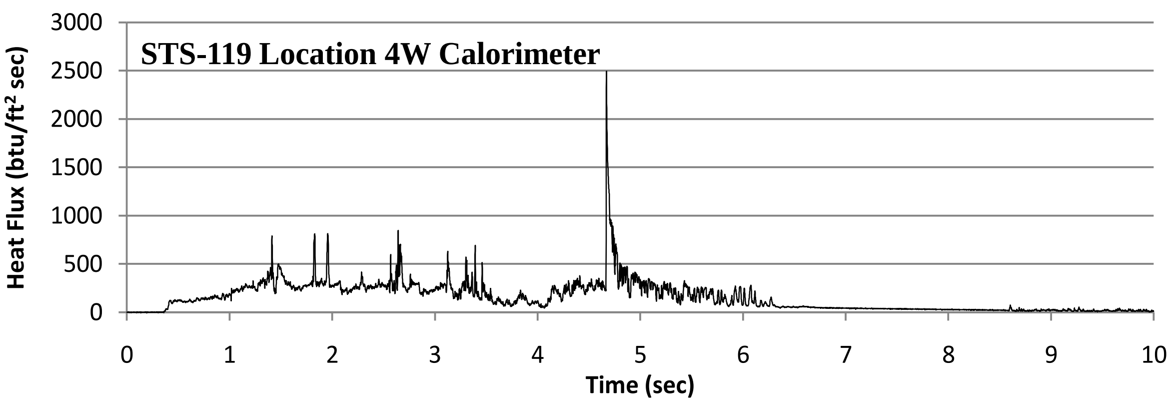
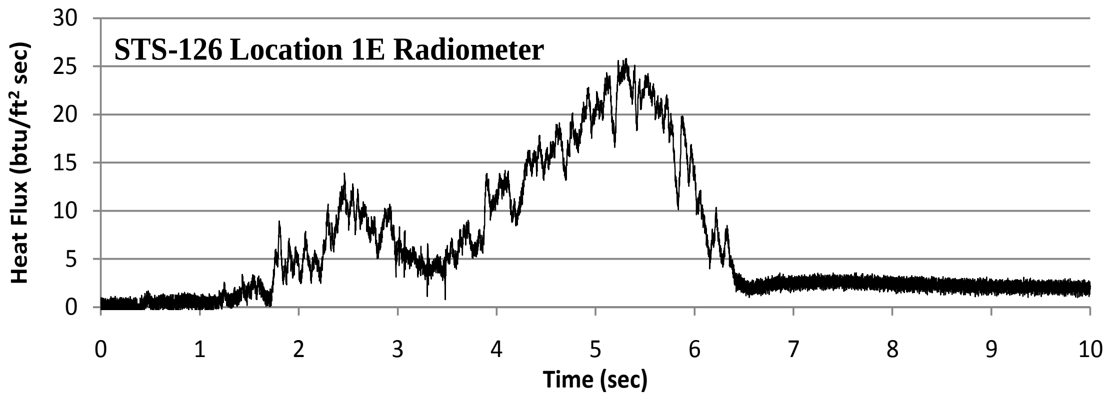
6
7
8
9
10

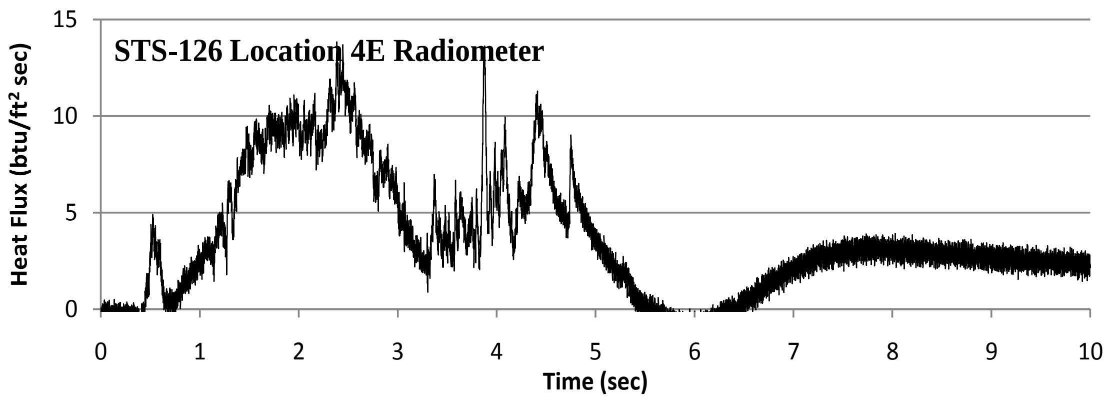

STS-119 Location 1W Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)

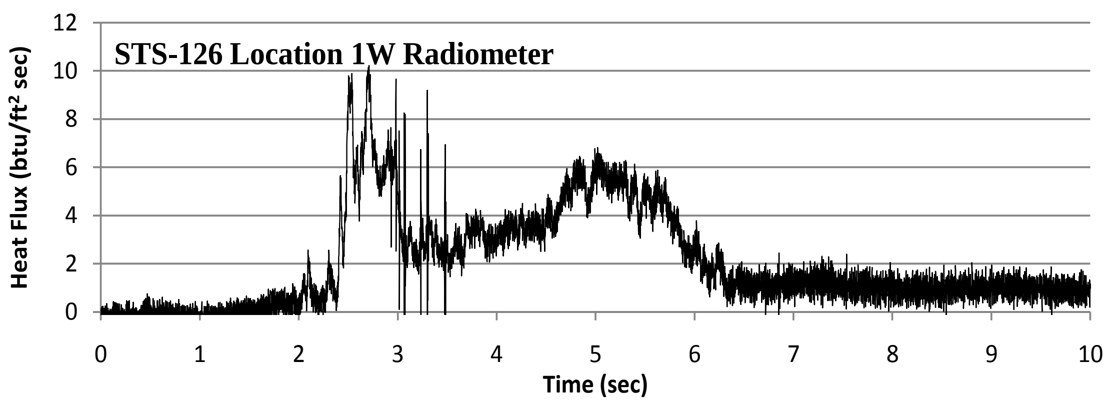

STS-119 Location 2W Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)

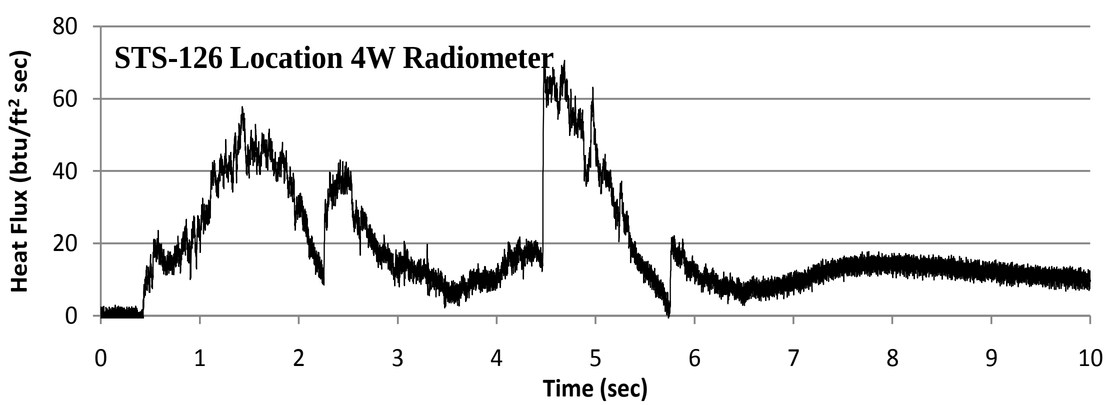

STS-119 Location 3W Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)

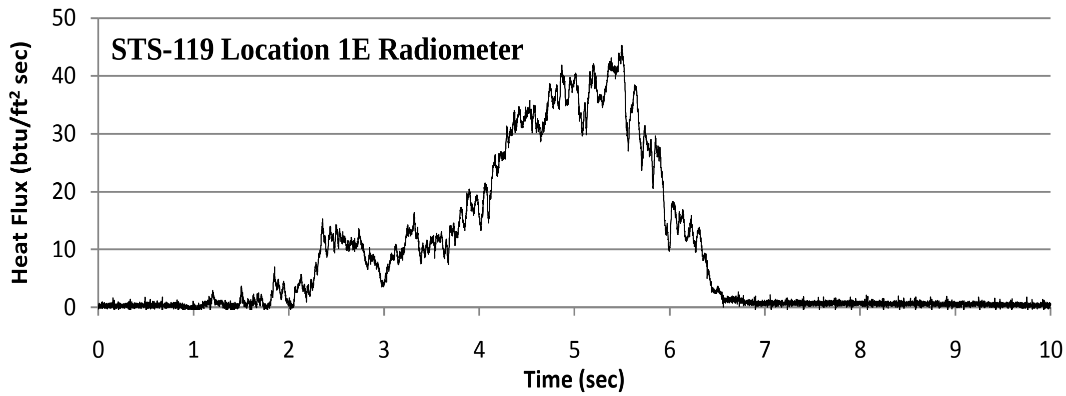

STS-119 Location 4W Calorimeter
Heat Flux (btu/ft² sec)
Time (sec)

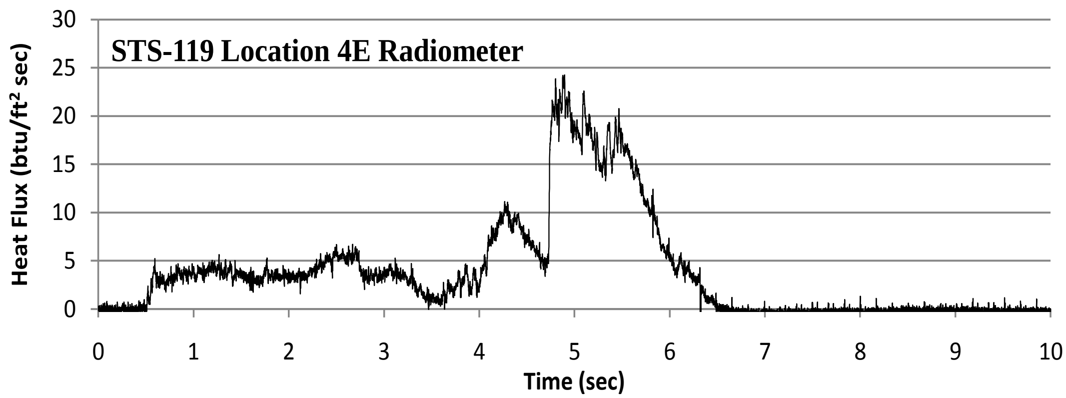

STS-126 Location 1E Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
5
10
15
20
25
30
0 1 2 3 4 5 6 7 8 9 10

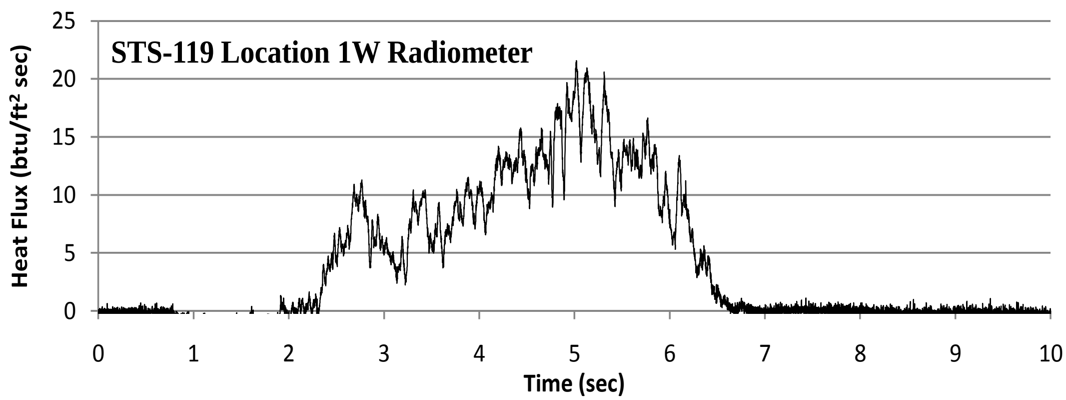

STS-126 Location 4E Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
5
10
15
0 1 2 3 4 5 6 7 8 9 10

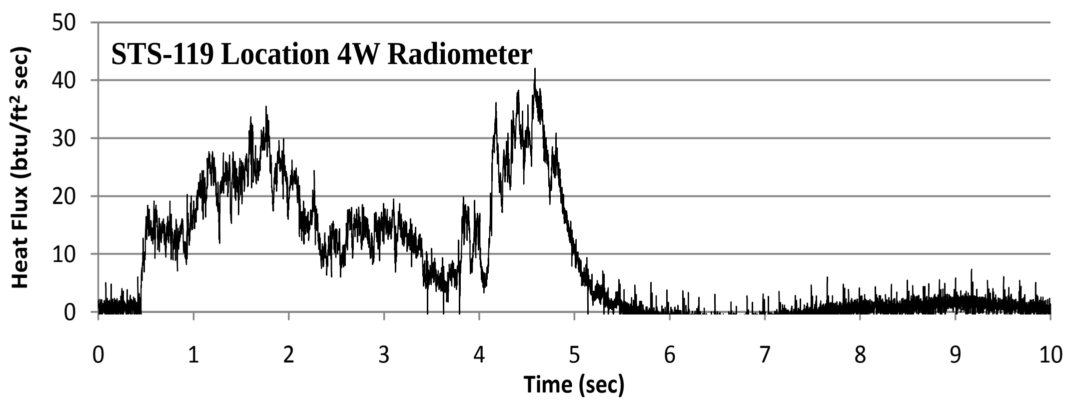

STS-126 Location 1W Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
2
4
6
8
10
12
0 1 2 3 4 5 6 7 8 9 10


STS-126 Location 4W Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
20
40
60
80
0 1 2 3 4 5 6 7 8 9 10

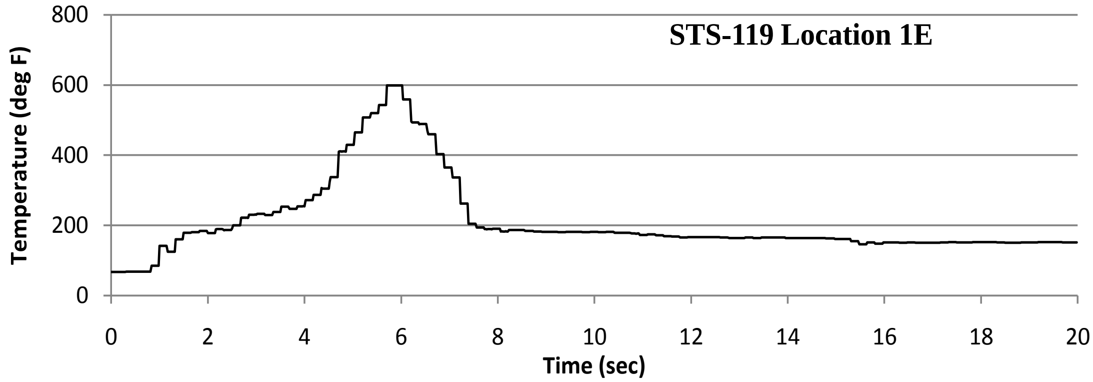

STS-119 Location 1E Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
8
9
10

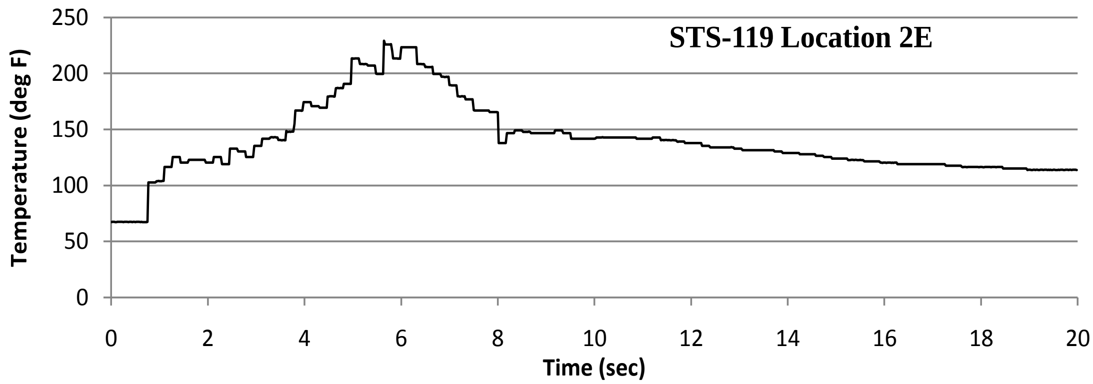

STS-119 Location 4E Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10

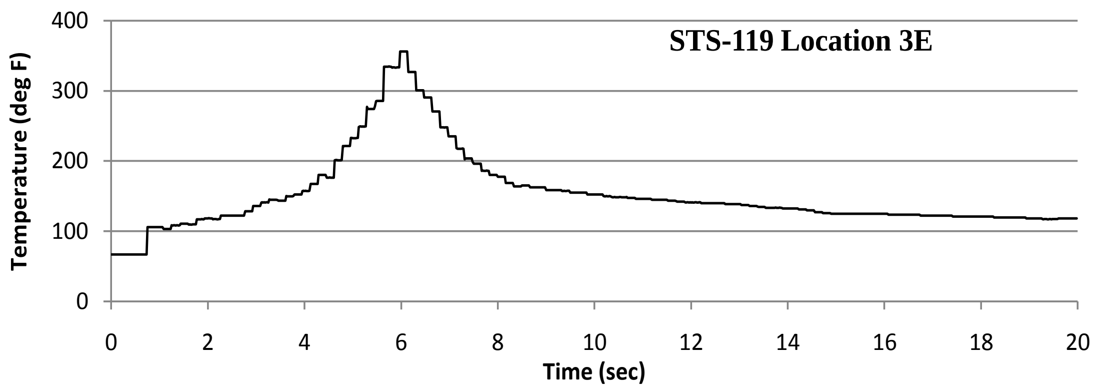

STS-119 Location 1W Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10

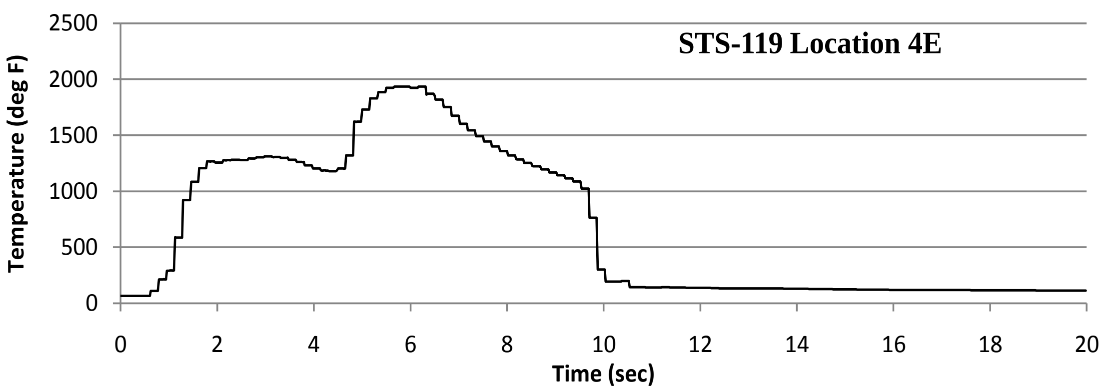

STS-119 Location 4W Radiometer
Heat Flux (btu/ft² sec)
Time (sec)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
8
9
10

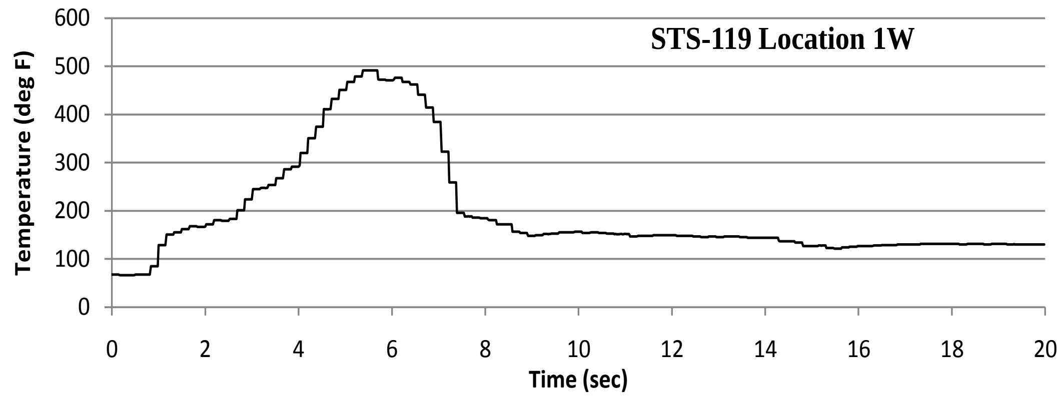
5.3 Charts of Temperature Data

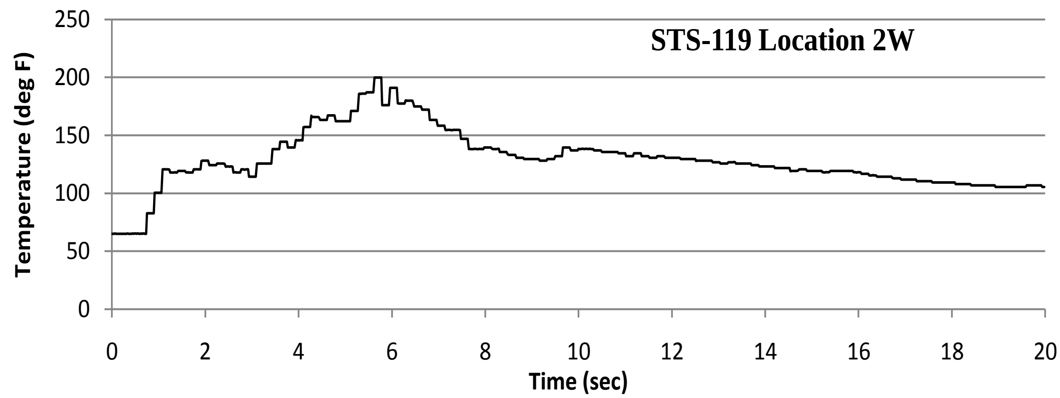


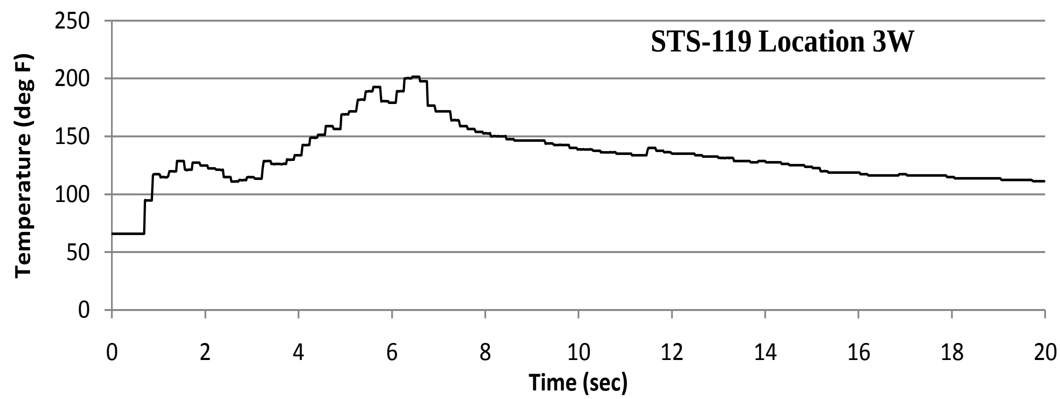


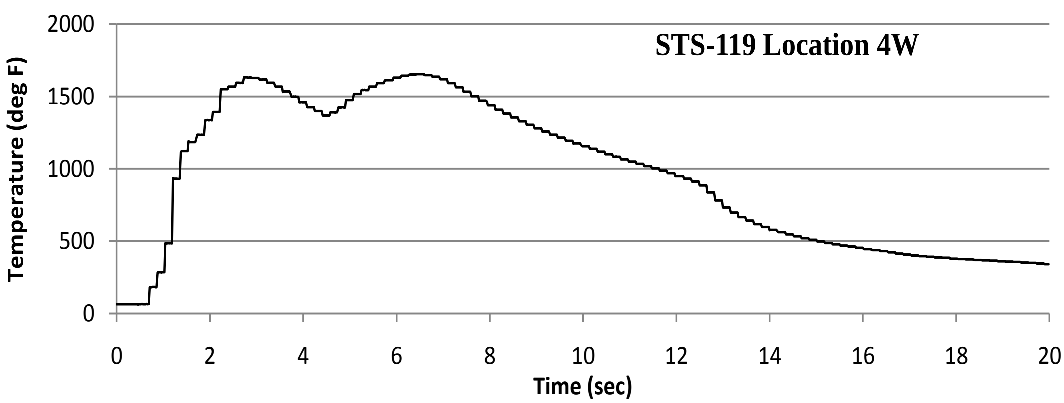


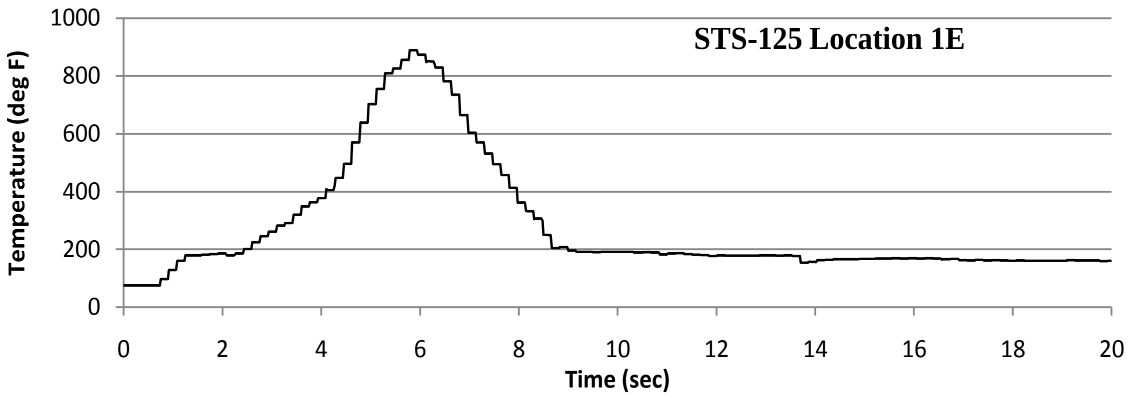


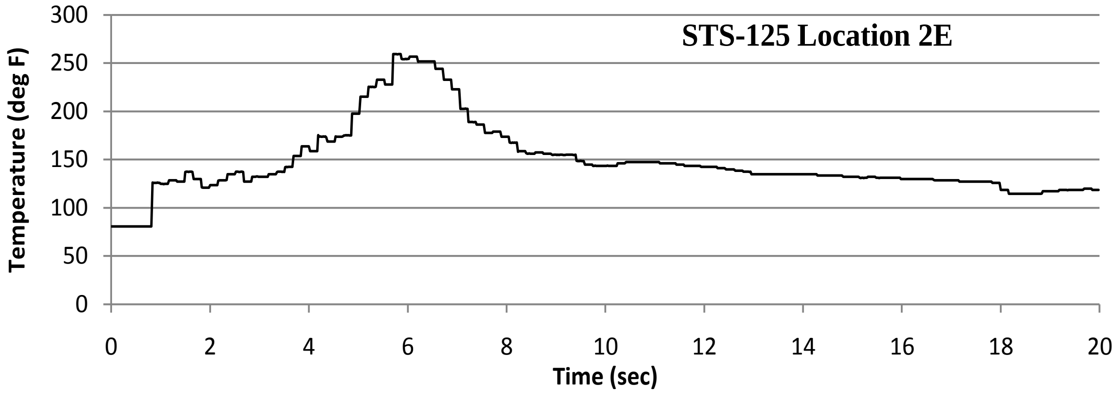

STS-119 Location 1W
Temperature (deg F)
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

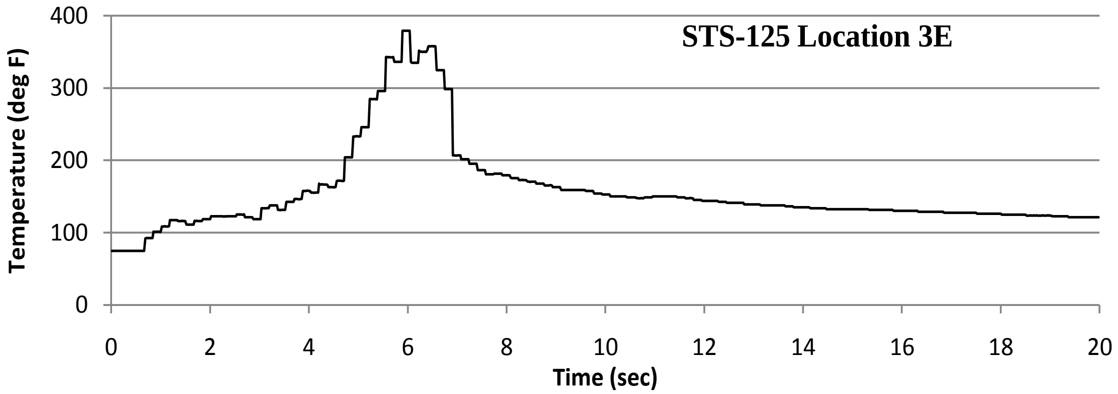

STS-119 Location 2W
Temperature (deg F)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

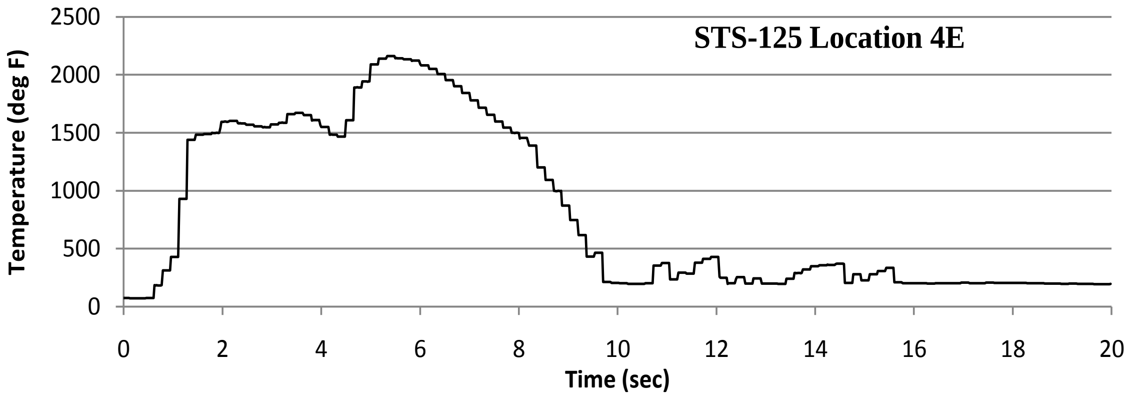

STS-119 Location 3W
Temperature (deg F)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

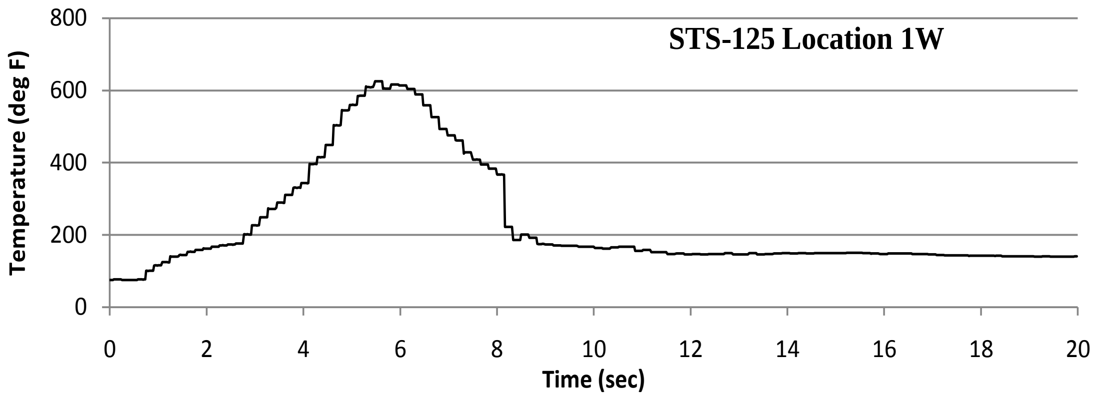

STS-119 Location 4W
Temperature (deg F)
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

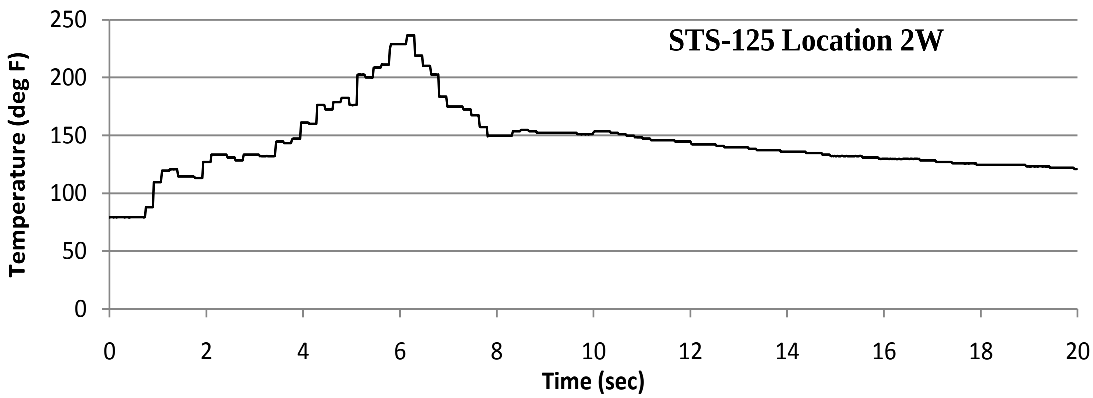

STS-125 Location 1E
Temperature (deg F)
Time (sec)
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
16
18
20

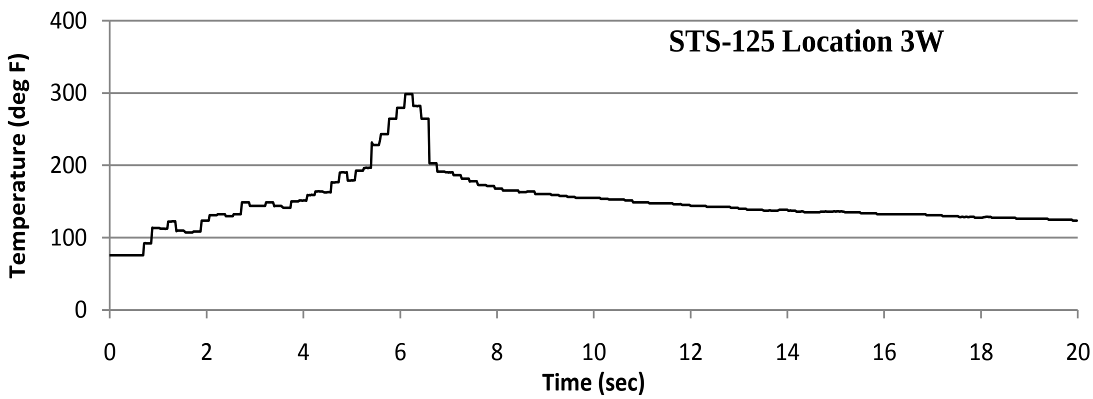

STS-125 Location 2E
Temperature (deg F)
Time (sec)
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20

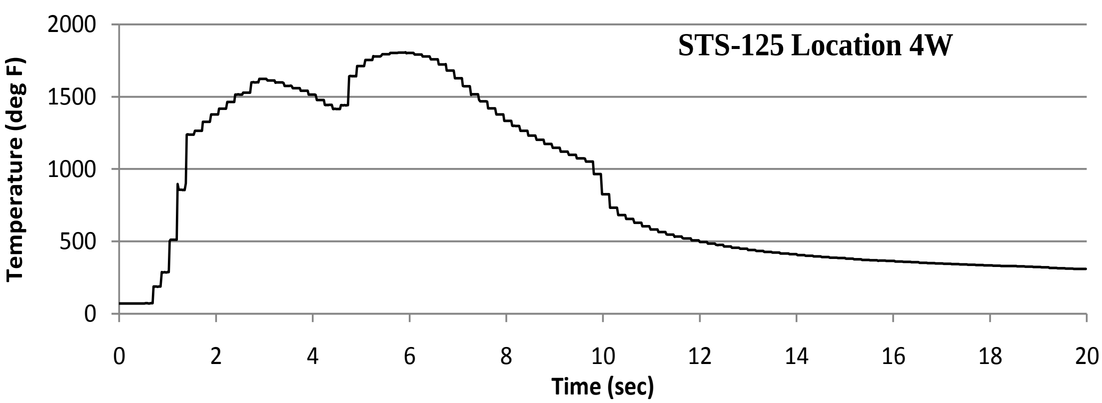

STS-125 Location 3E
Temperature (deg F)
Time (sec)
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20

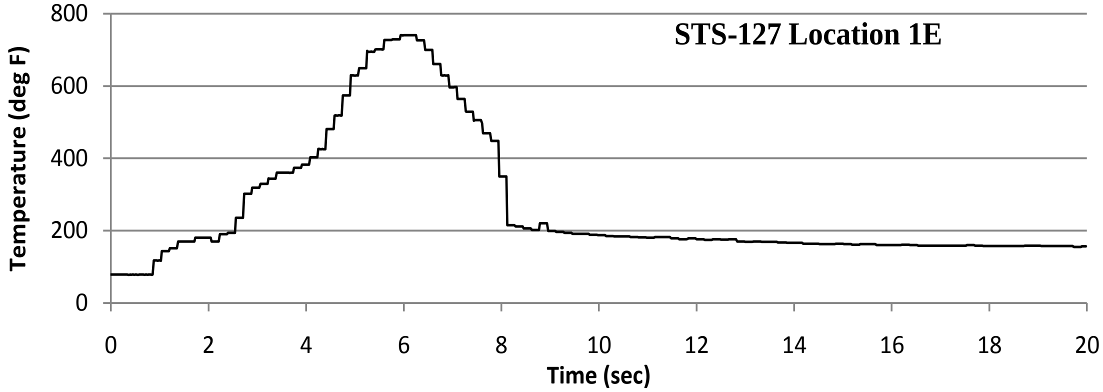

STS-125 Location 4E
Temperature (deg F)
Time (sec)
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
18
20

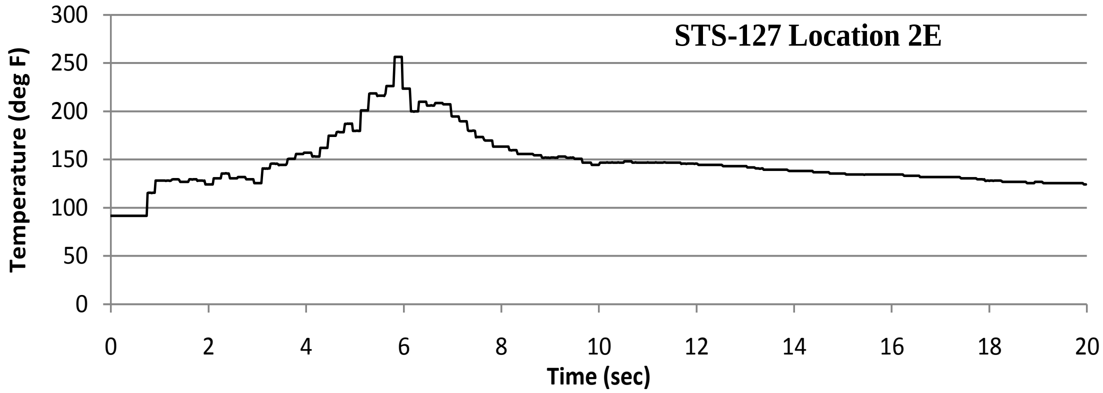

STS-125 Location 1W
Temperature (deg F)
Time (sec)
0
200
400
600
800
0
2
4
6
8
10
12
14
16
18
20

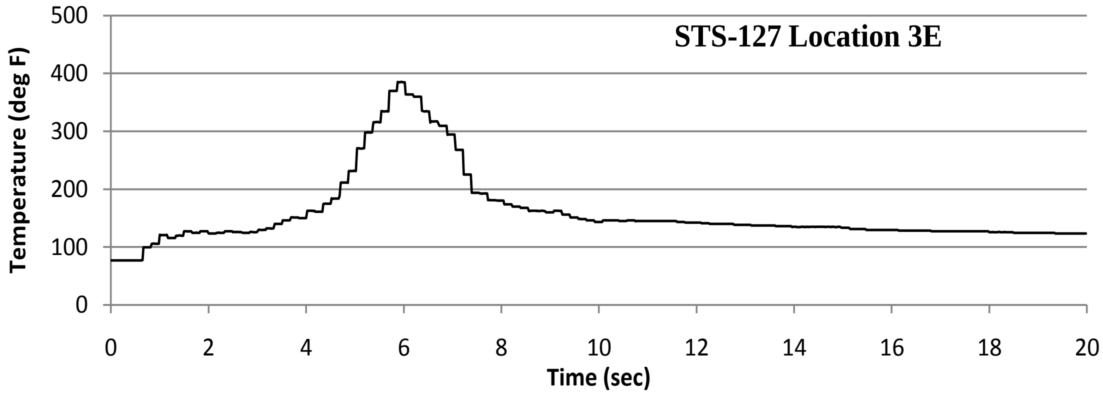

STS-125 Location 2W
Temperature (deg F)
Time (sec)
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
20

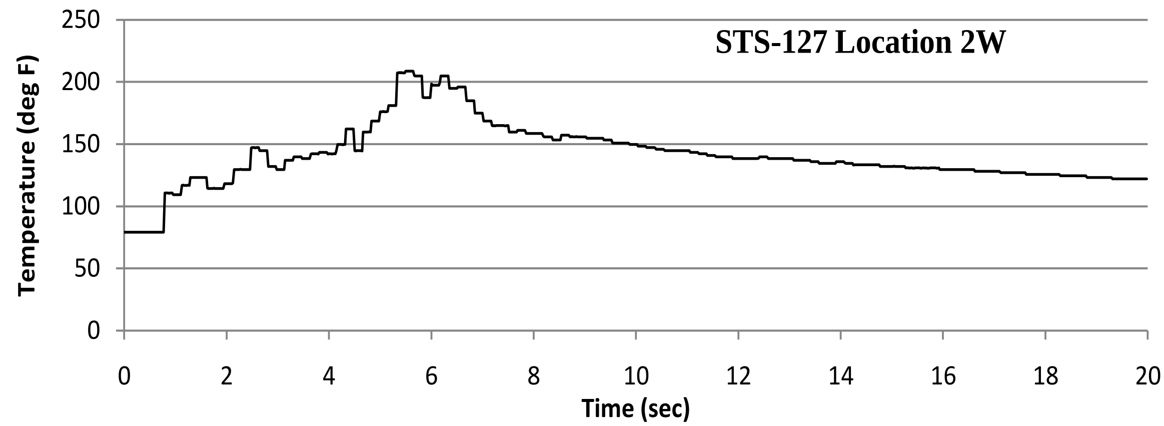

STS-125 Location 3W
Temperature (deg F)
Time (sec)
0
100
200
300
400
0
2
4
6
8
10
12
14
16
18
20

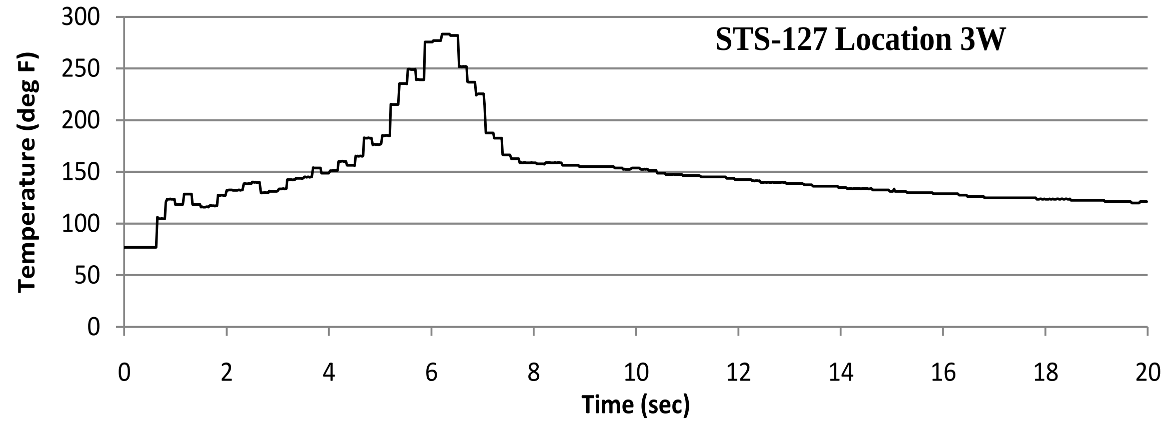

STS-125 Location 4W
Temperature (deg F)
Time (sec)
0
500
1000
1500
2000
0
2
4
6
8
10
12
14
16
18
20

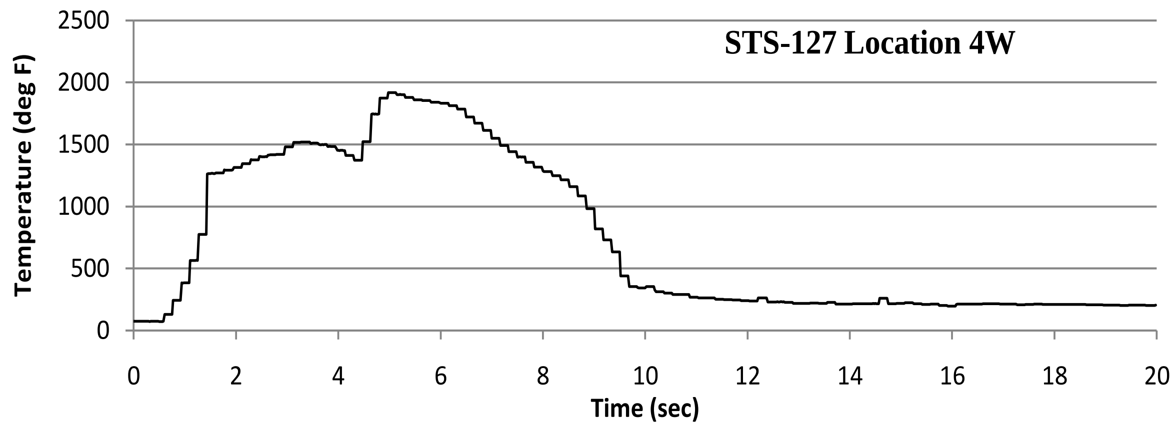

STS-127 Location 1E
Temperature (deg F)
800
600
400
200
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)


STS-127 Location 2E
Temperature (deg F)
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

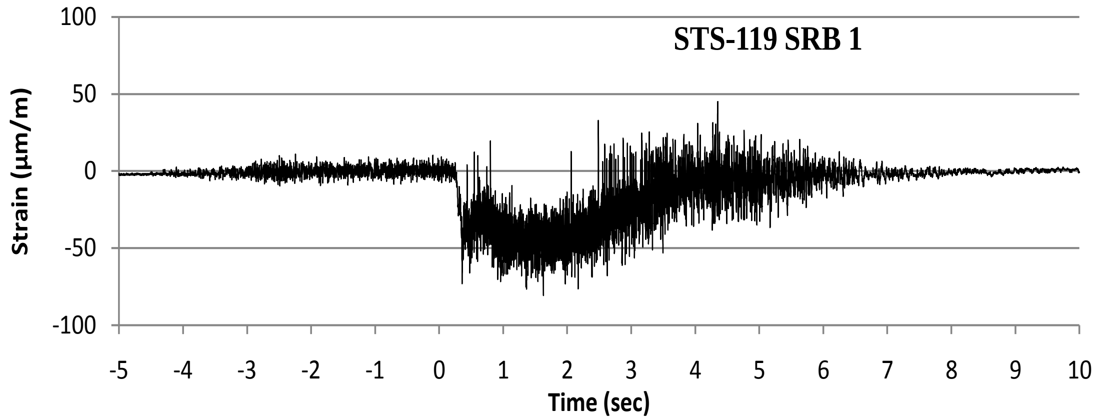

STS-127 Location 3E
Temperature (deg F)
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

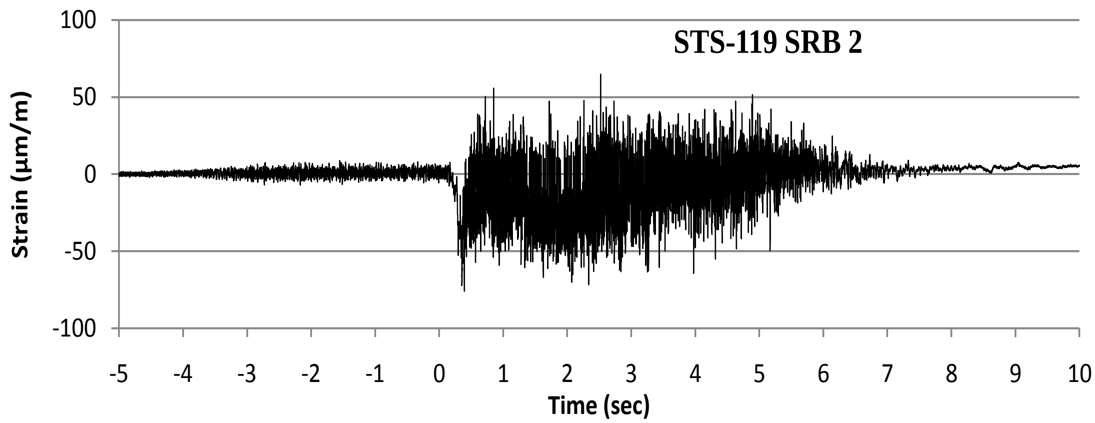

STS-127 Location 2W
Temperature (deg F)
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

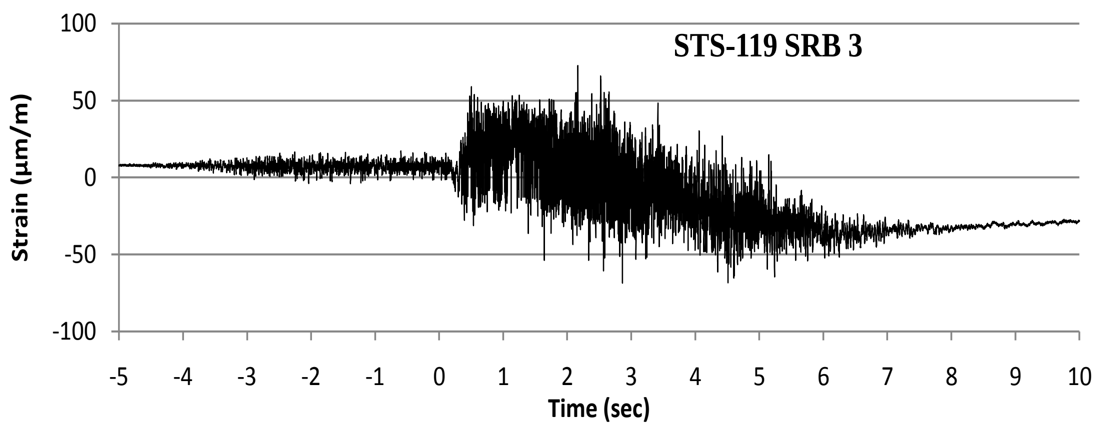

STS-127 Location 3W
Temperature (deg F)
0
50
100
150
200
250
300
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

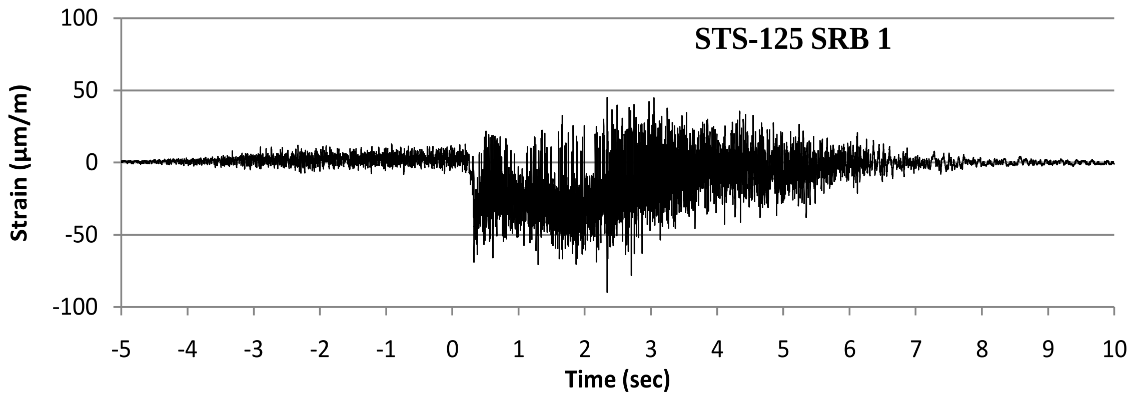

STS-127 Location 4W
Temperature (deg F)
0
500
1000
1500
2000
2500
0
2
4
6
8
10
12
14
16
18
20
Time (sec)

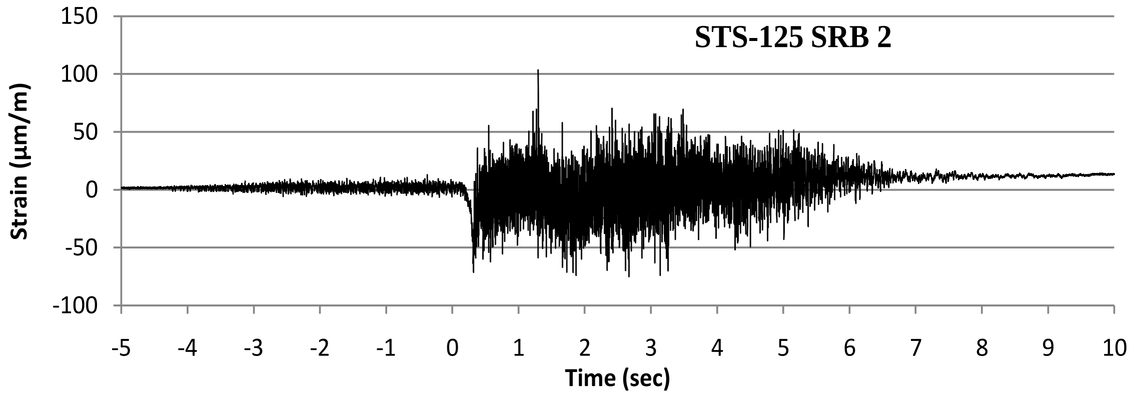
5.4 Charts of Strain Data

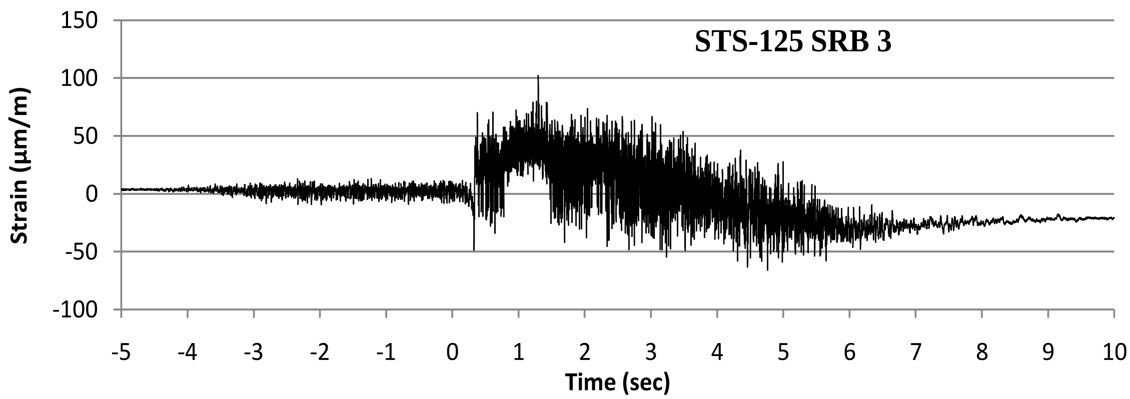


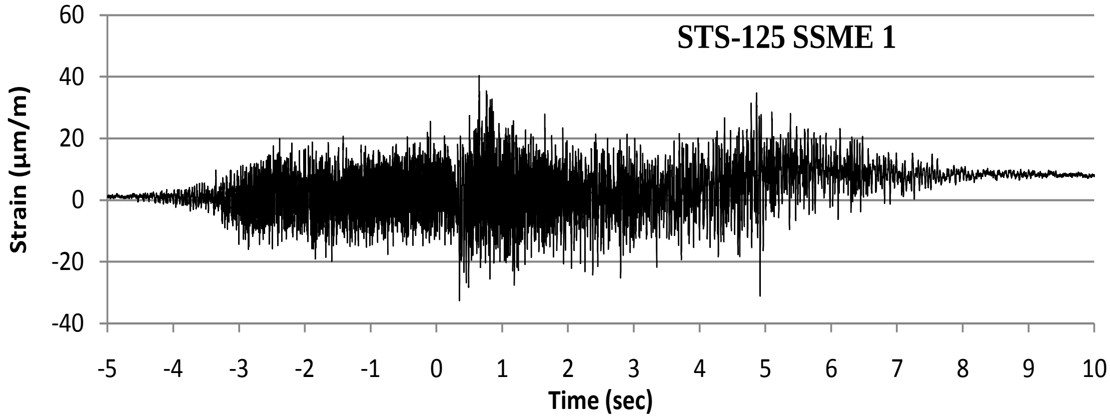


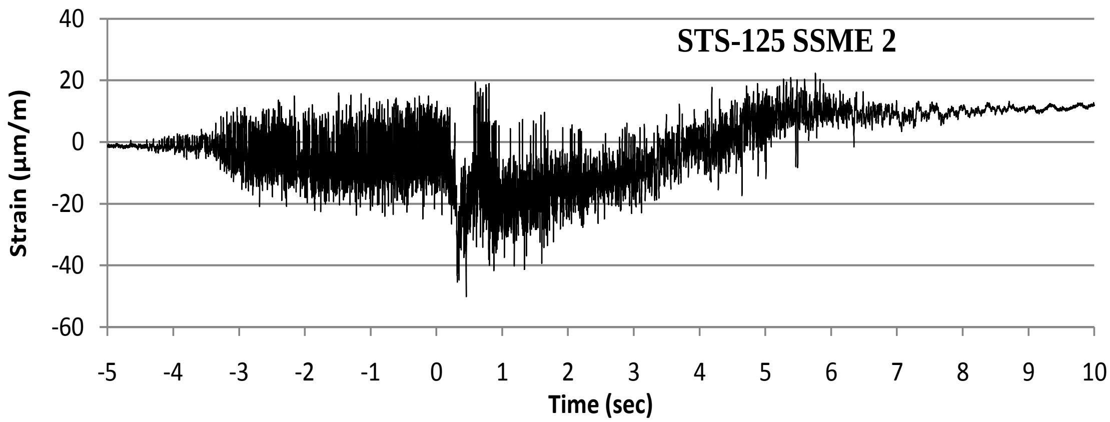


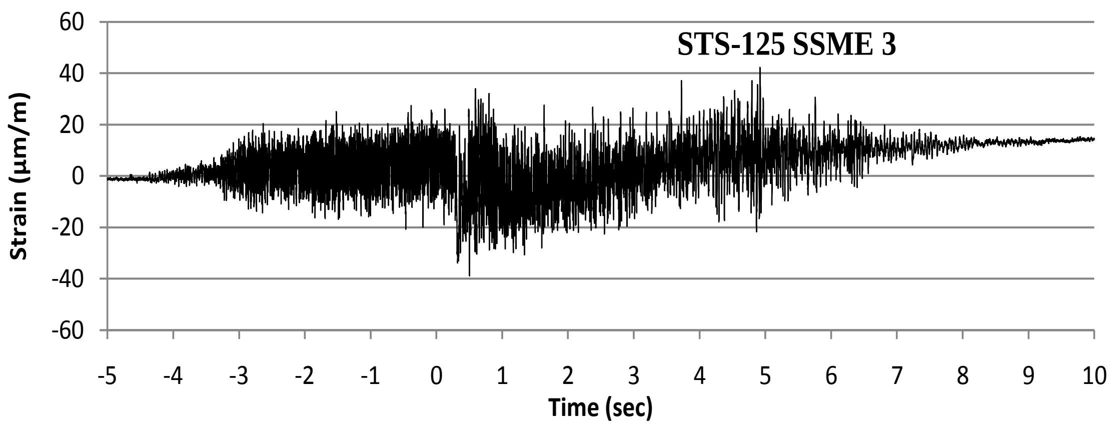

STS-125 SRB 1
Strain (µm/m)
Time (sec)

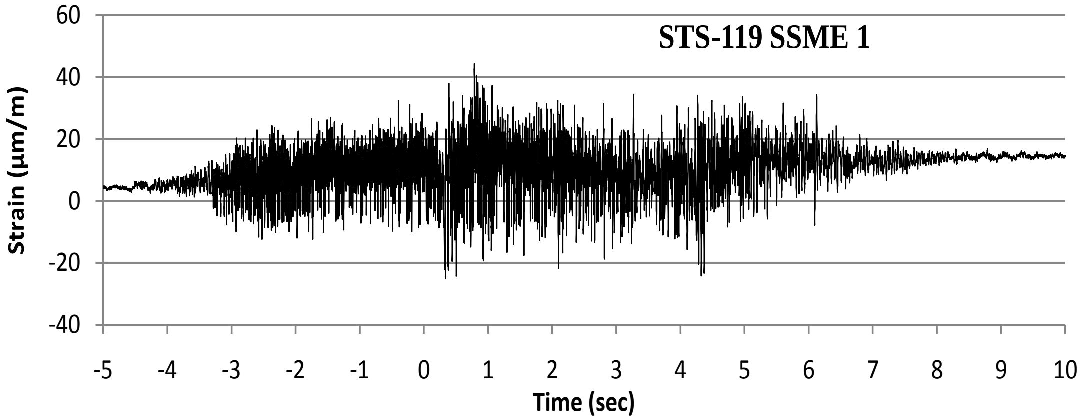

STS-125 SRB 2
Strain (µm/m)
Time (sec)

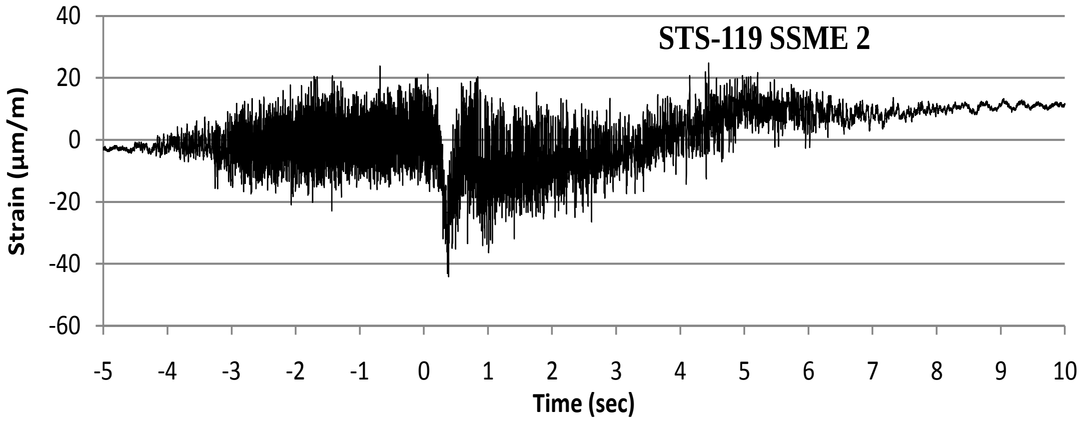

STS-125 SRB 3
Strain (µm/m)
Time (sec)

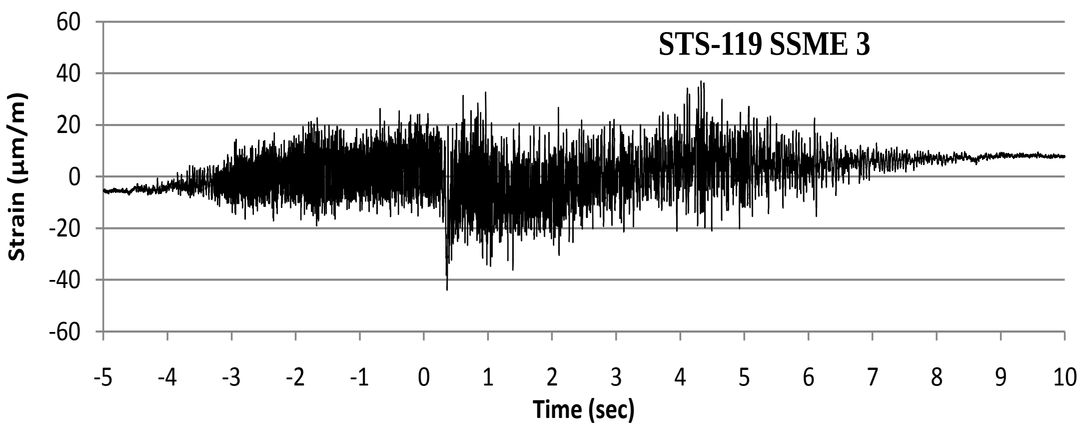

STS-125 SSME 1
Strain (µm/m)
Time (sec)
60
40
20
0
-20
-40
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10


STS-125 SSME 2
Strain (µm/m)
Time (sec)
40
20
0
-20
-40
-60
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

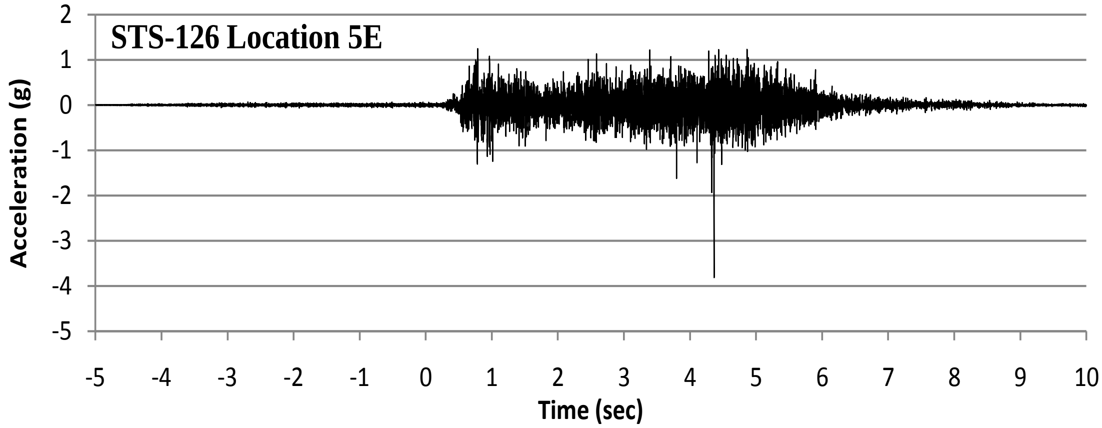

STS-125 SSME 3
Strain (µm/m)
Time (sec)
60
40
20
0
-20
-40
-60
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

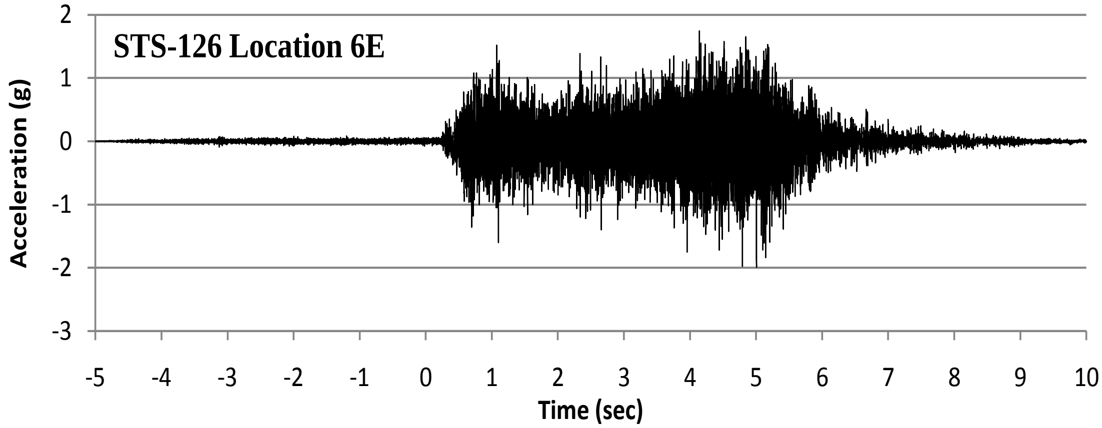

STS-119 SSME 1
Strain (µm/m)
Time (sec)
60
40
20
0
-20
-40
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

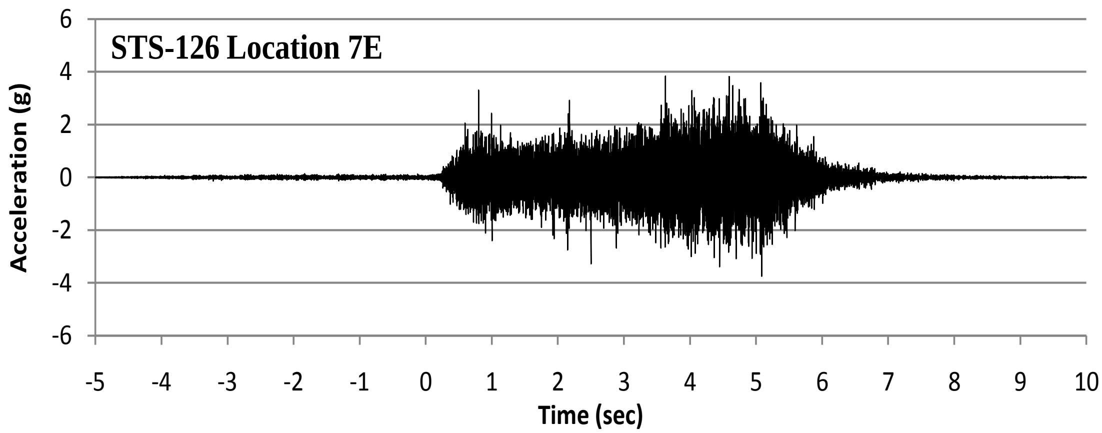

STS-119 SSME 2
Strain (µm/m)
Time (sec)
40
20
0
-20
-40
-60
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

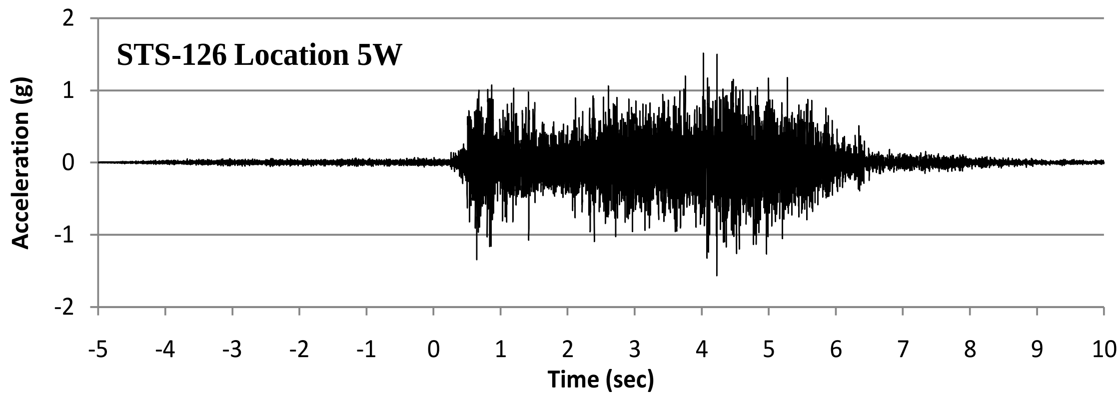

STS-119 SSME 3
Strain (µm/m)
Time (sec)
60
40
20
0
-20
-40
-60
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

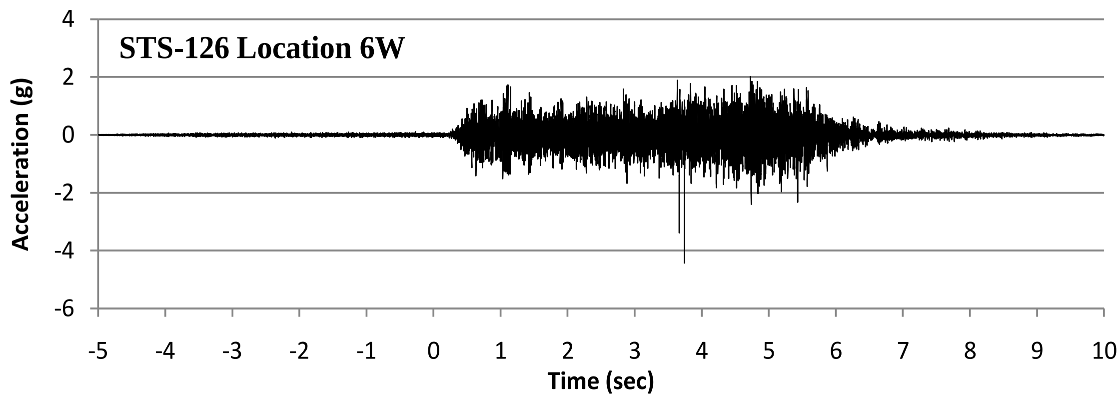
5.5 Charts of Acceleration Data

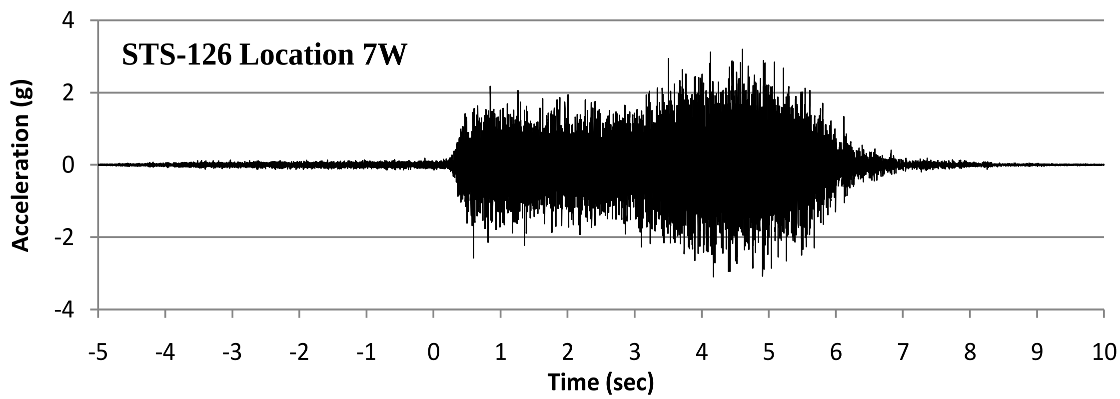


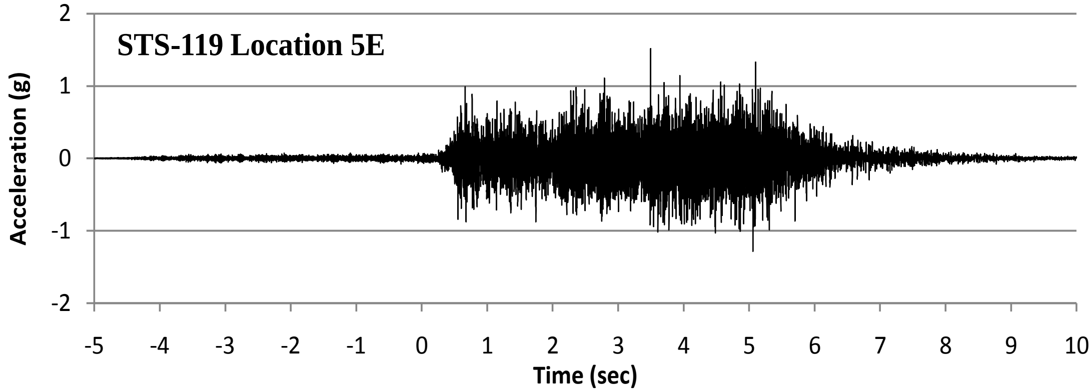


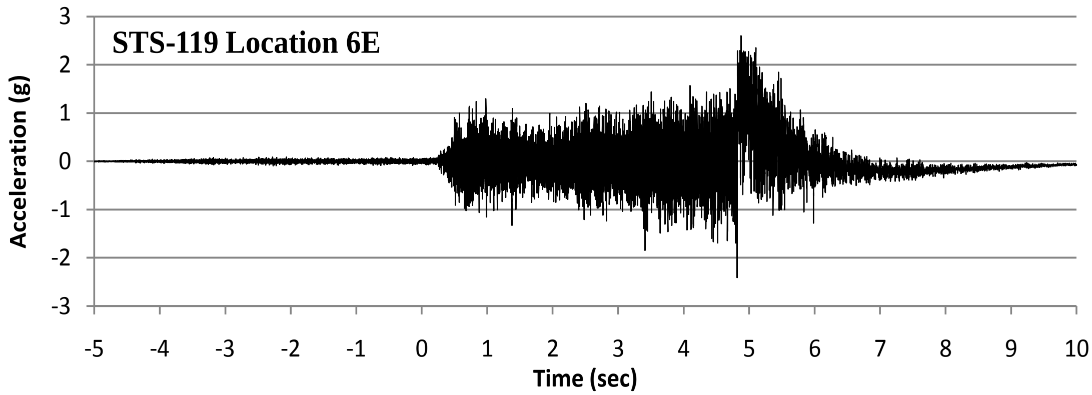


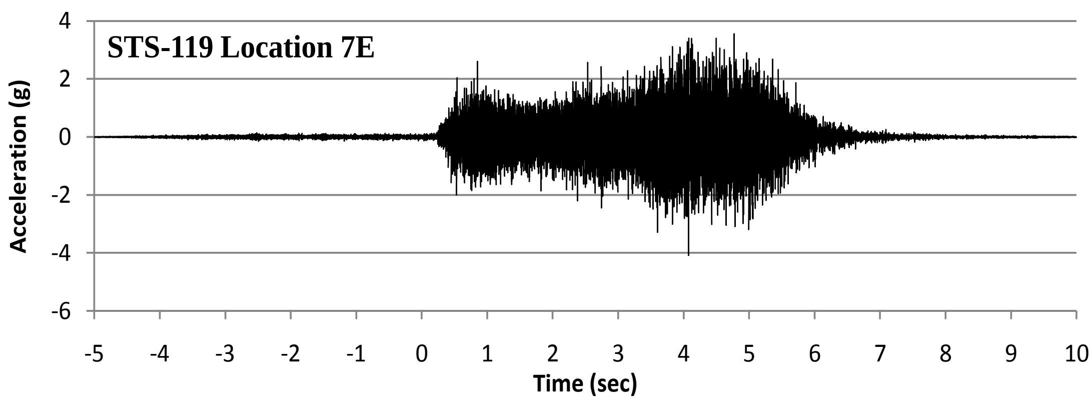

STS-126 Location 5W
Acceleration (g)
Time (sec)
2
1
0
-1
-2
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

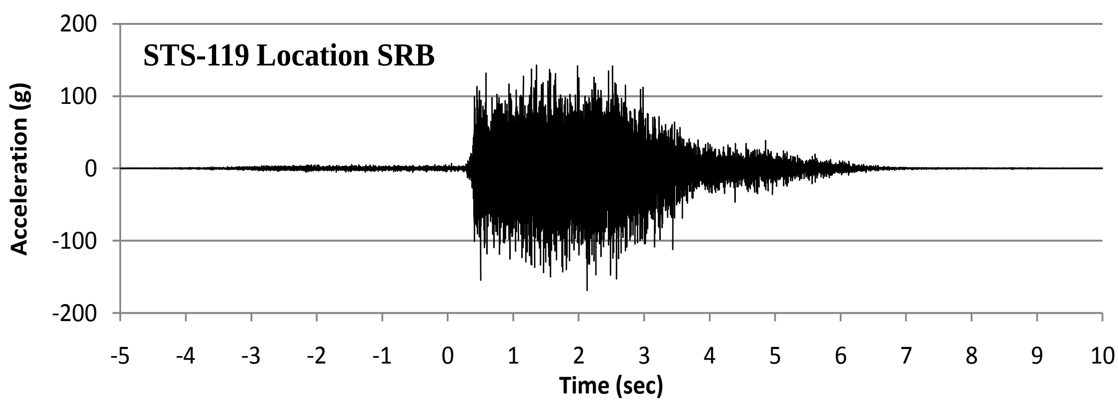

STS-126 Location 6W
Acceleration (g)
Time (sec)
4
2
0
-2
-4
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

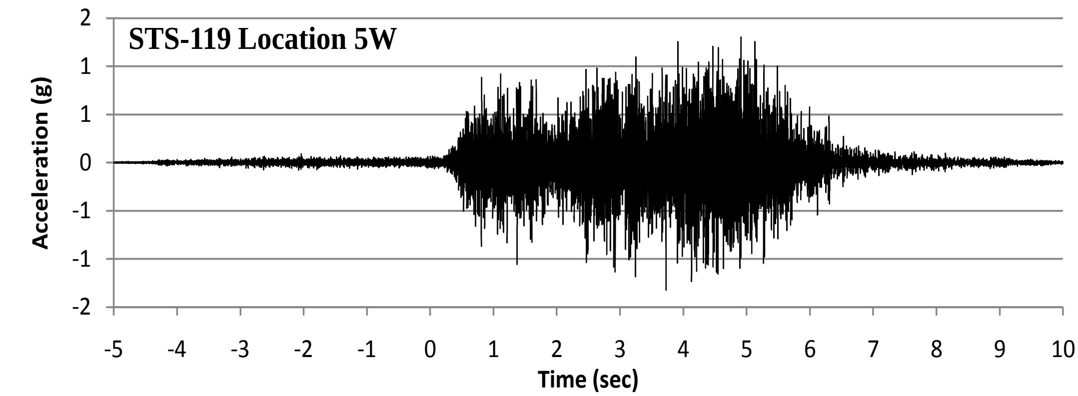

STS-126 Location 7W
Acceleration (g)
Time (sec)
4
2
0
-2
-4
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10

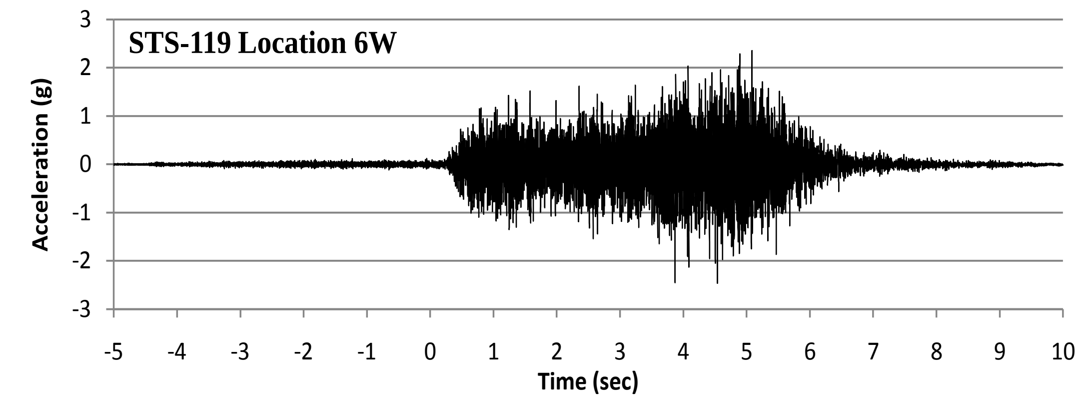

STS-119 Location 5E
Acceleration (g)
Time (sec)

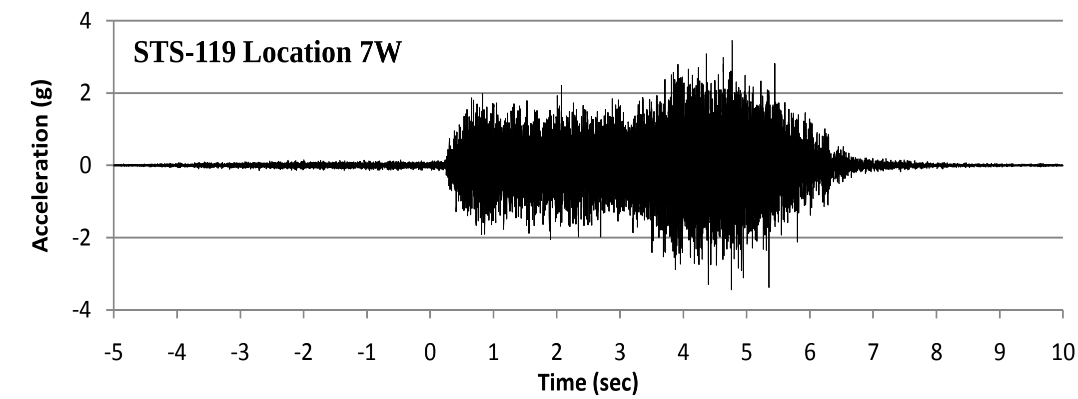

STS-119 Location 6E
Acceleration (g)
Time (sec)


STS-119 Location 7E
Acceleration (g)
Time (sec)


STS-119 Location SRB
Acceleration (g)
Time (sec)


STS-119 Location 5W
Acceleration (g)
2
1
1
0
-1
-1
-2
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-119 Location 6W
Acceleration (g)
3
2
1
0
-1
-2
-3
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-119 Location 7W
Acceleration (g)
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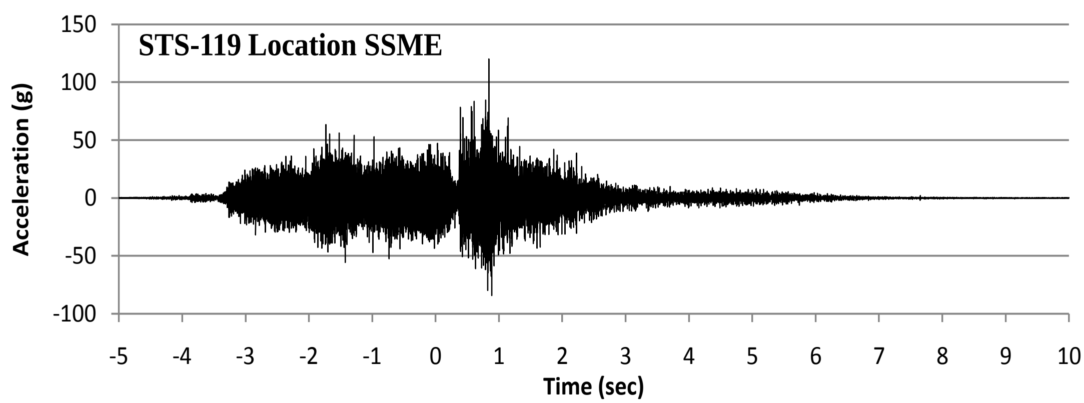
2
0
-2
-4
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-119 Location SSME
Acceleration (g)
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100
50
0
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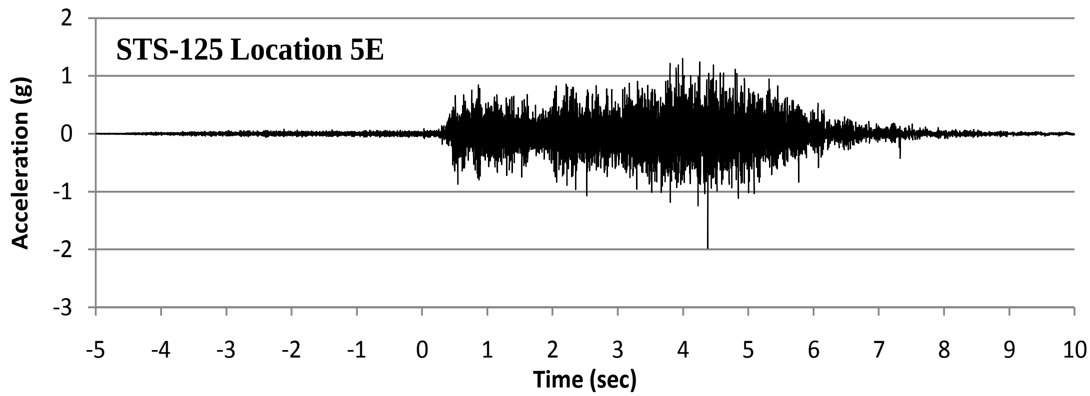
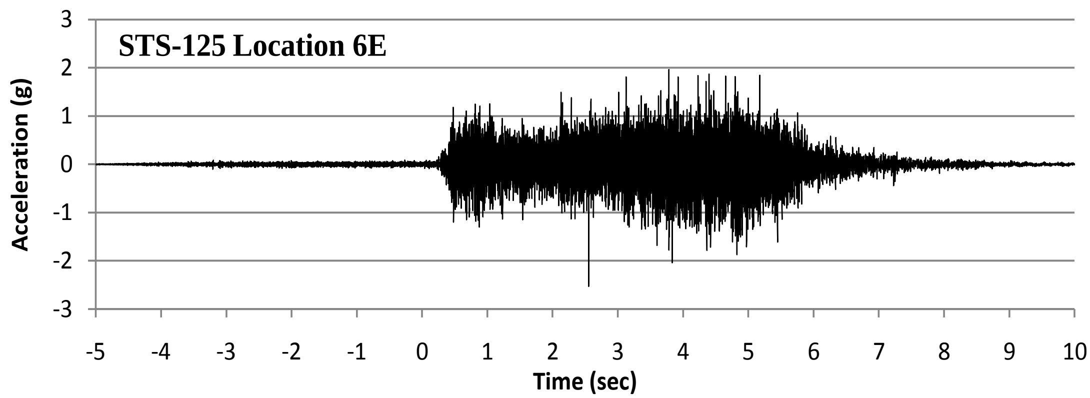
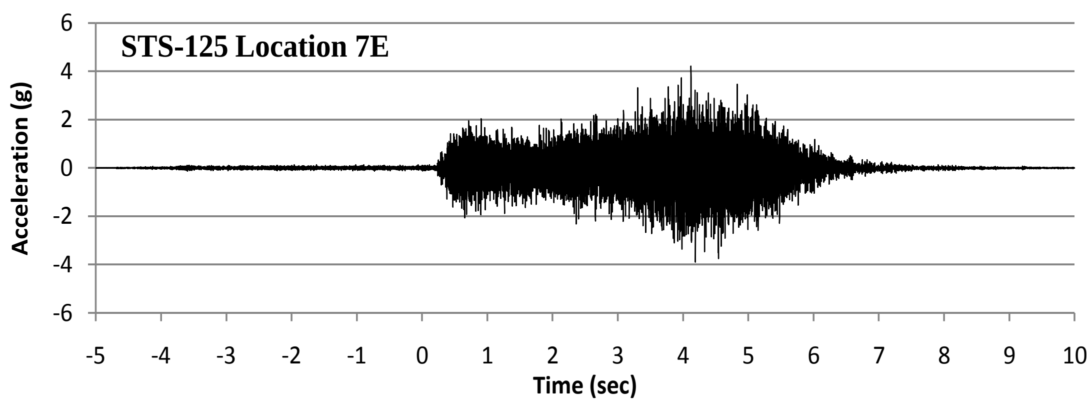
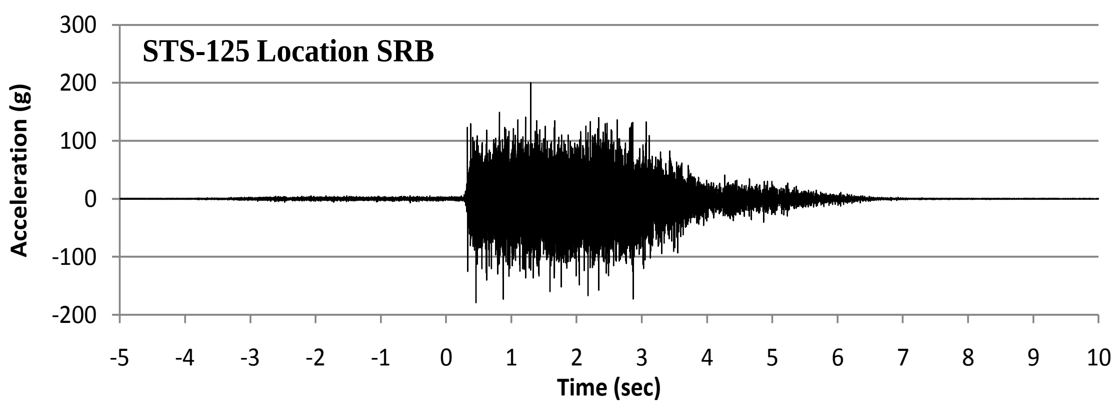
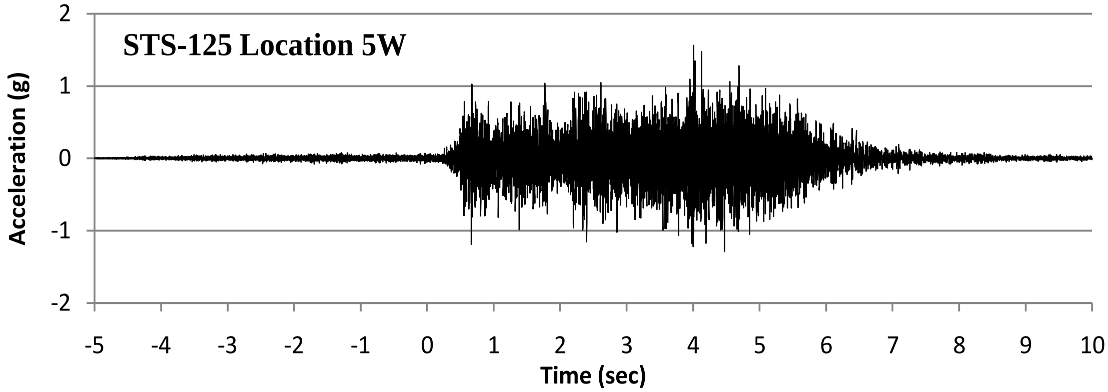
-100
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)

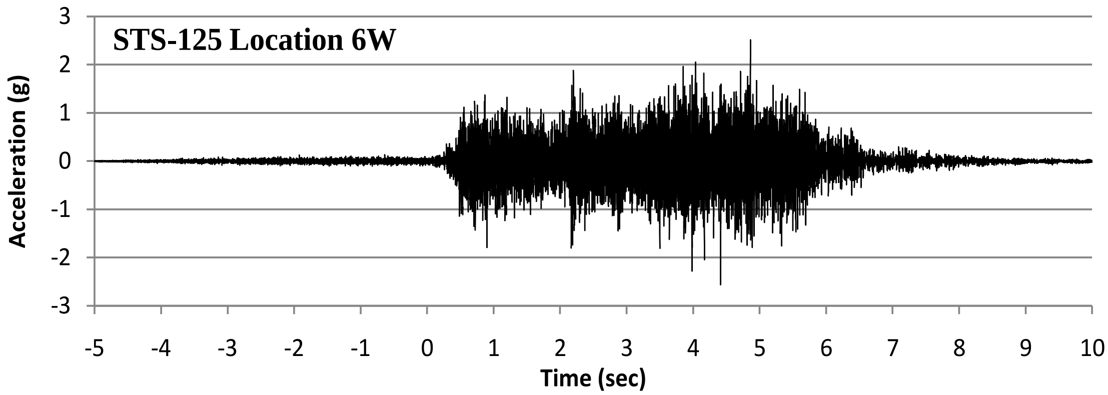

STS-125 Location 5E
Acceleration (g)
Time (sec)

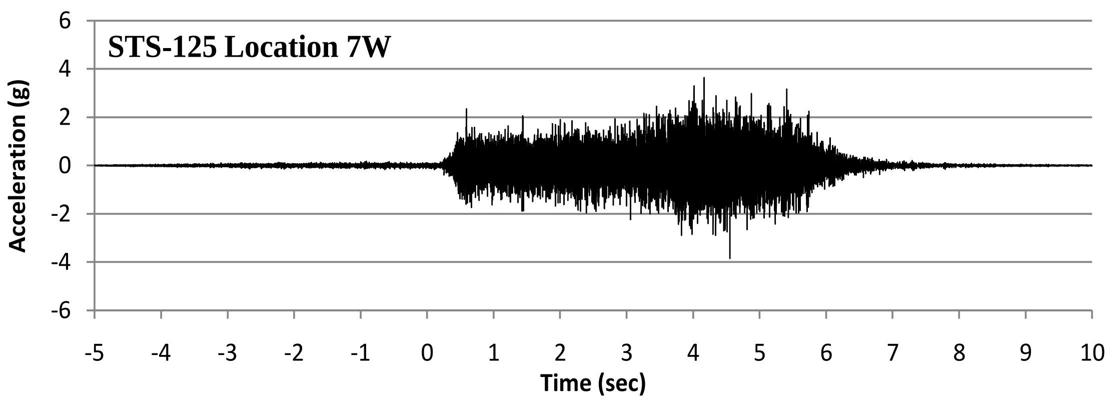

STS-125 Location 6E
Acceleration (g)
Time (sec)

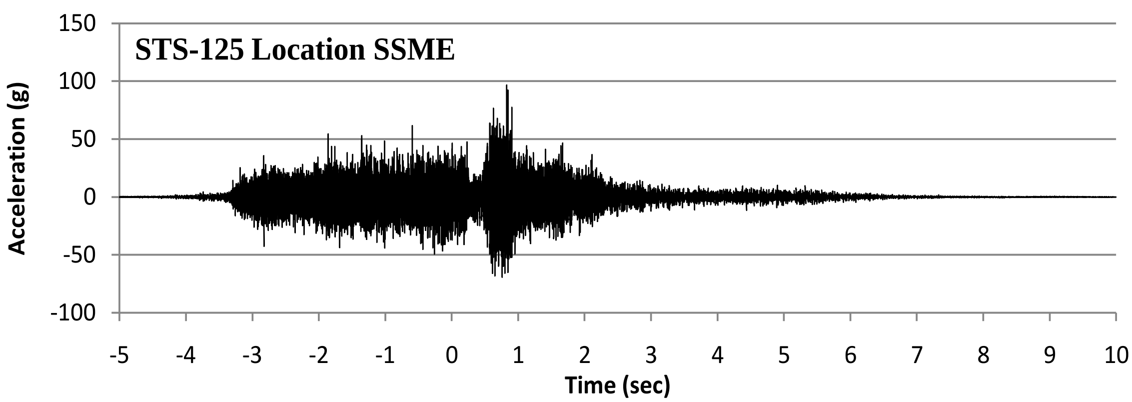

STS-125 Location 7E
Acceleration (g)
Time (sec)

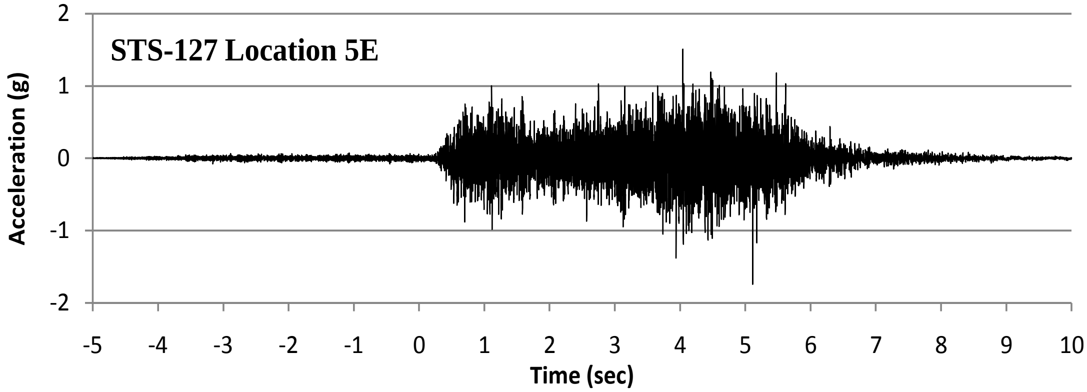

STS-125 Location SRB
Acceleration (g)
Time (sec)


STS-125 Location 5W
Acceleration (g)
Time (sec)


STS-125 Location 6W
Acceleration (g)
Time (sec)


STS-125 Location 7W
Acceleration (g)
Time (sec)


STS-125 Location SSME
Acceleration (g)
Time (sec)


STS-127 Location 5E
Acceleration (g)
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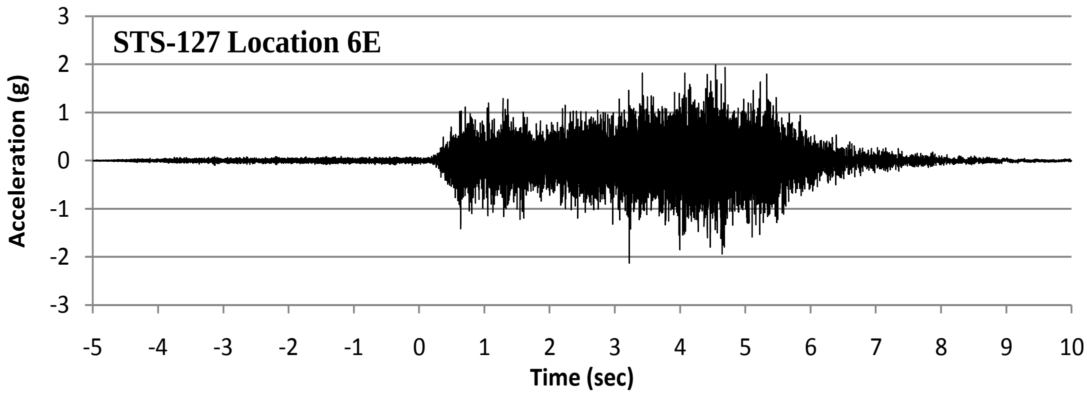
0
-1
-2
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Time (sec)


STS-127 Location 6E
Acceleration (g)
3
2
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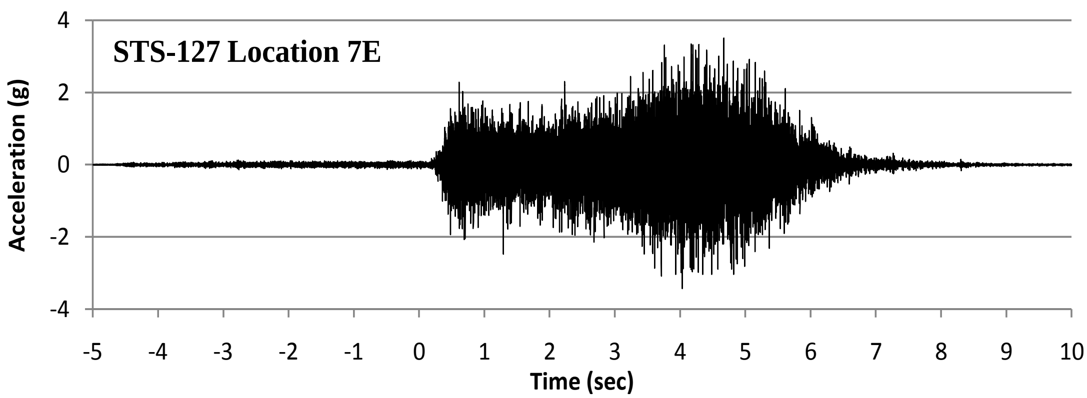
0
-1
-2
-3
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Time (sec)


STS-127 Location 7E
Acceleration (g)
4
2
0
-2
-4
-5
-4
-3
-2
-1
0
1
2
3
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5
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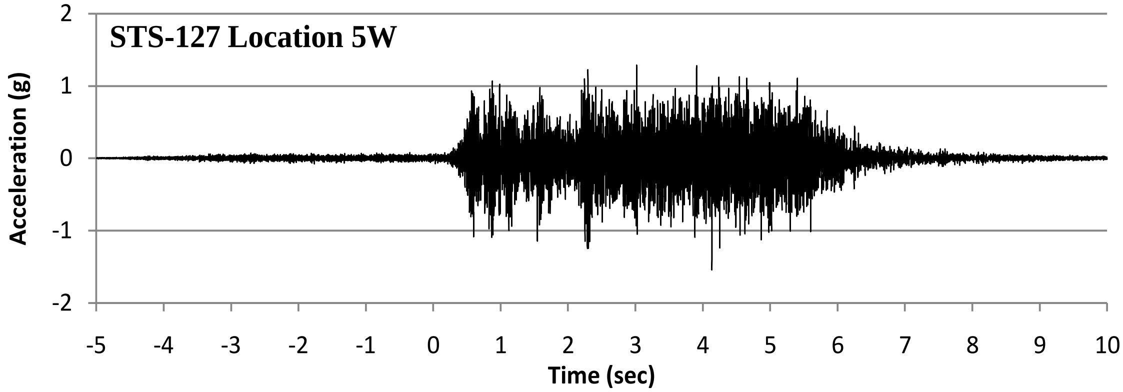
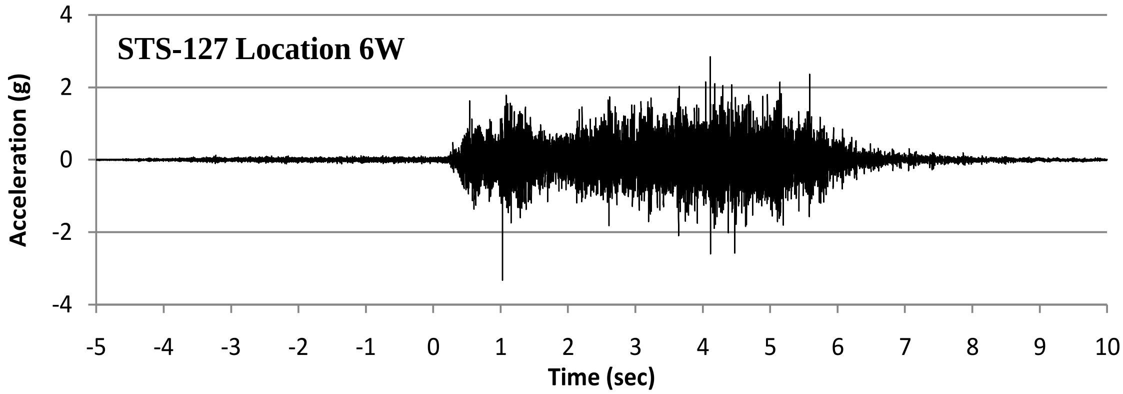
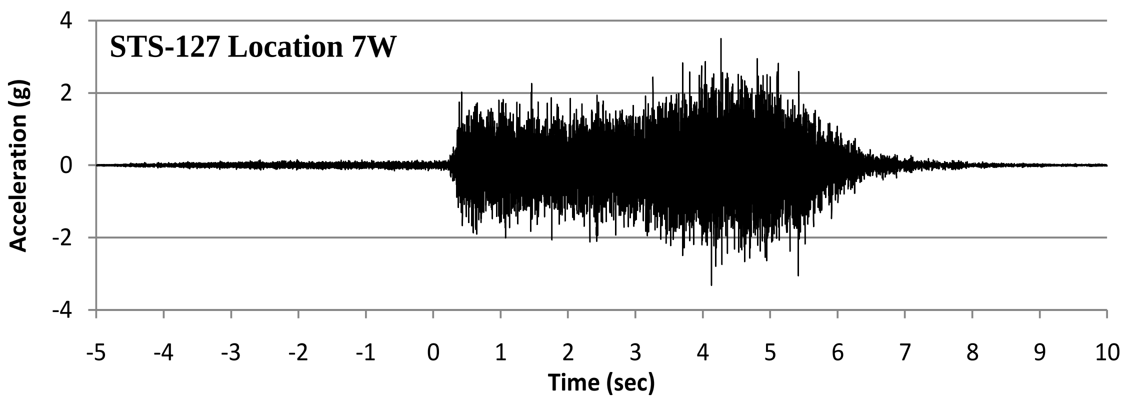
Time (sec)


STS-127 Location 5W
Acceleration (g)
2
1
0
-1
-2
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-127 Location 6W
Acceleration (g)
4
2
0
-2
-4
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)


STS-127 Location 7W
Acceleration (g)
4
2
0
-2
-4
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Time (sec)

6 LIST OF REFERENCES

Bahanja, S., and Sengupta, B., "Influence of Silica Fume on the Tensile Strength of Concrete," Cement and Concrete Research, pp. 743-747, April 2005.

Baker, R.F.M., "On the Cause of Increased Resistance of Concrete Made From Blast-Furnace Cement to the Alkali-Silica Reaction and to Sulfate Corrosion," Thesis, TH-Achen, Aachen, Federal Republic of Germany, 1980.

Campillo, I., Dolado J. S., and Porro A., "High-Performance Nano-Structured Materials for Construction," 1st International Symposium on Nanotechnology in Construction, Paisley, Scotland, pp. 215-225, 2003.

Cardenas, H., and Goli, N., "Electrokinetic Nanoparticle Treatment for Corrosion Mitigation in Reinforced Concrete," Proceedings of the Concrete Solutions Conference, St. Malo, France, June 2006.

Cardenas, H. and Kupwade-Patil, K., "Corrosion Remediation Using Chloride Extraction Concurrent With Electrokinetic Pozzolan Deposition in Concrete," Proceedings of the 6th Symposium on Electrokinetic Remediation, Vigo, Spain, June 2007.

Cardenas, H., and Struble, L., "Electrokinetic Nanoparticle Treatment of Hardened Cement Paste for Reduction in Permeability," American Society of Civil Engineers Journal of Materials in Civil Engineering, July/August 2006.

Cardenas, H., and Struble, L., "Modeling Electrokinetic Nanoparticle Treatment for Permeability Reduction in Hardened Cement Paste," American Society of Civil Engineers Journal of Materials in Civil Engineering, Nov. 2008.

Cardenas, H., "Investigation of Reactive Electrokinetic Processes for Permeability Reduction in Hardened Cement Paste," Ph.D. Thesis, University of Illinois, Urbana-Champaign, September 2002.

Chandra, S., and Bergqvist, H., "Interaction of Silica Colloid With Portland Cement," Proc. Int. Congress. Chem. Cem. Vol. 3, 1997.

Coburn, S., "Atmospheric Corrosion," American Society for Metals, Metals Handbook, Properties and Selection, Carbon Steels, Metals Park, Ohio, 1978. 9th ed., Vol. 1, p. 720.

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APPENDIX A. SENSOR DATA SHEETS

64 Series

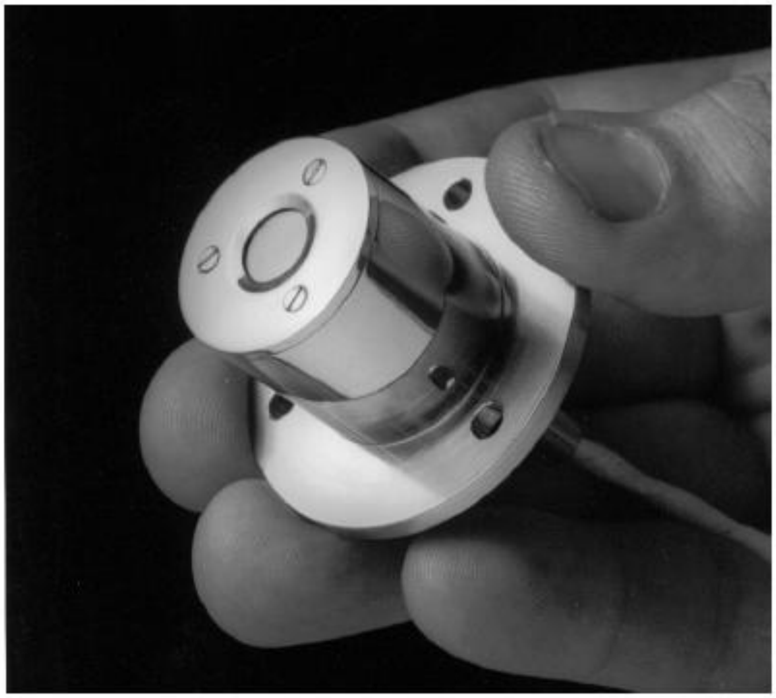
MEDTHERM
CORPORATION

HEAT FLUX TRANSDUCERS and INFRARED RADIOMETERS

for the DIRECT MEASUREMENT OF HEAT TRANSFER RATES

MEDTHERM 64 SERIES heat flux transducers and infrared radiometers have been proven in thousands of applications for over thirty years - in ground and flight aerospace testing, fire testing, heat flux standards for flammability testing, heat transfer research, materials development, and furnace development.

NIST traceable comparison calibrations to ISO/IEC 17025 are referenced both to blackbodies as standard sources and MEDTHERM Kendall Absolute Cavity (ECR) Radiometers as standard detectors.



- LINEAR OUTPUT
- OUTPUT DIRECTLY PROPORTIONAL TO HEAT TRANSFER RATE
- ACCURATE, RUGGED, RELIABLE
- UNCOOLED MODELS, WATER COOLED MODELS, GAS PURGED MODELS
- RADIOMETER AND LIMITED VIEW ACCESSORIES
- MEASURE TOTAL HEAT FLUX
- MEASURE RADIANT HEAT FLUX

64 SERIES HEAT FLUX TRANSDUCERS

DESCRIPTION

MEDTHERM 64 Series Heat Flux Transducers offer dependable direct measurement of heat transfer rates in a variety of applications due to careful design, rugged quality construction and versatile mounting configurations. Each transducer will provide a self-generated 10-millivolts (nominal) output at the design heat flux level. Continuous readings from zero to 150% design heat flux are made with infinite resolution. The linear transducer output is directly proportional to the net heat transfer rate absorbed by the sensor.

64 Series transducers have for almost forty years met thousands of application challenges in ground and flight aerospace testing, fire testing, flammability heat flux standards, heat transfer research, materials development, and furnace development.

CALIBRATION

Each transducer is provided with a certified comparison calibration per written procedures to ANSI/NCSL Z540-1, ISO 10012-1, and ISO/IEC 17025. Calibrations are traceable through temperature standards and electrical standards to the National Institute of Standards and Technology (NIST). Calibrations are radiant calibrations, referenced both to blackbody simulators as source standards and to a set of MEDTHERM Kendall Absolute Cavity (ECR) Radiometers as detector standards. Special calibrations are also available.

FEATURES

* LINEAR OUTPUT
* OUTPUT PROPORTIONAL TO HEAT TRANSFER RATE
* ACCURATE, RUGGED, RELIABLE
* CONVENIENT MOUNTING
* UNCOOLED, WATER COOLED, GAS PURGED MODELS
* RADIOMETER AND LIMITED VIEW ACCESSORIES
* MEASURE TOTAL HEAT FLUX
* MEASURE RADIANT HEAT FLUX

CONSTRUCTION

ACCURACY, RUGGEDNESS AND RELIABILITY are provided by the thoroughly proven Gardon and Schmidt-Boelter sensors.

LONG TRANSDUCER LIFE AND SIGNAL STABILITY are enhanced by the massive body of OFHC copper.

PROTECTION AGAINST ROUGH HANDLING in mounting is provided by a stainless steel flange when specified.

SIGNAL INTEGRITY is protected by the use of welded connections, stranded lead wire with braided copper shielding and Teflon insulation firmly secured in the transducer body with strain relief to ensure resistance to rough handling and stray signals.

ACCESSORIES

REMOVABLE WINDOW ATTACHMENTS, with the standard sapphire or optional window materials, are available to limit the basic transducer to measurement of radiation heat flux only.

VIEW RESTRICTOR ATTACHMENTS are available to limit the angle of view for the basic transducer to 150°, 120°, 90°, 60°, 30°, 15°, or 7° for narrow view angle measurements.

DIRECT READING HEAT FLUX INDICATORS Models H-201, H-203, and H-204 are available for direct digital readout in any heat flux units from any linear heat flux transducer input. An amplified analog output is provided on some. Ask for Bulletin.

BODY TEMPERATURE THERMOCOUPLE measurement can be provided by an optional copper/constantan 24 AWG solid conductor thermocouple, with TIG welded junction and Teflon insulated duplex wire.

MEDTHERM
CORPORATION

OPERATING PRINCIPLES

The 64 Series transducers are of two basic sensor types, the Gardon type sensor, standard in the ranges from 5 to 4000 Btu/(ft²·s), and the MEDTHERM Schmidt-Boelter thermopile type sensor, standard in the 0.2 to 4 Btu/(ft²·s) ranges. In both type sensors heat flux is absorbed at the sensor surface and is transferred to an integral heat sink that remains at a different temperature than the sensor surface. The difference in temperature between two selected points along the path of the heat flow from the sensor to the sink is a function of the heat being transferred, and a function of the net absorbed heat flux. At two such points, MEDTHERM transducers have thermocouples or thermopiles to form a differential thermoelectric circuit, thus providing a self-generated emf at the output leads that is directly proportional to the heat transfer rate. No power supply or thermoelectric reference junction is needed.

Gardon gages absorb heat in a thin metallic circular foil and transfer the heat radially (parallel to the absorbing surface) to the heat sink welded around the periphery of the foil. The emf output is generated by a single differential thermocouple between the foil center temperature and foil edge temperature.

MEDTHERM Schmidt-Boelter gages absorb the heat at one surface and transfer the heat in a direction normal to the absorbing surface. The emf output is generated by a multi-junction thermopile responding to the difference in temperature between the surface and a plane beneath the surface. The Schmidt-Boelter thermopile sensor is always used below 5 Btu/(ft²·s). It can be optionally specified up to 100 Btu/(ft²·s).

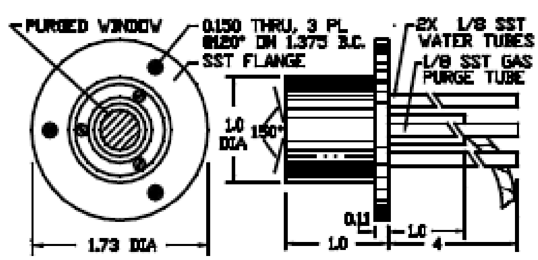
OPTIONAL FEATURES include four mounting configurations, window attachments, water cooling provisions, or thermocouples for body temperature measurement. Water-cooling should be specified if the uncooled transducer is expected to reach above 400°F.

The gas purging provision should be included on radiation transducers that are to be used in a sooty environment. The MEDTHERM purge is designed to pass rigid NASA performance tests with fuel-rich oxy-acetylene flames directed towards the window at close range.

STANDARD CONFIGURATIONS

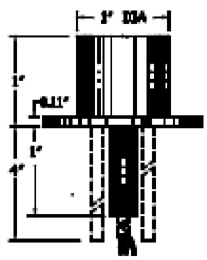
The basic transducer may be selected with either of four mounting configurations and with or without provisions for water cooling of the transducer body. The listed radiometers are provided with gas purging to keep the radiation-transmitting window clean. When the purge provision is included, the window is installed internally at MEDTHERM and is not an accessory. Basic transducers can be converted to unpurged radiometers by addition of a window attachment, but the standard purged radiometers can not be converted to basic transducers. (Inquire about other models with this feature.)

FLANGED RADIOMETER WITH GAS PURGING PROVISIONS



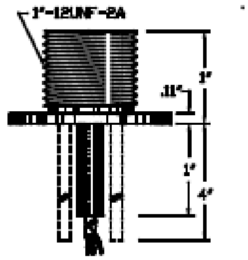
All listed gas purged models are provided with water cooling provisions. Call MEDTHERM for uncooled purged radiometers.

STANDARD MOUNTING CONFIGURATIONS ARE ILLUSTRATED BELOW. There is the smooth body with flange, the threaded body with flange, the smooth body without flange, and the threaded body without flange. All mounting flanges are 1.73" dia. with 0.150" dia. mounting holes equally spaced on a 1.375" dia. bolt circle. Water-cooling tubes (when specified) and gas purge tubes are 1/8" dia. SST. All tubes are 4" long. (Other tube diameters, lengths, and fittings are available.) All threaded bodies have 1-12UNF-2A threads.



SMOOTH BODY WITH FLANGE

DESCRIPTION:	MODEL NO.
BASIC, UNCOOLED	64-xx-16
WATER COOLED	64-xx-20
RADIOMETER, GAS PURGED, COOLED	64P-xx-24

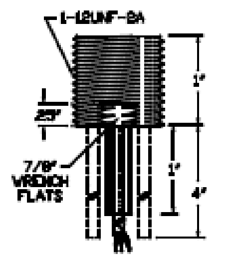


THREADED BODY WITH FLANGE

DESCRIPTION:	MODEL NO.
BASIC, UNCOOLED	64-xx-17
WATER COOLED	64-xx-21
RADIOMETER, GAS PURGED, COOLED	64P-xx-25

SMOOTH BODY, NO FLANGE

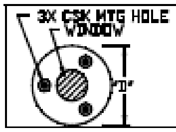
DESCRIPTION:	MODEL NO.
BASIC, UNCOOLED	64-xx-14
WATER COOLED	64-xx-18
RADIOMETER, GAS PURGED, COOLED	64P-xx-22



THREADED BODY, NO FLANGE

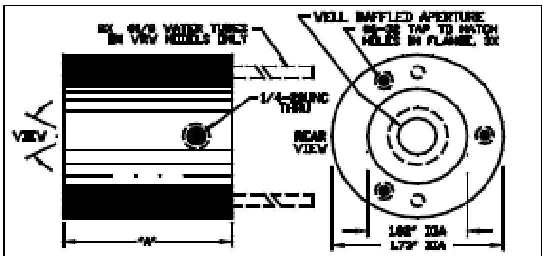
DESCRIPTION:	MODEL NO.
BASIC, UNCOOLED	64-xx-15
WATER COOLED	64-xx-19
RADIOMETER, GAS PURGED, COOLED	64P-xx-23

WINDOW ATTACHMENTS may be added for elimination of convective heat transfer, thus making the transducer a radiometer or radiation heat flux transducer. Sapphire is the standard window material. A broad selection of other materials is available per the list on page 4. Standard view angles available are: 90°, 120°, and 150°. Window attachments are removable and replaceable by the user. When the window is used the sensitivity of the basic transducer is reduced to a nominal fraction of the original as follows: 90°, 43%; 120°, 64%; and 150°, 79%. Thickness of the attachment varies with view angle and sensor type from1/16" to 3/8".



BODY TYPE	"D"	CALIB?	MODEL
SMOOTH	1.0	NO	SW-1-YY
THREADED	0.84	NO	SW-2-YY
SMOOTH	1.0	YES	SW-1C-YY
THREADED	0.84	YES	SW-2C-YY

VIEW RESTRICTOR ATTACHMENTS for limiting the area viewed or seen by the sensor are available for making spot radiation or remote temperature measurements. Attachments may be ordered with or without water-cooling and with or without an additional calibration with the attachment in place. Flanged transducers attach to the back. A ¼-20UNC set screw holds unflanged transducers and provides tripod mount access.



VIEW ANGLE	"A"	NOMINAL % BASIC SENSITIVITY	MODEL NO. UNCOOLED	MODEL NO. COOLED
7°	3.9"	0.4%	VR-7	VRW-7
15°	2.3"	1.7%	VR-15	VRW-15
30°	1.6"	6.6%	VR-30	VRW-30
60°	1.2"	25.0%	VR-60	VRW-60

MEDTHERM CORPORATION

SPECIFICATIONS

STANDARD RANGES AVAILABLE: Full scale design heat flux level: 4000, 3000, 2500, 2000, 1500, 1000, 500, 250, 200, 100, 50, 30, 25, 20, 15, 10, 5, 2, 1, 0.5, 0.2 Btu/(ft²-s). (Custom ranges available.)

OUTPUT SIGNAL: linear output, 10 millivolts nominal at full range.

MAXIMUM ALLOWABLE OPERATING BODY TEMPERATURE: 400 °F.

OVERRANGE CAPABILITY: to150% range for 2-1000 Btu/(ft²-s) ranges.

MAXIMUM NON-LINEARITY: ±2% of full range.

REPEATABILITY: ±1/2%

CALIBRATION EXPANDED UNCERTAINTY: ±3% for ranges to 250 Btu/(ft²-s), coverage factor k=2, for approximate 95% confidence level.

CALIBRATION: Each transducer is provided with a certified radiant heat flux comparison calibration to ANSI/NCSL Z540-1, and ISO/IEC 17025. Calibrations are traceable through temperature standards and electrical standards to the National Institute of Standards and Technology (NIST). Radiant comparisons are made to working standard heat flux transducers of similar type. The working standards are regularly calibrated versus both blackbody simulators as standard sources and versus a set of MEDTHERM Kendall Absolute Cavity (ECR) Radiometers as standard detectors. (The ECR is an electrical substitution calibrated cavity radiometer, an absolute detector in that it requires only NIST-traceable electrical standards of the volt and ohm to determine irradiance.) Special calibrations, including a direct comparison to a MEDTHERM absolute ECR, are available at additional cost.

SENSOR ABSORPTANCE (Hemispherical): Gardon gages, .92, nominal, from 0.6 to 15.0 µm. Thermopiles, .95, nominal, from 0.6 to 15.0 µm.

SPECTRUM TRANSMITTED BY SAPPHIRE WINDOW (When used): 85% nominal from 0.15 to 5.0 µm. Other window materials are optional.

LEAD WIRE: 24 AWG stranded copper twisted pair, Teflon insulation over each, braided copper shield, Teflon jacket overall, 36" standard length with stripped ends. (The optional body thermocouple wire is 24 AWG Teflon/Teflon insulated duplex solid conductor.)

TIME CONSTANT: (63.2% response to a step radiant heat input)

250 to 4000 Btu/(ft²-s): less than 50 ms.

50 to 200 Btu/(ft²-s): less than 100 ms.

2 to 30 Btu/(ft²-s): less than 250 ms.

SENSOR TYPE: (Standard, options available)

5 to 4000 Btu/(ft²-s): Gardon Gage (Except S-B for 64P-5 models)

0.2 to 4 Btu/(ft²-s): Schmidt-Boelter (Schmidt-Boelter sensors are also available as an option from 5 to 100 Btu/(ft²-s) ranges.

NOMINAL IMPEDANCE: (With standard leadwire)

Less than 10 ohms on Gardon Gages

Less than 250 ohms on Schmidt-Boelter Gages.

HEAT CAPACITY OF UNCOOLED UNITS: Energy that can be absorbed by transducer in an adiabatic installation (defined as all surfaces perfectly thermally insulated except for 1-inch diameter sensor face) before exceeding the 400 °F maximum body temperature limitation:

Model without water cooling provisions: 6.2 Btu

Models with water cooling provisions but without water: 4.2 Btu

MAXIMUM PURGE GAS PRESSURE: 150 psi over ambient

ORDERING INFORMATION:

DESCRIPTION	MODEL NO. (P/N)	PRICE Schmidt-Boelter Thermopile (SB) Heat Flux Range of 0.5, 1, 2 Btu/(ft²·s) **	PRICE Gardon Gage (GG) Heat Flux Range of 5 Btu/(ft²·s) and up *
****** BASIC TRANSDUCER, NO WATER COOLING PROVISIONS ******			
SMOOTH BODY, NO FLANGE	64-xx-14	$645.00	$562.00
THREADED BODY, NO FLANGE	64-xx-15	$694.00	$611.00
SMOOTH BODY, WITH FLANGE	64-xx-16	$666.00	$583.00
THREADED BODY, WITH FLANGE	64-xx-17	$727.00	$644.00
****** BASIC TRANSDUCER WITH WATER COOLING PROVISIONS ******			
SMOOTH BODY, NO FLANGE	64-xx-18	$843.00	$760.00
THREADED BODY, NO FLANGE	64-xx-19	$902.00	$818.00
SMOOTH BODY, WITH FLANGE	64-xx-20	$865.00	$782.00
THREADED BODY, WITH FLANGE	64-xx-21	$931.00	$848.00
****** RADIATION TRANSDUCER WITH SAPPHIRE WINDOW, GAS PURGE AND WATER COOLING PROVISIONS ******			
SMOOTH BODY, NO FLANGE	64P-xx-22	$1020.00	$937.00
THREADED BODY, NO FLANGE	64TP-xx-23	$1056.00	$973.00
SMOOTH BODY, WITH FLANGE	64P-xx-24	$1040.00	$957.00
THREADED BODY, WITH FLANGE	64TP-xx-25	$1094.00	$1011.00

1. Specify Model Number. Transducer price includes factory calibration to ISO/IEC 17025 and ISO 10012-1.
2. Insert desired design full-scale heat flux level in place of "xx" in the Model Number (P/N), in Btu/(ft²·s).
3. ** Add $131.00 to the 0.5 Btu/(ft²·s) basic price for the 0.2 Btu/(ft²·s) range, the most sensitive sensor.
4. SB sensor is optional in 5 Btu/(ft²·s) range at above SB price. Add SB after "xx" in P/N. For SB in ranges from 10 to 40 Btu/(ft²·s), add $83.00 to above SB price. Contact factory for SB price at higher range, up to 400 Btu/(ft²·s).
5. For copper/constantan body temperature thermocouple on any of the above transducers, add T to Model Number and $36.00 to price. For other thermocouple materials, substitute for T the desired ANSI letter code (K, E, or J), add $44.00 to basic price. For surface thermocouple on SB only, add S before ANSI letter code and $113.00 to SB price.
6. * The standard sensor for the 5 Btu/(ft²·s) 64P and 64TP radiometers is a Schmidt-Boelter thermopile. Use SB price.
7. Specify calibration units desired (W/cm², kW/m², etc.), if not Btu/(ft²·s), at same price. (1 Btu/(ft²·s) = 1.135 W/cm²)

ACCESSORIES

When ordered with a transducer, if unlisted calibration with an accessory is desired, add C to the Model Number and $116.00 to the basic price of the accessory, i.e., VRW-7C at $253.00 + $116.00 = $369.00 each.

DESCRIPTION	MODEL NO. (P/N)	PRICE
SAPPHIRE WINDOW ATTACHMENT without calibration	SW-1-YY or SW-2-YY	$ 136.00
SAPPHIRE WINDOW ATTACHMENT with calibration	SW-1C-YY or SW-2C-YY	$ 253.00
VIEW RESTRICTOR ATTACHMENTS	VR-7, VR-15, VR-30, VR-60	$ 175.00
VIEW RESTRICTOR ATTACHMENTS, WATER COOLED	VRW-7, VRW-15, VRW-30, VRW-60	$ 253.00
DIGITAL HEAT FLUX METER, with calibration certificate	H-201	$1119.00
RECALIBRATION OF TRANSDUCER (when returned after use)	ALL 64 SERIES	$ 274.00

TO SUBSTITUTE WINDOWS ON RADIOMETERS INSTEAD OF SAPPHIRE AT ADDITIONAL COST:

Substitute Window, (1mm unless noted)	Symbol, Insert in P/N	(Approximate Transmittance Data, Details Available) Useful Wavelength Range, micrometers	"Flat" Wavelength Range, micrometers	Additional Price
Sapphire (0.5 mm)		0.2 - 5.5	0.4 - 4.2	Included
Quartz (0.5 mm)	QW	0.12 - 4	0.27 - 3	ADD $ 23.00
Calcium Fluoride	CaF2W	0.3 - 11.5	0.7 - 9	ADD 78.00
KRS-5	KRS-5W	0.6 - 50	0.6 - 30	ADD 255.00
Zinc Sulfide	ZnSW	0.5 - 14.5	0.8 - 12	ADD 124.00
Barium Fluoride	BaF2W	0.2 - 12.5	0.3 - 10	ADD 100.00
Zinc Selenide	ZnSeW	0.5 - 22	0.7 - 17	ADD 129.00
Cadmium Telluride	CdTeW	0.8 - 30	1 - 20	ADD 185.00

OTHER WINDOW AND FILTER MATERIALS, RADIOMETERS WITHOUT GAS PURGE, LARGER WATER TUBES, PRECISELY TAILORED OUTPUTS, FAST RESPONSE TIMES, RESPONSE TIME TESTS, FLIGHT SIMULATIONS, OUTPUT WIRES AND COOLING TUBES OUT THE SIDE, HIGH TEMP WIRES, ABSOLUTE CAVITY RADIOMETER STANDARDS, SETS OF TRANSFER CALIBRATION STANDARDS, AND MORE ACCESSORIES ARE AVAILABLE.

In addition to the size ranges offered in the 64 Series Heat Flux Transducers (1 inch basic diameter) MEDTHERM offers the 4 Series (1/16 inch basic diameter), 8 Series (1/8 inch basic diameter), the 16 Series (1/4 inch basic diameter), the 24 Series (3/8 inch basic diameter), the 32 Series (1/2 inch basic diameter), 40 Series (5/8 inch basic diameter), and the 48 Series (3/4 inch basic diameter), as well as flat and rectangular transducers with a variety of sensor types. We specialize in the rapid design and manufacture of custom heat flux transducers for your particular applications. Write or call the factory for recommendations and quotations for your requirements.

FLIGHT QUALIFIED HEAT FLUX TRANSDUCERS (SINCE 1970) ARE AVAILABLE IN A WIDE VARIETY OF SHAPES, SIZES, RESPONSE TIMES, AND DESIGN HEAT FLUX LEVELS. PLEASE CONTACT THE FACTORY FOR DETAILS.

BULLETIN 118

MEDTHERM CORPORATION
POST OFFICE BOX 412
HUNTSVILLE, ALABAMA 35804
TELEPHONE (256) 837-2000
FAX (256) 837-2001

Model 797L

low frequency

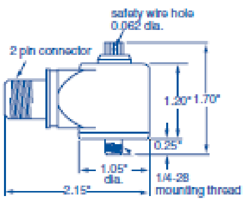
INDUSTRIAL

Model 797L

Premium, Low Frequency, Center Mount Accelerometer

FEATURES:

- High sensitivity
- Ultra low-noise electronics for clear signals at very low vibration levels
- Low pass filtered to attenuate high frequencies
- Hermetic seal
- ESD protection
- Miswiring protection
- Reverse wiring protection



DYNAMIC	
Sensitivity, ±5%, 25°C	500 mV/g
Acceleration Range	10 g peak
Amplitude Nonlinearity	1%
Frequency Response:	
–5%	0.6 - 850 Hz
–10%	0.4 - 1,500 Hz
–3 dB	0.2 - 3,700 Hz
Resonance Frequency	18 kHz
Transverse Sensitivity, max	7% of axial
Temperature Response	–50°C –8% +120°C +5%
ELECTRICAL	
Power Requirement: voltage source	18 - 30 VDC
current regulating diode	2 - 10 mA
Electrical Noise, equiv. g:	
Broadband 2.5 Hz to 25 kHz	12 µg
Spectral 2 Hz	2.0 µg/√Hz
10 Hz	0.6 µg/√Hz
100 Hz	0.2 µg/√Hz
Output Impedance, max.	100 Ω
Bias Output Voltage	10 VDC
Grounding	case isolated, internally shielded
ENVIRONMENTAL	
Temperature Range	–50 to 120°C
Vibration Limit	250 g peak
Shock Limit	2,500 g peak
Electromagnetic Sensitivity, equiv. g	5 µg/gauss
Sealing	Hermetic
Base Strain Sensitivity	0.001 g/µstrain
PHYSICAL	
Sensing Element Design	PZT ceramic / shear
Weight	148 grams
Case Material	316L stainless steel
Mounting	1/4-28 captive socket head screw
Mating Connector	R6 type
Recommended Cabling	J9T2A

CONNECTOR PIN	FUNCTION
SHELL	ground
A	power/ signal
B	common

ACCESSORIES SUPPLIED: #12105-01 captive socket head (International customers specify mounting requirements); Calibration data (level 3).

OPTIONS: Intrinsic safety certification

Optional Safety Approvals

WILCOXON RESEARCH, INC. • 1-800-945-2696 • TEL 301-330-8811 • FAX 301-330-8873 • EMAIL sensors@wilcoxon.com • WEB www.wilcoxon.com

KISTLER
measure. analyze. innovate.

Cylinder Pressure Sensor

for Continuous Monitoring

Type 6013C...

Life expectancy optimized sensor for continuous cylinder pressure measurement in gas and diesel engines. Because of its low thermal shock and high stability over the long term, this sensor is suitable for difficult monitoring and control tasks for internal combustion engines.

- Small thermal shock
- Long life
- Also available with integral charge amplifier

Description

As a result of its patented «anti-strain» design, the measuring element is insensitive to integral mounting, and largely insensitive to dirt and contamination. The rugged diaphragm permits the sensor to be used for knock detection.

The life expectancy of the sensor has been designed for a service life of >16'000 h in a gas engine running. With heavy-oil operation, its service life depends very much on the corrosion occurring, while extreme contamination can reduce measuring accuracy.

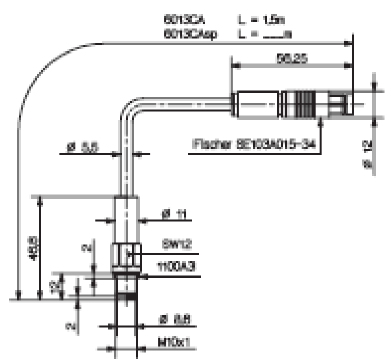
Application

Continuous Monitoring

Type 6013CA has been specially developed for the monitoring and control of medium and large size diesel and gas engines. Excellent thermodynamic characteristics enable high precision cylinder measurements. Sensor and cable together form an oil- and splash proof unit.

Test Bed

Most suitable for knock detection and long-term measurements. For test bed applications the sensor Type 6013C (without cable) can be used together with special connecting cables. For more information about cables refer to data sheet 000-352e (DB15.035e).



Technical Data

		Type 6013CA	Type 6013C
Range	bar	0 ... 250	
Calibrated partial range	bar	0 ... 50	
Overload	bar	300	
Sensitivity	pC/bar	21	
Natural frequency	kHz	85	
Linearity	%FSO	≤±1	
Sensitivity to acceleration	bar/g	0,001	
Operating temperature range	°C	-50 ... 350	
Change in sensitivity			
200 ± 150 °C	%	≤±2	
200 ± 50 °C	%	≤±1	
Thermal shock			
at 1'500 r/min, p_{mi} = 9 bar	bar	≤±0,5	
Insulation resistance at 20 °C	Ω	≥10^{13}	
Shock resistance	g	2000	
Tightening torque	Nm	15	
Output impedance	Ω	100	
Capacitance	pF	160	6
Weight	g	80	20
Connector	Type	Fischer SE103	10-32UNF

000-402e-11.03 (DB03.6013CAe)

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Tel +41 52 224 11 11, Fax 224 14 14, info@kistler.com, www.kistler.com

KISTLER
measure. analyze. innovate.

Installation

In order to minimize thermal stress on the sensor, it should be located so that good heat dissipation to colder components is possible. This can normally be achieved by a set-back location. Optimum sensor life is achieved at an average temperature of 200 ... 300 °C in the sensor body. In order to prevent singing oscillations, the lengths of the gas channel should not exceed 30 mm. Strong gas oscillations occur when the gas column between sensor and combustion chamber resonates. Superimposed on the cylinder pressure, these pressure oscillations impose an additional load on the sensor, resulting in reduced life of the sensor.

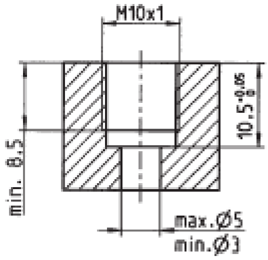


Fig. 1: Sensor bore

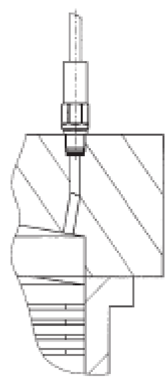


Fig. 2: Sensor fitted in a set-back location

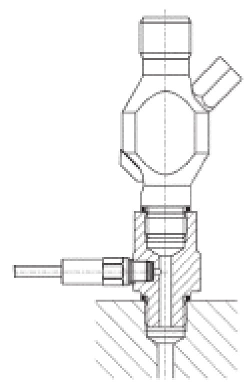


Fig. 3: Fitting example: sensor fitted below the indicator valve

Accessories Included	Type
• Cr-Ni seal	1100A3

Optional Accessories	Type
• Connecting cable, Fischer KE 103 – BNc pos.	1673A ...
• Socket wrench 16/12*	1300B7
• Fork wrench SW16 to 1300A11*	1300A33
• Torque wrench 8 ... 40 Nm*	1300A11
• Fork wrench insert SW12 to 1300A11*	1300A13
• Adapter M14x1,25	6582A1
• Adapter BSP 1/2" male thread	6582A2
• Socket wrench	1300A6

* refer to data sheet 000-068m (DB04.012m)
data sheet 000-352e (DB15.035e)

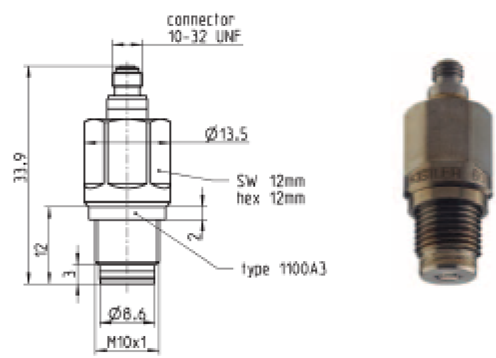
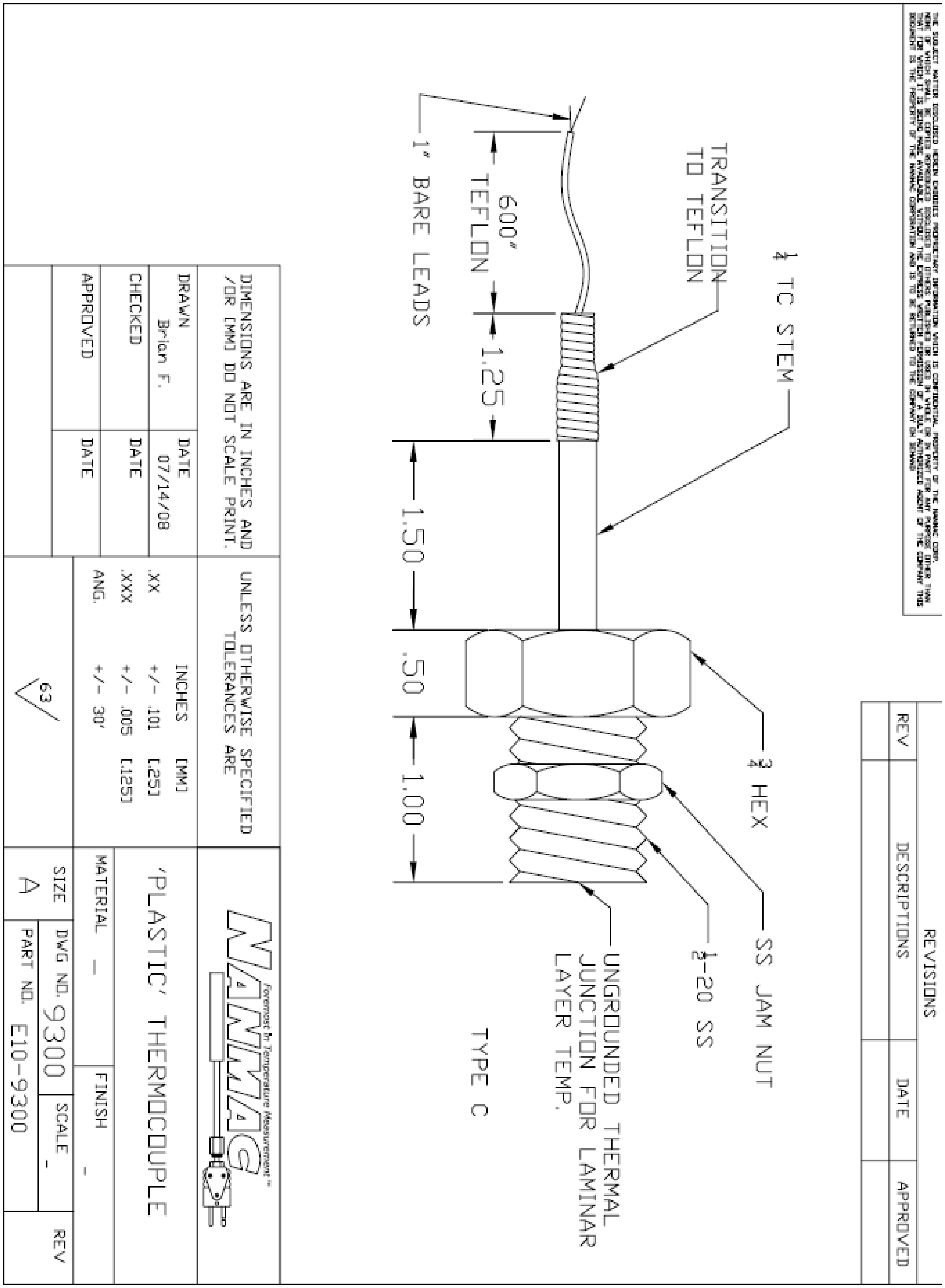


Fig. 4: Cylinder pressure sensor Type 6013C with 10-32UNF connector

000-402e-11.03 (DB03.6013CAe)


TRANSITION TO TEFLON
1/4 TC STEM
600" TEFLON
1" BARE LEADS
1.25
1.50
.50
1.00
3/4 HEX
SS JAM NUT
1/2-20 SS
UNGROUNDED THERMAL JUNCTION FOR LAMINAR LAYER TEMP.
TYPE C
REVISIONS
REV
DESCRIPTIONS
DATE
APPROVED
DIMENSIONS ARE IN INCHES AND /OR [MM] DO NOT SCALE PRINT.
DRAWN Brian F.
DATE 07/14/08
CHECKED
DATE
APPROVED
DATE
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE
INCHES [MM]
.XX +/- .101 [.25]
.XXX +/- .005 [.125]
ANG. +/- 30'
63
NANMAC
Foremost in Temperature Measurement
'PLASTIC' THERMOCOUPLE
MATERIAL –
FINISH –
SIZE A
DWG NO. 9300
SCALE –
REV
PART NO. E10-9300

Series ST150

Pressure Transducers

STELLAR TECHNOLOGY INCORPORATED

Description

The Series ST150 is a small, accurate, reliable pressure transducer for measuring dynamic and static pressures. Available in absolute, sealed gage, or true gage zero pressure reference, the unit is entirely welded of stainless steel. Features of design include long term stability, low sensitivity to shock and vibration, wide temperature range, excellent response to transient pressures, infinite resolution and built in over-pressure protection for ranges up to 2.5K PSI.

Standard Features

- Stainless Steel construction
- Hermetically sealed
- High accuracy
- NACE traceable
- Zero span shift less than .005° FS/°F

Optional Features

- Expanded temperature operating range
- Expanded compensated temperature range
- Alternative materials of construction
- Customer specified connector
- Alternative pressure ports

Your "Application-Solution℠" Source

Series ST150
Specifications

Baseline Configuration Specs Represented.
Modifications Encouraged - See Below

Performance

Static Accuracy
Linearity: ± 0.20% FS.
Hysteresis: ± 0.20% FS.
Repeatability: ± 0.10% FS.

Resolution
Infinite

Thermal Zero Shift
< ±0.005% FSO/°F.

Therm. Sens. Shift
< ±0.005% FSO/°F.

Input / Output Resistance
350 ± 3.5 ohms at 70°F.

Insulation Resistance
> 10K megohms at 50 Vdc at 70°F.

Zero Balance
± 1% FSO at 70°F.

Full Scale Output
3.0 ± 0.015 mV/V FSO at 70°F.

Natural Frequency
1.0 kHz at 15 PSI to 347 kHz at 30,000 PSI.

Acceleration Response
Less than ±0.15% FSO/G at 15 PSI to ±0.0015% FS/G at 30,000 PSI.

Mechanical Characteristics

Standard Ranges
0 - 15, 25, 30, 50, 75, 100, 200, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000, 15000, 20000, 25000 and 30000 PSIA / PSIG.

Proof Pressure
15 - 200 PSI ranges: 500 PSI.
500 PSI range and up: 1.5 times range.

Operating Media
Fluids and gases compatible with 316 and 347 or 17-4PH stainless steel.

Mechanical Characteristics

Pressure Fitting
7/16-20 per MS33656-4 for ranges up to and including 10,000 PSI.
AE F250-C, 9/16-18 UNF for ranges 15,000 PSI and up.

Weight
4.5 ounces maximum.

Electrical Characteristics

Excitation
10 Vdc recommended, 15 Vdc max.

Electrical Termination
PT1H-10-6P stainless steel connector or equivalent.

Wiring
Excitation +A, -D; Signal +B, -C;
No connection E, F. (Shunt avail.)

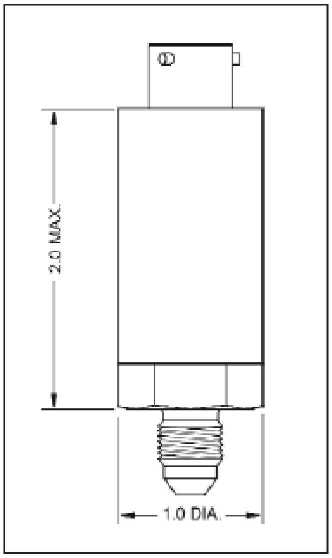
Environmental Characteristics

Compensated Temperature Range
-65°F to +250°F.
(-320°F to +425°F optional)

Operating Temperature Range
-100°F to +300°F.
(-320 to +450°F optional)

Enclosure
Body and pressure cavity of stainless steel, hermetically sealed.

Dimensions (inches)



Stellar Technology Incorporated is an
ISO 9001:2000
Registered Company

Modifications

We realize transducer applications vary greatly and as such our designs are flexible. Choice of pressure port, electrical termination, material compatibility and performance characteristics are a few of the many options available. Specifications on this datasheet represent the standard configuration only. Product and company names listed are trademarks of their respective companies. Specifications subject to change without notice. See accessory listing for additional choices.

Warranty

Stellar Technology warrants that its product shall be free from defective workmanship and/or material for a twelve month period from the date of shipment, provided that Stellar Technology's obligation hereunder shall be limited to correcting any defective material FOB our factory. No allowance will be made for any expenses incurred for correcting any defective workmanship and/or material without written consent by Stellar Technology. This warranty is in lieu of all other warranties expressed or implied.

Ordering Information

Contact the factory or your Authorized Stellar Technology, Inc. Representative.

Represented By:

Click For More Information at: stellartech.com

Due to the nature of technology, changes are inevitable. For latest technical specifications, see our website.

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Email: info@stellartech.com

STELLAR TECHNOLOGY INCORPORATED

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14. ABSTRACT
This report summarizes conditions in the Launch Complex 39 (LC-39) flame trenches during a Space Shuttle Launch, as they have been measured to date. Instrumentation of the flame trench has been carried out by NASA and United Space Alliance for four Shuttle launches. Measurements in the flame trench are planned to continue for the duration of the Shuttle Program. The assessment of the launch environment is intended to provide guidance in selecting appropriate test methods for refractory materials used in the flame trench and to provide data used to improve models of the launch environment in the flame trench.

15. SUBJECT TERMS
flame trench environment assessment, Corrosion Technology Laboratory, refractory materials, flame deflector

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