AN ANALYSIS OF THE SELECTED MATERIALS USED IN STEP MEASUREMENTS DURING PRE-FITS OF THERMAL PROTECTION SYSTEM TILES AND THE ACCURACY OF MEASUREMENTS MADE USING THESE SELECTED MATERIALS

by

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This Graduate Capstone Project was prepared under the direction of the candidate's Project Review Committee Member, Dr. Joanne J. Nesbitt, Adjunct Associate Professor, Worldwide Campus, and the candidate's Project Review Committee Chair, Dr. Charlie J. Allen, Professor, Worldwide Campus, and has been approved by the project Review Committee. It was summated to the Worldwide Campus in partial fulfillment of the requirements for the degree of Master of Science in Management

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ABSTRACT

Researcher: David William Kranz

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The goal of this research project was be to compare and contrast the selected materials used in step measurements during pre-fits of thermal protection system tiles and to compare and contrast the accuracy of measurements made using these selected materials. The reasoning for conducting this test was to obtain a clearer understanding to which of these materials may yield the highest accuracy rate of exacting measurements in comparison to the completed tile bond. These results in turn will be presented to United Space Alliance and Boeing North America for their own analysis and determination.

Aerospace structures operate under extreme thermal environments. Hot external aerothermal environments in high Mach number flights lead to high structural temperatures. The differences between tile heights from one to another are very critical during these high Mach reentries. The Space Shuttle Thermal Protection System is a very delicate and highly calculated system. The thermal tiles on the ship are measured to within an accuracy of .001 of an inch. The accuracy of these tile measurements is critical

to a successful reentry of an orbiter. This is why it is necessary to find the most accurate method for measuring the height of each tile in comparison to each of the other tiles.

The test results indicated that there were indeed differences in the selected materials used in step measurements during prefits of Thermal Protection System Tiles and that Bees' Wax yielded a higher rate of accuracy when compared to the baseline test. In addition, testing for experience level in accuracy yielded no evidence of difference to be found. Lastly the use of the Trammel tool over the Shim Pack yielded variable difference for those tests.

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CHAPTER 1

INTRODUCTION

Background of the Problem

The thermal protection system (TPS) consists of various materials applied externally to the outer structural skin of the orbiter to maintain the skin within acceptable temperatures, primarily during the entry phase of the mission. The orbiter's outer structural skin is constructed primarily of aluminum and graphite epoxy.

During entry, the TPS materials protect the orbiter outer skin from temperatures above 350 F. In addition, they are reusable for 100 missions with refurbishment and maintenance. These materials perform in temperature ranges from minus 250 F in the cold soak of space to entry temperatures that reach nearly 3,000 F. The TPS also sustains the forces induced by deflections of the orbiter airframe as it responds to the various external environments. Because the thermal protection system is installed on the outside of the orbiter skin, it establishes the aerodynamics over the vehicle in addition to acting as the heat sink (Dumoulin, 2008).

Aerospace structures operate under extreme thermal environments. Hot external aerospace thermal environments at high Mach number flights lead to high structural temperatures. The differences between tile heights from one to another are very critical during these high Mach reentries. A tile with a variation of as little as .050 of an inch or more in contrast to tiles surrounding it is considered a drastic variation in height and can cause a collapse the boundary layer spike and a premature transition to turbulent flow. This early transition of smooth, laminar airflow, in which provides a thin layer of insulation during peak heating, can change to the disturbed, turbulent flow that can cause downstream temperatures to climb, possibly affecting aerodynamics and cause excessive heat on various aero surfaces and can result in overheating of orbiter aluminum composite structures, slumping of tile surfaces, and up to, and including, the catastrophic loss of an orbiter (See Appendix O). Out-of-Tolerance tiles can cause as much as 6.34% of tile removals (Jones, 1999).

The boundary layer happens as an orbiter reenters the Earth's atmosphere, air pressure begins to build creating a laminar flow layer. This laminar flow layer acts as an insulation layer which keeps hot plasma at bay. This protective laminar layer is approximately 3 inches thick. This laminar layer will eventually turn turbulent, but much later in flight after most of the energy is dissipated. Early collapse of boundary layer puts vehicle at risk (over temp). The biggest cause of boundary layer collapse is "roughness" of the thermal protection system. Technicians keep TPS smooth by using specs to set requirements, and measurement tools to ensure accuracy. Better accuracy of TPS roughness leads to better TPS performance

This is why the Thermal Protection System (TPS) is so important in the Space Shuttle reentry phase into Earth's atmosphere as well as why the TPS technicians are so critical in their measurements of the aerospace surfaces. Each tile on the Space Shuttle is unique to its location, only fitting onto one specific location of the orbiter's surface. Each of these tiles is fabricated by machine and fitted by hand to its unique location taking the utmost care to ensure that a perfect fit is achieved.

When a technician begins the preparation of installing or pre-fitting a tile into its location, it is necessary for the technician to make sure to consult the tile drawing, which gives specific information such as: specific tile dimensions, whether or not abnormal structure variations exist, and/or what Nomex Felt material (filler bar) is used around the cavity of the tile for thermal and water vapor protection. Other requirements for the technician include the reviewing the required specification documentation for the specific area where the tile is being installed and other related documents. Reviews of all these documents are conducted in order to make the correct determination for the most accurate installation of the tile.

When performing these preparations for bonding a tile on the Space Shuttle, a technician is required to perform these tile pre-fits at 3 different stages of the bonding process (See Appendix D). As anything given three dimensional cubes, a tile has 6 sides; the top side or outer side of the tile is referred to as side 1 of the tile or commonly known as the tile Outer Mold Line (OML). Sides 2, 3, 4and 5 are the perpendicular sides to side 1 and start at the side facing toward the front-middle of the ship and running counter-clock-wise. Side 6 being the most crucial of the tile called the Inner Mold Line (IML) is delivered as undensified or soft silica which is highly delicate and impressionable. The IML of the tile will be fitted to the structure side of the ship to verify the correct contour (Appendix E). Densification is a process of hardening the tiles IML in one of the many steps before bonding to the ship to prevent crumbling. The reason a tile arrives undensified at first is so that a technician can match the structure of the ship to within .005 to .019 of an inch (location of tile on the orbiter determines specific accuracy requirements) or take steps to sand the soft silica to achieve a near perfect match. If a tile is not within the allowable range of accuracy the technician can sand the soft silica to match the orbiter and then send it to the Thermal Protection System Facility or Tile Shop to have it densified. Once densification is complete, a technician will check again to make sure nothing has changed. Once verification is complete, the tile is sent back to the Tile Shop a final time to have the Strain Isolated Pad (SIP) bonded to the bottom of the tile. To prevent damage to the tiles, Strain Isolation Pads - a layer of nylon felt Nomex (flame-retardant material) - are used between the tiles and the orbiter's surface. The pads are bonded to the tiles with RTV, a room-temperature vulcanizing silicone adhesive (Morgan, 1989). The tile surface bonded to the pads is densified with silica-type solutions for added tensile strength. Once the tile is received from the Tile Shop a final time, a technician will perform a final prefit and verify that none of the measurements have deviated from the predetermined maximum allowable measurements, once complete the structure surface is cleaned and prepared for bond (Appendix D).

Between the first and second pre-fit, nothing is on the bottom of the tile to makeup the gap of the missing SIP. The technician is therefore required to use one of three materials in processing the SIP gap. Stain isolator pad, heat sink, and bees wax vary close in size to one another but vary in their resistance to pressure. In current use all three materials are used during these test fits of tiles into their location on the orbiter. Only during certain circumstances will United Space Alliance engineering make a requirement for use a specific material. With this research project, I plan to test my hypothesis and present factual findings to NASA for the next generation of spacecraft and the use of next generation of Thermal Protection System tiles.

In TPS it is necessary to take step measurements in order to determine if tile to tile heights are within certain minimum/maximum criteria. Criteria for each tile are set by engineering. Set processes and drawings serve as guides to technicians from measurements taken using a calibrate dial tool called a trammel tool. These measurements are taken in increments of .001 of an inch and may be required to maintain a tolerance of up to .030 of an inch, depending on the location of the tile on the orbiter. TPS technicians use multiple methods of measuring tile steps or the height difference from one tile to the next. The accuracy of these measurements can vary greatly between each technician compared to the final step measurements. In order to maintain a higher accuracy rate between multiple personal, a standard in measurements in order to achieve the most accurate data compared to the final measurements taken after the bonding process. With a standard measuring method the ability to obtain accurate data will help reduce multiple extra steps required to fix inaccurate step issues.

History

The Space Shuttle Orbiter is an amazing technological achievement. It is the world's first and so far only reusable spacecraft. It is immensely complicated and certainly does not achieve the reusability of an airplane, requiring extensive (and expensive) overhaul and checkout after each flight. But the Orbiter still flies again and again using much of the same equipment, something that no other space vehicle has done (Day, 2009).

One of the keys to this reusability is the Orbiter's Thermal Protection System, or TPS. The most visible aspect of the TPS is the Orbiter's external tiles. But in reality, the TPS consists of a combination of materials and technologies that work together to protect the spacecraft and its human occupants. The TPS represents significant advances in aerodynamic design, metallurgy, and the understanding and manufacture of materials, a discipline known as materials science. Underneath its protective layer of tiles and other materials, the Space Shuttle is of rather ordinary aluminum construction, similar to many large aircraft (Day, 2009).

Early vehicles that had to reenter the Earth's atmosphere used a variety of techniques to keep from burning to a crisp. Some used heat sinks to absorb the heat. Others used ablative material that charred and vaporized. But none of the early vehicles had to be reusable and so they could use materials and techniques that protected the vehicle but rendered it essentially unusable afterwards. Some spacecraft designers did propose developing heat shields for spacecraft that could be completely replaced after flight, allowing a space capsule, such as the Apollo Command Module, to be reused, but these proposals never advanced very far. When spacecraft designers started thinking about reusable vehicles, they figured that they would have to use some combination of metals and ceramics that could survive high temperatures. Such an approach was considered for the canceled X-20 Dyna Soar spaceplane of the early 1960s (Day, 2009).

When the Space Shuttle was first proposed in the late 1960s, planners from the National Aeronautics and Space Administration (NASA) wanted a vehicle that would be much larger than any that had flown in space before. But the amount of high-temperature metal required to protect a large vehicle would have been very heavy and this would have affected vehicle performance. Designers chose to use conventional aluminum for the main body and to protect it with a layer of heat resistant material (Day, 2009).

The properties of aluminum demand that the maximum temperature of the Orbiter's structure be kept below 350 degrees Fahrenheit (175 degrees Celsius) in operations. But aerothermal heating during liftoff and reentry (in other words, heating caused by friction with the air) will create surface temperatures high above this level and in many places will push the temperature well above the melting point of aluminum (1,220 degrees Fahrenheit or 660 degrees Celsius). Clearly an effective insulator was needed (Day, 2009).

Fortunately, during the 1960s, Lockheed developed a silica-based insulation material for NASA. NASA designers decided to use this and similar materials to manufacture heat-resistant tiles and other coverings to protect the Orbiter's airframe (Day, 2009).

Thousands of tiles of various sizes and shapes cover a large percentage of the Space Shuttle Orbiter's exterior surface, although over the two decades of Shuttle operation, many tiles have been removed from the upper wings and fuselage of the

Orbiter and replaced with a lighter and less expensive material. Some tiles have a side dimension of six inches (15 centimeters) or less; others are about eight inches (20 centimeters) on a side. There are two main types of tiles, referred to as Low-temperature Reusable Surface Insulation (LRSI) and High-temperature Reusable Surface Insulation (or HRSI) (Day, 2009).

LRSI tiles cover relatively low-temperature areas of one of the orbiters, the *Columbia*, where the maximum surface temperature runs between 700 and 1,200 degrees Fahrenheit (370 and 650 degrees Celsius), primarily on the upper surface of fuselage around the cockpit. These tiles have a white ceramic coating that reflects solar radiation while in space, keeping the *Columbia* cool. HRSI tiles cover areas where the maximum surface temperature runs between 1,200 and 2,300 degrees Fahrenheit (650 and 1,260 degrees Celsius). They have a black ceramic coating, which helps them radiate heat during reentry. Most of these tiles cover the bottom of the Orbiter. Both LRSI and HRSI tiles are manufactured from the same material and their primary difference is the coating (Day, 2009).

Researchers Work Role and Setting

The researcher is a highly experienced Aerospace technician certified to instruct and supervise all the following tests, interpret drawings, specifications, and lead research subjects. This qualifies the author of this Capstone as a subject matter expert (SME).

Statement of the Problem

The focus of this study was to analyze the different materials used in the step measurements during pre-fits of Thermal Protection System tiles and investigate the accuracy of these materials in making these measurements. Three materials are being were considered for this research project, Dow Corning's' heat sink, Freeman Manufacturing's Adhesive Back Bees Wax, and Albany International's strain Isolator Pad.

Sub problems

The first Sub problem was to determine which of these three materials yielded the highest accuracy in step measurements to the tile once bonded.

The second Sub problem was to determine if there was a correlation between experience levels and the accuracy of measurements taken and recorded.

The third Sub problem was to determine how accuracy of the measurements that were taken using the approved trammel tool by the technicians differs in accuracy compared to the use of a flat card and a shim pack.

Assumptions

The sample size was sufficiently large and representative of the target population which was all the tiles on the actual shuttle.

Delimitations

The findings of this study applied only to the space shuttle or similar craft. The sample measurements were not made on the shuttle per se'. These measurements were made using a test plate with non flight tiles made with the same process as flight ready tiles. This test was conducted in a way to prevent damage to flight hardware and minimization of delays to flight manifest. The non flight hardware test plate that will be was used is an exact representation of the current configuration of all orbiters. Only materials that are currently authorized per the specification set forth by NASA and the Boeing Corporation will be used during these tests. This research only looked at elements from controlled bay environment and eliminated the variables of the VAB or Launch pad environment.

Definition of Terms

High-Temperature Reusable Surface Insulation (HRSI)-cover the lower surface of the orbiter, areas around the forward windows, upper body flap, the base heat shield, the "eyeballs" on the front of the Orbital Maneuvering System (OMS) pods, and the leading and trailing edges of the vertical stabilizer and the rudder speed brake. The black tiles are located where temperatures can reach as high as 2,300 degrees F (Morgan, 1989).

FRSI (Felt Reusable Surface Insulation) - FRSI is a flexible thermal blanket, heat treated felt, surface coated on one side. This product is installed as continuous panels for use in vehicle areas which can withstand up to 800°F. Each piece is uniquely identified and traceable to qualifying test data. The product is available in many thicknesses (Albany International, 2008).

Filler Bar - Filler Bar is a flexible, continuous strip of TPS felt, surface coated on one side with a silicone film, installed in arrays of varying widths to accommodate tile placement. This product is delivered to the customer as narrow strips, cut to customer-required widths. Each piece is uniquely identified and traceable to qualifying test data. The product is available in many thicknesses (Albany International, 2008).

Orbiter- Is a space vehicle such as the Space Shuttle without the external tank and the solid rocket busters.

RTV-560 –RTV 560 is used for aerospace applications such as potting, sealing and boding, where extreme high and low temperature service is required. A primer is required. The product comes complete with catalyst DBT (Offbeat Studio, 2007).) Vulcanized silicone rubber is prepared in two principal forms: (1) as low-molecular-weight liquid room-temperature-vulcanizing (RTV) polymers that are interlinked at room temperature after being cast or molded into a desired shape or (2) as heat-curable, high-temperature-vulcanizing (HTV) (Encyclopædia Britannica, 2009).

The Data Collection Device

A koropon coated aluminum plate with an array of TPS tiles bonded to mimic the orbiter underside was fabricated for this test. Step measurements were taken using a calibrated step tool using the same specification required on flight hardware tiles. Each of the test subjects were required to dial in the calibration of the trammel step tool before each measurement. The test subjects then took measurements across each tile interface between the test tile and surrounding tiles. This procedure was repeated for each of the materials tested during the trials. See Appendix G for example of the panel.

Treatment of the Data and Procedures

Hypothesis One: Of the three materials used, bees wax will yield the highest accuracy in comparison to SIP and heat sinks due to two reasons. First, Bees wax thickness most closely resembles the bonded SIP then both unbounded SIP and heat sink. Second, Bees wax tends to have a medium amount of give compared to SIP which has a high amount and heat sink which offers very little. This closely mimics the final results. Each of the measurements was compared to the baseline measurements made after the test tile was bonded. The data was evaluated to determine if a significant difference existed between each the test materials. All three materials were tested and compared in this manner and recorded in a table similar to Table 1-4.

Table 1

Tile Measurements (For illustrations use only)

SIP Measurement Data					
Participant ID Code	**-027**	**-034**	**-035**	**-290**	**-291**
101	-14	35	34	28	-26
102	-12	54	53	43	-20
103	-8	45	40	50	-24
201	-20	38	40	40	-25
202	-15	38	44	37	-21
203	-19	34	44	35	-29
301	-7	38	38	30	-32
302	-20	50	55	40	-25

Table 2

Tile Measurements (For illustrations use only)

Bees Wax Measurement Data					
Participant ID Code	**-027**	**-034**	**-035**	**-290**	**-291**
101	12	48	23	38	-14
102	-5	35	25	36	-22
103	-5	34	25	35	-21
201	-10	35	25	30	-10
202	-7	40	31	34	-15
203	-15	42	44	38	-21
301	-12	33	27	31	-4
302	-5	35	30	30	-20
303	-5	30	25	26	-24

Table 3

Tile Measurements (For illustrations use only)

Heat Sink Measurement Data					
Participant ID Code	**-027**	**-034**	**-035**	**-290**	**-291**
101	15	17	13	20	-5
102	0	23	10	20	-8
103	5	18	10	15	-12
201	-8	28	19	26	-15
202	-5	35	20	30	-25
203	-10	39	34	26	-16
301	0	13	20	38	-22
302	-4	30	22	28	-12
303	-5	25	22	20	-20

Table 4

Tile Measurements (For illustrations use only)

0.5 Inch Scale / Shim Pack Measurement Data					
Participant ID Code	**-027**	**-034**	**-035**	**-290**	**-291**
101	-7	15	12	10	-10
102	-10	24	14	24	-20
103	-15	33	24	24	-20
201	-20	25	20	20	-20
202	-10	35	20	30	-25
203	-10	38	19	35	-28
301	-10	30	25	30	-10
302	-10	30	30	25	-20
303	-10	30	30	25	-20

After the measurements were concluded, they were checked for accuracy and the error. Once completed, all data was evaluated and tested against the hypotheses.

A one-way ANOVA was used to test the null hypothesis determine that the mean errors for all three types of materials were equal. The tests were conducted at the 0.01 level. If the null is rejected, a Tukey post hoc test will be used to identify the material with the least mean error.

Hypothesis Two: The technicians who generate the sample data who have the most experience performed these measurements with a higher accuracy then less experienced technicians do to experience. This test will involved a group the technicians in the sample by experience level into categories of ten years. For example, the first group would contain the technicians from the first year experience to ten years experience. The second group contained participants from eleven to twenty years. The final group consisted of those participants with twenty one years experience onward.

The mean error for all measurements made by technicians in the sample were calculated and placed in a table then sorted by experience level.

A Chi-Square Goodness of Fit test was used to test the null hypothesis that the distribution of errors is uniform; that is, they are all statistically equal. If the null is rejected at the 0.01 level of experience, the research hypothesis was supported.

Hypothesis Three: Measurements made with the calibrated trammel were more accurate than the shim pack due to the fact that the trammel tool can measure in 1/100 of an inch compared to the shim packs .005 of inch accuracy. The raw data that was collected was analyzed to determine the accuracy of each of the step measurements from the different materials and comparing them to the baseline data that was collected.

CHAPTER IV

RESULTS

The results of the experimental quantitative research project are presented in tables 1, 2 and 3. Each table included the sample proportion of 31 employees collected during the 09/W1 winter term. The sample proportion for each item is the ratio of the numbered measurements in comparison to the measurements taken during post bond of the sample tile. The goal of this research project was to compare and contrast the selected materials used in step measurements during pre-fits of thermal protection system tiles and to compare and contrast the accuracy of measurements made using these selected materials. The reasoning for conducting this test was to obtain a clearer understanding as to which of these materials may yield the highest accuracy rate of exacting measurements in comparison to the completed tile bond. The sample proportion for each item is the ratio of the numbered measurements in comparison to the measurements taken during post bond of the sample tile.

Hypothesis One

Sub Problem 1

Hypothesis One: 20% of the Thermal Protection System population at United Space Alliance was used to test the accuracy of the materials used during prefits test. The data for sub-problem one and hypothesis one is summarized in Figure 1 through 4. Of the three materials used, bees wax will yield the highest accuracy in comparison to SIP and heat sinks. The data for sub-problem one and hypothesis one is summarized in Figure 6 through 8. First, Bees wax thickness most closely resembles the bonded SIP then both unbounded SIP and heat sink. Second, Bees wax tends to have a medium amount of give compared to SIP which has a high amount and heat sink which offers very little. This closely mimicked the final results. Each of these measurements was compared to the baseline measurements made after the test tile was bonded. The data was evaluated to determine if a significant difference existed between each the test materials.

After the collection of the raw data, the information was placed in an Excel spreadsheet in order to decipher the actual difference in height from the samples taken to the actual height of the completed bond. An example of this would be if a participant using Bees' wax, were to take a measurement from point A to point B on a test tile and the results from that single spot was -15 mils. Once bonded the test tile was remeasured at the same reference point and a baseline height measurement of -5 mils was achieved. The difference between the two reference points was-10 mils. In order to properly input data correctly into the database, all the reference points had to be recalculated to show the actual difference between the data collected and the reference data. A simple mathematical formula in Excel was created to translate all the data to what was considered the actual difference in the test.

Table 5

Example of data collection methods pre correction (For illustrations use only)

Data Collection Information	Baseline measurements -5	Baseline measurements 33	Baseline measurements 23
Participants #	Bees Wax Measurements		
101	-15	-34	-35
102	12	48	23
103	-5	35	25
201	-5	34	25

Table 6

Example of data collection methods post correction (For illustrations use only)

Data Collection Information	Baseline measurements -5	Baseline measurements 33	Baseline measurements 23
Participants #	Bees Wax Measurements		
101	-10	67	58
102	17	15	0
103	0	3	2
201	0	1	2

Once all the data was converted to actual differences in measurements, the process of compiling the results could then take place. An ANOVA analysis was then run at the 99% level of confidence to ensure the highest accuracy of the results and also checked for any type I error rates associated with the multiple comparisons often used to identify significant differences between specific factor levels in an ANOVA. An ANOVA analysis was used to compare the data collected to see if indeed there were any differences between SIP, Bees' Wax, Heat Sink, and Shim Pack tests. Figure 1 shows the results of the SIP data, as well as Figures 2, 3 and 4 shows the results of Bees' Wax, Heat Sink and Shim Pack respectively.

Figure 1

Descriptive statistics for all SIP measurements

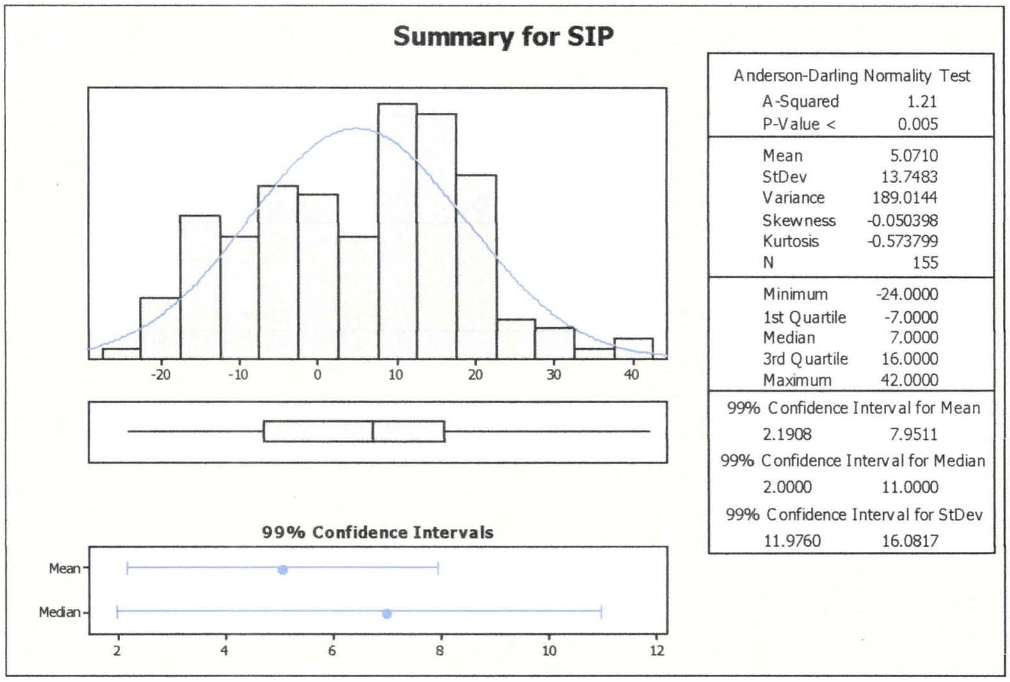


Figure 2

Descriptive statistics for all Bees' Wax measurements

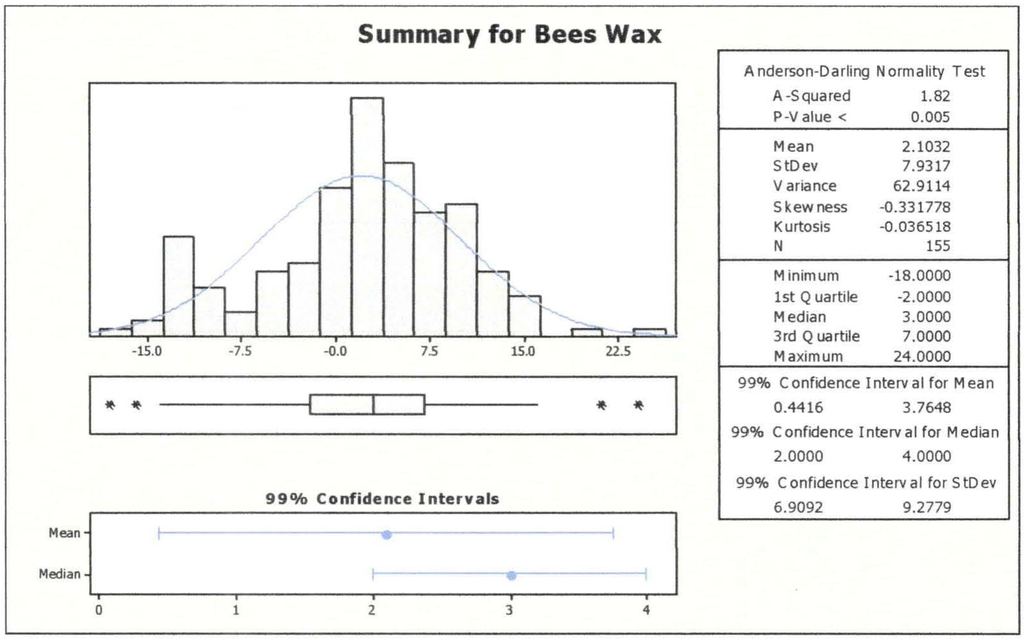


Figure 3

Descriptive statistics for all Heat Sink measurements

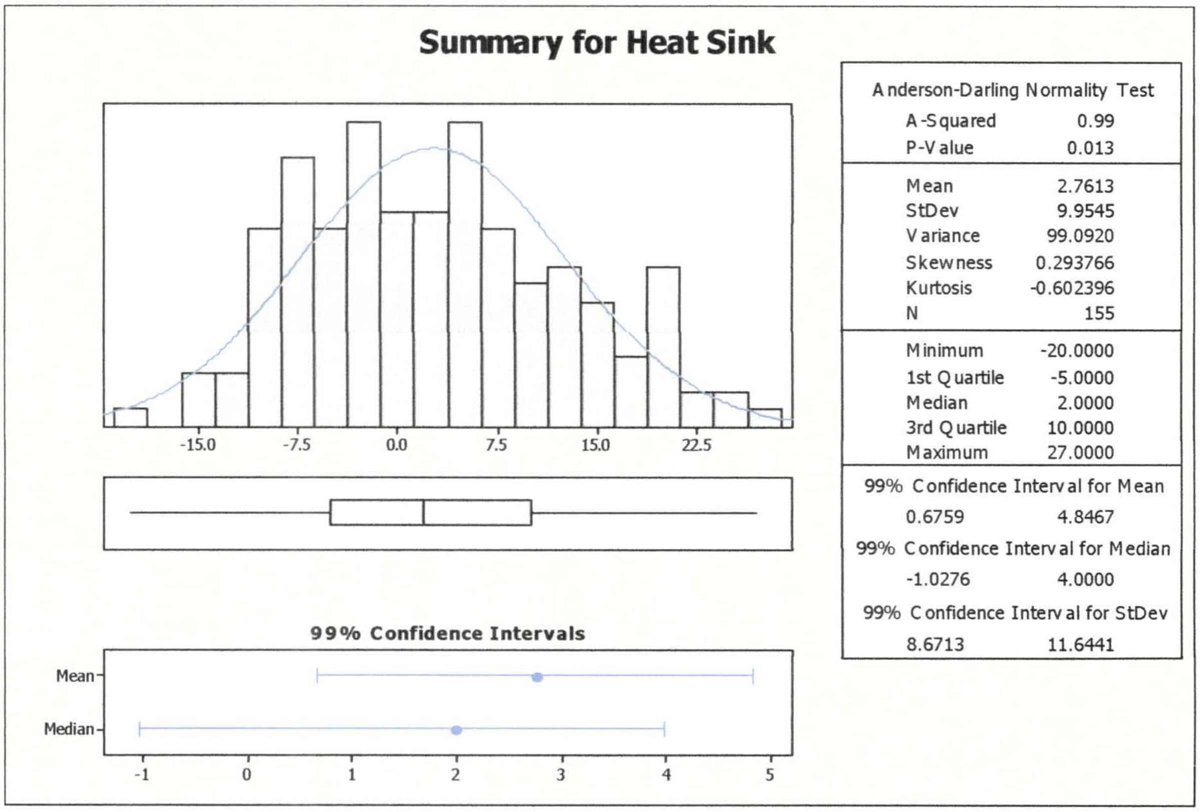
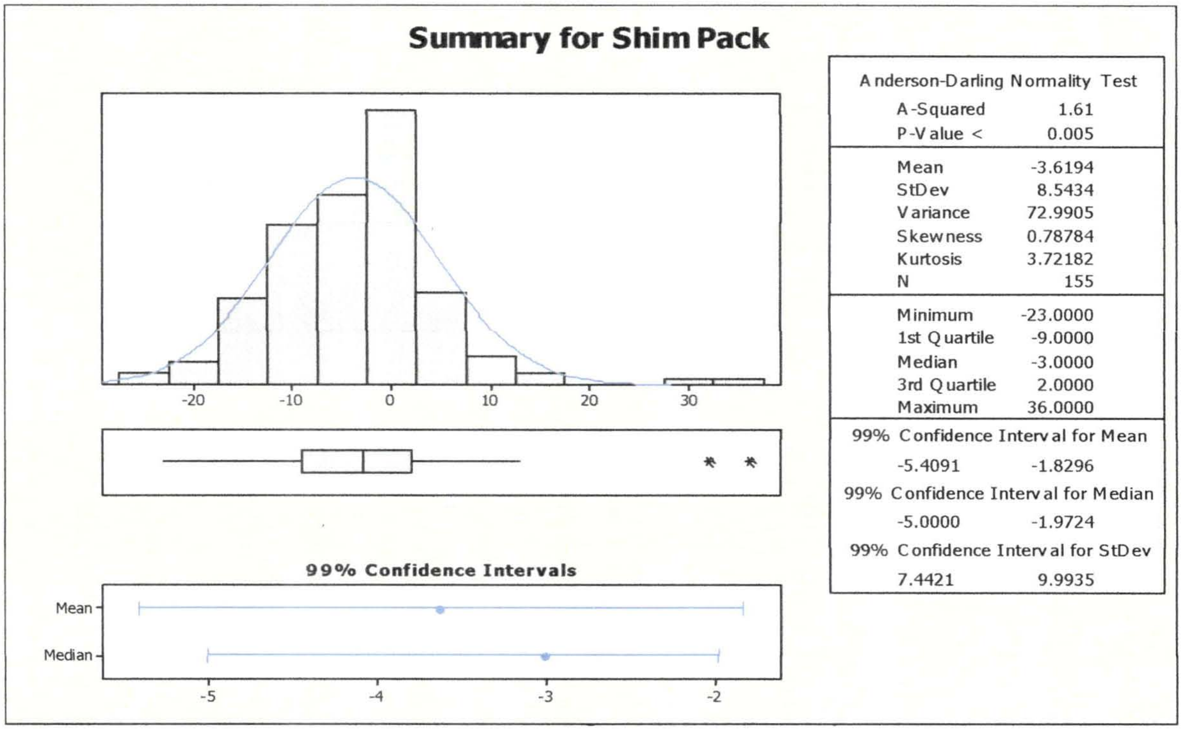


Figure 4

Descriptive statistics for all Shim Pack measurements



Minitab (both are highly useful statistical data analysis programs for this very kind of tests) derived from the data collected from each of these tests.

Table 7

Summary of One Factor ANOVA

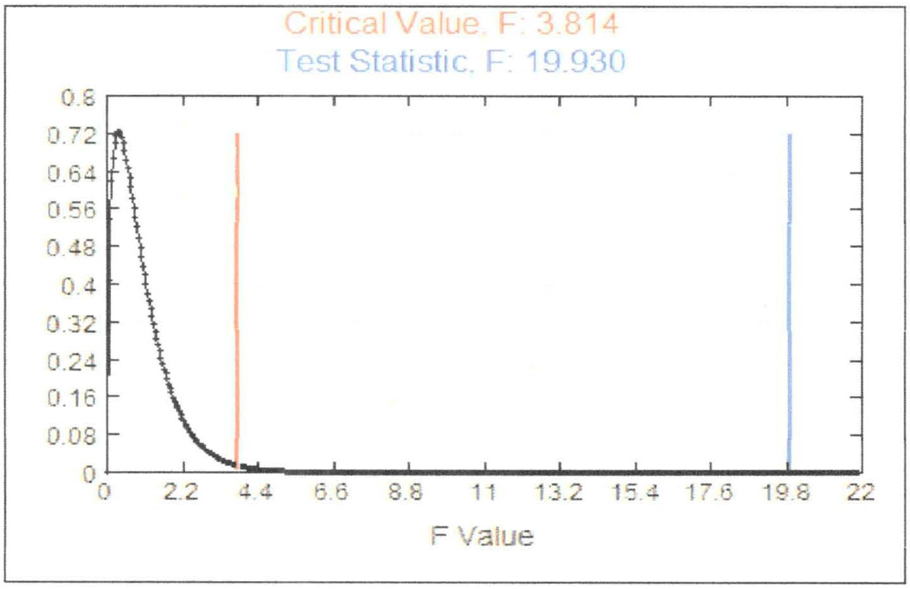
	Mean	n	Std. Dev
SIP	5.1	155	13.75
Bees' Wax	2.1	155	7.93
Group 3	2.8	155	9.95
Group 4	-3.6	155	8.54
Total	1.6	620	10.76

This data shows what the differences were for each of the data fields collected. Group 1 was the data from the SIP test, group 2 was the data from the Bees' Wax test, 3 was the heat Sink test, and 4 was the Shim Pack test in comparison to having Bees' Wax for a substrate.

In order to find out whether the differences between the four groups was actually significant or not additional tests had to be run. The next step was to run the Tukey test (Honest Significant Difference Test), the Tukey test compared each line of data to all the other lines of data statistically and showed if there indeed there was an honest difference between each collection of data tested. These results are posted in Figure 5 as well as Tables 8, 9, 10 and 11. The test was run as if the data was considered as equal.

Figure 5

Tukey test data on selected material testing



Summary of results from running a Tukey Test of the data collected for tile heights and the use selected materials.

Table 8

Tukey test results and hypothesis rejection

Source:	DF:	SS:	MS:	Test Stat, F:	Critical F:	P-Value:
Treatment:	3	6337.85	2112.616667	19.929956	3.813539	2.44E-12
Error:	616	65297.277419	106.002074			
Total:	619	71635.127419				
Reject the Null Hypothesis Reject equality of means						

Table 9

Comparision of results of selected materials during ANOVA Test

ANOVA Test results						
		Sum of Squares	df	Mean Square	F	Sig.
SIP	Between Groups	18843.2587	33	571.00783870	6.730853692	3.15E-15
	Within Groups	10264.9607	121	84.83438577		
	Total	29108.21940	154			
Heat Sink	Between Groups	8710.64368	33	263.95889940	4.876541642	6.9E-11
	Within Groups	6549.52406	121	54.12829803		
	Total	15260.16770	154			
Shim Pack	Between Groups	4125.68295	33	125.02069550	2.126184679	0.001644
	Within Groups	7114.85898	121	58.80048746		
	Total	11240.54190	154			

Comparable results of the Post hoc test run on the data collected for tile heights and the use selected materials.

Table 10

Tukey (HSD) comparison of most accurate measurement tests

		Shim Pack	Heat Sink	Bees' Wax	SIP
		-3.6	-1.6	1.8	5.1
Shim Pack	-3.6				
Heat Sink	-1.6	.0717			
Bees' Wax	1.8	9.44E-07	.0017		
SIP	5.1	1.16E-14	1.76E-09	.0032	
Tukey simultaneous comparison t-values (d.f. = 616)					

Table 11

Post-hoc analysis for the difference of means

		Shim Pack	Heat Sink	Bees' Wax	SIP	Shim Pack
		-3.6	-1.6	1.8	5.1	-3.6
Shim Pack	-3.6					
Heat Sink	-1.6	1.80				
Bees' wax	1.8	4.95	3.15			
SIP	5.1	7.91	6.11	2.96		
	0.05	2.60				
	0.01	3.18				
critical values for experiment wise error rate:						

Tables 9 and 10 are comparable results of the Post hoc test run on the data collected for tile heights of the selected materials.

Hypothesis Two

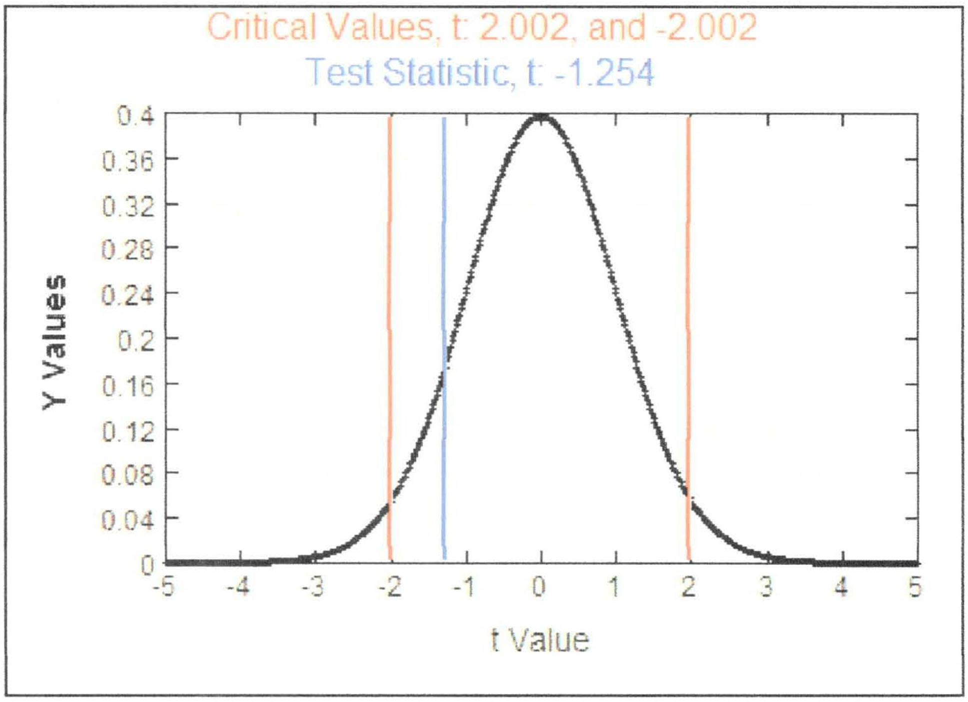
Sub Problem 2

Hypothesis Two: The technicians who generated the sample data who have the most experience performed these measurements with a higher accuracy then less experienced technicians do to experience. This test will involved grouping the technicians in the sample by experience level into categories of 1-5, 6-10, 11-20, and 21-30+ years. For example, first group contained the technicians from the first year experience through the fifth year experience. The second group contained participants from six to ten years. The next group will consist of those with eleven to 20 years experience. The final group will consisted of participants with twenty-one years experience onward.

The mean error for all measurements made by technicians in the sample was calculated and a comparison was made using the 21-30+ group as the standard while comparing the rest of the groups to them. A One Way Analysis of Variance (ANOVA) test was used to differentiate the data gathered for the experience level of technicians. In this test, Megastat statistical data software was used to run the test in addition it produced a post hoc analysis of the data automatically. The results of the test are shown in Figures 6, 7, and 8. Figure 6 is a comparison of the 21-30+ years of experience technicians to the 1-5 years experience level. Figure 7 is a comparison of the 21-30+ years of experience technicians to the 6-10 years experience level. Finally, Figure 8 is a comparison of the 21-30+ years of experience technicians to the 11-20 years experience level technicians.

Figure 6

Comparison of 21-30+ years againt 1-5 Year Experience Technicians



Not eq. vars: No Pool (and df calculated with Formula 9-1)

Claim: $\mu 1$ not equal $\mu 2$

Test Statistic, t: -1.2538
Critical t: ±2.664737
P-Value: 0.2150

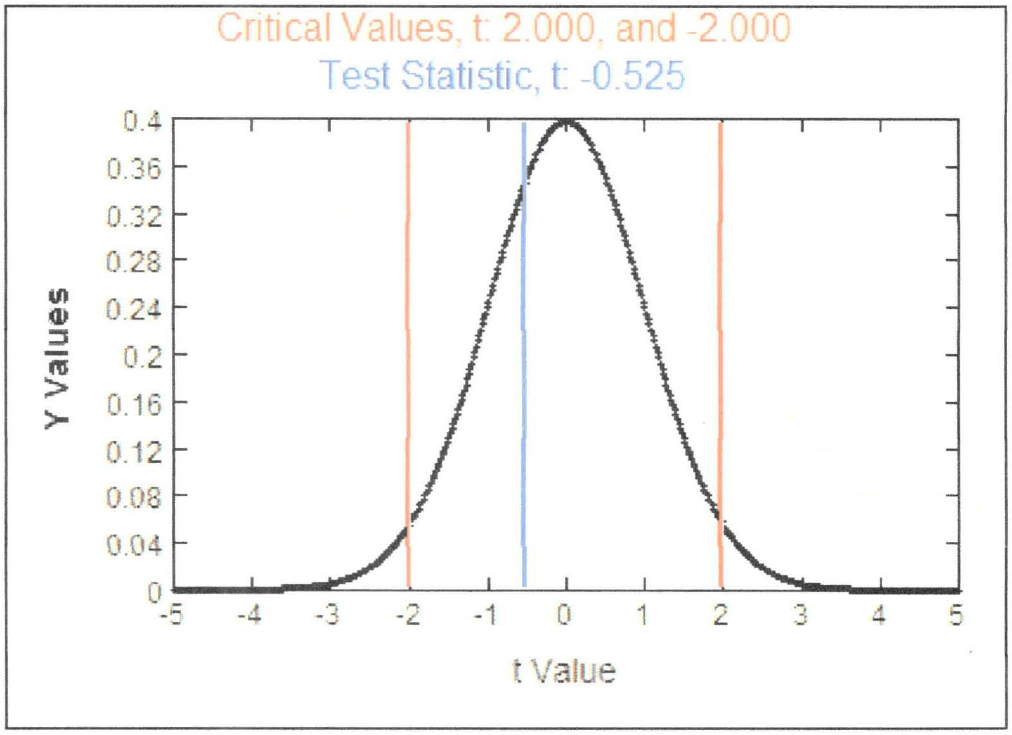
Degrees of freedom: 57.0843

99% Confidence interval:
$-7.813259 < \mu 1 - \mu 2 < 2.813259$

Fail to Reject the Null Hypothesis
Sample does not provide enough evidence to support the claim

Figure 7

Comparison of 21-30+ years againt 6-10 Year Experience Technicians



Not eq. vars: No Pool (and df calculated with Formula 9-1)

Claim: μ1 not equal μ2

Test Statistic, t: -0.5249
Critical t: ±2.658886
P-Value: 0.6015

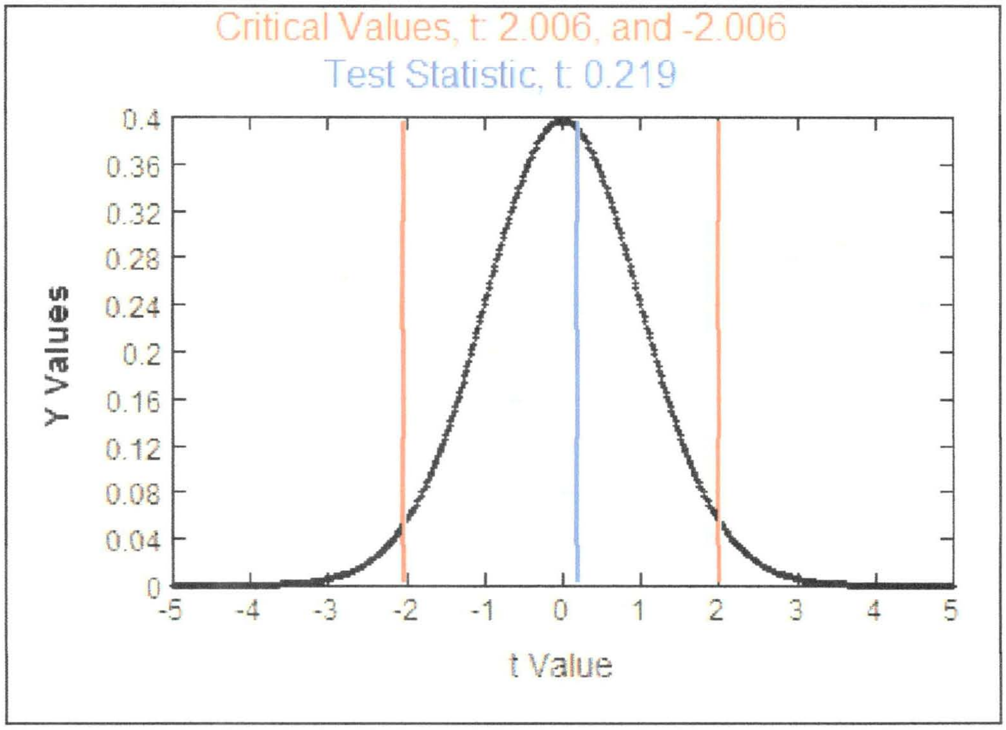
Degrees of freedom: 60.9816

99% Confidence interval:
-6.065395 < μ1-μ2 < 4.065395

Fail to Reject the Null Hypothesis
Sample does not provide enough evidence to support the claim

Figure 8

Comparison of 21-30 years againt 11-20 Year Experience Technicians



Not eq. vars: No Pool (and df calculated with Formula 9-1)

Claim: μ1 not equal μ2

Test Statistic, t: 0.2191
Critical t: ±2.672273
P-Value: 0.8274

Degrees of freedom: 52.7596

99% Confidence interval:
$-4.478346 < \mu1-\mu2 < 5.278346$

Fail to Reject the Null Hypothesis
Sample does not provide enough evidence to support the claim
There is no evidence to indicate that experience is related to accuracy of measurement.

Hypothesis Three

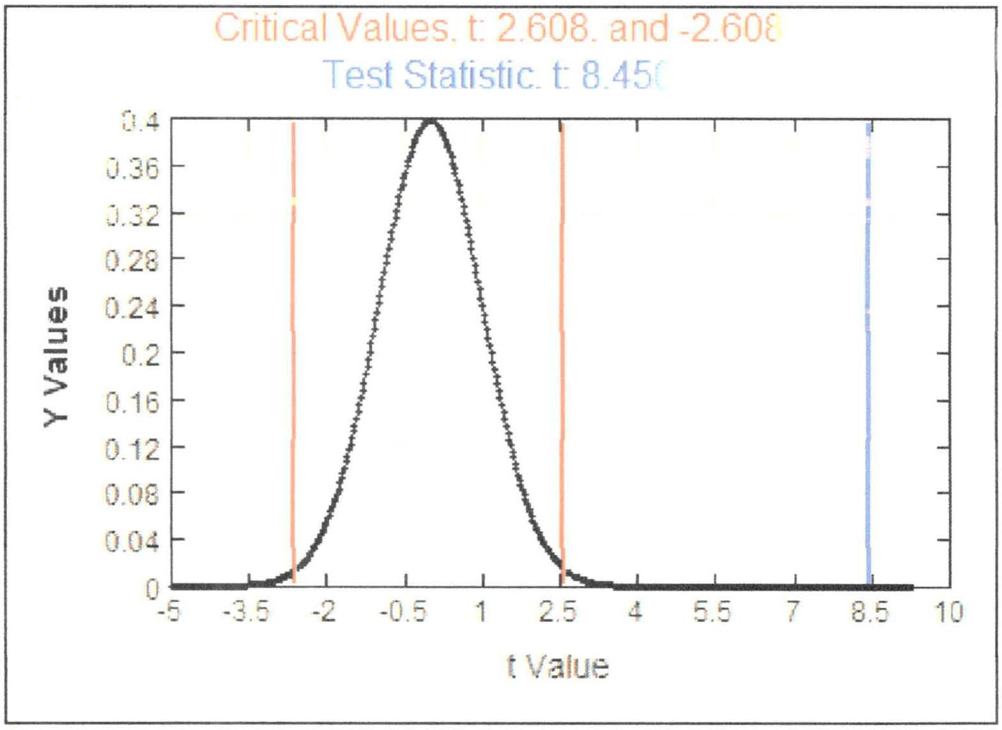
Sub Problem 3

Hypothesis Three: Measurements made with the calibrated trammel were more accurate than the shim pack due in part that the trammel tool can measure in 1/100 of an inch compared to the shim packs .005 of inch accuracy .

The raw data that was collected was analyzed to determine the accuracy of each of the step measurements from the Bees' wax materials and comparing them to the baseline data from the Shim Pack data collected. While collecting the data for the Bees' wax test, the test subjects were required to take further step measurements with a calibrated 6 inch scale and calibrated shim pack made exclusively for these tests. The data measurements were taken at the same reference points as the trammel tool to eliminate any inaccurate readings. Since the data collected for the shim pack was to be equally matched to the Bees' wax test the use of the hypothesis testing-matched pairs test was run. The set claim "Mean of differences not = 0" and the significance level (0.01) was chosen. The two columns were evaluated and the p-value indicated whether or not to reject the null. The program subtracts the values in column 2 from those in column 1. If the total difference on the screen is positive, then the population mean for column 2 is greater. If the total difference is negative then the population mean for column 1 is greater. The results of the hypothesis testing-matched pairs test can be seen in Figure 9 below.

Figure 9

Comparison of Trammel tool verses Shim Pack Measurements



Claim: μ not equal μ(hyp)

Sample size, n: 155
Difference Mean, d: 5.722581
Difference St Dev, sd: 8.431185
Test Statistic, t: 8.4502
Critical t: ±2.6081
P-Value: 0.0000

99% Confidence interval:
3.956329 < μd < 7.488832

Reject the Null Hypothesis
Sample provides evidence to support the claim

(The calibrate trammel does appear to more accurate than the shim pack.)

CHAPTER V

DISCUSSION

Data Collection Procedures

At the time of data collection there were approximately 155 active employed technicians available to help in the data gathering working three different shifts. Out of those 155 technicians, 31 volunteers agreed to participate in the data collection on their own personal time.

Each volunteering technician was asked to take step measurements of the 5 test tiles utilizing the tools and processes that are required during standard tile step and gap procedures. Provided to each tech was a calibrated trammel step tool with the same calibration I.D. to eliminate variation in data collection, one calibrated shim pack made specifically for this data collection, and one calibrated 6 inch scale for use in height determination. In addition calibrated marks were placed on each tile to indicate the exact position and location in which the trammel tool was to be placed therefore eliminating any chance of recording erroneous measurements.

Instructions were given to each participant that all rules were to be followed in measurements as if test were being conducted on actual flight hardware. Further instructions were also given to take step measurements starting with the SIP, once complete measurements were conducted with the Bees' wax. Since the Bees' wax was to be conducted using two types of test, each volunteer was asked to take all trammel tool readings first then move on to the shim pack test to minimize personal time usage. Finally the heat sink test was conducted and debriefing was followed up.

Hypothesis One

Sub Problem 1

The null hypothesis that the populations mean error was not the same for all substances investigated was tested using a One Way Analysis of Variance (ANOVA). The null was rejected, indicating a difference between at least two population means. The Tukey Test was then applied to determine which pairs of mean were significantly different. Based on the p-values of the post-hoc test of 0.0717, 0.0032, and 0.0017 that were less than 0.01, significant differences were found to be between Bees' Wax and Heat Sink and between Bees' Wax and SIP. Bees' Wax proved to yield the highest accuracy among the three materials used during this test.

Hypothesis Two

Sub Problem 2

The null hypothesis that technicians who generated the sample data who have the most experience would perform these measurements with a higher accuracy then less experienced technicians do to experience level was evaluated using the Megastat statistical data software with a One Way Analysis of Variance (ANOVA) test in addition to a post hoc analysis.

The test involved grouping the technicians in the sample by experience level into categories of 1-5, 6-10, 11-20, and 21-30+ years. The Post-hoc analysis in Figures 6, 7, and 8 indicated that the p-value was approximately 0.51, much larger than 0.05 of the test, so the null that all four population means are equal was not rejected. There was no statistical significant difference in the data to indicate that experience was related to accuracy.

Hypothesis Three

Sub Problem 3

Measurements made with the calibrated trammel will yielded a higher accuracy than the shim pack due in part that the trammel tool can measure in 1/100 of an inch compared to the shim packs .005 of inch accuracy. After the set claim "Mean of differences not = 0" and the significance level (0.01) was chosen. The two columns were evaluated and the p-value indicated that the error is greater for the column two populations and the Shim Pack yielded a higher error rate then did the Trammel tool test.

As shown in Figure 9, the Mean and the Confidence interval in the Chi Square test indicate that when the test of unequal means was run the data claim "Rejected the Null Hypothesis" and that the "Sample provides evidence to support the claim" that the Trammel tool yielded a higher accuracy then did the Shim Pack.

CHAPTER VI

CONCLUSIONS

Based on the data collected and analyzed, the use of Bees' Wax yielded a higher degree of accuracy than either SIP or Heat Sink. Additional tests would be needed to investigate the possibility that these inaccuracies would or could cause substantial issues with tile bonds and whether these issues would cause additional tile removals.

The analysis of data for hypothesis two indicated that experience was not related to accuracy of measurement. Additional analysis can be conducted at a later date using a larger sample and different classes of experience levels.

The analysis of sample data for hypothesis three indicated that the trammel tool was more accurate than the shim pack. Additional tests would have to be run to investigate the possibility that these inaccuracies would or could cause substantial issues with tile bonds and whether these issues would cause additional tile removals. Those analyses may be run at a later date and time to indicate if concern exists about the types of materials chosen for prefits of .160 SIP tiles.

CHAPTER VII

RECOMMENDATIONS

Based on the results of this study, Bees Wax should be the preferred material for tile measurement because it resulted in the most accurate measurements. Additional investigations of the types of materials for prefits of .160 SIP tiles should be conducted to see if a larger population might yield different results. The results of this study should be forwarded to United Space Alliance Engineering for additional analysis to include a comparison with data already on file.

Very little difference was found in experience level of technicians whom participated in these tests. No indication was found that experience level yielded a higher rate of accuracy during these test. Additional tests should be run to see if a larger population might yield different results but. There is always the possibility of alienating technicians who feel the test could harbor irreparable harm to their abilities. For this kind of testing a much larger sample would be needed. Since there is no reason to suspect different results, the cost of such as study should be weighed against the possibility of little gain.

The data collected in the Shim Pack verses Trammel tool yielded a higher accuracy rate for the Trammel tool over the Shim Pack. Further test should be run to indicate whether these inaccuracies would or could cause substantial issues with tile bonds and whether these issues would cause additional tile removals. A recommendation is that the trammel tool be used in lieu of the ship pack since it is more accurate. These results will be turned over to United Space Alliance Engineering for further analysis and compared to the data already on file.

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APPENDIX A

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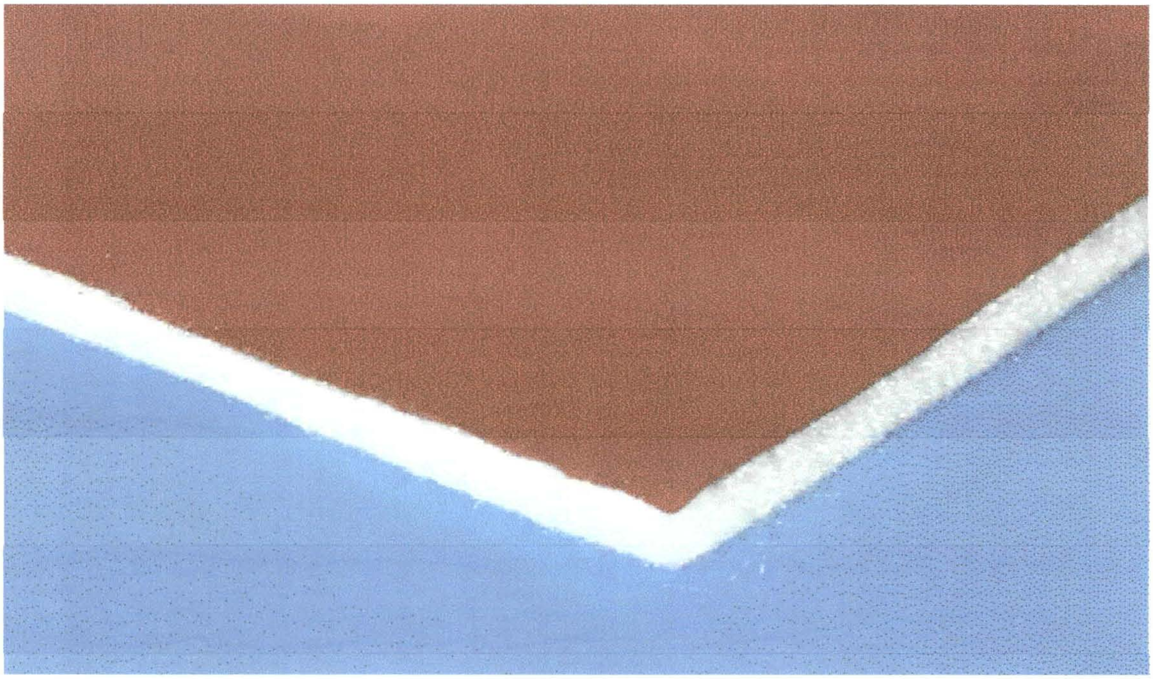
APPENDIX B

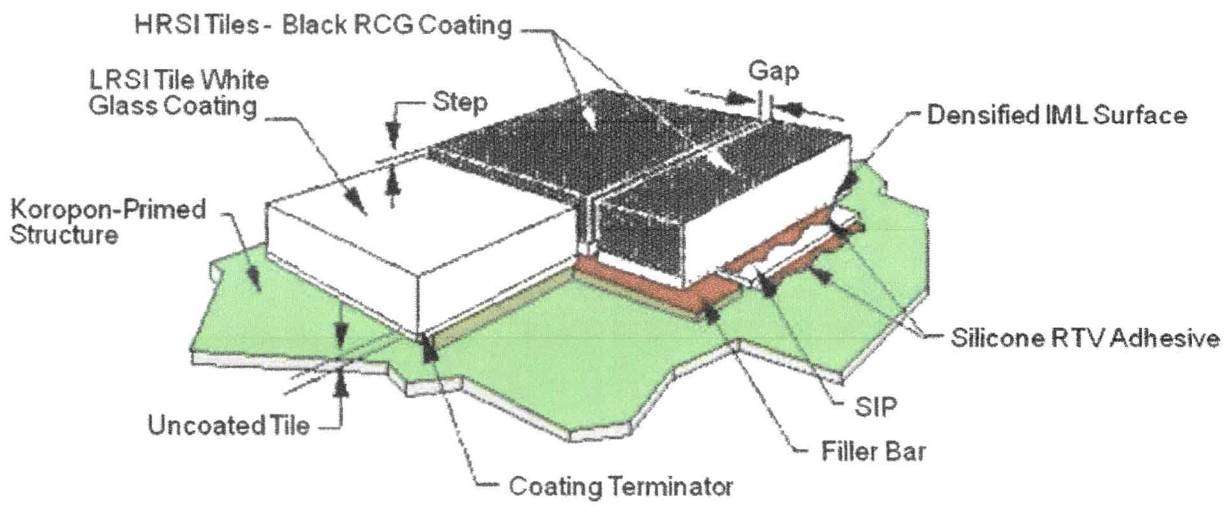
Picture of Strain Isolator Pad



SIP (Quinlan, 2003)

APPENDIX C

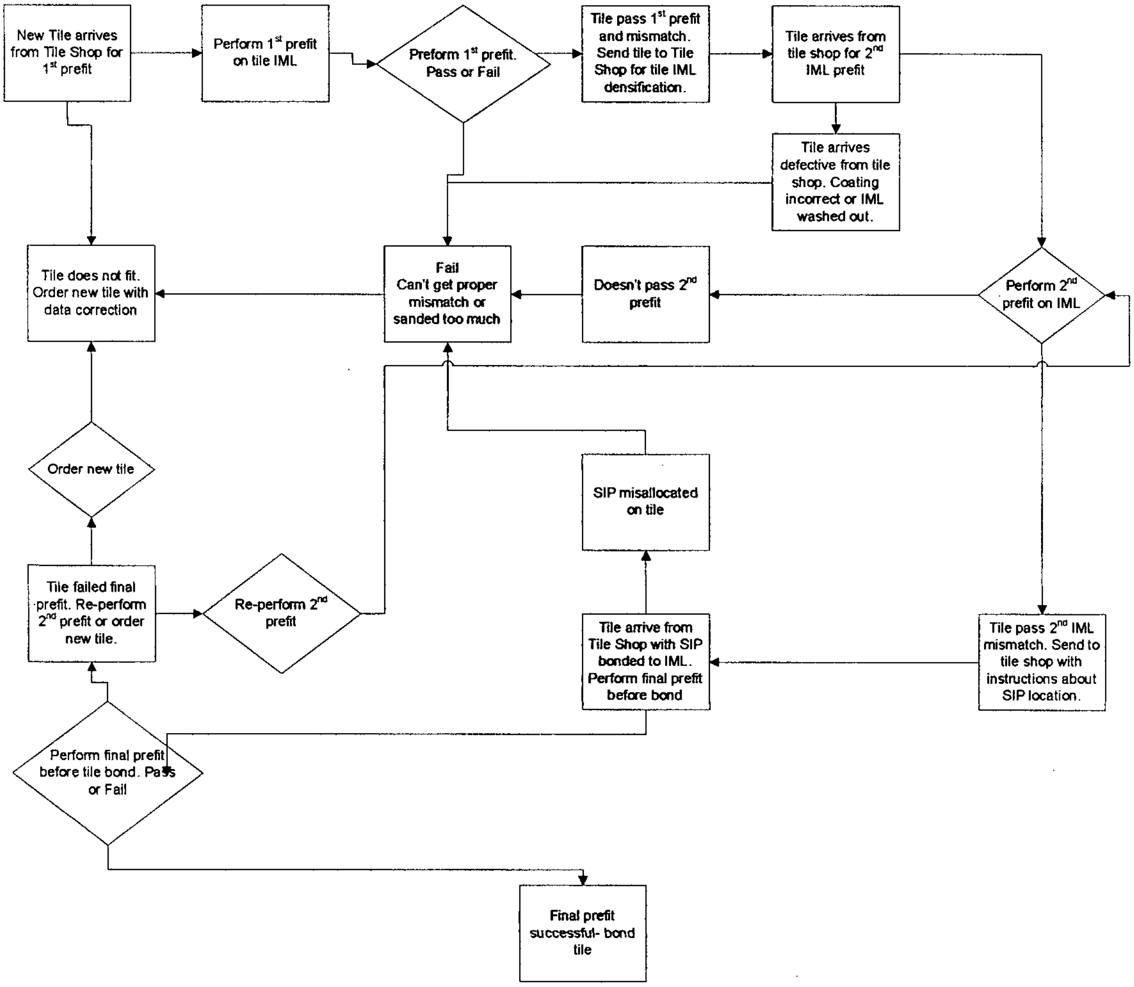
Side View Sketch of Tile



Tile Sketch (Jones, 1999)

APPENDIX D

Tile Processing Flow Chart



Bonding Flow Chart

APPENDIX E

Diagram of tile sides

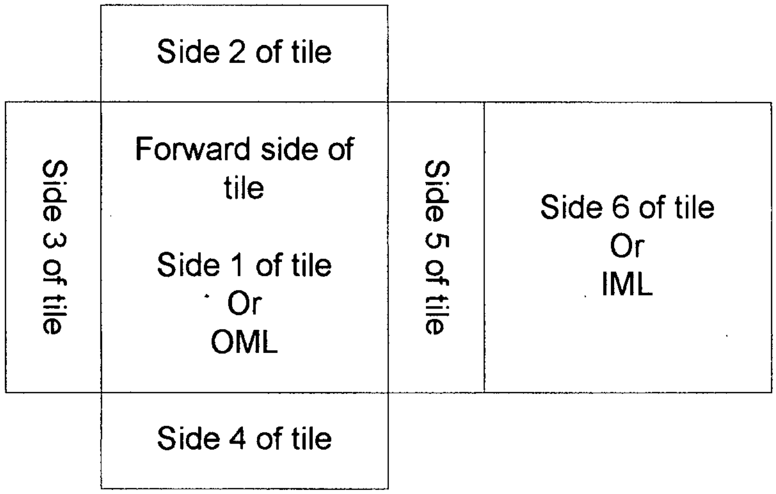
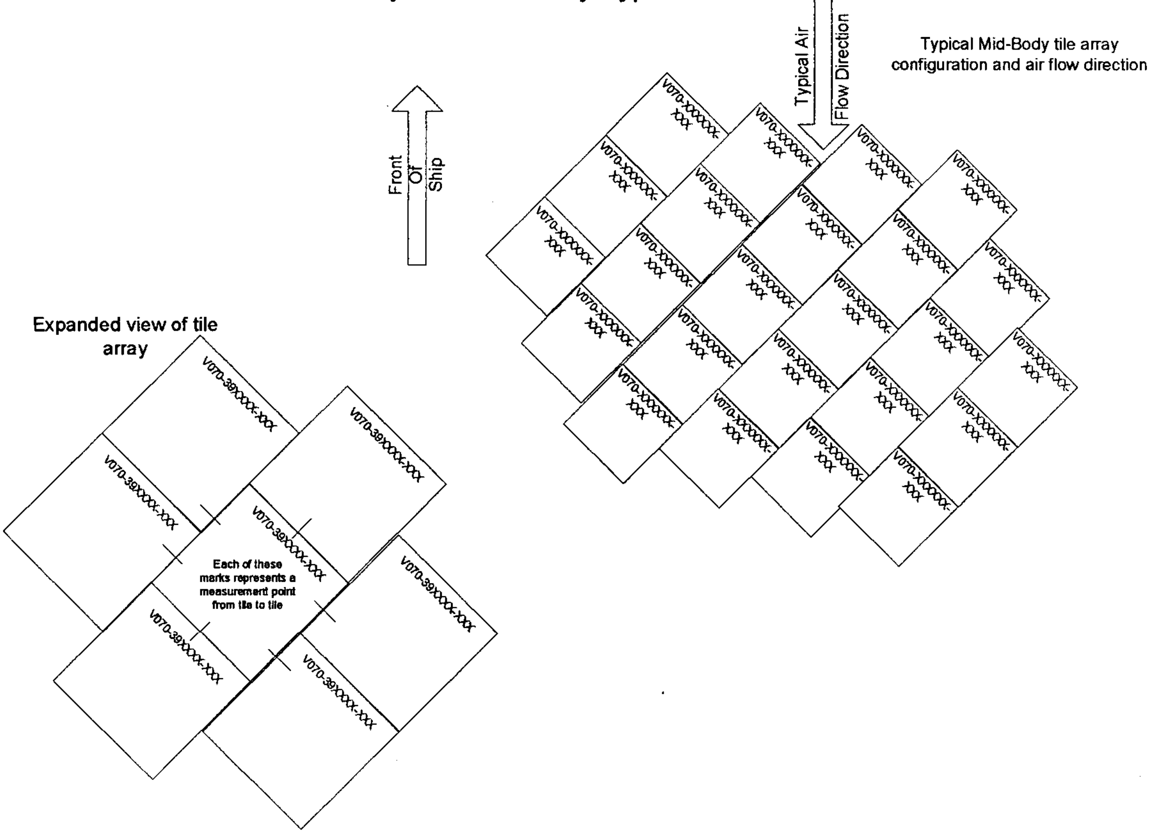


Diagram of Tile Sides

APPENDIX F

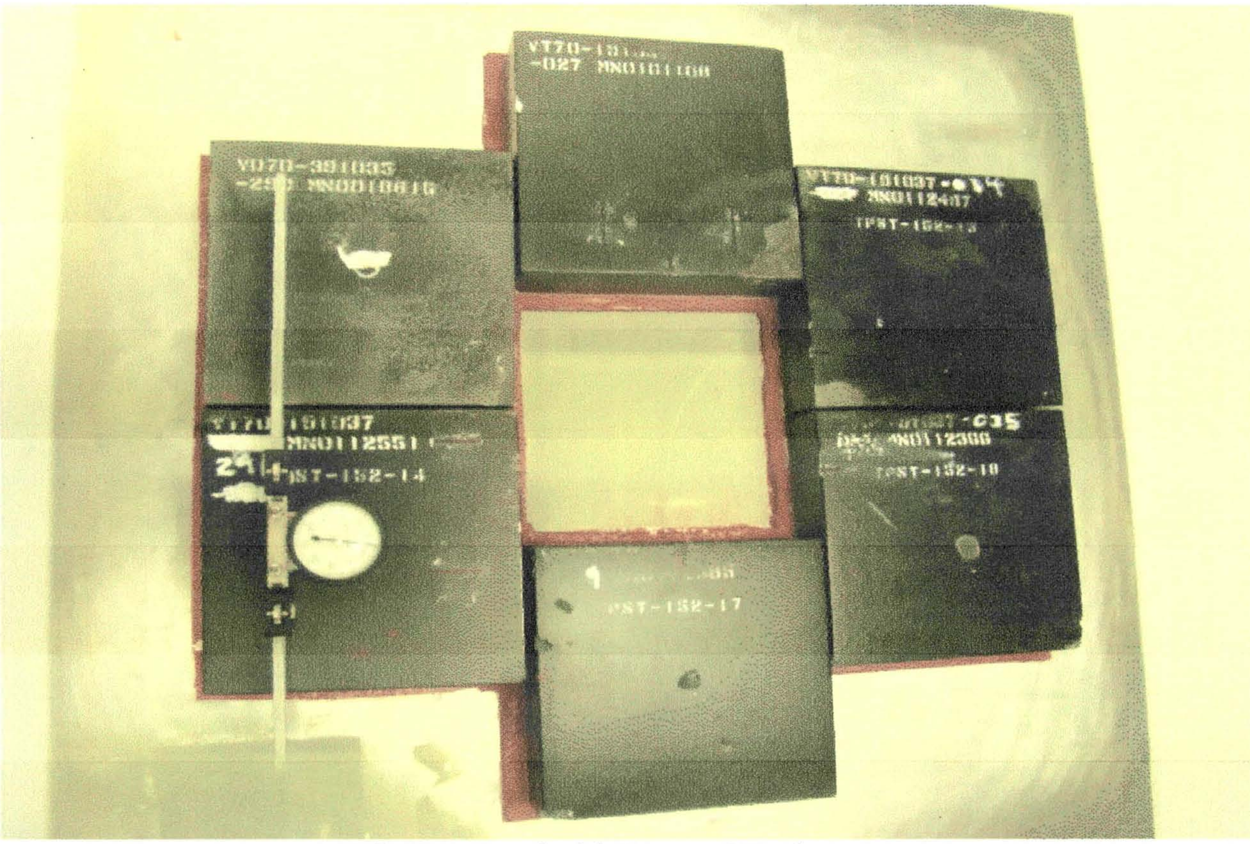
Thermal Protection System Tile Array Typical View



Tile Diagram

APPENDIX G

Trial Test Panel with Trammel Tool



Tile Test Panel with Trammel Tool

APPENDIX H

SIP Measurement Data					
PID	Tile -027	Tile -034	Tile -035	Tile -290	Tile -291
101	-14	35	34	28	-26
102	-12	54	53	43	-20
103	-8	45	40	50	-24
201	-20	38	40	40	-25
202	-15	38	44	37	-21
203	-19	34	44	35	-29
301	-7	38	38	30	-32
302	-20	50	55	40	-25
303	22	45	40	40	-25
304	-12	31	33	22	-15
305	-19	39	40	31	-16
401	0	40	65	38	-18
402	-10	41	44	40	-15
403	-10	41	44	40	-15
404	-16	53	46	48	-26
405	-18	38	36	30	-28
501	-23	55	62	45	-21
502	-10	47	43	30	-20
503	-4	43	44	38	-24
504	-15	33	38	32	-18
601	-10	35	32	39	-22
701	-15	30	22	30	-25
702	-19	37	43	44	-29
703	-21	48	46	40	-25
704	-18	45	31	38	-26
705	-20	44	39	32	-24
706	-20	35	36	34	-25
707	-16	45	38	35	-21
708	-8	35	32	33	-22
709	-15	40	39	38	-20
710	-18	45	37	36	-15

SIP Measurement Data

APPENDIX I

Bees Wax Measurement Data					
PID	Tile -027	Tile -034	Tile -035	Tile -290	Tile -291
101	12	48	23	38	-14
102	-5	35	25	36	-22
103	-5	34	25	35	-21
201	-10	35	25	30	-10
202	-7	40	31	34	-15
203	-15	42	44	38	-21
301	-12	33	27	31	-4
302	-5	35	30	30	-20
303	-5	30	25	26	-24
304	-5	35	30	27	-17
305	-9	31	35	27	-14
401	-19	38	36	24	-13
402	-6	36	25	33	-14
403	-6	36	25	33	-14
404	-17	38	29	33	-26
405	-10	35	21	28	-21
501	-15	45	34	35	-20
502	-13	34	27	28	-14
503	-2	39	34	37	-20
504	-11	34	33	33	-17
601	-12	27	26	34	-20
701	-9	31	26	32	-18
702	-15	34	25	25	-21
703	-12	35	30	30	-20
704	-13	34	29	31	-21
705	-11	34	26	26	-19
706	-14	33	25	30	-19
707	-10	36	27	32	-21
708	-7	32	27	25	-17
709	-5	42	35	33	-21
710	-11	38	26	33	-16

Bees' Wax Measurement Data

APPENDIX J

Heat Sink Measurement Data					
PID	Tile -027	Tile -034	Tile -035	Tile -290	Tile -291
101	15	17	13	20	-5
102	0	23	10	20	-8
103	5	18	10	15	-12
201	-8	28	19	26	-15
202	-5	35	20	30	-25
203	-10	39	34	26	-16
301	0	13	20	38	-22
302	-4	30	22	28	-12
303	-5	25	22	20	-20
304	-6	30	15	18	-10
305	-5	30	23	22	-9
401	-8	35	30	21	-10
402	-3	26	24	30	-10
403	-3	26	24	30	-10
404	-5	31	20	25	-20
405	-10	23	18	25	-16
501	-8	22	20	27	-15
502	0	30	22	14	-6
503	-2	26	20	25	-19
504	-9	28	17	26	-9
601	-11	18	13	21	-17
701	-7	23	14	26	-18
702	-9	24	17	19	-16
703	-5	28	20	20	-15
704	-8	25	11	18	-8
705	-10	24	15	14	-11
706	-8	22	18	20	-16
707	-7	22	16	21	-12
708	-2	25	15	15	-7
709	-5	29	28	25	-12
710	-8	35	16	23	-8

Heat Sink Measurement Data

APPENDIX K

0.5 Inch Scale / Shim Pack Measurement Data					
PID	Tile -027	Tile -034	Tile -035	Tile -290	Tile -291
101	-7	15	12	10	-10
102	-10	24	14	24	-20
103	-15	33	24	24	-20
201	-20	25	20	20	-20
202	-10	35	20	30	-25
203	-10	38	19	35	-28
301	-10	30	25	30	-10
302	-10	30	30	25	-20
303	-10	30	30	25	-20
304	-10	26	24	25	-25
305	-10	26	23	22	-31
401	-12	31	25	24	-24
402	-12	31	24	20	-19
403	-12	31	24	20	-19
404	-13	24	17	30	-15
405	-10	20	15	17	-18
501	-19	27	27	35	-26
502	-28	33	28	24	-25
503	-14	24	8	26	-20
504	-15	25	20	25	-20
601	-19	22	34	22	-31
701	-21	28	16	27	-22
702	-25	33	24	31	24
703	-20	25	20	24	-24
704	-15	20	15	20	-20
705	-14	26	20	26	-25
706	24	30	20	26	-25
707	-18	31	19	21	-21
708	-16	25	17	26	-25
709	-12	30	20	24	-28
710	-13	29	20	25	-19

Shim Pack Measurement Data

APPENDIX L

RESULTS COMPARISON BY PARTICIPANT IDENTIFICATION (PID)																				
	Tile -027 Test Results				Tile -034 Test Results				Tile -035 Test Results				Tile -290 Test Results				Tile -291 Test Results			
PID	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack
101	-2	24	27	5	2	15	-16	-18	11	0	-10	-11	6	16	-2	-12	-18	-6	3	-2
102	0	7	12	2	21	2	-10	-9	30	2	-13	-9	21	14	-2	2	-12	-14	0	-12
103	4	7	17	-3	12	1	-15	0	17	2	-13	1	28	13	-7	2	-16	-13	-4	-12
201	-8	2	4	-8	5	2	-5	-8	17	2	-4	-3	18	8	4	-2	-17	-2	-7	-12
202	-3	5	7	2	5	7	2	2	21	8	-3	-3	15	12	8	8	-13	-7	-17	-17
203	-7	-3	2	2	1	9	6	5	21	21	11	-4	13	16	4	13	-21	-13	-8	-20
301	5	0	12	2	5	0	-20	-3	15	4	-3	2	8	9	16	8	-24	4	-14	-2
302	-8	7	8	2	17	2	-3	-3	32	7	-1	7	18	8	6	3	-17	-12	-4	-12
303	34	7	7	2	12	-3	-8	-3	17	2	-1	7	18	4	-2	3	-17	-16	-12	-12
304	0	7	6	2	-2	2	-3	-7	10	7	-8	1	0	5	-4	3	-7	-9	-2	-17
305	-7	3	7	2	6	-2	-3	-7	17	12	0	0	9	5	0	0	-8	-6	-1	-23
401	12	-7	4	0	7	5	2	-2	42	13	7	2	16	2	-1	2	-10	-5	-2	-16
402	2	6	9	0	8	3	-7	-2	21	2	1	1	18	11	8	-2	-7	-6	-2	-11
403	2	6	9	0	8	3	-7	-2	21	2	1	1	18	11	8	-2	-7	-6	-2	-11
404	-4	-5	7	-1	20	5	-2	-9	23	6	-3	-6	26	11	3	8	-18	-18	-12	-7
405	-6	2	2	2	5	2	-10	-13	13	-2	-5	-8	8	6	3	-5	-20	-13	-8	-10
501	-11	-3	4	-7	22	12	-11	-6	39	11	-3	4	23	13	5	13	-13	-12	-7	-18
502	2	-1	12	-16	14	1	-3	0	20	4	-1	5	8	6	-8	2	-12	-6	2	-17
503	8	10	10	-2	10	6	-7	-9	21	11	-3	-15	16	15	3	4	-16	-12	-11	-12
504	-3	1	3	-3	0	1	-5	-8	15	10	-6	-3	10	11	4	3	-10	-9	-1	-12
601	2	0	1	-7	2	-6	-15	-11	9	3	-10	11	17	12	-1	0	-14	-12	-9	-23
701	-3	3	5	-9	-3	-2	-10	-5	-1	3	-9	-7	8	10	4	5	-17	-10	-10	-14
702	-7	-3	3	-13	4	1	-9	0	20	2	-6	1	22	3	-3	9	-21	-13	-8	32
703	-9	0	7	-8	15	2	-5	-8	23	7	-3	-3	18	8	-2	2	-17	-12	-7	-16
704	-6	-1	4	-3	12	1	-8	-13	8	6	-12	-8	16	9	-4	-2	-18	-13	0	-12
705	-8	1	2	-2	11	1	-9	-7	16	3	-8	-3	10	4	-8	4	-16	-11	-3	-17
706	-8	-2	4	36	2	0	-11	-3	13	2	-5	-3	12	8	-2	4	-17	-11	-8	-17
707	-4	2	5	-6	12	3	-11	-2	15	4	-7	-4	13	10	-1	-1	-13	-13	-4	-13
708	4	5	10	-4	2	-1	-8	-8	9	4	-8	-6	11	3	-7	4	-14	-9	1	-17
709	-3	7	7	0	7	9	-4	-3	16	12	5	-3	16	11	3	2	-12	-13	-4	-20
710	-6	1	4	-1	12	5	2	-4	14	3	-7	-3	14	11	1	3	-7	-8	0	-11

Tile to Tile Measurements Data

RESULTS COMPARISON BY YEARS OF EXPERIENCE																				
	Tile -027 Test Results 1-5 Years Experience				Tile -034 Test Results 1-5 Years Experience				Tile -035 Test Results 1-5 Years Experience				Tile -290 Test Results 1-5 Years Experience				Tile -291 Test Results 1-5 Years Experience			
PID	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack	SIP	Bees' Wax	Heat Sink	Shim Pack
101	-2	24	27	5	2	15	-16	-18	11	0	-10	-11	6	16	-2	-12	-18	-6	3	-2
103	4	7	17	-3	12	1	-15	0	17	2	-13	1	28	13	-7	2	-16	-13	-4	-12
203	-7	-3	2	2	1	9	6	5	21	21	11	-4	13	16	4	13	-21	-13	-8	-20
403	2	6	9	0	8	3	-7	-2	21	2	1	1	18	11	8	-2	-7	-6	-2	-11
405	-6	2	2	2	5	2	-10	-13	13	-2	-5	-8	8	6	3	-5	-20	-13	-8	-10
502	2	-1	12	-16	14	1	-3	0	20	4	-1	5	8	6	-8	2	-12	-6	2	-17
503	8	10	10	-2	10	6	-7	-9	21	11	-3	-15	16	15	3	4	-16	-12	-11	-12
	6-10 Years Experience				6-10 Years Experience				6-10 Years Experience				6-10 Years Experience				6-10 Years Experience			
102	0	7	12	2	21	2	-10	-9	30	2	-13	-9	21	14	-2	2	-12	-14	0	-12
202	-3	5	7	2	5	7	2	2	21	8	-3	-3	15	12	8	8	-13	-7	-17	-17
402	2	6	9	0	8	3	-7	-2	21	2	1	1	18	11	8	-2	-7	-6	-2	-11
404	-4	-5	7	-1	20	5	-2	-9	23	6	-3	-6	26	11	3	8	-18	-18	-12	-7
501	-11	-3	4	-7	22	12	-11	-6	39	11	-3	4	23	13	5	13	-13	-12	-7	-18
701	-3	3	5	-9	-3	-2	-10	-5	-1	3	-9	-7	8	10	4	5	-17	-10	-10	-14
704	-6	-1	4	-3	12	1	-8	-13	8	6	-12	-8	16	9	-4	-2	-18	-13	0	-12
706	-8	-2	4	36	2	0	-11	-3	13	2	-5	-3	12	8	-2	4	-17	-11	-8	-17
709	-3	7	7	0	7	9	-4	-3	16	12	5	-3	16	11	3	2	-12	-13	-4	-20
710	-6	1	4	-1	12	5	2	-4	14	3	-7	-3	14	11	1	3	-7	-8	0	-11
	11-20 Years Experience				11-20 Years Experience				11-20 Years Experience				6-10 Years Experience				11-20 Years Experience			
302	-8	7	8	2	17	2	-3	-3	32	7	-1	7	18	8	6	3	-17	-12	-4	-12
401	12	-7	4	0	7	5	2	-2	42	13	7	2	16	2	-1	2	-10	-5	-2	-16
504	-3	1	3	-3	0	1	-5	-8	15	10	-6	-3	10	11	4	3	-10	-9	-1	-12
601	2	0	1	-7	2	-6	-15	-11	9	3	-10	11	17	12	-1	0	-14	-12	-9	-23
702	-7	-3	3	-13	4	1	-9	0	20	2	-6	1	22	3	-3	9	-21	-13	-8	32
707	-4	2	5	-6	12	3	-11	-2	15	4	-7	-4	13	10	-1	-1	-13	-13	-4	-13
	21-30+ Years Experience				21-30+ Years Experience				21-30+ Years Experience				21-30+ Years Experience				21-30+ Years Experience			
201	-8	2	4	-8	5	2	-5	-8	17	2	-4	-3	18	8	4	-2	-17	-2	-7	-12
301	5	0	12	2	5	0	-20	-3	15	4	-3	2	8	9	16	8	-24	4	-14	-2
303	34	7	7	2	12	-3	-8	-3	17	2	-1	7	18	4	-2	3	-17	-16	-12	-12
304	0	7	6	2	-2	2	-3	-7	10	7	-8	1	0	5	-4	3	-7	-9	-2	-17
705	-8	1	2	-2	11	1	-9	-7	16	3	-8	-3	10	4	-8	4	-16	-11	-3	-17

Comparison of Data by Years of Experience

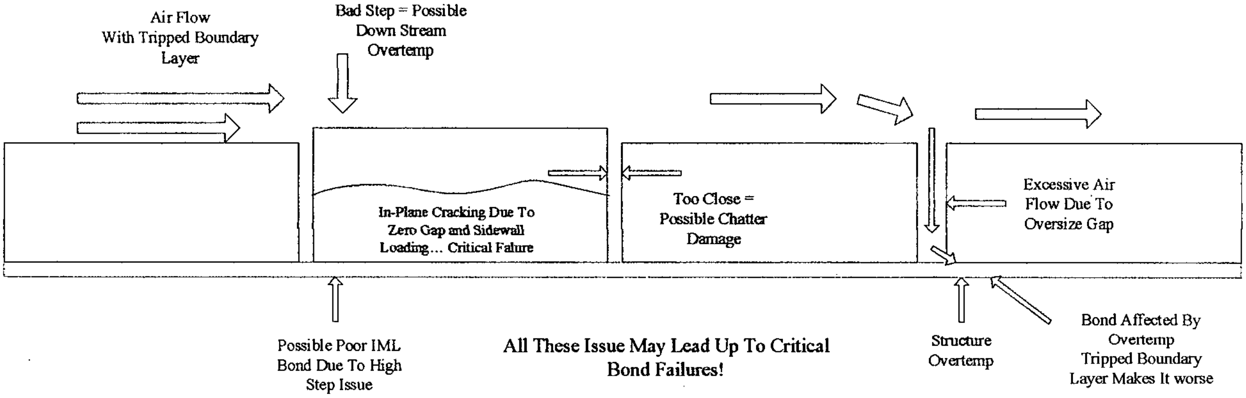
APPENDIX N

COMPARISON OF BEES' WAX TO SHIM PACK										
	Tile -027 Test Results		Tile -034 Test Results		Tile -035 Test Results		Tile -290 Test Results		Tile -291 Test Results	
PID	Bees' Wax	Shim Pack	Bees' Wax	Shim Pack	Bees' Wax	Shim Pack	Bees' Wax	Shim Pack	Bees' Wax	Shim Pack
101	24	5	15	-18	0	-11	16	-12	-6	-2
102	7	2	2	-9	2	-9	14	2	-14	-12
103	7	-3	1	0	2	1	13	2	-13	-12
201	2	-8	2	-8	2	-3	8	-2	-2	-12
202	5	2	7	2	8	-3	12	8	-7	-17
203	-3	2	9	5	21	-4	16	13	-13	-20
301	0	2	0	-3	4	2	9	8	4	-2
302	7	2	2	-3	7	7	8	3	-12	-12
303	7	2	-3	-3	2	7	4	3	-16	-12
304	7	2	2	-7	7	1	5	3	-9	-17
305	3	2	-2	-7	12	0	5	0	-6	-23
401	-7	0	5	-2	13	2	2	2	-5	-16
402	6	0	3	-2	2	1	11	-2	-6	-11
403	6	0	3	-2	2	1	11	-2	-6	-11
404	-5	-1	5	-9	6	-6	11	8	-18	-7
405	2	2	2	-13	-2	-8	6	-5	-13	-10
501	-3	-7	12	-6	11	4	13	13	-12	-18
502	-1	-16	1	0	4	5	6	2	-6	-17
503	10	-2	6	-9	11	-15	15	4	-12	-12
504	1	-3	1	-8	10	-3	11	3	-9	-12
601	0	-7	-6	-11	3	11	12	0	-12	-23
701	3	-9	-2	-5	3	-7	10	5	-10	-14
702	-3	-13	1	0	2	1	3	9	-13	32
703	0	-8	2	-8	7	-3	8	2	-12	-16
704	-1	-3	1	-13	6	-8	9	-2	-13	-12
705	1	-2	1	-7	3	-3	4	4	-11	-17
706	-2	36	0	-3	2	-3	8	4	-11	-17
707	2	-6	3	-2	4	-4	10	-1	-13	-13
708	5	-4	-1	-8	4	-6	3	4	-9	-17
709	7	0	9	-3	12	-3	11	2	-13	-20
710	1	-1	5	-4	3	-3	11	3	-8	-11

Bees' Wax to Shim Pack Comparison Data

APPENDIX O

Out of tolerant Step and Gap may lead to critical bond failures of TPS and possible Overtemp of Vehicle structure



Out of Tolerance Step and Gap Diagram