Study of Measurement Variation in IR Images of COTS Computer Boards

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Introduction:

A NASA GSFC experiment is planned for a Spartan spacecraft and COTS boards were being considered for use to decrease hardware lead time. The management of the procurement of these boards, the testing performed to characterize them including the use of infrared (IR) imaging has been described in prior publications[1][2]. IR imaging was used on samples from the flight lots to understand their thermal behavior and to enable the project to design a ruggedization scheme which would enable their survival in space. IR imaging was again employed for the actual flight boards and for those reserved as spares, to verify that they are sufficiently similar, thermally, to the sample boards. If they were found to be similar than there would be confidence that the thermal ruggedization modifications and enclosure would provide sufficient thermal protection for the flight boardds. The results of the first and second round of testing is shown in the Appendix and can be used as an example of the variability in thermal behavior of a large set of typcial COTS boards.

Background:

The boards were photographed with an IR camera and the images were post-processed to determine the temperature at all the individual part locations on each of the boards. The boards were connected to extender cards so that they would operate electrically as they would in the intended configuration but so that they were still visible to the camera. The assembly was housed in a five-sided black box to reduce detection of peripheral sources of IR energy. The room was kept at 25°C +3°C -0°. The room was isolated from pedestrian traffic by a door.

The data consists of a temperature for each part location on a given board. The locations correspond to a part which is soldered to the board. Between three and ten boards were tested depending on the board type, giving a corresponding three to ten measurements for each part. Prior testing showed good correlation between thermocouple data and the IR signature derived temperature. The analysis here will focus on the variability of the data and not on the absolute value.

Results:

The data shown in Appendix A includes measurements performed in one time period (Non-flight 1) and measurements performed many months later (Non-Flight 2 and all Flight data). The IR images are shown as well. Some are not represented in the accompanying table and are marked as such. Standard deviations including all of the data and those including only the data taken during the second test period, are shown. The resulting numbers show that there may have been significant differences in measurement conditions between the first and second rounds of measurements. When the data set for the all inclusive data shows many standard deviations which are more than one degree higher than those shown for the second round data only, the second round data is used in the Table 1 analysis.

Table 1 shows the type of board tested, the average temperature of the hottest part on that board and the average temperature of the coolest part on that board type. The standard deviation has been calculated for the part temperatures (one std dev for each part). The average temperature for the part whose standard deviation is highest is also shown.

The data in Table 1 indicates that the variability does not always correlate directly with the hottest or coolest part. It appears by comparison to the part maps (Appendix) to correlate to location of the part with respect to other hot parts or to the edge of the board. In two cases, high variability in measurement

occurred where a part or parts were in or near an array of heat dissipating parts. These observations, and the large standard deviations for the data which includes the first round measurements indicates that the test set-up should be better characterized with respect to the enclosure geometry, air flow, ambient temperature control, and camera calibration.. Thermocouples should be used for sensitive parts near groups of heat dissipating parts.

Conclusion:

IR imaging is a useful tool for identifying hot spots on COTS boards and for quantifying their temperatures. It is important to characterize the set-up to limit measurement variability associated with the test environment. By using a five-sided, black box as the enclosure, operating in a room that is closed to pedestrian traffic, and controlling the ambient temperature one should expect measurement accuracy generally between $\pm$ 1.2 °C and $\pm$ 6 °C. Depending on the application and the temperatures, this may suffice. To reduce the variation, more stringent control must be placed on the ambient temperature and the airflow in the measurement environment.

References:

(1) Spartan 251 IR Imaging Test Results, N. Helmold, C. Eveland, J. Plante, 1998

(2) Assurance of COTS Boards for Space Flight, J. Plante, COTS Journal, May/June 1999

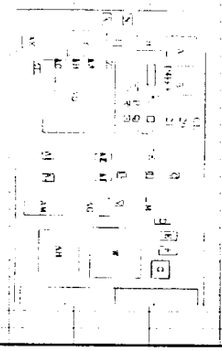
Table 1. COTS Thermal Data Variability

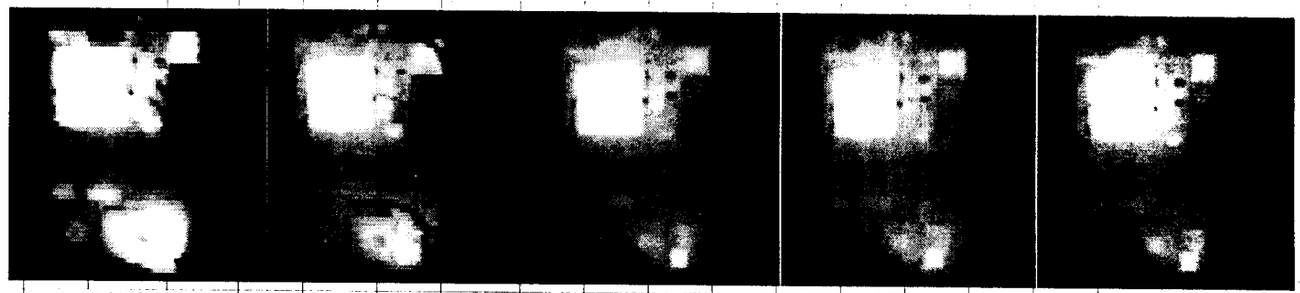
Board	Number of Parts Monitored on the	Number of Boards Tested	Temperature of Hottest Part (Average, °C)	Standard Deviation for Hottest Part	Temperature of Coolest Part (Average, °C)	Standard Deviation for Coolest Part	Average Part Temperature for Part with Largest Standard Deviation	Largest Standard Deviation	Comments
Processor Board Front	13	4	69.8	1.39	45.3	1.04	50.2	1.69	Variability largely in hotter parts near board edges
Processor Board Back	7	4	66.3	1.30	48.0	0.64	66.3	1.30	Variability largely in hotter parts near board edges
6U Carrier Board	10	8	64.7	0.81	30.3	0.46	30.4	4.01	
IP 220-16 Module	6	4	64.4	2.75	52.9	3.31	62.0	6.40	Std dev's for all parts were high as was the temperature
IP 320 Module	6	3	53.4	0.71	42.0	0	50.2	0.78	Std dev's for all parts were low
IP 440-1 Module	1	3	N/A	N/A	N/A	N/A	43.2	0.50	Not enough data for statistics
IP 445 Module	9	3	40.7	0.14	31.2	0.14	38.3	0.21	Std dev's for all parts were low
IP Serial Module	8	4	55.9	0.68	48.6	0.23	55.9	0.68	Std dev's for all parts were low
IP MP-Serial Module	14	3	41.0	0.92	32.2	0.64	40.3	1.98	Variability was near board edges
IP OptoDriver Module	4	4	46.1	0.35	34.6	0.40	34.6	0.40	Std dev's for all parts were low
IP Thermistor Module	5	3	32.0	0.28	27.6	0.28	32.0	0.28	Std dev's for all parts were low
IP UniDig-D Module	24	3	57.2	1.67	40.2	0.51	54.4	2.02	Variability was in array of hot parts
IP UniDig-E-48 Module	4	3	27.3	0.60	26.0	0.31	27.3	0.60	Std dev's for all pats were low
IP SCC-04BH Module	5	4	58.2	2.77	44.0	1.46	58.2	2.77	Variability occurred at top board edge
IP Flash Memory Module	12	3	47.5	0.93	33.5	0.61	39.6	4.57	Variability occurred at the bottom edge

APPENDIX A

Processor Board, Front

	Non-Flight1	Non-Flight2	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
A	51.1	57.7	58.6	56.3	55.9	3.35	57.5	1.16
AD	63.5	68.3	68.6	66.9	66.8	2.34	67.9	0.91
AG	43.9	48.0	49.6	48.8	47.6	2.54	48.8	0.80
AH	44.9	44.5	46.5	45.0	45.2	0.88	45.3	1.04
AK	47.8	48.3	50.6	51.6	49.6	1.82	50.2	1.69
AM	43.2	45.4	47.1	46.1	45.5	1.65	46.2	0.85
CE20,21	52.4	53.2	51.5	53.6	52.7	0.93	52.8	1.12
E	50.5	53.8	55.6	54.8	53.7	2.24	54.7	0.90
F	50.1	54.1	56.0	55.4	53.9	2.65	55.2	0.97
G	63.4	70.2	71.0	68.3	68.2	3.41	69.8	1.39
I	52.2	57.8	57.8	59.3	56.8	3.13	58.3	0.87
IND1	53.4	54.6	54.9	54.7	54.4	0.68	54.7	0.15
W	49.4	54.8	55.8	55.4	53.9	2.99	55.3	0.50

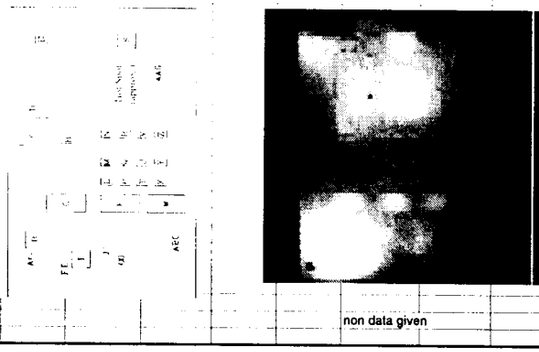




no data shown | non-flight I | non-flight 2 | Flight 1 | Flight 2

Processor Board, Back

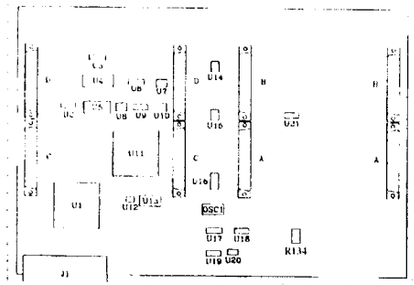
	Non-Flight1	Non-Flight2	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
B	56.7	64.8	64.2	65.5	62.8	4.10	64.8	0.65
E	47.3	51.7	51.5	51.4	50.5	2.12	51.5	0.15
G	47.1	51.4	51.4	50.7	50.2	2.06	51.2	0.40
I	56.1	63.8	65.3	66.4	62.9	4.66	65.2	1.31
K	45.5	51.0	50.4	49.8	49.2	2.50	50.4	0.60
S	57.0	67.6	65.0	66.3	64.0	4.77	66.3	1.30
W	43.5	48.5	48.3	47.3	46.9	2.33	48.0	0.64

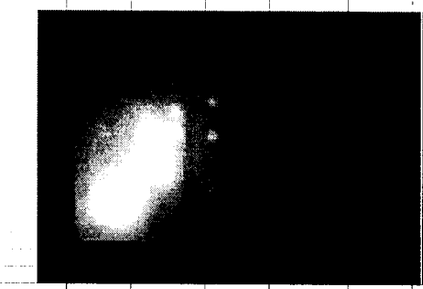


non data given | non-flight I | non-flight 2 | Flight 1 | Flight 2

6U Carrier Board

	NonFlight1	Flight #1	Flight #2	Flight #3	Flight #4	Flight #5	Flight #6	Flight #7	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
R134	28.7	30.7	30.5	30.4	31.0	29.6	30.2	30.0	30.1	0.72	30.3	0.46
U1	50.0	63.2	64.9	65.5	65.6	64.3	64.8	64.9	62.9	5.27	64.7	0.81
U10	36.6	38.8	41.8	39.6	40.8	39.0	39.5	41.0	39.6	1.61	40.1	1.13
U11	41.5	51.3	50.6	50.5	49.8	50.4	51.8	50.8	49.6	3.32	50.7	0.65
U14	32.3	33.3	35.1	35.6	34.5	33.9	34.5	34.5	34.2	1.04	34.5	0.75
U15	32.8	35.0	35.9	35.2	34.3	33.4	34.1	34.6	34.4	1.00	34.6	0.81
U16	30.5	31.7	33.2	32.6	32.3	30.7	31.4	31.9	31.8	0.92	32.0	0.82
U21	28.4	29.2	29.2	39.4	29.6	28.4	28.8	28.1	30.1	3.78	30.4	4.01
U7	34.5	37.1	38.5	38.4	38.7	36.9	38.5	38.9	37.7	1.49	38.1	0.80
U8	40.2	46.9	46.3	48.0	43.0	46.1	47.2	47.3	45.6	2.66	46.4	1.63





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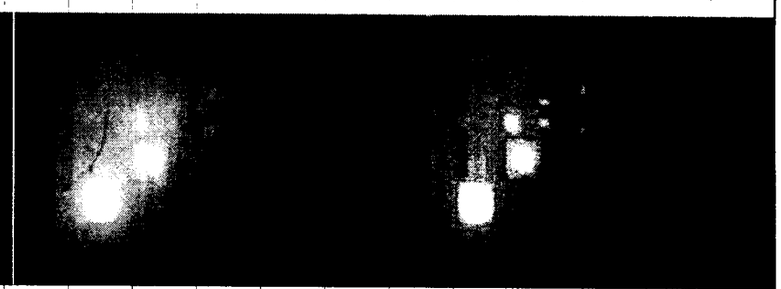
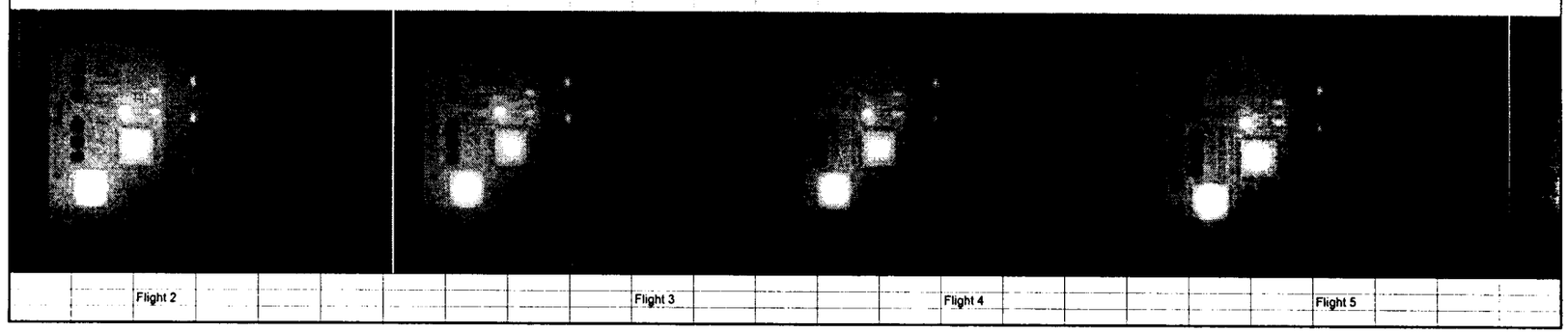


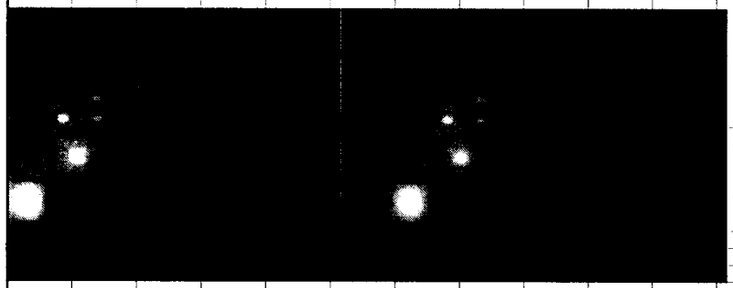
non-flight 1

Flight 1

6U Carrier Board Continued



6U Carrier Board Continued

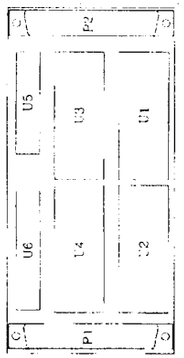


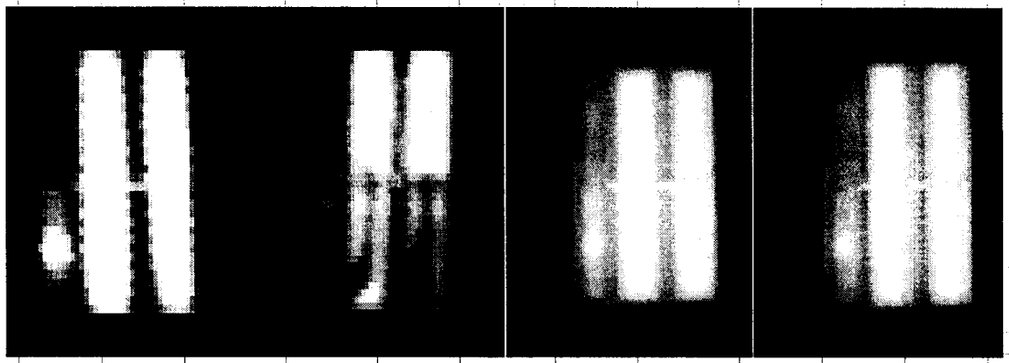
Flight 6

Flight 7

IP 220-16 Module

	Non-Flight1	Non-Flight2	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U1	62.9	59.20	65.2	66.6	63.5	3.23	63.7	3.93
U2	54.7	60.30	66.7	67.0	62.2	5.86	64.7	3.78
U3	62.1	62.10	66.0	67.5	64.4	2.75	65.2	2.79
U4	57.1	62.10	67.8	68.2	63.8	5.26	66.0	3.41
U5	No Data	49.10	54.2	55.3	52.9	3.31	52.9	3.31
U6	52.7	63.00	66.4	66.0	62.0	6.40	65.1	1.86

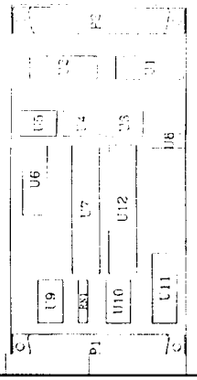


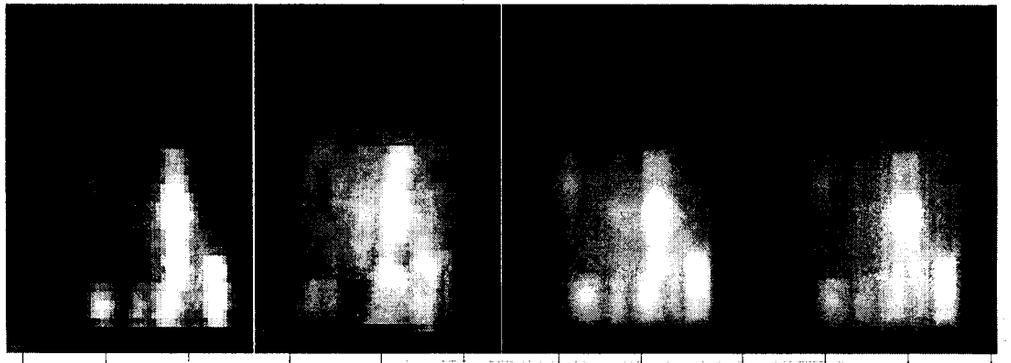


no data given | non-flight 1 | flight 1 | flight 2

IP 320 Module

	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
RN1	38.5	45.3	44.9	42.9	3.82	45.1	0.28
U10	41.3	48.5	48.2	46.0	4.07	48.4	0.21
U11	41.1	49.6	50.7	47.1	5.25	50.2	0.78
U12	43.3	52.9	53.9	50.0	5.85	53.4	0.71
U6	37.4	42.0	42.0	40.5	2.66	42.0	0.00
U9	37.9	47.1	46.6	43.9	5.17	46.9	0.35

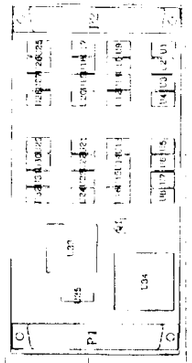




no data given | non-flight 1 | flight 1 | flight 2

IP 440-1 Module

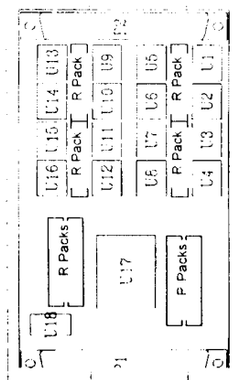
	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U34	43.7	42.7	43.1	43.2	0.50	42.9	0.28



no data given | non-flight 1 | flight 1 | flight 2

IP 445 Module

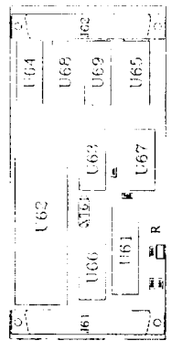
	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
R Pack 1	38.6	38.3	38.2	38.4	0.21	38.3	0.07
R Pack 2	38.6	38.1	38.4	38.4	0.25	38.3	0.21
R Pack 3	41.4	40.0	40.2	40.5	0.76	40.1	0.14
R Pack 4	41.3	40.6	40.8	40.9	0.36	40.7	0.14
R Pack 5	42.1	33.9	34.1	36.7	4.68	34.0	0.14
R Pack 6	43.3	31.9	31.7	35.6	6.64	31.8	0.14
R Pack 7	44	32.3	32.1	36.1	6.81	32.2	0.14
R Pack 8	43.1	31.3	31.1	35.2	6.87	31.2	0.14
U17	35.8	35.6	35.5	35.6	0.15	35.6	0.07

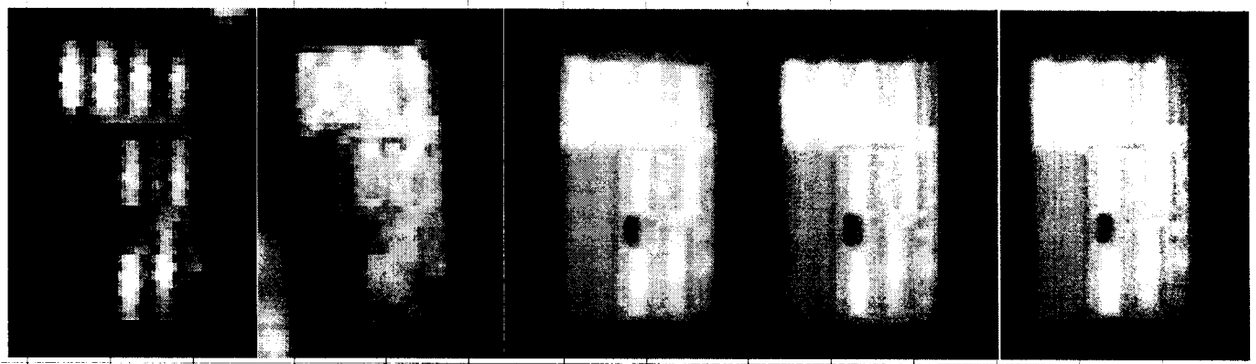


no data given | screen capture not avail: non-flight 1 | flight 1 | flight 2

IP Serial Module

	Non-Flight1	Flight #1	Flight #2	Flight #3	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U61	39.5	49.6	49.9	50.0	47.3	5.17	49.8	0.21
U63	39.8	49.0	48.8	49.1	46.7	4.59	49.0	0.15
U64	39.8	54.7	55.2	54.3	51.0	7.48	54.7	0.45
U65	42.7	50.2	49.9	49.2	48.0	3.56	49.8	0.51
U66	38.5	52.2	53.0	52.1	49.0	6.98	52.4	0.49
U67	40.3	48.5	48.9	48.5	46.6	4.17	48.6	0.23
U68	42.4	56.4	55.1	56.1	52.5	6.76	55.9	0.68
U69	43.5	52.8	52.2	52.0	50.1	4.43	52.3	0.42

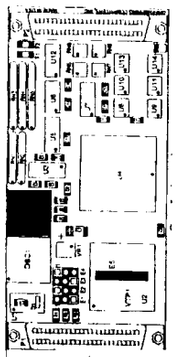




no data given | non-flight 1 | flight 1 | flight 2 | flight 3

IP MP-Serial Module

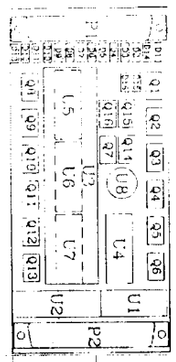
	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
RN1	31	32.6	34.7	32.8	1.86	33.7	1.48
RN2	29.7	32.6	34.7	32.3	2.51	33.7	1.48
RN3	34.6	36.2	38.0	36.3	1.70	37.1	1.27
RN4	35.6	36.2	38.0	36.6	1.25	37.1	1.27
RN5	38.7	36.2	38.0	37.6	1.29	37.1	1.27
RN6	no data	37.4	38.7	38.1	0.92	38.1	0.92
RN7	no data	37.4	38.7	38.1	0.92	38.1	0.92
RN8	no data	37.4	38.7	38.1	0.92	38.1	0.92
RN9	no data	37.4	38.7	38.1	0.92	38.1	0.92
U10	36.5	38.4	38.8	37.9	1.23	38.6	0.28
U11	35.7	36.8	38.7	37.1	1.52	37.8	1.34
U2	31.2	31.7	32.6	31.8	0.71	32.2	0.64
U3	37.4	38.9	41.7	39.3	2.18	40.3	1.98
U7	37.5	40.3	41.6	39.8	2.10	41.0	0.92

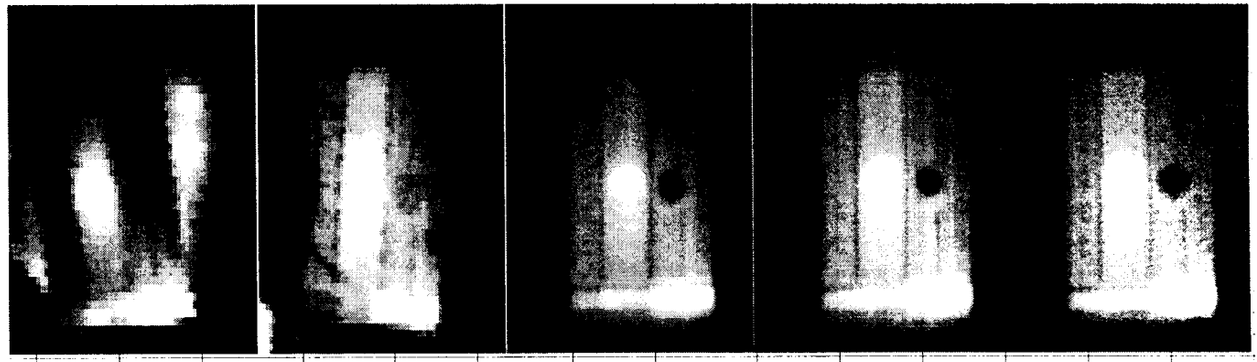


no data given | non-flight 1 | flight 1 | flight 2

IP OptoDriver Module

	Non-Flight1	Flight #1	Flight #2	Flight #3	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
Q5	33.7	34.2	34.6	35.0	34.4	0.56	34.6	0.40
U1	38.7	46.1	46.5	45.8	44.3	3.73	46.1	0.35
U2	32.5	40.5	41.0	41.1	38.8	4.19	40.9	0.32
U3	36.4	43.4	43.8	44.0	41.9	3.68	43.7	0.31

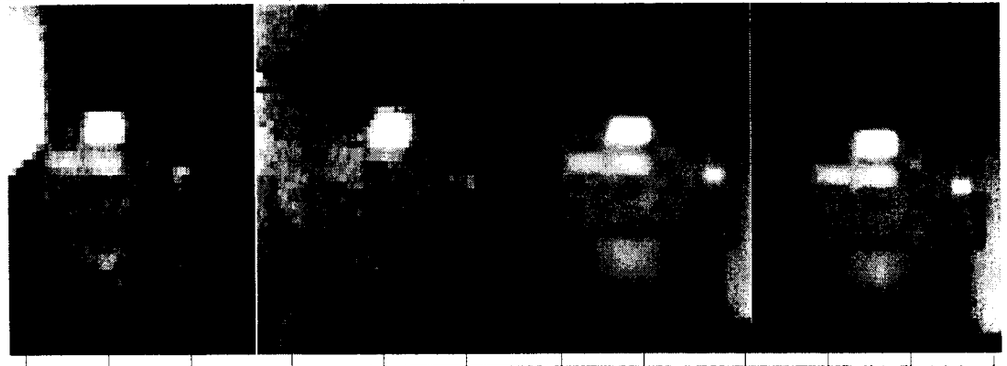




no data given | non-flight 1 | flight 1 | flight 2 | flight 3

IP Thermistor Module

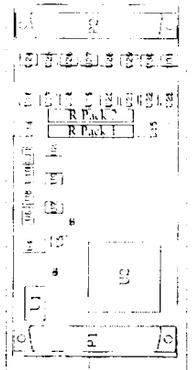
	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U1	25.9	27.4	27.8	27.0	1.00	27.6	0.28
U5	26.9	27.9	28.3	27.7	0.72	28.1	0.28
U6	26.9	28.1	28.4	27.8	0.79	28.3	0.21
U7	26.5	28.6	28.8	28.0	1.27	28.7	0.14
U9	29.5	31.8	32.2	31.2	1.46	32.0	0.28

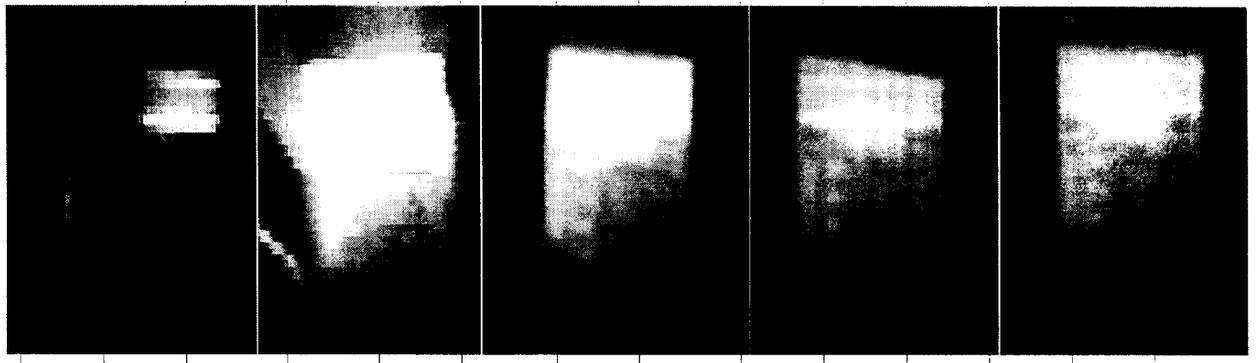


no data given | non-flight 1 | flight 1 | flight 2

IP UniDig-D Module

	Non-Flight1	Flight #1	Flight #2	Flight #3	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U10	40.5	49.2	46.2	48.1	46.0	3.87	47.8	1.52
U11	44.6	50.3	47.4	48.8	47.8	2.43	48.8	1.45
U16	40.0	56.2	52.2	54.7	50.8	7.37	54.4	2.02
U17	No Data	57.7	54.1	56.7	56.2	1.86	56.2	1.86
U18	No Data	58.5	55.3	57.7	57.2	1.67	57.2	1.67
U19	No Data	58.5	55.1	57.6	57.1	1.76	57.1	1.76
U2	No Data	50.0	48.3	49.9	49.4	0.95	49.4	0.95
U20	48.3	57.5	54.1	56.5	54.1	4.12	56.0	1.75
U21	No Data	56.1	53.1	54.9	54.7	1.51	54.7	1.51
U22	No Data	54.0	51.4	52.9	52.8	1.31	52.8	1.31
U23	48.5	52.3	50.1	51.4	50.6	1.65	51.3	1.11
U24	No Data	56.3	53.4	56.0	55.2	1.59	55.2	1.59
U25	No Data	58.2	54.9	57.3	56.8	1.71	56.8	1.71
U26	No Data	58.6	55.4	57.6	57.2	1.64	57.2	1.64
U27	48.3	58.7	55.3	57.1	54.9	4.58	57.0	1.70
U28	No Data	57.1	54.2	56.1	55.8	1.47	55.8	1.47
U29	No Data	56.2	53.5	55.3	55.0	1.37	55.0	1.37
U30	No Data	55.7	52.5	54.4	54.2	1.61	54.2	1.61
U31	51.7	54.5	51.5	53.1	52.7	1.40	53.0	1.50
U5	No Data	39.8	40.1	40.8	40.2	0.51	40.2	0.51
U6	40.3	44.1	43.1	44.5	43.0	1.89	43.9	0.72
U7	No Data	44.6	43.4	44.4	44.1	0.64	44.1	0.64
U8	41.7	47.0	44.9	46.0	44.9	2.30	46.0	1.05
U9	No Data	47.6	46.0	47.5	47.0	0.90	47.0	0.90

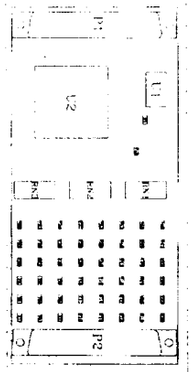


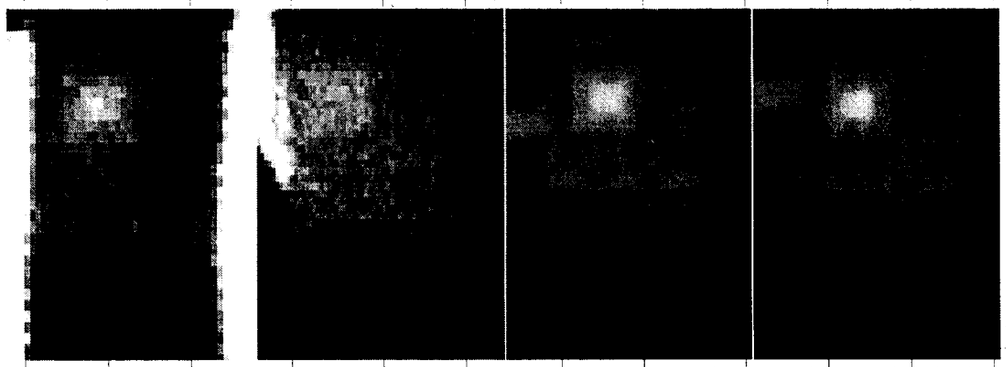


no data given | non-flight 1 | flight 1 | flight 2 | flight 3

IP UniDig-E-48 Module

	Non-Flight1	Flight #1	Flight #2	including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
RN1	25.7	25.9	26.3	26.0	0.31	26.1	0.28
RN2	25.9	26.1	26.5	26.2	0.31	26.3	0.28
RN3	25.9	26.0	26.5	26.1	0.32	26.3	0.35
U2	26.7	27.4	27.9	27.3	0.60	27.7	0.35

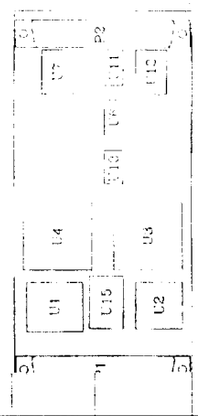


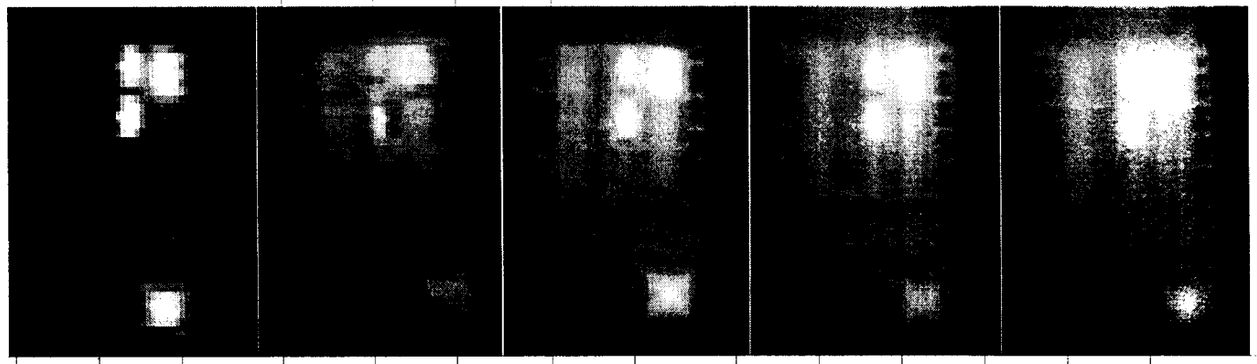


no data given | non-flight 1 | flight 1 | flight 2

IP SCC-04BH Module

	Non-Flight1	Flight #1	Flight #2	Flight #3	Including 1st Rnd Data		w/o 1st Rnd Data	
Part #	Temp	Temp	Temp	Temp	Average	Std. Dev.	Average	Std. Dev.
U11	40.2	52.8	56.1	55.5	51.2	7.44	54.8	1.76
U12	42.3	55.3	60.8	58.6	54.3	8.28	58.2	2.77
U2	39.8	49.5	50.2	50.2	47.4	5.09	50.0	0.40
U6	39.9	53.4	54.7	52.9	50.2	6.93	53.7	0.93
U7	37.5	42.4	45.2	44.5	42.4	3.48	44.0	1.46

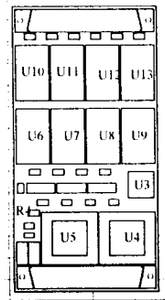


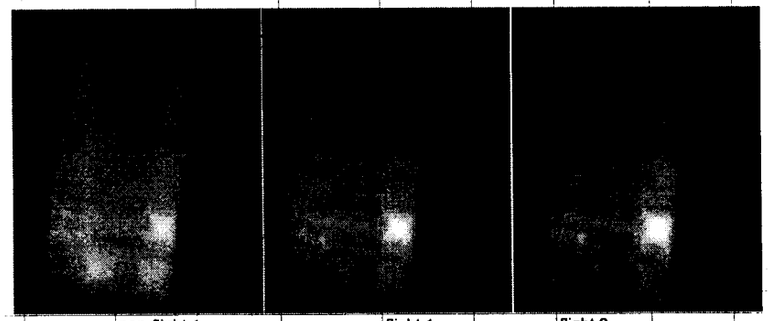


no data given | non-flight 1 | flight 1 | flight 2 | flight 3

IP Flash Memory Module

	Non-Flight2	Flight #1	Flight #2	(1st Rnd Data N/Avail)	
Part #	IR	IR	IR	Average	Std. Dev.
R4	41.7	39	38.2	39.6	1.83
U10	33.9	33.8	32.8	33.5	0.61
U11	35.7	32.9	33.6	34.1	1.46
U12	34.9	32.6	33.2	33.6	1.19
U13	35.3	33.1	33.4	33.9	1.19
U3	48.5	46.7	47.2	47.5	0.93
U4	45.2	38.0	38.1	40.4	4.13
U5	44.9	36.8	37.2	39.6	4.57
U6	35.9	34.3	35.1	35.1	0.80
U7	36.8	35.7	35.2	35.9	0.82
U8	37.4	36.4	35.7	36.5	0.85
U9	37.3	36.4	36.5	36.7	0.49





non-flight 1 flight 1 flight 2