D0 ENGINEERING NOTE

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D0 SILICON UPGRADE

H-disk Aluminum Prototype
Heat Transfer Test Summary

Bruce Squires

July 28, 1998

Approved: _____

W. E. Cooper

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INTRODUCTION

The aluminum H-disk was instrumented with heaters (156 ohm on average) and 100 ohm platinum RTD's. Each heater supplies the heat of a double sided H-wedge. Since the flow splits into two flow directions at the inlet fitting, only half of the cooling channel is fully instrumented with RTD's. The other path has a single RTD to check for flow balancing. These items were installed after Greg Derylo performed the first pressure drop tests.

At the time of the test, the desired adhesive for gluing the two halves of the channel together was not available. Therefore, 5-minute epoxy was used on the inner and outer diameters of the halves. Tape was used to set the gap between the two halves. This form of attachment does not make a strong bond between the two halves so the differential pressure between the inside and the outside of the channel was limited to a couple of psi. Therefore, the tests were not conducted in a vacuum.

SETUP

The heaters were adhered onto an aluminum plate to more closely mimic a wedge. The aluminum plate has the same ledge contact area as a wedge and there was a heater at each wedge location. Vacuum grease was used to decrease the thermal resistance between the heater and the cooling channel. On one of the flow paths, RTD's were mounted on the cooling channel just downstream of each aluminum heater plate. I refer to this cooling path as the instrumented side. For the opposite cooling path, a single RTD was mounted about half way down the channel in a similar location to one on the instrumented side. These two RTD's were checked against each other before installation to understand the offset between them. The offset was measured to be about 0.05°C or less. See the attached drawing for further details.

The resistance of each heater was measured and documented. The heaters were placed on the cooling channel so as to evenly distribute the heat and reduce error when looking for balanced flow between the two cooling paths. The heaters were split into two groups; instrumented side and uninstrumented side. These two groups were supplied power from the same power supply but on different leads. Each group of heaters were wired in parallel and the voltage supplied was measured at this point to provide better accuracy when calculating the actual heater power. The current for each group of heaters was measured across a 1 ohm resistor that was cooled in order to provide a stable resistance. See the heater table for more information.

The RTD's are read by a strip chart recorder connected to a PC. The reading on the PC is generally very good for constant inputs. The RTD's are supplied current from a constant current source in the strip chart and the voltage read into the PC do vary. This leads me to believe that the current source is unsteady. Therefore, multiple points are taken and the data averaged after throwing out obviously invalid data. The standard deviation before throwing out data is between 0.02 and 0.18°C. After throwing out data that is quite high or low, the standard deviation is typically 0.06°C or less. A couple of channels tend to have a larger scatter and cannot be reduced to less than about 0.1°C (RTD 13 is the worst).

RESULTS

All of the heat transfer tests were performed at -10°C. The first test performed was with the heater power off. This was to establish the baseline for the powered tests. It was later determined that the disk had not come into equilibrium during this test before gathering the data so it was re-run the next day. The second test was with the heaters powered to mimic a 640 mW chip power. The third test was for 500 mW chip power. During the initial checking of the data, it was noted that Greg's pressure drop data and the pressure drop gathered here were slightly off.

When re-running the unpowered case, I gathered data at 0°C as well as -10°C to determine if my previous pressure drop data was in error. The data came out very close to the same although still less than Greg's. The major difference between my setup and Greg's was the length of tubing between the pressure tap location and the cooling channel. Greg had about an additional 2 inches on one leg and 7 inches on the other leg. This can account for some of the difference. For fully developed flow, 9 inches of the ¼" ID tubing is about 0.2 psi for the highest flow rate I ran at -10°C. This will be higher for our case since it is developing flow.

To eliminate the heat load on the coolant due to the environment, the unpowered data is subtracted from the powered data. Since the supply coolant temperature varies slowly during the testing period, the inlet coolant temperature difference (powered minus unpowered) is subtracted from the temperature data. This results in the temperature rise of the cooled ledge over the inlet coolant temperature over and above the ambient heat load effect. This also has the convenience of eliminating any offset of the RTD's. For reference, RTD 7 and RTD 14 are very close to each other and I estimate that they are within 0.05°C of the true temperature. The inlet RTD's (16) reads about 0.3°C lower than the outlet RTD (15) and is about 1°C below the true temperature. These two RTD's are in the coolant about 10 inches from the cooling channel.

The results indicate that the flow might be slightly biased towards the uninstrumented side. This can be seen by looking at the data for RTD's 7 and 14. For the unpowered case, they are different although some of this can be accounted for since the dry gas purge was blowing near the instrumented side and there are more RTD wires on this side. But the balancing is best determined by looking at how different these values are after subtracting out the temperatures as noted in the previous paragraph. The instrumented side is about 0.2°C warmer. The difference in the heat load up to this point is less than 0.1 watts. The overall difference in the heat load between these sides is about

0.2 watts. The standard deviation for these temperatures is typically 0.06°C or less. The difference however appears to be independent of flow rate. Therefore it is not 100% clear that the flow is imbalanced but if it were, the data that we are getting is conservative since the flow for the instrumented side could be slightly reduced.

The results of the tests can be found in the attached tables and graphs. It is important to note that the flow direction for these tests were from RTD 13 to RTD 1 with RTD 16 in the coolant before the channel and RTD 15 in the coolant after the cooling channel. The actual temperature rise of the coolant for the heat input is reasonably close to the estimated rise.

The results of the tests are best viewed in the attached graphs. The estimated operating pressure drop for the H-disk is 4 psi. This leads to a flow rate of approximately 1.5 lpm for -10°C coolant. For this flow rate and 640 mW chips, the highest measured temperature increase over the unpowered case is about 3.5°C . For the 500 mW case, this temperature increase is about 2.8°C .

RTD 16 IN FLUID

RTD 15 IN FLUID

Heaters

Power	Q	184.32 W	total	for 640 mW Chips			
		7.68 W	each				
Current	I	0.222 A	average				
Voltage	V	34.64 Vdc	supplied				
	Rave	156.2 ohm	for Path 1				
Location	Heater	Resistance	Power	Location	Heater	Resistance	Power
A1	14	160.2 ohm	7.49 W				
B1	19	160.1 ohm	7.49 W	L2	10	160.0 ohm	7.50 W
C1	6	159.8 ohm	7.51 W	K2	2	159.6 ohm	7.52 W
D1	5	150.4 ohm	7.98 W	J2	11	149.6 ohm	8.02 W
E1	7	148.1 ohm	8.10 W	I2	8	149.5 ohm	8.03 W
F1	24	159.5 ohm	7.52 W	H2	21	159.5 ohm	7.52 W
G1	3	159.1 ohm	7.54 W	G2	15	158.9 ohm	7.55 W
H1	17	151.3 ohm	7.93 W	F2	12	151.3 ohm	7.93 W
I1	23	153.7 ohm	7.81 W	E2	9	155.4 ohm	7.72 W
J1	20	158.1 ohm	7.59 W	D2	1	157.8 ohm	7.60 W
K1	16	157.4 ohm	7.62 W	C2	13	157.3 ohm	7.63 W
L1	18	157.1 ohm	7.64 W	B2	4	155.9 ohm	7.70 W
				A2	22	147.5 ohm	8.13 W
Path Power	Flowing From A1 to A2						
~RTD	Path 1	Path 2	Difference				
2	3.74 W	3.74 W	0.00 W				
3	11.24 W	11.24 W	0.00 W				
4	18.75 W	18.76 W	-0.01 W				
5	26.73 W	26.78 W	-0.06 W				
6	34.83 W	34.81 W	0.02 W				
7	42.35 W	42.33 W	0.02 W				
8	49.89 W	49.88 W	0.01 W				
9	57.82 W	57.81 W	0.01 W				
10	65.63 W	65.53 W	0.10 W				
11	73.22 W	73.14 W	0.08 W				
12	80.84 W	80.77 W	0.08 W				
13	88.48 W	88.46 W	0.02 W				
	92.55 W	92.53 W	0.02 W				
Path Power	Flowing From A1 to A2						
Along Top Surface				Along Bottom Surface			
~RTD	Path 1	Path 2	Difference	~RTD	Path 1	Path 2	Difference
3	7.49 W	7.50 W	0.00 W	2	3.74 W	3.74 W	0.00 W
5	15.47 W	15.52 W	-0.05 W	4	11.25 W	11.26 W	-0.01 W
7	23.00 W	23.04 W	-0.05 W	6	19.36 W	19.29 W	0.07 W
9	30.93 W	30.97 W	-0.05 W	8	26.90 W	26.84 W	0.06 W
11	38.51 W	38.58 W	-0.06 W	10	34.70 W	34.56 W	0.14 W
13	46.15 W	46.27 W	-0.12 W	12	42.33 W	42.19 W	0.14 W
					46.39 W	46.26 W	0.14 W

	Flow	RTD 1	RTD 2	RTD 3	RTD 4	RTD 5	RTD 6	RTD 7	RTD 8	RTD 9	RTD 10	RTD 11	RTD 12	RTD 13	RTD 14	RTD 15	RTD 16	Uninstrumented Side		Instrumented Side		Chiller T	Pressure	dP
Unpowered from HDSKHT2																								
	2.628 lpm	-8.96°C	-8.33°C	-8.97°C	-7.70°C	-8.38°C	-9.00°C	-8.33°C	-7.78°C	-7.99°C	-7.65°C	-8.43°C	-7.78°C	-7.31°C	-8.08°C	-10.40°C	-10.99°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.64°C	16.4 psia	7.13 psid
	2.123 lpm	-8.93°C	-8.31°C	-8.93°C	-7.71°C	-8.36°C	-8.93°C	-8.30°C	-7.78°C	-7.96°C	-7.62°C	-8.36°C	-7.75°C	-7.28°C	-7.99°C	-10.38°C	-10.92°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.67°C	13.9 psia	5.82 psid
	1.655 lpm	-8.63°C	-8.07°C	-8.70°C	-7.44°C	-8.12°C	-8.68°C	-8.02°C	-7.54°C	-7.79°C	-7.43°C	-8.17°C	-7.50°C	-7.16°C	-7.79°C	-10.12°C	-10.70°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.48°C	11.1 psia	4.36 psid
	1.232 lpm	-8.34°C	-7.75°C	-8.32°C	-7.10°C	-7.79°C	-8.34°C	-7.71°C	-7.27°C	-7.45°C	-7.15°C	-7.85°C	-7.26°C	-6.86°C	-7.50°C	-9.75°C	-10.44°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.27°C	8.7 psia	3.10 psid
	0.845 lpm	-7.90°C	-7.37°C	-7.95°C	-6.78°C	-7.41°C	-7.96°C	-7.34°C	-6.94°C	-7.12°C	-6.83°C	-7.56°C	-6.98°C	-6.55°C	-7.10°C	-9.31°C	-10.04°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.06°C	6.7 psia	1.98 psid
184.4 watts from HDSKHT1																								
	2.628 lpm	-6.53°C	-5.11°C	-6.63°C	-5.24°C	-6.33°C	-6.50°C	-6.39°C	-5.70°C	-6.36°C	-6.54°C	-7.01°C	-6.68°C	-6.75°C	-6.21°C	-8.78°C	-10.44°C	34.39 Vdc	2.67 Amp	34.63 Vdc	2.66 Amp	-10.16°C	15.6 psia	6.83 psid
	2.123 lpm	-6.20°C	-4.93°C	-6.32°C	-5.00°C	-6.08°C	-6.36°C	-6.08°C	-5.55°C	-6.18°C	-6.41°C	-6.91°C	-6.63°C	-6.65°C	-6.05°C	-8.54°C	-10.35°C	34.43 Vdc	2.68 Amp	34.62 Vdc	2.66 Amp	-10.19°C	13.2 psia	5.61 psid
	1.655 lpm	-5.51°C	-4.24°C	-5.70°C	-4.42°C	-5.53°C	-5.83°C	-5.58°C	-5.13°C	-5.77°C	-5.99°C	-6.53°C	-6.24°C	-6.47°C	-5.56°C	-7.88°C	-10.17°C	34.47 Vdc	2.68 Amp	34.67 Vdc	2.66 Amp	-10.01°C	10.3 psia	4.09 psid
	1.232 lpm	-4.61°C	-3.46°C	-4.95°C	-3.81°C	-4.90°C	-5.27°C	-5.05°C	-4.63°C	-5.38°C	-5.59°C	-6.20°C	-5.97°C	-6.17°C	-5.04°C	-7.07°C	-9.99°C	34.46 Vdc	2.68 Amp	34.67 Vdc	2.66 Amp	-9.97°C	8.0 psia	2.87 psid
	0.845 lpm	-3.01°C	-2.07°C	-3.58°C	-2.64°C	-3.80°C	-4.28°C	-4.18°C	-3.81°C	-4.64°C	-4.97°C	-5.70°C	-5.45°C	-5.76°C	-4.20°C	-5.53°C	-9.69°C	34.47 Vdc	2.68 Amp	34.68 Vdc	2.66 Amp	-9.95°C	6.0 psia	1.78 psid
Powered minus Unpowered																		91.85 Watt	92.16 Watt					
		2.43°C	3.22°C	2.34°C	2.46°C	2.06°C	2.51°C	1.94°C	2.08°C	1.63°C	1.11°C	1.42°C	1.10°C	0.56°C	1.87°C	1.63°C	0.55°C	92.09 Watt	92.07 Watt					
		2.73°C	3.38°C	2.61°C	2.71°C	2.28°C	2.57°C	2.22°C	2.23°C	1.77°C	1.21°C	1.45°C	1.12°C	0.62°C	1.94°C	1.85°C	0.57°C	92.31 Watt	92.38 Watt					
		3.13°C	3.83°C	3.00°C	3.01°C	2.59°C	2.85°C	2.44°C	2.41°C	2.02°C	1.44°C	1.65°C	1.26°C	0.69°C	2.23°C	2.24°C	0.53°C	92.24 Watt	92.37 Watt					
		3.73°C	4.29°C	3.37°C	3.29°C	2.89°C	3.07°C	2.67°C	2.64°C	2.07°C	1.56°C	1.65°C	1.30°C	0.69°C	2.46°C	2.69°C	0.45°C	92.29 Watt	92.41 Watt					
		4.89°C	5.30°C	4.37°C	4.14°C	3.62°C	3.67°C	3.17°C	3.13°C	2.48°C	1.86°C	1.86°C	1.53°C	0.79°C	2.90°C	3.77°C	0.34°C	184.01 Watt						
																		184.16 Watt						
Subtract out RTD 16																		184.69 Watt						
		1.88°C	2.67°C	1.79°C	1.91°C	1.51°C	1.96°C	1.39°C	1.54°C	1.08°C	0.56°C	0.87°C	0.55°C	0.01°C	1.33°C	1.08°C	0.00°C	184.61 Watt						
		2.16°C	2.81°C	2.04°C	2.14°C	1.71°C	2.00°C	1.65°C	1.66°C	1.20°C	0.64°C	0.88°C	0.55°C	0.05°C	1.37°C	1.28°C	0.00°C	184.69 Watt						
		2.60°C	3.30°C	2.47°C	2.48°C	2.06°C	2.32°C	1.91°C	1.88°C	1.49°C	0.91°C	1.12°C	0.73°C	0.16°C	1.70°C	1.71°C	0.00°C							
		3.28°C	3.84°C	2.92°C	2.84°C	2.44°C	2.62°C	2.21°C	2.19°C	1.62°C	1.11°C	1.20°C	0.85°C	0.24°C	2.01°C	2.24°C	0.00°C							
		4.55°C	4.96°C	4.03°C	3.80°C	3.27°C	3.33°C	2.83°C	2.79°C	2.14°C	1.52°C	1.52°C	1.19°C	0.44°C	2.56°C	3.43°C	0.00°C							
	Flow																Expected Rise							
	2.628 lpm																1.11°C							
	2.123 lpm																1.38°C							
	1.655 lpm																1.77°C							
	1.232 lpm																2.38°C							
	0.845 lpm																3.47°C							

	Flow	RTD 1	RTD 2	RTD 3	RTD 4	RTD 5	RTD 6	RTD 7	RTD 8	RTD 9	RTD 10	RTD 11	RTD 12	RTD 13	RTD 14	RTD 15	RTD 16	Uninstrumented Side		Instrumented Side		Chiller T	Pressure	dP
Unpowered from HDSKHT2																								
	2.628 lpm	-8.96°C	-8.33°C	-8.97°C	-7.70°C	-8.38°C	-9.00°C	-8.33°C	-7.78°C	-7.99°C	-7.65°C	-8.43°C	-7.78°C	-7.31°C	-8.08°C	-10.40°C	-10.99°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.64°C	16.4 psia	7.13 psid
	2.123 lpm	-8.93°C	-8.31°C	-8.93°C	-7.71°C	-8.36°C	-8.93°C	-8.30°C	-7.78°C	-7.96°C	-7.62°C	-8.36°C	-7.75°C	-7.28°C	-7.99°C	-10.38°C	-10.92°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.67°C	13.9 psia	5.82 psid
	1.655 lpm	-8.63°C	-8.07°C	-8.70°C	-7.44°C	-8.12°C	-8.68°C	-8.02°C	-7.54°C	-7.79°C	-7.43°C	-8.17°C	-7.50°C	-7.16°C	-7.79°C	-10.12°C	-10.70°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.48°C	11.1 psia	4.36 psid
	1.232 lpm	-8.34°C	-7.75°C	-8.32°C	-7.10°C	-7.79°C	-8.34°C	-7.71°C	-7.27°C	-7.45°C	-7.15°C	-7.85°C	-7.26°C	-6.86°C	-7.50°C	-9.75°C	-10.44°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.27°C	8.7 psia	3.10 psid
	0.845 lpm	-7.90°C	-7.37°C	-7.95°C	-6.78°C	-7.41°C	-7.96°C	-7.34°C	-6.94°C	-7.12°C	-6.83°C	-7.56°C	-6.98°C	-6.55°C	-7.10°C	-9.31°C	-10.04°C	0.00 Vdc	0.00 Amp	0.00 Vdc	0.00 Amp	-10.06°C	6.7 psia	1.98 psid
144.4 watts from HDSKHT1																								
	2.628 lpm	-6.80°C	-5.56°C	-6.86°C	-5.56°C	-6.59°C	-6.85°C	-6.49°C	-5.89°C	-6.51°C	-6.61°C	-7.08°C	-6.66°C	-6.56°C	-6.38°C	-8.93°C	-10.32°C	30.49 Vdc	2.37 Amp	30.63 Vdc	2.36 Amp	-10.03°C	15.3 psia	6.65 psid
	2.123 lpm	-6.64°C	-5.40°C	-6.75°C	-5.45°C	-6.44°C	-6.75°C	-6.41°C	-5.85°C	-6.45°C	-6.58°C	-7.06°C	-6.69°C	-6.66°C	-6.33°C	-8.81°C	-10.33°C	30.48 Vdc	2.37 Amp	30.62 Vdc	2.35 Amp	-10.10°C	13.2 psia	5.55 psid
	1.655 lpm	-6.29°C	-5.05°C	-6.40°C	-5.16°C	-6.16°C	-6.50°C	-6.19°C	-5.65°C	-6.34°C	-6.46°C	-6.92°C	-6.57°C	-6.55°C	-6.11°C	-8.41°C	-10.34°C	30.48 Vdc	2.37 Amp	30.63 Vdc	2.36 Amp	-10.17°C	10.4 psia	4.14 psid
	1.232 lpm	-5.48°C	-4.34°C	-5.68°C	-4.59°C	-5.52°C	-5.93°C	-5.62°C	-5.16°C	-5.84°C	-6.07°C	-6.55°C	-6.25°C	-6.22°C	-5.61°C	-7.66°C	-10.11°C	30.49 Vdc	2.37 Amp	30.63 Vdc	2.36 Amp	-10.09°C	8.0 psia	2.90 psid
	0.845 lpm	-4.04°C	-3.14°C	-4.50°C	-3.52°C	-4.55°C	-5.04°C	-4.83°C	-4.44°C	-5.25°C	-5.44°C	-6.06°C	-5.75°C	-5.78°C	-4.86°C	-6.36°C	-9.74°C	30.49 Vdc	2.37 Amp	30.63 Vdc	2.35 Amp	-9.95°C	6.1 psia	1.83 psid
Powered minus Unpowered																		72.25 Watt		72.15 Watt				
		2.16°C	2.77°C	2.11°C	2.14°C	1.80°C	2.15°C	1.84°C	1.89°C	1.48°C	1.04°C	1.35°C	1.12°C	0.74°C	1.70°C	1.48°C	0.67°C	72.21 Watt		72.08 Watt				
		2.29°C	2.91°C	2.18°C	2.26°C	1.91°C	2.18°C	1.89°C	1.93°C	1.50°C	1.04°C	1.31°C	1.06°C	0.62°C	1.66°C	1.57°C	0.59°C	72.21 Watt		72.13 Watt				
		2.34°C	3.02°C	2.31°C	2.27°C	1.96°C	2.19°C	1.84°C	1.89°C	1.45°C	0.97°C	1.25°C	0.93°C	0.61°C	1.68°C	1.71°C	0.36°C	72.29 Watt		72.17 Watt				
		2.86°C	3.41°C	2.64°C	2.51°C	2.27°C	2.40°C	2.09°C	2.11°C	1.61°C	1.08°C	1.30°C	1.01°C	0.64°C	1.90°C	2.09°C	0.33°C	72.29 Watt		72.12 Watt				
		3.86°C	4.23°C	3.45°C	3.26°C	2.86°C	2.91°C	2.51°C	2.50°C	1.87°C	1.39°C	1.49°C	1.23°C	0.76°C	2.24°C	2.95°C	0.29°C			144.40 Watt				
																			144.29 Watt					
Subtract out RTD 16																				144.34 Watt				
		1.49°C	2.10°C	1.44°C	1.47°C	1.13°C	1.48°C	1.17°C	1.23°C	0.81°C	0.37°C	0.68°C	0.46°C	0.08°C	1.04°C	0.81°C	0.00°C			144.46 Watt				
		1.70°C	2.32°C	1.59°C	1.67°C	1.32°C	1.59°C	1.30°C	1.34°C	0.91°C	0.45°C	0.71°C	0.47°C	0.03°C	1.07°C	0.98°C	0.00°C			144.41 Watt				
		1.99°C	2.66°C	1.95°C	1.92°C	1.61°C	1.83°C	1.48°C	1.53°C	1.10°C	0.61°C	0.89°C	0.57°C	0.25°C	1.32°C	1.35°C	0.00°C							
		2.53°C	3.08°C	2.31°C	2.18°C	1.94°C	2.08°C	1.76°C	1.78°C	1.28°C	0.75°C	0.97°C	0.68°C	0.31°C	1.57°C	1.76°C	0.00°C							
		3.57°C	3.94°C	3.16°C	2.97°C	2.57°C	2.62°C	2.22°C	2.21°C	1.58°C	1.09°C	1.20°C	0.94°C	0.47°C	1.95°C	2.66°C	0.00°C							
	Flow															Expected Rise								
	2.628 lpm															0.87°C								
	2.123 lpm															1.08°C								
	1.655 lpm															1.39°C								
	1.232 lpm															1.86°C								
	0.845 lpm															2.72°C								

**H-Disk (Aluminum)
Water/Ethylene Glycol 30%w**

HDSKHT2

B. Squires
24-Jul-98

**H-Disk (Aluminum)
500 mW Chip Power
-10 °C Water/Ethylene Glycol 30%w**

H-Disk (Aluminum)
640 mW Chip Power
-10 °C Water/Ethylene Glycol 30%w