MIniature STudent satellite

M632

UPDATED MIST TBT PLAN

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1 TEST PURPOSE AND BASIC PRINCIPLE

To get good measurements on the temperature difference over the component interfaces the TBT (Thermal Balance Test) needs strong gradients across the satellite. For this reason, it has been decided to place eight heaters on MIST. Four heaters are to be placed on the cover plates around the middle stack. To obtain symmetry two heaters are placed on the bottom cover plate and similarly two are to be placed on the top. None of the heaters in this presented configuration close to being at capacity, so they double as safety heaters able to prevent cooling components from getting damaged.

The thermal balance test will be done manually along with the external heaters. The thermal balance test will start at minimum pressure at the hot case shroud temperature 0°C and hold until stability, then decrease the temperature 1.5°C/min to the cold case shroud temperature of -50°C and hold until stability.

2 TEST SETUP

2.1 Test article mounting in Thermal Vacuum Chamber

2.1.1 Location in chamber

Once in the chamber, MIST should be suspended according to the specifications provided in document M632-020 regarding heater locations and heights (Figure 1).

The suspension device must comply with the TVAC internal dimensions. It is still unclear if the table in the chamber could be helpful or an impediment during the satellite positioning. The device is designed to have adjustable hanging wires lengths. With the current specifications MIST is positioned almost in the centre of the chamber. If the table is removed the wires can be adjusted accordingly.

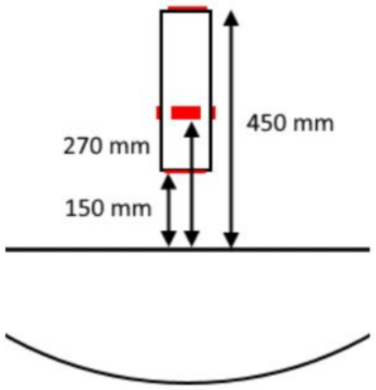


Figure 1 Heater locations over TVAC table

2.1.2 Suspension system

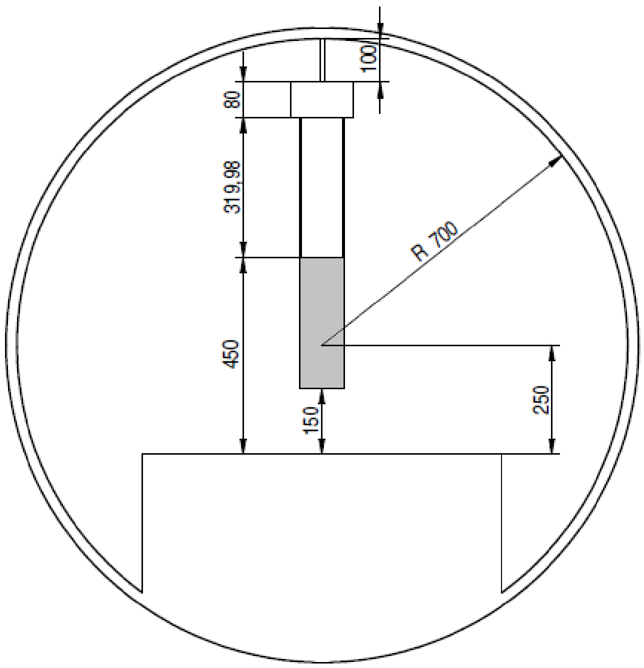


Figure 2 Location in TVAC of the satellite.

The device is suspended and connected to the TVAC ceiling rail with two rollers. One roller was enough for the purpose of suspending MIST, but this solution allows to have only one degree of freedom for the whole system. The suspension device can only move along the rail and will not swing back and forth during MIST positioning.

The eye nuts are positioned at the corner of a 100 mm side square, as the wire mount hinges of MIST. It is true that this make the device specific for MIST, but it is also unlikely that a future project will have a considerable larger size.

Moreover, if the cross section of a future project is symmetric and the mass comparable to the one of MIST, it will not be a problem if the hanging wires are not extending in a completely vertical configuration.

Thermal insulation between the satellite and the suspension device is necessary to prevent, or at least reduce, thermal exchange that could alter the test results.

The critical interface is between the wire mount hinges and the hanging wire. A thermally insulating washer is necessary at the mock solar panel hinges. In addition, also the wires could be insulated, for instance using Kapton tape.

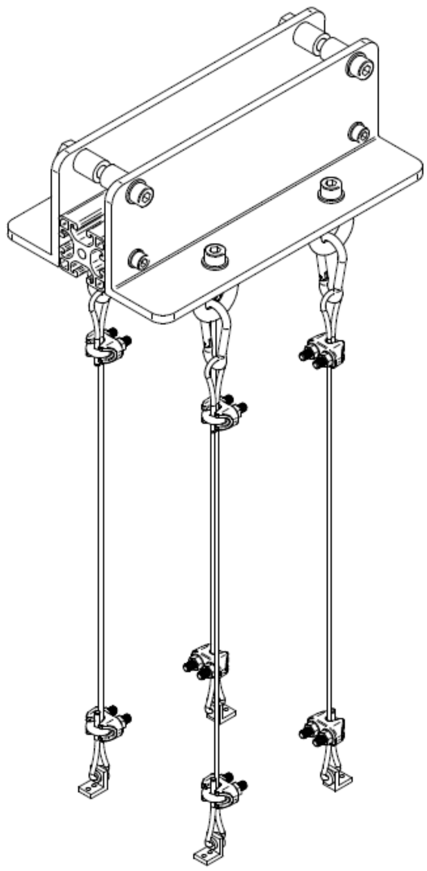


Figure 3 TVAC suspension system.

This configuration is easy to set up and there is no direct interface between the hanging system and the satellite. The suspension system design is described in [RD1].

2.2 Test article mechanical configuration

2.2.1 Subsystems

- **All subsystems shall be installed.**
- **All subsystems shall be turned ON** except the AntS. **(TBD).**
- **The TRXVU shall not transmit**, and its function replaced by the TRXVU simulator.

2.2.2 Experiments

- **All experiments shall be installed**.
- **All experiments shall be turned ON** during the test. The level of operation is **TBD** but their heat dissipation shall be reflected in the modelling of the test.
- **NanoProp shall NOT be filled with propellant**.

2.2.3 Solar panels & cover plates

- **Dummy solar panels** will be used including the deployable panels
- **Deployed dummy solar panels** will be attached by fixed brackets.
- **Surface treatment:** the dummy solar panels shall be black anodized.
- **The top and bottom cover plates** shall be flight units and be black anodized **(TBD)**.

2.3 Test article instrumentation

2.3.1 Thermocouples

The thermocouples will be placed to test important and representative interfaces. Aluminium-aluminium, PCB-aluminium and titanium-aluminium interfaces will be tested among which are interfaces like bus spacer-hex nut and rib-rail. Thermocouples will be Welded Tip PFA Thermocouples from TC Direct, Article 401-324, a type T thermocouple with 0.2 mm diameter (AWG 32) wires and equipped with a plug.

2.3.1.1 Thermocouple mounting

The methods for attaching of the thermocouples are set out in the document M632-030.

2.3.1.2 Thermocouple location

Table 1, Figure 4 and Figure 5 are taken directly from [RD5]. Figure 6 shows the thermocouple locations in three dimensions. The thermal model meshing is also shown in this figure. The thermocouples should probably be placed not too far from the centre of each mesh element.

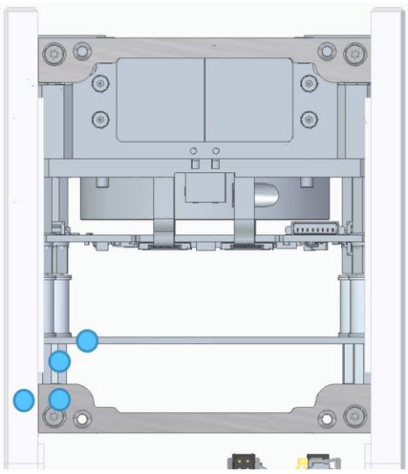


Figure 4 Top stack with approx. TC placements

Thermocouple #	Component and node	Interface
Top Stack		
1	Dummy Plate 114	1
2	Top Cover Plate 528	1
3	Dummy plate 7500	2
4	Hexnut 727	2, 3
5	Rib 625	3, 4
6	Rail 401	4
Bottom Stack		
7	Bus Spacer 752	5
8	Bus Spacer 738	5
Integrated sensor #		
101-106	NANOPROP 1-6	ON
107-108	CUBES 1-2	OFF
109-113	LEGS 1-4	OFF
114-115	SIC 1-2	ON
116	SEUD	ON

Table 1 Thermocouple placement and respective interfaces, and sensors

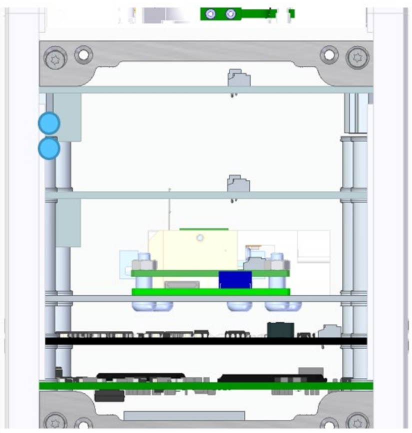


Figure 5 Bottom stack with approx. TC placements

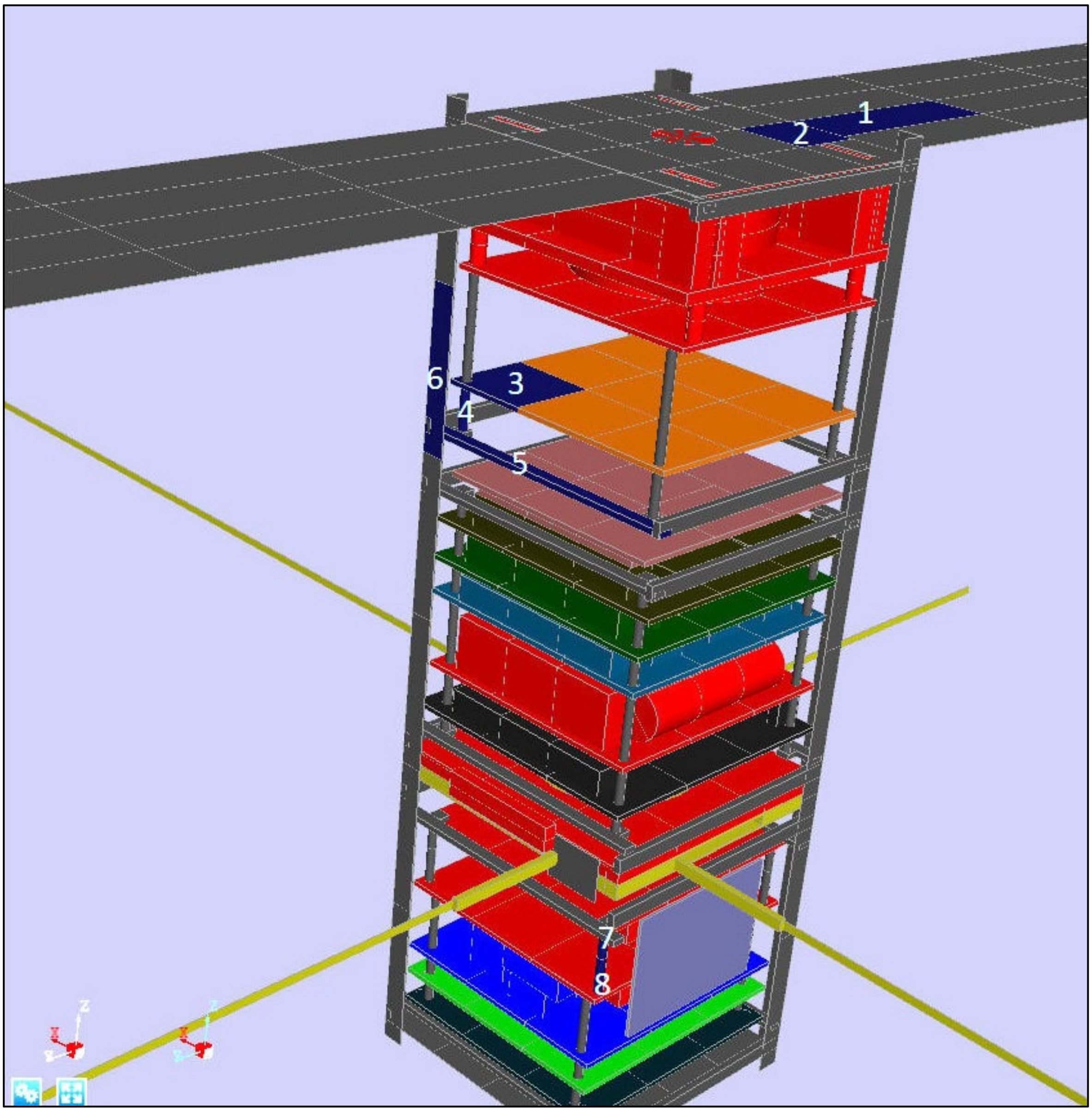


Figure 6 3-D locations of thermocouples.

2.3.1.3 Thermocouple readout

The regular temperature display system of the TVAC shall be used to read out thermistor temperature values.

2.3.2 Other temperature sensors

See section 4.2.5 in the Appendices for a list of experiment and subsystem sensors.

2.4 Test support systems

2.4.1 Umbilical

The umbilical shall be used to communicate with MIST satellite while in the thermal vacuum test chamber. The umbilical shall connect to the satellite's umbilical connector (a.k.a. the ABF connector location) on one end and to the EPS-EGSE on the other end – outside the tank. For more details see [RD4].

2.4.1.1 Umbilical routing

The umbilical is split into two parts.

Part 1: Omnetics A28000-037 to D-SUB 37 connector (socket). This is basically the standard ISISPACE umbilical built around the connector plus pigtails and is spliced with a cable to terminate at a D-SUB 50 connector (pin). Length: 1300 mm (L1 in Figure 6).

Part 2: A cable that connects the 50-pin connector on the outside tank wall to the EPS-EGSE. Length: 1600 mm (L2 in Figure 6).

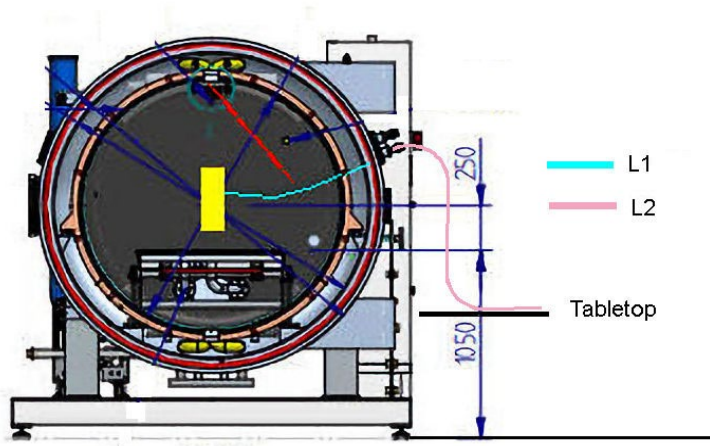


Figure 7 Umbilical routing from satellite to EPS-EGSE.

2.4.1.2 Satellite control via the umbilical

- **Inhibitions of deployments:** The AntS and HDRM deployments are inhibited since the ABF connector is not attached. The umbilical connector does not "arm" these functions.
- **Powering on the satellite:** The "kill switch" is activated via the umbilical and the EPS-EGSE which is connected to the umbilical outside the tank. Activating the "kill switch turns on the power system" of MIST.

- **Sending commands and receiving telemetry:** Subsystems and experiments are controlled during the test by using the TRXVU simulator. The TRXVU simulator (Arduino-based) is connected to the umbilical outside the TVAC via the EPS-EGSE and commands are sent to the TRXVU from “TestStand” **(TBC).**

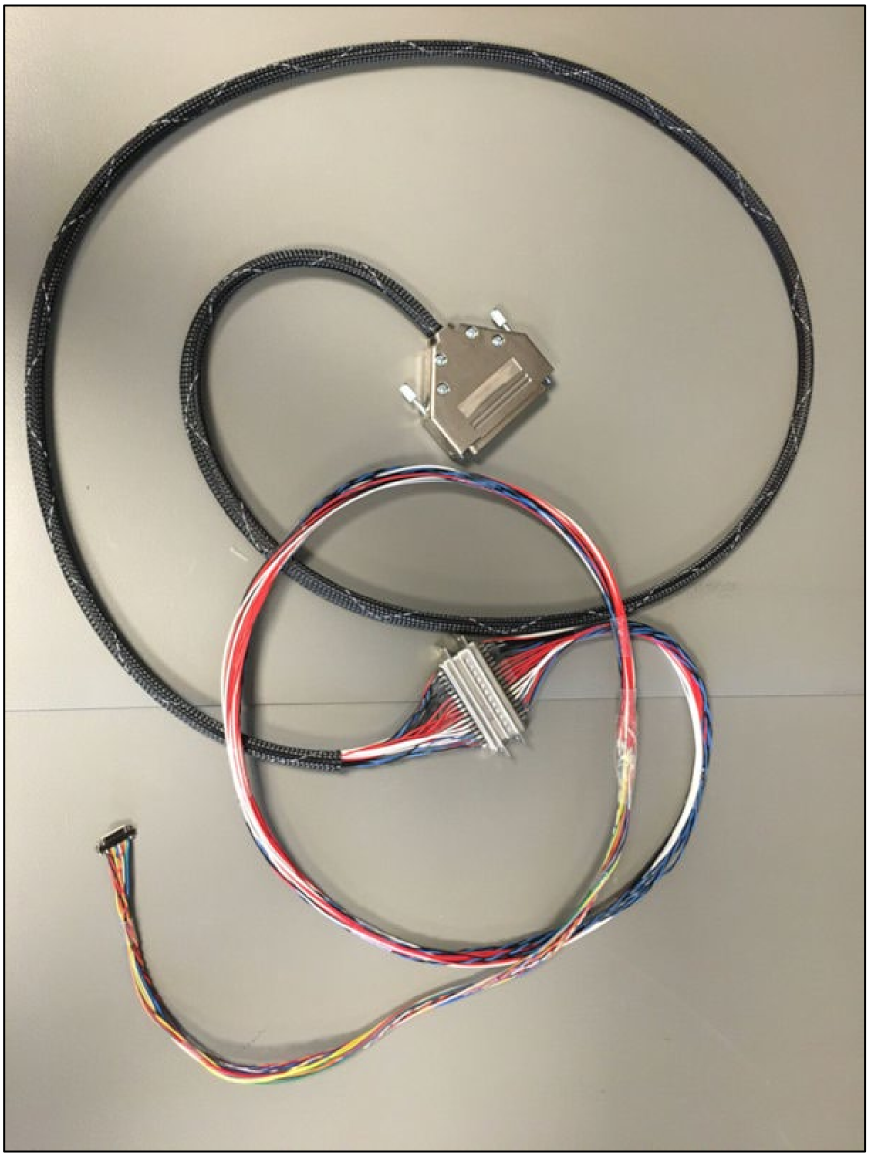


Figure 8 Completed umbilcal. Coloured part is the section inside the TVAC.

2.4.2 Heaters

2.4.2.1 Heater locations

The location of the heaters is shown in Table 3 and Figure 8. Please note that the outline of experiments in the part of the satellite outer surface not covered by solar panels is obsolete, but this has no effect on the location of the heaters.

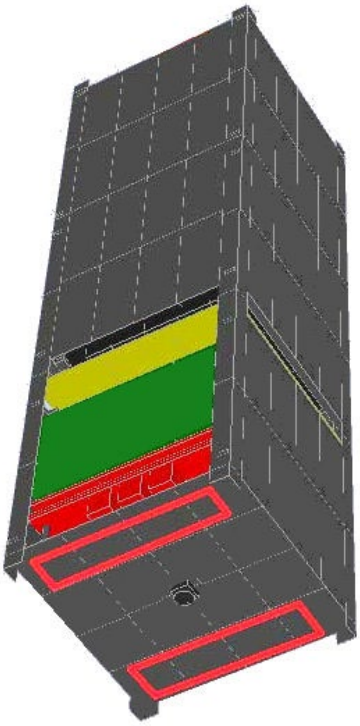
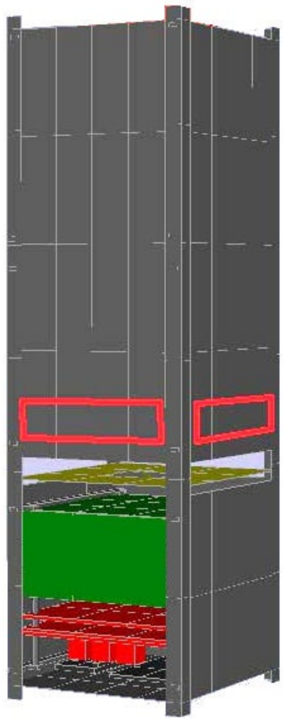
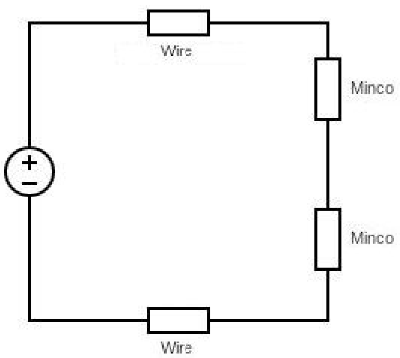
	
Heaters on the **bottom cover plate.** The heaters on the top cover plate are located at the corresponding locations.	The location of the **mid-stack heaters.** There are four heaters – one on each face of the satellite.

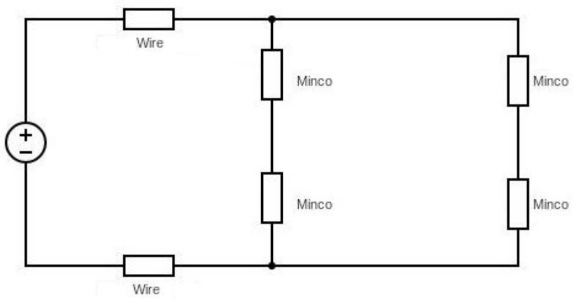
Figure 9 Heater locations.

Location	**Config.**	**Schematic**	**Heater placement**
Top cover plate	2s	1	+Z (one each along +X,-X side of plate)
Bottom cover plate	2s	1	-Z (one each along +X,-X side of plate).
Side cover plates	2s/2p	2	-X,+X,-Y,+Y, just above Antenna/HDRM.

Table 2 Heater locations table.

2.4.2.2 Heater circuit connections





The top and bottom cover plate heaters are just two heaters in series. "Minco" stands for "Minco heater"

The "mid-stack" or "mid-section" heaters are connected two pairs in series that are connected in parallel.

Figure 10 Electrical connection of heaters.

2.4.2.3 Heater harness and patch panel

The heater harness connects the heaters on the satellite to power supplies on the outside of the tank. The way the heaters are connected to power supplies is shown in Figure 10.

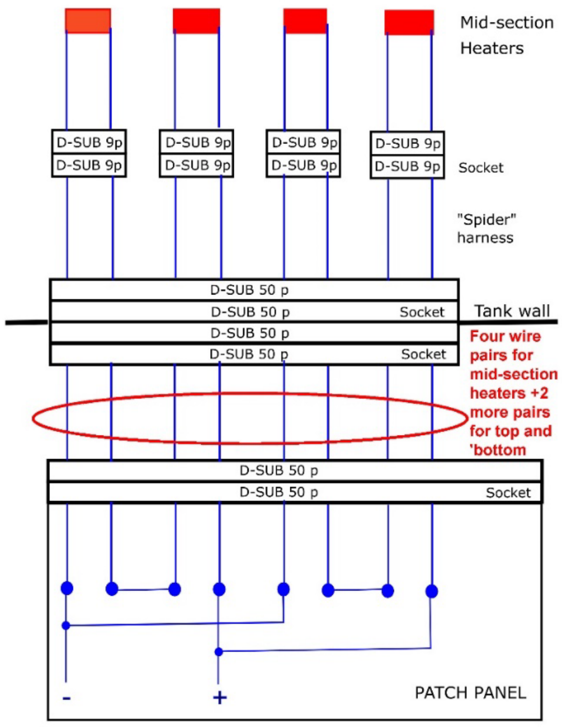


Figure 11 Mid-section heaters and patch panel

The detailed specification of pin assignment in the heater harness is set out on [RD2]. The detailed design of the patch panel is described in [RD3].

2.4.2.4 Heater installation

- **Pre-assembly:** The heater harness and heater elements shall be pre-assembled as set out in [RD2].
- **Heater attachment:** The heaters shall not be attached to the dummy body solar panels until just before the satellite is placed in the TVAC.
- **Heater "burn-in":** Heaters may be "burned" in by applying power to them for a short time – before the TBT commences. **TBD**.
- **Heater shelf life** [See RD2].

2.4.2.5 Heater and wire data needed to compute settings of power supplies.

- **Harness wire gauge**: AWG 22 (0.38 mm^2): 4.6 Ω/100 m.
- **Harness wire length**: 2.7 m (**TBC**)
- **Heater type and resistance**: Minco HK6907, 47.78 Ω.

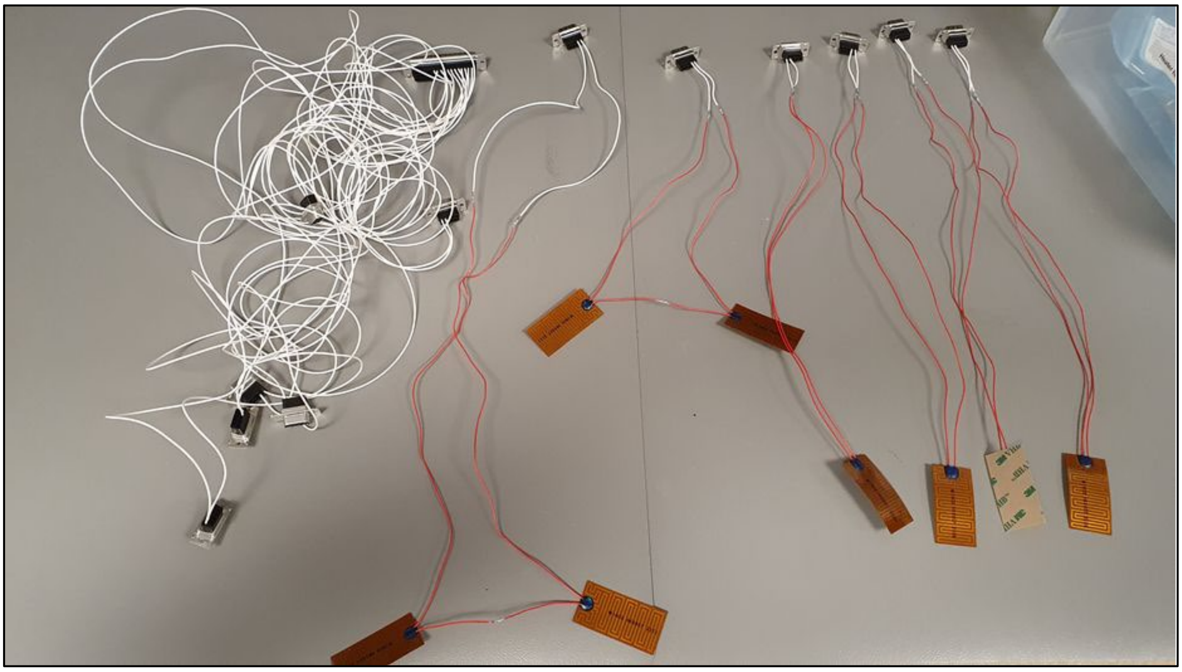


Figure 12 Heater harness.

2.4.2.6 Internal heaters

The internal heaters are:

- NanoProp Tank heater– max power 1.4 W (used to supply extra heat in NanoProp **is that OK?**)
- NanoProp Thruster heaters– max power 4 x 0.25 W **(Can/will these be used? TBD)**
- Battery max power – 3.5 W (kept as a safety heater, **TBD**).

2.4.2.7 Safety monitoring of heaters

To avoid the risk of heaters disconnecting from the cover plates and overheating thermocouples could be connected to the cover plates and monitored through the normal TVAC temperature display system. On the ±Z cover plates it is proposed that only one thermocouple is used to check if the temperature of the cover plate suddenly drops during the test. On the mid-stack there should be a safety thermocouple near each heater. Figure 13 shows these approximate locations for the -Z cover plate and the mid stack. On the +Z cover plate there is also only one safety thermocouple.

2.5 Location of the control of the test

- Thermocouple monitoring will be done in the room just outside the TVAC room.
- Control of the heaters needs to be made close to the TVAC unless a very long cable connects the heater patch panel to the heater harness. **(TBD)**
- Control of the satellite and monitoring of internal temperature sensors needs to be performed via the laptop connected to the EPS-EGSE and the TRXVU simulator. This computer could possibly be remotely controlled from the room just outside the TVAC room. **(TBD)**

2.6 Control functions from the ground support equipment

- Turn experiments and subsystems ON/OFF.
- Set operations mode of experiments by command.
- Command heaters in NanoProp and BP4 Battery Pack ON/OFF.
- Collect housekeeping telemetry readings of temperatures in experiments and subsystems (see section 2.3.2) at **TBD** intervals and **TBD** times.

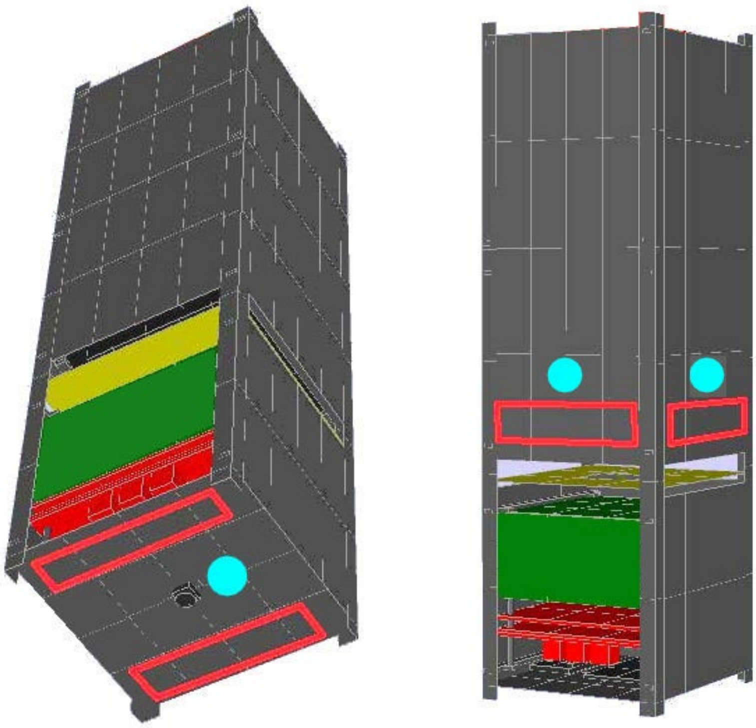


Figure 13 Locations of safety thermocouples.

3 OVERALL TEST SEQUENCE AND EXECUTION

3.1 Pre-test preparation sequence

Step	Details in	Description
1	MAM[1]	Assemble MIST according to [RD6] excluding the cover plates.
2	MAM	Attach thermocouples to assigned components described in section **TBD**.
3	This doc.	Take photo of attached thermocouples and thermocouple ID for documentation
4	MAM	Attach cover plates to MIST.
5	MAM	Attach heaters on designated locations.
6	This doc.	Take photo of heaters attached for documentation
7	MAM	Attach heater harness (spider part) to internal & external feedthrough flanges.
8	This doc.	Connect heater harness to the power supply.
9	MAM	Attach MIST to the TVAC suspension device
10	MAM	Attach the TVAC suspension device to the rail in the top of the TVAC.
11	MAM	Connect heater “spider heater harness” to heater circuits.
12	This doc.	Perform a burn in test with the heaters. **TBD**
13	MAM	Install and connect the umbilical cable (part 1, see 2.4.1.1)
14	This doc.	Install the umbilical cable (part 2, see 2.4.1.1) to the TVAC and the EPS-EGSE
15	This doc.	Perform communications test with MIST

3.2 Shroud temperature profile

In [RD5] the TVAC shroud temperature set points are outlined and the time to reach equilibrium at each temperature set point derived from simulations is shown. As can be seen from the graph the entire test may last two full days.

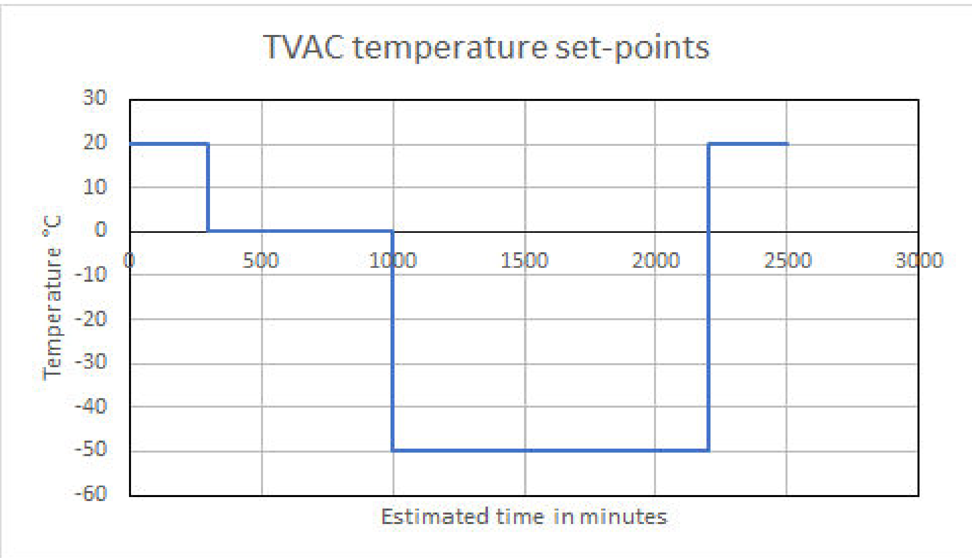


Figure 14 TVAC shroud temperature set points.

[1] Mechanical Assembly Manual [RD6]

3.3 Step-by-step test procedure

Step	Description
1	**Start computer controlling the vacuum chamber** and start WinKratos.
2	**Close vacuum chamber door**.
3	**Start the logging of temperature and pressure** in WinKratos. Enter desired name on the log file and hit "Start data acquisition". (Figure 13
4	**Open charts and display attached thermocouples**. Mark desired channels for thermocouples. Two different chart sections can be made to separate the curves into the two different sections) (Figure 14)
5	**Open Probe windows for current temperature readings** of attached thermocouples. Open enough windows to show all necessary temperature readings and configure the different probe windows to show the correct channels for desired thermocouples. (Figure 15).
6	**Turn on vacuum pumps.** Set Primary vacuum pumps to ON. Set Primary vacuum valve to ON. Set Turbo pump to ON. Set High vacuum turbo to ON. Hit "Execute". (Figure 15). Set all four pumps to ON at once. The Primary pumps will warm up for approximately 20 minutes before they start working. Once the pressure reaches 10^{-2} the turbo pump will start warming up for 5 minutes before starting. When the left box is yellow, the command is recognized and when the right box is green it is active. The right box for "Primary vacuum pump" and "Primary vacuum Valve" will be green when above 10^{-2}, after that the turbo pump will take over.
7	Wait until pressure is below 10^{-5} mbar.
8	**Start subsystems and experiments in MIST.** Start sequence TBD
9	Start recording internal sensor temperatures. Start sequence TBD
	First temperature setpoint
10	**Set new temperature setpoint** for the vacuum chamber to 0°C. Set New final setpoint to 0°C. Set New Slope to -1.5°C/min. Mark Control box. Hit "Execute"
	Set top and bottom heater power
11	When sensor number # (top cover plate) shows temperature # °C, **set Top cover plate heater to 1.2 W**. Estimated time to reach # °C is # minutes.
12	When sensor number # (bottom cover plate) shows temperature # °C, **set Bottom cover plate heater to 1.5 W.** Estimated time to reach # °C is # minutes.
13	Let the temperature settle in the satellite and take continuous temperature readings to make sure temperature does not go below or above temperature limits described in section **(Enter reference).**
14	When the temperatures have not changed more than 0.5 degrees the last 2 hours, mark that time for future data handling and take temperature readings. Estimated time to reach equilibrium is # hours.

Step	Description
	Second temperature setpoint and turn off all heaters
15	**Set new temperature set point for the vacuum chamber to -50°C**. Set New final setpoint to -50°C. Set New Slope to -1.5°C/min. Mark Control box. Hit "Execute"
16	**Turn off all heaters**. Set NanoProp tank heater to 0 W. Set Bottom cover plate heater to 0 W. Set Side cover plate heaters to 0 W. Set Top cover plate heater to 0 W.
	Set NanoProp tank and bottom and side cover plate heater power
17	When sensor number # shows temperature #°C **set NanoProp tank heater to 1.4 W**, set **Bottom cover plate heater to 3 W, set Side cover plate heaters to 12 W.**
18	Let the temperature settle in the satellite and take continuous temperature readings to make sure temperature does not go below or above temperature limits according to section 2.4.
19	When the temperatures have not changed more than 0.5 degrees the last 2 hours, mark that time for future data handling and take temperature readings. Estimated time to reach equilibrium is # hours.
	Third temperature setpoint
20	**Set new temperature setpoint to 20°C**. Set New final setpoint to 20°C. Set New Slope to 1.5°C/min. Mark Control box. Hit "Execute"
	Turn off all heaters
21	When the shroud has reached # °C, turn off heaters to avoid components overheating.
22	When shroud has reached ambient temperature start pre-prepared WinKratos programme and wait until programme termination.
23	When shroud has reached ambient temperature wait one hour.
24	Turn off vacuum pumps and break vacuum.
25	Shut down logging.
26	Convert logfile to ASCII for data handling. (Figure 17). Enter "Col. Selection": mark all the thermocouple channels used Hit "Start conversion"
27	Save both log files and converted ASCII files to MIST backup drives

4 REFERENCES

4.1 Reference Documents (RD)

RD#	Document Title
1	M620-002 MIST TVAC Suspension Device
2	M632-020 Heater Harness Pre-Assembly
3	M632-025 Patch Panel Design
4	M632-016 Thermal Test Umbilical Requirements Specification
5	M632-004 Thermal Balance Vacuum Test
6	M110-031 Assembly Manual for Thermal Testing **(in preparation)**

4.2 Appendices

4.2.1 Unit temperature limits

	Non Operative		Operative		
	Min [C]	Max [C]	Min [C]	Max [C]	
TRXVU	**-40**	**60**	-40	60	OFF
Battery	-5	45	**-5**	**45**	ON
IGIS	-30	70	**-30**	**70**	ON
Antenna	**-50**	**85**	-20	60	OFF
IMTQ	-40	70	**-40**	**70**	ON
OBC	-40	80	**-25**	**65**	ON
Camera	-30	70	**0**	**70**	ON
SiC	-40	105	**-40**	**105**	ON
SEUD	-65	150	**0**	**85**	ON
NanoProp	-10	50	**0**	**50**	ON
LEGS	**-30**	**70**	10	40	OFF
Cubes	**-20**	**60**	-20	30	OFF

8°C safety margin applied. Time plots for each subsystem in appendix. Subsystems are simulated to be in their designated state during the entire test. They usually have a smaller acceptable temperature range when ON. Most systems ON/OFF have a small effect on even their own temperature, so the plots in the appendix are a good estimate of the possibility of switching the state of a subsystem, although a re-simulation is recommended to get good certainty on estimated temperatures [RD5]. **(Why is CUBES OFF? TBD)**

4.2.2 Heater power and internal dissipators used in test simulation.

The table below comes from [RD5]. It needs to be updated.

Chamber Temperature	20 C	0 C	-50C
Top Heaters – max 10,6 W	0 W	1,2 W	3 W
Mid Heaters – max 21,2 W	0 W	0 W	12 W
Bottom Heaters – max 10,6 W	0 W	1,5 W	3 W
Internal Heaters/Dissipators			
OBC	0,5 W	0,5 W	0,5 W
IMTQ	1 W	1 W	1 W
Nanopower	0,2 W	0,2 W	0,2 W
NanoProp Tank Heater	0 W	0 W	1.4 W

Internal dissipations to be checked with current figures (TBD).

Table in which to insert updates.

Chamber Temperature	**20 C**	**0 C**	**-50C**
Top Heaters – max 10,6 W	0 W	1,2 W	3 W
Mid Heaters – max 21,2 W	0 W	0 W	12 W
Bottom Heaters – max 10,6 W	0 W	1,5 W	3 W

Internal Heaters/Dissipators			
OBC	0,5 W	0,5 W	0,5 W
IMTQ (Idle)	0.1 W	0.1 W	0.1 W
TRXVU (Receiver only)	0.44	0.44	0.44
NanoPower a.k.a. P31us	0.7[2] W	0.7 W	0.7 W

Experiment Dissipations			
SEUD	1 W	1 W	1 W
SIC	0.3 W	0.3 W	0.3 W
LEGS (will this be ON?)	0.4 W	0.4 W	0.4 W
CUBES (Will this be ON?)	0.9 W	0.9 W	0.9 W
NanoProp (PCB)	0,2 W	0,2 W	0,2 W
NanoProp Tank Heater	0 W	0 W	1.4 W
Nanoprop helper board[3]	0 W	0 W	0.2 W

Table 3 External/internal heater and subsystem dissipations.

[2] This is assuming there is no input converter losses. This corresponds to dissipation in eclipse.
[3] Efficiency 89%. So the loss when running tank heater is 1.4*(1-0.89/0.89)=0.§7 W

4.2.3 Illustrations related to the test procedure

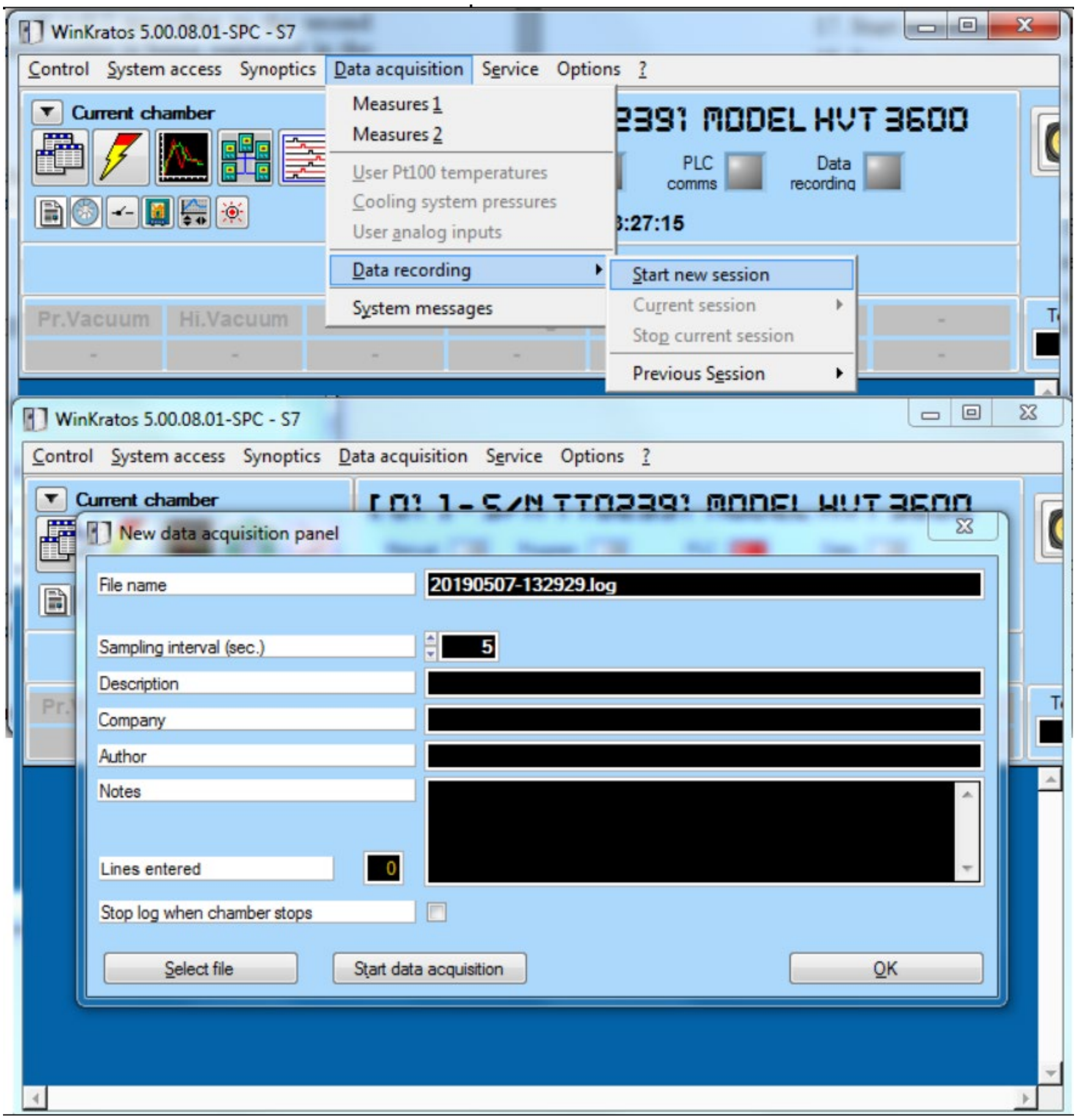


Figure 15 Start data acquisition.

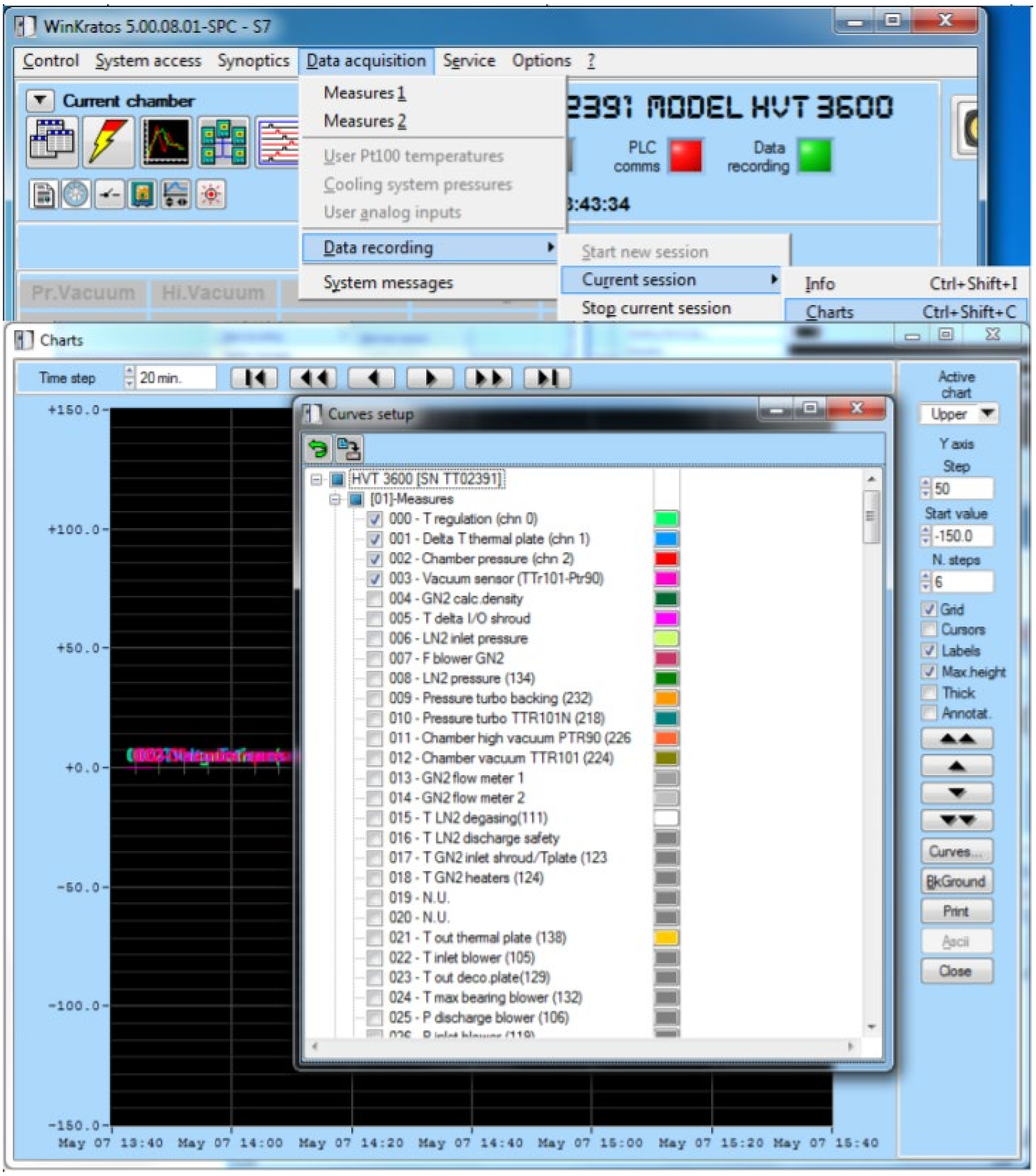


Figure 16 Attach thermocouples.

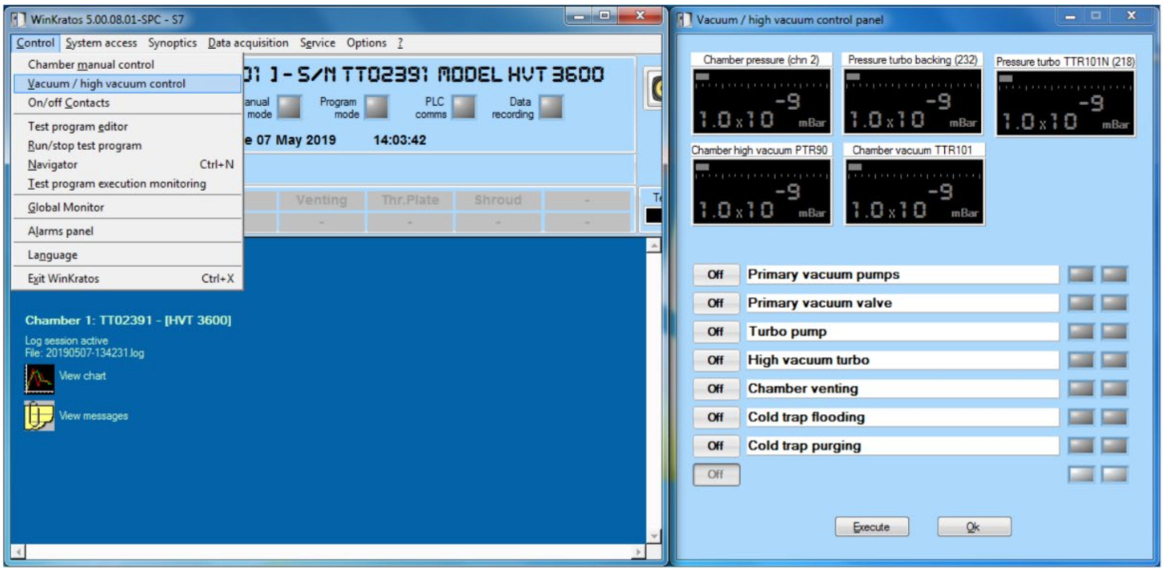


Figure 18 Start vacuum pumps.

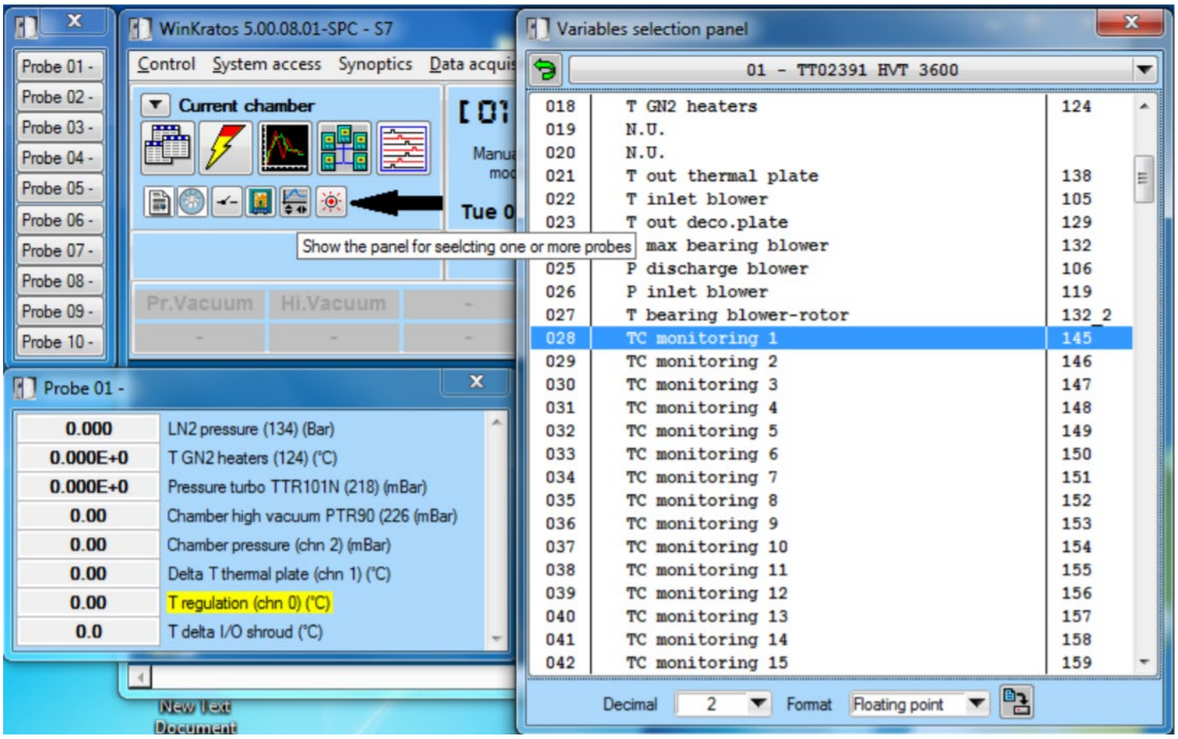


Figure 17 Open probe windows to check temperatures

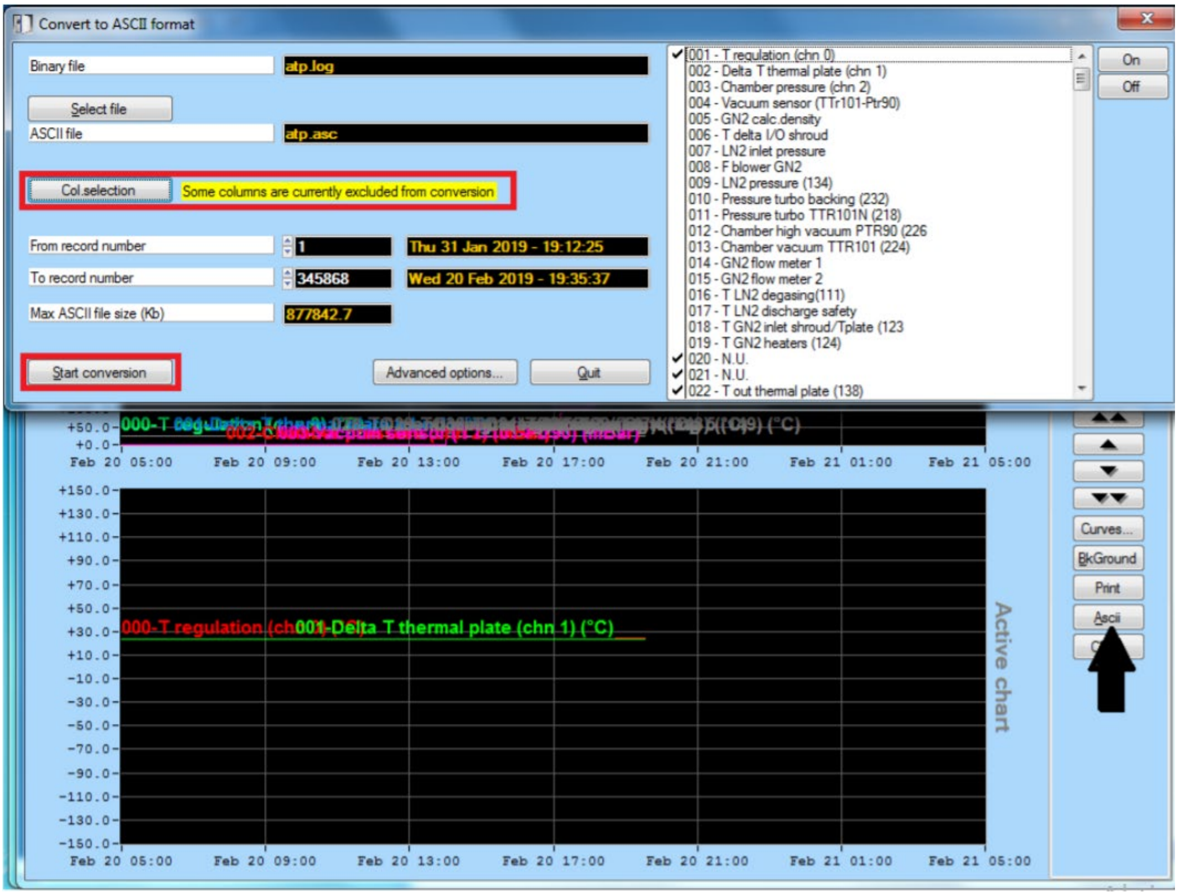


Figure 19 Convert logfile to ASCII

4.2.4 Predicted thermocouple values

Chamber Temperature	0°C	-50°C	20°C	
Time to Settle	150 min*	200 min*	200 min	Interface
Top Dummy Plate 114	4,01°C	-19,74°C	21,23°C	1
Top Cover Plate 528	13,62°C	8,21°C	21,66°C	1
Dummy Plate 7500	7,46°C	-6,69°C	24,87°C	2
Hexnut 727	6,55°C	-8,72°C	29,83°C	2, 3
Rib 625	5,62°C	-10,74°C	22,06°C	3, 4
Rail 401	5,42°C	-11,15°C	21,84°C	4
Bus Spacer 752	7,15°C	-8,40°C	21,66°C	5
Bus Spacer 738	7,41°C	-7,32°C	21,68°C	5

Table 4 Predicted thermocouple values.

This table needs to be updated with new simulations.

4.2.5 Experiment and subsystem temperature sensors

Experiment	# of sensors	Location	Remarks
CUBES 1	2	See M120-022	-
CUBES 2	2	See M120-022	-
LEGS	1	See M120-022	Four NTC resistors in parallel.
NanoProp	6	See M120-022	Two on Tank, one each on thrusters.
SEUD	1	See M120-022	In Artix-7 FPGA
SIC	2	See M120-022	-

Table 5 Experiment temperature sensors.

Subsystem	# sensors	Location	Remarks
TRXVU	2	Power Amp., Local Osc.	-
IOBC	?	See below	-
EPS	4	Converters	Check why 4. There are only 3 converters
BP4	2	Battery	-
iMTQ	4	3 x Coils, 1 x MCU	-
AntS	2	One on each microcontr.	-

Table 6 Subsystem temperature sensors

Regarding the location of the temperature sensor on the IOBC, please see the below screenshot (Figure 20) of the iOBC revB, and the red circled component marked U29, which is the temperature sensor in question. I have attached the datasheet for that specific board sensor, which include an explanation of how to translate the output voltage value into temperature values. The sensor is of the type LM94022/-Q1 1.5-V, SC70, Multi-Gain Analog Temperature Sensor With Class-AB Output.

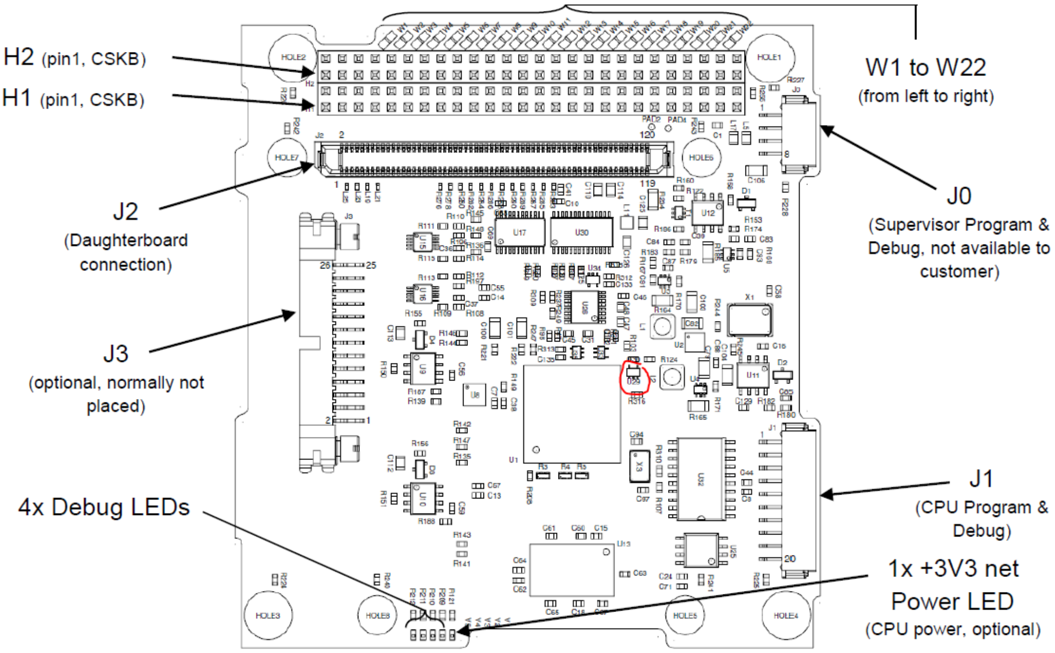


Figure 20 Location of iOBC thermal sensor

The following questions about the iOBC thermal sensors remain to be answered:

- What iOBC ADC channel is the temperature sensor connected to (if any)?
- Is this the sensor that can be read out via the supervisor?
- Where is the RTC located on the board (interesting since it has a temperature sensor)?