Studies on the performance of firefighter's gas cooling technique

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Abstract

Gas cooling is a technique used within the fire service to reduce the risks of the hot gaseous layer and create a better visibility. It is achieved by applying water into the gaseous layer. Successfully performing or implementing this technique is something that has not yet been accomplished in every brigade.

This work has been focused on an experimental research towards different parameters that affect gas cooling. Tests were conducted in a half scaled ISO 9705 room using a fixed nozzle position angled at 45° with the floor. A sensitivity analysis was performed to investigate how the flow rate, droplet size, application time and spray pattern affect the cooling and contraction of the gaseous layer.

Out of the experimental results, the conclusion could be drawn that gas cooling was most effective using sprays with the smallest droplets that can reach the end of the room. In this work, a hollow cone nozzle with droplet diameters of 500 μm performed the best results.

The water should be applied in the gaseous layer as fast as possible whether it be in short pulses or as a continuous flow. If pulses are used, the time in between a pulse should not exceed 0.5 seconds. A gas layer contraction was not observable at this small scale although velocity decreases of the outgoing gases were measured.

After the water application, gas cooling provided a buffer time of at least 7 to 10 seconds before the gases returned at their initial temperatures.

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28th of May, Lund

"Read and approved"

Abstract

Gas cooling is a technique used within the fire service to reduce the risks of the hot gaseous layer and create a better visibility. It is achieved by applying water into the gaseous layer. Successfully performing or implementing this technique is something that has not yet been accomplished in every brigade.

This work has been focused on different parameters that affect gas cooling and is studied by the use of experiments. Tests were conducted in a half scaled ISO 9705 room using nozzles at a fixed position and angled at 45° with the floor. A sensitivity analysis was performed to investigate how the flow rate, droplet size, application time and spray pattern affect the cooling and contraction of the gaseous layer.

Out of the experimental results, conclusions could be drawn that gas cooling was most effective using sprays with the smallest droplets that can reach the end of the room. In this work, a hollow cone nozzle with droplet diameters of 500 μm performed the best results.

Water should be applied in the gaseous layer as fast as possible whether it be in short pulses or as a continuous flow. If pulses are used, the time in between a pulse should not exceed 0.5 seconds. A gas layer contraction was not observable at this small scale although a velocity decrease of the outflowing gases was measured.

After the water application, gas cooling provided a buffer time of at least 7 to 10 seconds before the gases returned at their initial temperatures.

Abstract (Dutch)

Rookgaskoeling is een brandweertechniek die gebruikt wordt om de risico's van de hete rooklaag te verminderen alsook een betere zichtbaarheid te creëren. Het wordt uitgevoerd door water in de rooklaag aan te brengen. Een succesvolle beheersing of invoering van de techniek bestaat nog niet in elk brandweerkorps.

De focus van dit werk werd gelegd op experimenteel onderzoek naar de verschillende parameters die gaskoeling kunnen beïnvloeden. Testen met een vast gepositioneerde straalpijp werden uitgevoerd in een ISO 9705 kamer op halve schaal. Een sensitiviteitsanalyse werd uitgevoerd om te onderzoeken hoe het debiet, druppelgrootte, applicatietijd en sproeipatroon een effect hebben op de koeling en volumereductie van de rookgaslaag.

Uit de experimentele resultaten werd de conclusie getrokken dat gaskoeling het effectiefst is met waterstralen die een zo klein mogelijke druppelgrootte hebben zonder dat de reikwijdte kleiner is dan de verste muur. In dit werk leverde een straal met een sproeipatroon als een holle kegel en een druppelgrootte van 500 μm de beste resultaten.

Het water dient zo snel mogelijk aangebracht te worden ware het in korte pulsen of een continue stroom. Indien pulsen gebruikt worden dient de tijd tussen elke puls lager gehouden te worden dan een halve seconde. Een volumereductie van de gaslaag was niet waarneembaar op deze schaal alhoewel snelheidsafnames van de uitgaande rookgassen geregistreerd werden.

Gaskoeling leverde na water applicatie een buffertijd van 7 tot 10 seconden voordat de gassen terug opwarmen naar hun initiële temperaturen.

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List of abbreviations

FDS	Fire Dynamics Simulator
HRR	Heat Release Rate
IMFSE	International Master in Fire Safety Engineering
ISO	International Organisation for Standardisation

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1 Introduction

Gas cooling is a technique used by firefighters to reduce the dangers posed by the hot smoke layer that arises at enclosure fires. Firefighters often have to perform an interior attack in pre-flashover conditions. In the growth phase a fire is typically characterized by a fire seat, smoke plume, an upper hot smoke layer and an ambient layer. The high temperatures and low visibility caused by the smoke layer can create a difficult and stressful environment for the operating crew. Moreover, this layer could ignite or produce a substantial amount of radiation which may lead to a flashover.

By focusing the attack on the smoke gases, the risks can be kept as low as possible while the crew advances to the fire seat. When the technique is applied well, the gas layer will cool down and contract, hence creating a better and safer work environment. If applied wrong however, too much steam will be produced and will only worsen the work scene.

1.1 Background of Gas Cooling

In the 80's, the fire service in Scandinavia introduced trainings with the use of Flashover Containers [1]. It is important to note that the training in these containers does not involve flashover but rollover (or flameover) [2]. Within the fire service, these terms are often mixed and treated the as the same [3]. The ISO definition for flashover is as follows [4]:

The rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure.

Rollover however, is defined as the ignition of unburned fire gases that are built up in the upper layer [5]. This ignition often produces the required radiation for a flashover and often precedes a flashover, hence the confusion within the fire service [3].

The goal of the flashover container was to teach firefighters about the fire dynamics and to show that a fire is not limited to the surfaces that are burning. It was thus more focused on rollover rather than flashover. In between the different sessions, the rollover was extinguished by the use of water to allow a next training session [1]. Because the dimensions were rather small (approximately 3m x2.4m x2.4m for the fire room and 6m x2.4m x2.4m for the observer room [6]) and the fuel load was rather small, short pulses appeared to be sufficient to cool down the flames and gases [1].

Since this container was too small to experiment with different suppression techniques, a larger container was developed for a more realistic nozzle training [1]. Throughout the years fire instructors realized that applying a small volumes of water with fine droplets was an efficient way of cooling the gaseous upper layer which leads to a safer working environment [7]. It is important that as much water as possible goes through the gas layer and does not touch the walls. This latter creates steam with a reduced gas cooling efficiency and can can worsen the visibility [8].

Figure 1 - Suppression of the burning gas layer performed in the extinguishing training containers at MSB Revinge. The gas cooling technique can also be used to suppress a rollover. Picture by Stefan Svensson

Several fire brigades such as in as Belgium [9], The United Kingdom [7], Central Whidbey Island [10], The Netherlands [8], Australia and Sweden [9] have implemented the pulsing gas cooling in their tactic assets and some are experimenting further with it. The most known technique that implements gas cooling is known as the 3D technique [11]. This 3D technique covers nozzle techniques which combine a fire suppression of both the burning fuel surfaces as the gaseous layer.

Since there are drawbacks when applied wrongly, many fire brigades in the USA [12] are reluctant to this method of handling the smoke layer. More research could bring convincement to reluctant brigades but also create more efficient equipment or techniques to deal with gas cooling.

The strong advantage of gas cooling opposed to other methods of dealing with the hot gas layer is the fact that a hose line is already at hands of the interior firefighting team. Unexpected rapid fire progression can in many cases be caused because of hot smoke gases [2]. Mastering the technique of gas cooling can save one from any of these surprises…

1.2 Objectives

The purpose of this work is to experimentally investigate different parameters that affect gas cooling. The most important parameters that were studied were the flow rate, droplet size, application time and spray pattern. The primary objective is to perform a comparative study with different nozzles and altering the previous discussed parameters. This research focuses on what happens to the smoke gases after applying the gas cooling.

Secondly the theoretical cooling efficiency shall be compared to the experimental results. A last objective is to look at secondary effects caused by gas cooling such as a contraction of the smoke layer and the buffer time between the cooling and the reheating towards the original temperatures before water was applied.

1.3 Methodology

This work was started with a background study on how the techniques are performed within the fire service. Questions such as how, when and why gas cooling is applied were handled.

This background check was then followed up with a thorough literature study. The scientific reasons to why this technique is applied were sought and treated in depth. Different aspects that might affect the process were then summed up in order to know which parameters can be studied through experiments.

The experiments were performed in a lab to allow a better consistency and exclude exterior interferences of wind, humidity and temperatures. A half scaled ISO 9705 room was chosen for the experimental setup.

Calculations and FDS simulations were performed to find the ideal conditions and requirements to perform this research.

1.4 Limitations

These experiments were limited to a half scaled ISO-room. In this work, 4 different nozzles were used to alter different parameters that may affect gas cooling. The application of water on the thermocouples may give false readings so the placement of the thermocouple trees was narrowed to places were the water spray was limited. Because the flames can introduce interference with the thermocouples, the fire seat has been shielded and placed in a room adjacent to the scaled ISO-room.

2 Literature study

2.1 Gas cooling in the fire service

During the early 1980s two Swedish fire chiefs (Mats Rosander & Krister Giselsson) introduced new nozzle techniques aimed at fire gas cooling and contraction [7] [11]. In the 2000s, fire officers Paul Grimwood, Ed Hartin, John McDonough and Shan Raffel implemented research to develop better firefighting tacticts [11]. They developed the 3D technique which no longer focuses suppression on the burning fuel surfaces alone. Instead of seeing a fire as a 2 dimensional problem, they emphasized these techniques on the fully involved enclosure, including the fire gases above the fuel, hence the name 3D technique.

The 3D pulsing technique is considered as the method to deal with hot fire gases. Cooling these gases would result in a reduced risk for flashover and rollover, reducing the heat stress and better visibility due to the contraction of cooled gases. In order to cool this layer down, short bursts of water are sufficient to bring the temperatures of the gas layer down to a safe level. The reason behind the different bursts is that the volume of the water can be kept to a low level, preventing excessive use and the creation of too much steam. Long pulses of water are generally used to penetrate the fire.

Grimwood et al. describe that the results are at its best using a fog nozzle at a cone angle of about 60° and that the nozzle should be aimed towards the gaseous layer at an angle of roughly 45° with the floor [11]. This latter results in an optimal reach and height. Grimwood suggests a flow of 2.51 lpm/m^3 of smoke in pre-flashover conditions [11], based on the research of the optimal water use by Särdqvist [13]. Based on studies on the interaction of water-sprays with a burning gas layer by Alageel [14], a droplet size of 300 μm seems to deliver the most effective cooling. A smaller droplet size vaporizes too fast and results in a small reach whereas a larger droplet vaporizes too slow and does not allow fast cooling when required.

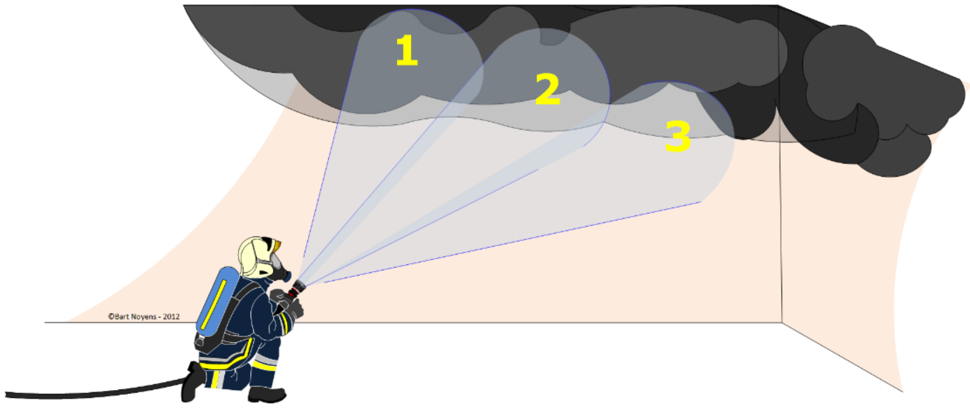

Figure 2 - Short pulses are used to cool the gaseous layer. The reference pulse should be angled 45° with the floor (number 2). Changing the angle vertically allows the spray to reach further as well as extra protection above the head. (Image by Bart Noyens)

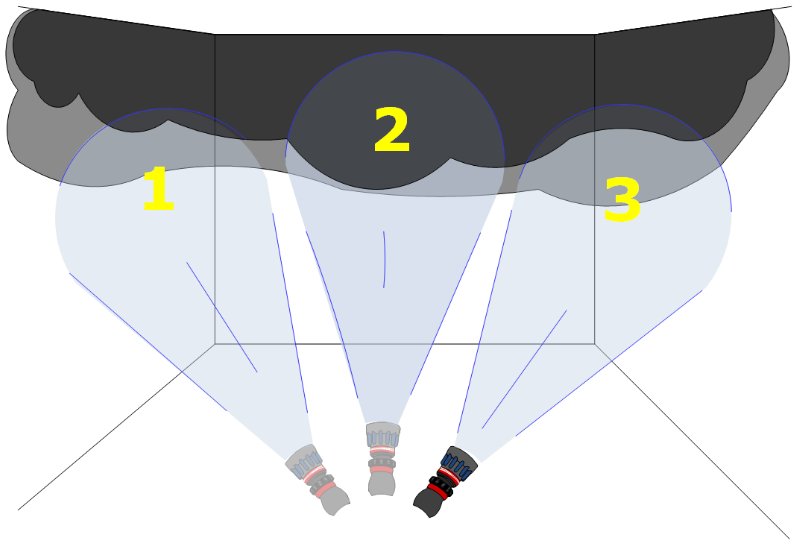

Figure 3 - The pulses should be spread horizontally over the width. (Image by Bart Noyens)

2.2 Cooling efficiency of water

For years, water has been used as an extinguishing agent. It is the most accessible and cheapest extinguishing agent available [13]. It is particularly an interesting resource for the fire service as it occurs naturally in both its solid, liquid and gaseous states. Because water has a low boiling point compared to the general temperatures in a fire, it evaporates easily and allows to cool its surroundings with a high efficiency.

	Water	Smoke/hot air	
Freezing point	0	Not of interest (N/I)	°C
Boiling point	100	N/I	°C
Specific heat capacity of solid form	2.09	N/I	kJ/kgK
Specific heat capacity of liquid at 15 °C	4.18	N/I	kJ/kgK
Specific heat capacity of gas phase at 700 °C	2.0	1.04	kJ/kgK
Fusion heat	334	N/I	kJ/kg
Latent heat of vaporization	2260	N/I	kJ/kg

Table 1 - Water properties of interest for gas cooling [13]

The cooling of the hot fire gases is based on the heat transfer caused by water being at a colder temperature. When two items at different temperatures are brought in contact, a heat transfer occurs driven by the need of a thermal balance [15]. Energy of the warmer system will be transferred to the cooler one, resulting in cooling of the first and heating of the latter.

The temperature of this thermal balance is not simply the average temperature of the two. It also depends on the heat capacity and mass of the entities. The results of a heat change can result in a temperature change:

$$Q = m \cdot c_p \cdot \Delta T \qquad \text{(Eq. 1)}$$

Q [kJ] Energy, in this case heat
m [kg] Mass
C_p [kJ/kgK]
ΔT [K] Temperature difference

The only material dependent parameter in this equation is the specific heat capacity. Smoke can generally be considered as hot air, which has a heat capacity of 1.040 kJ/kgK [16]. This is about 4 times less than that of liquid water. This means that if an equal amount of water and smoke exchange heat, smoke will result in a temperature difference that is 4 times higher than that of water. Likewise for steam or ice, this temperature difference would be twice as large for smoke (Table 1).

At 100°C, water will use any heat that it receives to vaporize rather than increasing its temperature any further. The vaporization process requires a lot of energy. The energy that is required to fully evaporate a certain amount of water can be described as:

$$Q = m \cdot L_v \qquad \text{(Eq. 2)}$$

L_v [kJ/kg] Latent heat of vaporization

If this energy were to be taken from a same mass of smoke, the latter could theoretically cool down by 2260°C. Since the gas cooling technique is used for advancing in pre-flashover conditions, temperature changes of 300-500°C are averagely needed. This means that small volumes of water can create relatively large temperature drops.

After the water is vaporized, the steam can continue to heat up and rise in temperature. The thermal equation of water can thus be written as the combination of heating water, vaporization and heating steam:

$$Q_{water} = \underbrace{m_w \cdot c_{p,w} \cdot (100 - T_w)}_{Water\ heating} + \underbrace{m_w \cdot L_v}_{Vaporization} + \underbrace{m_w \cdot c_{p,steam} \cdot (T_e - 100)}_{Steam\ heating} \quad \text{(Eq. 3)}$$

T_e [°C] End temperature

As mentioned earlier, the energy that water will be using to heat up and vaporize will come from the hot gases. Due to conservation of energy, this heat exchange will be identical. Equating these two and combining the thermal equations allows to find how much water is needed to bring a hot gaseous volume down to a desired temperature.

$$Q_{water} = Q_{smoke} \quad \text{(Eq. 4)}$$

$$m_w = \frac{m_{smoke} \cdot c_{p,smoke} \cdot (T_e - T_{smoke})}{c_{p,w} \cdot (100 - T_w) + L_v + \cdot\, c_{p,steam} \cdot (T_e - 100)} \quad \text{(Eq. 5)}$$

2.3 Volumetric consequences of changing gas temperatures

The behavior of a gas can be described by the ideal gas law:

$$PV = nRT \quad \text{(Eq. 6)}$$

P [Pa] Pressure
V [m^3] Volume
n [mol] Number of gas molecules
R [J/molK] General gas constant; 8,31
T [K] Temperature

If the pressure and gas molecules are kept constant, this equation can be rewritten as Charles' Law. This law describes a linear correlation between absolute temperature and volume.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{(Eq. 7)}$$

If the smoke gases are examined in isolation from the water, a temperature drop of the hot gases would result in a contraction of the volume.

Since the vaporization of water is the main contributor to the gas cooling, steam gets introduced to the gas layer. Water that vaporizes to steam will expand. Since steam is a gas, the ideal gas law can be used to calculate how much the water will expand because of the phase change. The quantity of molecules in Eq. 6 can be expressed as the mass divided by the molecular weight:

$$PV = \frac{m}{M}RT \qquad \text{(Eq. 8)}$$

m [g] Mass
M [g/mol] Molecular weight; 18 for water

Calculating this for 1kg of water at 100°C under atmospheric pressure results in a gaseous volume of 1700l. If this steam would heat even further to 200°C it would take a volume of 2156l. This is a tremendous volume increase so even though a small volume of water is needed for the cooling, the total gas layer volume might expand.

Knowing how these gases individually act makes it easier to comprehend how they work together. Both before and after the application of water, the gaseous state can be described by the ideal gas law. Although the pressure is assumed to be roughly a constant, the molecular composition of the gas layer will change. The combination of the two gas layer states can be written as followed [13]:

$$\frac{V_1}{V_0} = \frac{n_1 T_1}{n_0 T_0} \qquad \text{(Eq. 9)}$$

V [m3] volume
n [mol] number of gas molecules
T [K] temperature
0 hot gases
1 steam + hot gases

If the water takes heat from the hot gases, the gas layer will contract due to the cooling. However, if the water vaporizes due to the heat of the walls or ceiling, the smoke gases do not cool and thus keep the same volume whilst new steam is added to the layer and thus creating a larger total gas volume. This means that the volume of the gaseous layer after the application of water depends on how water receives heat. In order to find a relationship with the volume equation, Särdqvist expresses the thermal equation for the gaseous phase of the cooling [13]. He also includes an efficiency factor that determines whether the water is heated by the gases or the walls:

$$n_0 C_{p,g}(T_0 - T_1) = (n_1 - n_0)(bM_w L_{v,w} + C_{p,w}(T_1 - 373)) \qquad \text{(Eq. 10)}$$

$C_{p,g}$ [J/molK] Specific heat capacity of smoke; 33.2 at 1000K
b proportion of water that vaporizes due to the smoke
M_w [g/mol] molecular weight of water; 18
$L_{v,w}$ [J/g] Latent heat of water; 2260
$C_{p,w}$ [g/mol] Specific heat capacity of steam; 41.2 at 1000K

Combining this with the volume relation from before results in:

$$\frac{V_1}{V_0} = (\frac{C_{p,g}(T_0 - T_1)}{bM_w L_{v,w} + C_{p,2}(T_1 - 373)} + 1)\frac{T_1}{T_2} \qquad \text{(Eq. 11)}$$

2.4 Droplet size

Applying water in the hot gas layer will induce a thermodynamic relation and yield a heat exchange between the water and the gases. It was mentioned before that only a relative small amount of water is required for cooling a larger quantity of smoke gases. These conclusions were drawn out of both the heat capacity of water and hot air as well as the large latent heat of vaporization of water. However, the time and mechanics to acquire this heat exchange has not been included in this explanation.

Due to gravity, water will remain in the gas layer only for a short amount of time. The heat exchange, which is the driving force for the vaporization, is caused by surface contact between the water and smoke. The water will receive more heat and evaporate faster if more of its surface is exposed to the smoke.

The droplet size is the factor which determines to what extent the water will be vaporized and how far it will travel [13]. Very small droplets evaporate faster than droplets with a larger diameter. They have a larger surface to volume ratio hence heat up and evaporate fasters [17]. Additionally, small droplets have a lower inertia than bigger droplets and are so more prone to air resistance. This results in a smaller reach and lower falling velocity. Bigger droplets on the other hand might reach further but will require more time to vaporize and might hit the floor before they do.

The time for a droplet to completely vaporize can be expressed by a set of properties of the droplet and the surrounding gas. However, the equation differs for different ranges of droplet sizes.

$$t_{life} = \frac{d_0^2 L_v \rho}{8\,k\Delta\mathrm{T}} \qquad (d_0 < 0.1mm) \qquad \text{(Eq. 12)}$$

$$t_{life} = \frac{d_0 L_v \rho}{2kC\Delta\mathrm{T}} \qquad (d_0 > 0.5mm) \qquad \text{(Eq. 13)}$$

$$With: C = \frac{Nu\sqrt{4 \cdot 10^3}}{\sqrt{vd}}$$

t_{life}	[s] Time before droplet has completely evaporated
d_0	[m] Initial droplet diameter
L_v	[J/kg] Latent heat of water; 2,260,000
ρ	[kg/m^3] Density; 1.2
k	[W/mK] Conductivity; 0.1
ΔT	[K] Temperature difference
Nu	Nusselt number

v Falling velocity (Table 3)

ΔT (°C)	100 (μm)	200 (μm)	300 (μm)	500 (μm)	1000 (μm)
200	0.8 s	1.6 s	2.4 s	4.0 s	8.0 s
300	0.533 s	1.06 s	1.6 s	2.66 s	5.33 s
400	0.4 s	0.8 s	1.2 s	2.0 s	4.0 s
600	0.26 s	0.52 s	0.78	1.3 s	2.6
800	0.2 s	0.4 s	0.6 s	1.0 s	2.0 s
1000	0.16 s	0.32 s	0.48 s	0.8 s	1.6 s

Table 2 - Variation of Lifetime of Droplets With Temperature

Another factor which will determine how long a droplet will remain in the gas layer is the falling velocity. A falling object will continue to accelerate until the forces of gravity and air resistance are in balance [13]. The velocity at which this occurs, known as the terminal velocity, depends on the droplet diameter. Table 3 shows the terminal falling velocity for droplets of several diameters.

Droplet diameter, d [mm]	Falling velocity, v [m/s]
0-0.1	$31 \cdot 10^6 \cdot d^2$
0.1-1	$4 \cdot 10^3 \cdot d$
1-4	$150 \cdot \sqrt{(d)}$

Table 3 - Approximate terminal velocity of water droplets falling freely at room temperature and atmospheric pressure (Herterich, 1960)

Combining the falling velocity with the vaporization time results in the falling length it traverses in a hot layer. The result of integrating the falling velocity over time gives the falling length:

$$l_{max} = 31 \cdot 10^6 \cdot \frac{d_0^2}{2} \cdot t_{life} \qquad (d_0 < 0.1mm) \tag{Eq. 14}$$

$$l_{max} = \frac{4 \cdot 10^3 d_0}{2} \cdot t_{life} \qquad (d_0 > 0.5mm) \tag{Eq. 15}$$

Figure 4 graphically illustrates the relationship between droplet diameter and fall length in hot smoke gases.

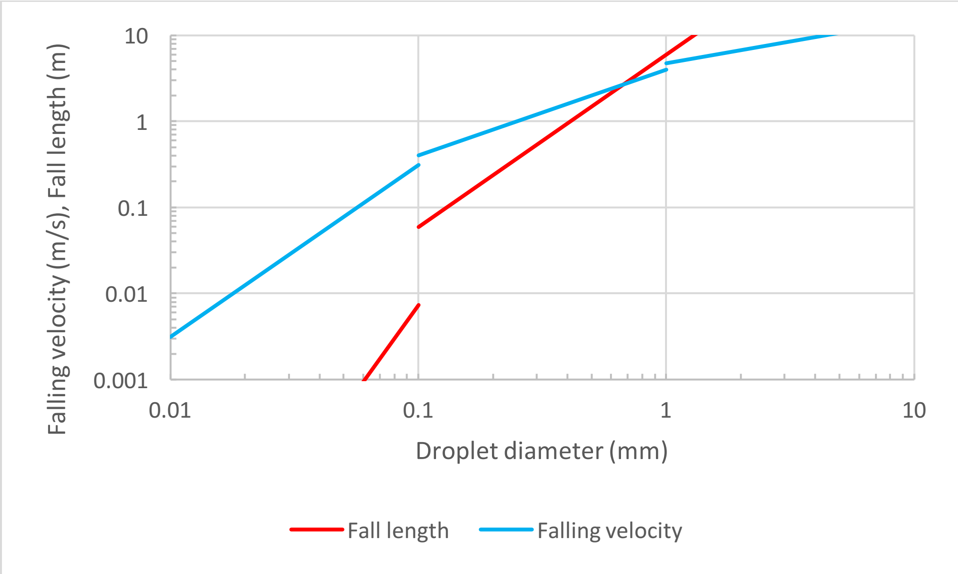

Figure 4 - Graph that shows the relation between droplet diameter and its fall length and falling terminal velocity. This graph is based on a gas temperature of 700°C, Thermal conductivity of 0.1W/mK and a C constant of 100

Knowing the fall length of droplets allows to give an estimate how long the droplets will survive in the gaseous layer. A droplet of 0.3mm for example will vaporize completely after falling for 0.53m in a gaseous layer of 700°C whereas droplets of 0.5mm needs to travel for 2m to completely evaporate.

Having nozzles that produce one single and exact droplet size is not realistic off course. Nozzles are classed by a mean or median droplet size. This mean or median droplet size represents the statistical mean or median of all droplets that are present. There are several ways of describing these values. The droplet distribution for the nozzles that were used in these experiments is the volume median diameter. This is the diameter of the droplet in a spray which has a smaller volume than half of all the droplets and larger than the other half [13].

2.5 Steam

As shown in section 2.2, water cools gases most efficiently by evaporation, which means that steam will arise in the atmosphere. Steam will inert the gas layer as it is not combustible [7]. This lowers the chances for igniting the gas layer. Because steam has a temperature of 100°C or higher, it can cause burn injuries. Although the turnout gear protects a firefighter against heat, moisture can be absorbed by it [18]. Water is a better conductor than air, so it imposes more threats for heat transfer opposed to air [18]. The heat can thus be conducted through the turnout gear and cause burn wounds to the firefighter [19].

Water has a lower molecular weight than air so it will rise above air due to buoyancy. However, depending on how fast the droplets will evaporate, it might transform into steam along its way and impacting the nozzle operator due to its expansion. Turbulence can also cause the steam to descend at the height of the nozzle operator.

2.6 Leidenfrost effect

Previous sections indicated that gas cooling occurs due to the heat transfer of hot gases to water. This is most effective if this heat can be used to evaporate water since the heat used for this phase change results in a high cooling of the hot gases. If water gets this energy from somewhere else, the gases will not cool as much. The hot surfaces of the ISO room could also provide this heat.

The efficiency of the evaporation of a droplet on a surface does not continuously increase together with the surface temperature. There is an upper limit for the surface temperature, above which the heat transfer from surface to liquid is obstructed [13]. At this upper limit, the Leidenfrost point, the surface is so hot that the first contact of the droplet results in a partial vaporization and creates a vapor barrier between the surface and the droplet [20].

The Leidenfost temperature of a surface depends on the liquid that is applied, the surface material and finishing, the pressure [21] and porousness [22]. The theoretical model of Gottfried et al. showed that the Leidenfrost temperature for water on a metal plate lied between 250°C to 310°C [21] whilst experiments by Bernardin et al. showed a range of 170°C to 280°C [20].

It is important to know that this temperature is based on experiments on a horizontal plate where water was applied from above. Gas cooling is performed by applying water from the lower regions aimed at the ceiling. It is unsure whether this effect occurs at the ceiling or a vertical wall. As steam is lighter than air, it might induce a similar barrier as it does on the ground. This barrier could bounce of newly applied droplets. For the same reason it might be less likely for this effect to occur as the gases would rise to the ceiling hence droplets can always come in contact with the wall.

3 Experimental preparations and calculations

3.1 Room dimensions

3.1.1 Scaled ISO room

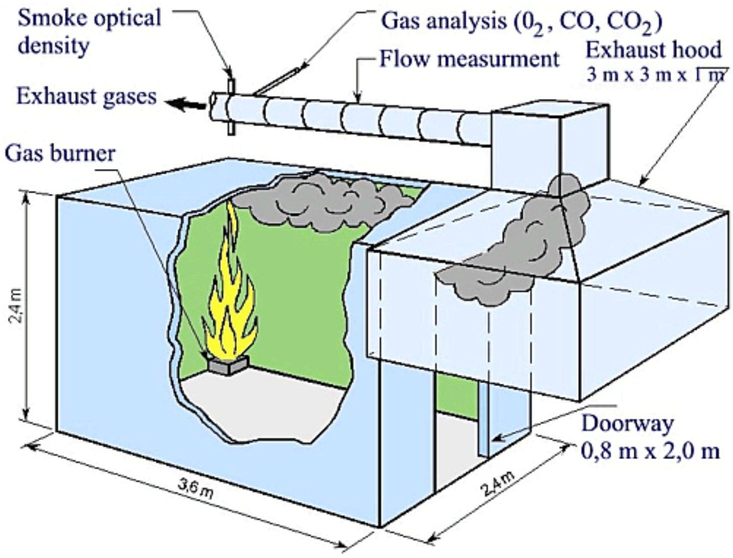

Figure 5 - ISO 9705 room [23]

The experiments were conducted in a half scaled ISO 9705 room. Everything was scaled geometrically with the exception of the opening. The dimensions of the room are 1.8 m x 1.2 m x 1.2 m. The opening was scaled by the opening factor [24] which allows a better transition for ventilation induced effects to a full scaled room. Scaling by the opening factor implies that this factor needs to be the same for both the full scaled as the half scaled room:

$$\frac{A_{o,1}\sqrt{H_{o,1}}}{A_{t,1}} = \frac{A_{o,2}\sqrt{H_{o,2}}}{A_{t,2}} \quad \text{(Eq. 16)}$$

A_o Area of opening
H_o Height of opening
A_t Total enclosure area (area of opening included)

Assuming that the width of the opening takes 40% of the height, the dimensions for the scaled door can be found:

Opening dimension ½ scale	Length (m)
Height, $H_{o,2}$	0.87
Width, $W_{o,2}$	0.35

Table 4 - Door dimensions ½-scale ISO room

3.1.2 Shielding fire

In this work it was chosen to focus solely on gas cooling itself and to try and isolate this from the fire. Flames could have interfered with parameters that are being investigated. First of all, the temperature readings by the thermocouples would have heavily been influenced by the radiation of the flames. The flame temperature would have also been responsible for a substantial amount of evaporation, leaving it very hard to know which part of the water-spray evaporated due to the gases or the flames. Cooling the flames would also result in less radiation and thus a different amount of plume entrainment, which would result in a different mass flow all the time. For these reasons, a separate room was built adjacent to the ISO room where the burner could be placed.

The fire room was constructed with the remaining parts of the Cembrit Multi Force boards [25]. This resulted in dimensions of 762 mm x 1200 mm x 1200 mm.

	Value for 9mm thick plate	Unit
Density	1150	kg/m^3
Water absorption	32	%
Moisture content	2-4	%
Thermal conductivity	0.25	W/mK
Coefficient of thermal expansion	7x10^{-6}	m/m°C
Specific heat	0.9	kJ/kg°C
Temperature range maximum	150	°C

Table 5 - Properties of Cembrit Multi Force boards

The geometry of the opening from the fire room to the ISO room was based on the same opening factor as the exterior opening of the ISO-room. This allows a similar ventilation pattern for the opening in the fire room and the opening from the ISO room to the exterior environment. Applying the Eq. 16 to the dimensions of the fire room gives the following door dimensions:

Opening dimensions fire room	Length (m)
Height, $H_{o,3}$	0.62
Width, $W_{o,3}$	0.25

Table 6 - Door dimensions fire room

Throughout the rest of this report, the door from fire room to ISO room shall be referred as the “fire opening” and the opening from the ISO room to the outside will be referred as the “exterior opening”.

3.2 FDS simulation

A FDS simulation was used to predict the required HRR to use for the experiments but also to give a prediction on the gas layer volume. The aim for the experiment was to get gas temperatures within the vicinity of 200°C. To find these results, a simulation with a HRR of 100 kW was required. However, during the test burns after building the room, it was observed that a HRR higher than 90 kW might damage the experimental setup.

A simulation for a HRR of 90 kW, using a propane burner has been made. The fire was modeled 100 mm x 100 mm and was raised 100 mm from the floor. A steady state was reached after about 70s. The smoke layer in the ISO-room descended to about 40 cm from the floor. The average upper layer temperature has also been modeled and is predicted to be around 150°C.

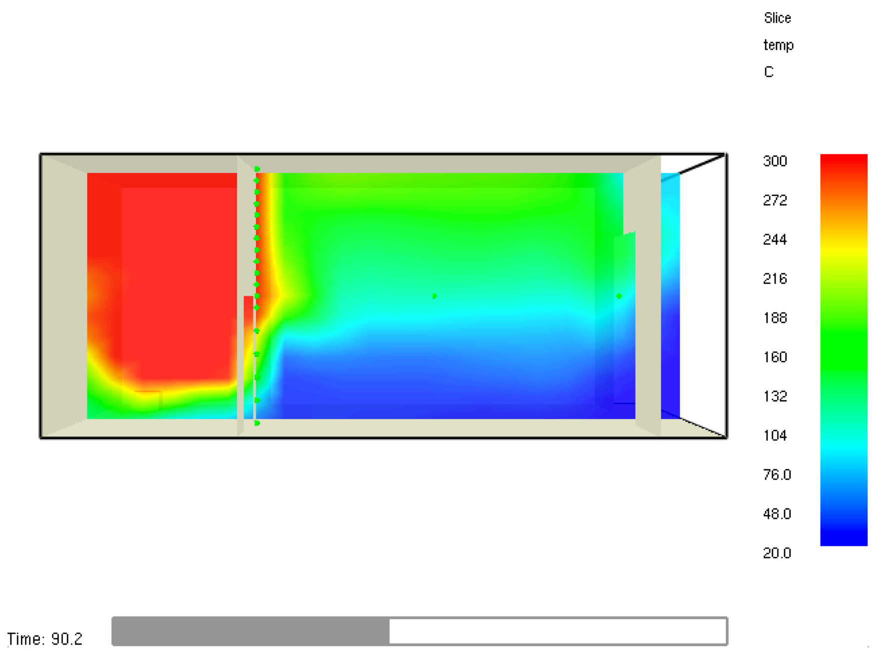

Figure 6 - Temperature distribution at the center plane for a 90 kW FDS simulation

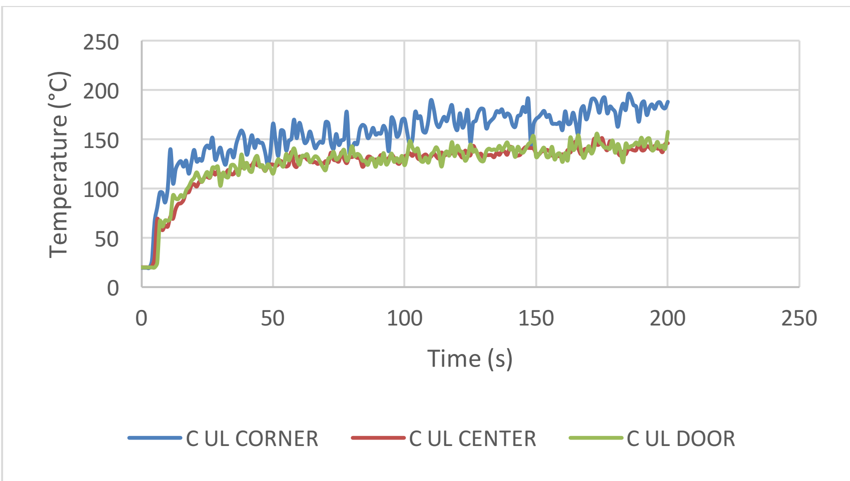

Figure 7 - Average upper layer temperature integrated at the corner close to the fire opening, the center and at the exterior opening.

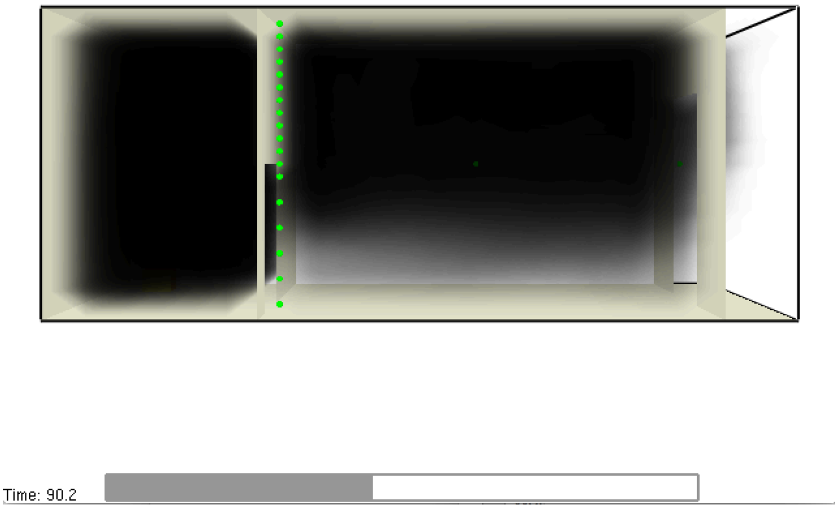

Figure 8 - Smoke production for a 90 kW FDS simulation

The water flow that needs to be applied to cool the gases is dependent on the incoming fire gases from the fire room. The mass flow through the fire opening as well as the temperature distribution has been measured. Figure 9 shows that the average mass flow is 0.62 kg/s whereas the temperature distribution can be seen in the graph in Figure 10. The entering temperatures lie between 180°C and 280°C. A good average estimate would be 230°C.

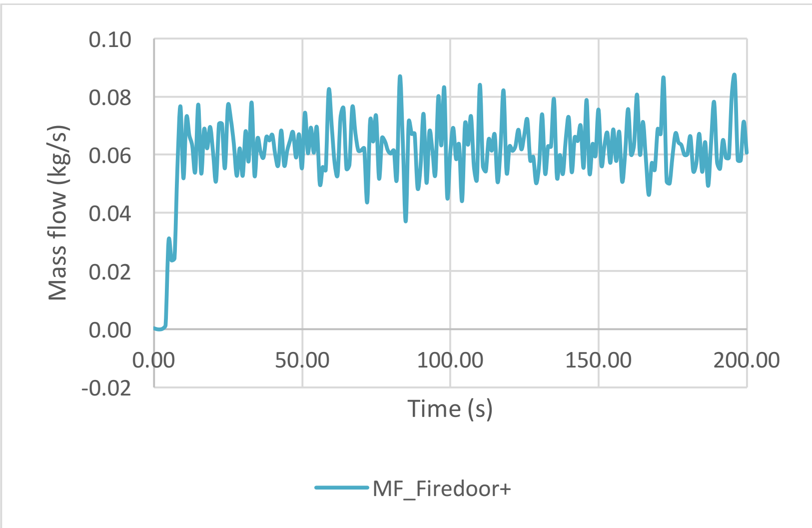

Figure 9 - Mass flow of fire gases entering the ISO room

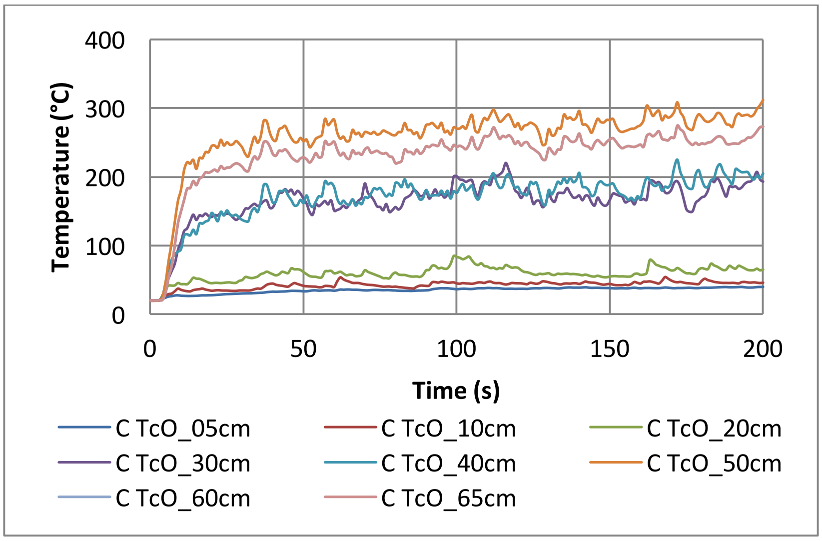

Figure 10 - Temperatures of fire gases entering ISO-room. The temperatures lie between 180°C and 270°

3.3 Flow rates

In the literature section Eq. 5 presented how the required amount of water can be found. This is mainly depending on the initial fire gas temperature and the desired ending state. Since the FDS simulation predicted an average gas temperature of 150°C, the desired end temperature was chosen at 100°C. Lower than this would make less sense since the biggest cooling contribution of water comes from its vaporizing effect. Due to this end temperature, the heating factor of steam in Eq. 5 is reduced to 0.

$$m_w = \frac{m_{smoke} \cdot c_{p,smoke} \cdot (T_e - T_{smoke})}{c_{p,w} \cdot (100 - T_w) + L_v} \qquad \text{(Eq. 17)}$$

2 factors need to be taken into account for the gas cooling.

1. The (steady state) gaseous volume that is present in the ISO room [FIXED VOLUME]
2. The entering flow of fire gases from the [VOLUME FLOW]

Using the average gas layer temperature and gas layer height from the FDS simulation, an estimate can be found for the needed water to cool the fixed volume. Similarly, the same can be done for the mass flow that was modeled by FDS accompanied by the temperatures that were measured in the opening.

	Required water (ml)		
Gas temperature (°C) / Gas layer depth (m)	150	300	500
0.6	21	62	91
0.8	28	82	122
1	35	103	152

Table 7 - Theoretically required volume of water for "fixed" gaseous volume in steady state. Given for several gas layer temperatures and gas layer depths.

Mass flow (m/s) \ Gas temperature (°C)	Required water flow (lpm)		
	150	300	500
0.062	0.07	0.3	0.6
0.1	0.12	0.5	0.9
0.2	0.2	0.9	1.9

Table 8 - Theoretically required flow of water to compensate inflowing fire gases. Given for several mass flows and temperatures

3.4 Effects on the gas layer depth

The effects of the volume change have been discussed in the literature section and can be calculated by Eq. 11:

$$\frac{V_1}{V_0} = \left(\frac{C_{p,g}(T_0 - T_1)}{bM_w L_{v,w} + C_{p,2}(T_1 - 373)} + 1\right)\frac{T_1}{T_2} \qquad \text{(Eq. 11)}$$

As mentioned earlier, the volume of the gas layer might increase if the steam production dominates the contraction of the smoke gas cooling. A gas contraction will only occur if the smoke gives its heat away. If the water gets heat from another source, it will evaporate and create steam without cooling the smoke. In Eq. 11, “b” stands for the amount of water that evaporates due to the hot gases. When b gets lower than 0.3, the steam production generally dominates the gas contraction.

Table 9 gives some examples how the gas layer would reduce in volume for different temperatures and for different vaporization efficiencies. The negative values represent a layer expansion rather than a contraction.

b \ Temperature (°C)	Volume reduction (%)		
	150	300	500
1	8.2	24.3	36
0.75	7	20.8	30.7
0.6	5.8	17.2	25.5
0.5	4.6	13.7	20.2
0.35	1.5	4.5	6.7
0.3	-0.17	-0.5	-0.76
0.2	-6.17	-18.22	-27

Table 9 - Reduction of the gas layer volume for various temperatures and vaporization efficiencies

A gas temperature of 150°C was predicted which results in a volume reduction of maximum 8.2%. The width and length of the gas layer stay the same so the reduction can go integrally to the gas layer depth. For a gas layer of 80cm, this means a reduction of 7cm. This means that if all the water gets vaporized by the hot gases, only 7 cm would become clearer. Such a difference is very hard to see, especially if gases with low soot concentrations like propane are used. For higher temperatures or bigger volumes, the change in layer height would be noticeable.

3.5 Nozzle choice

A selection of four nozzles was made. The nozzle choice was based on different parameters such as droplet size, flow, and spray pattern. Both the droplet size and flow for a nozzle are dependent on the operating pressure. Table 10 shows how other parameters affect droplet size [26].

Parameter	Droplet size
Pressure increase	Decrease
Viscosity increase	Increase
Fluid temperature increase	Decrease
Surface tension increase	Increase

Table 10 - Droplet size parameters

All nozzles were based on a pressure range of 1 to 7 bar although 4 bar was the maximum pressure that was used during the experiments. The spray angle was kept in the same order for all the nozzles. Table 11 shows the different nozzles that were used with their different parameters. All nozzles were delivered from Spraying Systems CO® [26].

Type	Capacity size[1]	Pressure (bar)	1	1.5	2	3	4
Fulljet full cone jet	25	Flow rate (l/min)	11.5	13.5	15.4	18.6	21
		Median droplet diameter (μm)	3700	3000	2750	2500	2300
		Angle (°)	65	67	66	65	64
Whirljet hollow cone	10	Flow rate (l/min)	4.6	5.6	6.4	7.9	9.1
		Median droplet diameter (μm)	640	600	580	560	500
		Angle (°)	69	72	72	73	74
Whirljet hollow cone	25	Flow rate (l/min)	11.4	14	16.1	19.7	23
		Median droplet diameter (μm)	1020	980	920	860	800
		Angle (°)	67	70	71	72	73
Fogjet hydraulic mist	22	Flow rate (l/min)		8	8.9	10.1	12.4
		Median droplet diameter (μm)				300	280

Table 11 - Different nozzles and their characteristics

3.5.1 Two Hollow cone nozzles

A hollow cone nozzle produces a spray pattern in the form of a hollow cone, as its name implies. If the spray were to be applied vertically from the ceiling to the ground, then ideally the impact area with the floor would be a ring.

Two hollow cone nozzles were chosen. The biggest one was used as a reference nozzle. All other nozzles have a similar flow to this one. The smaller hollow cone nozzle was chosen for its smaller droplet production.



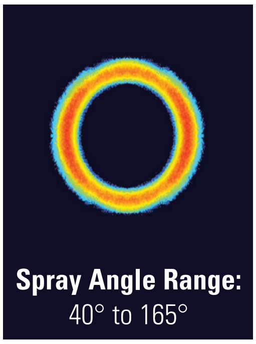

Figure 11 - Hollow cone nozzle (Spraying Systems CO®). The two nozzles at the right were used.

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[1] The capacity size is the id number for a certain nozzle type of Spraying Systems CO®. Combined with the desire thread and material, the order can be placed. More information on http://www.spray.com.

3.5.2 One full cone nozzles

Like the hollow cone nozzle, the name implies its spray pattern. A vertical application would ideally result in a circle with more water impacting in the center. The hollow cone nozzle has a similar flow to the larger hollow cone nozzle but produces substantial bigger droplets. A full cone spray pattern does provide more droplets into the gas layer.

Figure 12 - Full cone nozzle (Spraying Systems CO®)

3.5.3 One hydraulic atomized fine mist nozzle

The hydraulic atomized fine mist nozzle produces the smallest droplets. Atomization stands for the production of very small droplets and hydraulic means that liquid pressure alone is sufficient.

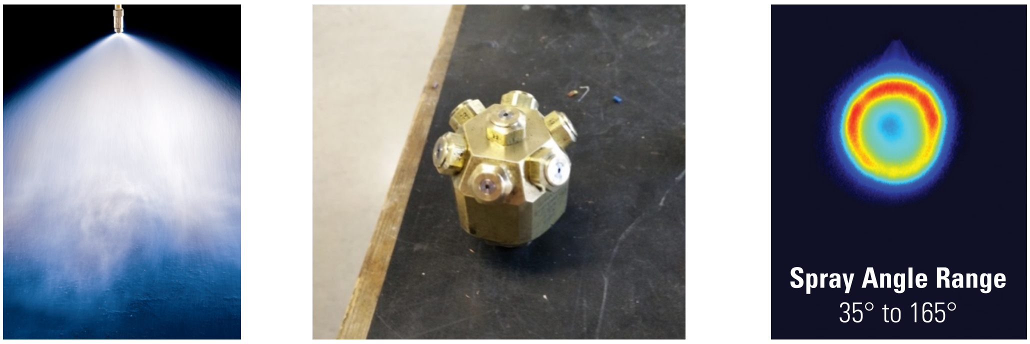

Figure 13 - Fine mist nozzle (Spraying Systems CO®)

3.6 Experimental setup

3.6.1 Room setup and measuring apparatuses

The experimental room was made out of Cembrit Multi Force boards [25]. An extra casing was made around the fire room to allow expansions of the inner walls without having too much leakages.

Figure 14 - Back side of experimental room. An extra casing allows the first layer of boards to expand due to the heat. The outer boards are used to contain the smoke. A hatch is used to reach the burner for ignition.

The burner was positioned at a quarter of the width on the opposing side of the door. The center of this door is also located at a quarter of the width. Throughout all of the experiments, propane was used as fuel. The advantage of having a gaseous fuel is control and consistency. Using a gas allows easy starting and stopping of the fuel. A sootier fuel would show better results for the volume change of the gas layer but the consistency of the cooling remains the primary objective.

Throughout all the experiments, a similar fire was used by using the same flow rate. This flow rate was set at 64 l/min which led to a HRR of 90 kW.

Two thermocouple trees were added to measure the temperatures in the room. The first one was placed in the corner next to the exit, a second one in the back corner at the opposing side of the fire door. Each tree consisted of 10 thermocouples. Three additional thermocouples were placed at the ceiling in the central vertical plane. They were located at 0.45m, 0.9m and 1.35m away from the exterior opening. These were added to see the different effects throughout the length of the room. One more thermocouple was hung at the ceiling of the fire room to know when has sufficiently cooled down to start a next experiment.

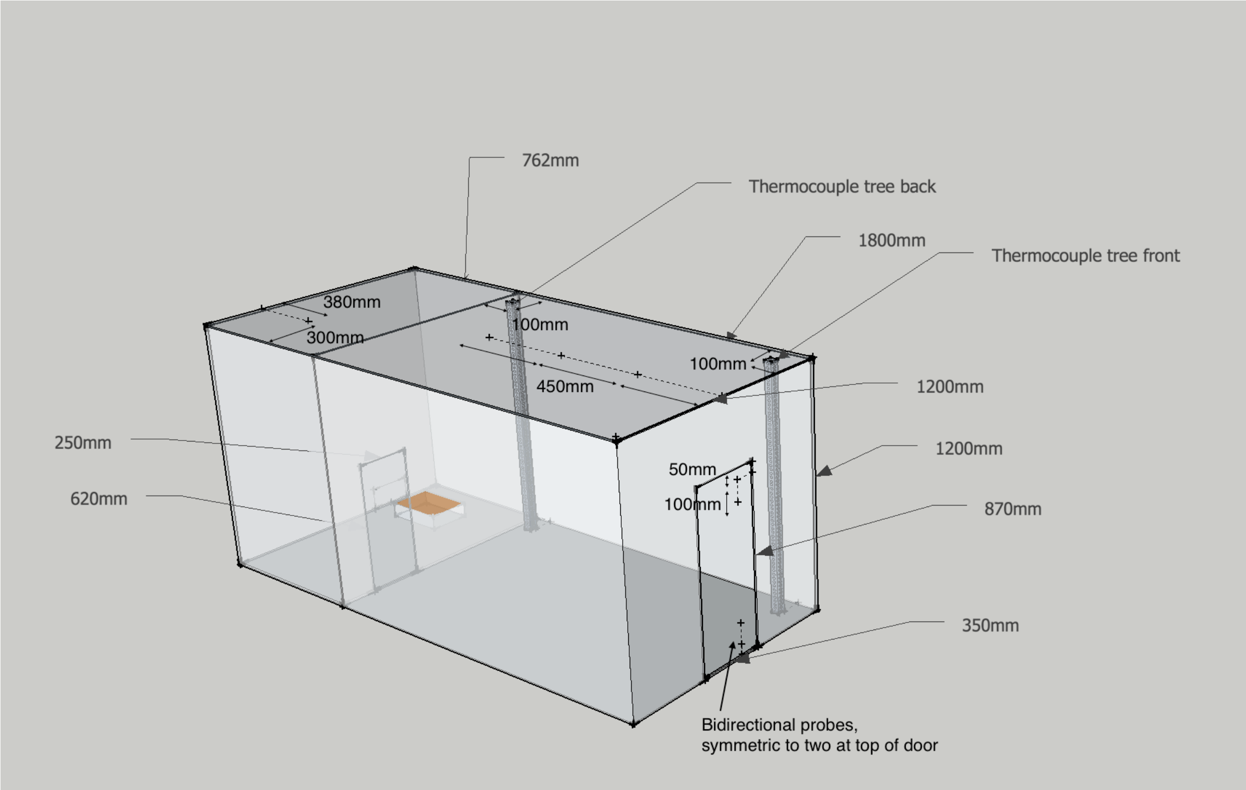

Figure 15 - Room configuration. ½-scale ISO room on the right hand side. Fire room on the left hand side. Thermocouple trees are shown in the corners. The points on the ceiling are the extra thermocouples as points of interest. The burner is shown in orange.

For collecting the data, a Datataker DT85 was used. Because of the limited channels, only two thermocouple trees were used with each 10 beads. They were not distributed evenly over the height but rather condensed in the center of the gas layer.

Since the gas layer contraction was predicted not to be very visible, resort was sought to velocity measurements of the gases at the opening. A contraction of a volume would result in a pressure drop and should reduce the flow of outgoing gases and increase the inflowing air track. Vice versa, if any of these velocity decreases are seen after the water is applied, this could imply a volume change. 4 bidirectional probes were placed in the exterior opening. They were placed in pairs respectively 5 and 15 cm from the top and bottom of the opening. In the datataker they were numbered in ascending order from bottom to top. Bidirectional probe 1 is the closest to the bottom whilst number 4 is the closest to the top.

Figure 16 - Distribution of the bidirectional probes

3.6.2 Nozzle setup

A stand was constructed to hold the nozzle in a fixed position of 45° with the floor. The height of the nozzle was placed at half the height of the door replicating a crouched firefighter. The nozzle was connected to a small water tank where the liquid was brought under pressure by air. The pressure in the tank was adjustable. A solenoid valve allows the passage and shutoff of the water feed. Since several tests desired the application of water in bursts, a timer was used which allows to open and close the solenoid for an adjustable time set (Figure 18).

Figure 17 - Nozzle setup positioned at the middle of the door opening.

Figure 18 - Timer used to operate a solenoid valve that controls the water feed to the nozzle. The On-state allows signals up to increments as low as 0.05s. The off-state has increments in the order of 1s.

3.7 Experimental procedure

Every set of experiments went through a same set of procedures. Following steps were followed in chronological order:

1. **Set desired pressure**
   The pressure of the water tank was regulated in order to determine the droplet size. With increasing pressure, the droplet diameter decreases.
2. **Set desired volume of one burst by adjusting the on-state of the timer**
   Since the flow rate also increases with the pressure, a timer was used in order to regulate the volume of water. This timer closes the valve as soon as the desired volume has passed.
3. **Check the reach and height accompanied with the settings**
   Another consequence of raising the pressure is the increase of range and height. These are noted down in order to know how much water reaches the walls and ceiling. They are measured by placing the nozzle outside and using a ruler.
4. **Define the amount of burst and the interval in between**
   Depending on the total volume that is desired for a test, the amount of bursts should be decided. The off-state of the timer was used to set the amount of time in between each burst.
5. **Put everything in place**
6. **Ignite the burner**
7. **Pre-burn for 90s**
8. **Operate the nozzle**
   This is done by manually activating the timer. At the same time, a switch gives a 12DC volt signal to the logger to see in the data when the water is applied.
9. **After last burst, let burner continue for 5 more seconds**
   This allows to see what happens after the water is applied
10. **Cool down until the fire room reaches 75°C**

Continuing the burn for some additional seconds allows a realistic approach whilst also creating the opportunity to whiteness what happens after the gas cooling.

4 Experimental results

Table 12 shows a list of all the tests that were performed. This section shows the data that will be treated in the discussion section. All other data can be found in the appendices.

In this table the used nozzle can be found together with the water pressure that was used. As mentioned before, the pressure affects the flow, droplet size, reach and height of the flow. In the first tests, water was applied in different bursts. In order to maintain a comparable flow, a fixed volume was chosen to be applied at every burst and spreading it over an equal time. This removes one of the parameter alternations and allow a better comparison on the other factors. The on-time was generally a lot lower than the off-time of the valve which justifies neglecting this time.

In the first tests, the volume of every burst was aimed at a similar volume to what is theoretically required to cool the steady state volume of gases. At higher pressures, the opening and closing time of the solenoid dominated the on-state time of the timer. Recreating the same volumes as the previous tests was not possible at these higher pressures. This resulted in a change of 50ml per burst starting from test 9.

Test number	Nozzle	Pressure (bar)	Flow (lpm)	Reach (m)	Height (m) (from floor)	Drop size (µm)	Volume per burst (ml)	Amount of bursts	Time open (s)	Time closed (s)	Total volume (ml)
Test1	Full cone	1	11.5	1.8	/	3700	22	5	0.1	2	110
Test2	Full cone	1	11.5	/	/	3700	30	5	0.2	2	150
Test3	Full cone	1.5	13.5	2	/	3000	32	5	0.1	2	160
Test4	Full cone	1.5	13.5	2	/	3000	32	5	0.1	2	160
Test5	Full cone	4	21	4	1.7	2300	59	5	0.1	2	295
Test6	Full cone	4	21	4	1.7	2300	59	5	0.1	2	295
Test7	Full cone	4	21	4	1.7	2300	44	5	0.05	2	220
Test8	Full cone	4	21	4	1.7	2300	44	5	0.05	2	220
Test9	Fine mist	4	12.4	1.85	0.7	290	51	5	0.2	2	255
Test10	Fine mist	4	12.4	/	/	290	51	5	0.2	2	255
Test11	Fine mist	4	12.4	/	/	290	51	5	0.2	2	255
Test12	Fine mist	4	12.4	1.85	0.7	290	34	5	0.1	2	170
Test13	Fine mist	4	12.4	1.85	0.7	290	34	5	0.1	2	170
Test14	Fine mist	4	12.4	1.85	0.7	290	34	5	0.1	2	170
Test15	Fine mist	4	12.4	1.85	0.7	290	50	1	0.2	2	50
Test16	Fine mist	4	12.4	1.85	0.7	290	50	2	0.2	2	100
Test17	Medium sized hollow cone	2	16.1	2	1.55	920	32	5	0.05	2	160
Test18	Medium sized hollow cone	2	16.1	2	1.55	920	32	5	0.05	2	160
Test19	Medium sized hollow cone	3	19.7	2.65	2.8	860	50	5	0.15	2	250

Test20	Medium sized hollow cone	3	19.7	2.65	2.8	860	50	5	0.15	2	250
Test21	Medium sized hollow cone	4	23	2.65	2.95	800	49	1	0.1	2	49
Test22	Medium sized hollow cone	4	23	2.65	1.95	800	49	1	0.1	2	49
Test23	Medium sized hollow cone	4	23	2.65	1.95	800	49	1	0.1	2	49
Test24	Medium sized hollow cone	4	23	2.65	1.95	800	49	2	0.1	2	98
Test25	Medium sized hollow cone	4	23	2.65	1.95	800	49	2	0.1	2	98
Test26	Medium sized hollow cone	4	23	2.65	1.95	800	49	5	0.1	2	245
Test27	Small sized hollow cone	4	9.1	3.75	2.7	500	29	5	0.1	2	145
Test28	Small sized hollow cone	4	9.1	3.75	2.7	500	50	2	0.25	5	100
Test29	Small sized hollow cone	4	9.1	3.75	2.7	500	50	5	0.25	2	250
Test30	Small sized hollow cone	4	9.1	3.75	2.7	500	50	1	0.25	2	50
Test31	Small sized hollow cone	4	9.1	3.75	2.7	500	50	2	0.25	2	100
Test32	Small sized hollow cone	3	7.9	3	1.7	560	50	5	0.35	2	250
Test33	Small sized hollow cone	3	7.9	3	1.7	560	48	5	0.35	2	240

Test34	Small sized hollow cone	4	9.1	3.75	2.7	500	50	5	0.25	1	250
Test35	Small sized hollow cone	4	9.1	3.75	2.7	500	50	5	0.25	0.5	250
Test36	Small sized hollow cone	4	9.1	3.75	2.7	500	50	5	0.25	0.5	250
Test37	Small sized hollow cone	4	9.1	3.75	2.7	500	250	1	1.2	/	250
Test38	Medium sized hollow cone	4	23	3.75	2,7	500	250	1	1.2	/	250
Test39	Small sized hollow cone	4	9.1	3.75	2.7	500	150	1	1.2	/	150
Test40	Small sized hollow cone	4	9.1	3.75	2.7	500	50	5	1.2	2	250
Test41	Full cone	4	21	4	1.7	2300	50	1	0.05	2	50
Test42	Full cone	4	21	4	1.7	2300	50	2	0.05	2	100
Test43	Full cone	4	21	4	1.7	2300	250	1	1.2	/	250
Test44	Fine mist	4	12.4	1.85	0.7	290	250	1	1.5	/	250

Table 12 - List of tests that were performed

4.1 Cooling results by applying bursts

The first experiments comprise of tests where water was applied in several bursts of small volumes. The time in between the bursts is kept constant at 2s. A 12V DC signal has been used to monitor when the nozzle was operated. The signal of 12V implies the moment when power is fed to the timer, so the pulses are not visible at the chart. The signal stops after the last pulse is applied.

4.1.1 Full cone nozzle

Throughout all of the experiments, the gases showed a cooling for all water applications with droplets smaller than 3000 μm. Only two tests were applied with larger droplets. Both of these tests were applied with full cone nozzles and a median droplet size of 3700 μm at 1 bar [26].

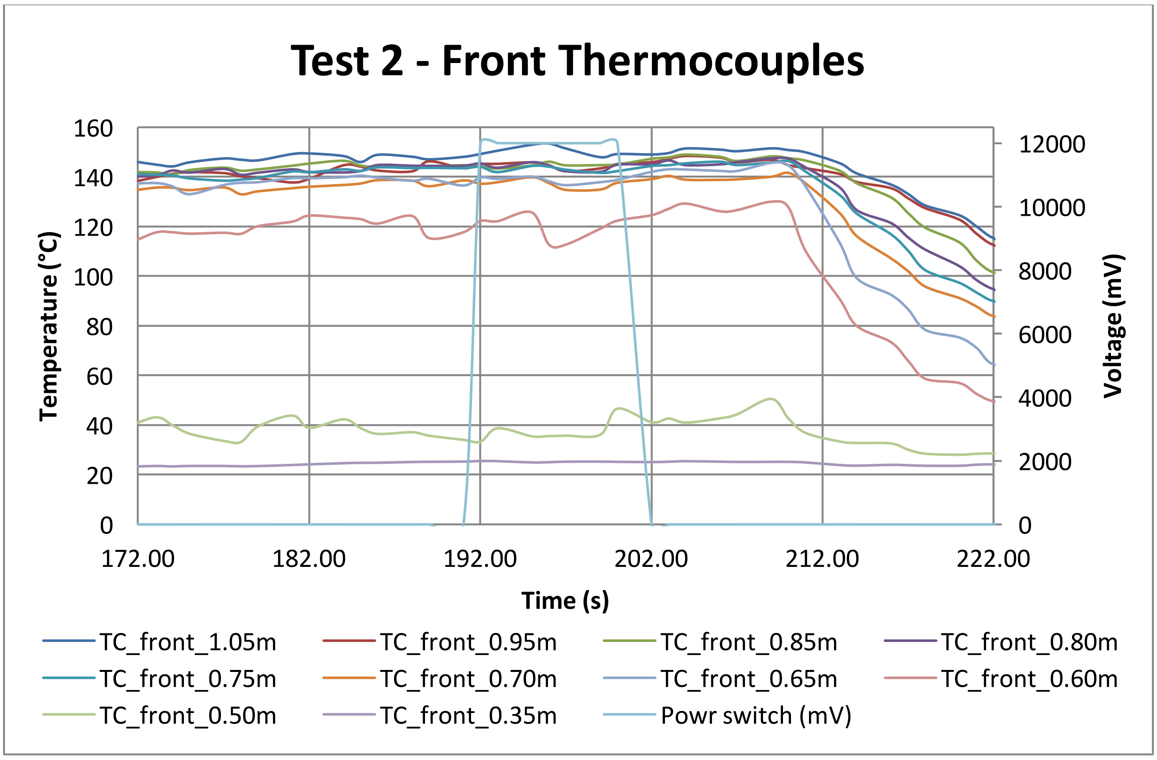

Figure 19 - Test with full cone nozzle at 1 bar. 5 bursts of 30 ml were applied with intervals of 2s. Medium droplet size is 3700μm A small drop in the temperature of the thermocouple at 60 cm can be seen.

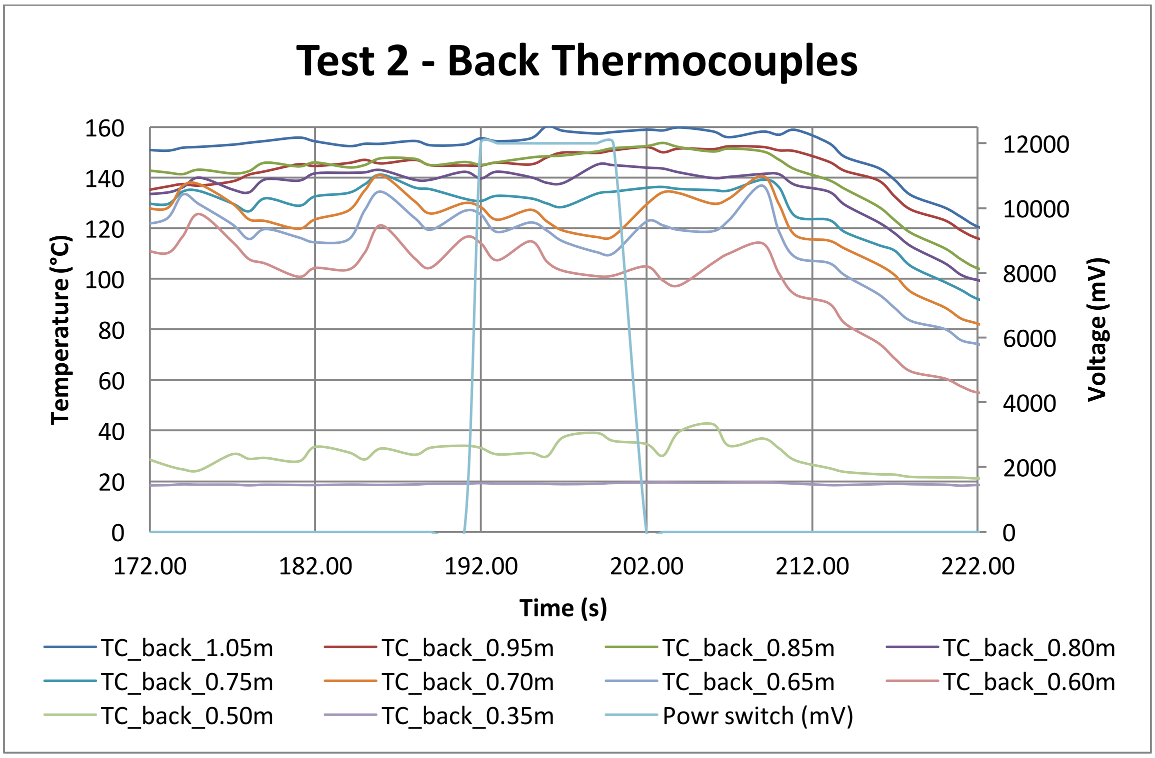

Figure 20 - Back thermocouples test 2

The largest drop size where cooling was visible was with the application of droplets with a median diameter of 3000 μm. Even though the temperature of the thermocouple at 0.60m dropped, this might be interpreted as noise. The thermocouples placed in the back do show cooling from 0.60 m to 0.75m. For this particular test, the height of the flow at 1.5 bar was not measured, however there was water reaching the ceiling.

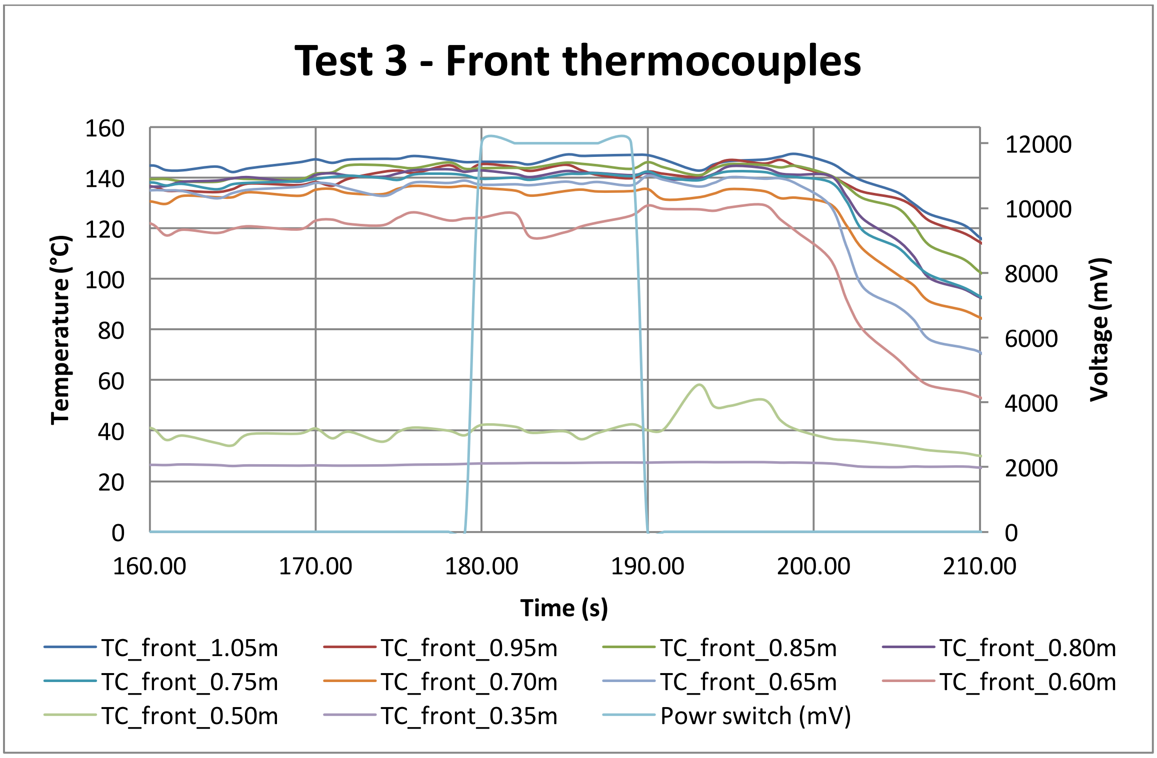

Figure 21 - Test with full cone nozzle at 1.5 bar. 5 bursts of 32 ml were applied with intervals of 2s. The median droplet diameter was 3000 μm. A small drop of the temperature is visible at 0.60 cm.

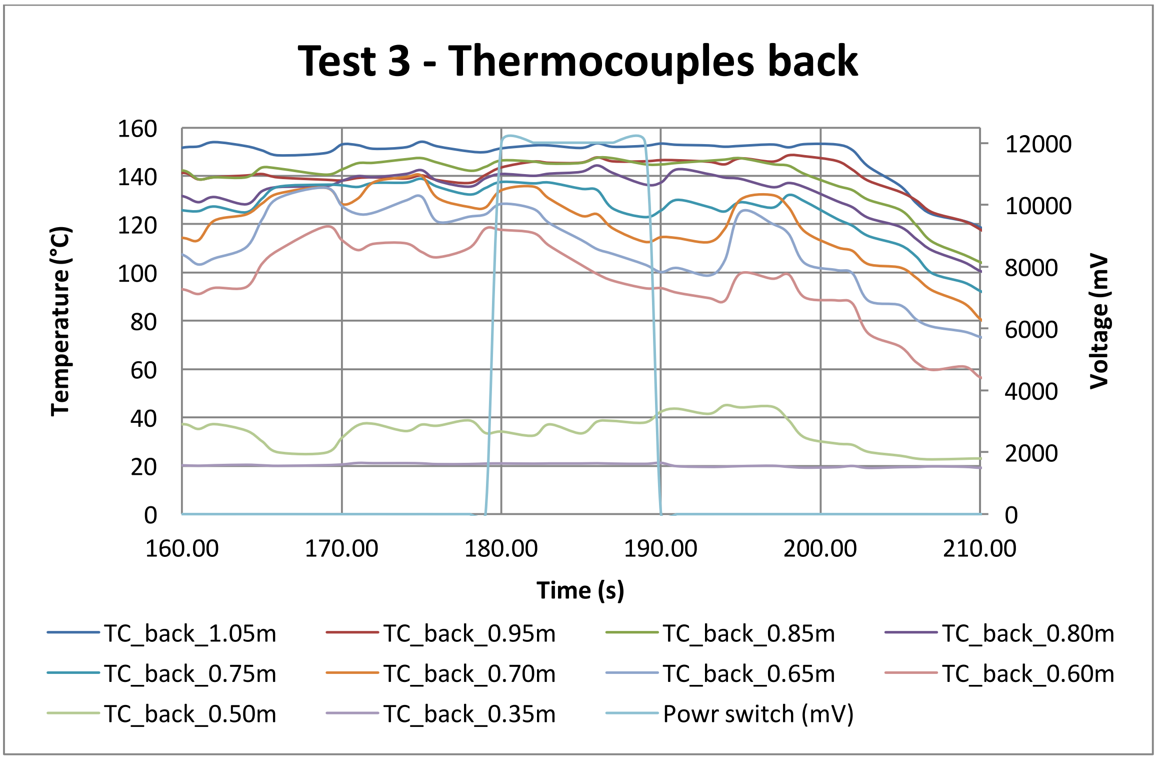

Figure 22 - Back thermocouples test 3

Even though the spray reached 1.7m high and 4m far at a setting of 4 bar, it did provide the best cooling results for the full cone nozzle by applying bursts. At this pressure, water droplets were in the range of 2300 μm or about 25% smaller than in test 3. One important remark is that more water has been used in this test. At 4 bar it was harder to get a volume in the range of 30 ml out of a single burst. A volume of 59 ml was used for test 5 and 6 which was managed to fine tune even lower to 44 ml for test 7 and 8.

Figure 23 and Figure 24 show a significant cooling for the front thermocouples compared to test 3. In test 6 a higher volume of water was used which resulted in a stronger effect. What is more important is that the temperatures throughout the whole layer decreased whereas in test 3 only the lower parts of the gas layer were affected.

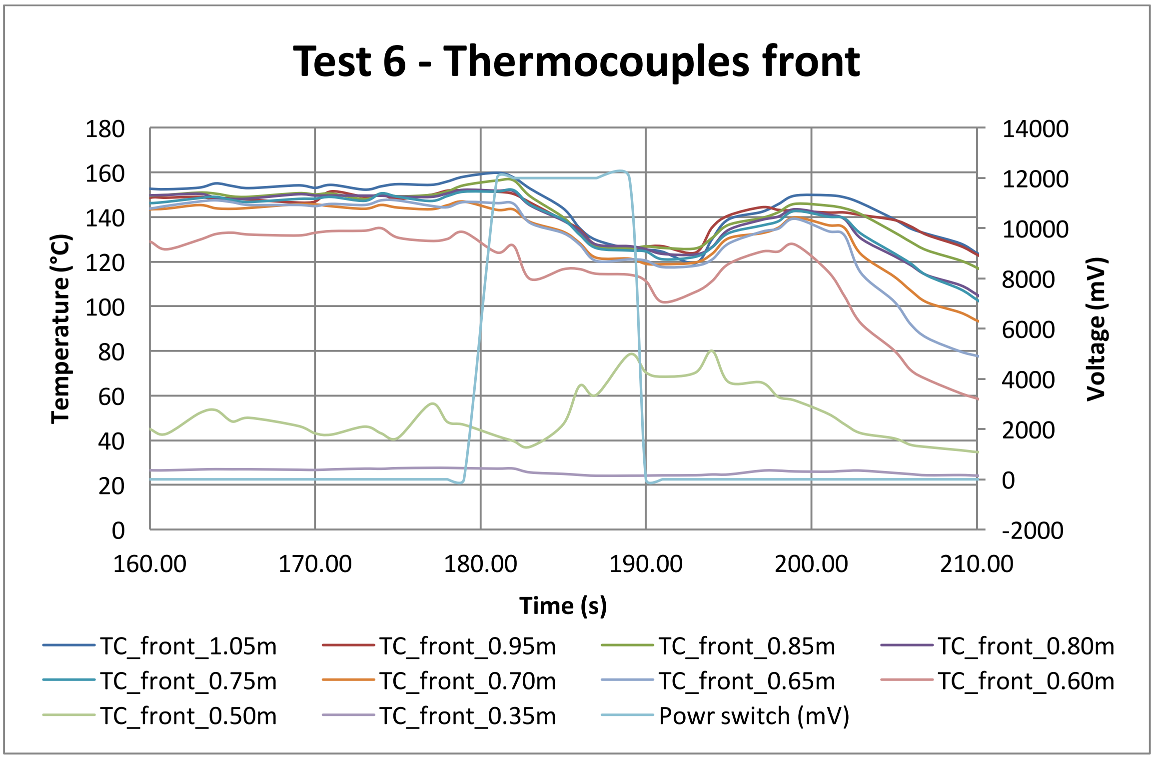

Figure 23 - Test 6: Full cone nozzle operated at 4 bar. 5 bursts of 59 ml in an interval of 2s were used. The median droplet diameter was 2300 μm. An average cooling of 40°C was made possible even with these coarse droplets. After the water is applied there are about 4s of buffering time before the gases start to reheat.

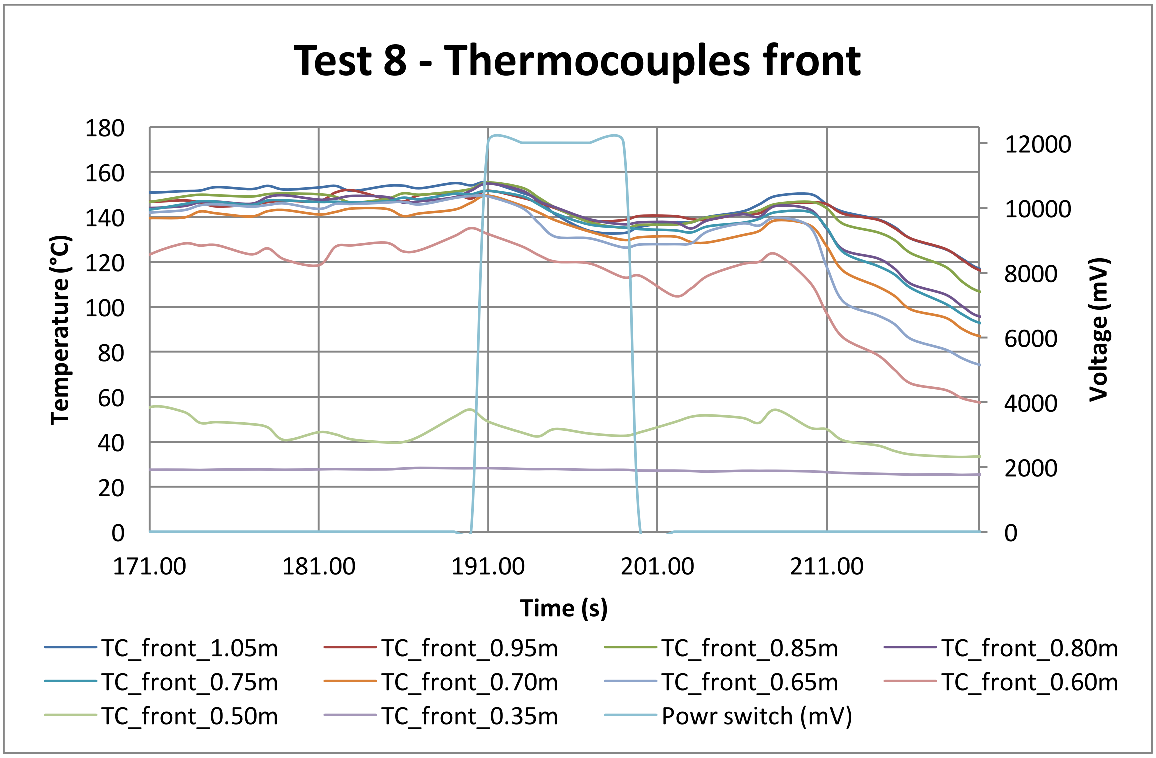

Figure 24 - Test 8: Full cone nozzle operated at 4 bar. 5 bursts of 44 ml in an interval of 2s were used. The median droplet diameter was 2300 μm. With the use of 25% less water compared to test 6, only the half of temperature decrease has been reached.

The differences on the effects of the back temperatures are smaller. The larger pressure allows a further reach resulting in temperature drops at the back of the room too. One thing that is clearly visible compared to the front temperatures is that the changes are much more turbulent. This is most likely due to the velocity of the water flow that is introduced by the nozzle. This inward flow pushes the gases towards the back wall. Once they hit the wall, the horizontal momentum is transferred to a vertical momentum which pushes the gases downwards. This explains the rise in temperature that can be seen in the lower thermocouples on Figure 25, Figure 26 and Figure 27.

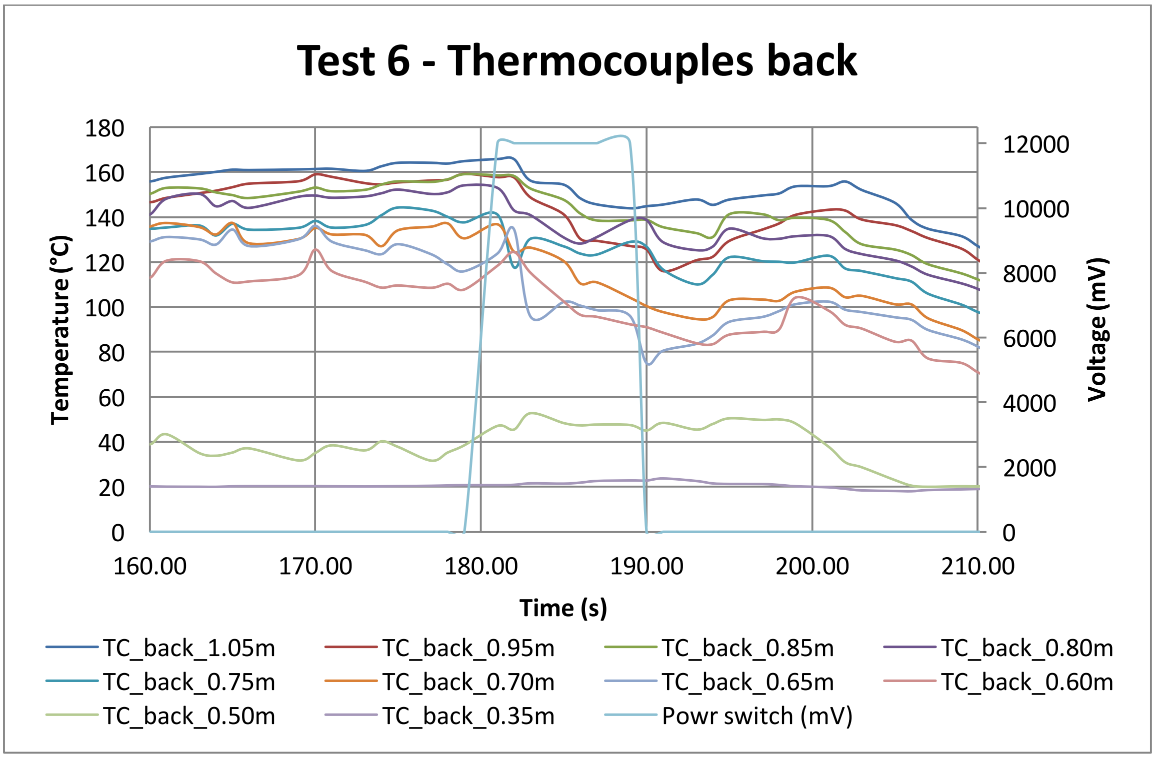

Figure 25 - Back thermocouples of test 6. The cooling reached all the way to the back. The changes in temperature are not as uniform as with the front temperatures. This is most likely due to the turbulence induced by the entraining velocity of the water flow.

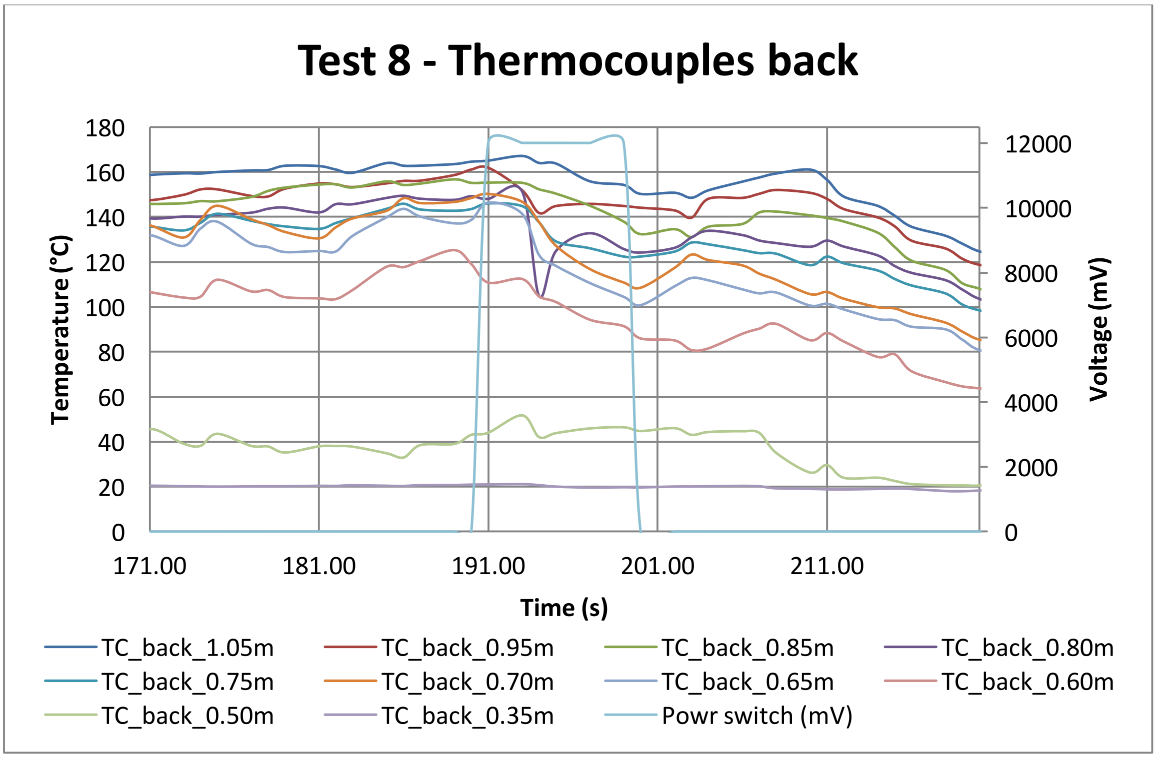

Figure 26 - Back thermocouples of test 8.

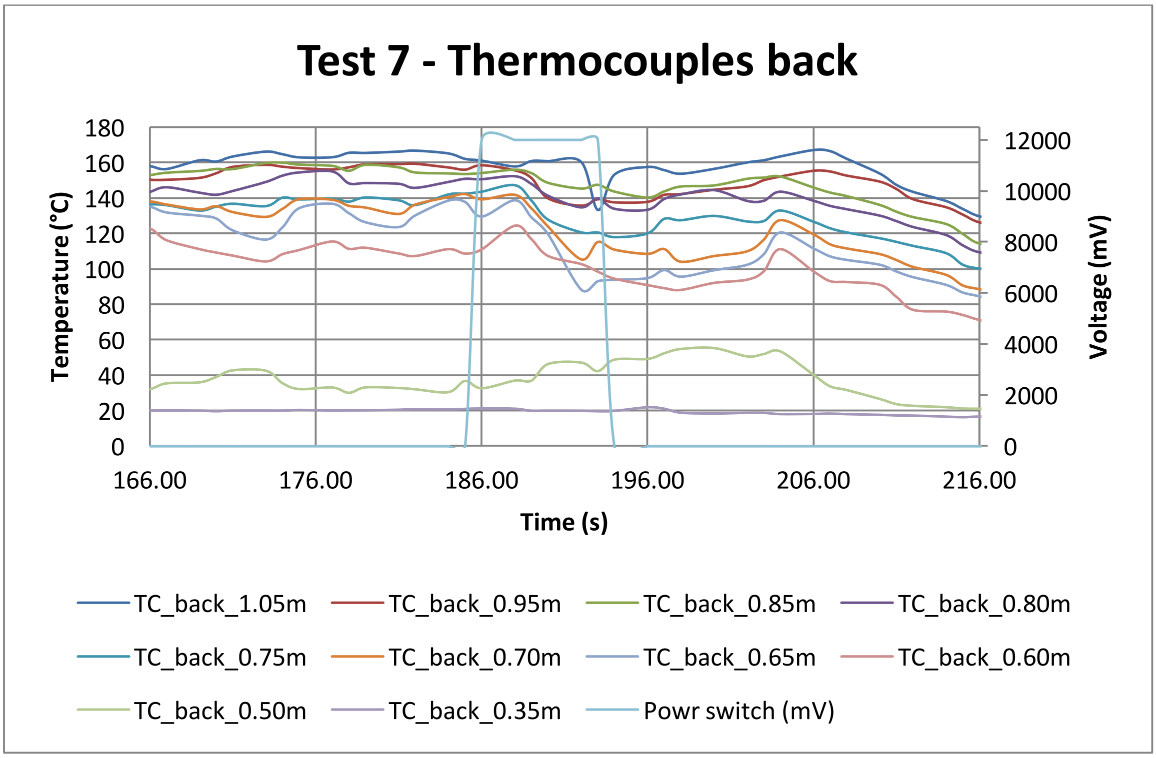

Figure 27 - Back thermocouples of test 7. Test 7 is identical to test 8 but has a better reading on the temperature rise of the lower thermocouples.

4.1.2 Fine mist nozzle

The fine mist nozzles had a very good cooling effect in the front. The produced flow was formed like a cloud around the nozzle. One of the smaller nozzles where the actual nozzle is build of faced outwards due to the 45° angle of the setup (Figure 28). This resulted in a small efficiency loss of the nozzle. Even though the pressure was constantly set to 4 bar, the reach and height of the water flow did not vary much and remained relatively small. The highest droplets reached to about 0.7m from the floor. The furthest horizontal reach was about 1.85m although the majority of the droplets did not reach further than 0.5m. Nevertheless, these limitations, the spray was able to cool the gases in the close vicinity significantly and even managed to cool gases as high as the top thermocouple. Due to the cloud-like spray pattern, the turbulence was very high. This can clearly be seen on the temperature fluctuations in Figure 29.

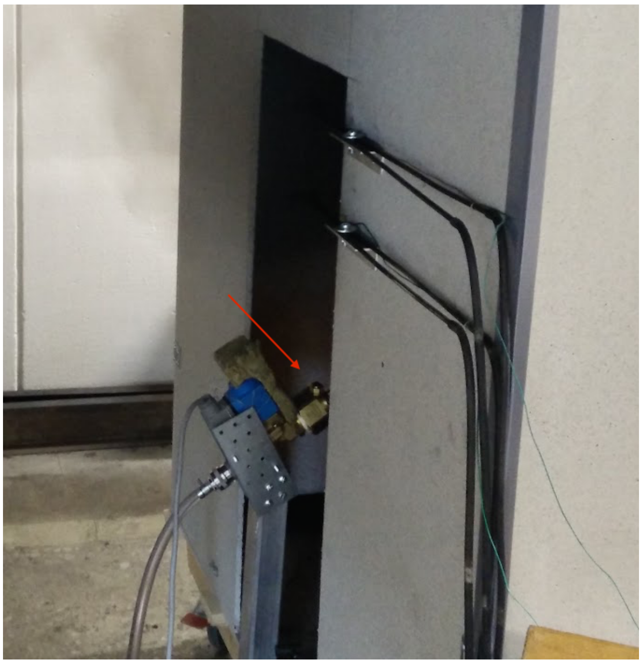

Figure 28 - The fine mist nozzle consists of 7 smaller nozzles which are also seen on Figure 13. Due to 45° angle of the actual setup, one of these smaller nozzles faced towards the outside.

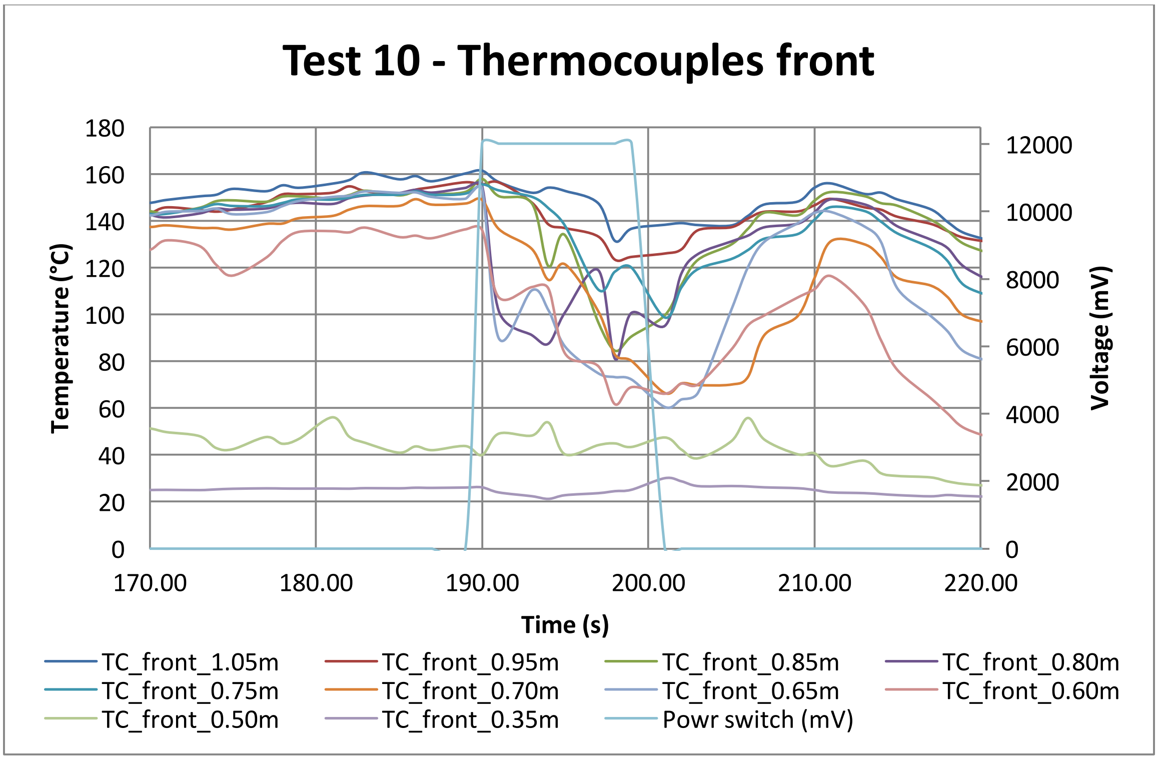

Figure 29 - Test 10: Fine mist nozzle at 4 bar. 5 bursts of 51 ml were applied in an interval of 2s. The median droplet diameter was about 290 μm. A lot of turbulence is present due to the spray flowing in every direction.

Even though the reach was rather small, there were some temperature drops present up until the height of 0.70m.

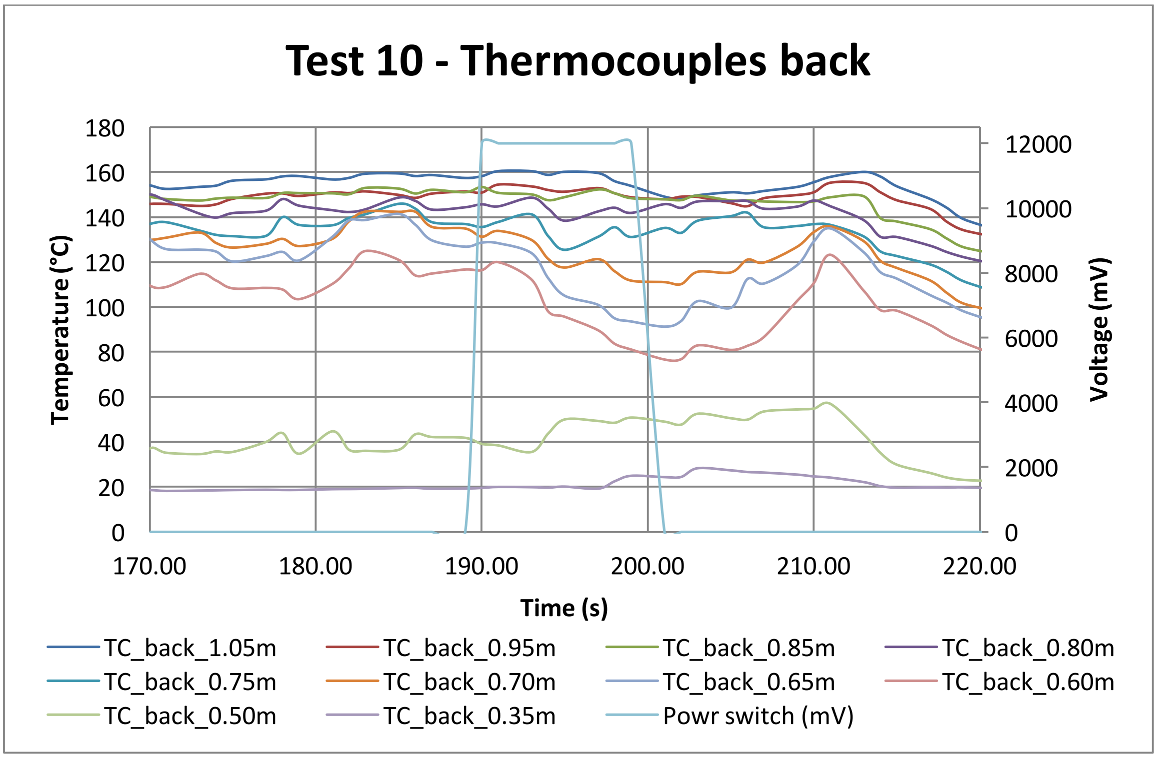

Figure 30 - Back thermocouples of test 10. Even though the reach was small, some cooling was present up until 0.70m.

In test 14 a lower volume was used per burst. This volume was comparable to the full cone test of test 3 (Figure 21 and Figure 22). Whereas in test 3 a smaller volume per burst resulted in a much lower cooling compared to test 5 and 6, it did not impact the results by much for the fine mist nozzle. The temperature decrease was a little lower but the buffer time for the reheating was significant faster.

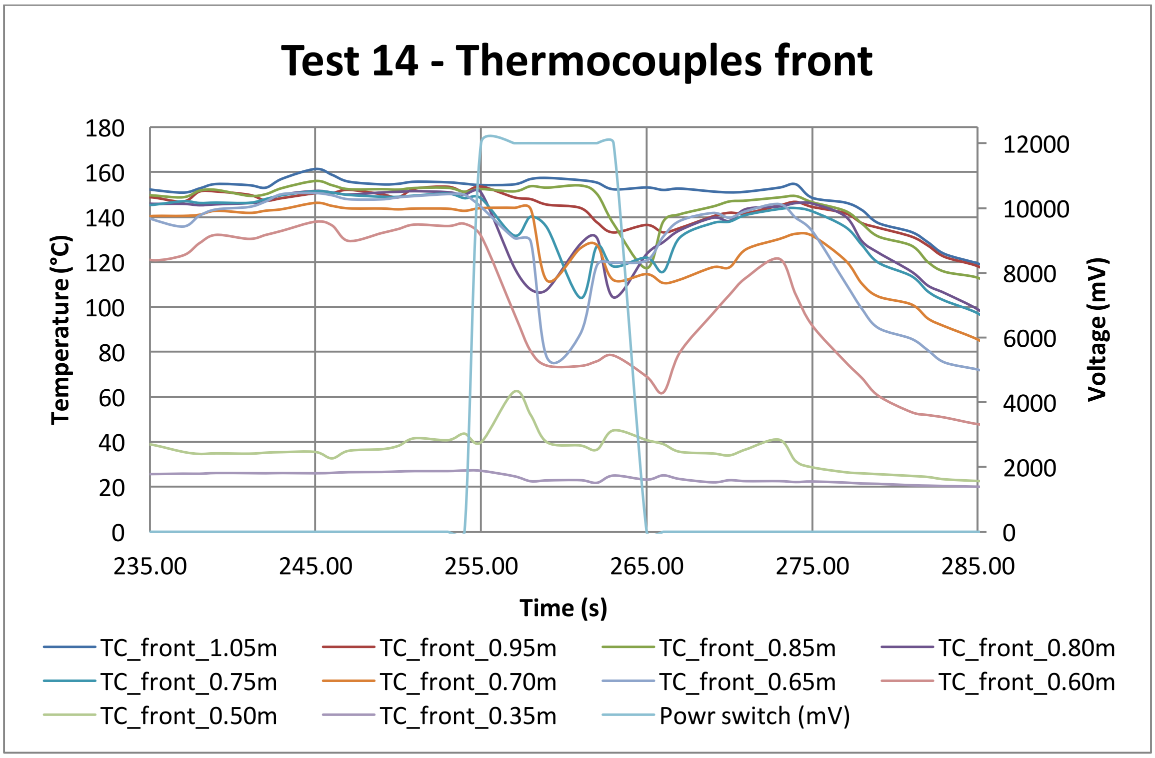

Figure 31 - Test 14: Fine mist nozzle at 4 bar. 5 bursts of 34 ml were applied in an interval of 2s. The median droplet diameter was about 290 μm.

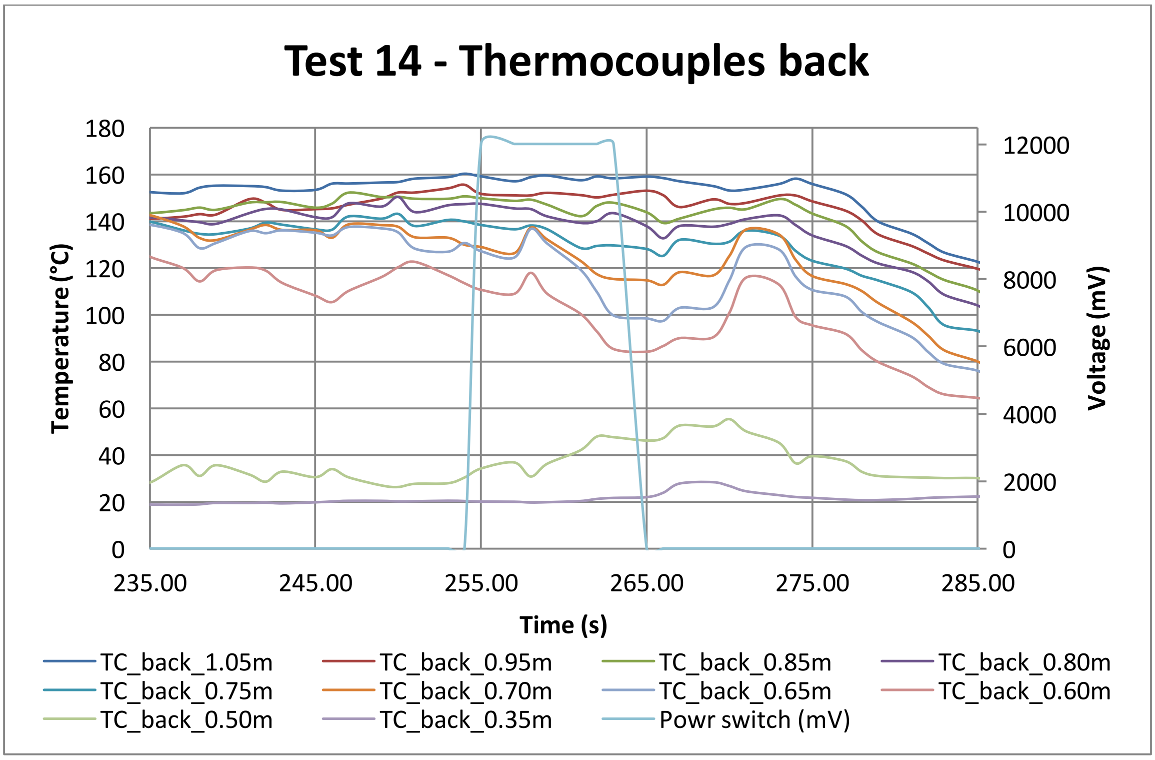

Figure 32 - Back thermocouples of test 14

4.1.3 Hollow cone nozzles

Figure 33 and Figure 34 show the temperature readings of test 17. For this test, the medium hollow cone nozzle was used at a low pressure. At 2 bar the height of the water flow reached 1.85m whereas the distance stretched to 1.7m. Even though this was not measured for test 3, the values of test 17 come close to what was observed in test 3. With 5 bursts of 32ml, an equal amount of water was chosen to perform a comparative test. Just like in test 3 the frontal temperatures did not change that much. Similarly, the back temperatures cooled down until 0.75m from the ground.

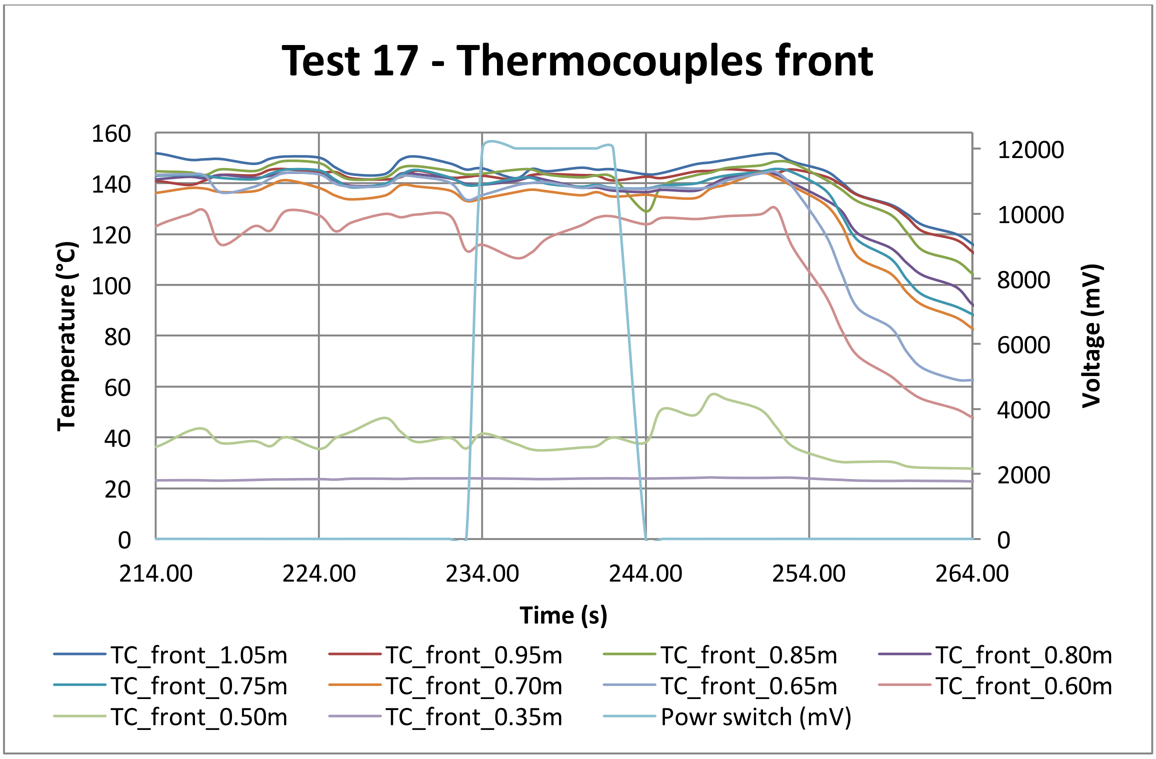

Figure 33 - Test 17: Medium sized hollow cone nozzle at 2 bar. 5 bursts of 32 ml were applied in intervals of 2s. The median droplet diameter was about 920 µm.

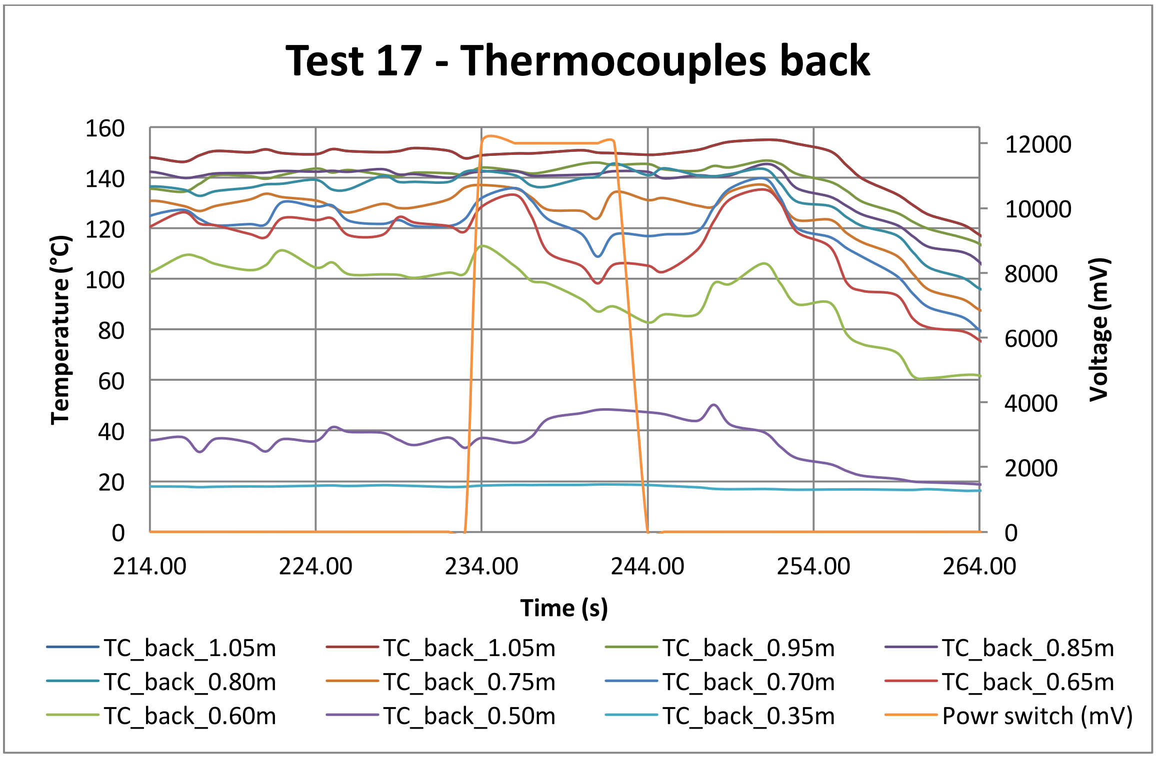

Figure 34 - Back thermocouples of test 17. More cooling is present in the back compared to the front.

As with the full cone experiments, the best cooling results were achieved with the smallest droplets, regardless of the reach and height of the flow (at least within the margins of this experiment). Figure 35 and Figure 36 show the temperature readings of the application of 5 bursts of 50 ml at 4 bar. The droplets have a mean diameter of 800 μm at this pressure. The temperatures in the front corner go under 120°C up until 0.75m whilst the higher part of the upper layer stays very close above the 120°C. The temperatures in the back go below 120°C up to a height 0.95m. Some of the lower thermocouples show a slight temperature increase before the water has been stopped. This is most likely due to the turbulence created by the flow.

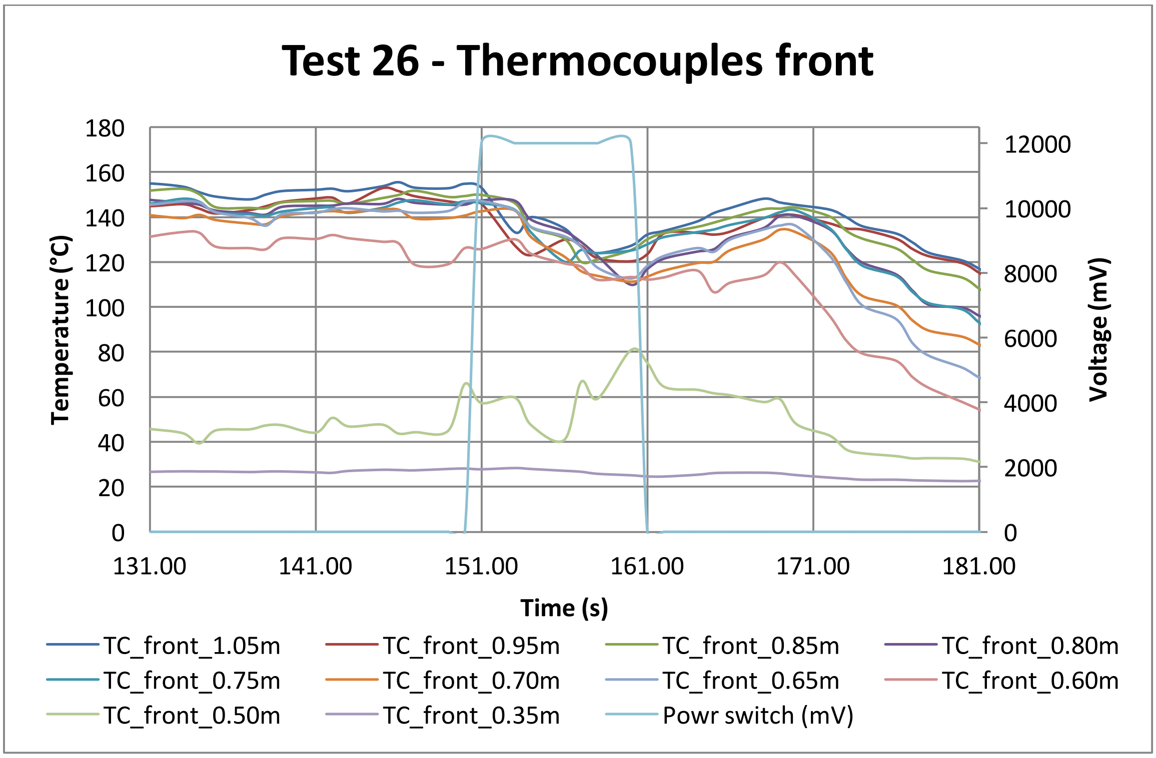

Figure 35 - Test 26: Medium sized hollow cone nozzle at 4 bar. 5 bursts of 50 ml were applied in an interval of 2s. The median droplet diameter was about 800 µm. The whole gas layer cooled down to 120 °C.

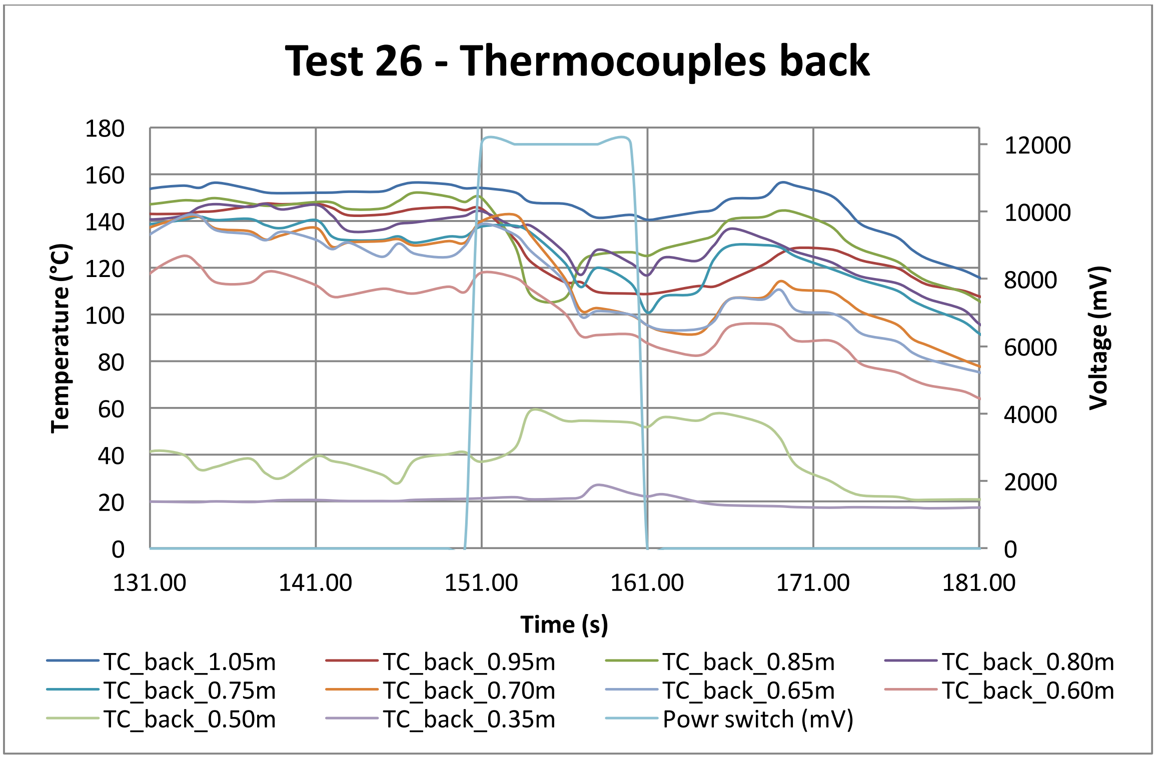

Figure 36 - Test 26: back thermocouples

Like the other nozzles, the small hollow cone nozzle showed the best results at a pressure of 4 bar. The droplets were 500 μm and visually looked very similar to those of the fine mist nozzle. Even though it had small droplets, the water flow maintained a high reach and spread out to 3.75m far and 2.7m high. From all the tests with separate burst, the cooling with the small hollow cone nozzle at 4 bar outclassed the other settings bringing all frontal temperatures below 100 °C. The temperatures at the back cooled down to about the same extent as those of test 26 with the medium sized hollow cone. The reheating is faster than previous tests, but this is most likely due to a bigger temperature difference with the cooled gases and the newly introduced fire gases.

Figure 39 shows the distribution of the 3 thermocouples that were placed at 0.15m from the ceiling in the central vertical plane which cuts the door in half. In this graph it can be seen that the cooling effects are even better in the center of the room.

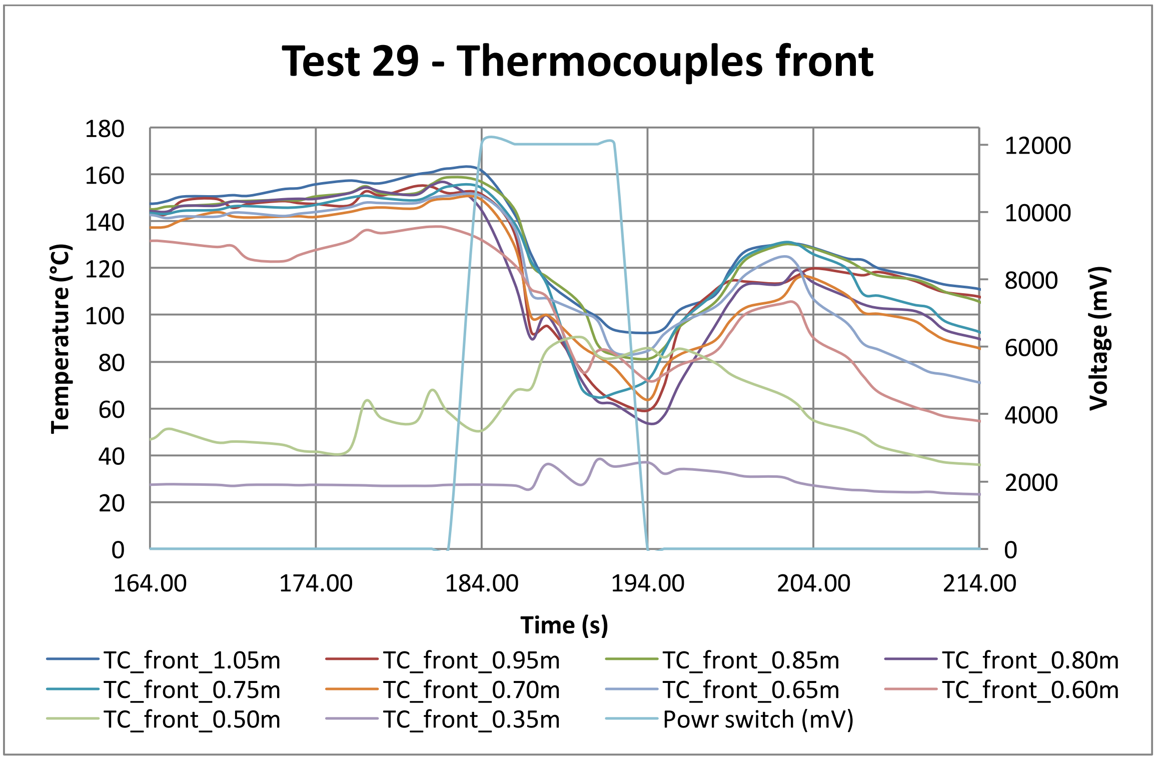

Figure 37 - Test 29: small sized hollow cone nozzle at 4 bar. 5 bursts of 50 ml were applied in intervals of 2s. The median droplet diameter was about 500 μm. A significant cooling occurred with the whole gas layer descending below 100°C.

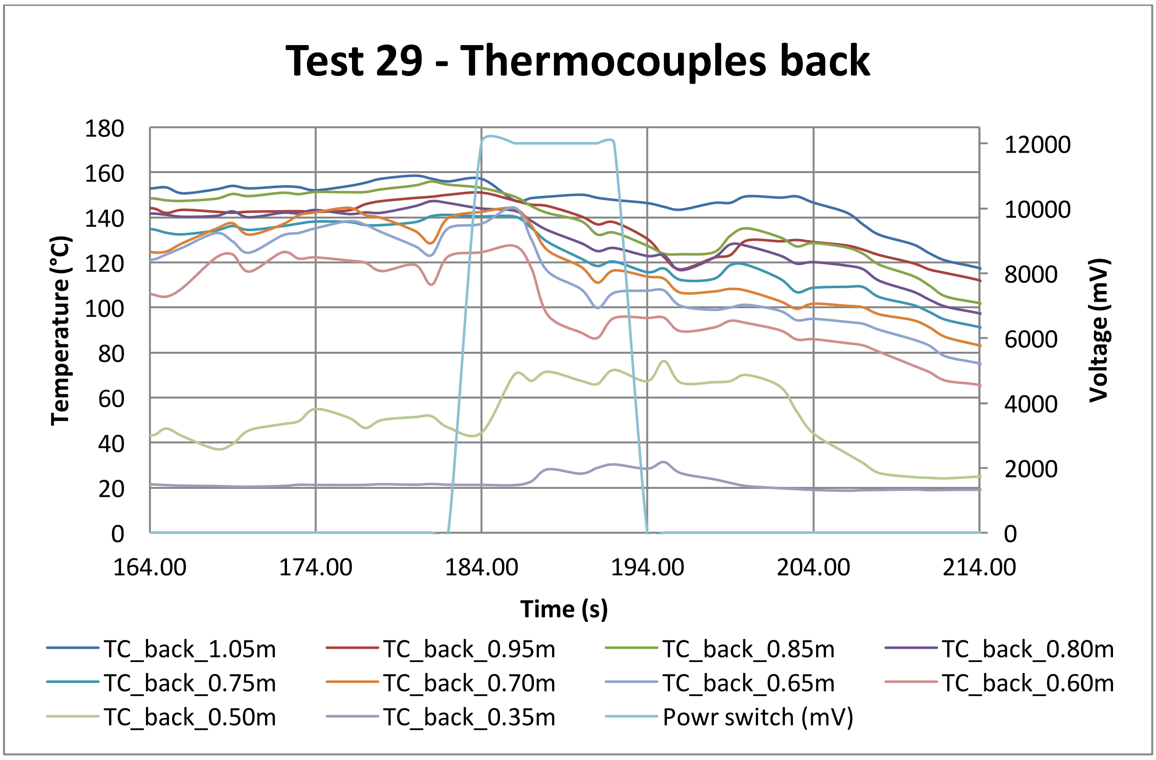

Figure 38 - Test 29, back thermocouples

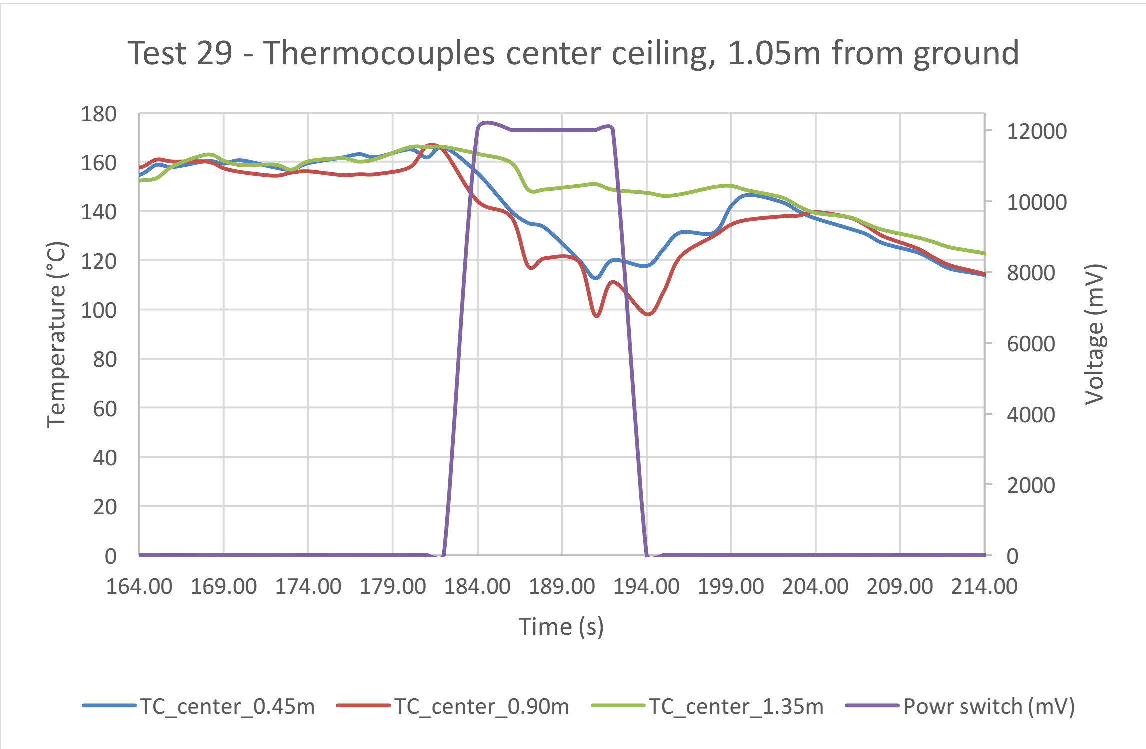

Figure 39 - Test 29: thermocouples placed at ceiling in the vertical plane that intersects the middle of the door. The cooling effect shows even stronger results in the middle of the room.

Test 40 was performed as a replication of test 29 to acquire video material. The cooling in the front was less effective but was still rather effective. The temperature distribution in the back was more or less the same.

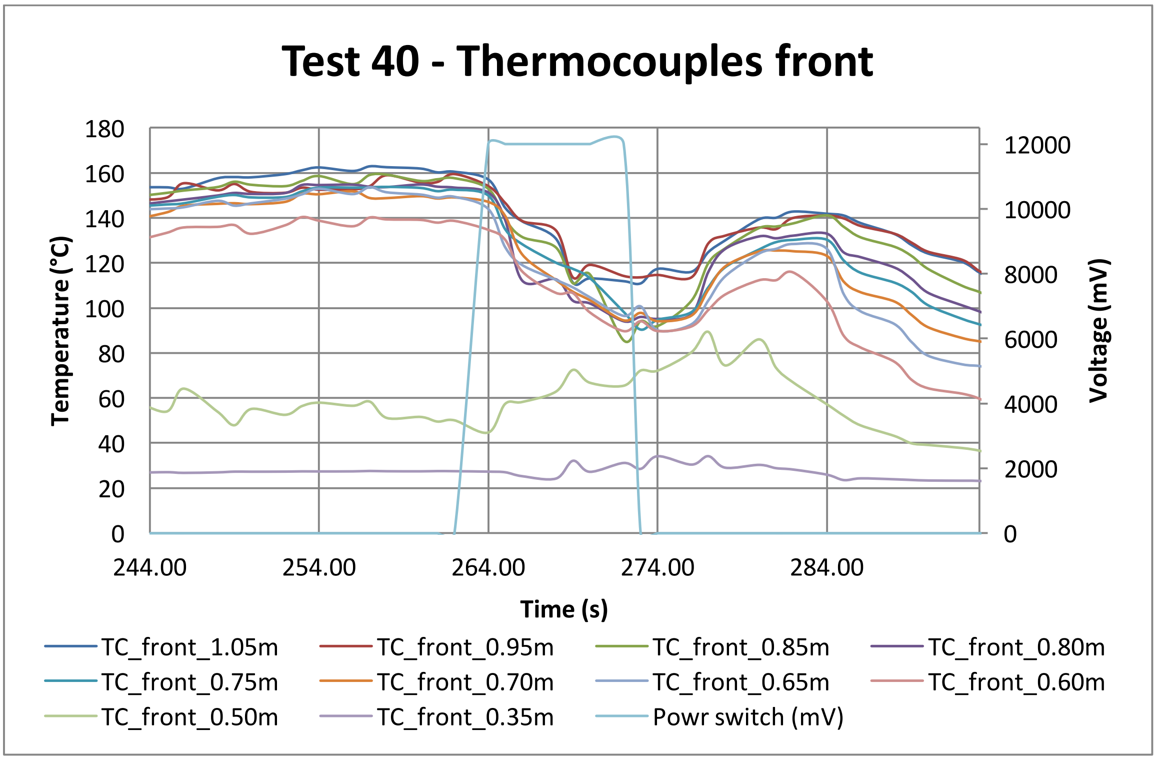

Figure 40 - Test 40: Replication of test 29. The cooling was slightly less but yet very much present.

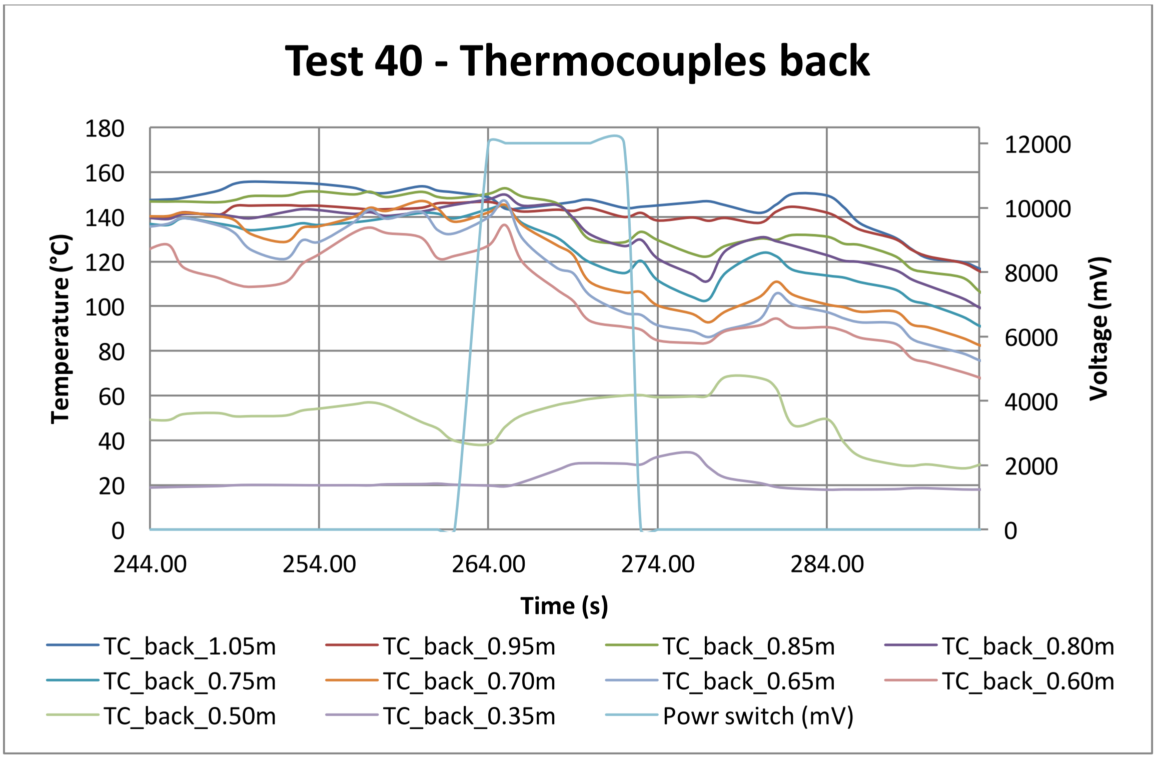

Figure 41 - Test 40, back thermocouples

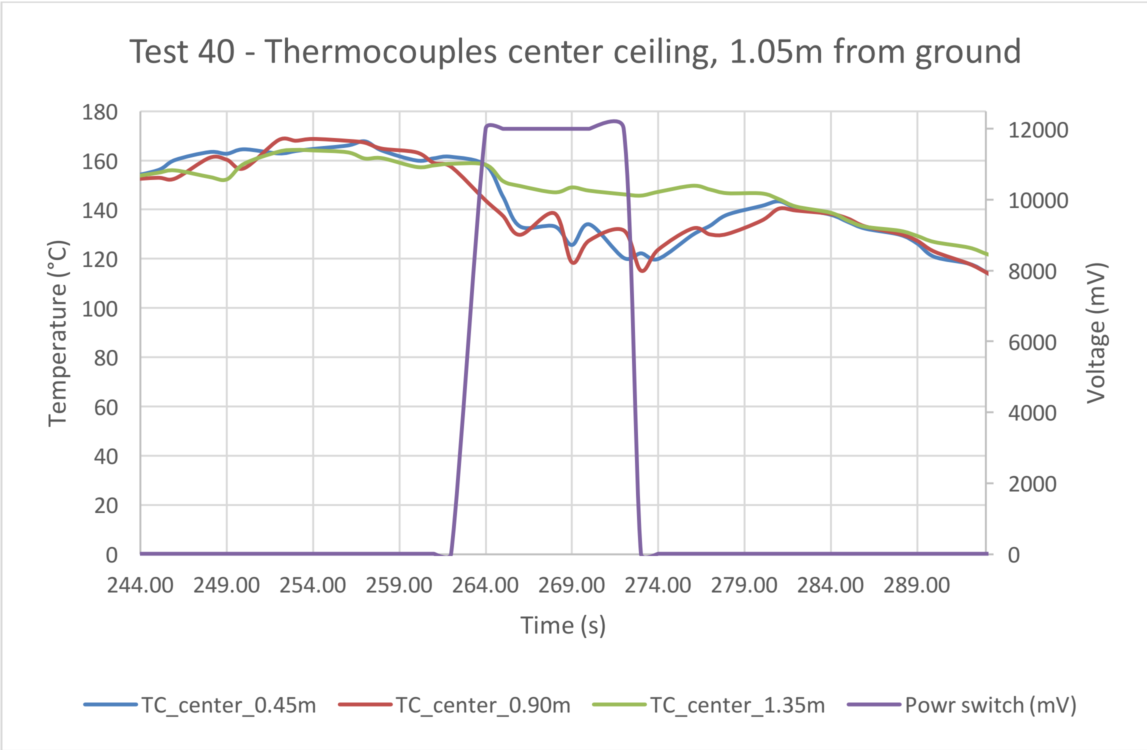

Figure 42 - Test 40, center ceiling thermocouples

In test 31 the small cone nozzle was operated at 4 bar but only 2 bursts of 50 ml were applied. As seen in Figure 43, the front temperatures get very close to 100°C too. For only using 40% of the water used in test 29 and 40, the temperature decrease in the front is very similar.

The major difference of using less water lies in the temperatures at the back as seen in Figure 44.

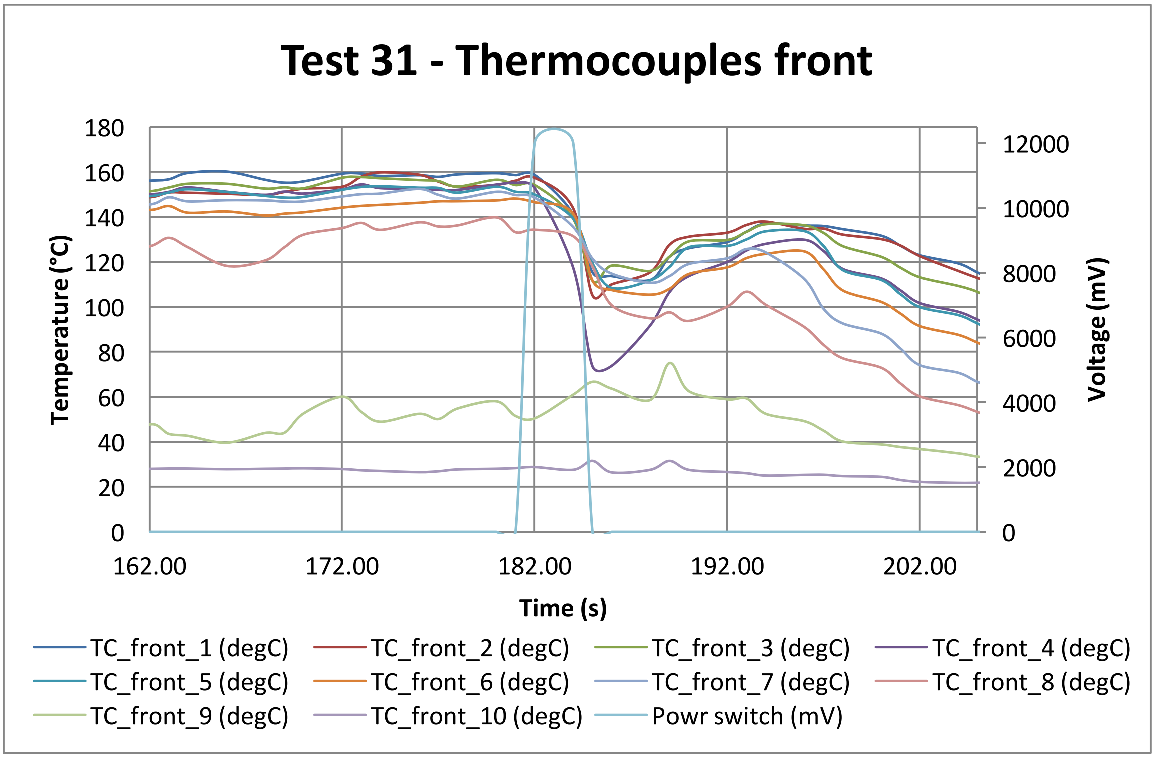

Figure 43 - Test 31, front thermocouples

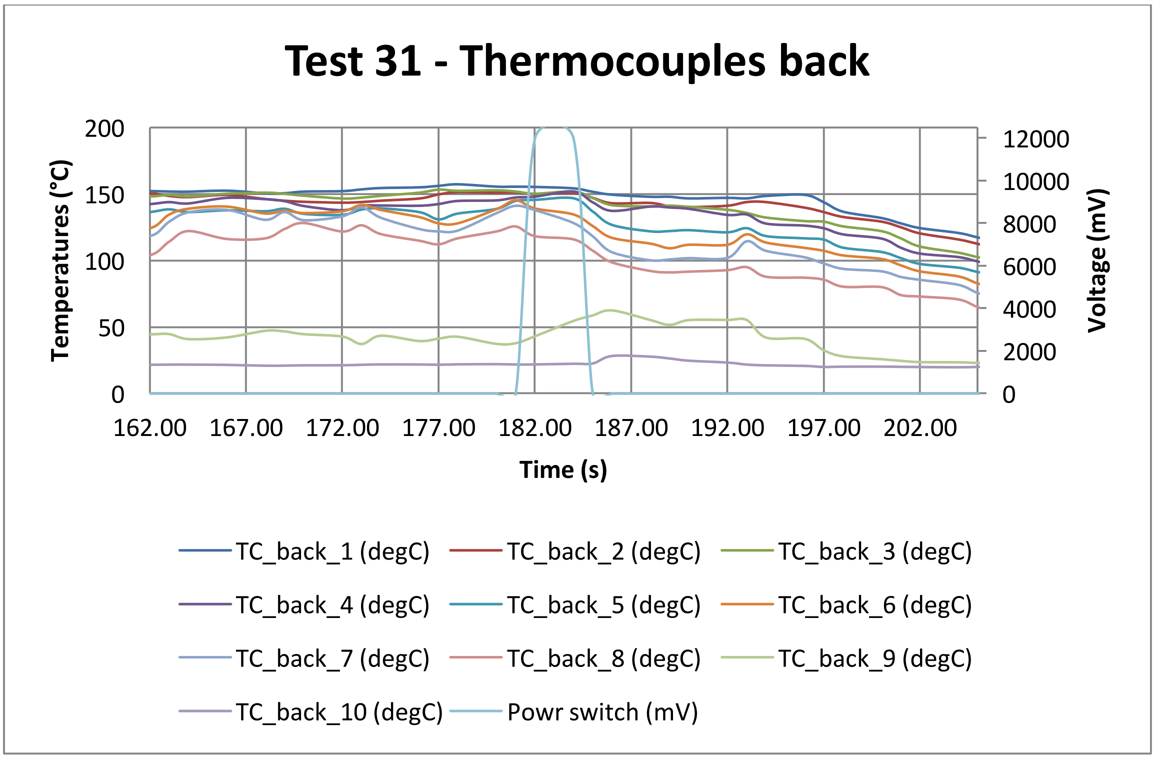

Figure 44 - Test 31, back thermocouples

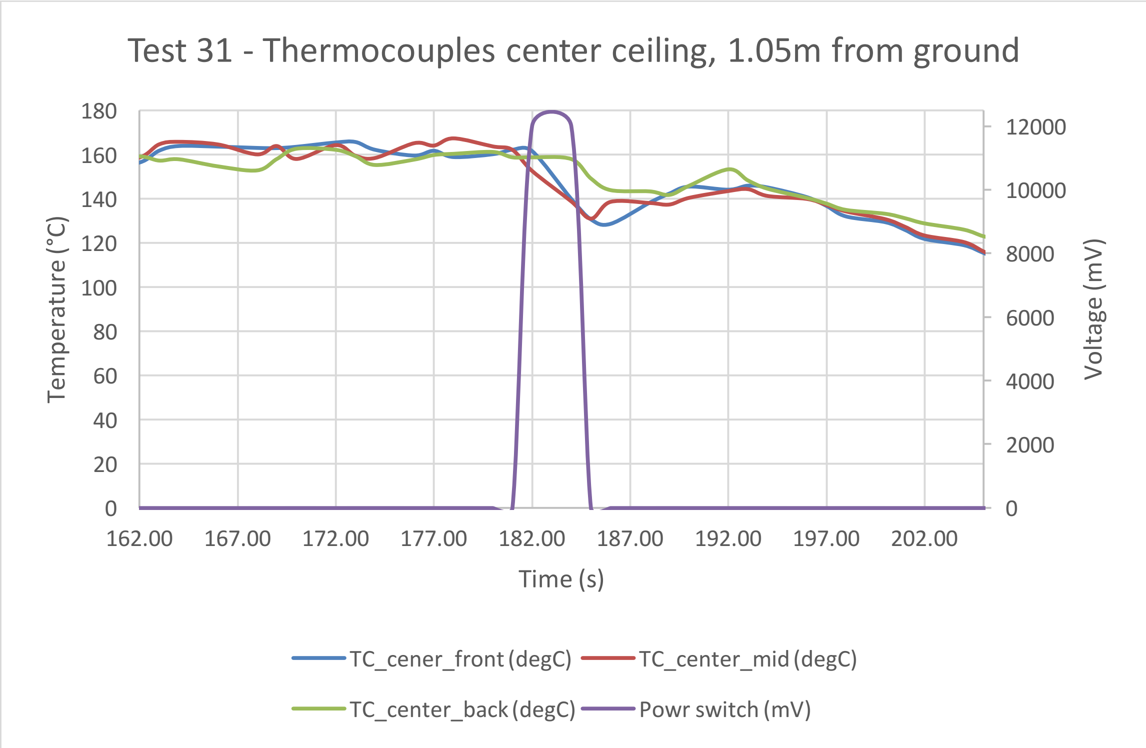

Figure 45 - Test 31, center ceiling thermocouples

4.2 Cooling with altered techniques

After seeing that the small hollow cone nozzle at 4 bar showed the best cooling results, experiments were conducted to alter the interval time. Tests with faster bursts and even a continuous flow were examined. The better setup with a pressure of 4 bar has been used throughout these alterations.

From test 34 to 36, faster bursts were applied. Test 34 had half of the interval time of the original tests whereas test 35 and 36 had a quarter of the original interval time. Figure 46 to Figure 51 show the results of the faster bursts. It can be seen that the faster the water is applied, the stronger the cooling effect is. Even though the differences are not that major in the measurements of the front thermocouples, the application time does show a large impact on the temperature readings of the center and back of the ISO room.

Opening and closing the nozzles at a faster rate does create a lot more turbulence though. This is most likely due to the fact that the upper layer has less time to stabilize itself before a new change of motion is introduced.

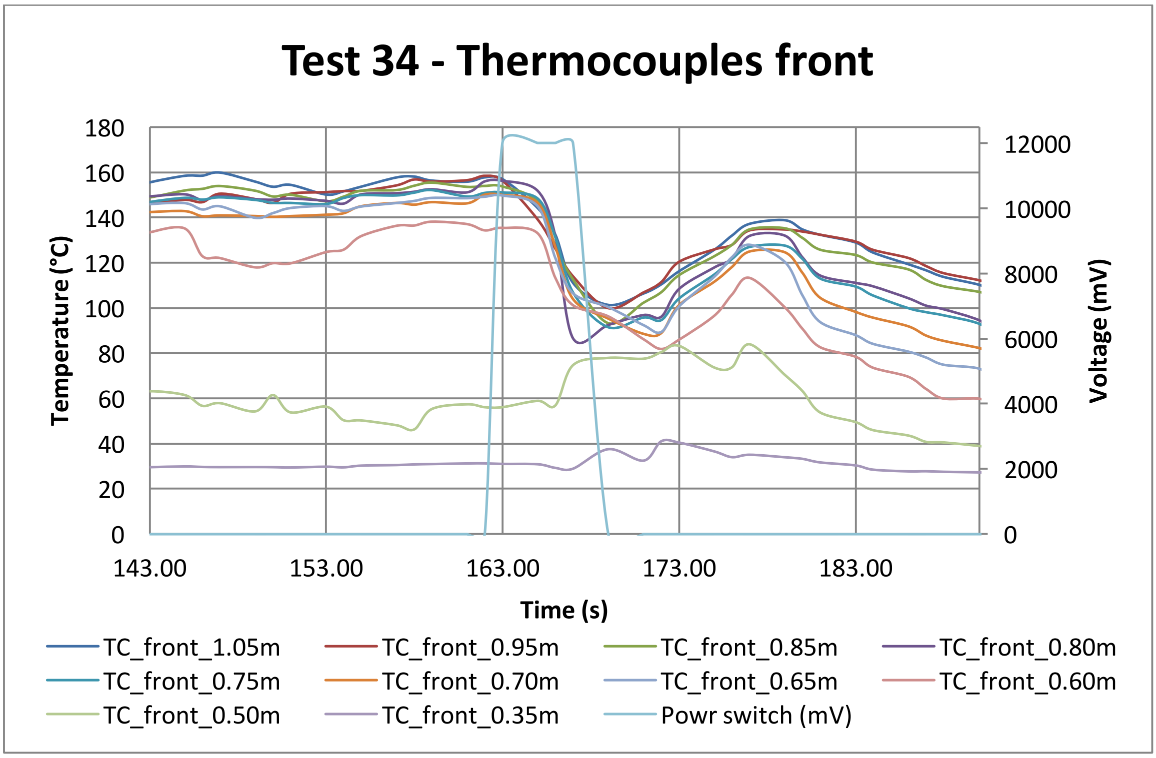

Figure 46 - Test 34: 5 bursts of 50 ml in an interval of 1s. Cooling lies in between the results of test 29 and 40.

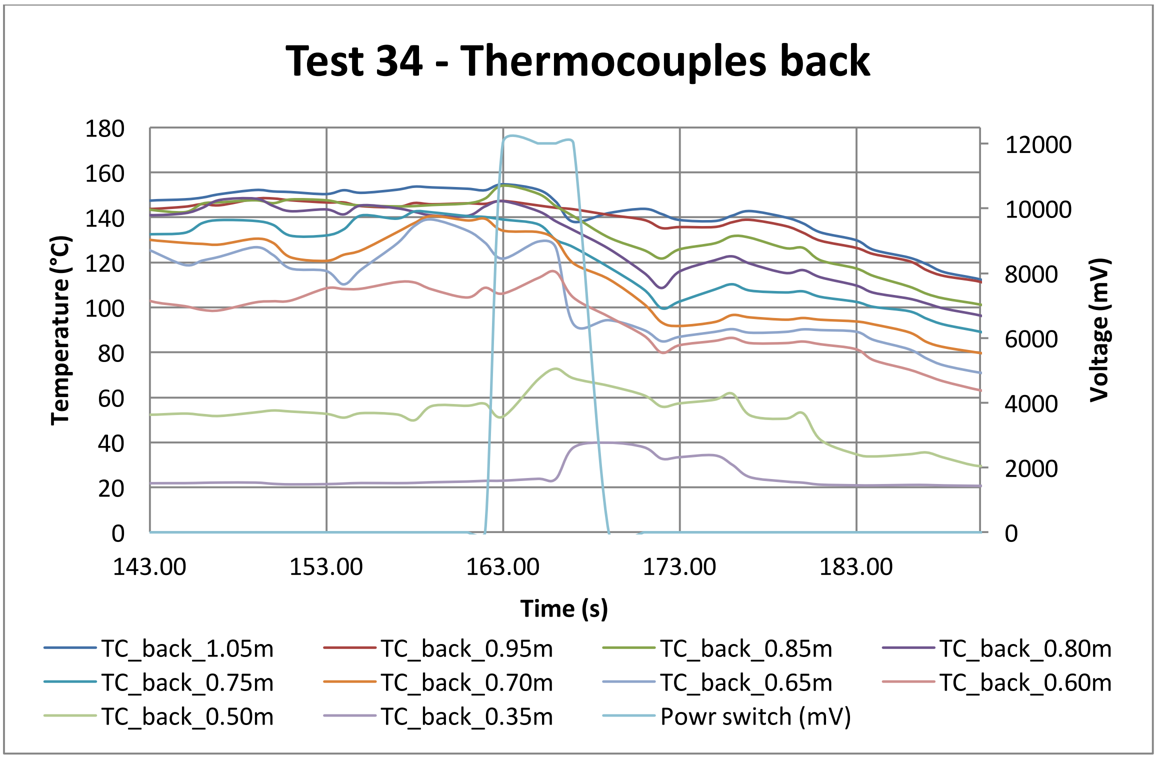

Figure 47 - Test 34: Thermocouples back. Cooling is also similar to test 29 and 40.

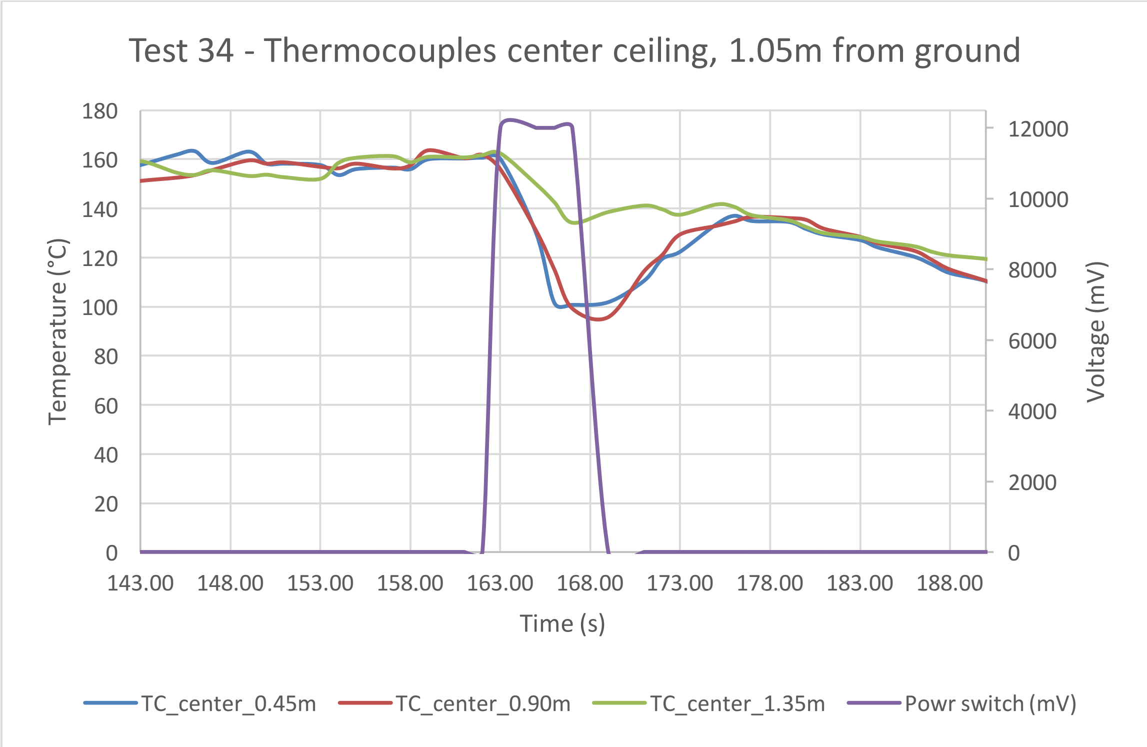

Figure 48 - Test 34: center ceiling thermocouples. These results are slightly better than test 29 but definitely better than test 40. The thermocouple at 1.35m shows more cooling here.

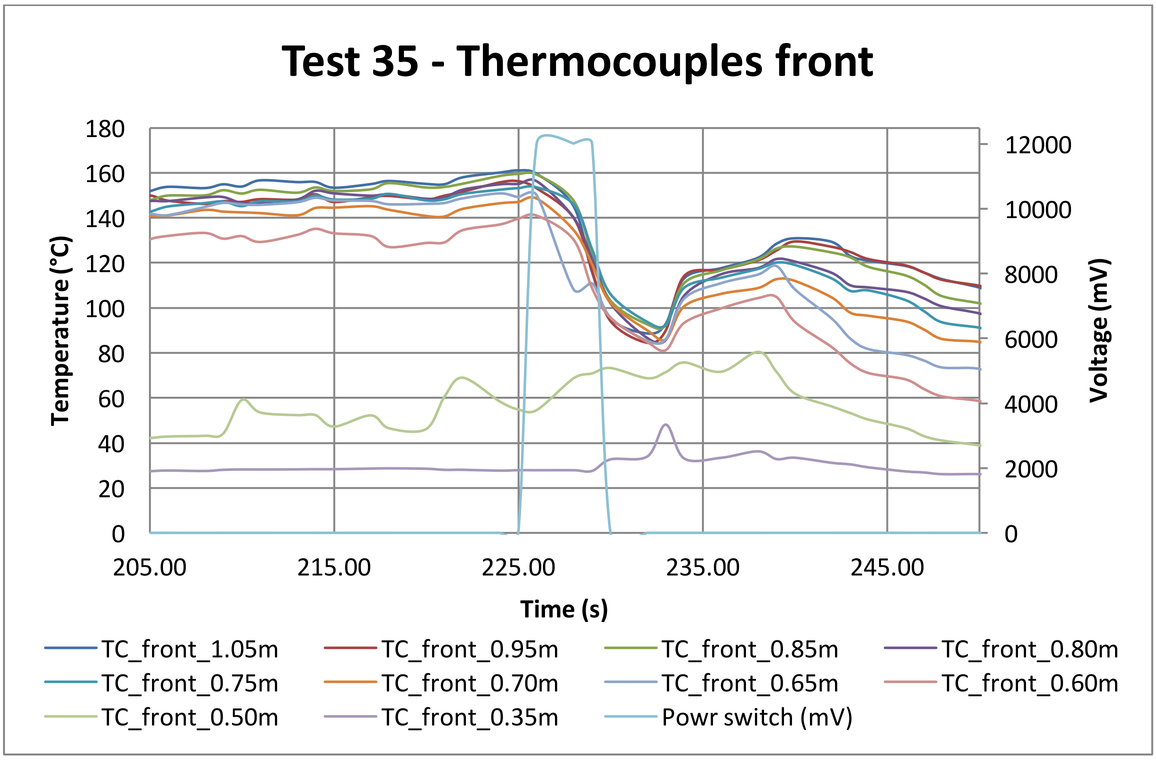

Figure 49 - Test 35: 5 bursts of 50 ml in an interval of 0.5s. The cooling is better than test 29 whilst the buffer time to reheat remains the same.

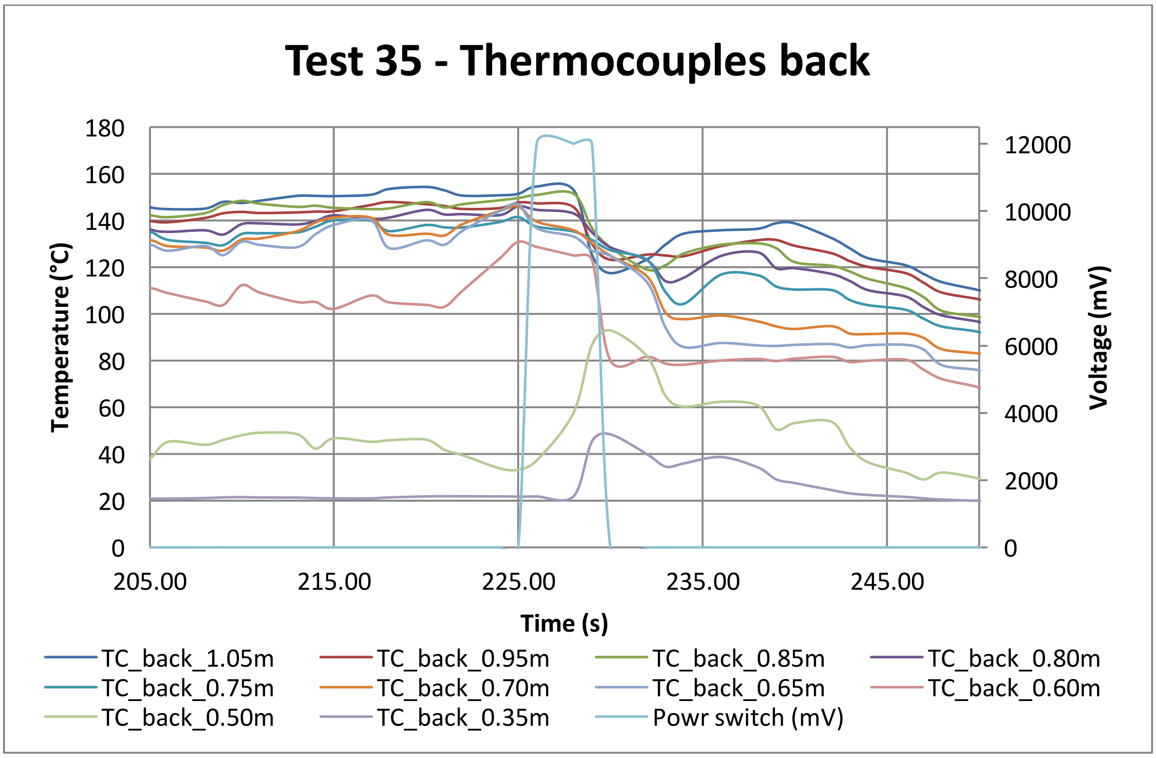

Figure 50 - Test 35: Thermocouples back. Again, are the temperature decreases higher than with the original interval times. The lower thermocouples show higher temperature readings, indicating a higher amount of turbulence.

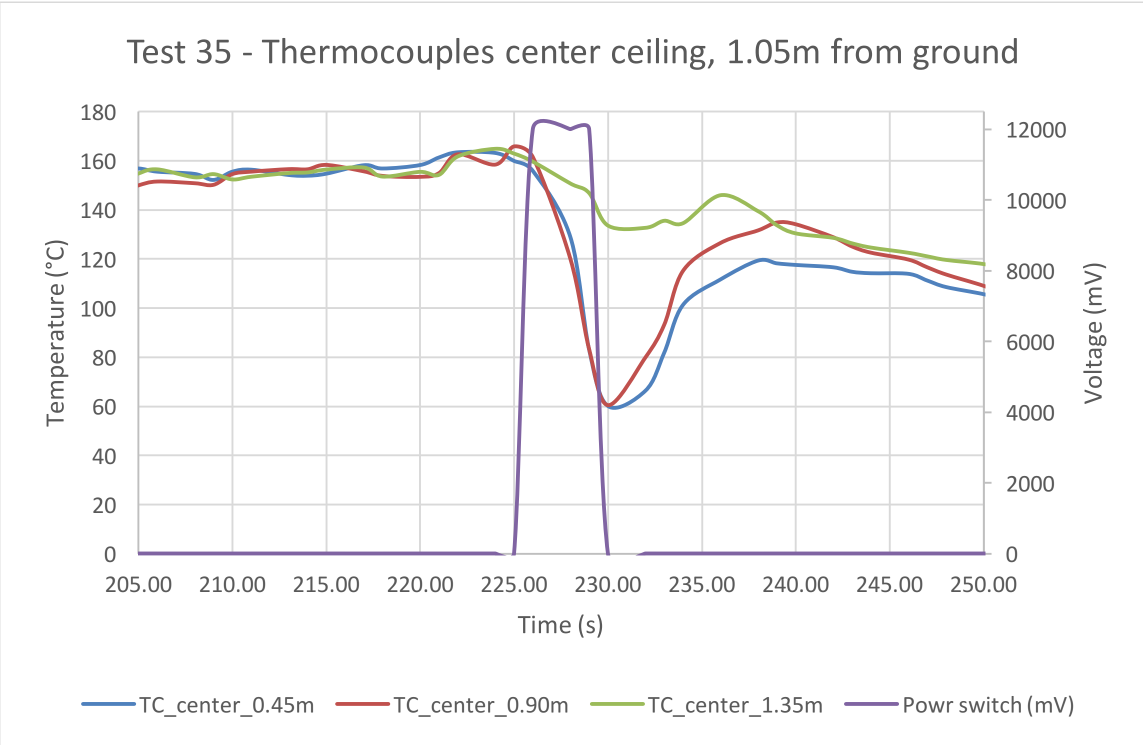

Figure 51 - Test 35: Center ceiling thermocouples. The more efficient cooling seems to be distributed over the whole room.

The application of a continuous stream did not seem to change the results too much compared to the fastest bursts as shown in test 35 and 36. The center ceiling thermocouples in test 36 (Figure 55) did show less cooling in the center. However, since there was only one test performed with a continuous spray, it cannot be concluded that this is better. Clearly, the results are alike.

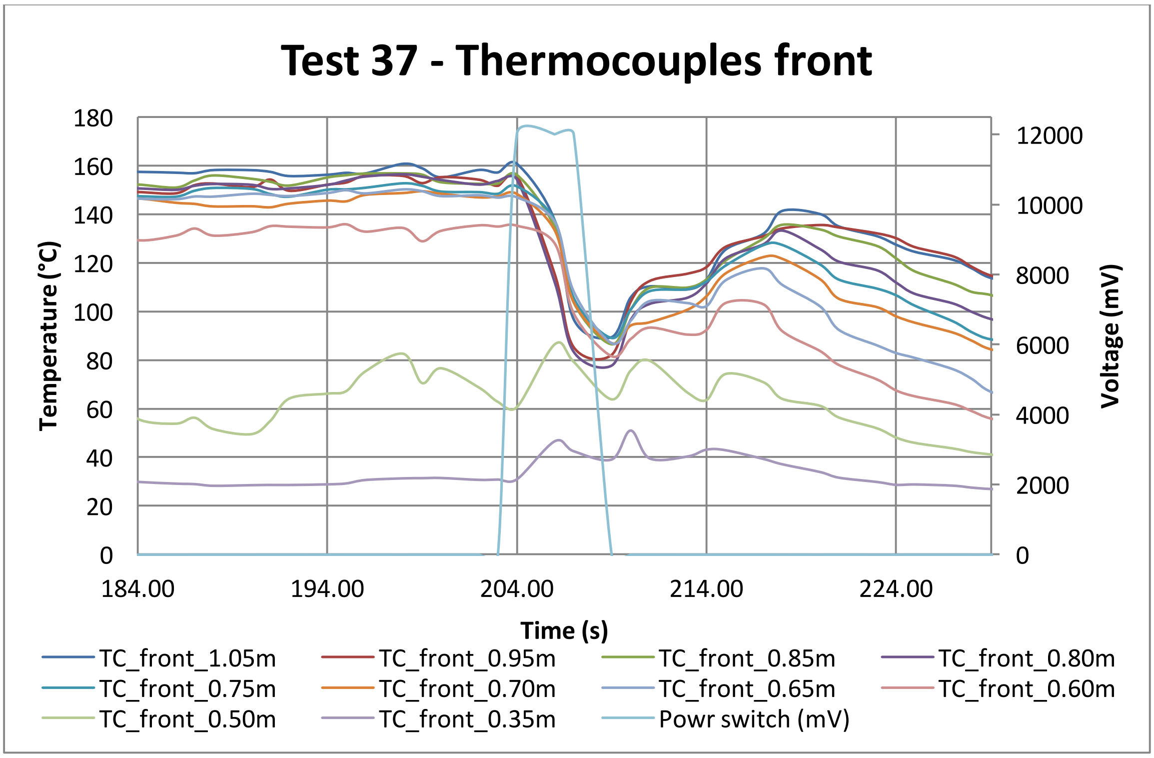

Figure 52 - Test 37: Continuous flow of 250 ml at 4 bar. The cooling is very effective and more or less the same as with test 35

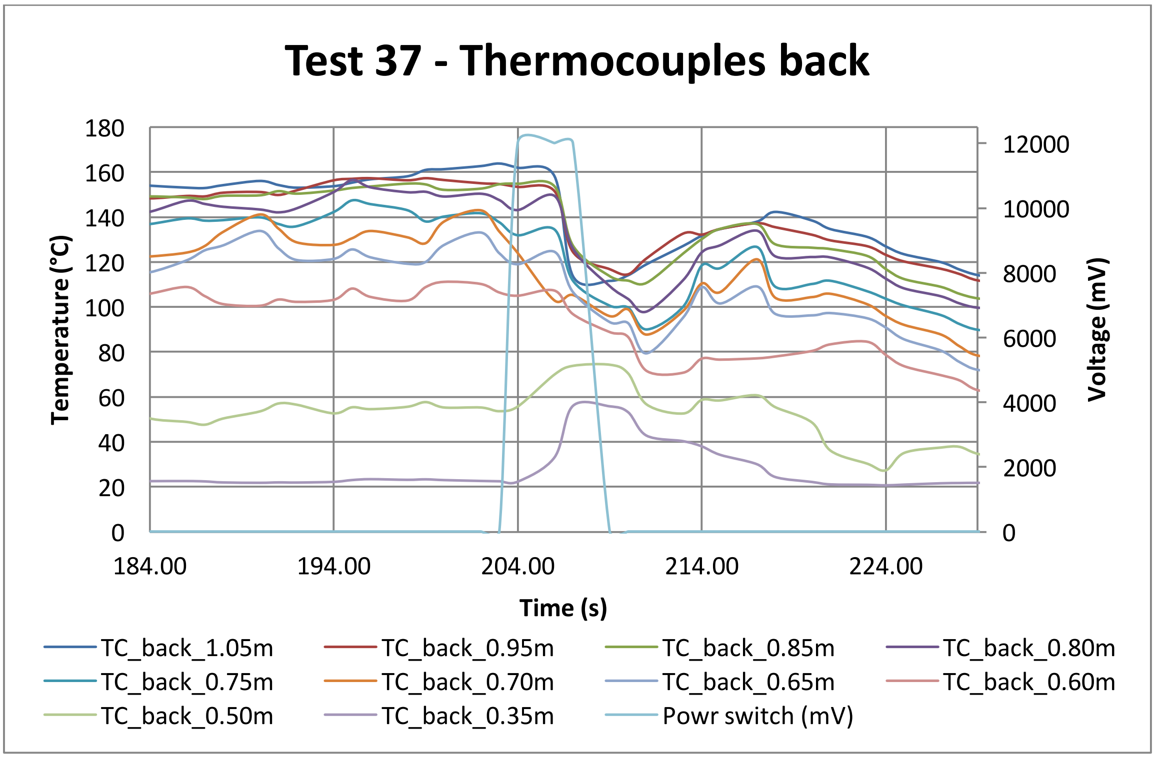

Figure 53 - Test 37: back thermocouples. Not much difference is seen in the temperature decrease compared to test 35. The lowest thermocouple gives higher readings, but the second one reads lower temperatures.

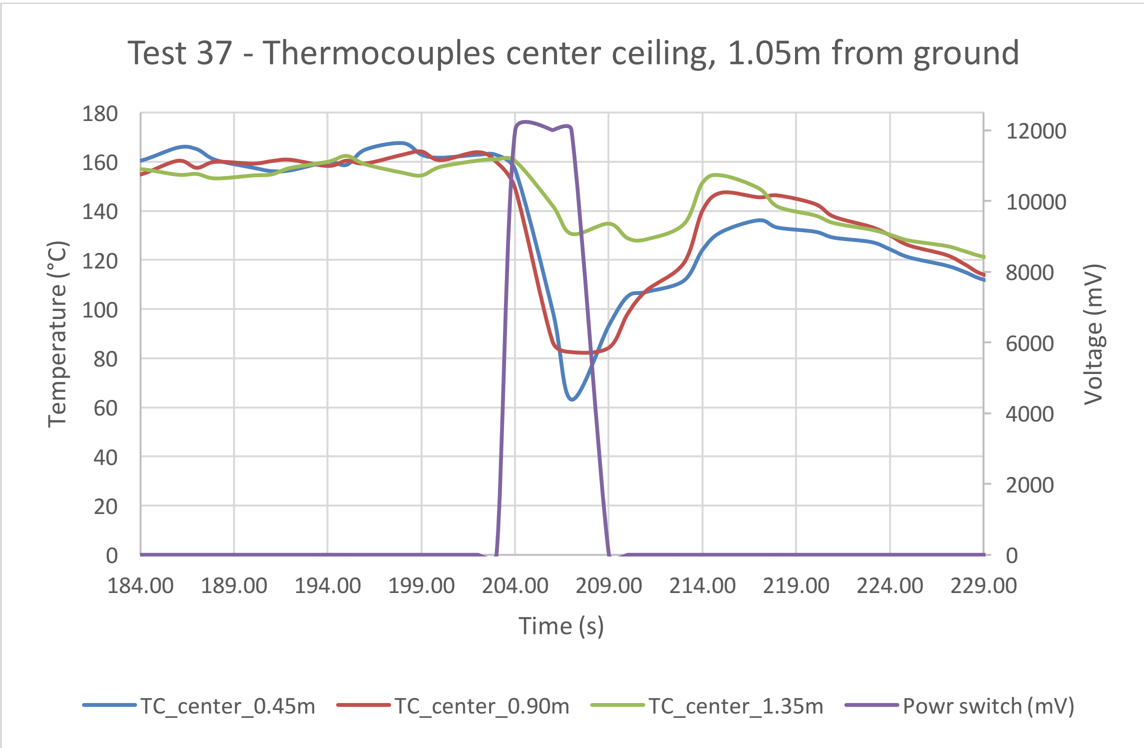

Figure 54 - Test 37: Center ceiling thermocouples.

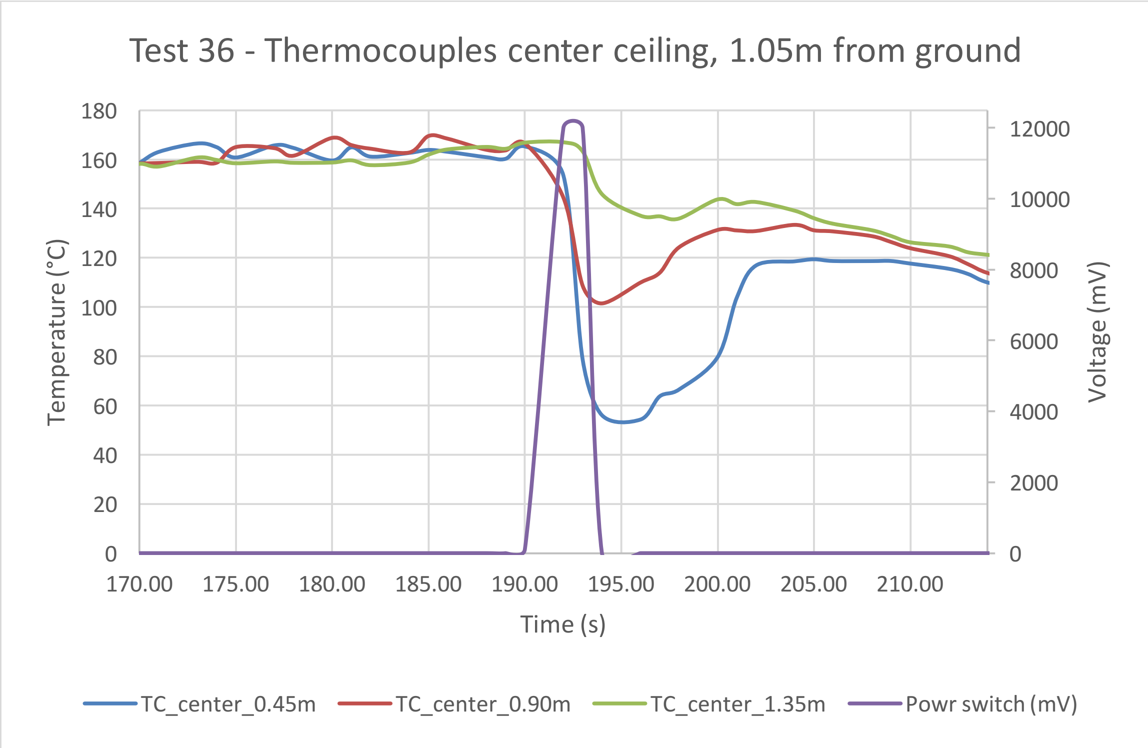

Figure 55 - Test 36: Same test as test 35. Center ceiling thermocouples.

In test 39 a continuous stream was used to spray 150ml of water in the gas layer. This test showed better results than test 29 and 40, even though only 60% of the water volume of those tests has been used. Figure 56 to Figure 58 show the temperature readings of this test with a lower volume. All different thermocouple sets showed an equal to better cooling.

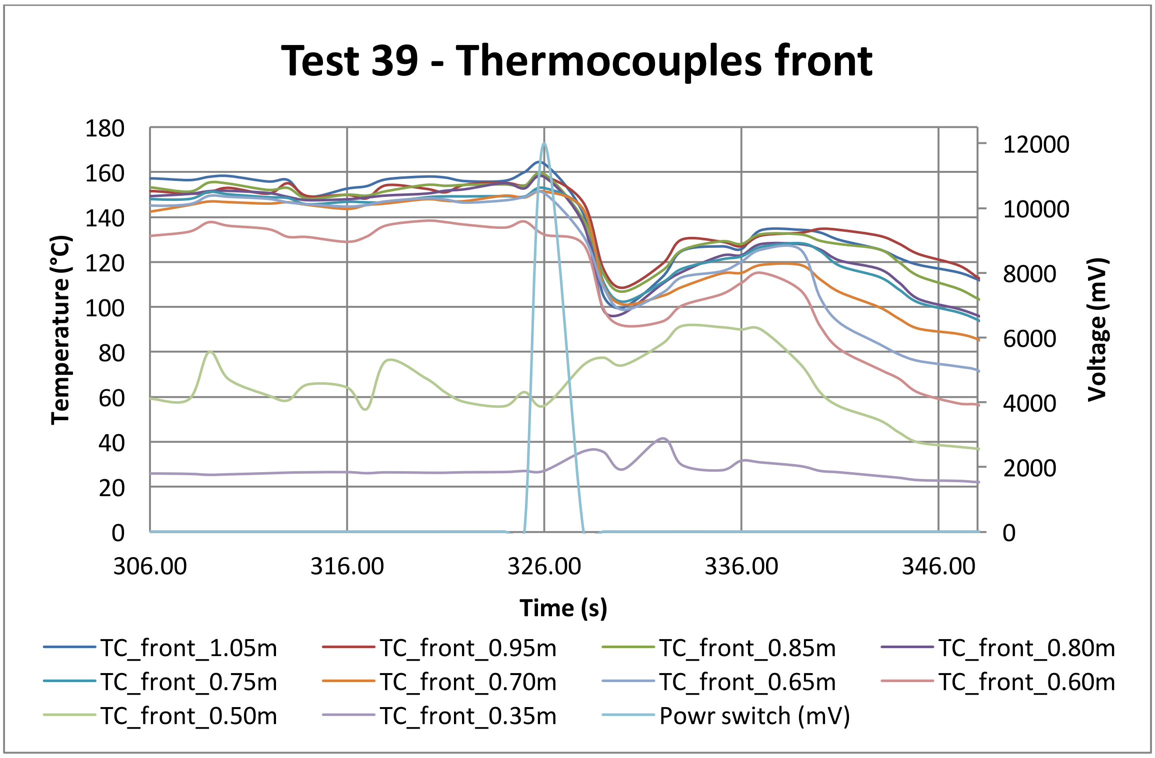

Figure 56 - Test 39: Continuous flow of 150ml at 4 bar. Using only 60% of the water which is used in the tests with bursts in intervals of 2s, an even better cooling occurs.

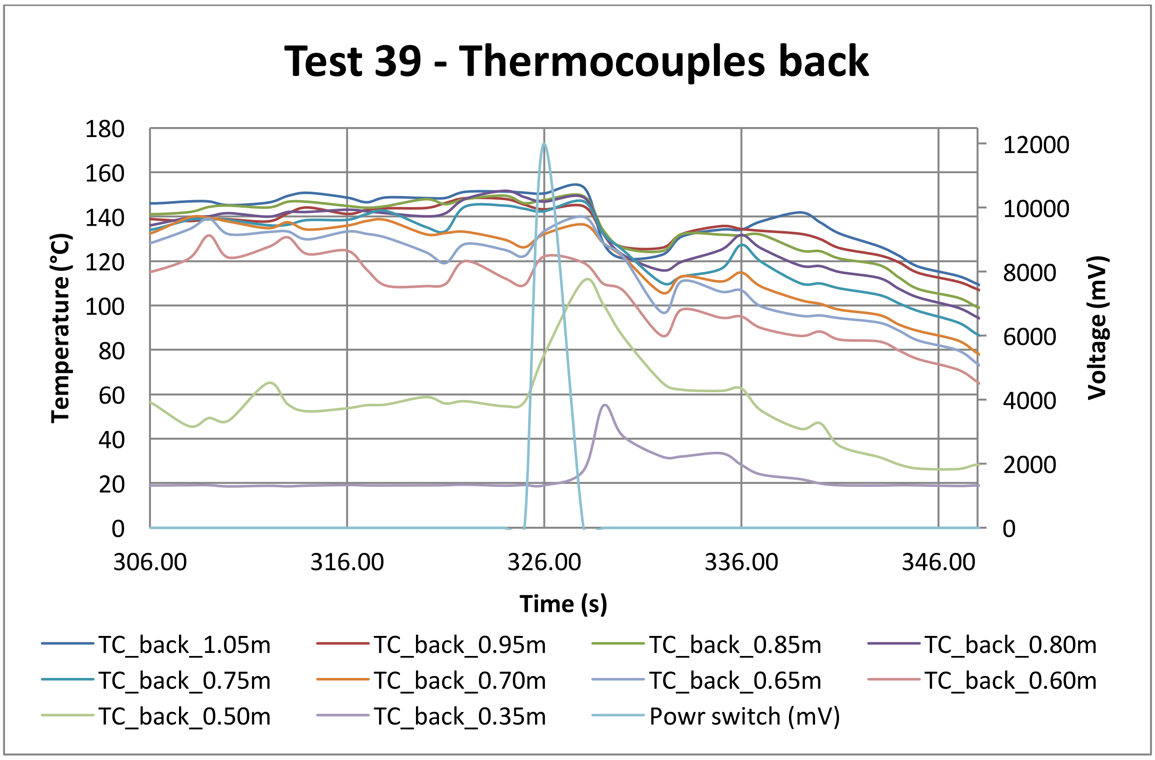

Figure 57 - Test 39: The back temperatures are also significantly better even though less water is applied

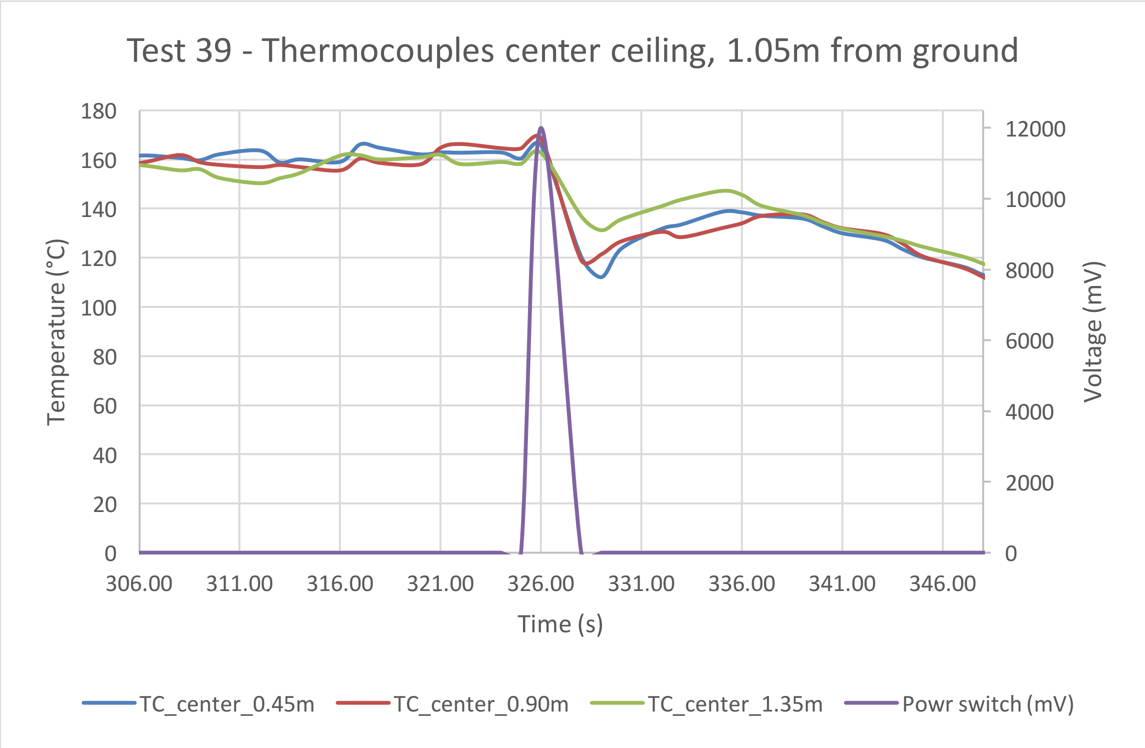

Figure 58 - Test 39: Center ceiling thermocouples

The continuous stream has been repeated for all the other nozzles at the 4 bar setting too. Of those tests, the full cone nozzle showed the most impressive improvement compared to the other two. The back and center thermocouples (Figure 57, Figure 58) give readings that are better than the ones of the small hollow cone nozzle by the application of bursts (Figure 38, Figure 39, Figure 41, Figure 42).

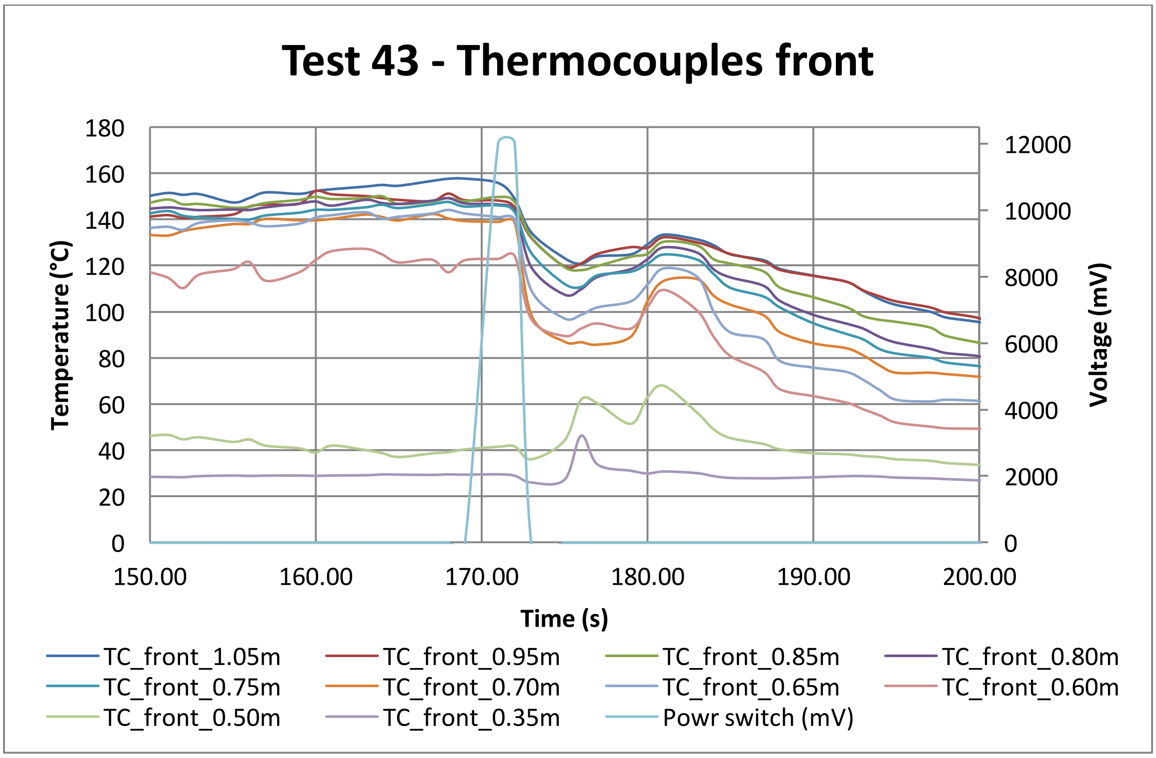

Figure 59 - Test 43: Continuous stream of full cone nozzle. 250ml at 4 bar with a droplet size of 2300 μm

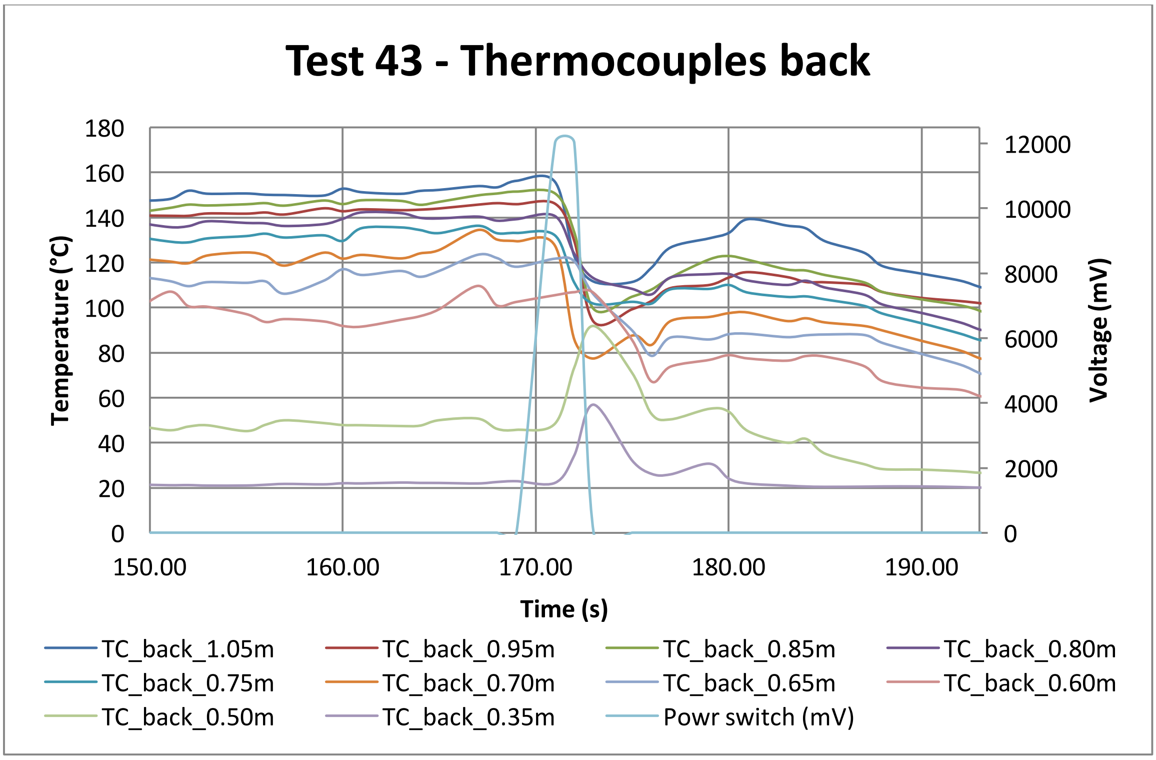

Figure 60 - Test 43: back thermocouples

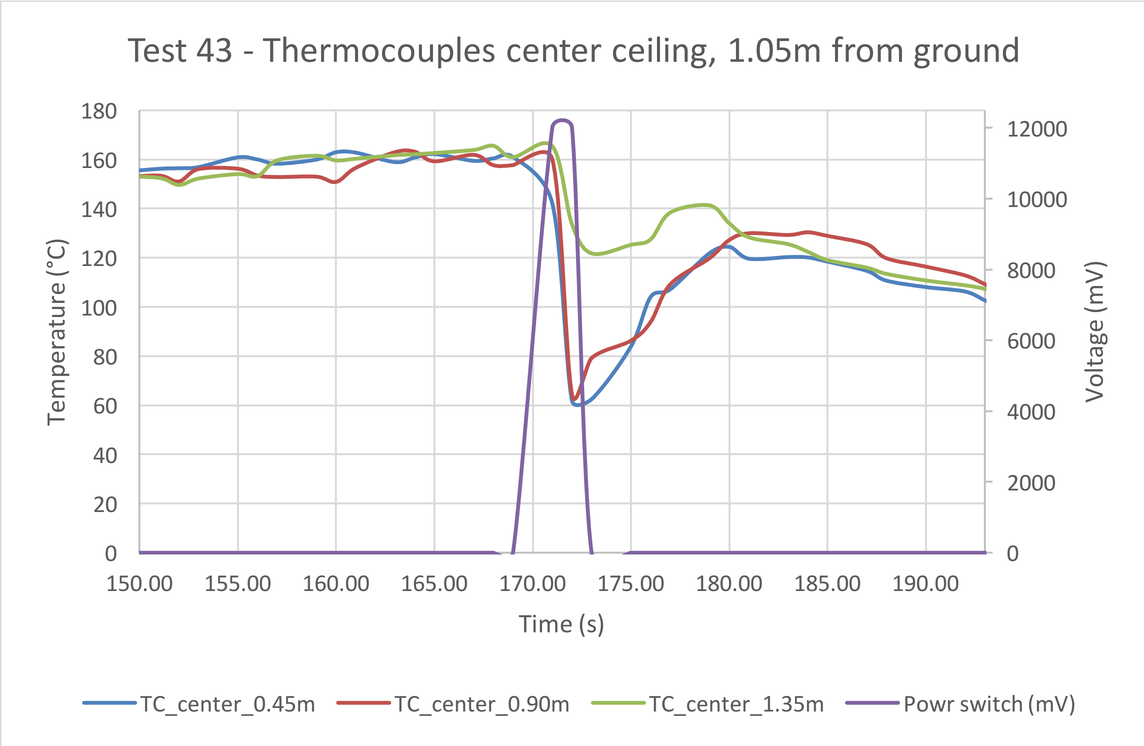

Figure 61 - Test 43: Center ceiling thermocouples

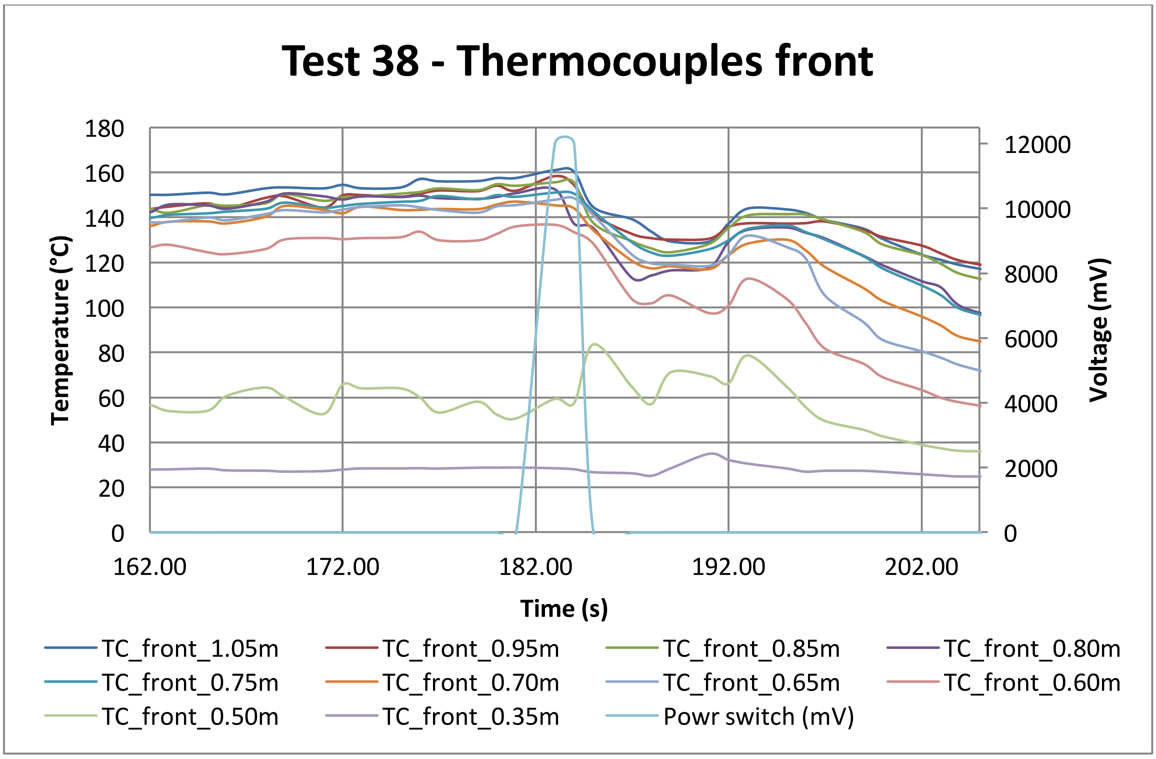

Figure 62 - Test 38: Medium hollow cone nozzle at 4 bar. Continuous spray of 250 ml with a median droplet size.

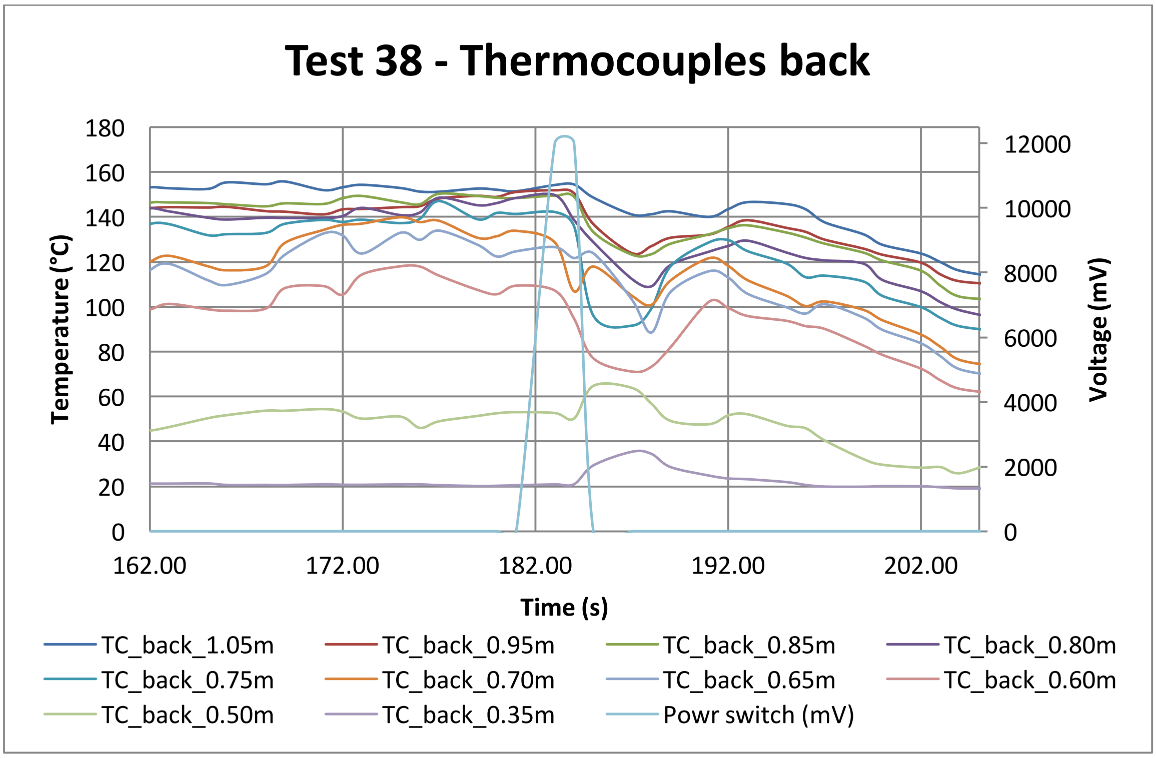

Figure 63 - Test 38: Back thermocouples

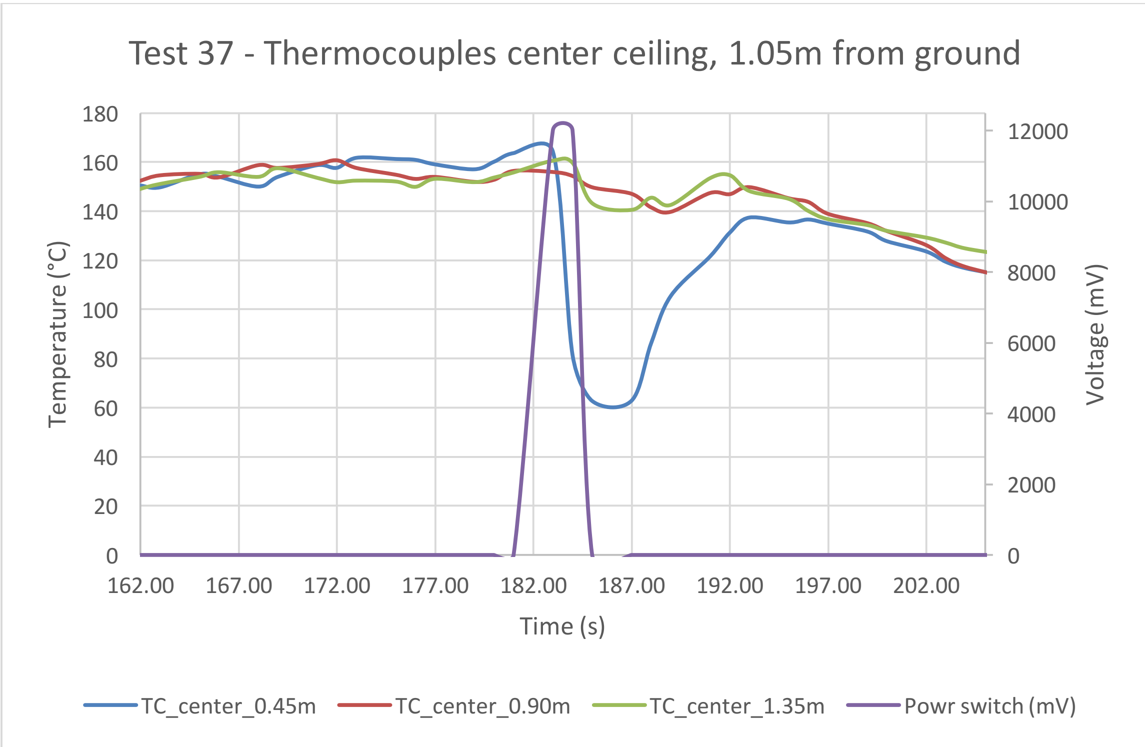

Figure 64 - Test 38: Center ceiling thermocouples

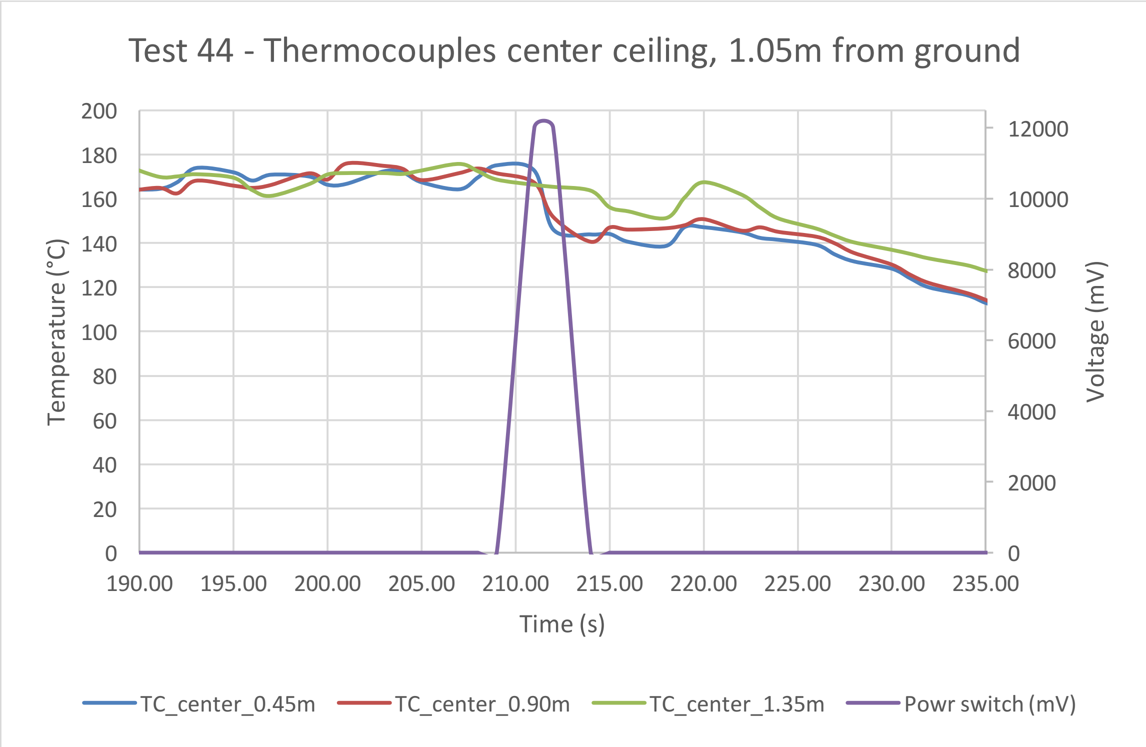

Figure 65 - Test 44: Fine mist nozzle at 4 bar. Continuous spray of 250 ml with a median droplet size.

4.3 Velocity changes measured over the opening

Even though gas layer contractions were hard to notice with the bare eye, the velocity readings do tell small changes. Overall throughout all the experiments, the velocity decrease was proportional to the cooling. Test 14 showed the best visual contraction of the gas layer with every burst. Figure 66 does not seem to show this difference by much. There is a slight decrease noticeable in bidirectional probe 3 (15 cm from the top). Test 29 and test 40 show a small velocity decrease but the outward velocities of test 40 then grow larger than before the water was applied.

Just as with the cooling, test 37 shows the best results closely followed up by test 36. As all the outgoing velocities decrease, the absolute values of the inward velocities seems to decrease as well. When the outgoing flow recovers itself, the absolute values of the incoming velocity seem to rise even higher than before the water application.

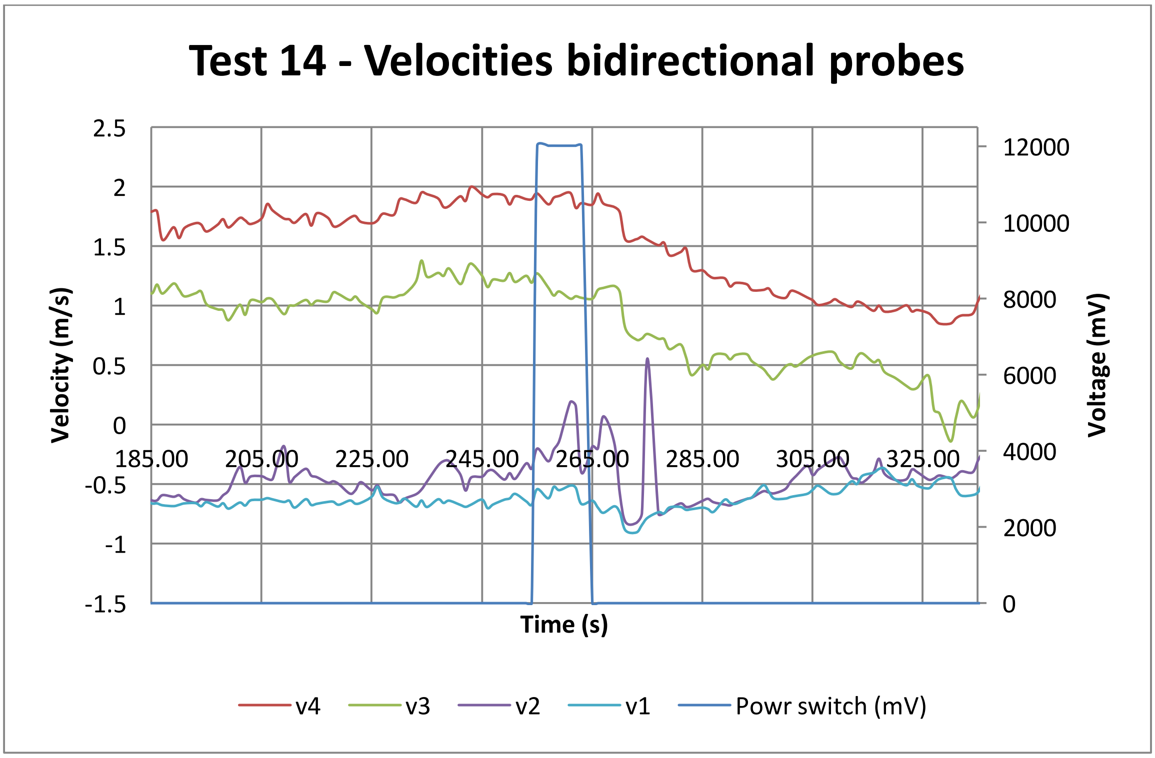

Figure 66 - Test 14: Velocities bidirectional probes

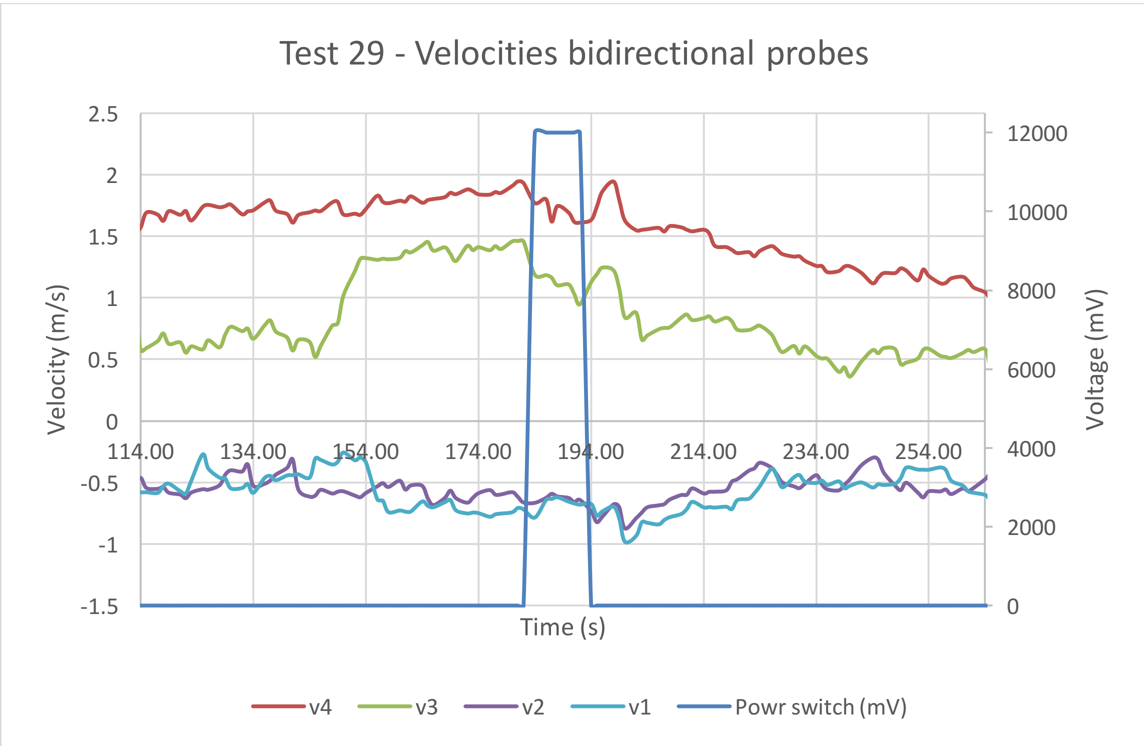

Figure 67 - Test 29: Velocities bidirectional probes

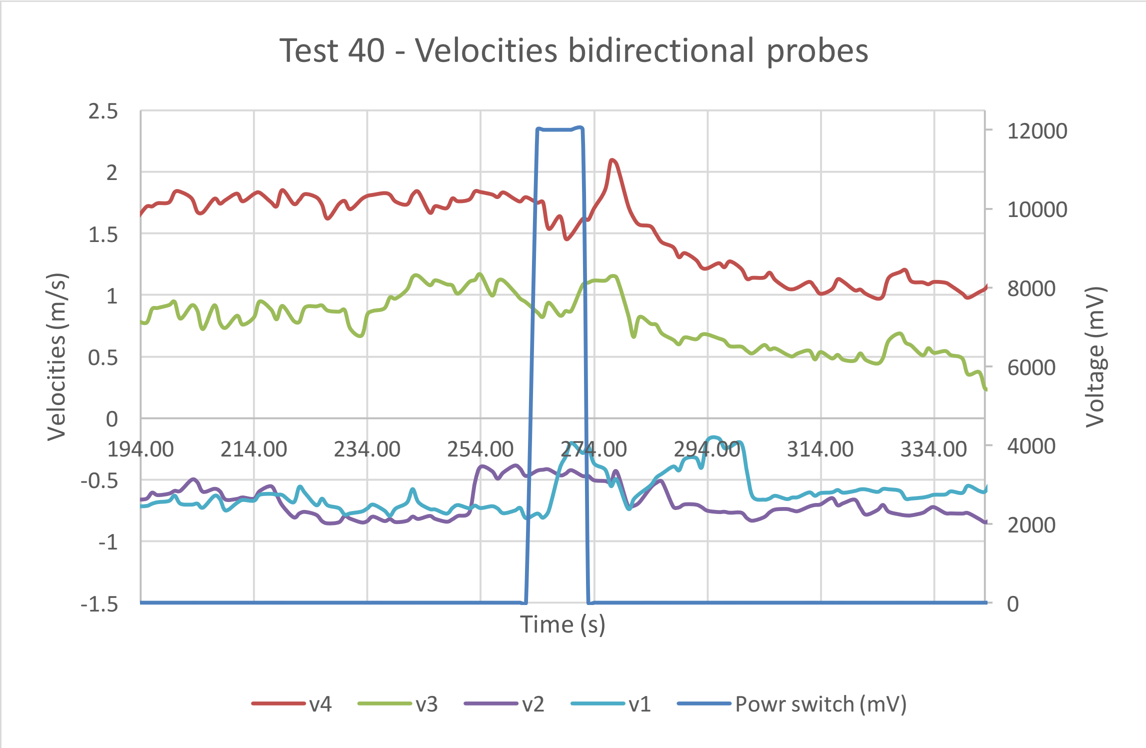

Figure 68 - Test 40: Velocities bidirectional probes

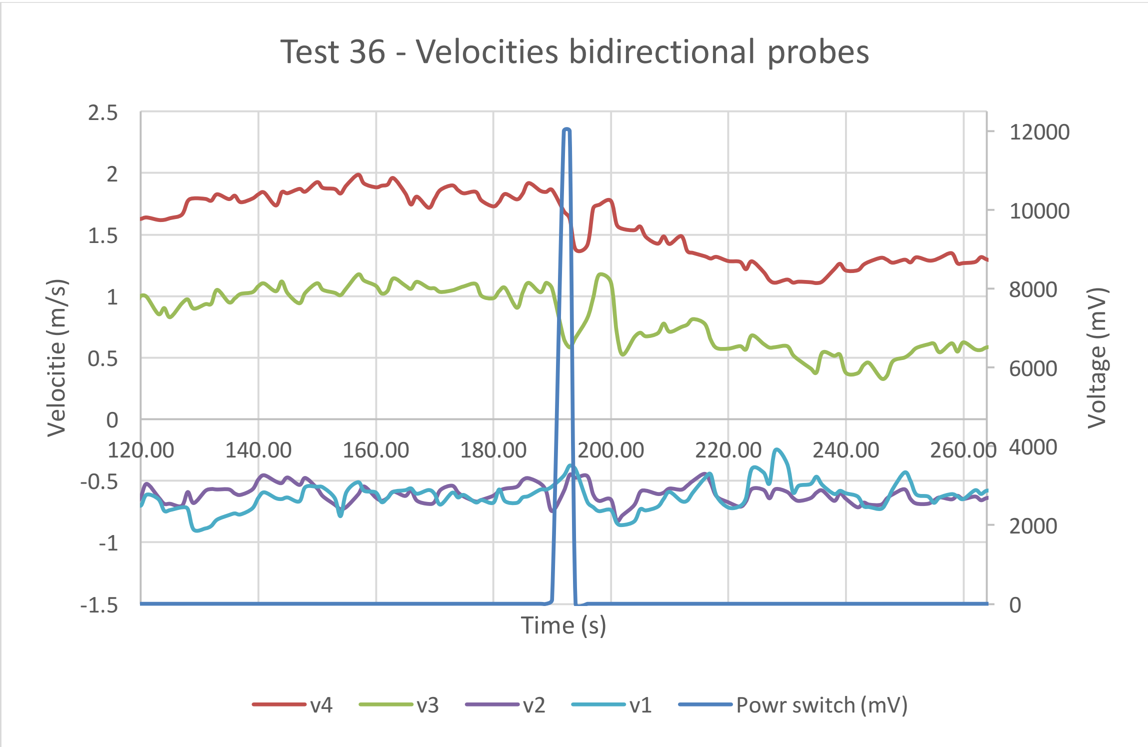

Figure 69 - Test 36: Velocities bidirectional probes

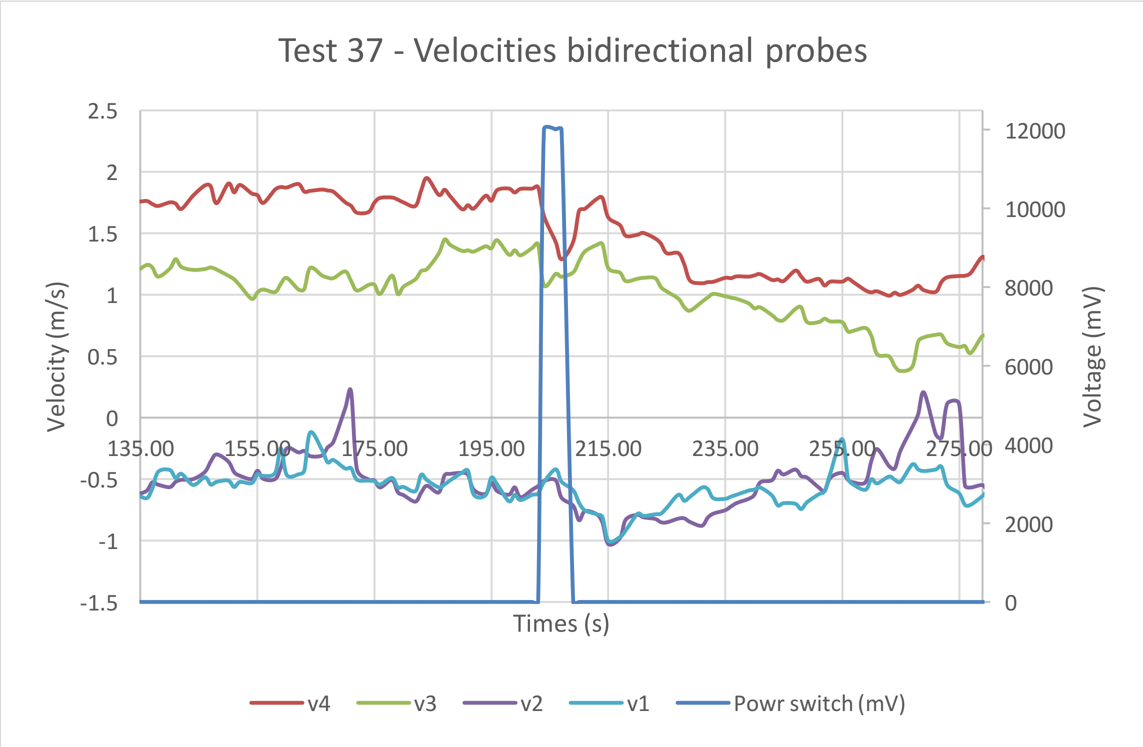

Figure 70 - Test 37: Velocities bidirectional probes

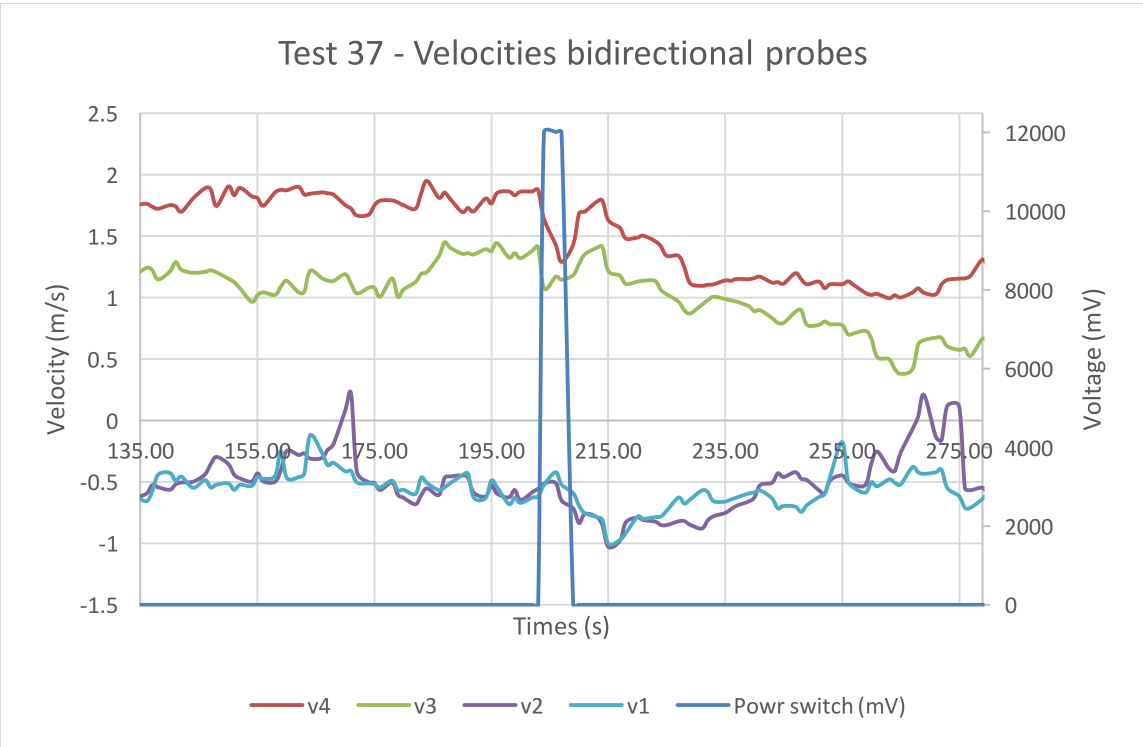

Figure 71 - Velocities bidirectional probes

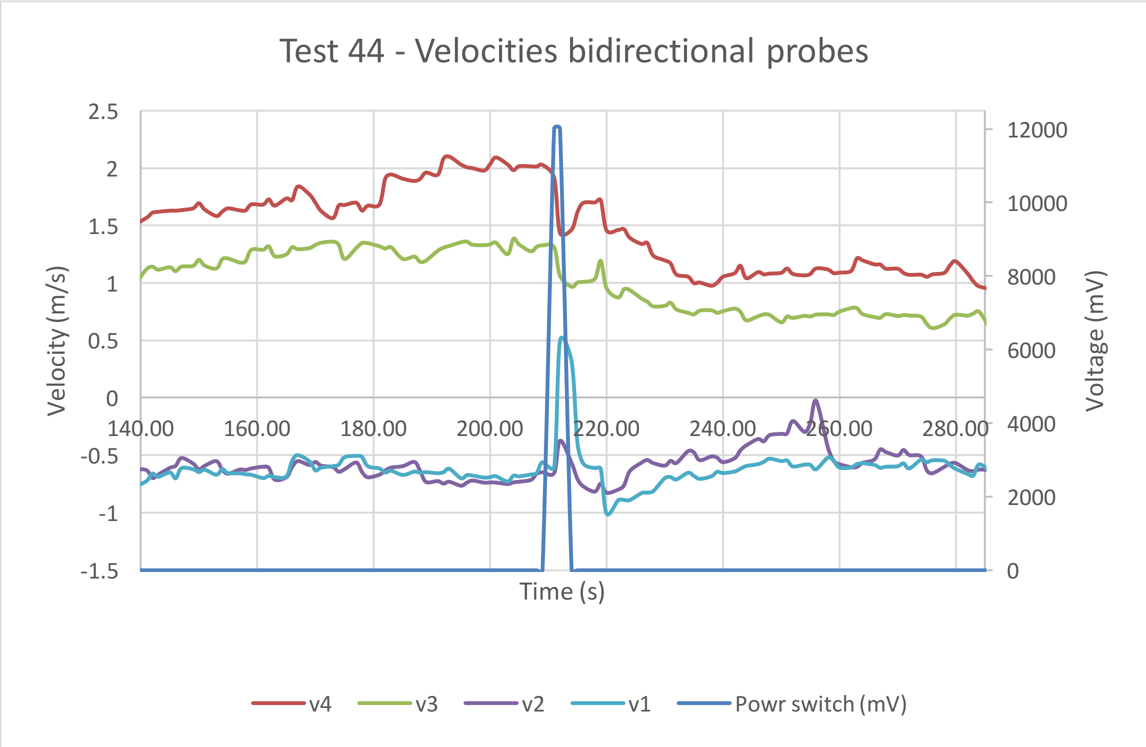

Figure 72 - Test 44: Velocities bidirectional probes

5 Discussion

The experiments delivered interesting results. This section will discuss what was noticed in the different output files that were presented in the previous section.

5.1 Droplet size

As the properties of water already showed, the most efficient cooling will result if the water evaporates. A fixed volume of water will evaporate faster when it is split into smaller droplets. Looking to the results, it can be seen that for every single nozzle the cooling efficiency gets better the higher the pressure is and thus the smaller the droplets are. A higher pressure also results in a larger velocity of the stream which creates both a higher and a further reach. This means that it is more likely that water hits the ceiling or the walls which results in a heat exchange between the water and the wall rather than the water and the hot gases. However, the temperatures decreased more at higher pressures even though the efficiency dropped because of the collision with the walls. One of the possible explanations could be that the ceiling is at the Leidenfrost temperature and is protected with a vapor layer, preventing further vaporization of the droplets. Video footage showed a wet ceiling during the water application, so this reason would be less likely. Another one could be that the Weber number is great enough for the water droplets to shatter in even smaller droplets allowing a better vaporization by the gas layer.

5.2 Efficiency of the full cone nozzle

Even though a better cooling was achieved with smaller droplets, it does not mean that larger droplets have no purpose at all. Larger droplets need more time to evaporate. The more they evaporate, the smaller they get and thus the faster they evaporate. This means that the further these droplets get, the more effective their evaporation becomes, which results in a better cooling at the back. Comparing the back temperatures of the full cone nozzle in test 8 (Figure 26) with the performance of the medium hollow cone nozzle of test 26 (Figure 36), little difference can be seen even though the median droplet diameter of the full cone nozzle is more than double than that of the hollow cone nozzle. When operated as a continuous flow, Figure 60 and Figure 63 show the full cone nozzle performed even better cooling than the medium hollow cone nozzle.

One reason that the full cone nozzle performs that well considering its larger droplets might be that the spray pattern allows more water into the gas layer compared to a hollow cone. The spray is also directed more towards the front as it sprays all the water within the boundaries of the cone whereas the hollow cone only sprays the water at the edges of the cone.

Having a full cone spray pattern also results in more water hitting the ceiling or boundaries. This allows the water to split into smaller droplets due to the impact.

It is interesting that this full cone nozzle only performs better than the medium hollow cone when the spray is used as a continuous spray. In the separate bursts, the hollow cone performs slightly better but the results are almost comparable. Every time a nozzle opens and closes, the droplets tend to get bigger during this action. This has been observed for all the nozzles while measuring the flow and reach. By performing a continuous spray, this flaw is reduced and might be the deciding factor for the full cone nozzle to outperform the hollow one instead of having equal results.

Another reason might be that the mixing of the gases is better than with a hollow cone spray. All the gases within the cone get pushed towards the back while at the same time they are being cooled. The hollow cone nozzle will not push any gases within the cone. It could be said that the cooling of the hollow cone nozzles relies more on the evaporative cooling whereas the full cone nozzle also depends on the momentum it transfers. It could also very well be that there is a reading error since these tests have only been performed once. The center ceiling thermocouples at Figure 61 for once, show a huge difference compared to those of test 38 at Figure 64. Even if the efficiency of the hollow cone nozzle is bigger, it makes no sense that these large droplets would be more efficient closer to the front. It is most likely that these readings are due to the thermocouples getting covered by the water. More tests are therefore required with a possible shielding of the thermocouples.

Having a more efficient cooling in the back also results in a slower reheating time in the front. Since the gases move from the back to the front, the colder gases now mix which results in a slower temperature increase.

5.3 Reach

The finer the droplets are, the better the efficiency, however, this is useless if the spray cannot reach the gas layer. The fine mist nozzle had the smallest droplets of all the nozzles but did not perform well because it did not have enough momentum. The momentum of the gas layer was stronger, which pushed a lot of the water outside. In the close vicinity it did perform very well which was to be expected. This nearby field where the cooling does work is very small though. Height wise the thermocouples only showed significant cooling up to 0.80m. The reach is harder to tell since only the lower thermocouples showed significant temperature drops. Nevertheless, Figure 65 shows a similar cooling of 45 cm and 90 cm in front of the nozzle.

5.4 Interval time

For the majority of the tests, an interval time of 2s was chosen in between the different bursts. This seems very long considering the constant inflow of new hot gases. However, this allows a better understanding of what actually happens in between those bursts. It has been seen that about 30 to 50% of the water droplets reached the floor. The motion of the gas layer was also easily seen in those 2s. On top of that it also gives a representation of a lower limit to how long this time in between the bursts really can be.

Nonetheless, it was clear from the results that the shorter the interval time between the bursts was, the better the gases cooled. This is very logic since there is less time for new hot gases to be introduced to the ISO room. The best results were seen for the tests with intervals of 0.5s (test 35 and test 36) and the continuous flow (test 37). There were no major differences for the frontal temperatures compared to the tests with intervals of 2s, although test 40 did show that the higher two thermocouples did not cool below 115°C (Figure 40) whilst the others did show temperature drops slightly below 100°C for all the front thermocouples (Figure 37, Figure 49, Figure 52).

The biggest differences are seen more towards the back. Both the central ceiling thermocouples and the back thermocouples show a tremendous better cooling. While all the fast applications result in a cooling below 120°C for the upper thermocouples at the back, test 29 and test 40 show hardly no cooling for the upper thermocouples at all (Figure 38,Figure 41). For the lower thermocouples, the cooling was more or less the same for all the tests that were applied in separate bursts. The continuous flow did show better cooling with an average difference of 10°C for the lower thermocouples and up to 20°C of difference for the upper ones.

Because of the faster application, the gas layer has lesser time to reheat. The more the frontal temperatures decrease, the less droplets evaporate there and consequently reach further towards the back. Assuming that the vertical temperature distribution is similar to that of the frontal thermocouple tree if both upper temperatures are alike, Figure 54 and Figure 58 show that the gas layer has completely descended to 100°C up until the half of the ISO room.

One drawback that has been seen with the continuous flow is that after the coldest point, the reheating occurs much faster and the final temperatures get higher than those at the tests with separate bursts. One explanation for this might be that the higher momentum of the continuous flow results in more turbulence at the back walls which leads to better mixing of the reintroduced gases.

5.5 Buffer time

The most important result of these experiments is that there is a certain buffer time before the temperatures start to rise again after the water application. As firefighters use this technique to advance in their interior attack, it is favorable to have some time in between the nozzle application and the movement.

These experiments showed that there is quite some time after the application of water. Test 29, test 40, test 36 and test 37 all showed a buffer time of about 10s. Since the burner was stopped 5s after the nozzle was shut off, they could not heat up further. However, in 10s a crew can have advanced a lot further and could apply gas cooling again. In those 10s of reheating, the temperatures also did not reach their initial states from for the water application. The upper temperatures were about 20°C lower than initially whilst the lower ones could differ 30 to 40°C.

On top of that, test 29 and 40 show a short stagnation of the lower frontal temperatures for about 3s after the water application. In test 36 the frontal temperatures remained under 100°C for 5s.

5.6 Theoretically required volume compared to practice

The theoretical calculations showed that a 28 ml of water was required to cool the fixed gaseous layer of the steady state condition to the desired end temperature of 100°C. An additional 0.3 l/min or 5 ml/s would be required to control the new incoming gases from the fire room. These numbers are based on ideal conditions such as an immediate and equally distributed heat transfer of the water with the gas layer, no losses and no extra factors such as motion and turbulence. In practice, these conditions do not occur.

In the experiments, the most effective cooling will occur close to the cone of the water spray. Moving away from the cone will initially improve cooling as droplets get smaller due to the evaporation and the drag they experience. At one point the evaporation will be complete and moving further from this point will not yield any major cooling.

The outwards flow of the gases will result that cooling closer to the opening is easier since the hot gases both get cooled and constantly replaced by cooled gases from further in the room. The gases that are cooled in the back, constantly mix with new incoming hot gases which makes it harder to bring these temperatures down.

The tests with the small hollow cone nozzle performed the best cooling at a tank pressure of 4 bar. It was observed that about 30 to 50% of the water droplets reached the floor. Using Eq. 13, which predicts the droplet life time, it can be seen that the life time and resulting fall length will be 12 times larger than seen in Figure 4. From the remaining 50 to 70% of the droplets that do not fall on the floor about 10 to 15% appeared to hit the ceiling. Some of the water that reached the floor is due to hitting the hitting the ceiling and falling back.

The majority of the tests introduced water pulses with a volume of 50 ml each, a volume that theoretically should be sufficient to cool the initial gas layer. A test with one burst of 50 ml was applied but did not bring the temperatures to 100°C, not even in the front. Tests with two bursts did succeed to bring the frontal temperatures to almost 100°C which can be seen in Figure 43. Figure 45 shows that the temperature readings at the top thermocouples show temperatures that are about 10°C more. The back temperatures of the gas layer decreased about 20 to 30°C up to 0.75m.

Applying more bursts without changing the speed does not seem to change very much in the frontal part of the ISO room. The temperatures are overall about 10°C lower but the back temperatures are more or less the same.

Test 37 managed to cool the entire gas layer the best. A flow rate of 9.1 l/min was necessary to achieve this. About 1.7s was needed to create 250 ml with this flow rate. Theoretically, 0.3 l/min is required to neutralize the inflowing gases from the fire room whereas 28ml over 1.7s comes down to a flow rate of 1 l/min. Combining those two results in a theoretically required flow of 1.3 l/min. A flow rate of 7 times the theoretical one was required to cool all temperatures to 100°C.

This efficiency rate would obviously increase if higher temperatures are used and a larger scale is being used. The first would result in a smaller droplet life time while the latter creates a larger gas layer where it can travel through.

5.7 Layer height

As mentioned before in section 3.4, the gas layer changes are hard to notice with the used gas temperatures and small scaled gas layer. Considering the observed values of about 30 to 50% of the water hitting the floor and 10 to 15% hitting the ceiling, this means that about 35 to 60% of the droplets vaporize in the gas layer. The proportion of water that gets vaporized in the gas layer was given as the b-factor in Eq. 11. These percentages can therefore be used written in their decimals. Table 9 has included the reduction rate for these b-factors of 0.35 and 0.60. In that table it can be seen that only a theoretical reduction of 1.5 to 5.8% would be possible. It is also worth noticing that if 35% would be an accurate observation, it is very close to the 30% or 0.3 b-factor which results in a gas layer expansion rather than a contraction.

At the location of the nozzle the gas layer was clearly observed going up. This is mainly because of the velocity of the water flow but could possibly be due to the cooling as well. At the edges of the room, the smoke descends. This is also due to the introduced motion of the water-spray. As mentioned before, the hot gases get pushed by the spray and this momentum is then transferred to a vertical motion once it hits the walls. The layer descents at the sides by about 5 to 10cm however it is hard to see whether the complete layer descents. Less than 20% of the water should be vaporized by the layer in order to make it descent more than 5cm. Based on the observations, it is unlikely that such few water was vaporized although it should not be excluded since there were no exact measurements. The disruption does recover itself relatively quick. For the tests with bursts applied every 2 seconds this is within the second and goes up to 3 seconds for the long continuous spray. Test 39 where very fast burst with 0.5s in between were applied, combined the cooling effect of a continuous flow with a 1s recovery of the layer height.

The bidirectional probes do show small velocity decreases for the outgoing gases during the operation of the spray. This is most likely again due to the momentum of the spray since they immediately return to their original states after the spray is stopped. However, the 3rd bidirectional probe has a lower recovery time which could imply that a gas layer contraction did occur.

The inflowing velocities also decrease in absolute value when the nozzle is operated. This is probably due to the momentum that changes directions once the gas motion reaches the walls. After the nozzle operation these velocities increase again and reach even higher values than before the water application. This could also imply a contraction of the gas layer as this would create an under pressure which allows more entrainment from the inside.

The fine mist application in test 44 shows that the velocity changes direction at the position of the 2nd bidirectional probe (Figure 72). As mentioned before, the fine mist nozzle creates a cloud of water droplets around the nozzle. This cloud disrupts the motion of the outgoing gases. The higher momentum of the gases push some of the lower layers to the outside as well due to this disruption. After the nozzle is shut off, the upper velocities don't reach their initial velocity and at the height of the 3rd probe, the velocity stays constant to the lowered state for a couple of seconds. The smaller droplets are, the slower they fall and the more time they have to evaporate. Consequently, the cooling can last a little longer and therefore also the contraction.

One particular interesting observation was the outgoing velocities exceeding their initial values after the application of water in test 40 (Figure 68). This was also seen in several other tests where the bursts were applied by the 2s intervals. Since the total time is larger than the continuous stream or the faster bursts, more gases are added to the ISO room. It could be that these gases are built up during the cooling time and that the contraction simply is not enough to compensate these extra gases.

5.8 Steam

Although thermocouples measured temperature changes, they are not able to read the moisture or gas concentrations. As the water droplets vaporize, steam arises. All nozzles but the fine mist nozzle, produced a high velocity, pushing the gases forward. It is most likely that formed steam would follow this flow pattern as well.

The spray of the fine mist nozzle however did not have a very high velocity. The droplets were sprayed as a cloud and remained close to the nozzle. A substantial amount of the spray was pushed outwards with the fire gases. This could bring the nozzle operator in danger as steam could be blown in his face.

A more thorough research on the gas concentration after the cooling could give clearer answers.

5.9 Translation to reality

These experiments were applied in a half scaled ISO room. Changing the room set-up to a full scale ISO room would surely impact some parameters. On the real fire ground, rooms are typically even larger than an ISO-room.

For equal temperatures, the translation to practical situations is fairly simple. Eq. 5 expressed how to find the right amount of water in order to cool the gases to a desired temperature. If the temperatures of the experiment are kept the same, the only variable that is left in the equation is the mass of the gases. The required amount of water is directly proportional to the mass of the gases. If the temperature stays the same as in the experiments, it is proportional to the volume of the gases. In other words, assuming that the gaseous layer also has been geometrically scaled, this would mean that the volume would be 8 times bigger, hence the flow rate should be 8 times bigger. Scaling the flow proportionally with the volume is a conservative action. According to this work, a flow of 72.8 l/min would be needed for similar conditions in a full scale setup. At higher temperatures, the droplet life time will be smaller, so better cooling will certainly occur.

The droplet size should also remain the same to achieve the same cooling efficiency. There are several nozzles on the market that allow larger flows yet maintain a small droplet size. Svensson et al. [17] have used nozzles from Akron™ [27] that can provide droplets of 200 μm at a flowrate of 170 l/min. TFT G-Force® have nozzles that can deliver a flow of 250 l/min while still having very small droplets. The latter has no exact data, but visually they look the same as the tests with 500μm droplets.

These flows are quite larger than the 72.8 l/min but rooms of a house are generally larger than an ISO room. Also, the gas temperatures of a house fire will most likely rise above the 150°C were this research has been based on. Lastly, gas cooling is not the only purpose of the fire service. It is important to realize that it is a way to protect themselves while the crew advances towards the fire seat. In the end, the crew will still have to tackle the fire seat which generally requires a larger flow.

6 Conclusions

These experiments provide several conclusions that can deliver a better understanding of gas cooling as a well as an optimization of the technique.

First off, all nozzles are able to provide a decent cooling if one knows their characteristics. Full cone nozzles have larger droplets but allow a better distribution in the gas layer. They are very much suited for cooling the back and for having more stable temperatures in the front. They are not suited for fast and close gas cooling though.

Fine mist nozzles have small droplets that cool gases almost instantaneously. However, the nozzle provided in this work did not have a sufficient reach, resulting in a cooling only in the direct environment of the nozzle operator. A fine mist nozzle could perform well if it has a stronger momentum than the outgoing gases.

Hollow cone nozzles performed the best due to their combination of a far reach and the smaller droplet size. A temperature decrease from 160°C to 100°C was achieved over the whole ISO room having the nozzle at a fixed position.

Of all the nozzle setups, a higher pressure, and thus a lower droplet diameter, for a same nozzle always resulted in a better cooling regardless of the fact that parts of the stream hit the ceiling or the walls. It is likely that an upper limit exists, but this has not been reached in this work.

Secondly, the time in between different bursts should be kept as short as possible. In this experimental setup, a continuous water flow performed slightly better than pulses every half a second although the reheating was also slightly faster.

Although the layer height was not observed to change very much, the conditions did not get worse! Even though the height stays stationary, the gases have been cooled. It was predicted that changes would be hard to notice at these gas temperatures and room dimensions. The gas layer goes up at the nozzle interface but goes down at the edges. The layer descent is minimal and recovers within the 3 seconds.

There is a relative long buffer time after the application of the water, especially in the front. The first two seconds after the nozzle closes, the gases continue to cool for 2 seconds. The speed of reheating afterwards depends on the droplet size and interval time. This was generally slower for larger droplets and for the bursts with longer interval times. This stagnation time was only true for the tests where fast bursts and a continuous flow were used. The continuous flow that performed the best cooling did not show this stagnation time but rather heated as soon as the nozzle closed.

Lastly, a complete cool down of the gas layer below 100°C was not achieved in this research. Comparing this with real life scenarios, the need to apply water sprays at different locations is required.

7 Future work

Although this study delivered fruitful information on gas cooling, it also crafted new ideas on how to improve the experimental setup and create an even better understanding and optimization of the technique.

This work has been limited to a fixed nozzle position to cool an entire room. In reality a nozzle operator can apply its spray over the entire width of the room. This could be replicated with a nozzle that can rotate around its z-axis. This rotation could cover both fast bursts and a continuous burst as the motion of the gases will be completely different.

The nozzle was positioned at an angle of 45° with the floor. This was done in order to obtain a maximum reach of the spray. Rather then trying to cover the whole room from one position, research can be performed to optimize the gas cooling in the direct environment of the nozzle and subsequently let the nozzle advance more towards the fire seat. Thermocouples or radiometers could be placed on the nozzle to know what the thermal impact on the nozzle operator is.

During the experiments, the full cone nozzle at a continuous stream performed better results than the continuous stream of the medium hollow cone nozzle. This is particular interesting since the droplets of the full cone nozzle were more than twice as big and its reach was also further. More research on these thicker droplets could provide a deeper understanding.

Although propane is an easy to control fuel, a sootier fuel could deliver better visual observations.

At a firefighting scene, no thermocouples are present to show the exact temperatures of the gases. Finding measuring methods or patterns that can be performed or seen could be an interesting development towards the practical implementation.

Steam is more dangerous than smoke gases for a nozzle operator. A humidity meter could measure the amount of steam at the height of the nozzle operator rather than solely focusing on the temperatures.

This research mainly focused itself on the cooling of the gas layer and the possible gas layer contraction. However, applying water to this layer also results in inerting the layer. The ignitability of the layer could be another interesting objective for further research.

Lastly, once an adequate understanding of gas cooling in a small scale environment is grasped, a transition to a full scale should be performed. Full scale tests are the closest to reality so they could deliver the most accurate data.

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10 Appendices

10.1 FDS CODE

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&BNDF QUANTITY='WALL TEMPERATURE'/


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10.2 Cembrit Multi Force Data Sheet (Swedish)

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AMA-kod: KBB
Uppdateringar se: www.cembrit.se
Sid 1(2)

Cembrit Multi Force **Produktblad**

Cembrit Multi Force (Minerit Normal)

MINERIT CONCEPT

Produkt

Cembrit Multi Force är en cementbunden byggskiva och är därför stark, fuktbeständig och mögelresistent. Den är också brandsäker, har hård yta och bra ljudisolerande förmåga. Skivan är cementgrå och har en glittrande yta, fasade långkanter och förborrade hål.

Cembrit Multi Force är klassad som NT C2 I enligt EN 12467:2005 "Plana skivor av fibercement - Produktspecifikation och provningsmetoder".

NT	Skivan är asbestfri.
C	Skivan är avsedd för invändigt bruk och kan utsättas för fukt, kyla och värme, men ej för frost (i vått tillstånd).
2	Skivan har en böjstyrka på min. 7 MPa.
I	Skivans dimensioner håller den bästa toleransklassen.

Fuktbeständig
Skivan försvagas inte nämnvärt av att bli våt. Den tål högtryckspolning och kan ta upp och avge fukt i obegränsat antal cykler utan att hållfasthetsegenskaperna försämras.

Motstånd mot röta och mögelangrepp
Det höga pH-värdet (11) försvårar tillväxt av mögelsporer och andra mikroorganismer. Skivan kan inte ruttna, rosta eller på annat sätt brytas ned i fuktiga miljöer. SP har funnit det nästan omöjligt att provocera mögelpåväxt på Cembrit Multi Force och använder därför skivan som likare i mögeltester av andra material.

Brandklassad
Brandtekniskt är skivan klassad enligt SS/EN 13501-1:2002 och SS/EN 13501-2:2003. Den nya Euro-klassningen placerar Cembrit Multi Force i högsta nivån – klass A1 – för obrännbara material. Cembrit Multi Force uppfyller också kravet på beklädnad K_210.

Motstår biologisk påverkan
Skivan påverkas inte av mikroorganismer, alkalier eller organiska lösningsmedel. Skivan kan dock påverkas av syror exempelvis svavelsyra och salpetersyra. Skadedjur såsom möss och insekter rår inte på Cembrit Multi Force.

Tål rengöring
En obehandlad Cembrit Multi Force tål rengöring med högtryckspolning och med mekaniska hjälpmedel. En annan metod för rengöring är att använda såplösning med riklig sköljning.
Vid förväntad kraftig nedsmutsning och höga påfrestningar av kemikalier, oljor o dyl rekommenderas ytbehandling med silan/siloxan eller betongbinder. De är färglösa vätskor som gör ytan smuts- och vattenavvisande.

Klarar höga belastningar
Väggar kan dimensioneras för olika belastningar. Skivtjocklek, antal skivor och stommens c avstånd kan kombineras för olika krav.

Användningsområde

Cembrit Multi Force är en skiva som används i mellanväggar och invändig beklädnad i tex. soprum, trapphus, korridorer, lager/förråd, garage, industrier, lantbruksbyggnader barnstugor, skolor, sjukhus mm

Cembrit Multi Force **Produktblad**

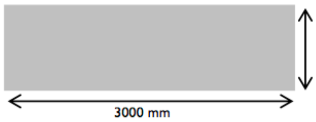
Innehåll

Cembrit Multi Force består av cement, kalksten, glimmer och cellulosafibrer. Den innehåller inga hälsovådliga ämnen. Emissionsprover visar att skivan inte heller avger några farliga gaser (SP 93 KI 0437). Joniserande gamma- och radiumstrålning är ca 90 % under BBR´s krav. Då skivan varken ruttnar eller möglar är den extra trygg ur hälsosynpunkt.

Det damm som bildas vid bearbetning är inte hälsovådligt. I Folksams Byggmiljöguide är Minerit® miljömässigt bästa valet. I Milab miljöbedömningssystem får Cembrit Multi Force bedömningen "rekommenderas". Skivan är också kvalificerad i BASTAS databas. Se även Säkerhetsdatablad och Byggvarudeklaration för Cembrit Multi Force.

Dimensioner, vikter och förpackning

Tjocklek mm	Format mm	Lev.vikt kg/m²	Vikt kg/st	Antal/ pall	m²/pall	Pallvikt c:a kg
9	1200 x 2550	11,0	33,7	45	137,7	1545
	1200 x 3000	11,0	39,6	45	162,0	1812
	900 x 2550	11,0	25,2	55	126,2	1418
	900 x 3000	11,0	29,7	55	148,5	1664
12	1200 x 2550	15,1	46,2	30	91,8	1416
	1200 x 3000	15,1	54,4	30	108,0	1661
	900 x 2550	15,1	34,7	40	91,8	1416
	900 x 3000	15,1	40,8	40	108,0	1661



Toleranser

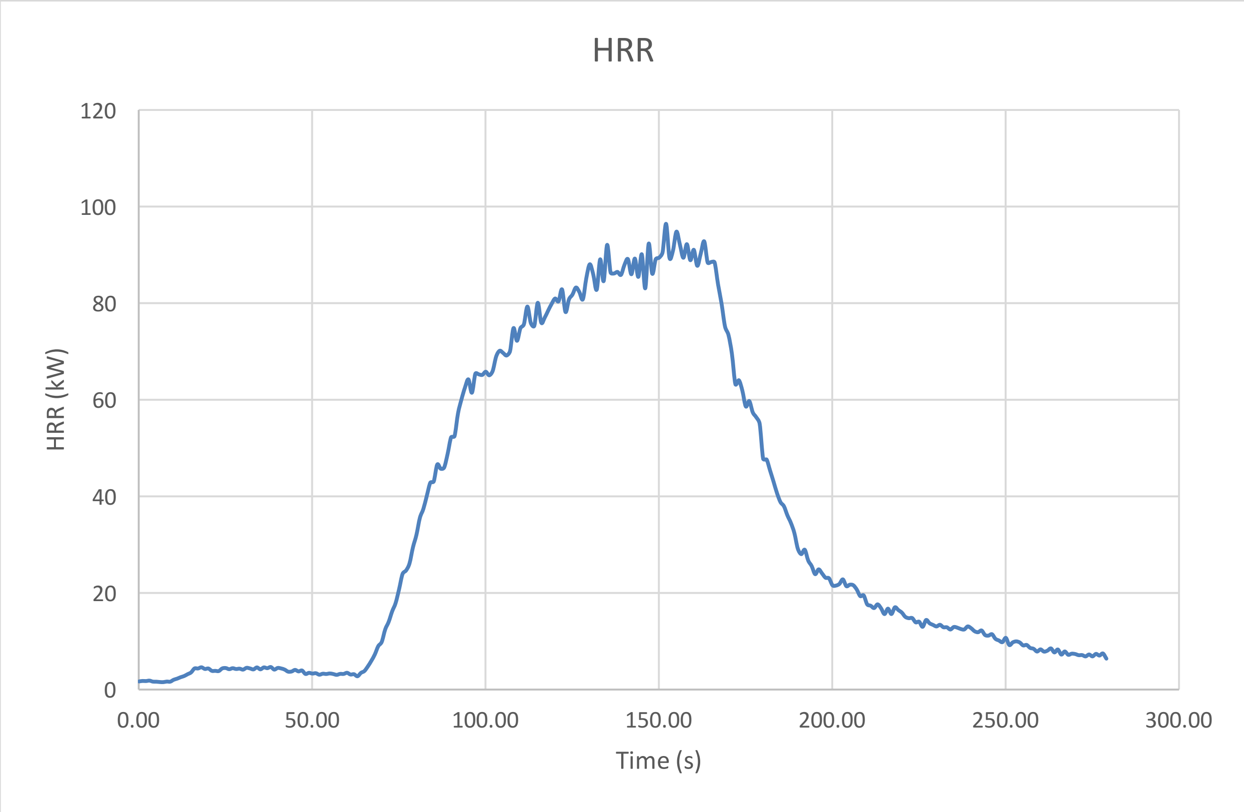
Angivna toleranser är maxvärden enligt Europastandard EN 12467.

	Enhet	Max. avvikelse
Tjocklek	%	+/-10
Längd	mm	+/- 3
Bredd	mm	+/- 5

Tekniska data

	Enhet	9 mm	12 mm
Densitet	kg/m³	1150	1150
Vikt per m², torr	kg/m²	10,5	14,0
E-modul torr: I skivans längdriktning I skivans tvärriktning	GPa, GN/m²	4 3	4 3
Böjdraghållfasthet, torr I skivans längdriktning I skivans tvärriktning	MPa	10 8	10 8
Fuktrörelse Rh 30-50% Fuktrörelse Rh 50-90%	mm/m mm/m	0,4 0,8	0,4 0,8
Vattenabsorption (2 dygn)	%	32	32
pH i skivans yta	pH	11	11
Värmeledningsförmåga (λ-värde)	W/m °C	~0,25	~0,25
Specifik värmekapacitet	kJ/kg °C	0,9	0,9
Värmeutvidgningskofficient (c)	mm/m °C	0,007	0,007
Användningstemperatur, max	°C	150	150
Ånggenomgångsmotstånd (z)	s/m	17 000	24000
Luftljudreduktion (R'_w)	dB	28	31
Dynamisk E-modul	Gpa	7	7
Böjningsradie i längdriktning	m	4	6
Böjningsradie i tvärriktning	m	5	7,5
Brandklass enl. EN 13501	A-F	A1	A1
Kategori och klass enl. EN 12467	A-D,1-5	NT C21	NT C21

10.3 Heat release rate of burn (similar throughout the rest of the experiments)



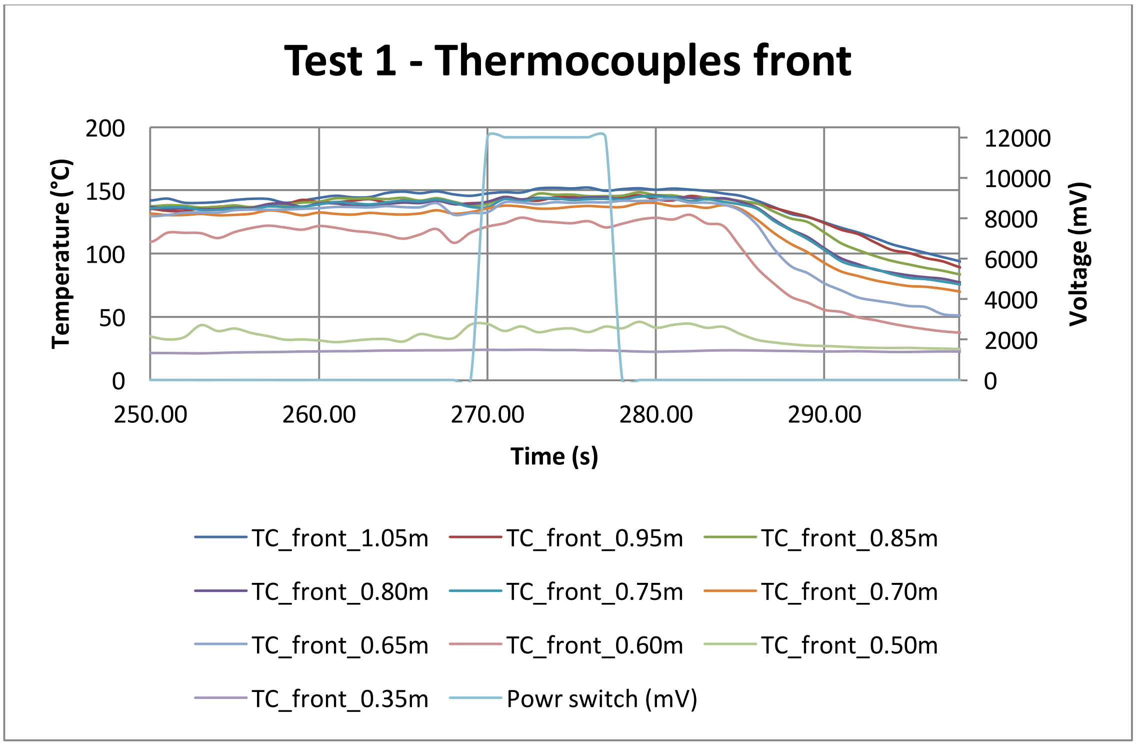
10.4 List of experiments

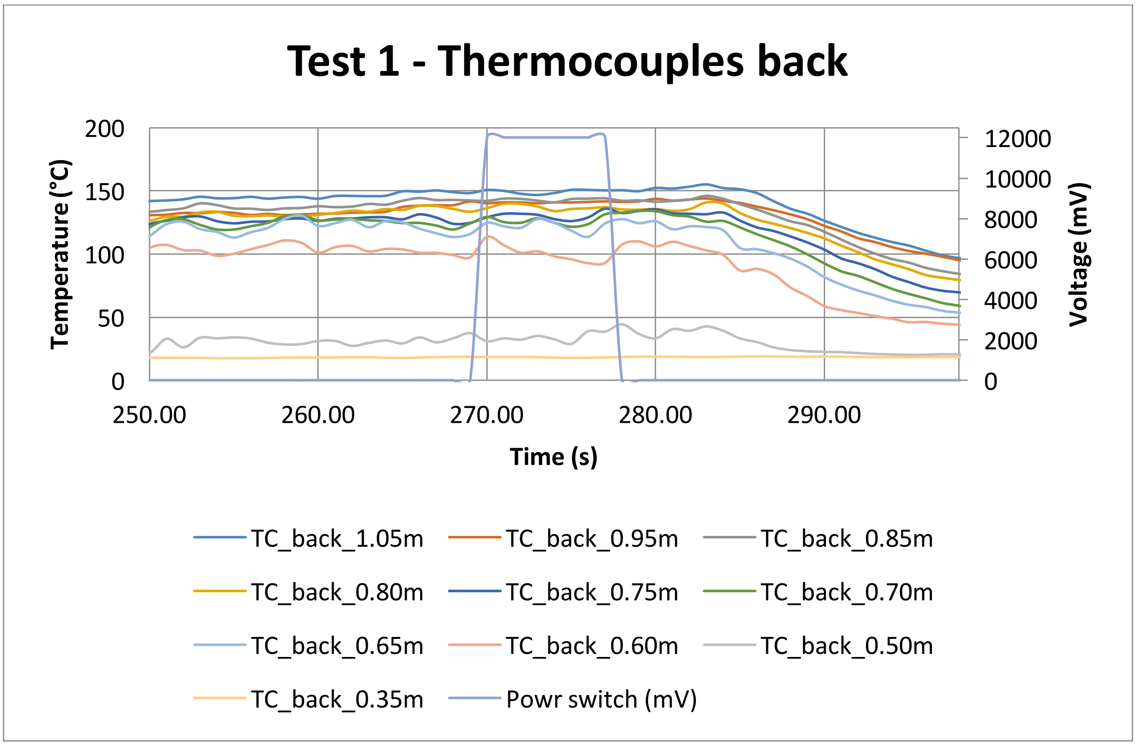
Test number	Nozzle	Pressure (bar)	Flow (lpm)	Reach (m)	Height (m) (from floor)	Height (m)	Drop size (µm)	Volume per burst (ml)	Amount of bursts	Time open (s)	Time closed (s)	Total volume (ml)
Test1	Full cone	1	11.5	1.8	/	/	3700	22	5	0.1	2	110
Test2	Full cone	1	11.5	/	/	/	3700	30	5	0.2	2	150
Test3	Full cone	1.5	13.5	2	/	/	3000	32	5	0.1	2	160
Test4	Full cone	1.5	13.5	2	/	/	3000	32	5	0.1	2	160
Test5	Full cone	4	21	4	1.7	2	2300	59	5	0.1	2	295
Test6	Full cone	4	21	4	1.7	2	2300	59	5	0.1	2	295
Test7	Full cone	4	21	4	1.7	2	2300	44	5	0.05	2	220
Test8	Full cone	4	21	4	1.7	2	2300	44	5	0.05	2	220
Test9	Fine mist	4	12.4	1.85	0.7	1	290	51	5	0.2	2	255
Test10	Fine mist	4	12.4	/	/	/	290	51	5	0.2	2	255
Test11	Fine mist	4	12.4	/	/	/	290	51	5	0.2	2	255
Test12	Fine mist	4	12.4	1.85	0.7	1	290	34	5	0.1	2	170
Test13	Fine mist	4	12.4	1.85	0.7	1	290	34	5	0.1	2	170
Test14	Fine mist	4	12.4	1.85	0.7	1	290	34	5	0.1	2	170
Test15	Fine mist	4	12.4	1.85	0.7	1	290	50	1	0.2	2	50
Test16	Fine mist	4	12.4	1.85	0.7	1	290	50	2	0.2	2	100
Test17	Medium sized hollow cone	2	16.1	2	1.55	1.85	920	32	5	0.05	2	160
Test18	Medium sized hollow cone	2	16.1	2	1.55	1.85	920	32	5	0.05	2	160

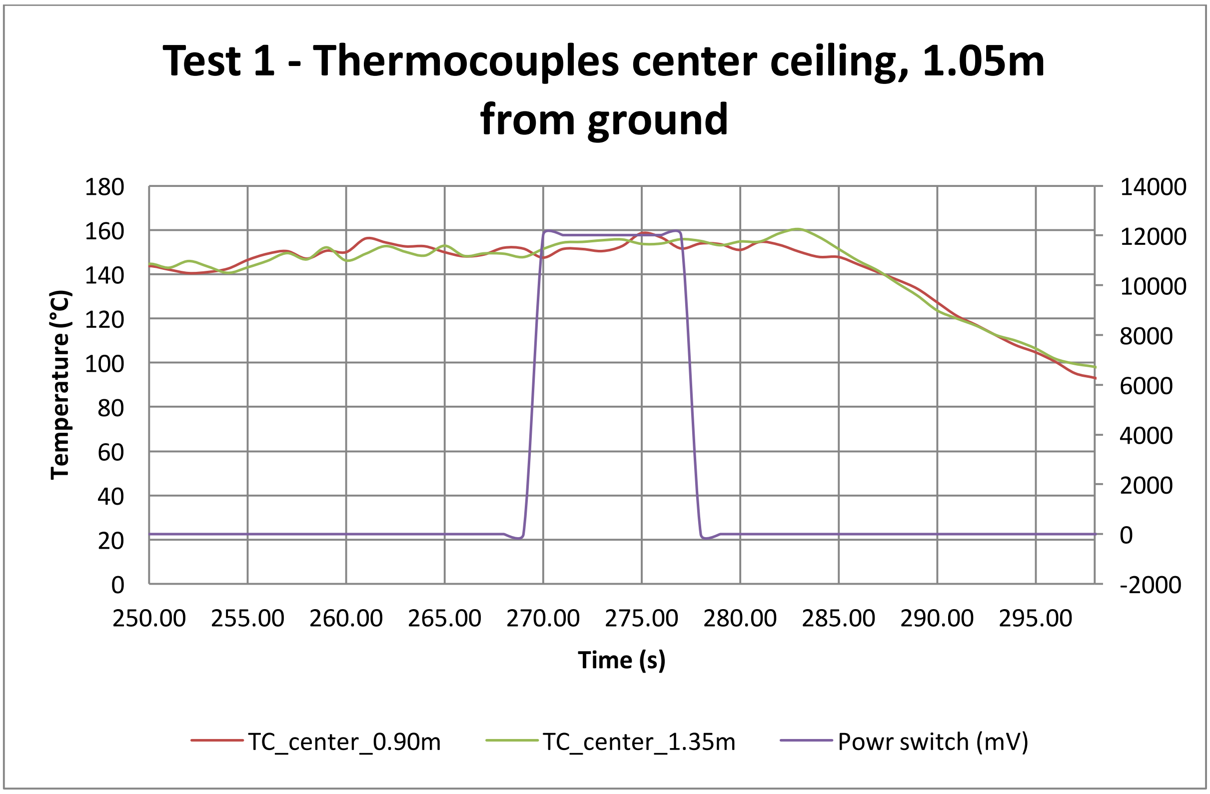
Test19	Medium sized hollow cone	3	19.7	2.65	2.8	2.1	860	50	5	0.15	2	250
Test20	Medium sized hollow cone	3	19.7	2.65	2.8	2.1	860	50	5	0.15	2	250
Test21	Medium sized hollow cone	4	23	2.65	2.95	2.25	800	49	1	0.1	2	49
Test22	Medium sized hollow cone	4	23	2.65	1.95	2.25	800	49	1	0.1	2	49
Test23	Medium sized hollow cone	4	23	2.65	1.95	2.25	800	49	1	0.1	2	49
Test24	Medium sized hollow cone	4	23	2.65	1.95	2.25	800	49	2	0.1	2	98
Test25	Medium sized hollow cone	4	23	2.65	1.95	2.25	800	49	2	0.1	2	98
Test26	Medium sized hollow cone	4	23	2.65	1.95	2.25	800	49	5	0.1	2	245
Test27	Small sized hollow cone	4	9.1	3.75	2.7	3	500	29	5	0.1	2	145
Test28	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	2	0.25	5	100
Test29	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	5	0.25	2	250
Test30	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	1	0.25	2	50
Test31	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	2	0.25	2	100
Test32	Small sized hollow cone	3	7.9	3	1.7	2	560	50	5	0.35	2	250

Test33	Small sized hollow cone	3	7.9	3	1.7	2	560	48	5	0.35	2	240
Test34	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	5	0.25	1	250
Test35	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	5	0.25	0.5	250
Test36	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	5	0.25	0.5	250
Test37	Small sized hollow cone	4	9.1	3.75	2.7	3	500	250	1	1.2	/	250
Test38	Medium sized hollow cone	4	23	3.75	2,7	3	500	250	1	1.2	/	250
Test39	Small sized hollow cone	4	9.1	3.75	2.7	3	500	150	1	1.2	/	150
Test40	Small sized hollow cone	4	9.1	3.75	2.7	3	500	50	5	1.2	2	250
Test41	Full cone	4	21	4	1.7	2	2300	50	1	0.05	2	50
Test42	Full cone	4	21	4	1.7	2	2300	50	2	0.05	2	100
Test43	Full cone	4	21	4	1.7	2	2300	250	1	1.2	/	250
Test44	Fine mist	4	12.4	1.85	0.7	1	290	250	1	1.5	/	250

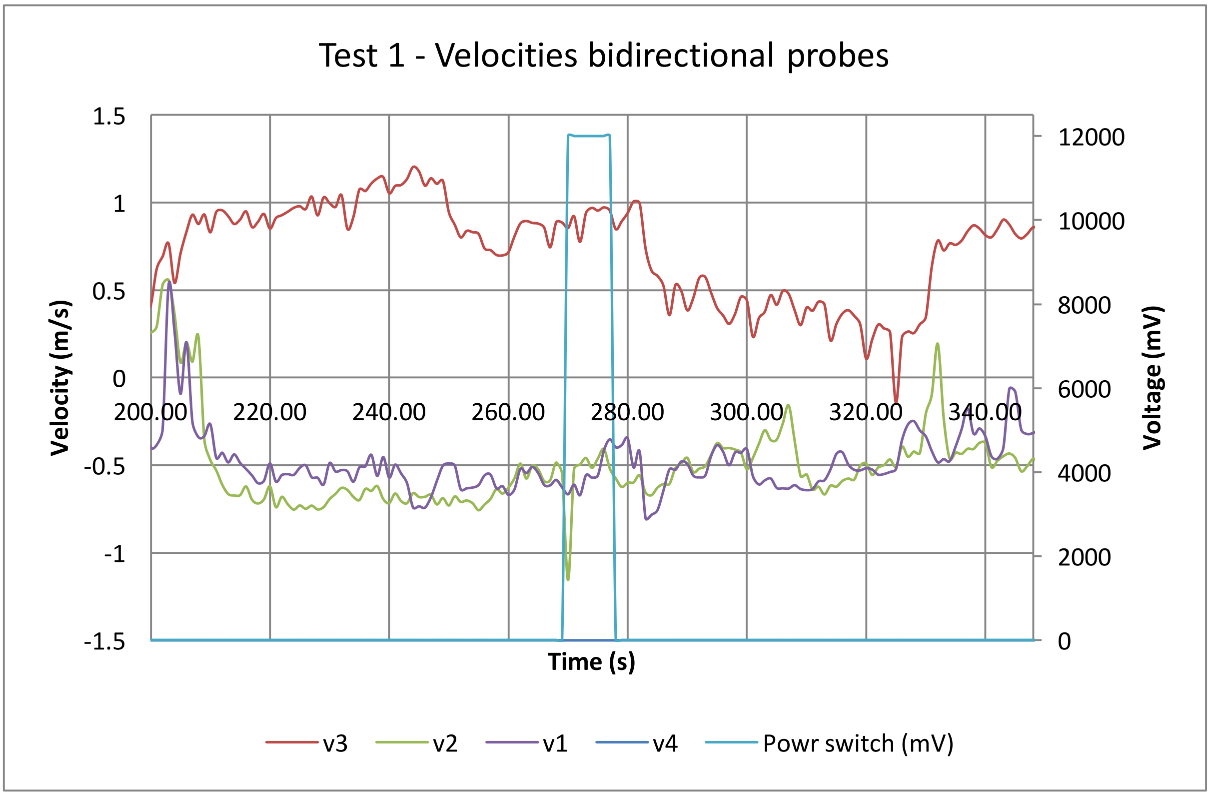
10.5 Experimental results



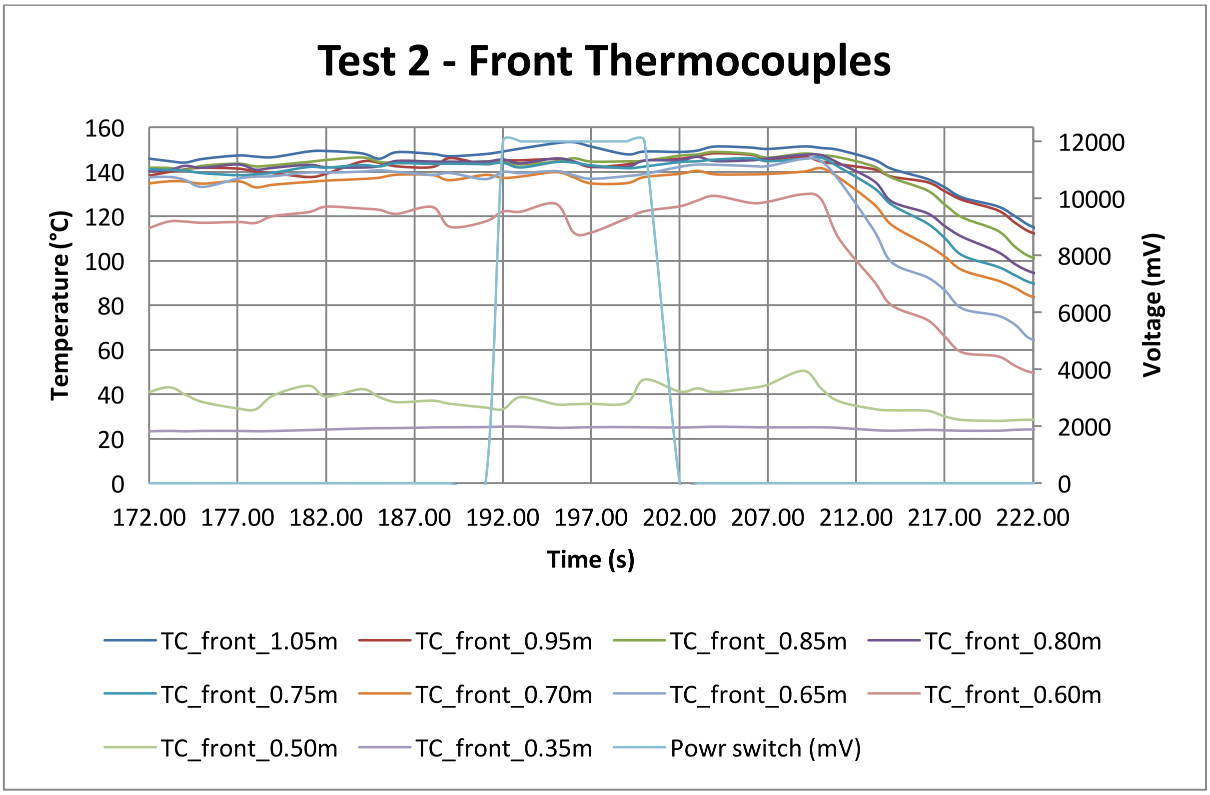




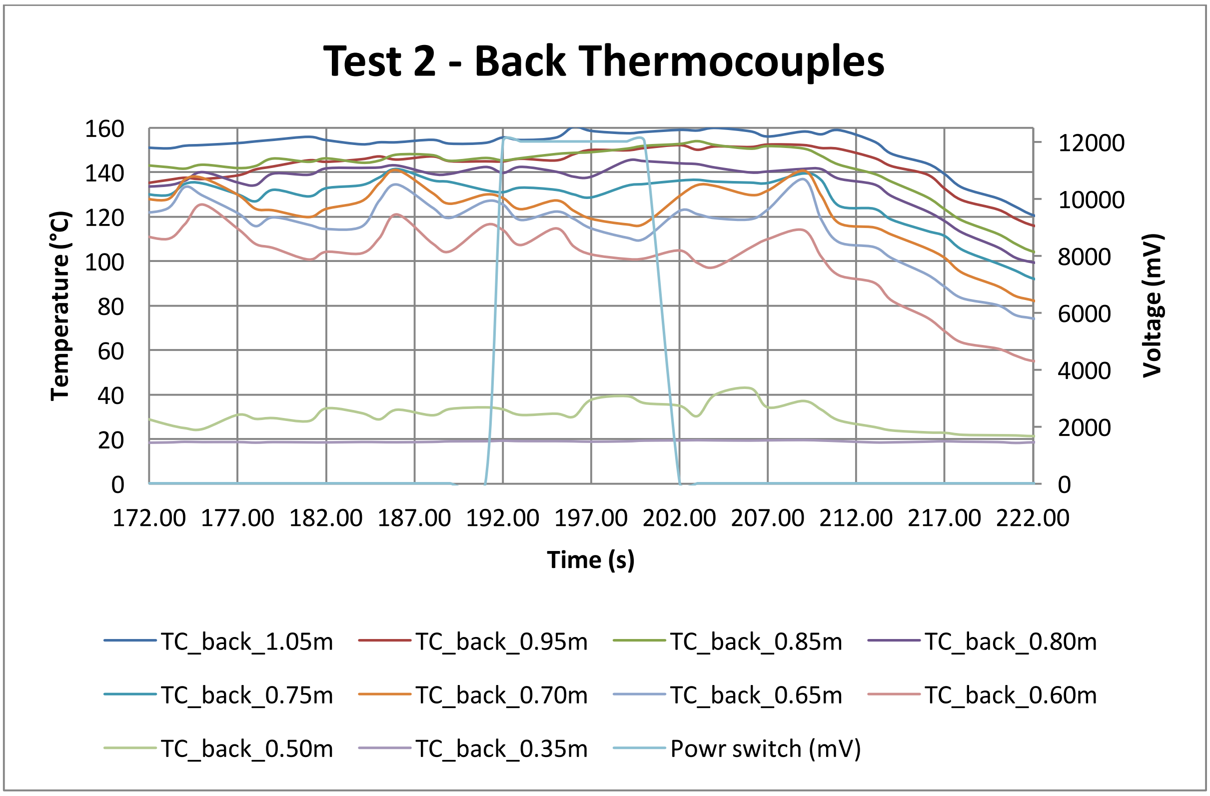
Test 1 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
250.00
255.00
260.00
265.00
270.00
275.00
280.00
285.00
290.00
295.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)



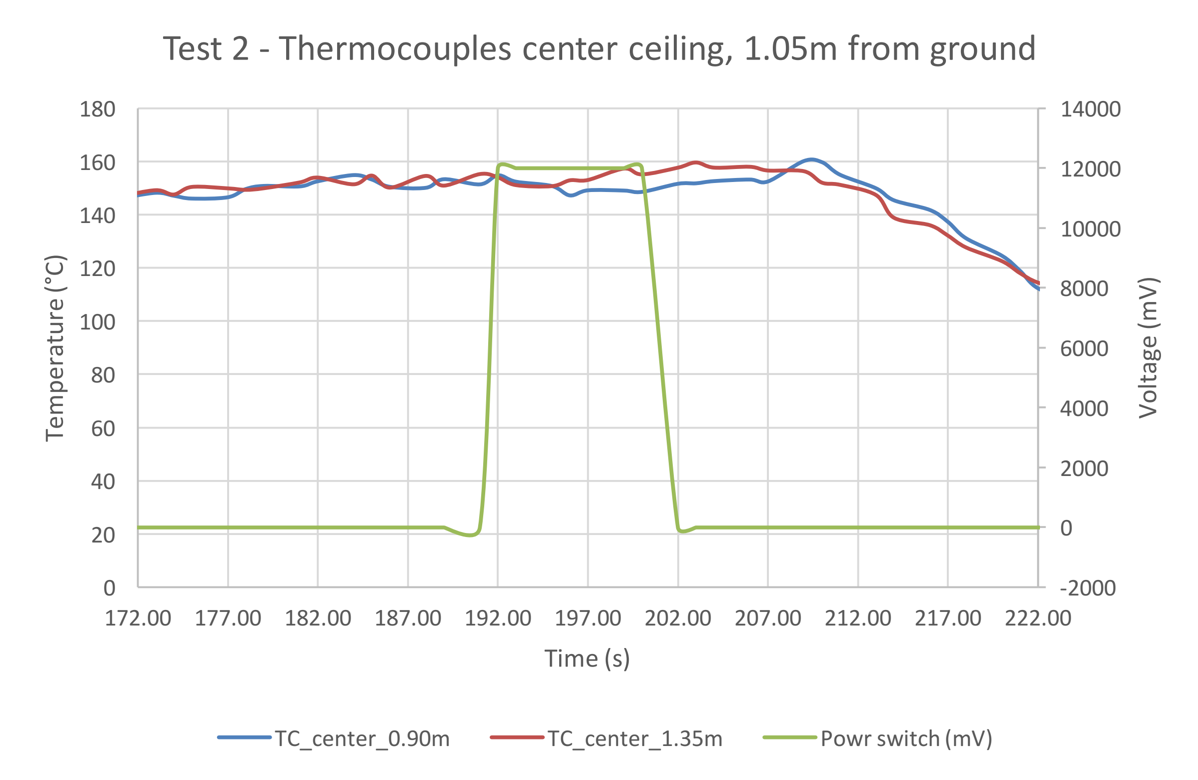
Test 1 - Velocities bidirectional probes
Velocity (m/s)
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
200.00
220.00
240.00
260.00
280.00
300.00
320.00
340.00
Time (s)
v3
v2
v1
v4
Powr switch (mV)



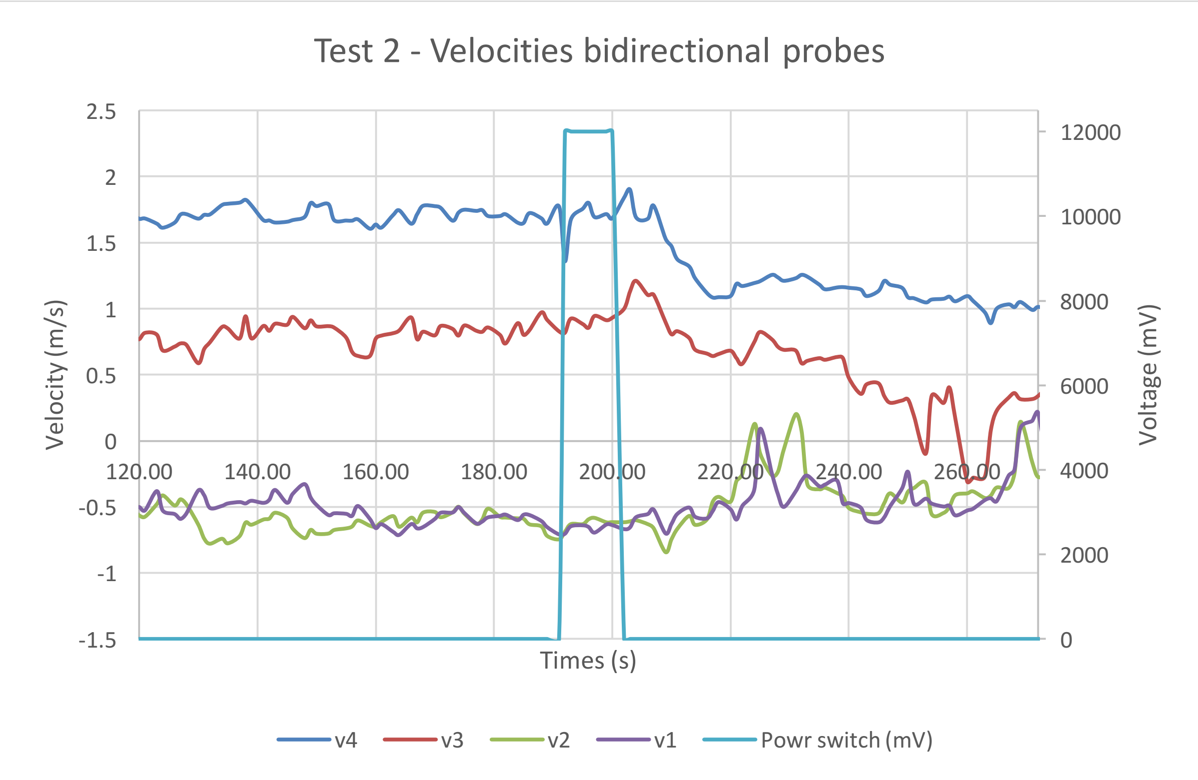
Test 2 - Front Thermocouples
Temperature (°C)
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
172.00 177.00 182.00 187.00 192.00 197.00 202.00 207.00 212.00 217.00 222.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)



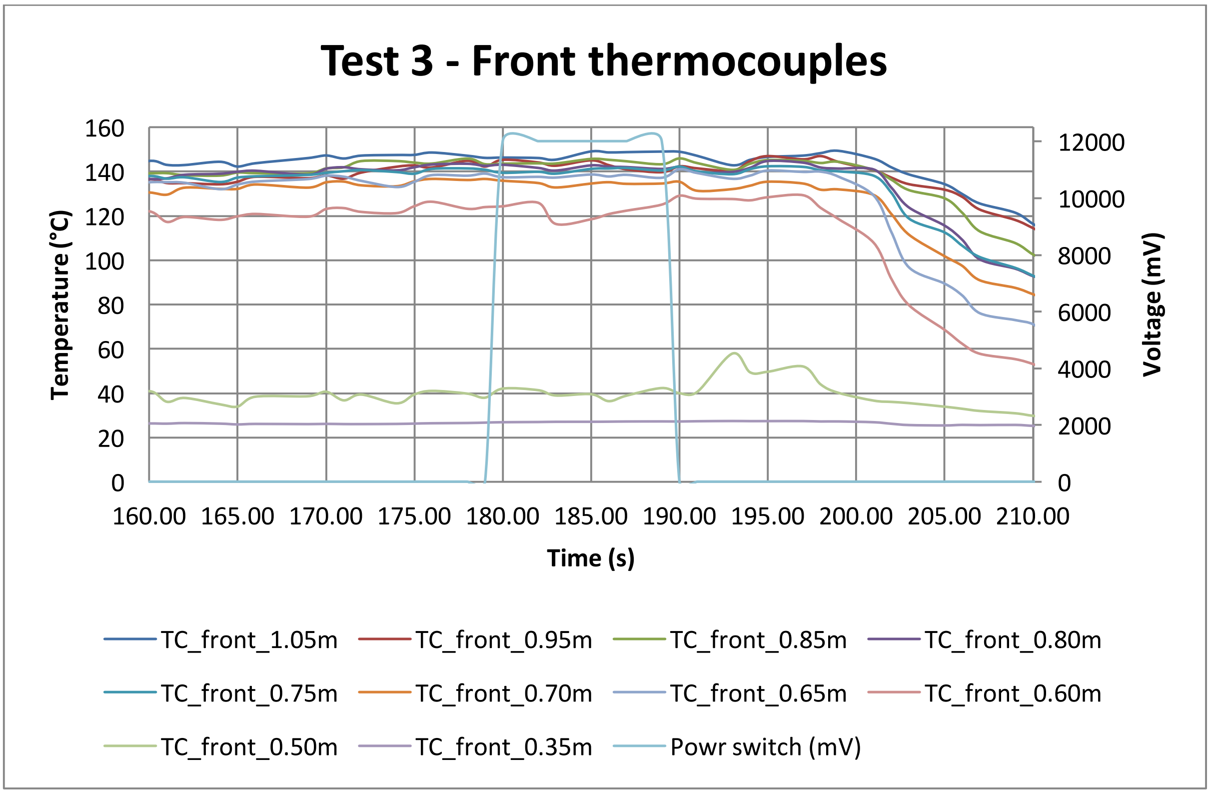
Test 2 - Back Thermocouples
Temperature (°C)
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
172.00 177.00 182.00 187.00 192.00 197.00 202.00 207.00 212.00 217.00 222.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

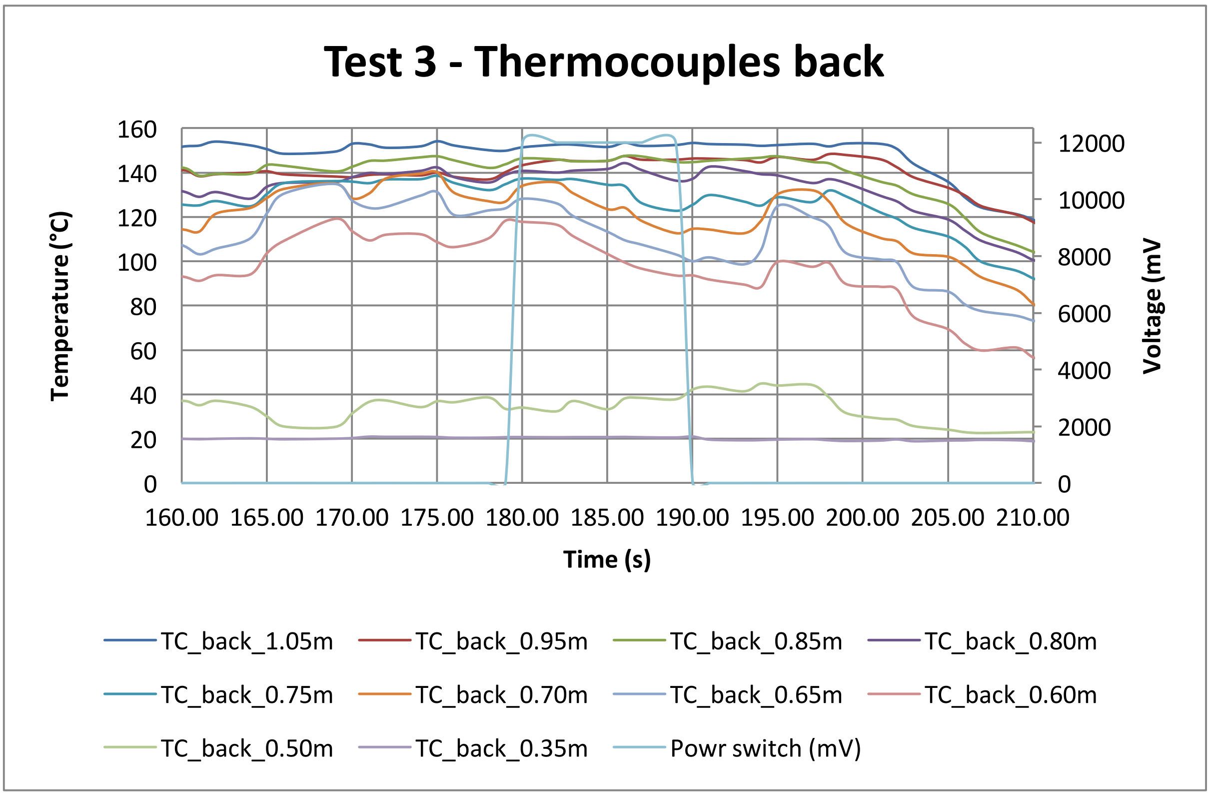


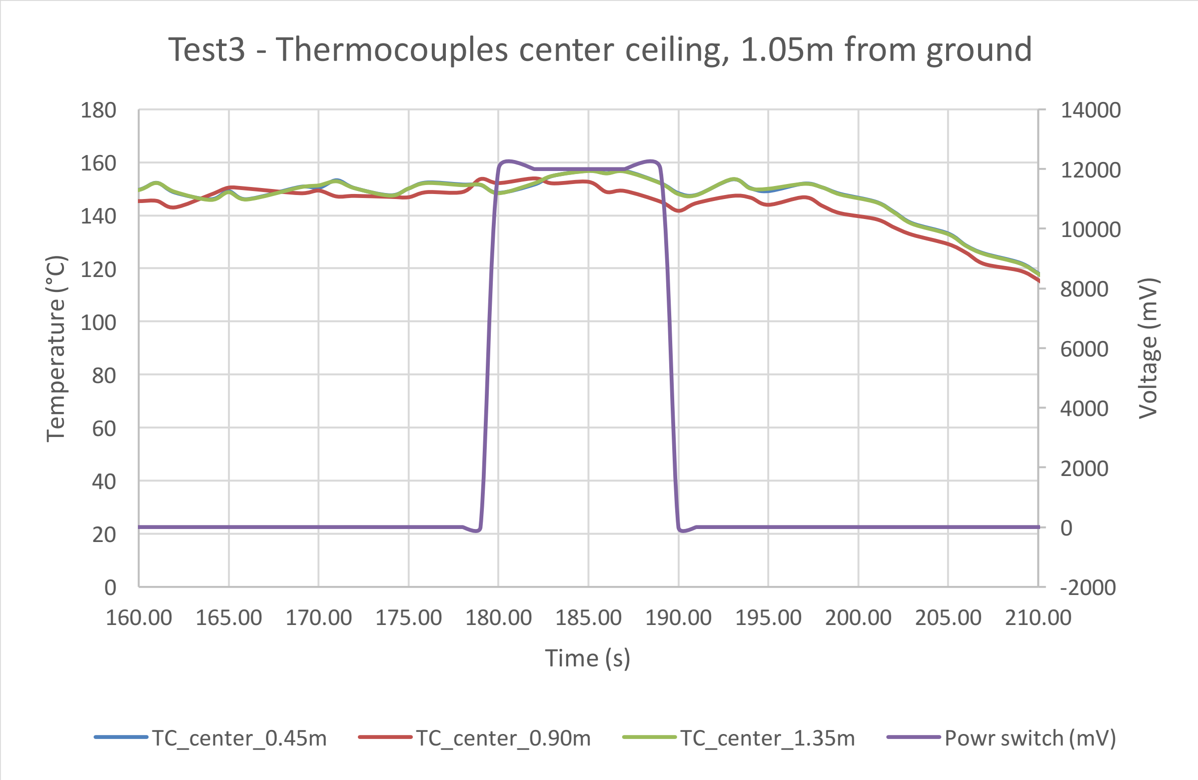
Test 2 - Thermocouples center ceiling, 1.05m from ground
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
172.00
177.00
182.00
187.00
192.00
197.00
202.00
207.00
212.00
217.00
222.00
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

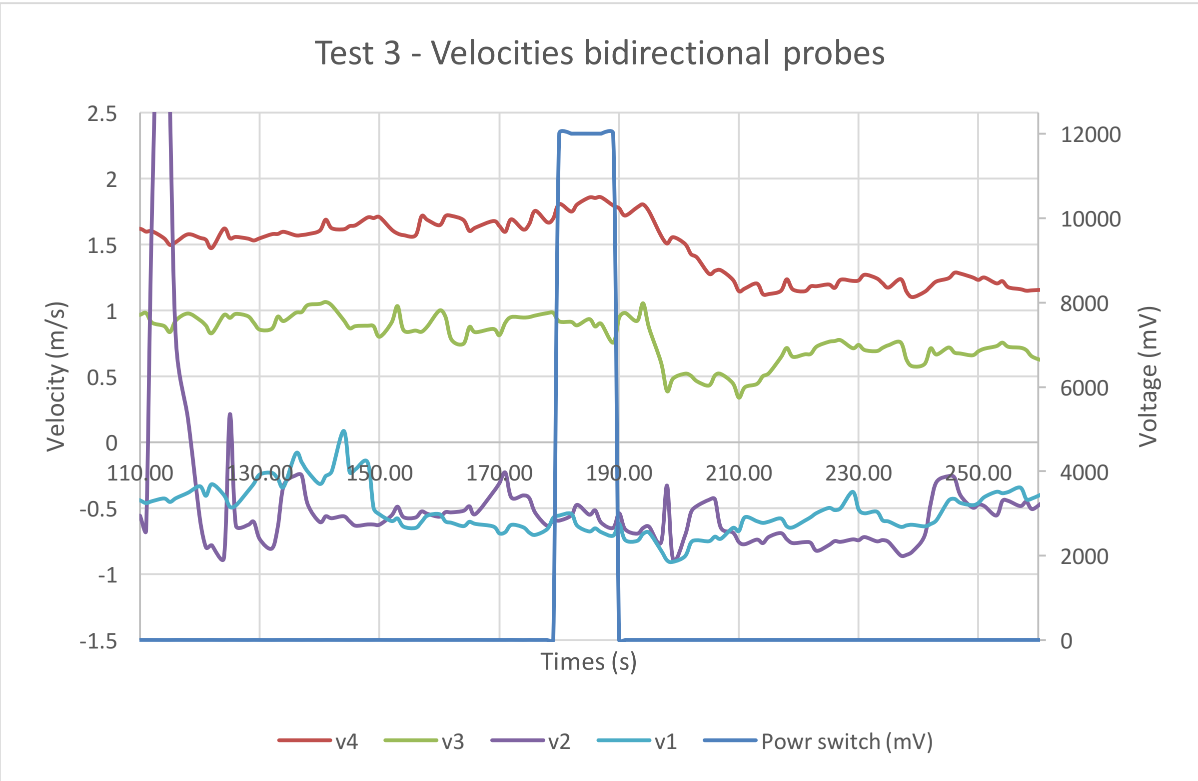


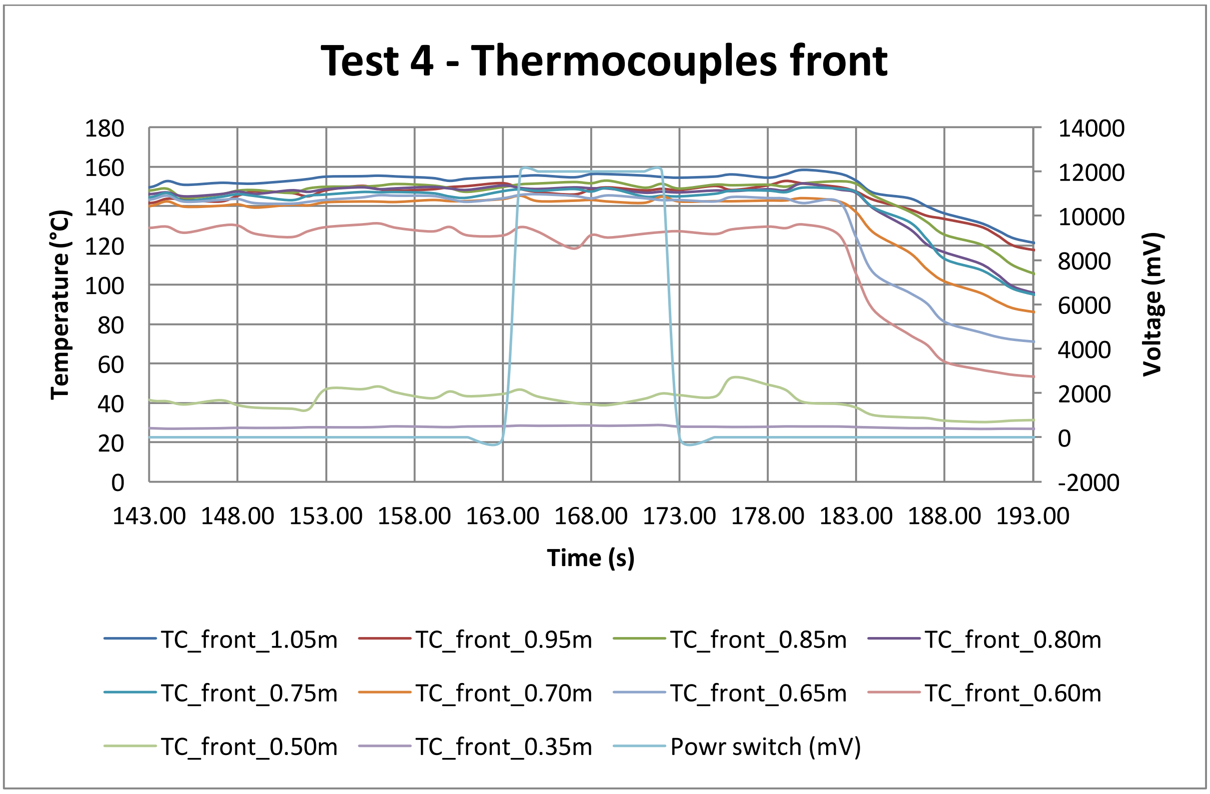
Test 2 - Velocities bidirectional probes
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 3 - Front thermocouples
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
0
2000
4000
6000
8000
10000
12000
160.00
165.00
170.00
175.00
180.00
185.00
190.00
195.00
200.00
205.00
210.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

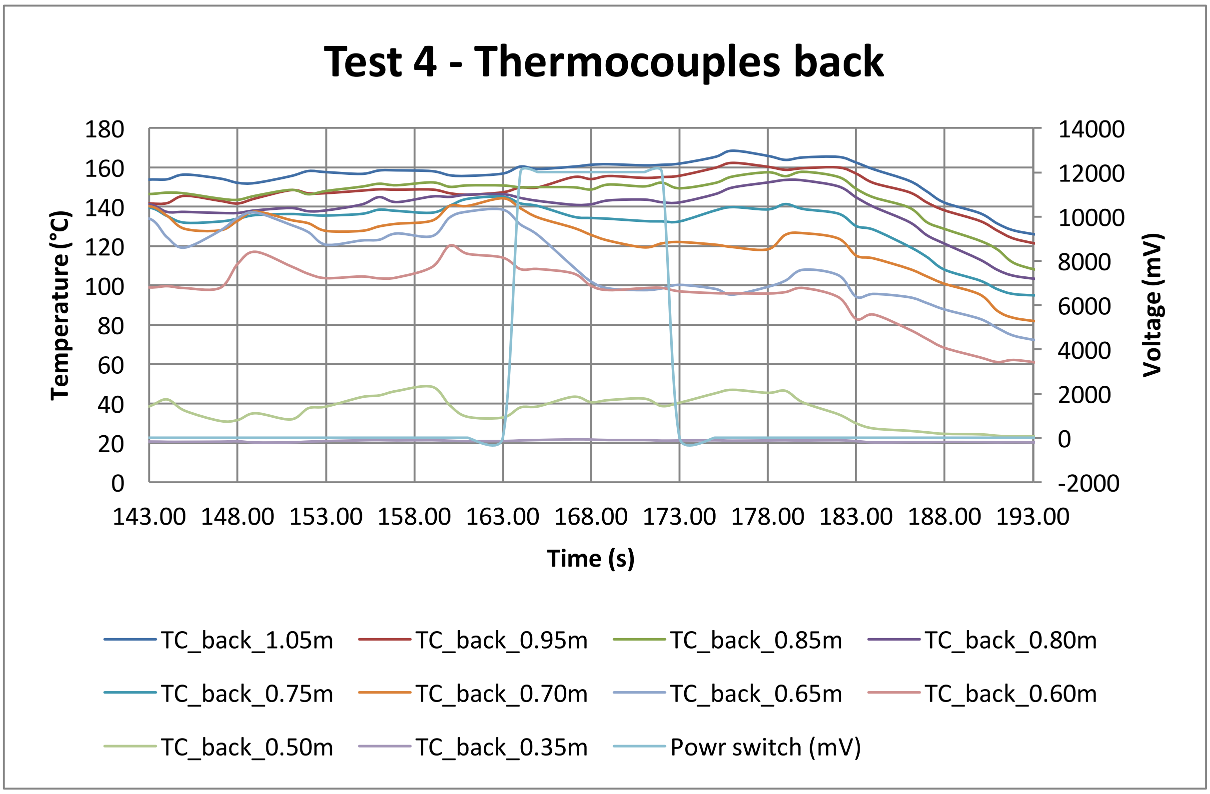

Test 3 - Thermocouples back
Temperature (°C)
Voltage (mV
Time (s)
0
20
40
60
80
100
120
140
160
0
2000
4000
6000
8000
10000
12000
160.00
165.00
170.00
175.00
180.00
185.00
190.00
195.00
200.00
205.00
210.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test3 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

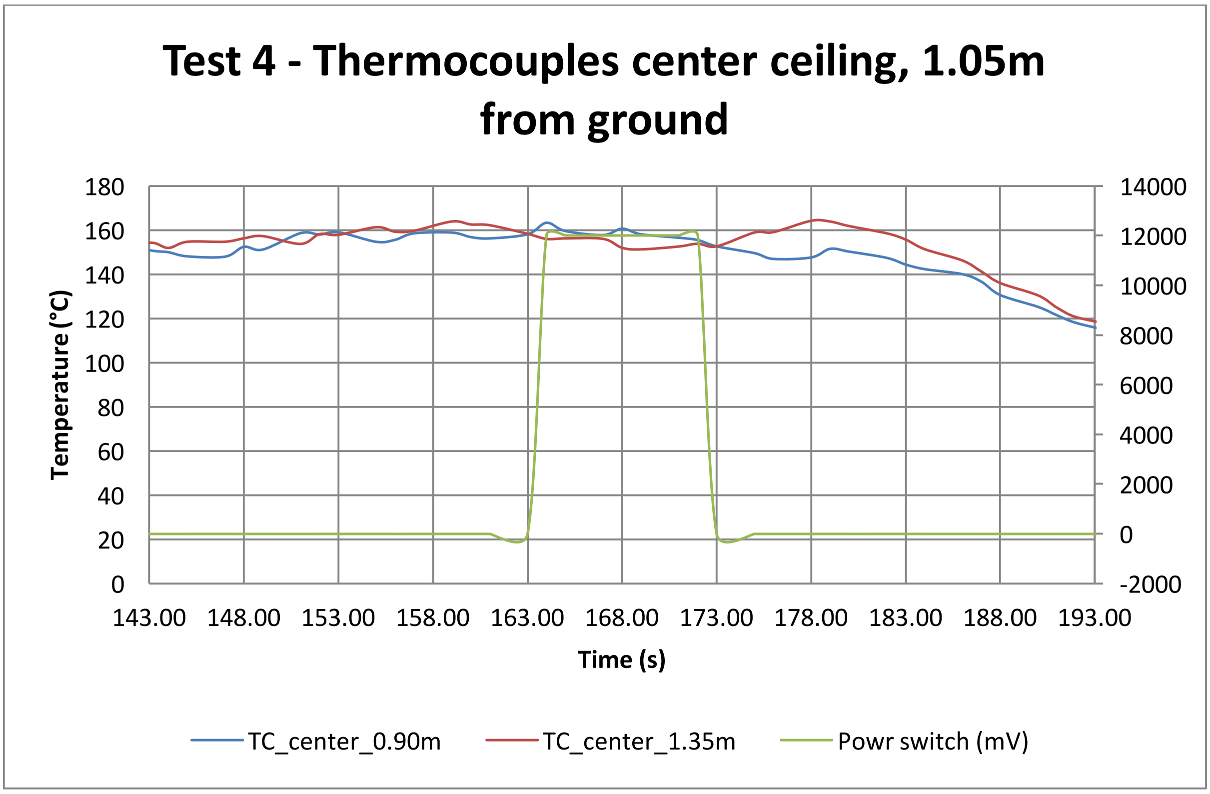

Test 3 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)



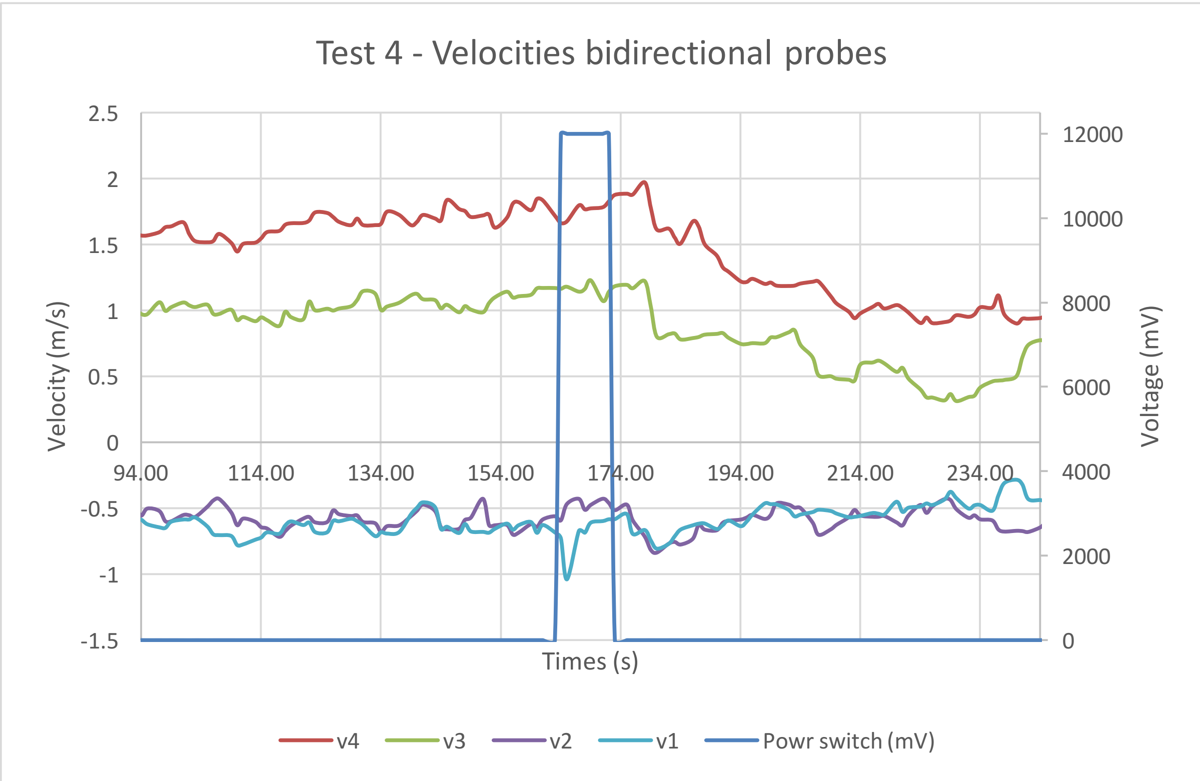
Test 4 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00 193.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)



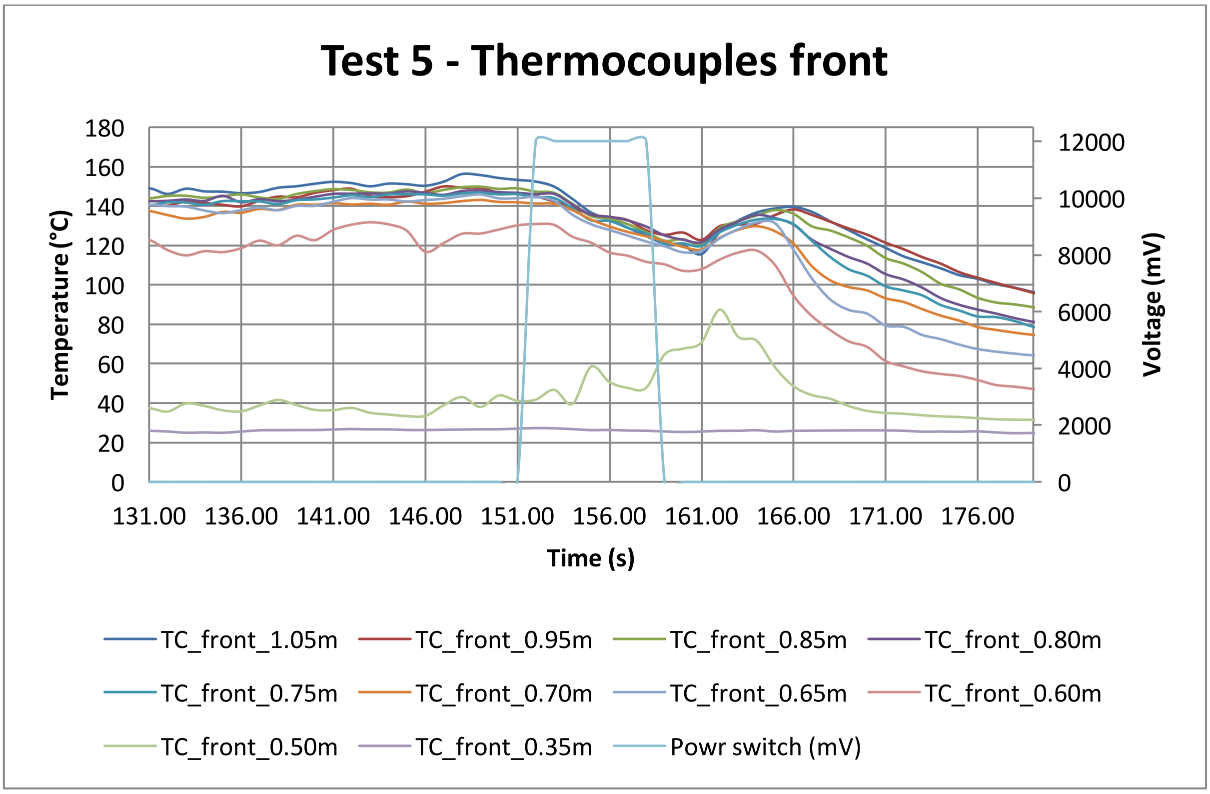
Test 4 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00 193.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

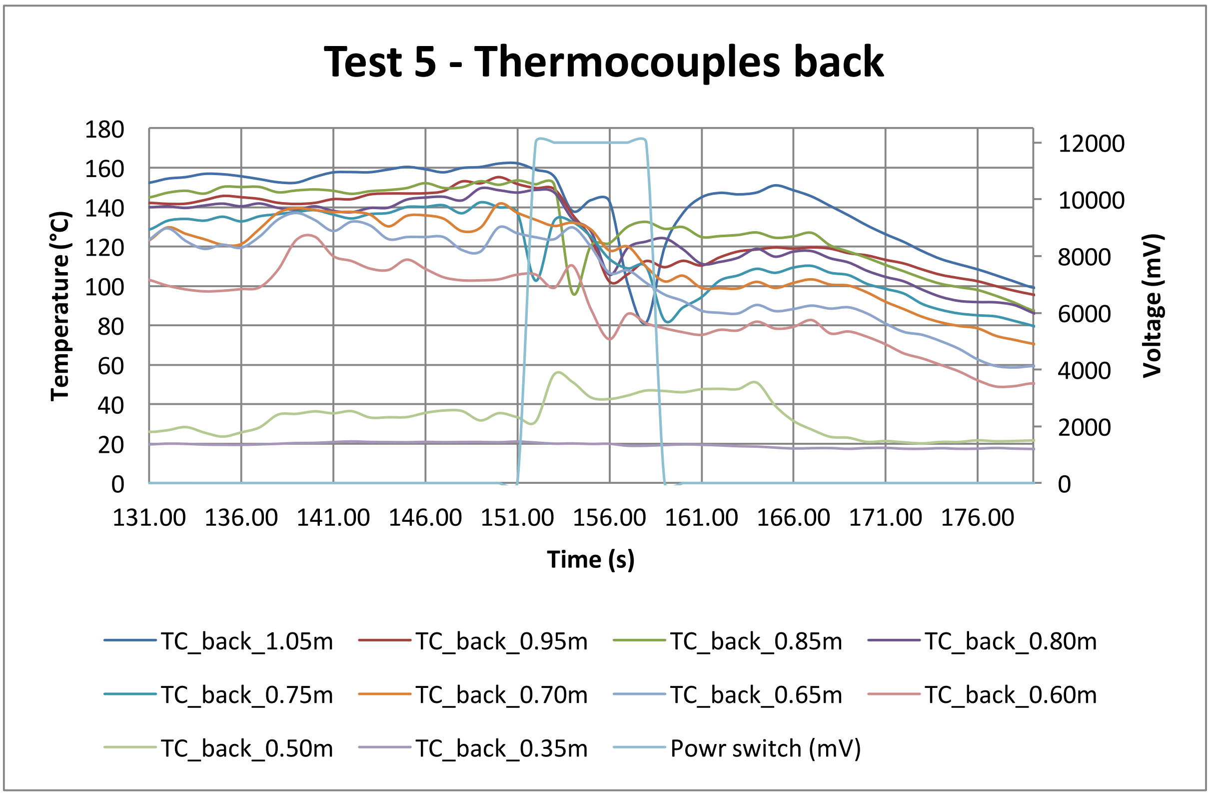


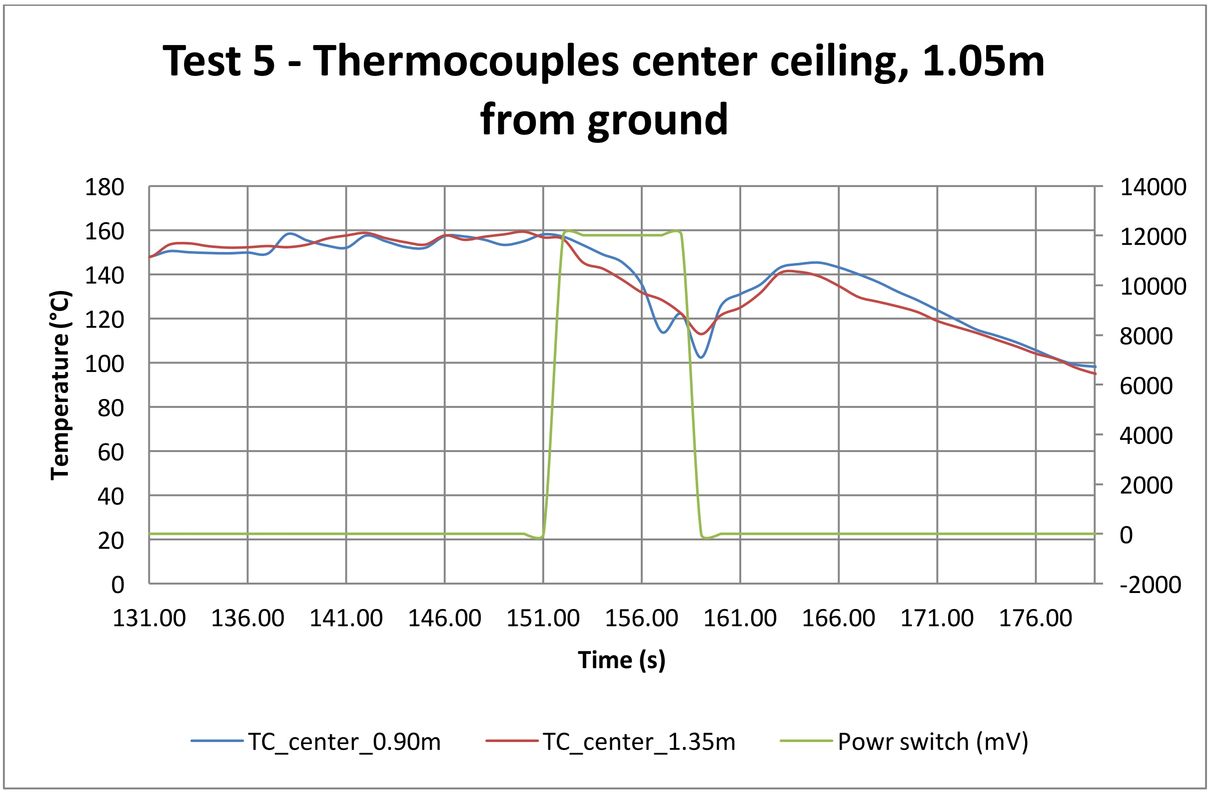
Test 4 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00 193.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)



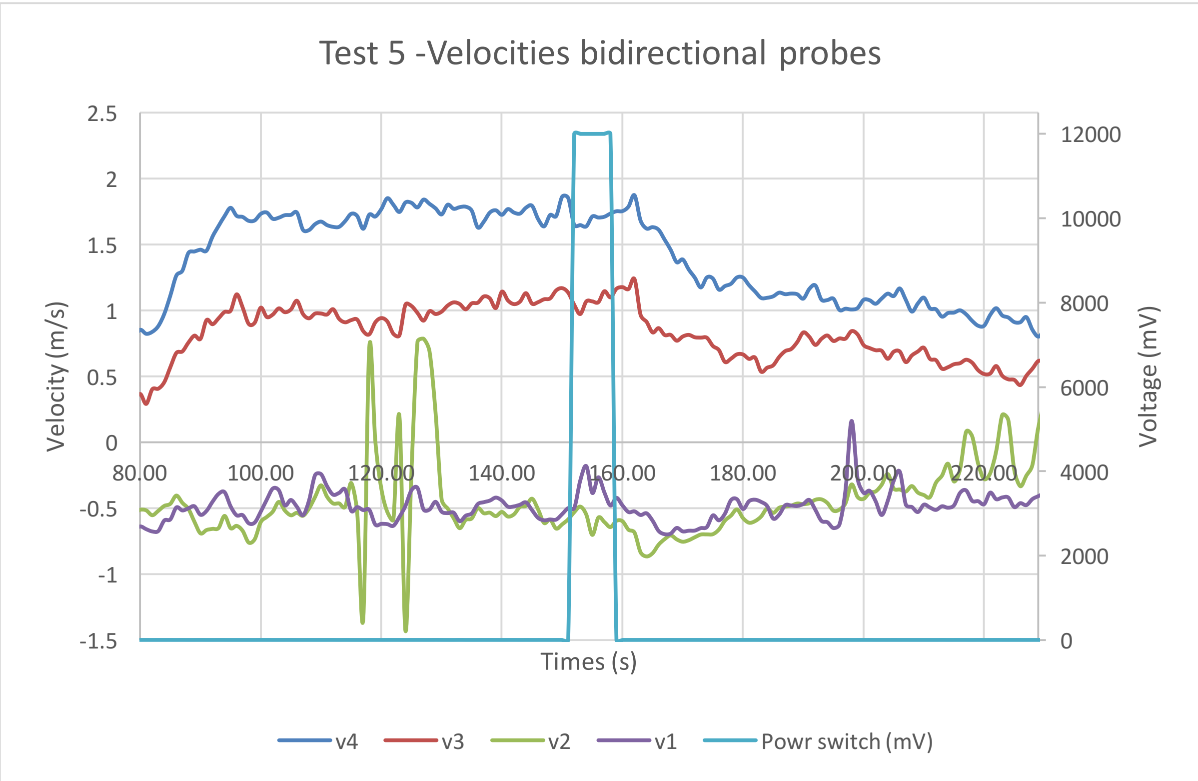
Test 4 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
94.00 114.00 134.00 154.00 174.00 194.00 214.00 234.00
Times (s)
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
v4
v3
v2
v1
Powr switch (mV)


Test 5 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
176.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

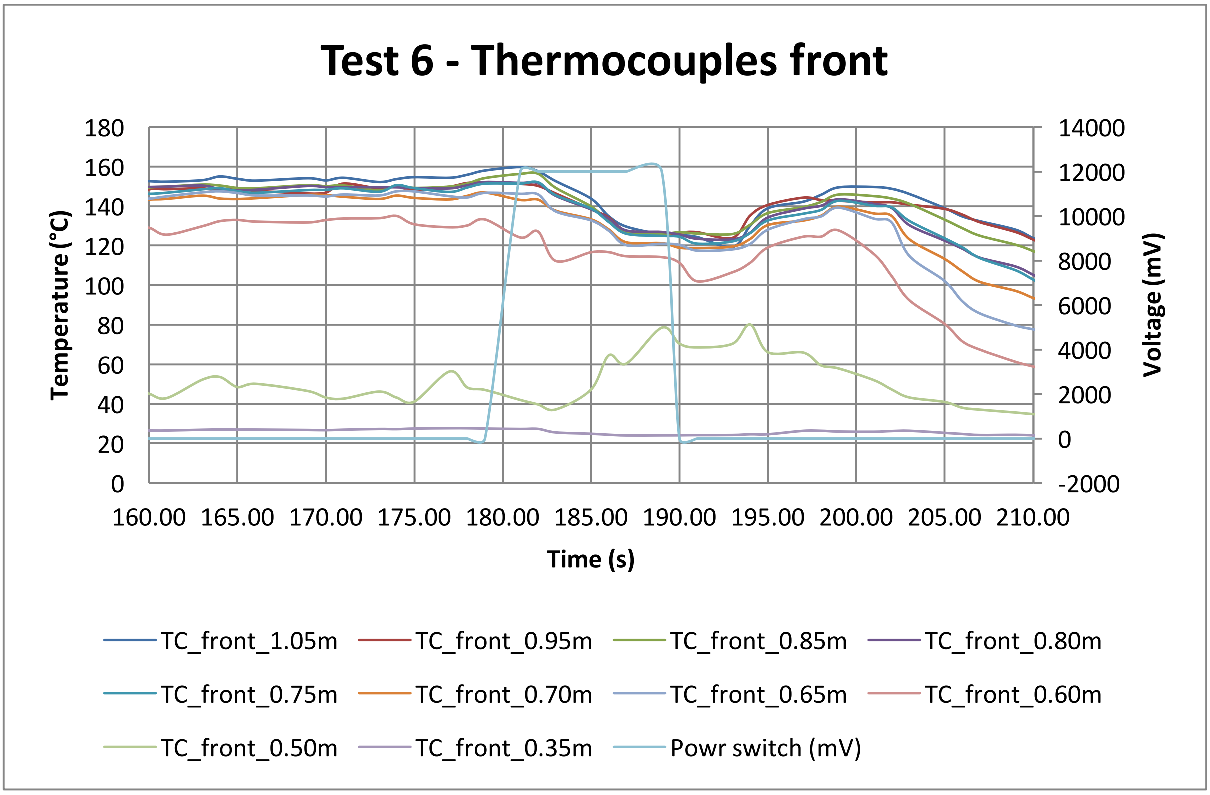

Test 5 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
176.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

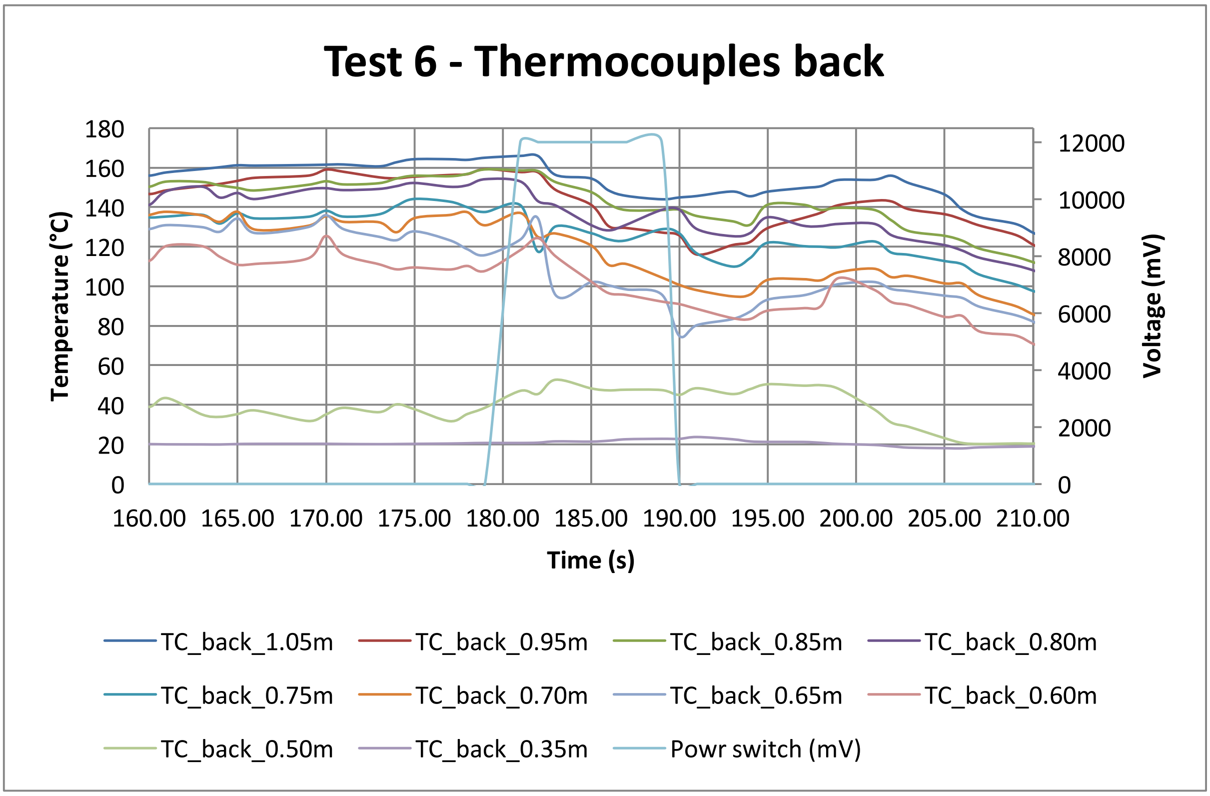


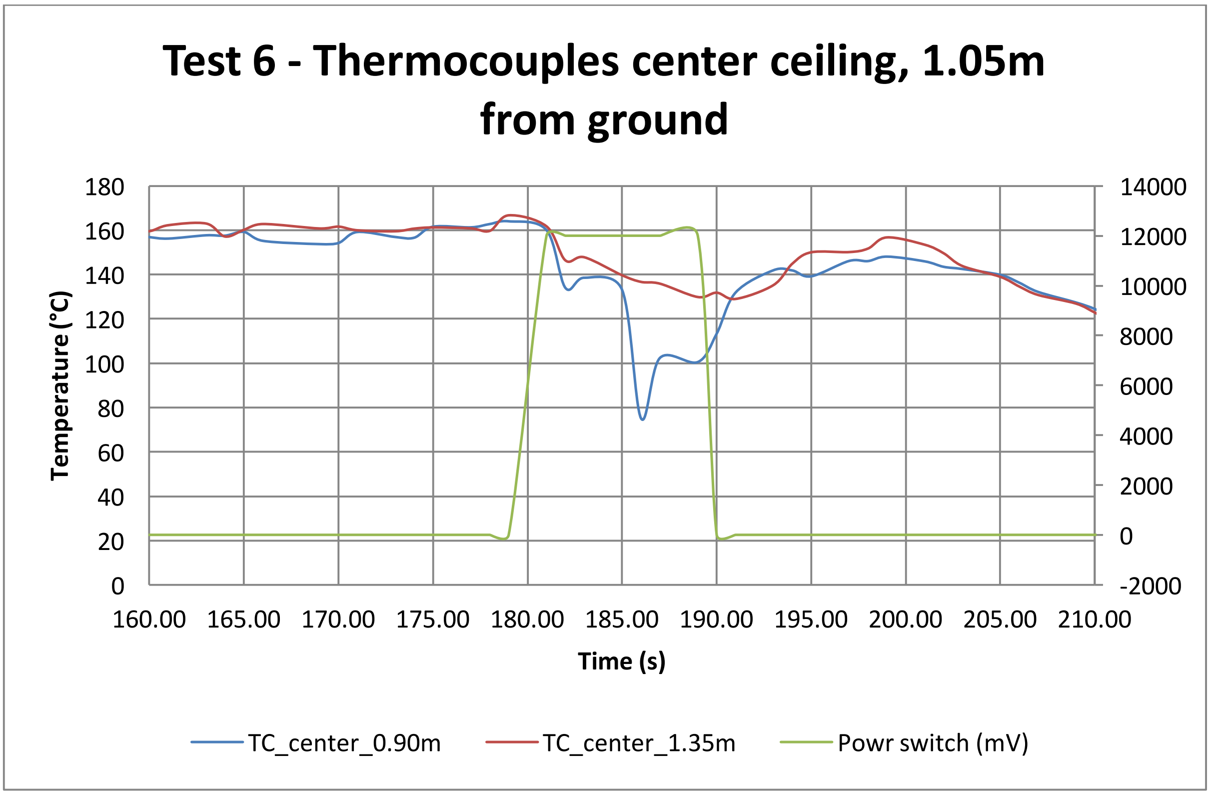
Test 5 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
131.00 136.00 141.00 146.00 151.00 156.00 161.00 166.00 171.00 176.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

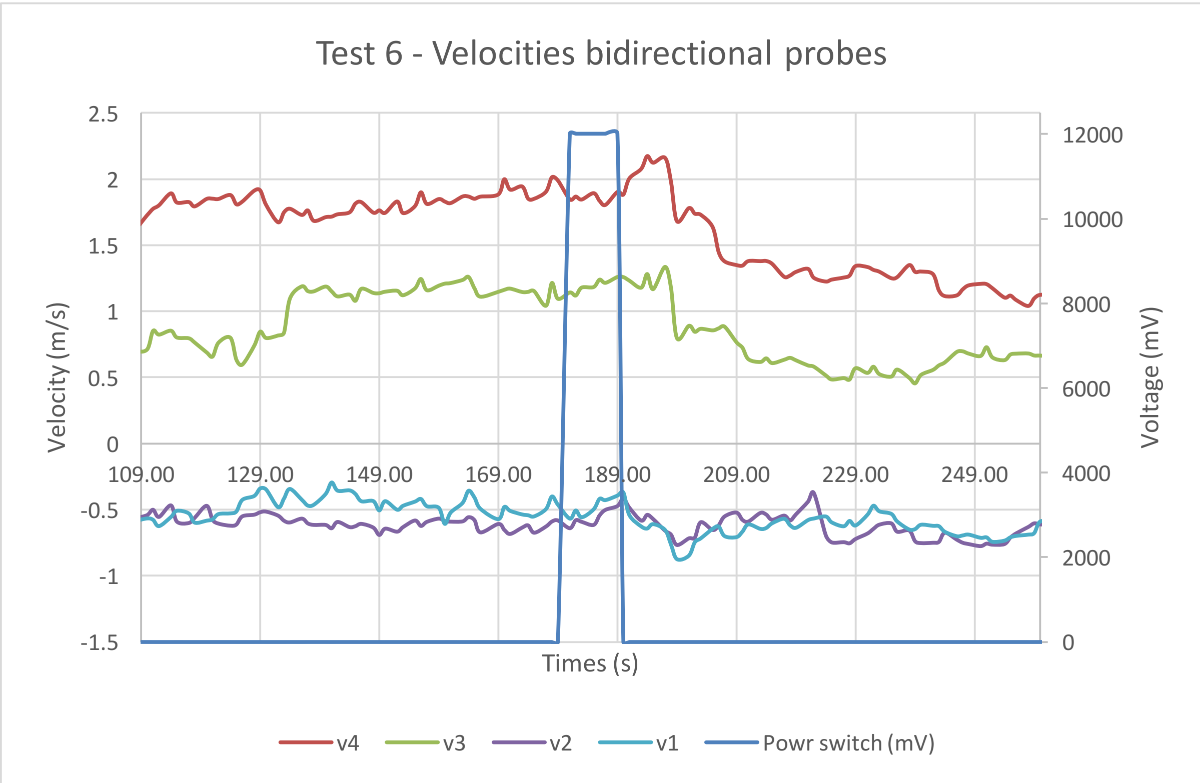


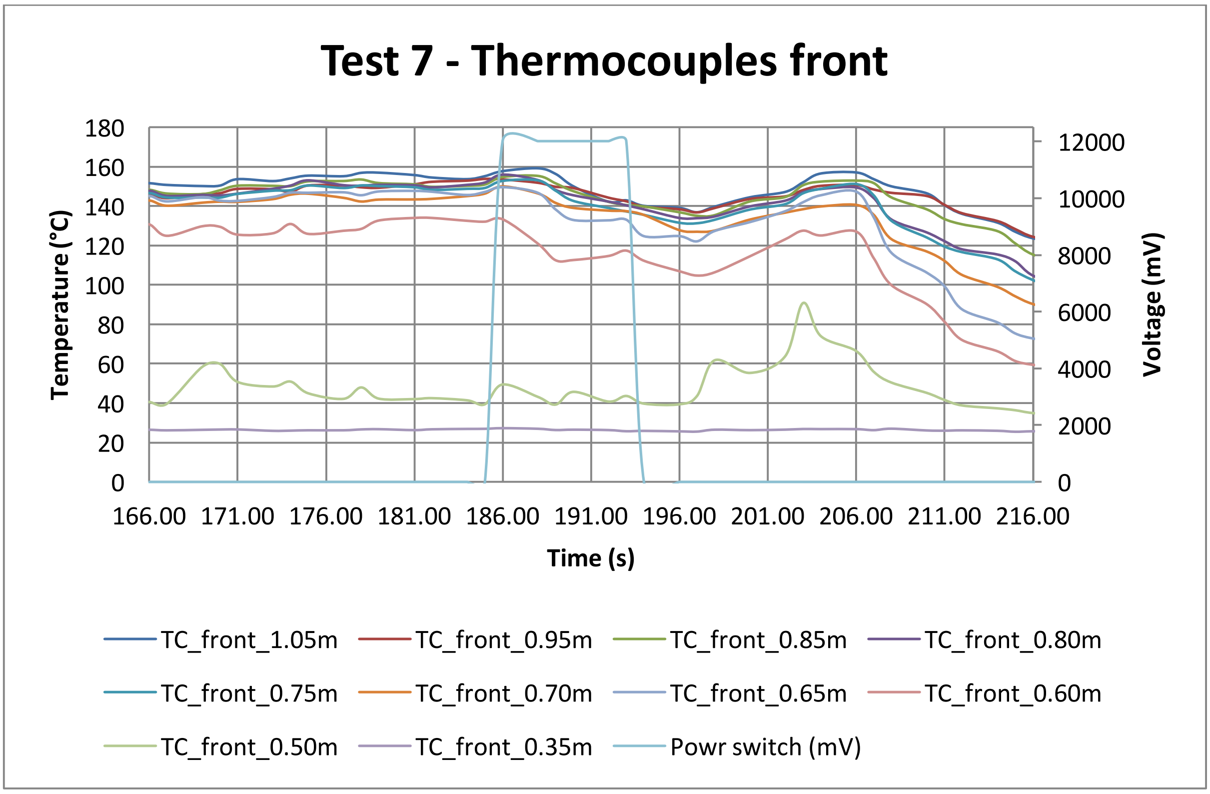
Test 5 -Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
80.00 100.00 120.00 140.00 160.00 180.00 200.00 220.00
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)

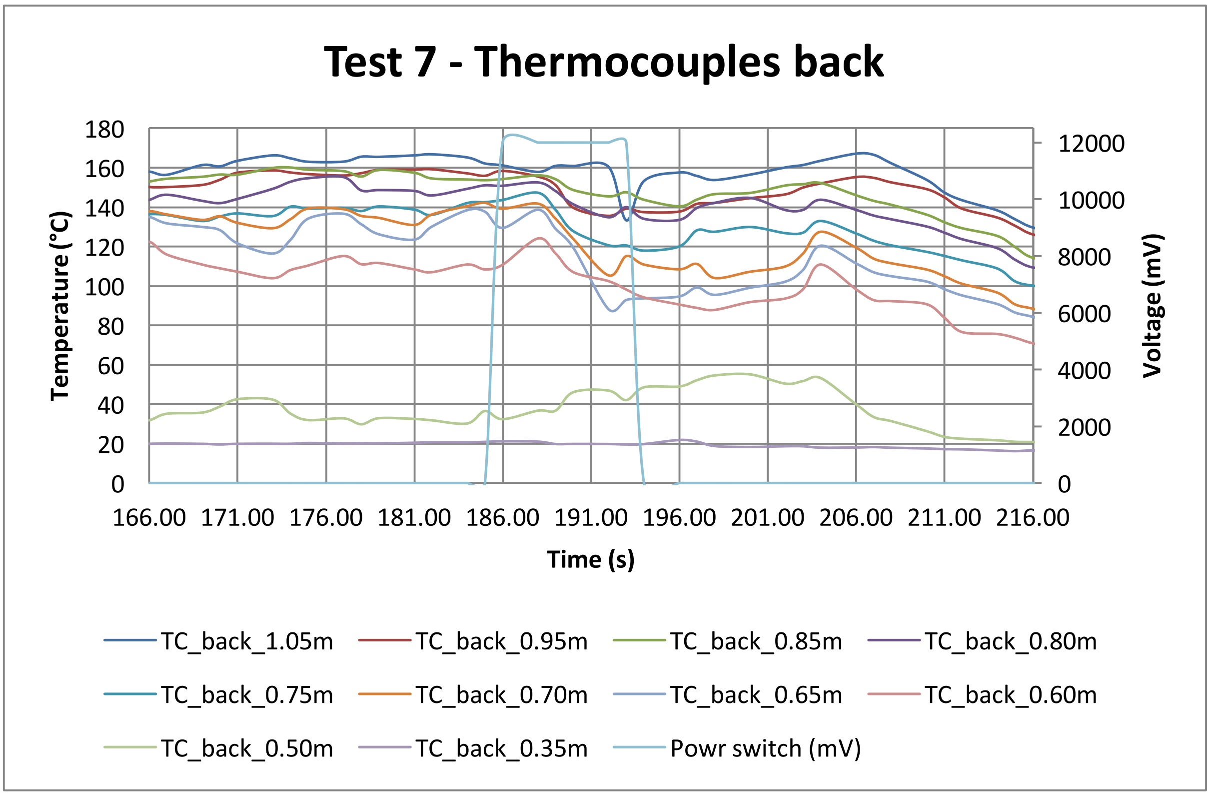

Test 6 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
14000
12000
10000
8000
6000
4000
2000
0
-2000
160.00 165.00 170.00 175.00 180.00 185.00 190.00 195.00 200.00 205.00 210.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

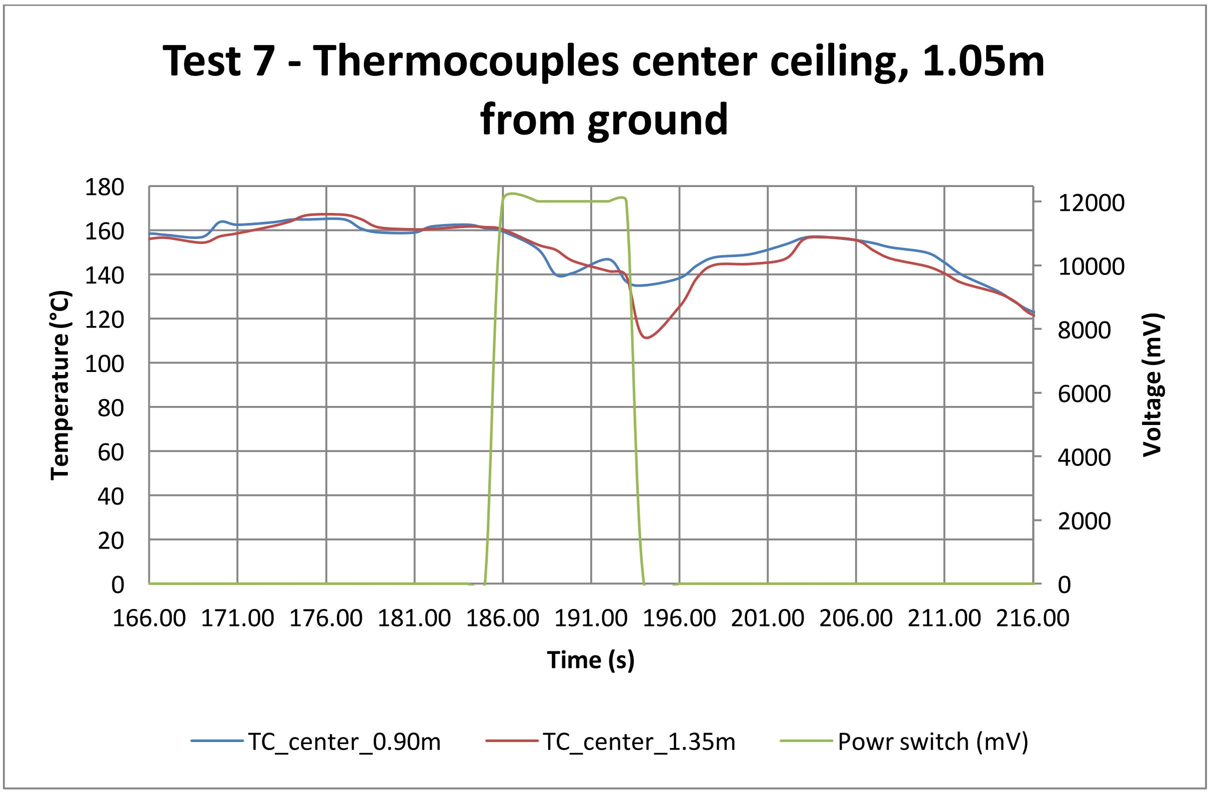

Test 6 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
160.00 165.00 170.00 175.00 180.00 185.00 190.00 195.00 200.00 205.00 210.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

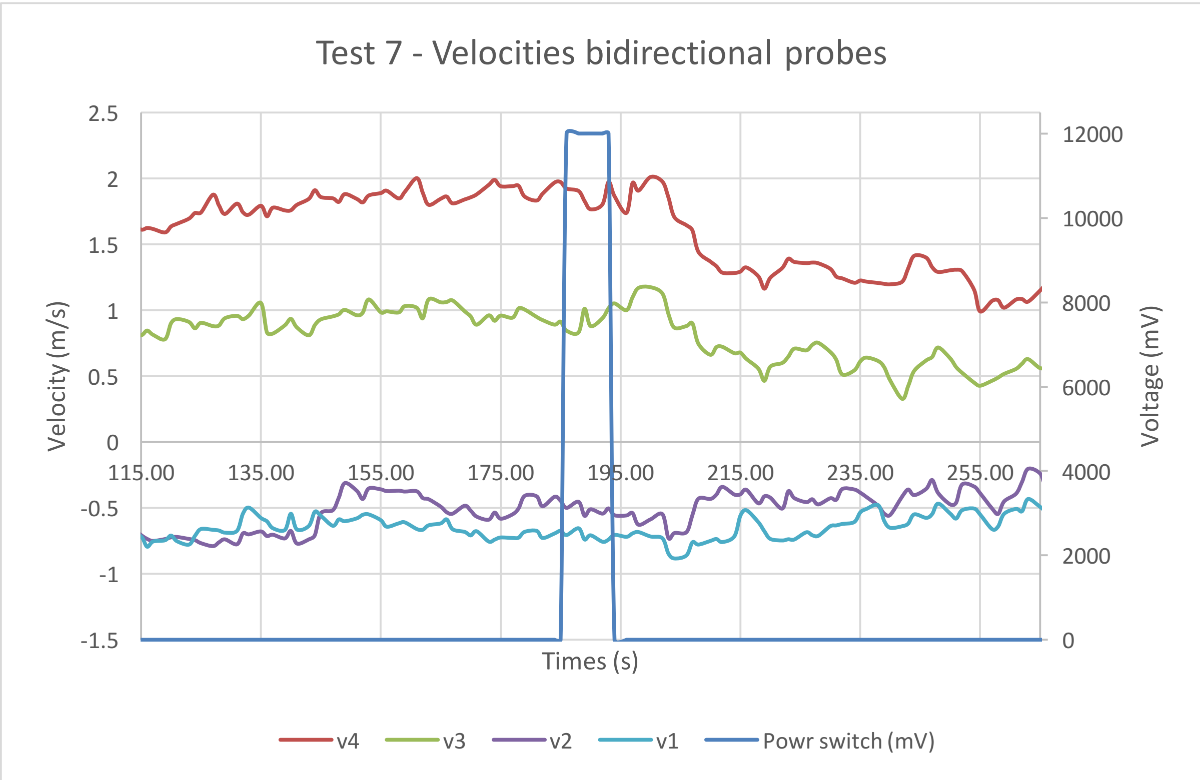

Test 6 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
160.00 165.00 170.00 175.00 180.00 185.00 190.00 195.00 200.00 205.00 210.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

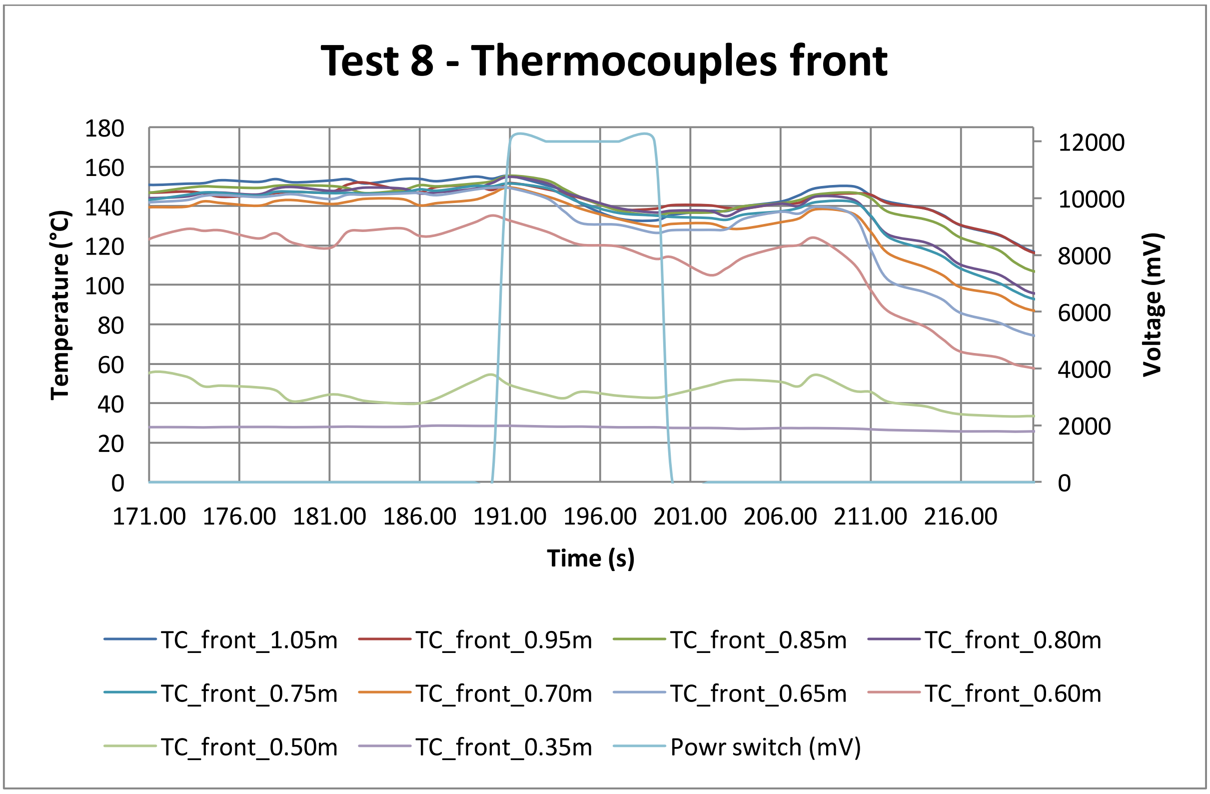

Test 6 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
109.00 129.00 149.00 169.00 189.00 209.00 229.00 249.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

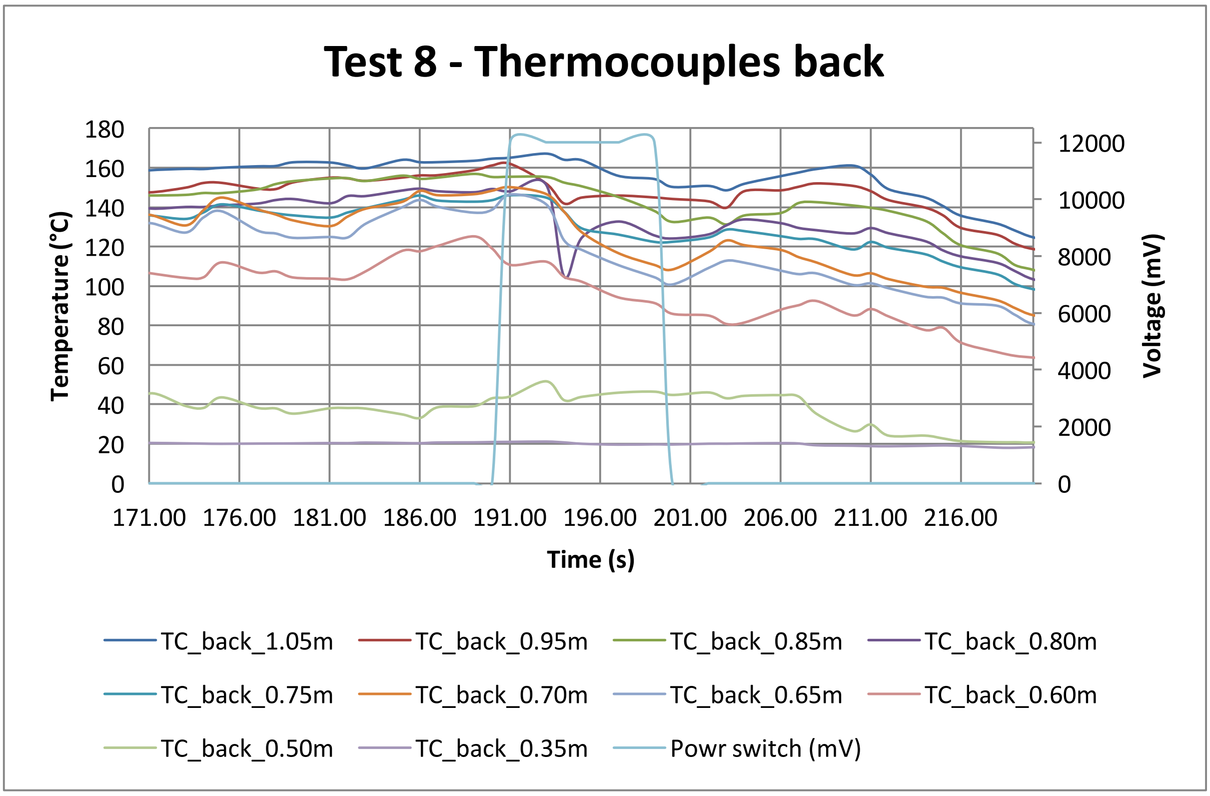

Test 7 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
166.00 171.00 176.00 181.00 186.00 191.00 196.00 201.00 206.00 211.00 216.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

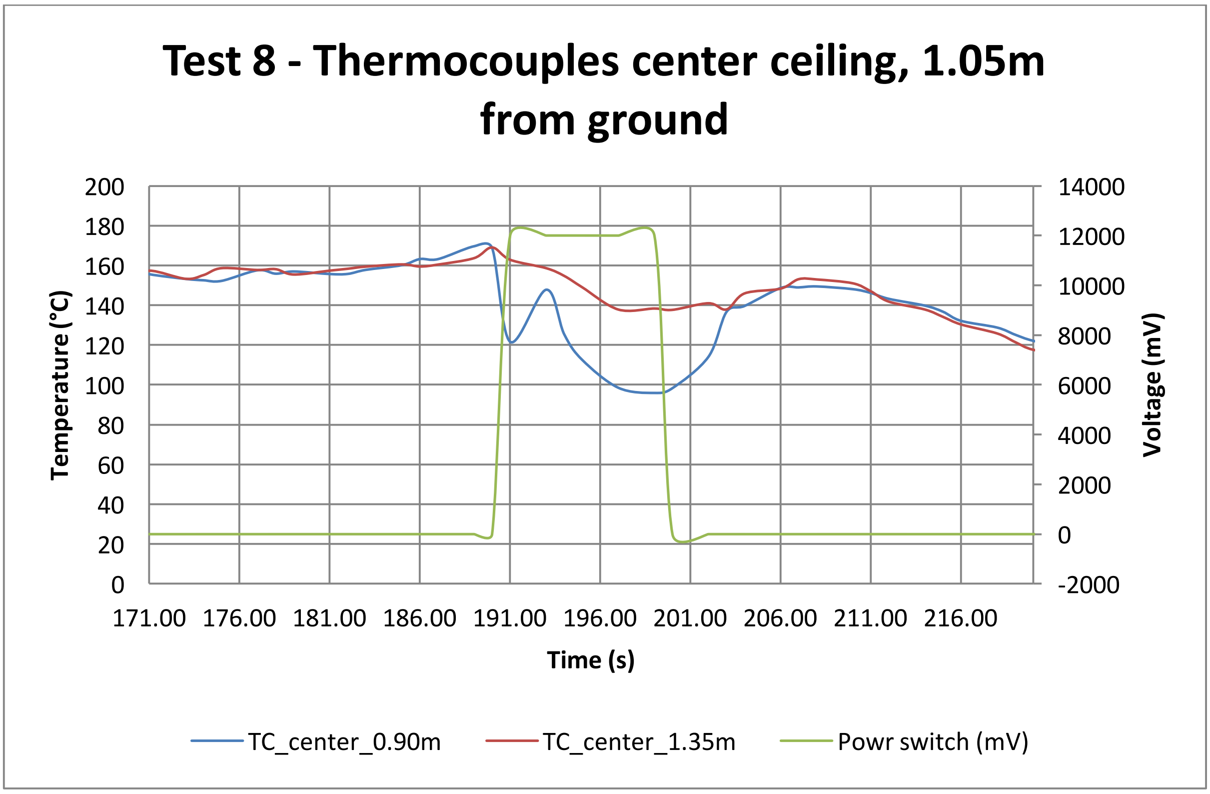

Test 7 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
166.00 171.00 176.00 181.00 186.00 191.00 196.00 201.00 206.00 211.00 216.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 7 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
166.00 171.00 176.00 181.00 186.00 191.00 196.00 201.00 206.00 211.00 216.00
Time (s)
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

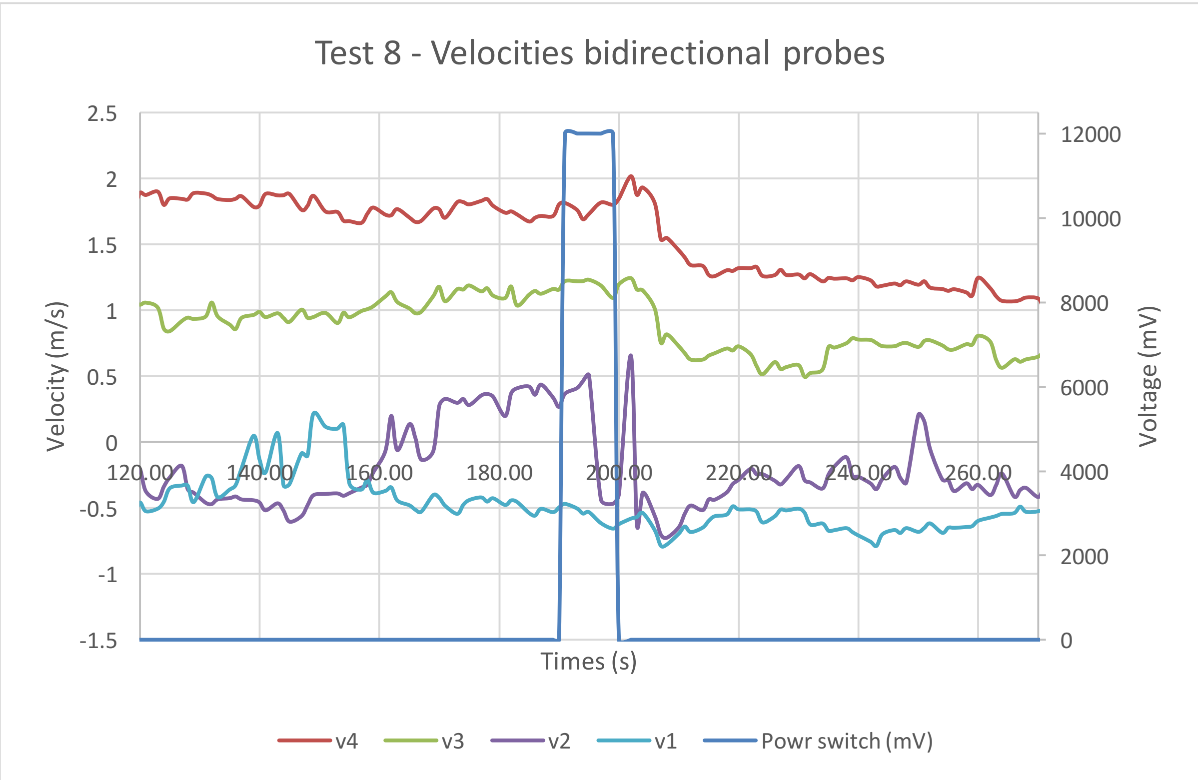

Test 7 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
115.00 135.00 155.00 175.00 195.00 215.00 235.00 255.00
Times (s)
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
v4
v3
v2
v1
Powr switch (mV)


Test 8 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
171.00
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

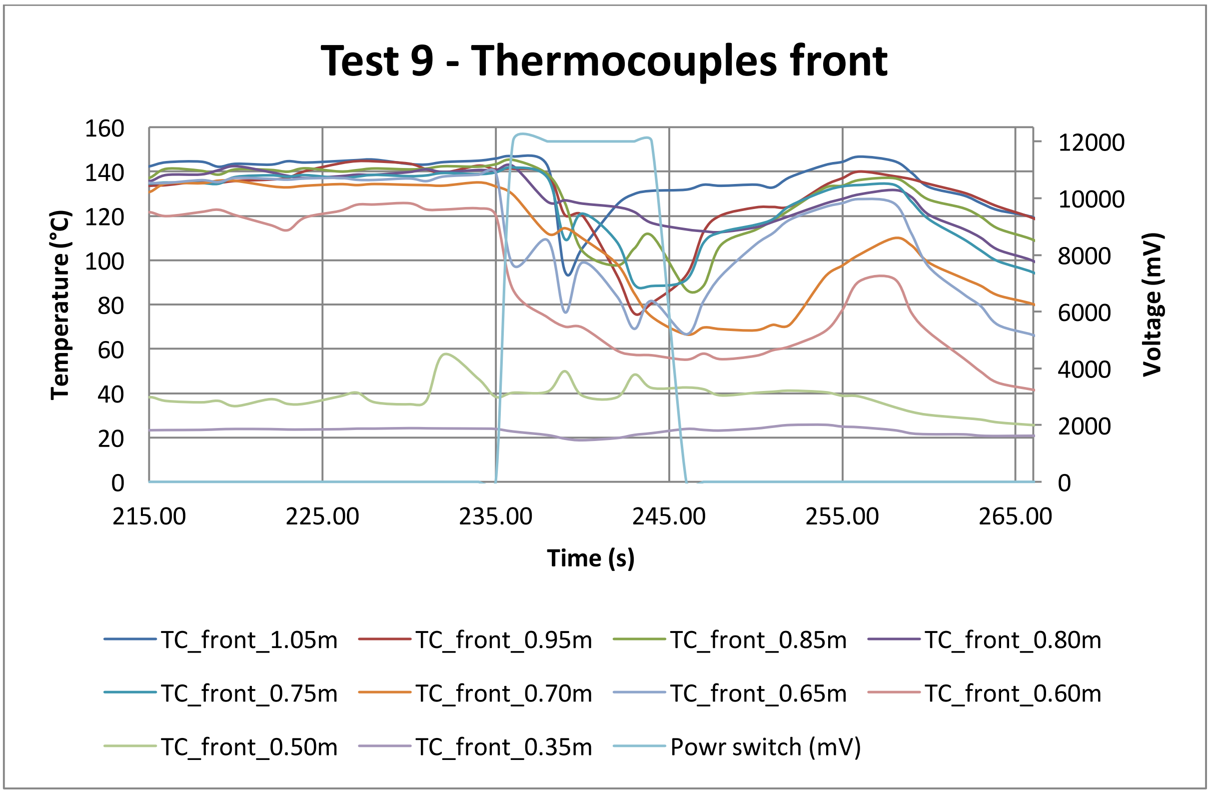

Test 8 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
171.00
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

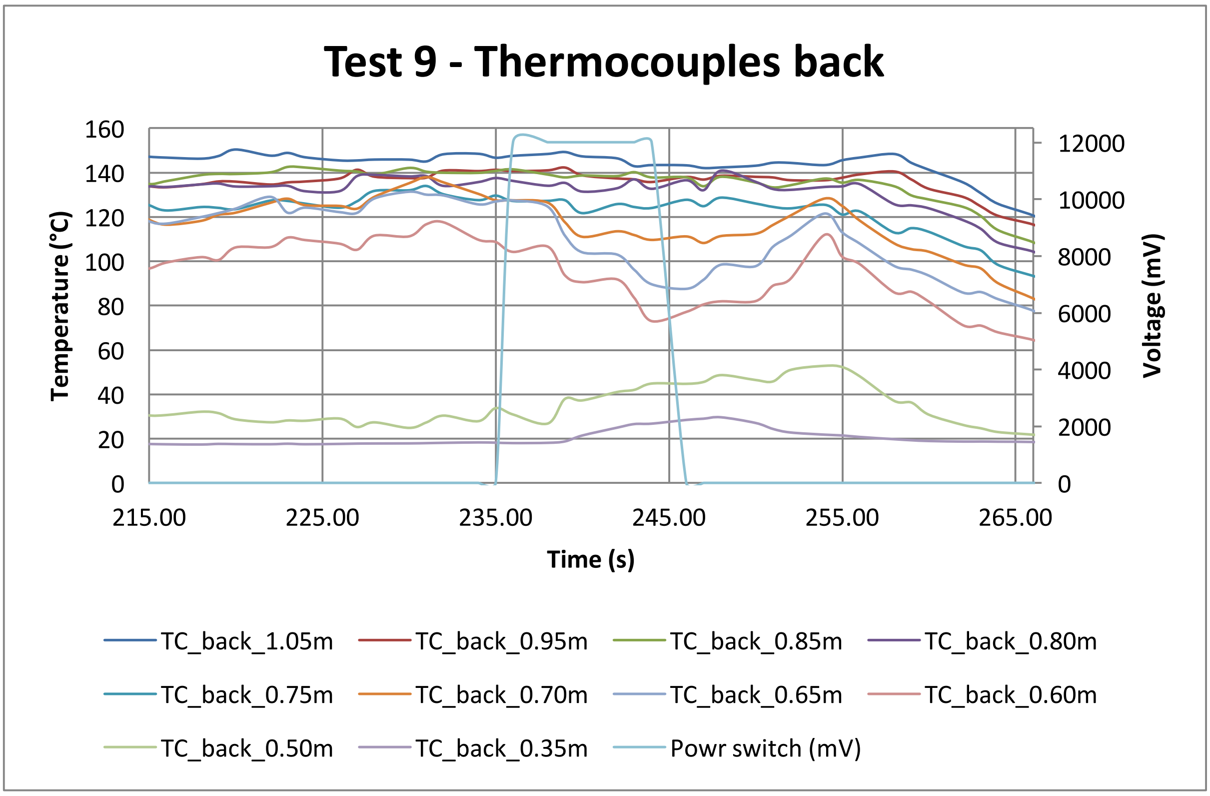


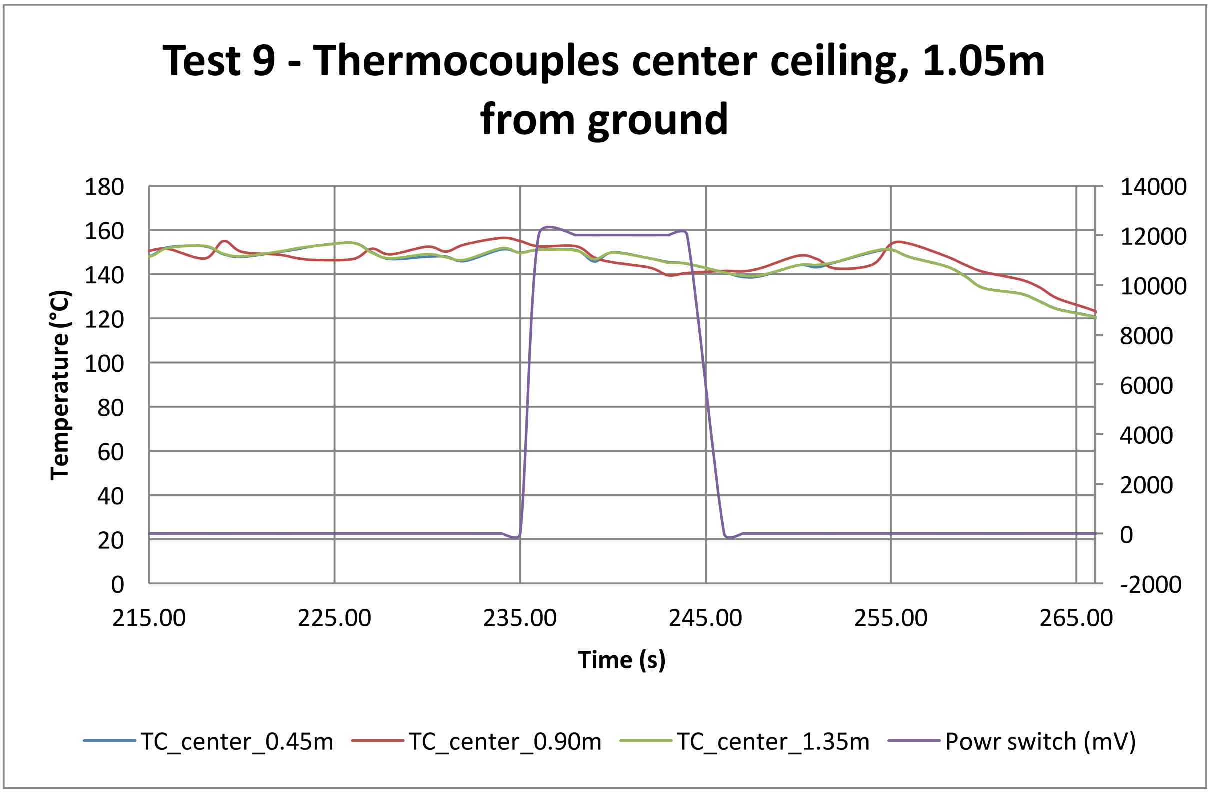
Test 8 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
200
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
171.00 176.00 181.00 186.00 191.00 196.00 201.00 206.00 211.00 216.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

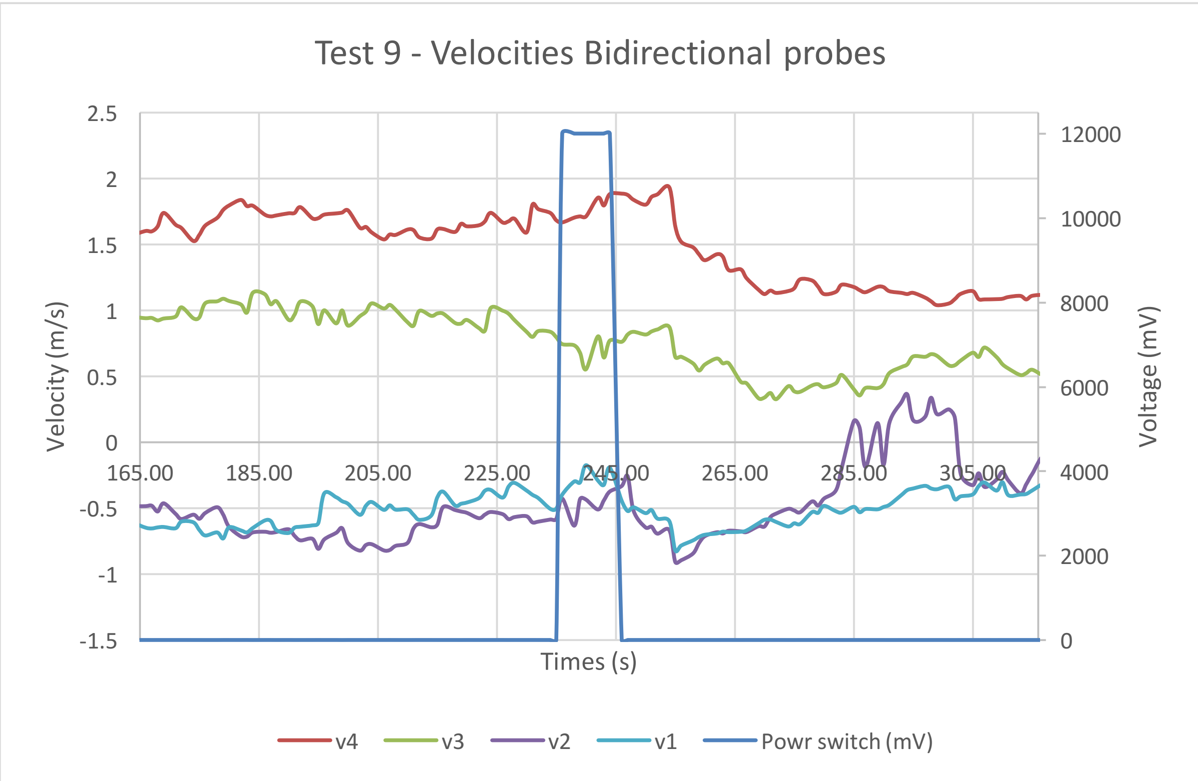


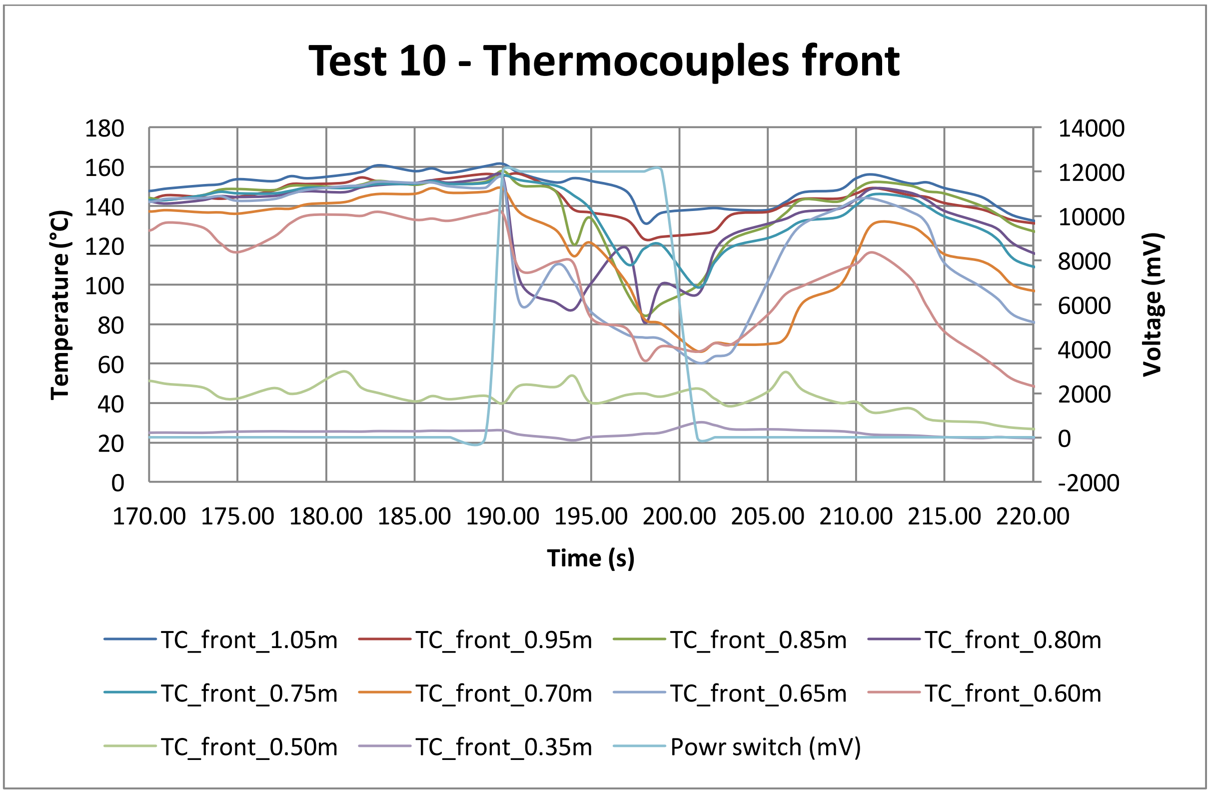
Test 8 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
120.00 140.00 160.00 180.00 200.00 220.00 240.00 260.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

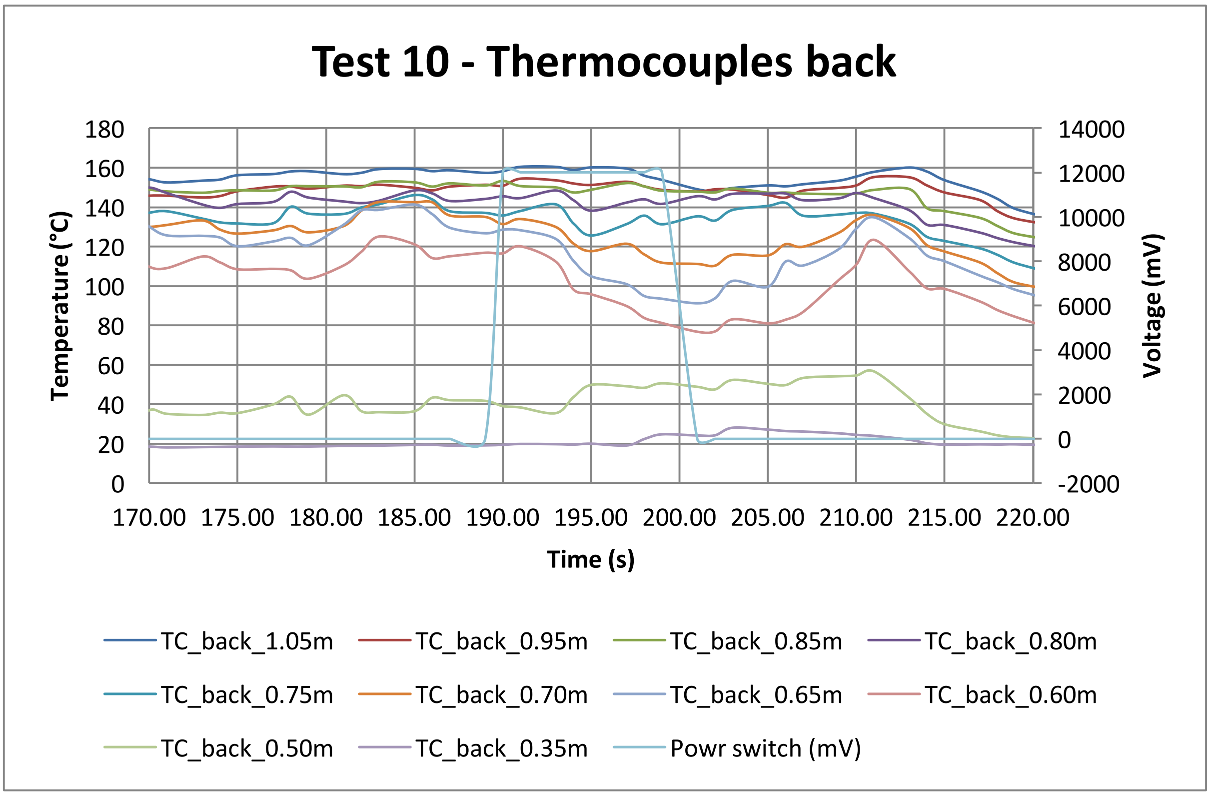

Test 9 - Thermocouples front
Temperature (°C)
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
215.00
225.00
235.00
245.00
255.00
265.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

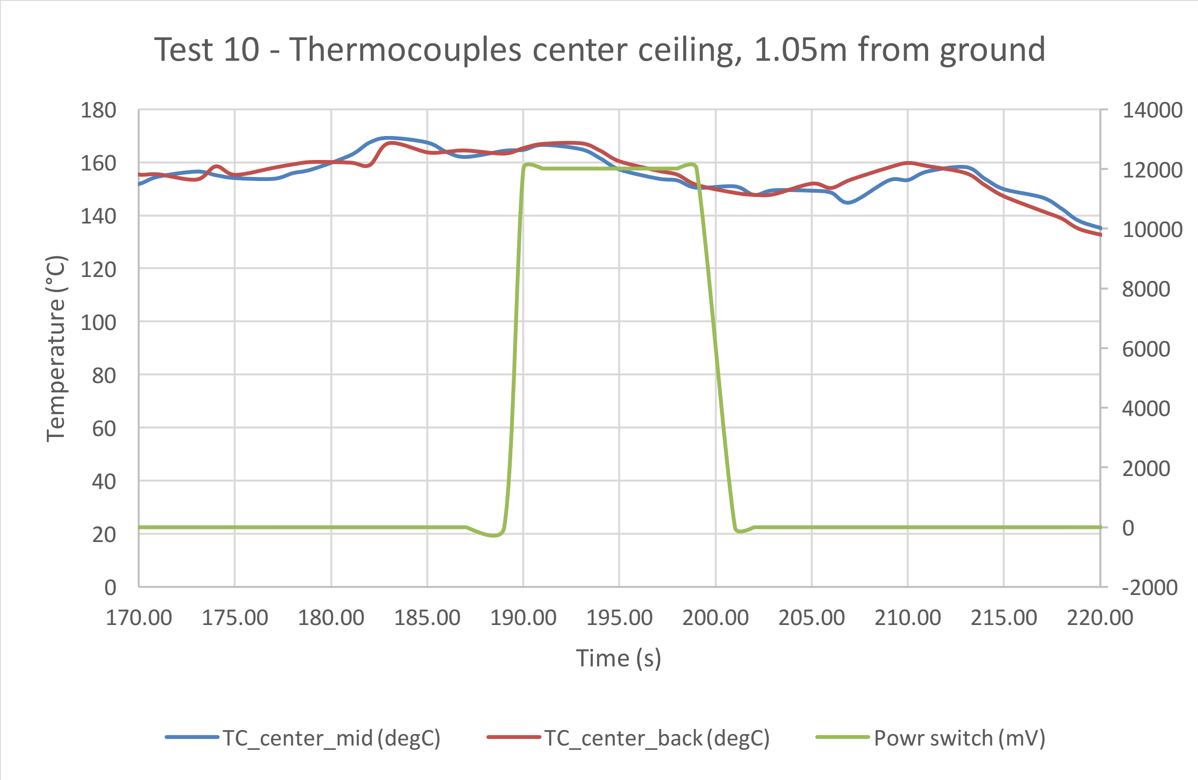

Test 9 - Thermocouples back
Temperature (°C)
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
215.00
225.00
235.00
245.00
255.00
265.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

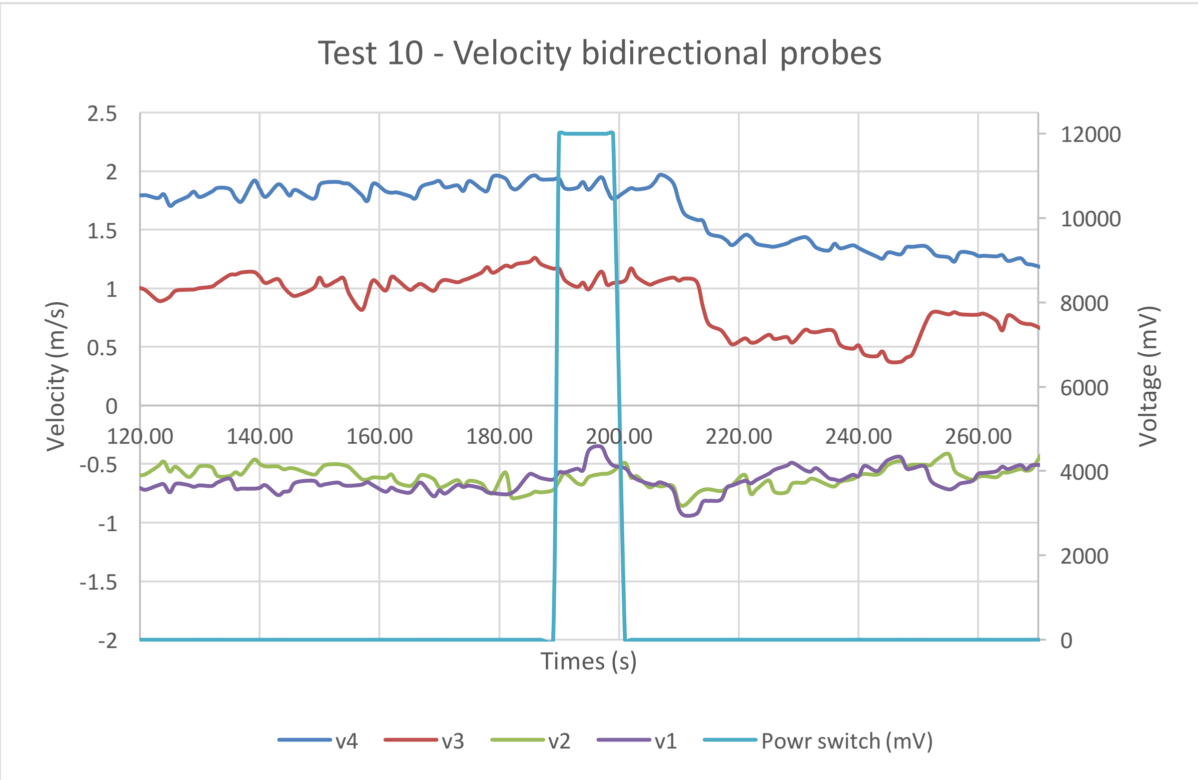

Test 9 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
215.00
225.00
235.00
245.00
255.00
265.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

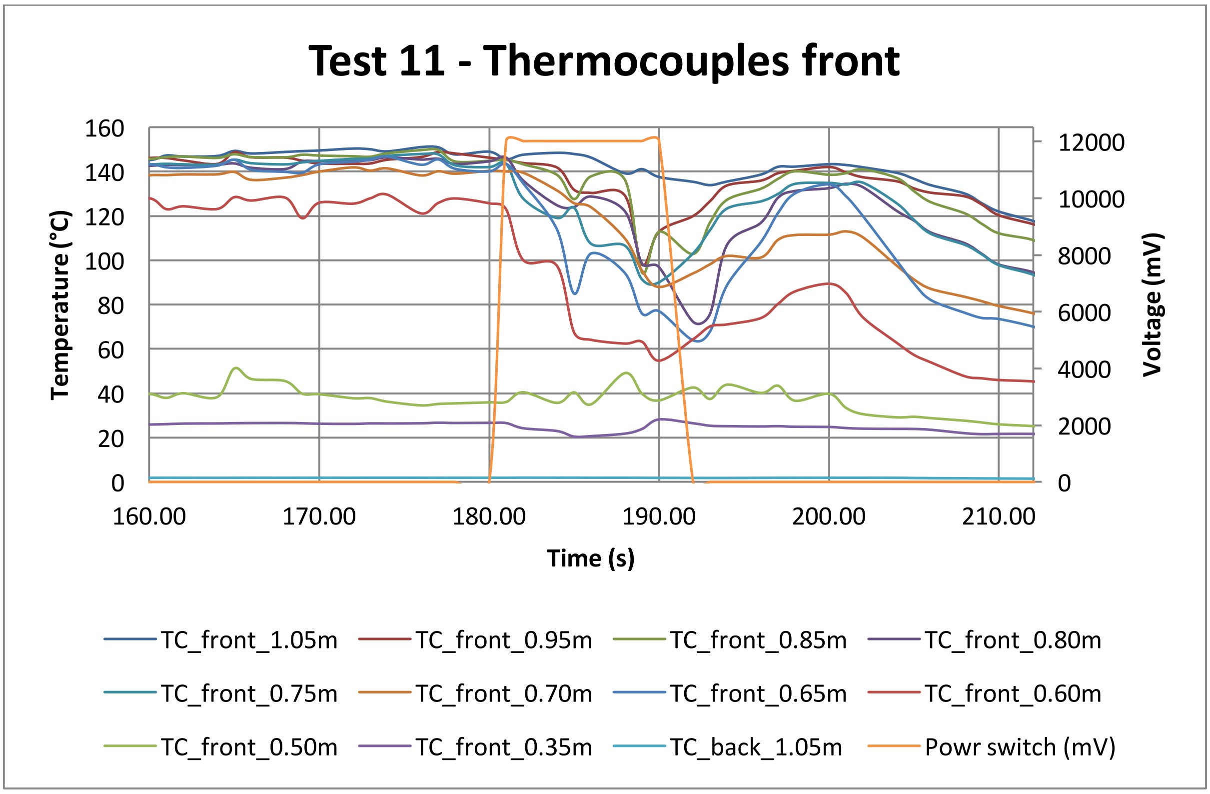

Test 9 - Velocities Bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
165.00
185.00
205.00
225.00
245.00
265.00
285.00
305.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

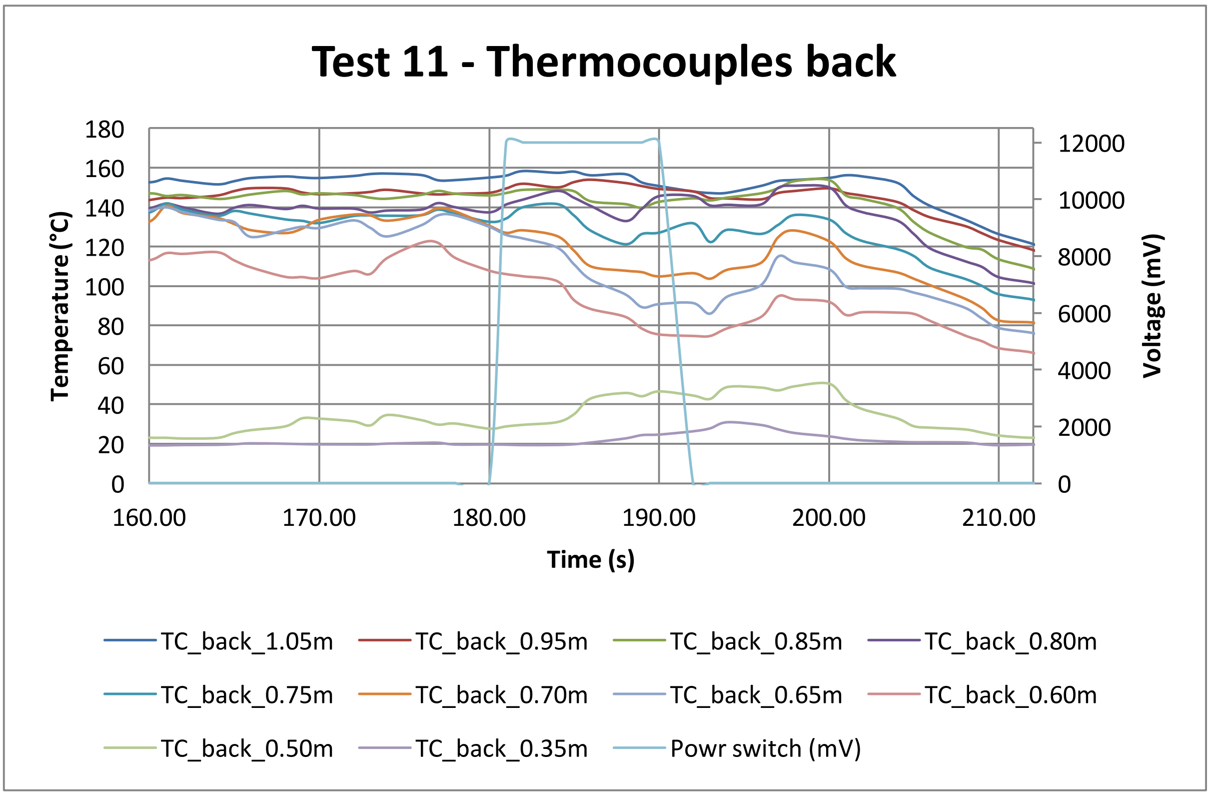

Test 10 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

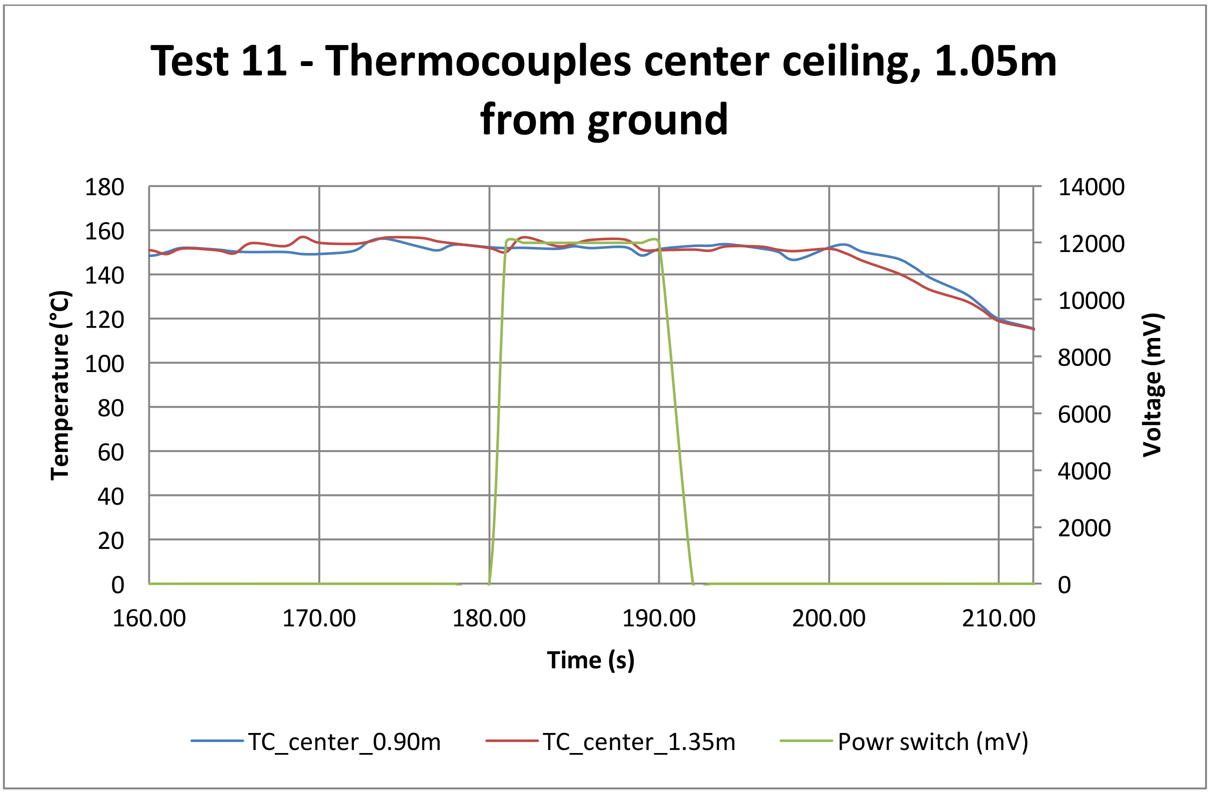

Test 10 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 10 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
170.00
175.00
180.00
185.00
190.00
195.00
200.00
205.00
210.00
215.00
220.00
Time (s)
TC_center_mid (degC)
TC_center_back (degC)
Powr switch (mV)

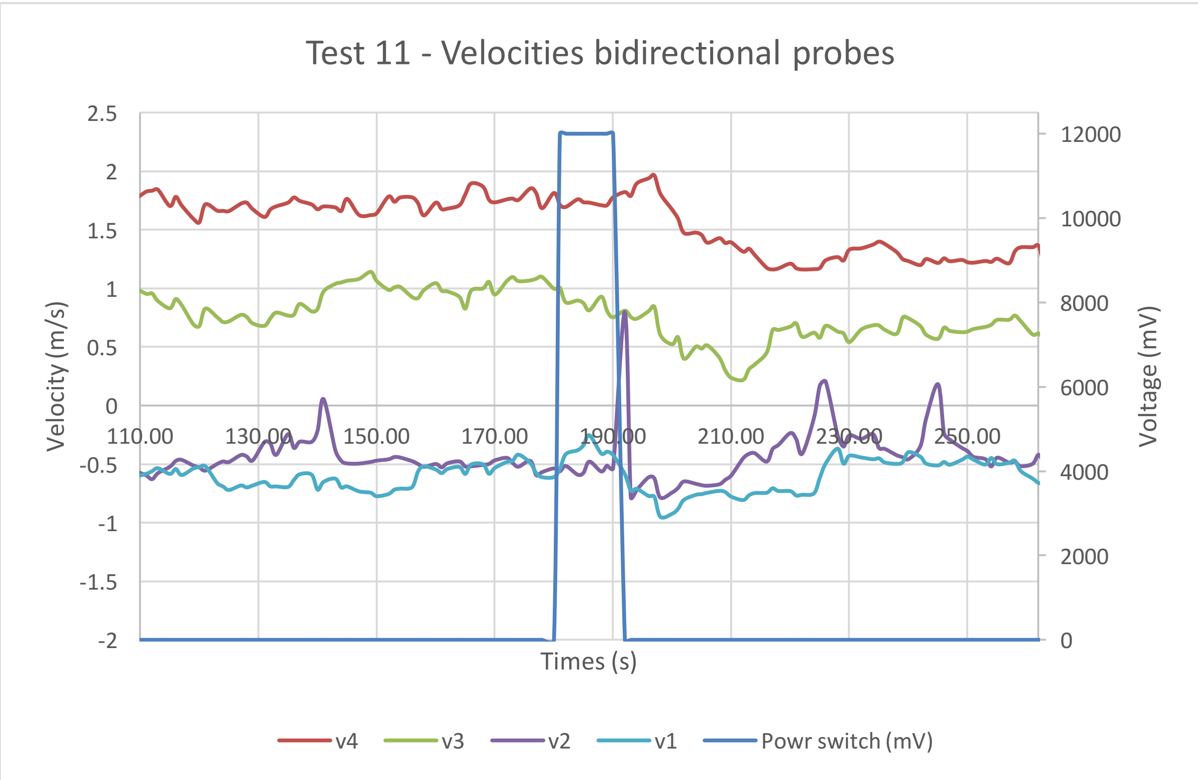

Test 10 - Velocity bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 11 - Thermocouples front
Temperature (°C)
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
160.00
170.00
180.00
190.00
200.00
210.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
TC_back_1.05m
Powr switch (mV)

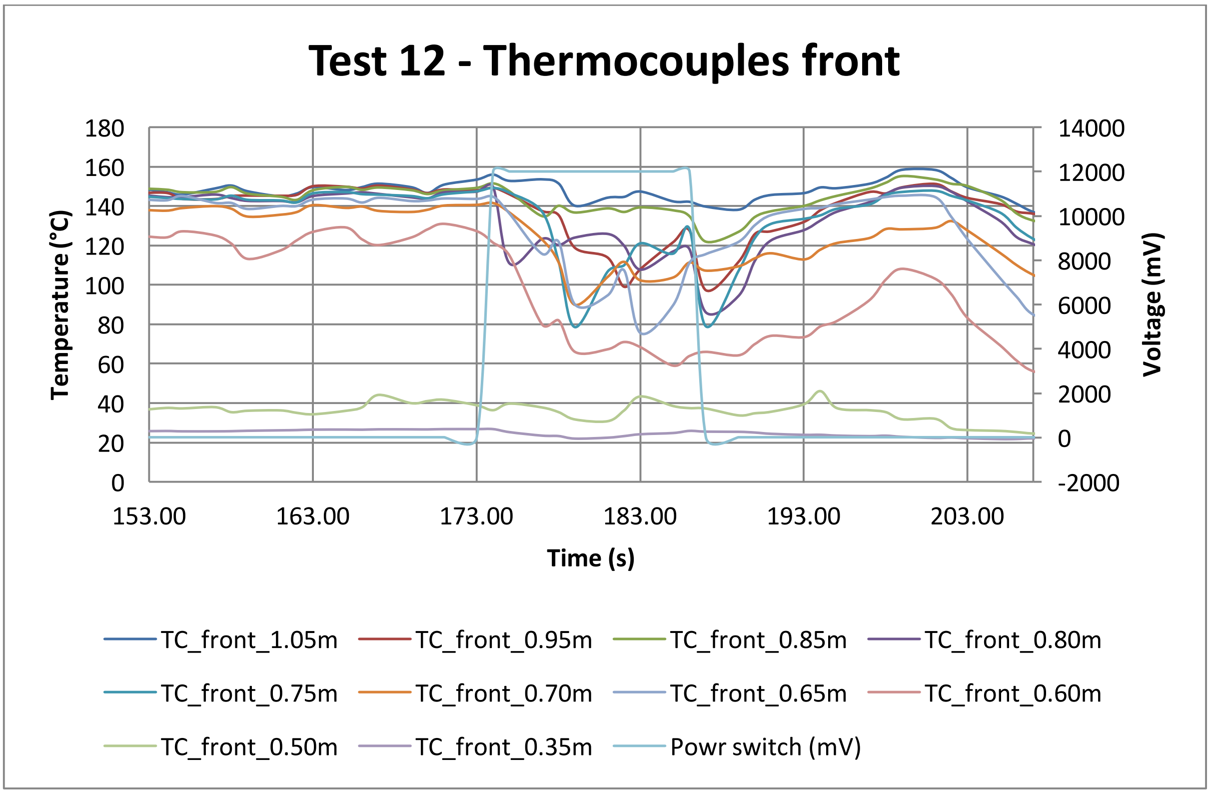

Test 11 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
160.00
170.00
180.00
190.00
200.00
210.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

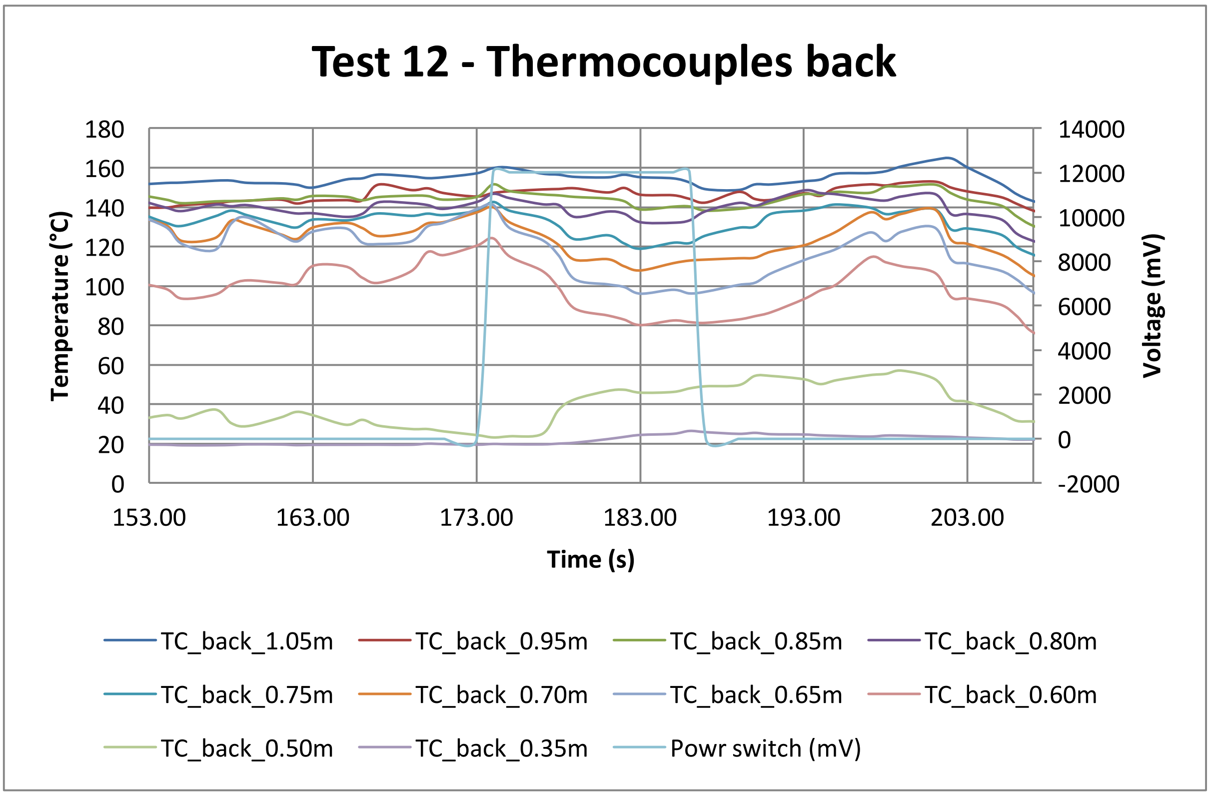


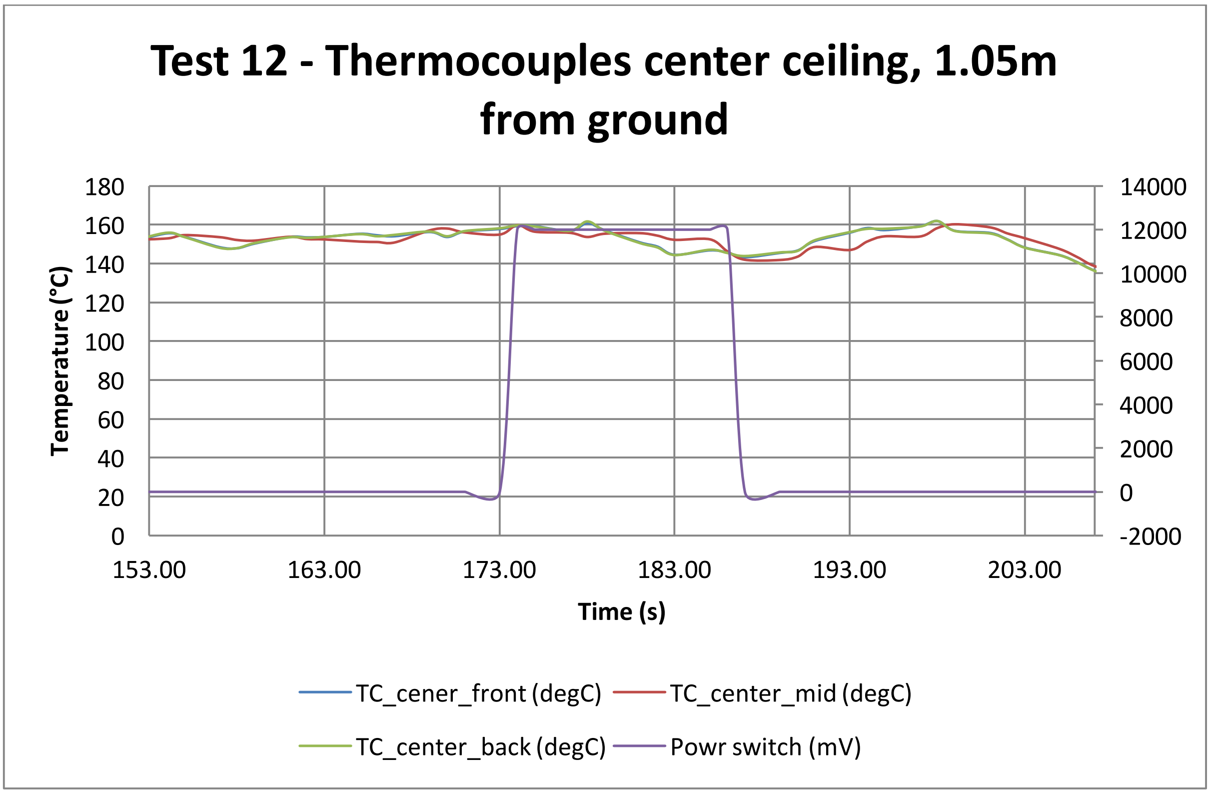
Test 11 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

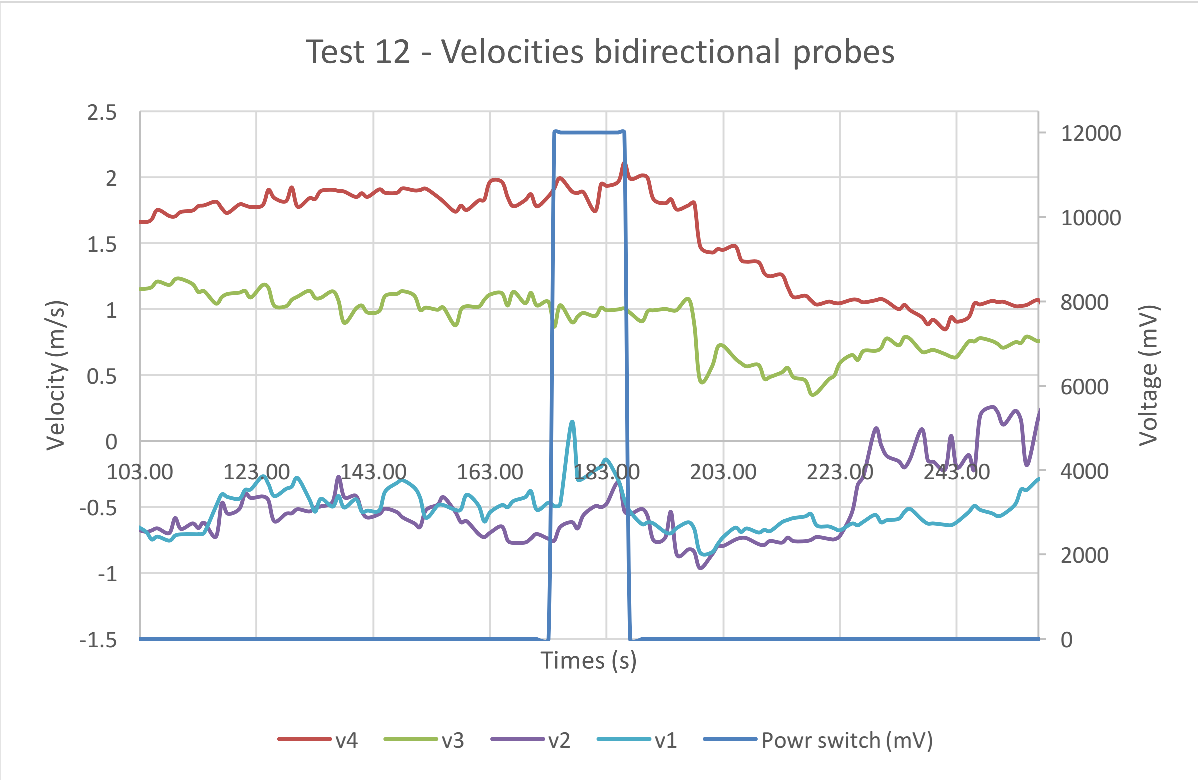


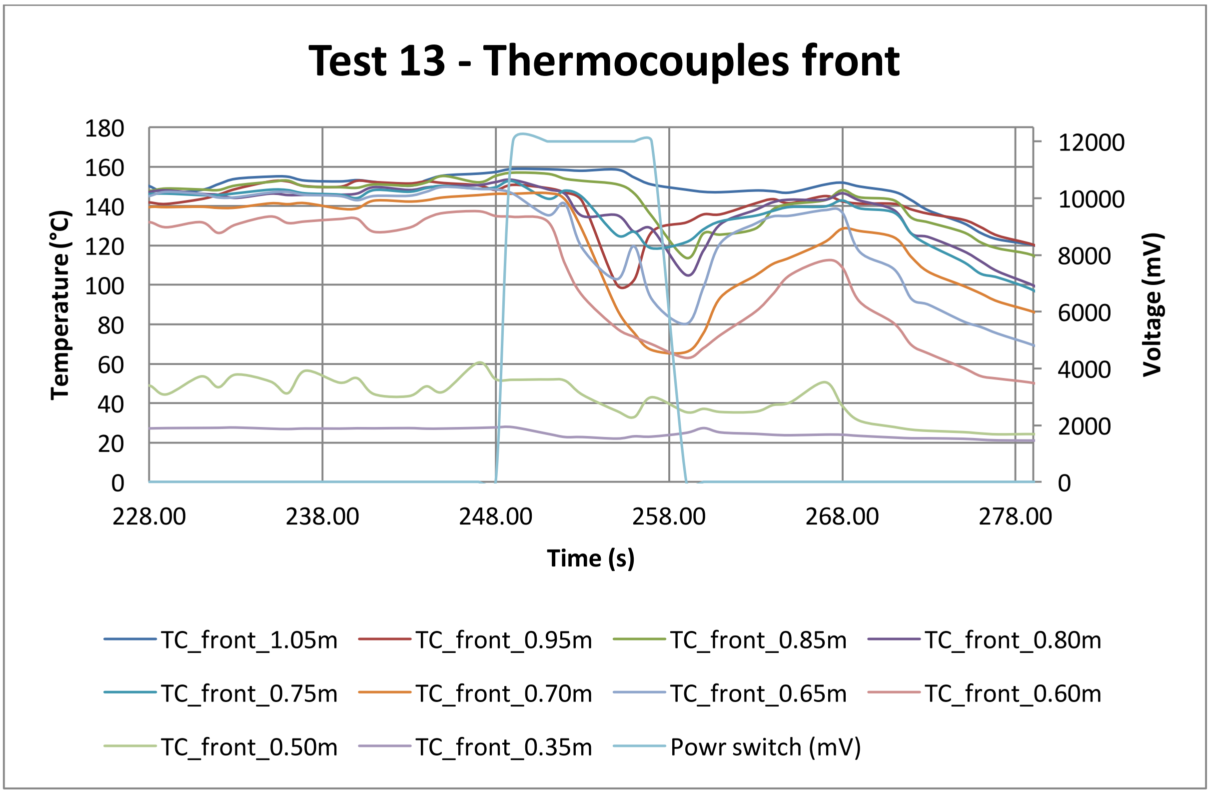
Test 11 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)

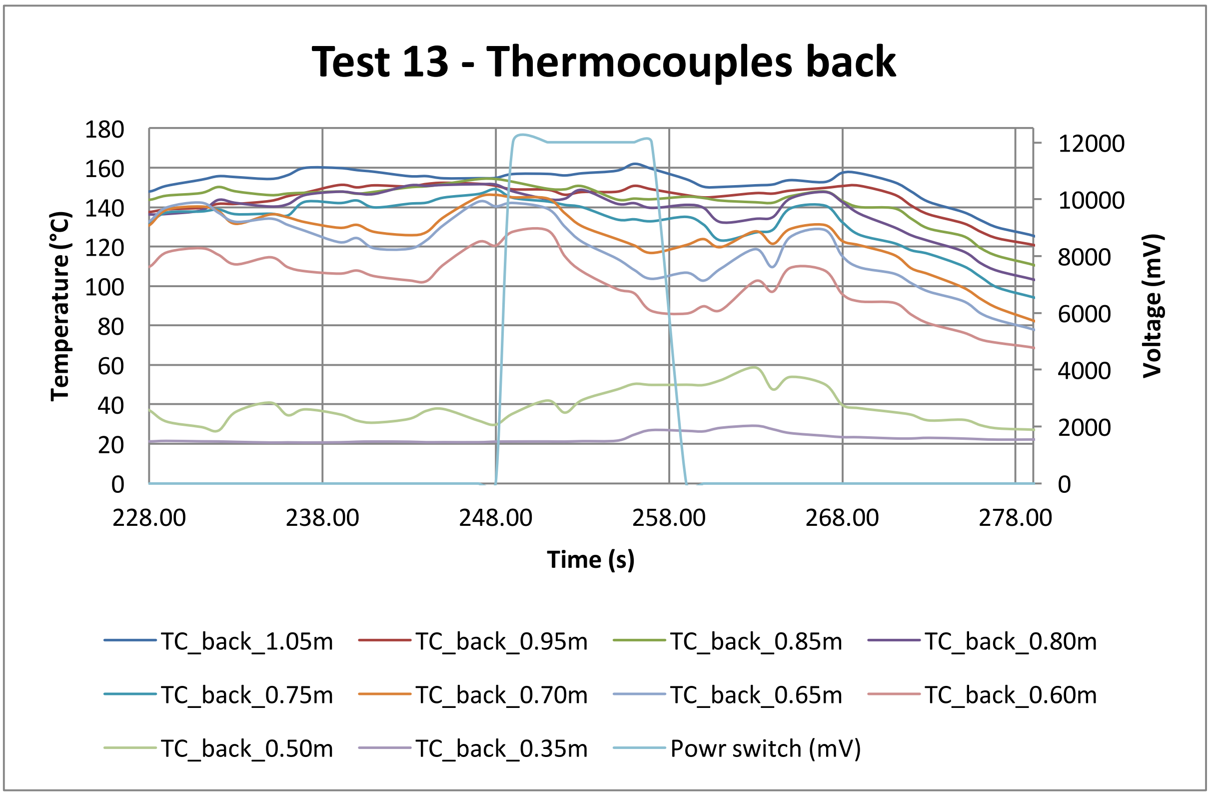

Test 12 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
-2000
0
2000
4000
6000
8000
10000
12000
14000
153.00
163.00
173.00
183.00
193.00
203.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

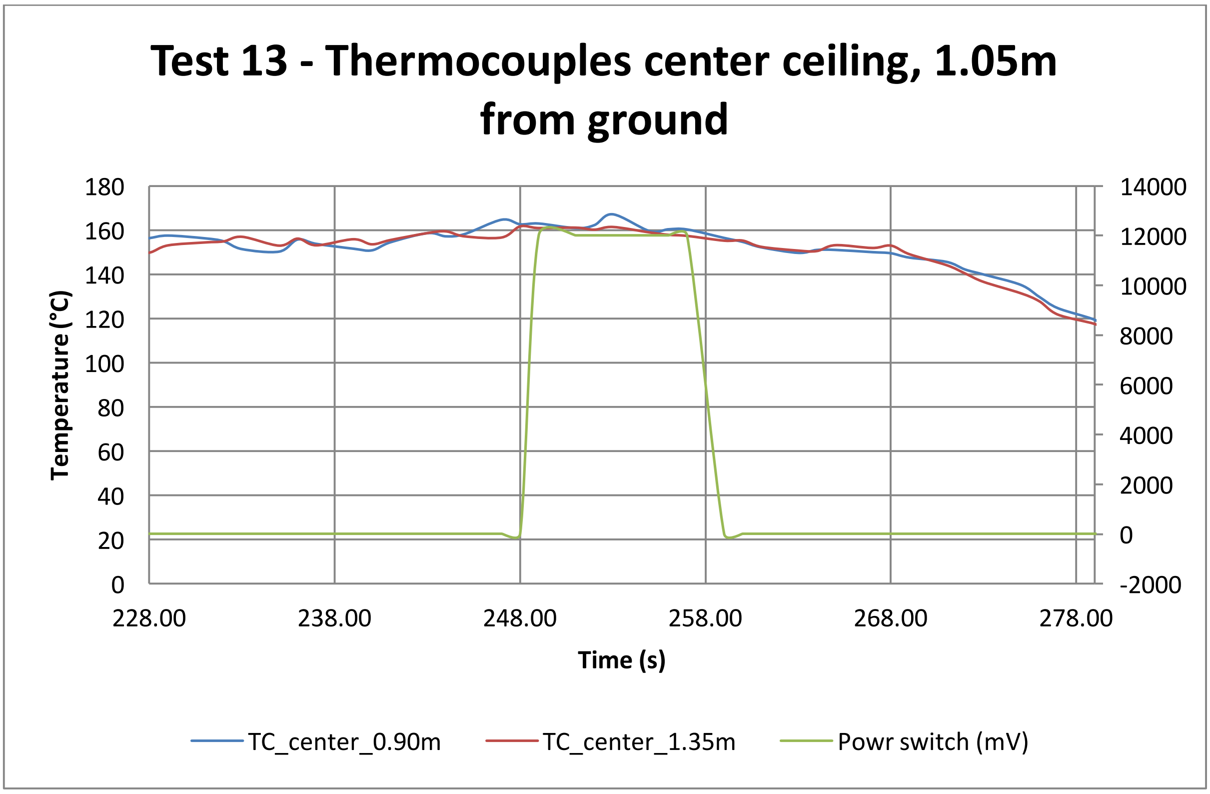

Test 12 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
-2000
0
2000
4000
6000
8000
10000
12000
14000
153.00
163.00
173.00
183.00
193.00
203.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 12 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
153.00
163.00
173.00
183.00
193.00
203.00
Time (s)
TC_cener_front (degC)
TC_center_mid (degC)
TC_center_back (degC)
Powr switch (mV)

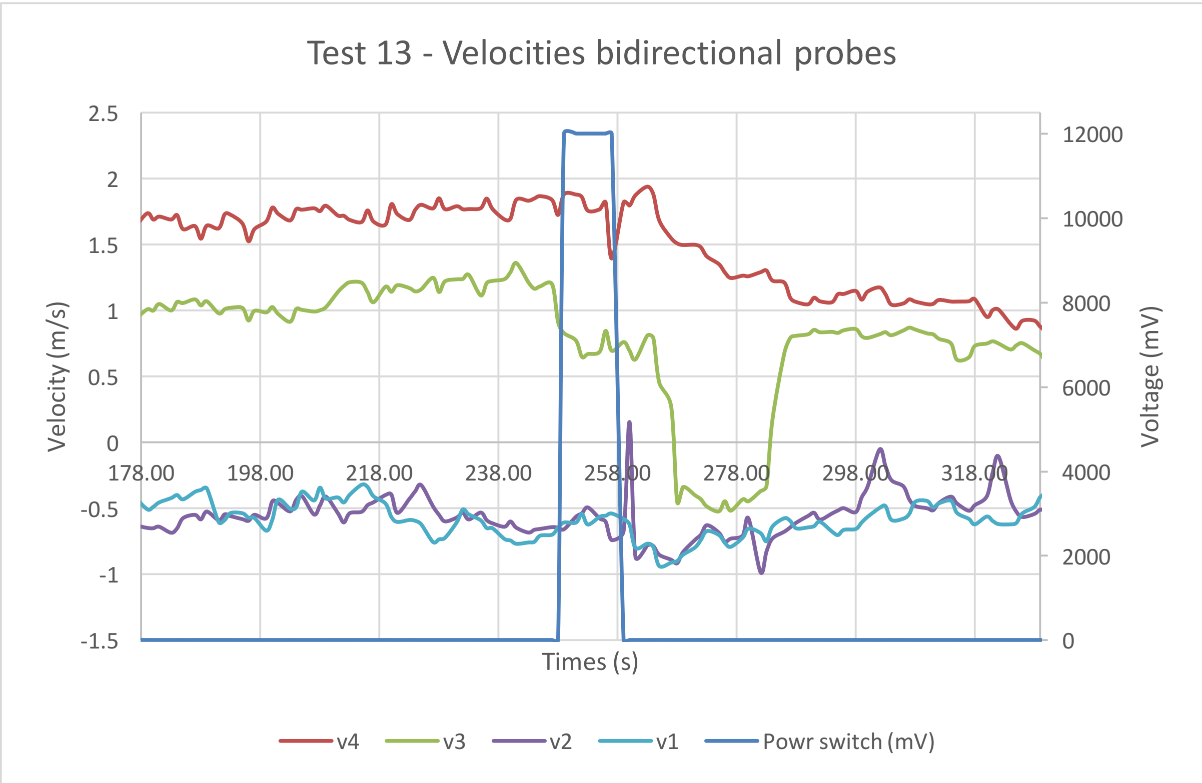

Test 12 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
103.00
123.00
143.00
163.00
183.00
203.00
223.00
243.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 13 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
228.00
238.00
248.00
258.00
268.00
278.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

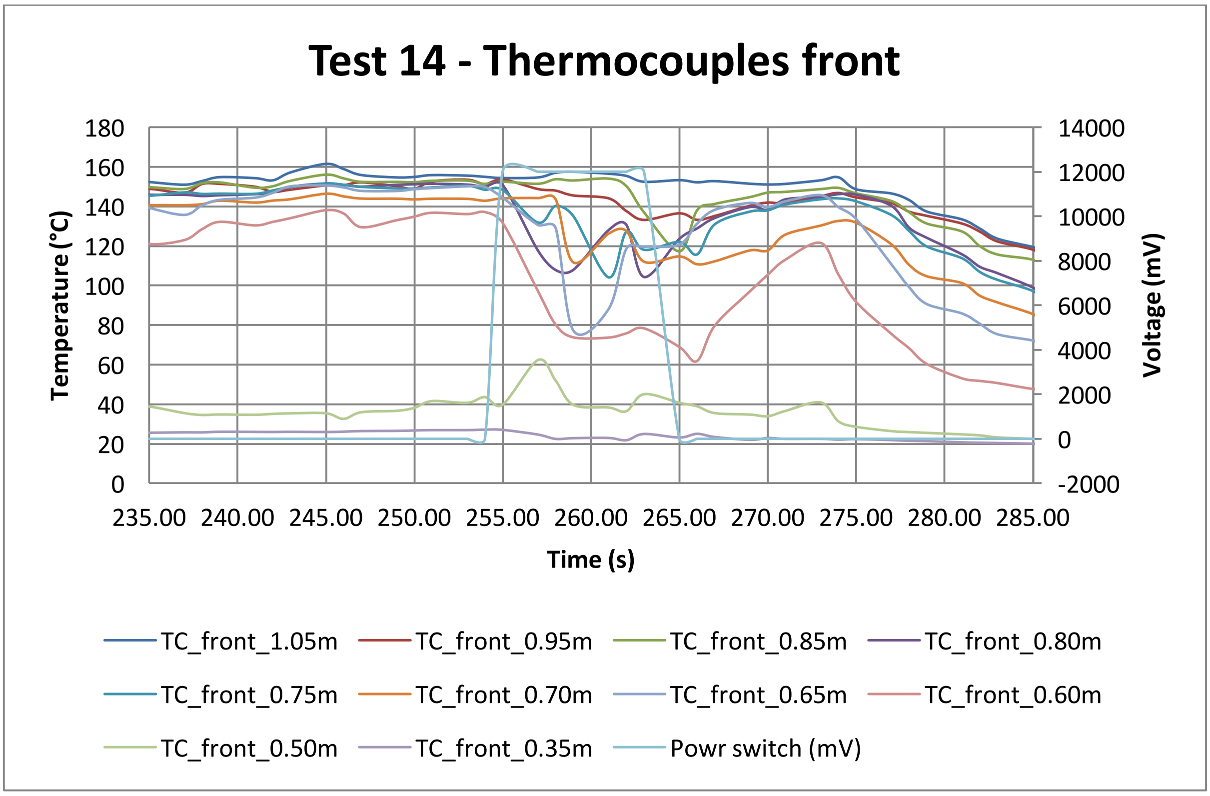

Test 13 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
228.00
238.00
248.00
258.00
268.00
278.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)



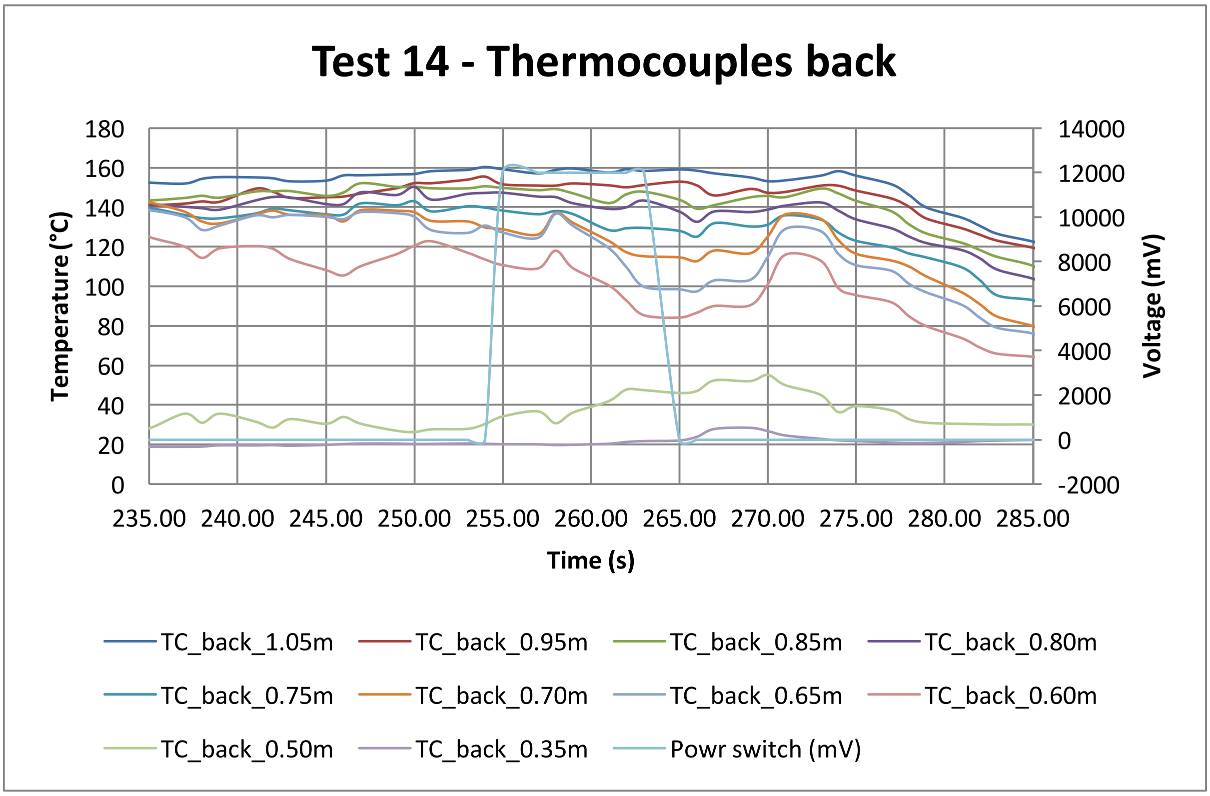
Test 13 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
228.00
238.00
248.00
258.00
268.00
278.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)



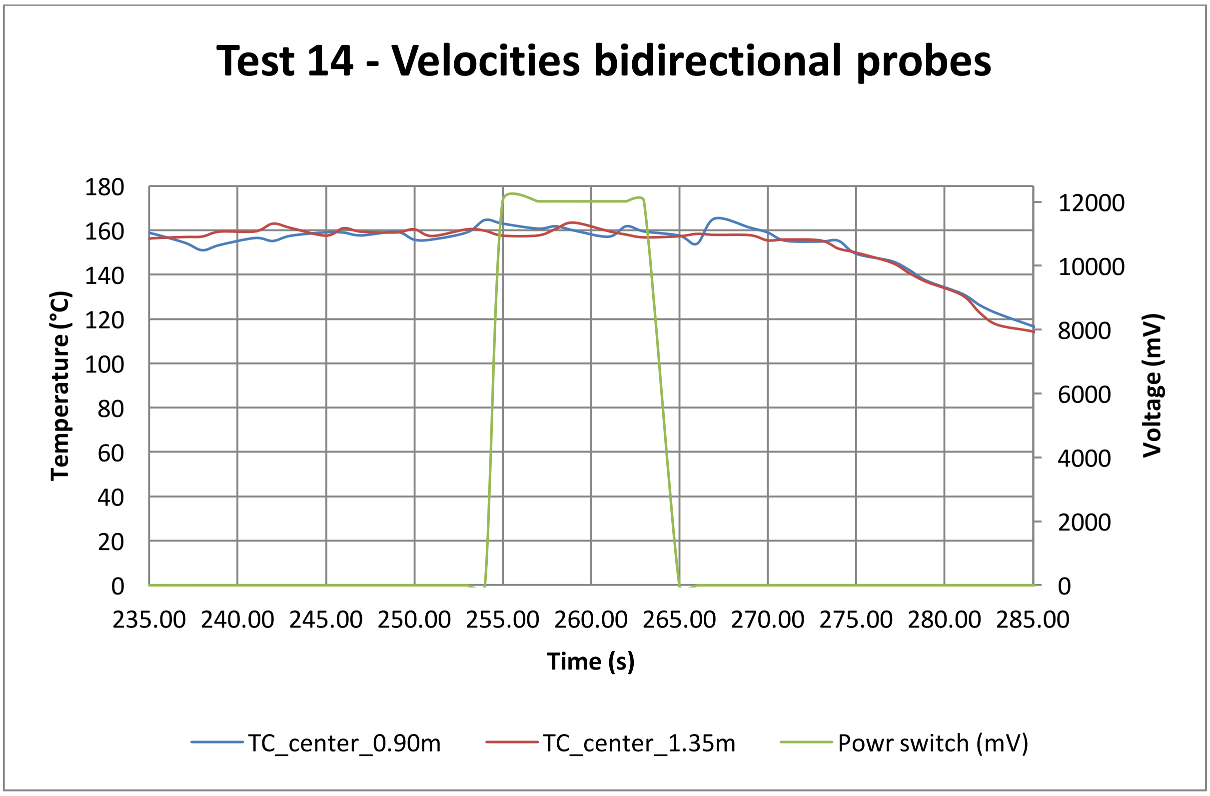
Test 13 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
178.00
198.00
218.00
238.00
258.00
278.00
298.00
318.00
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)

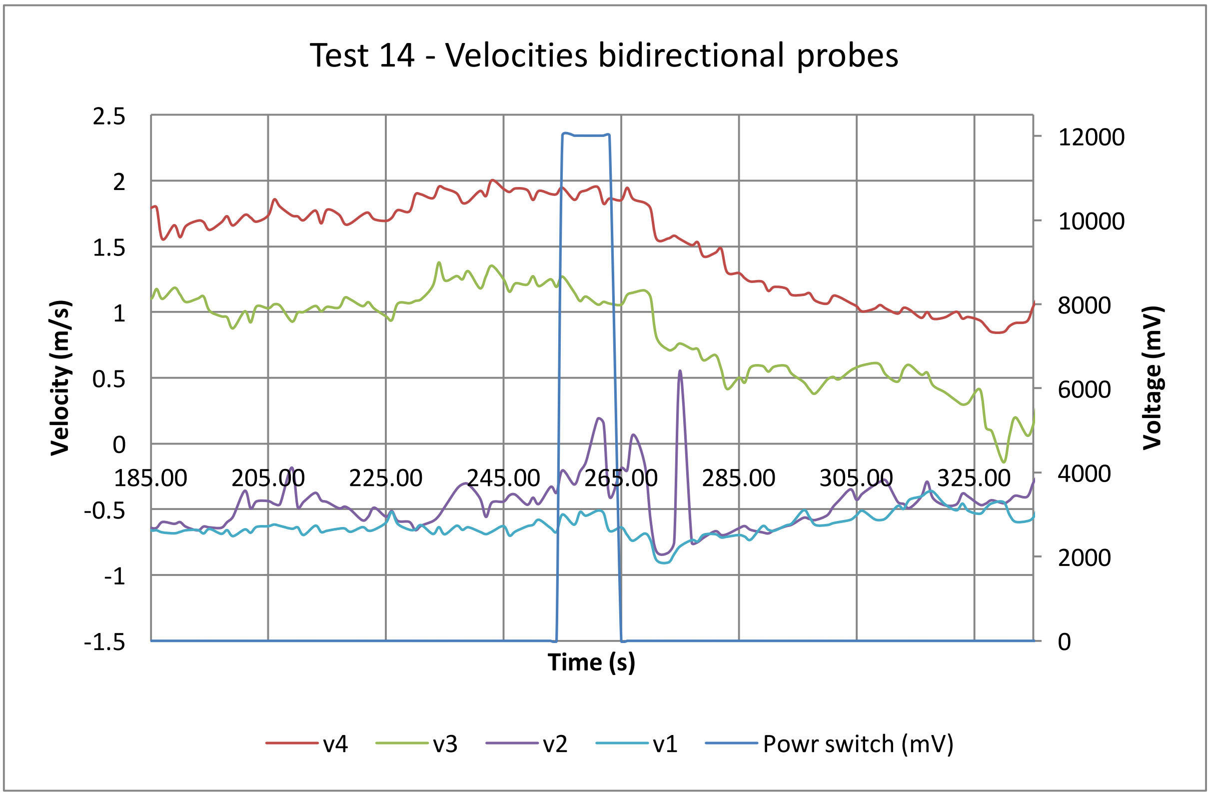


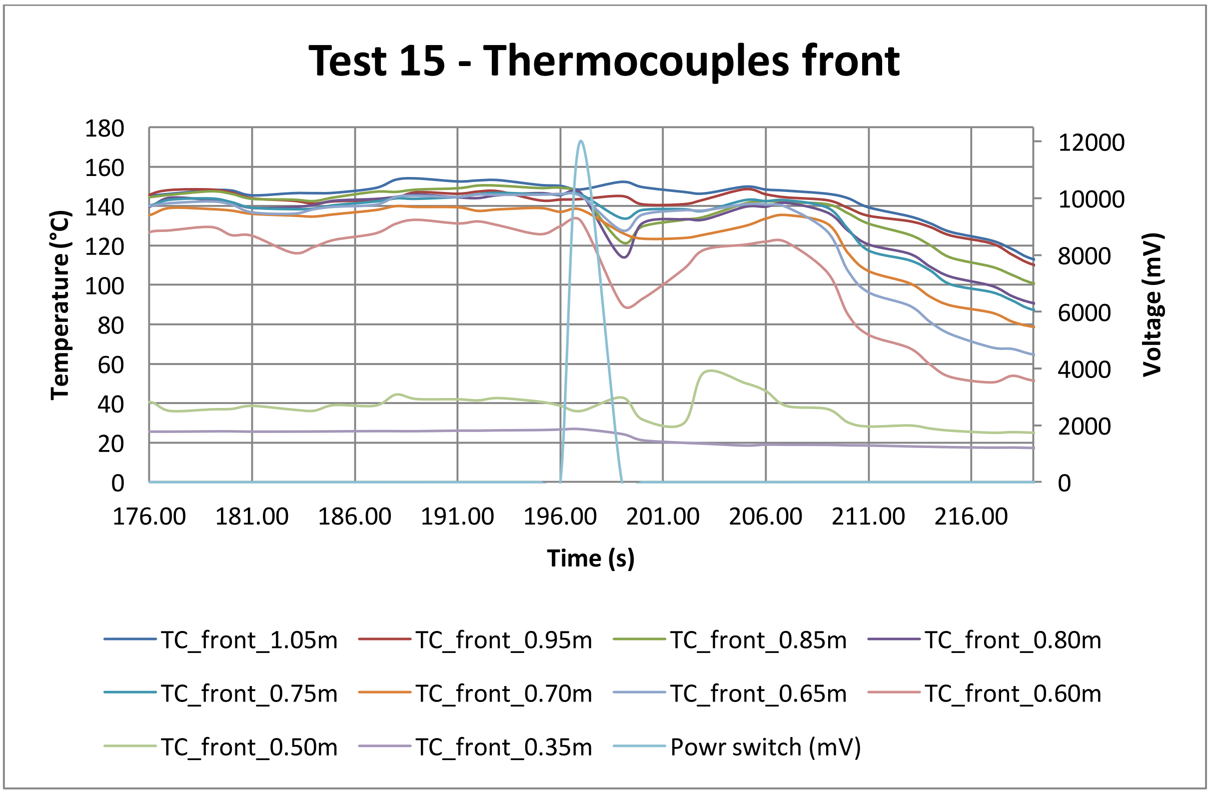
Test 14 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
235.00 240.00 245.00 250.00 255.00 260.00 265.00 270.00 275.00 280.00 285.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

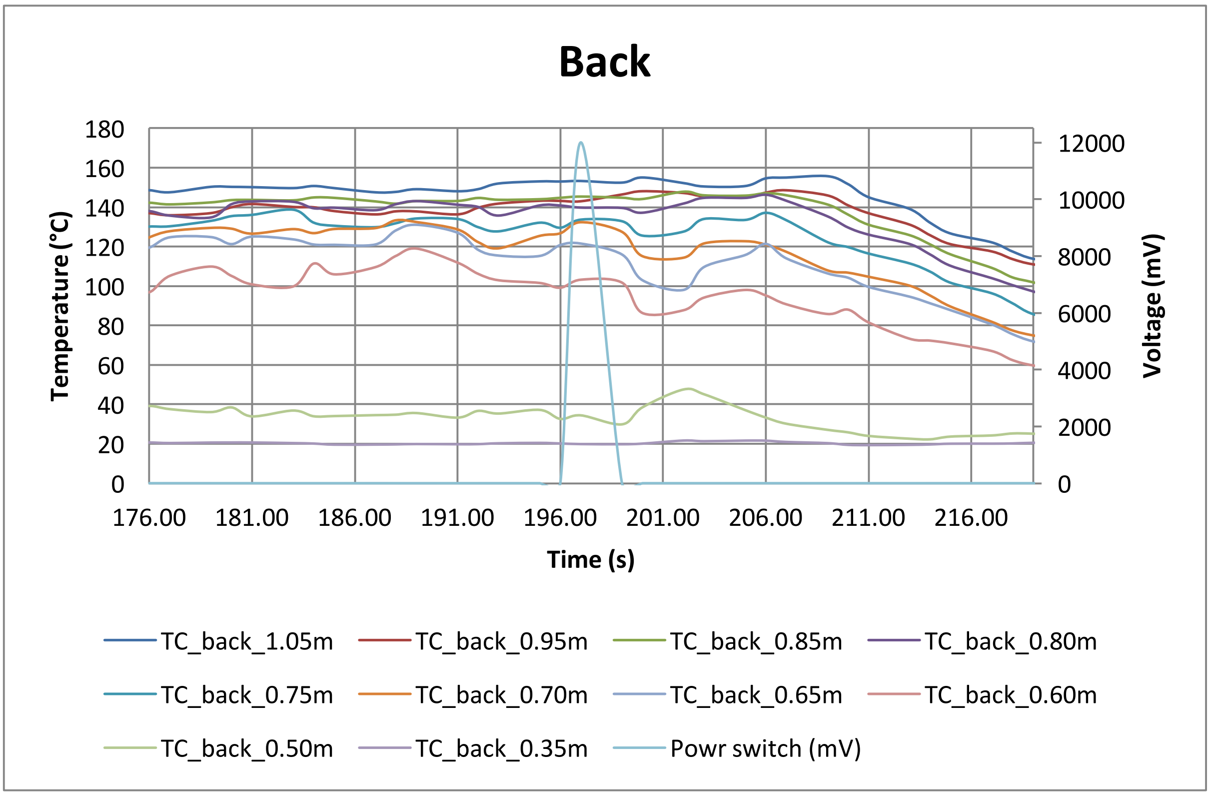


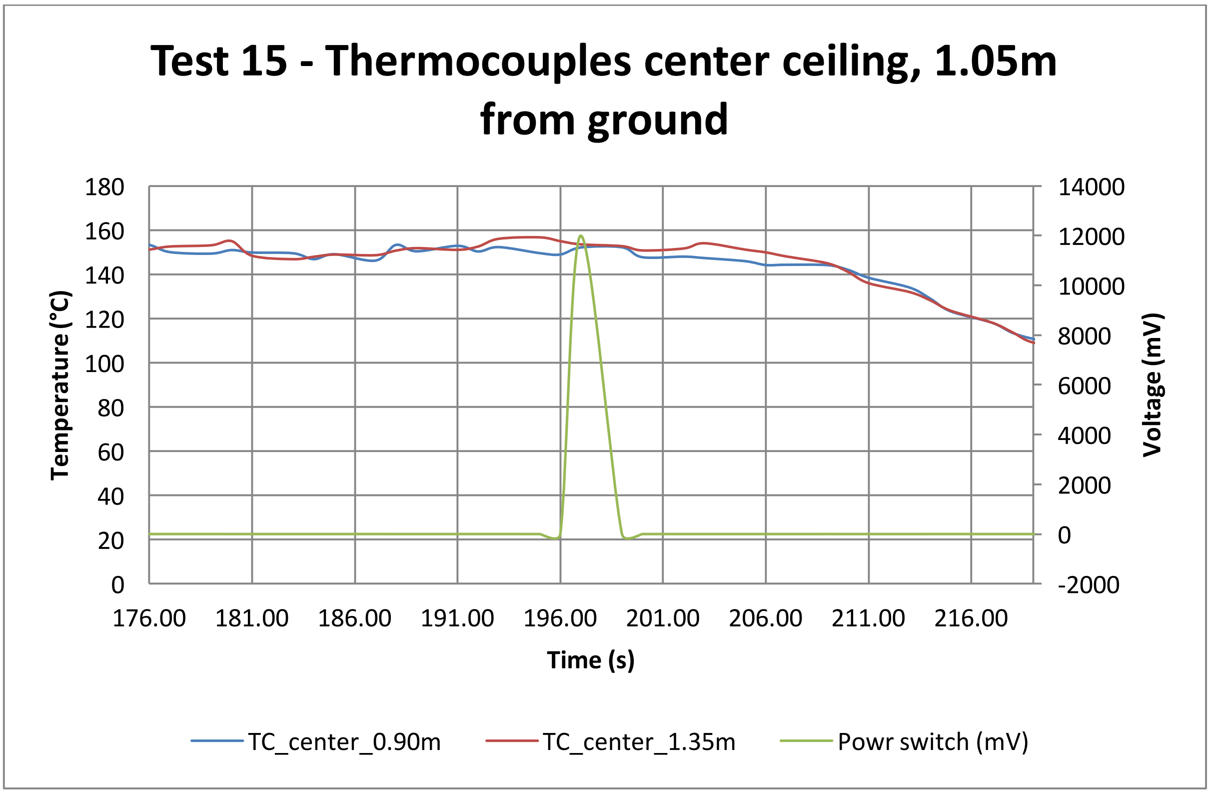
Test 14 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
235.00 240.00 245.00 250.00 255.00 260.00 265.00 270.00 275.00 280.00 285.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

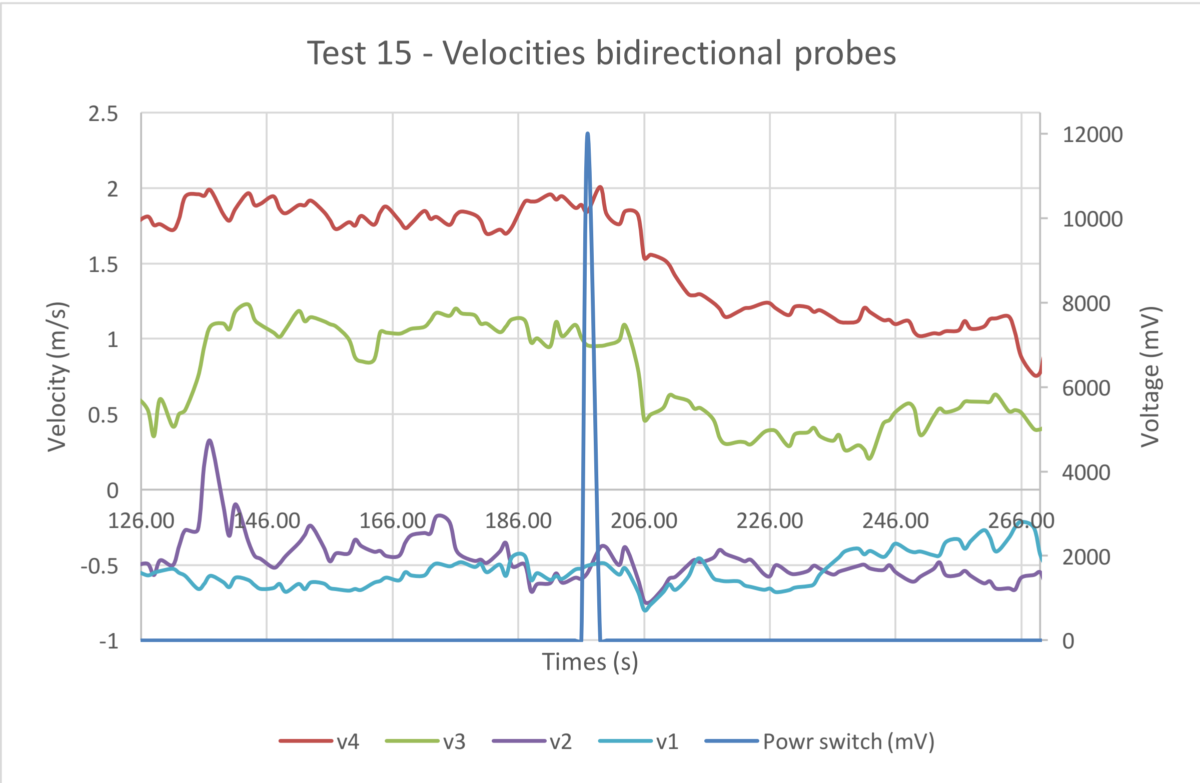

Test 14 - Velocities bidirectional probes
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
235.00 240.00 245.00 250.00 255.00 260.00 265.00 270.00 275.00 280.00 285.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

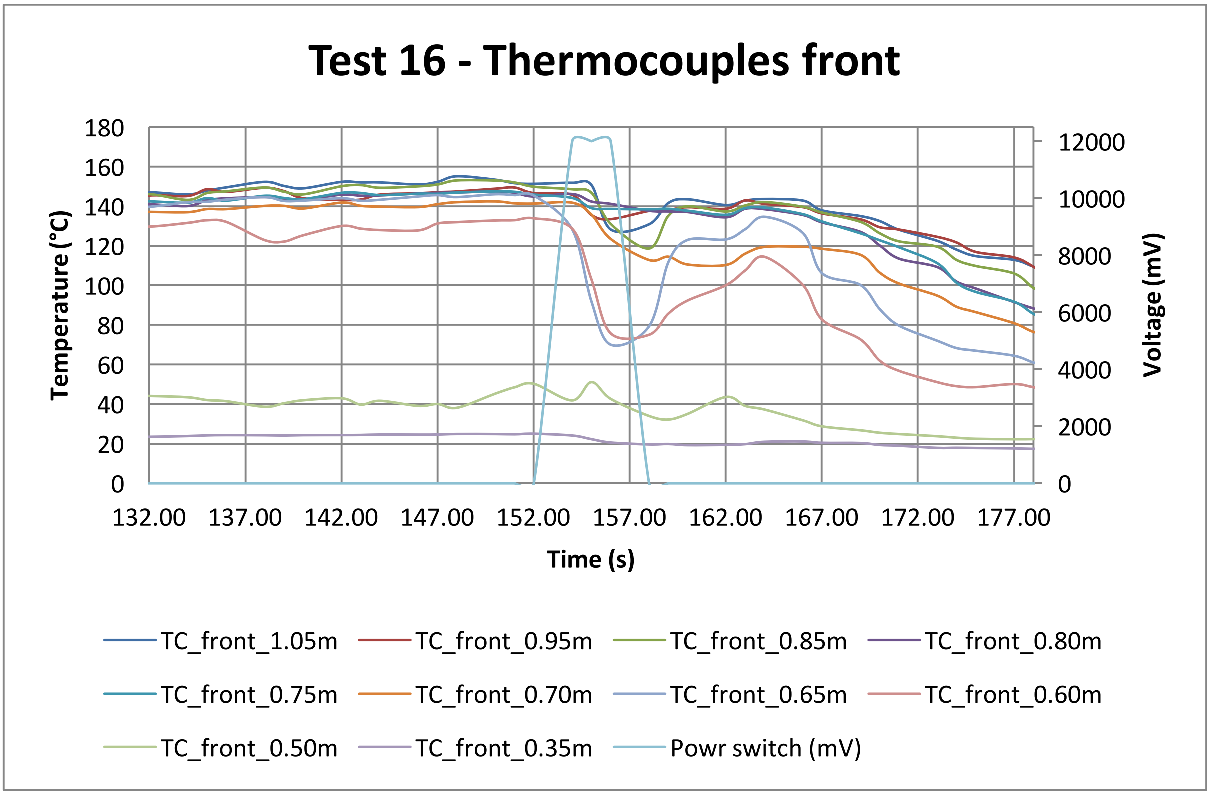

Test 14 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
185.00 205.00 225.00 245.00 265.00 285.00 305.00 325.00
Time (s)
v4
v3
v2
v1
Powr switch (mV)

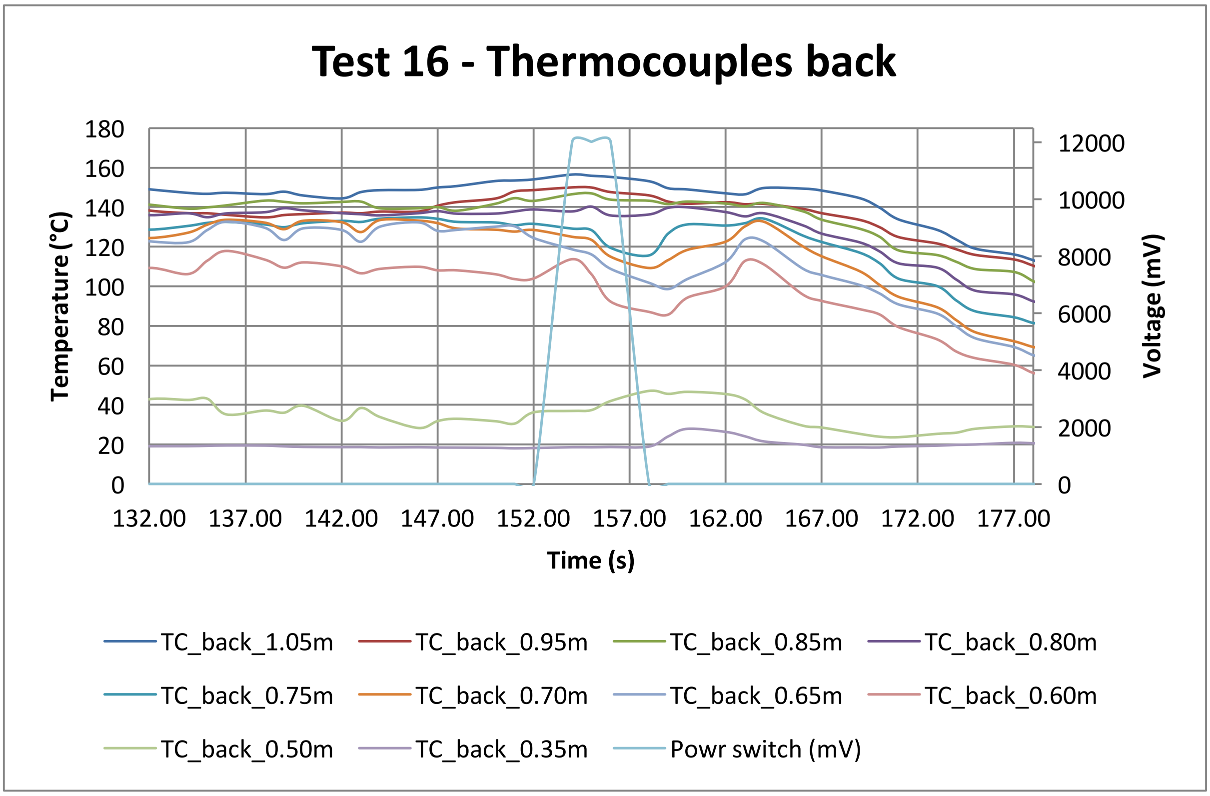

Test 15 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

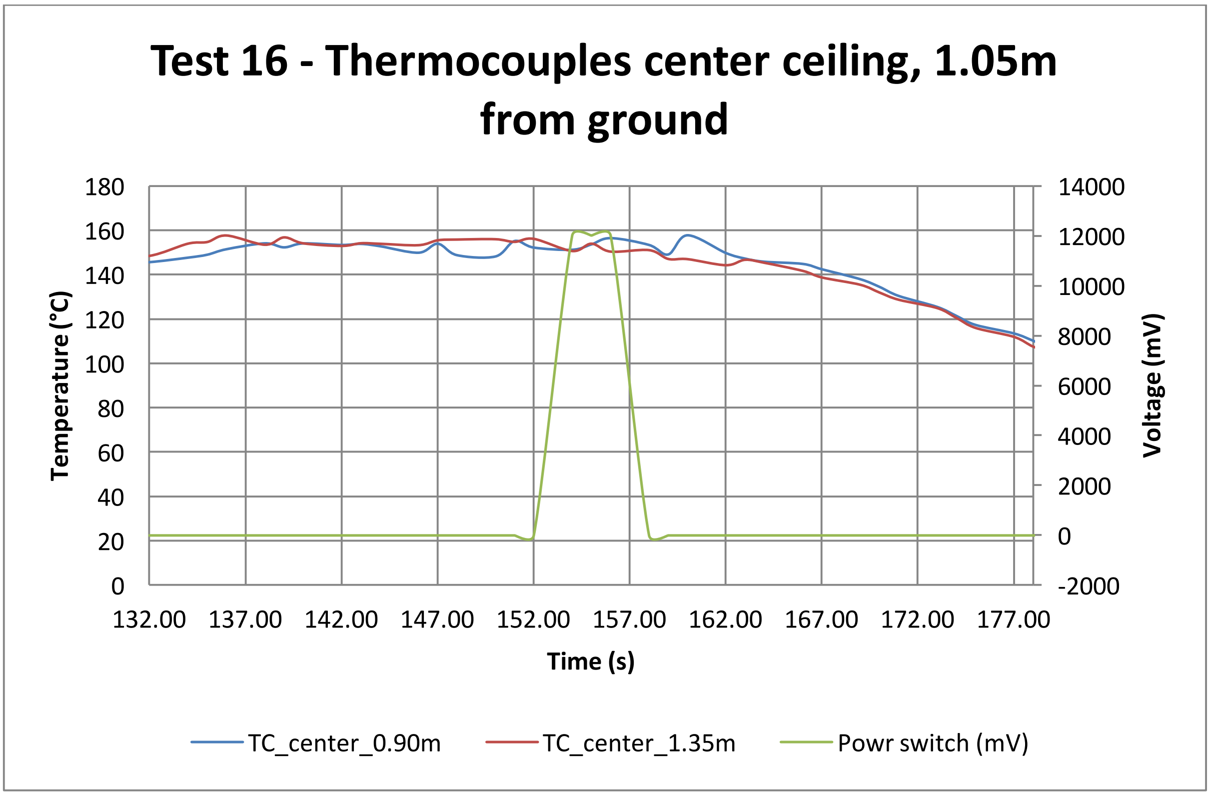

Back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

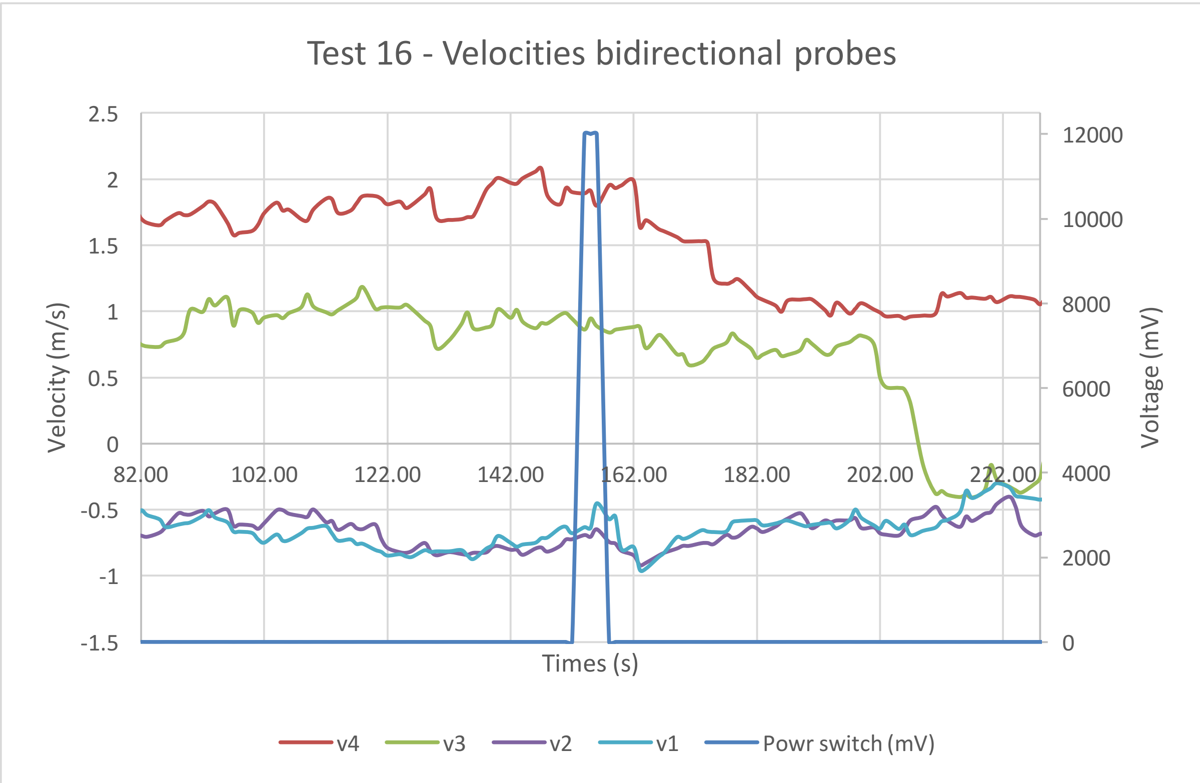

Test 15 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

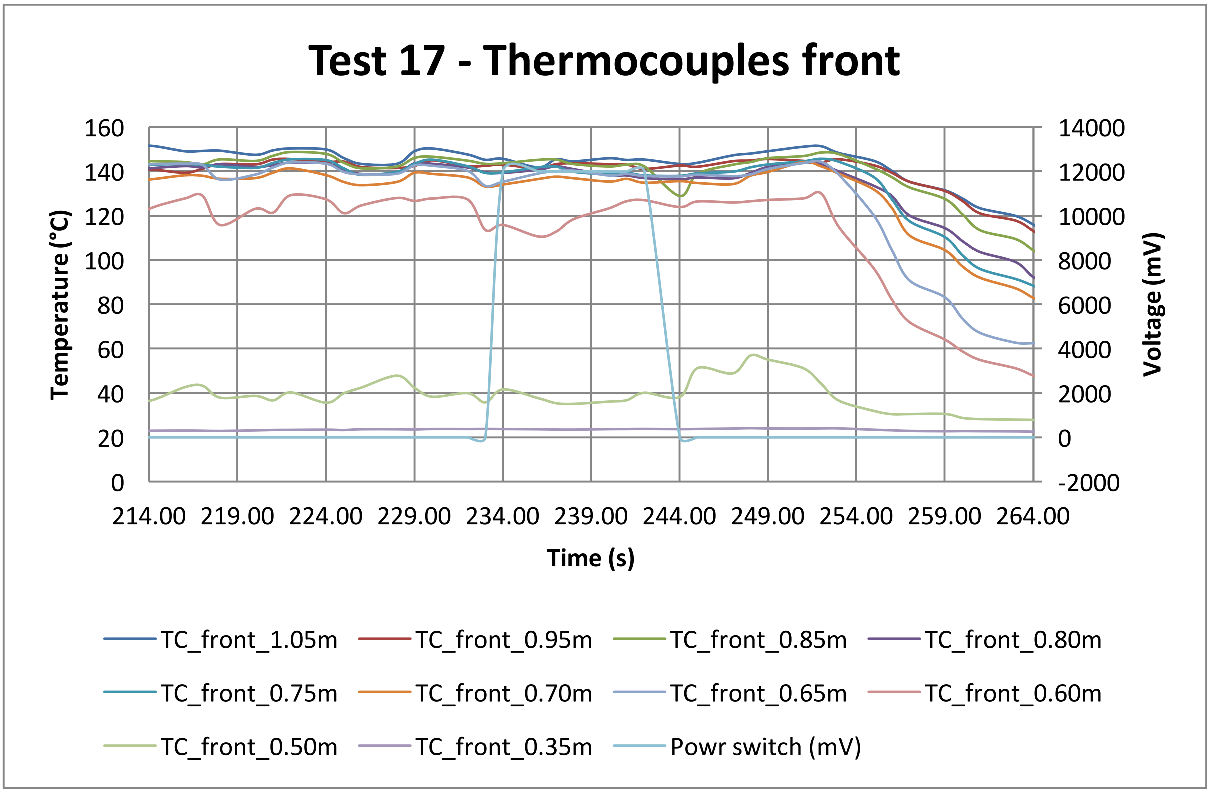

Test 15 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
12000
10000
8000
6000
4000
2000
0
126.00
146.00
166.00
186.00
206.00
226.00
246.00
266.00
v4
v3
v2
v1
Powr switch (mV)

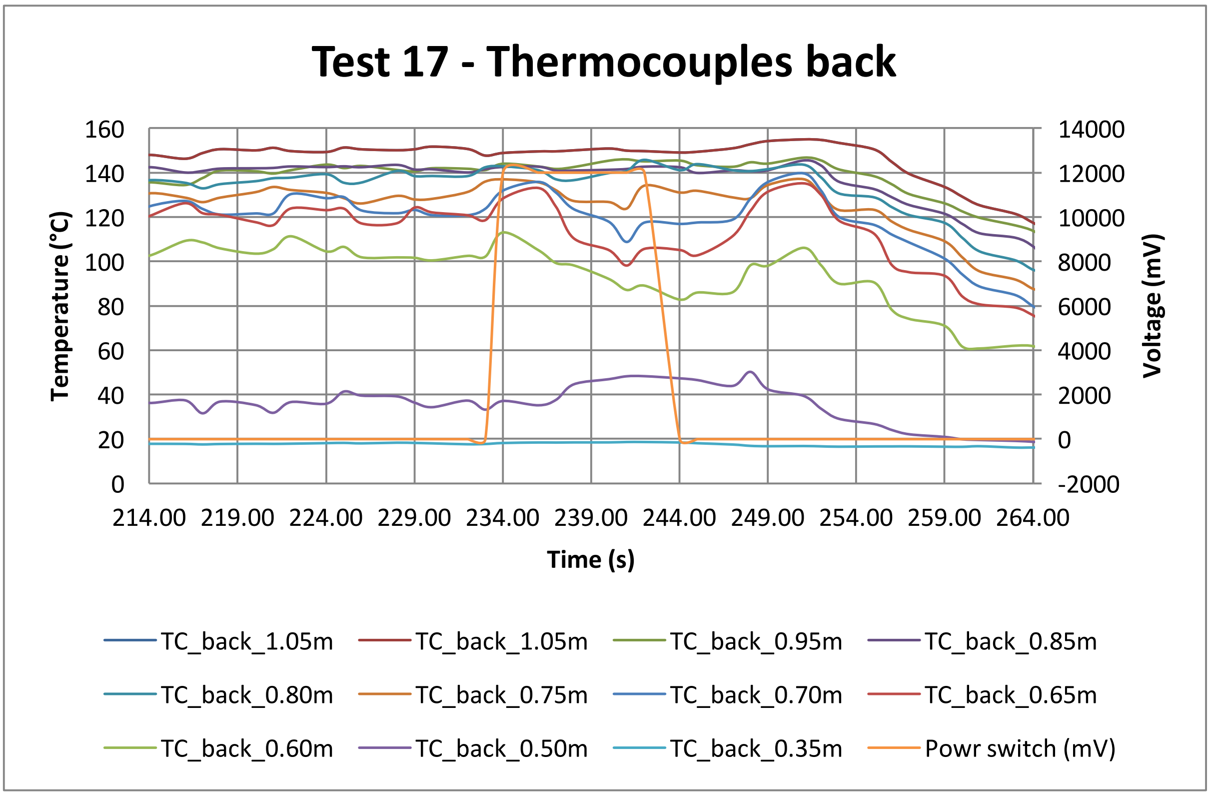

Test 16 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
132.00
137.00
142.00
147.00
152.00
157.00
162.00
167.00
172.00
177.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

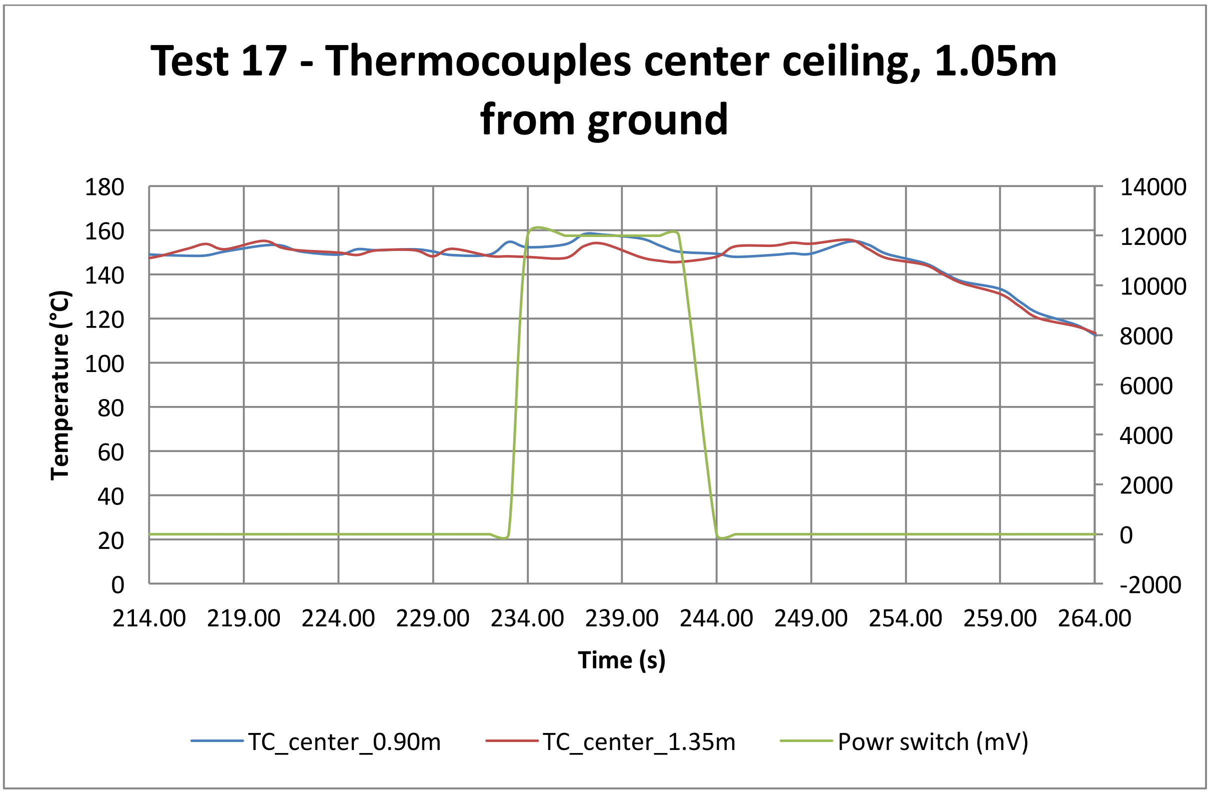

Test 16 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
132.00
137.00
142.00
147.00
152.00
157.00
162.00
167.00
172.00
177.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

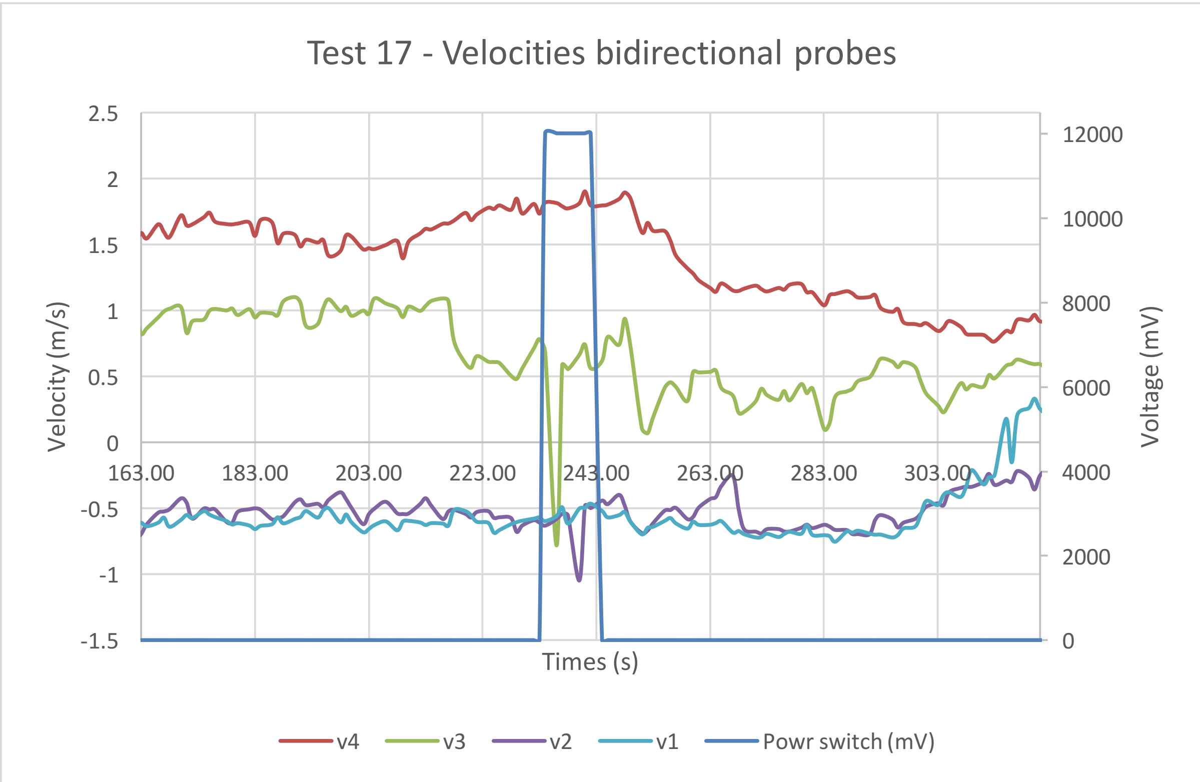

Test 16 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
132.00
137.00
142.00
147.00
152.00
157.00
162.00
167.00
172.00
177.00
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

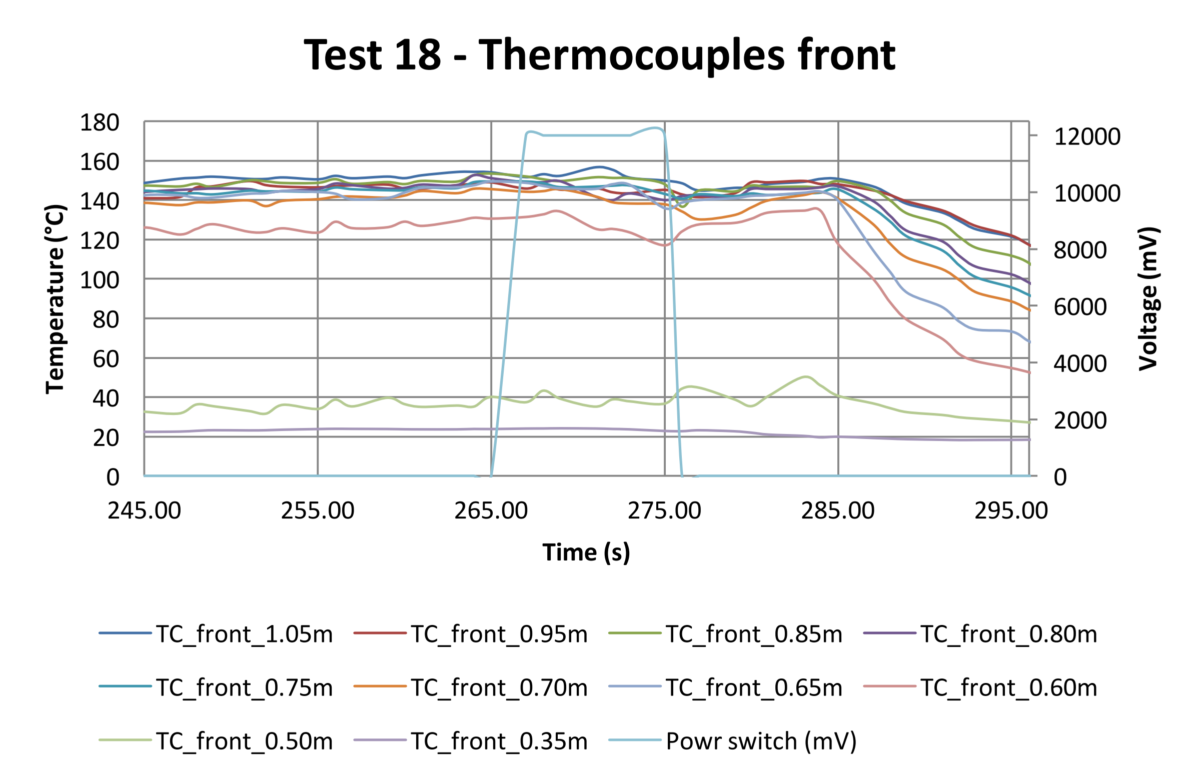

Test 16 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
82.00
102.00
122.00
142.00
162.00
182.00
202.00
222.00
v4
v3
v2
v1
Powr switch (mV)

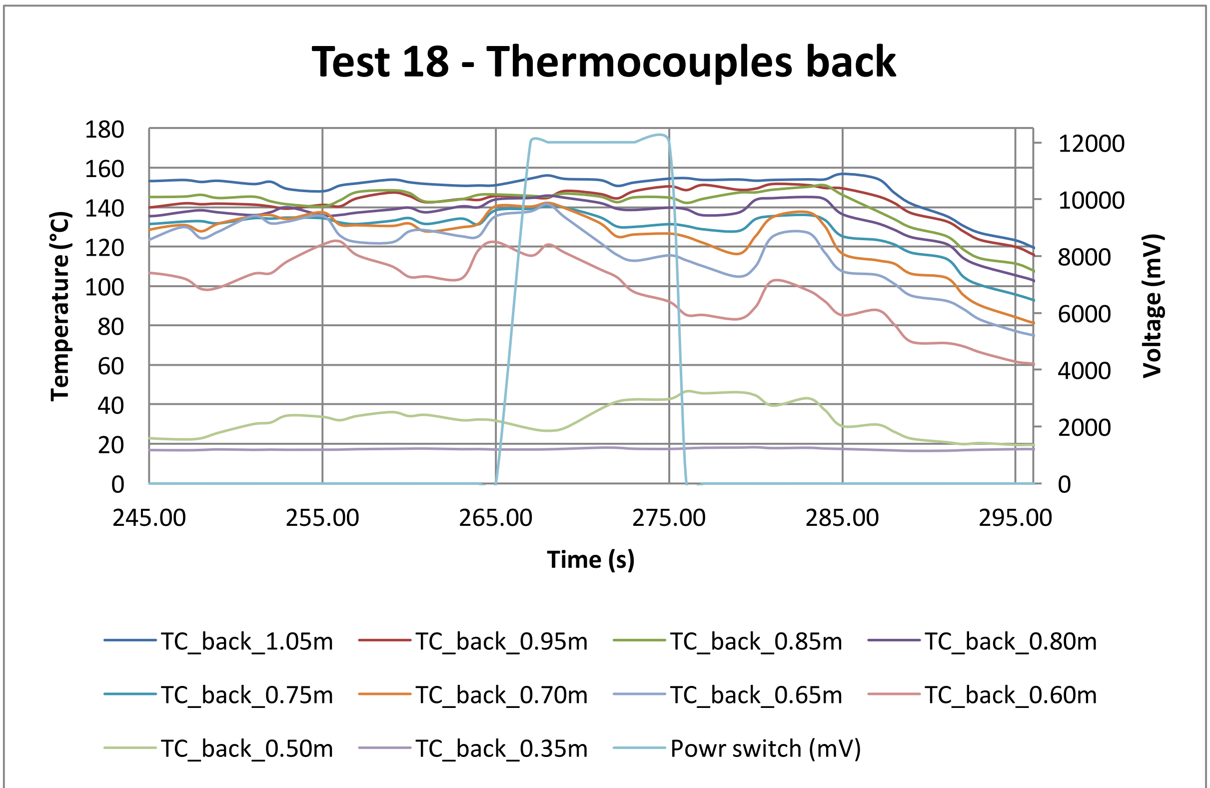

Test 17 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
214.00
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
264.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

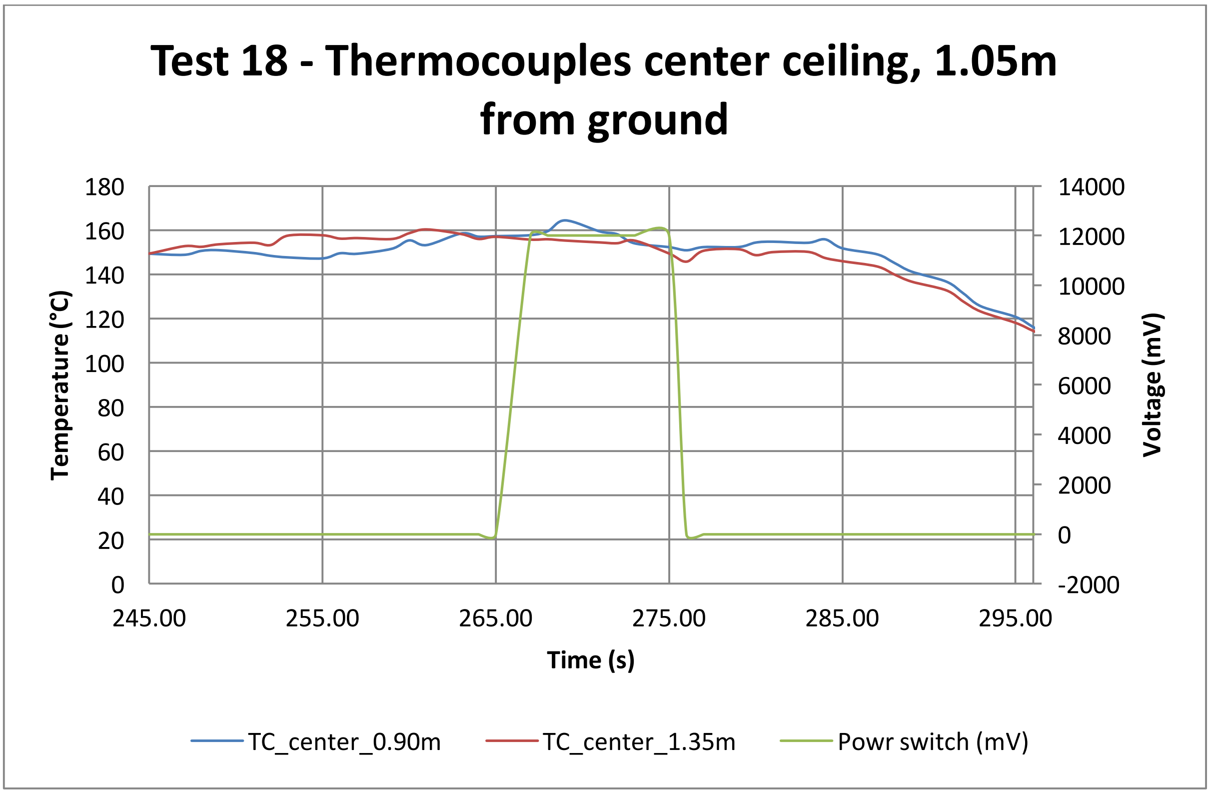

Test 17 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
214.00
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
264.00
TC_back_1.05m
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 17 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Time (s)
214.00
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
264.00
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

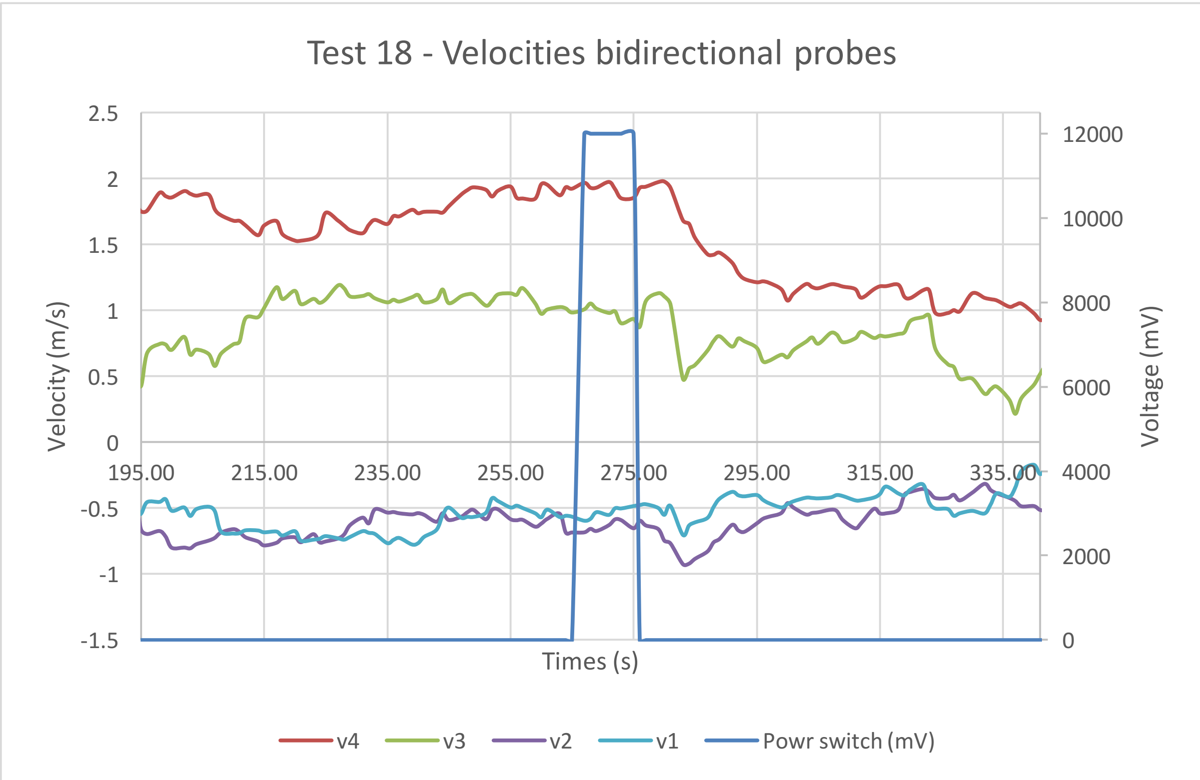

Test 17 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
163.00
183.00
203.00
223.00
243.00
263.00
283.00
303.00
v4
v3
v2
v1
Powr switch (mV)


Test 18 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
245.00
255.00
265.00
275.00
285.00
295.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

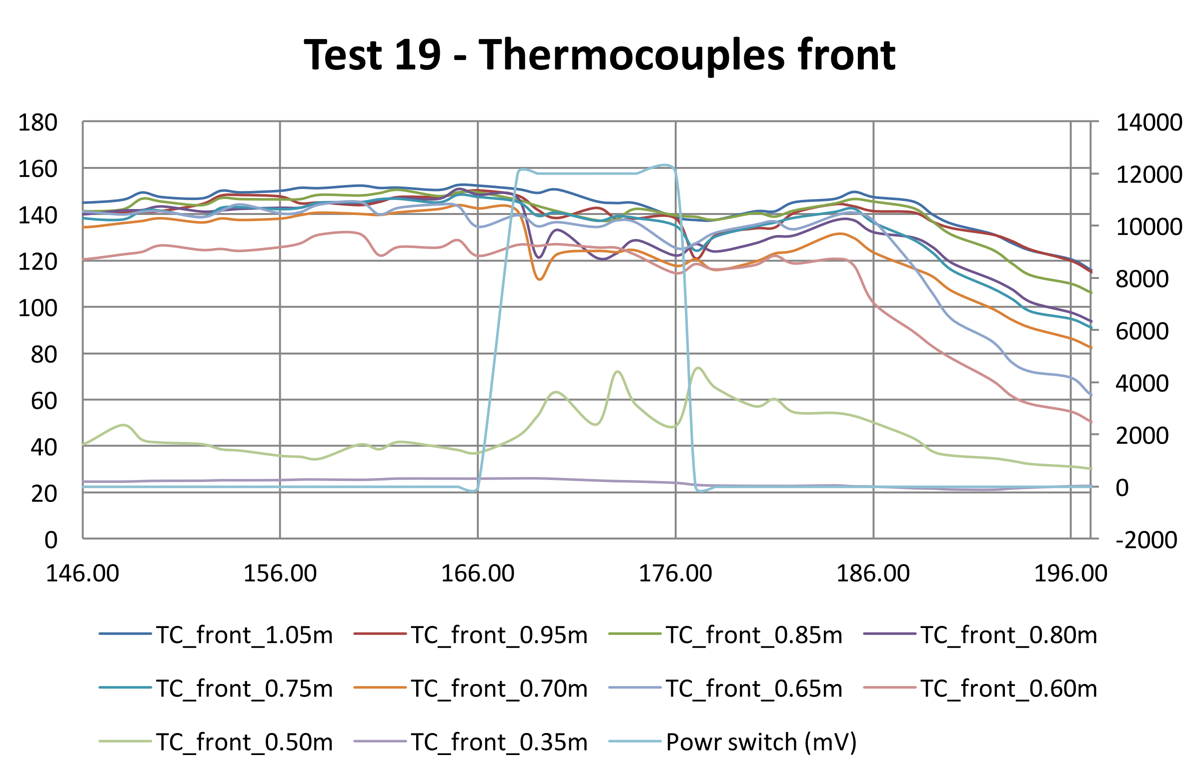

Test 18 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
245.00
255.00
265.00
275.00
285.00
295.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

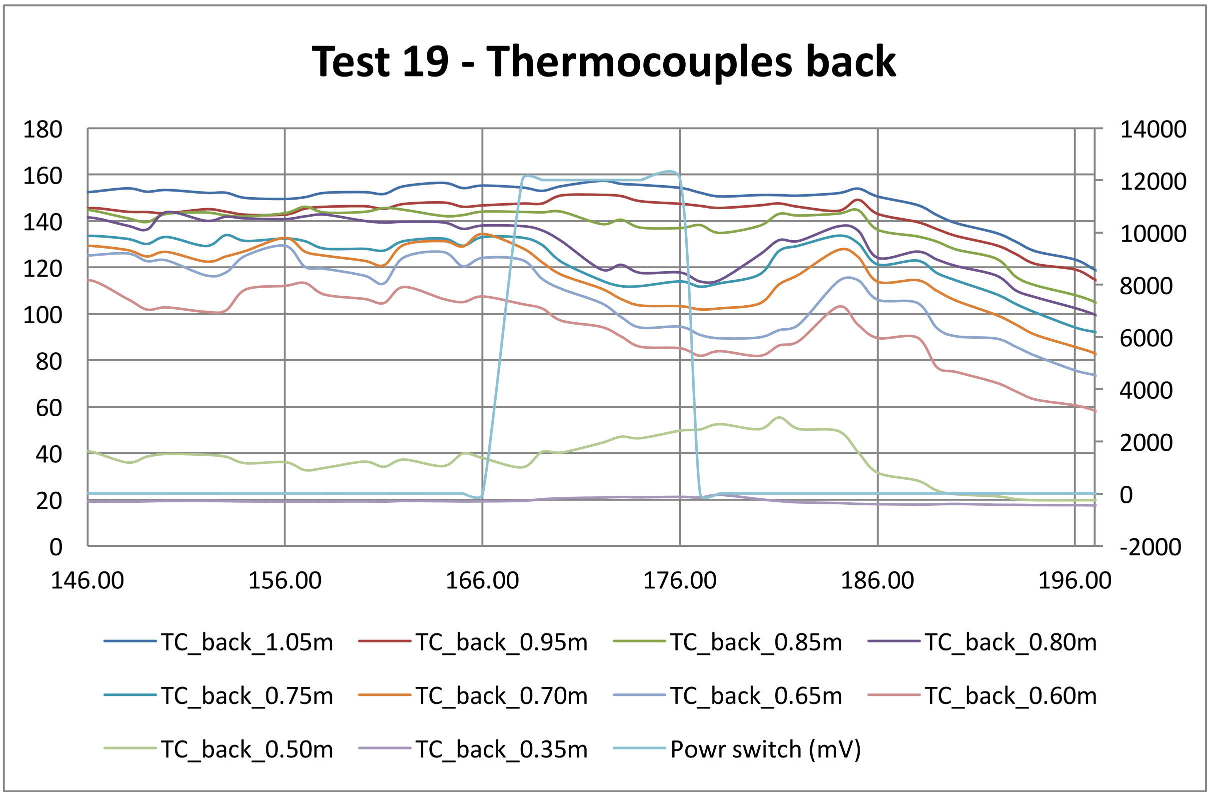


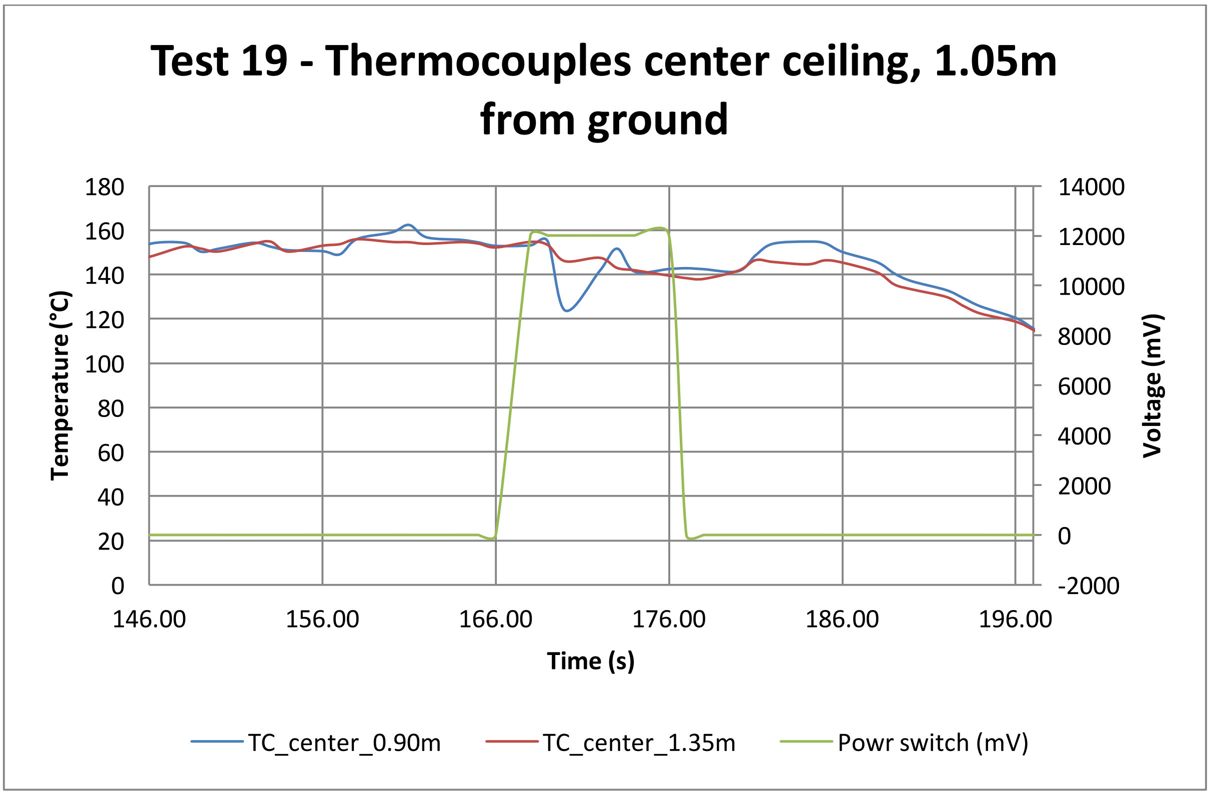
Test 18 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
Voltage (mV)
245.00
255.00
265.00
275.00
285.00
295.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

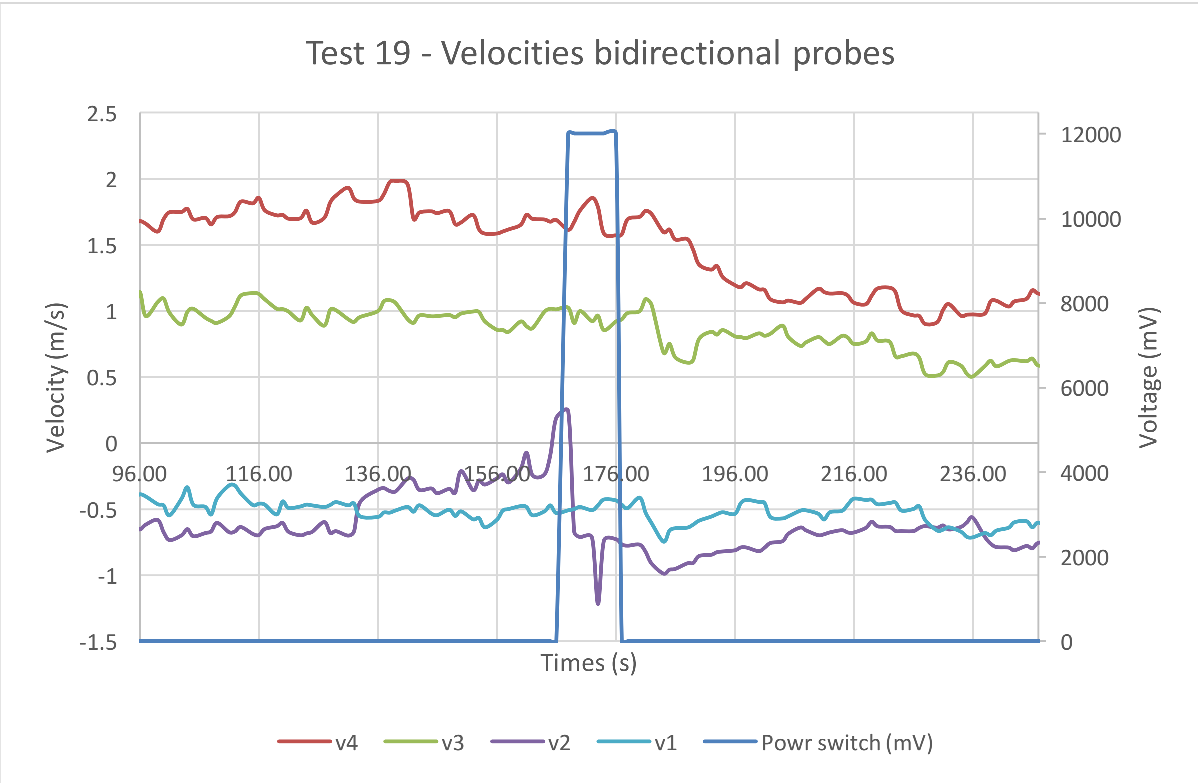


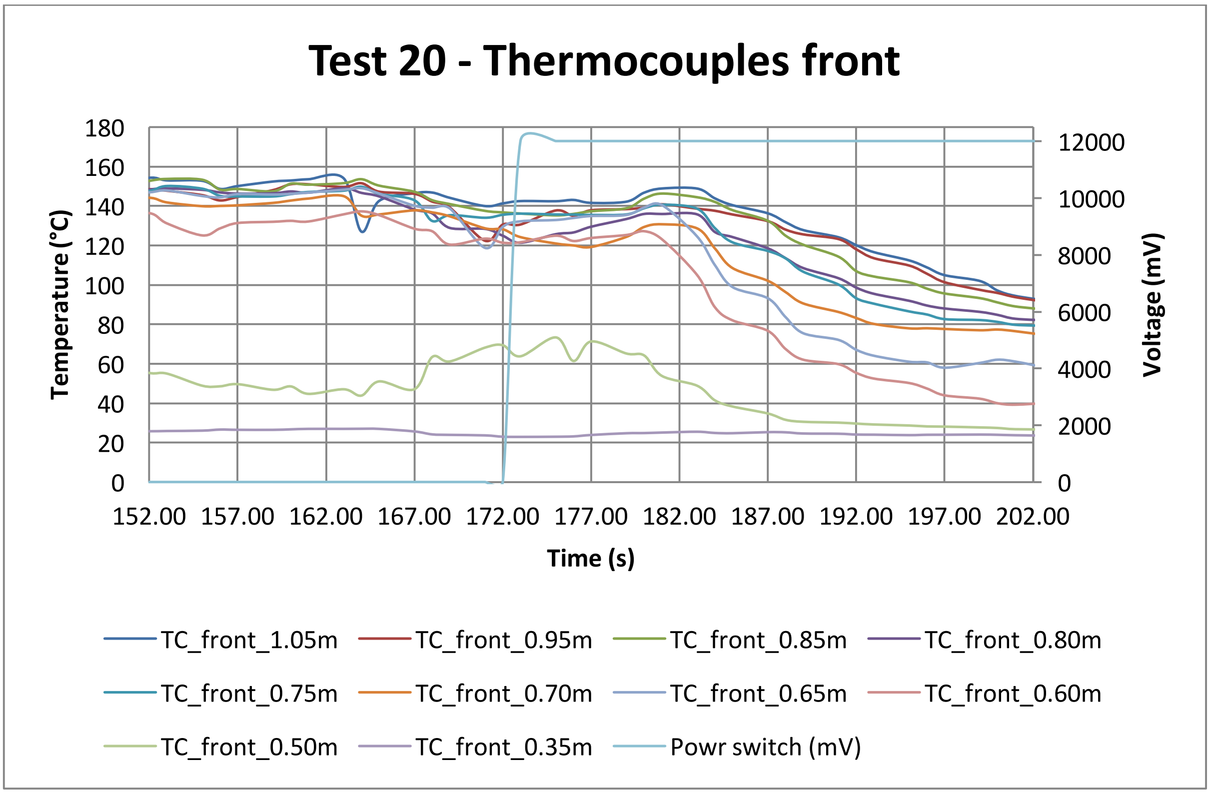
Test 18 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
195.00
215.00
235.00
255.00
275.00
295.00
315.00
335.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

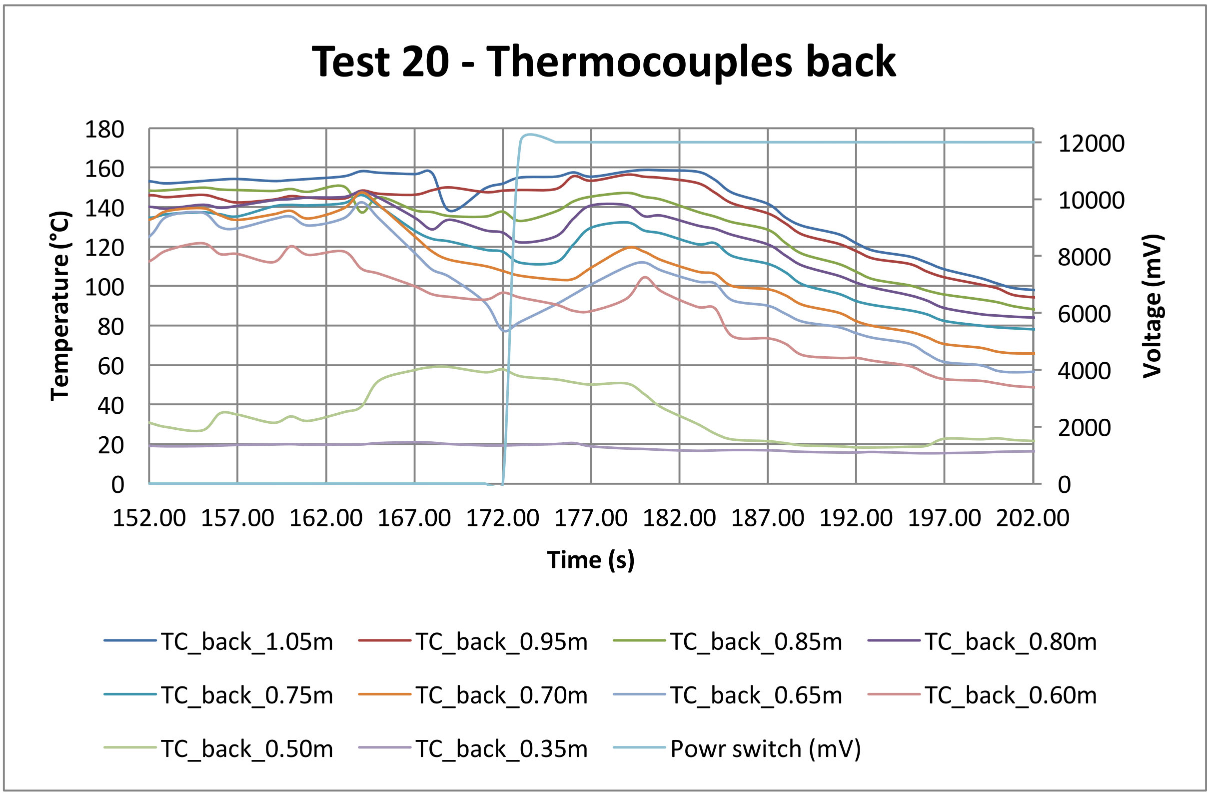

Test 19 - Thermocouples front
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
146.00
156.00
166.00
176.00
186.00
196.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

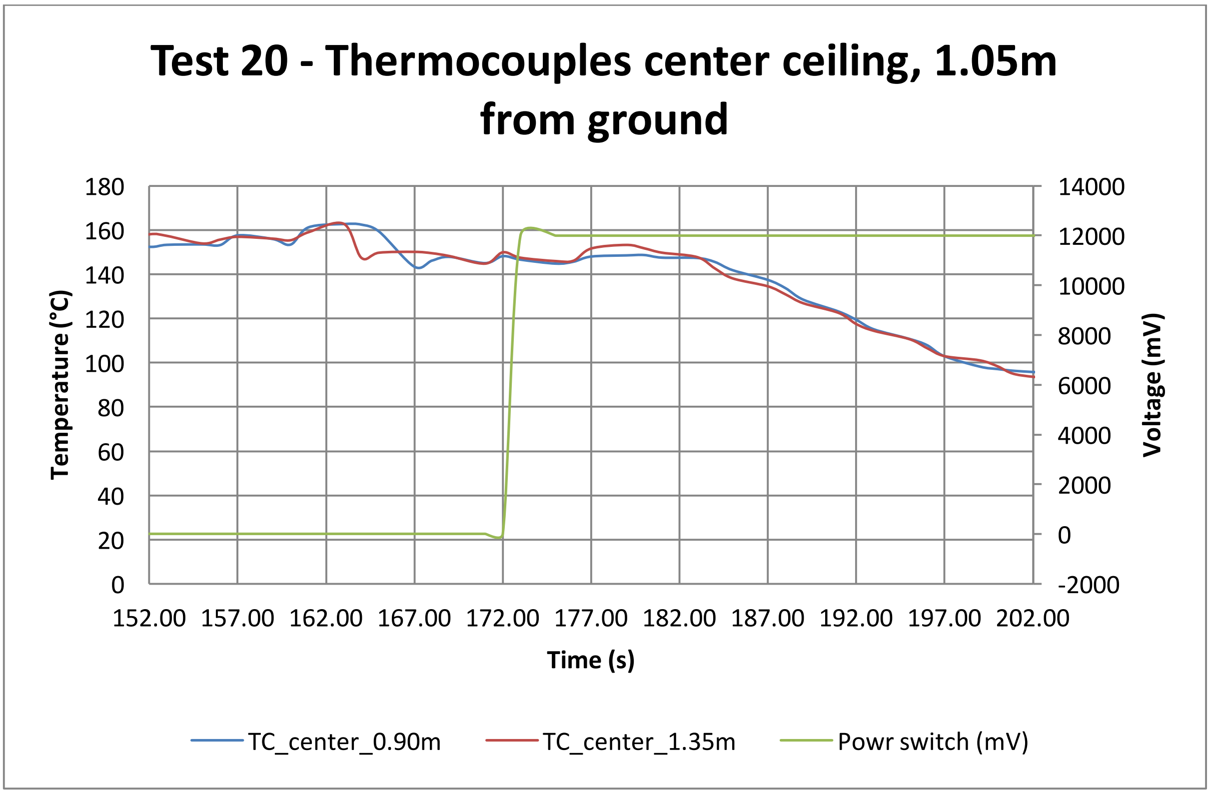

Test 19 - Thermocouples back
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
146.00
156.00
166.00
176.00
186.00
196.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 19 - Thermocouples center ceiling, 1.05m from ground
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
146.00
156.00
166.00
176.00
186.00
196.00
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

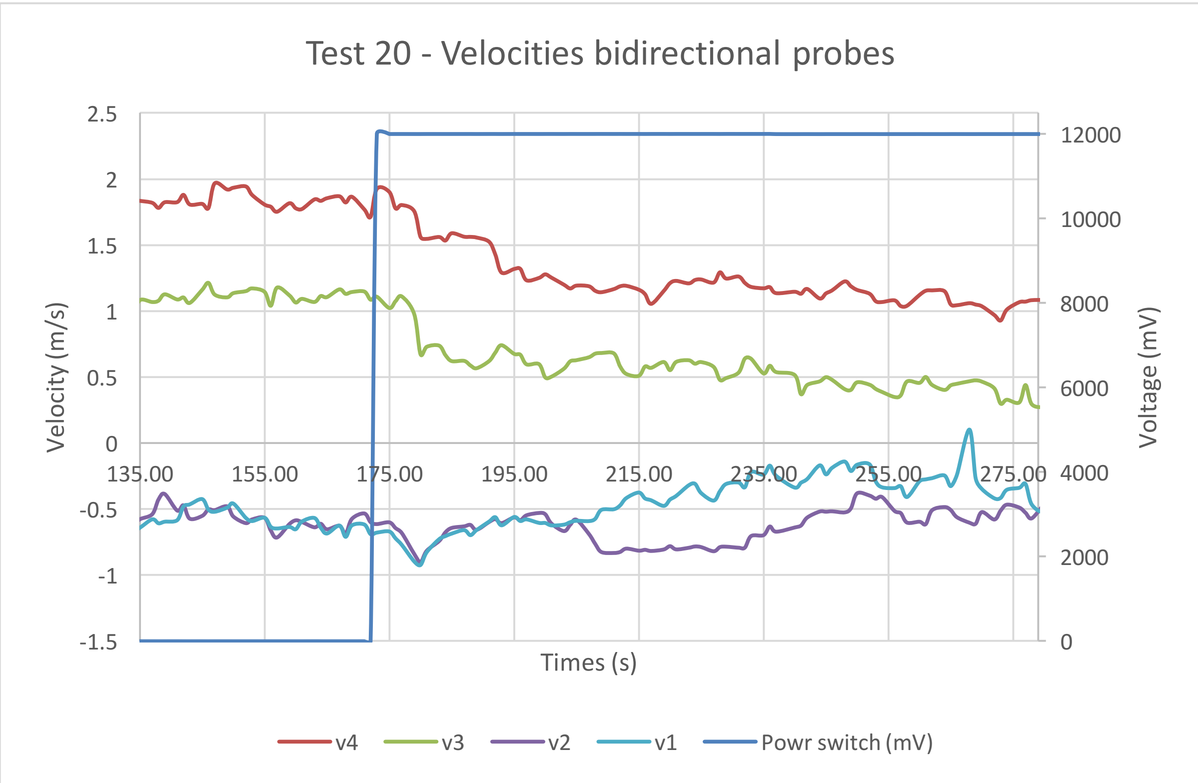

Test 19 - Velocities bidirectional probes
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
96.00
116.00
136.00
156.00
176.00
196.00
216.00
236.00
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 20 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
152.00
157.00
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

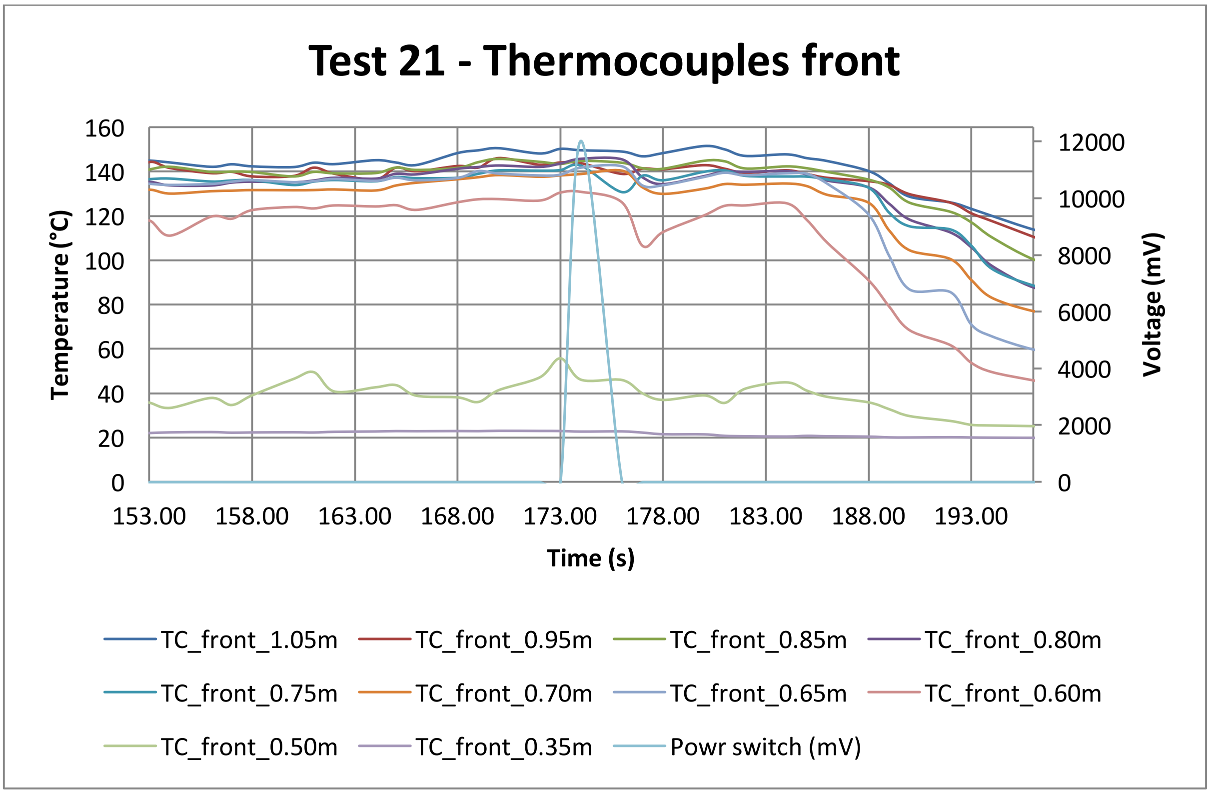

Test 20 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
152.00
157.00
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

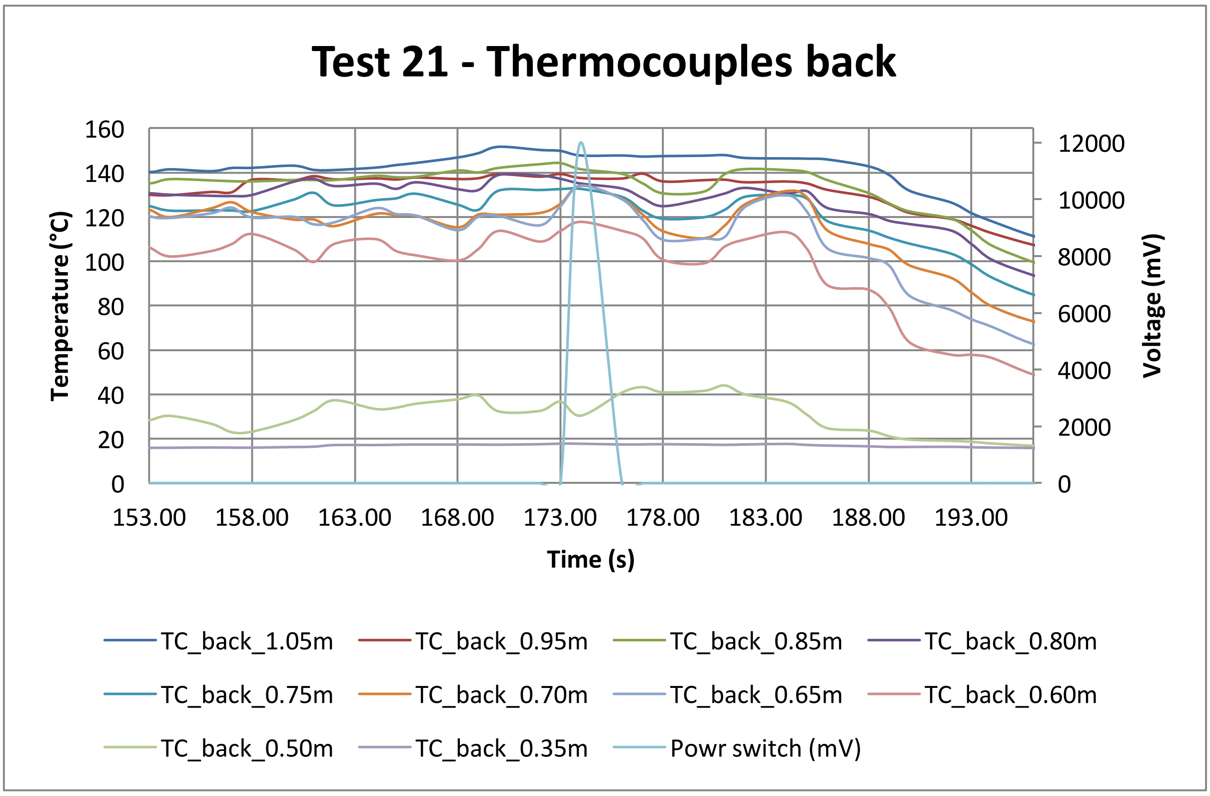


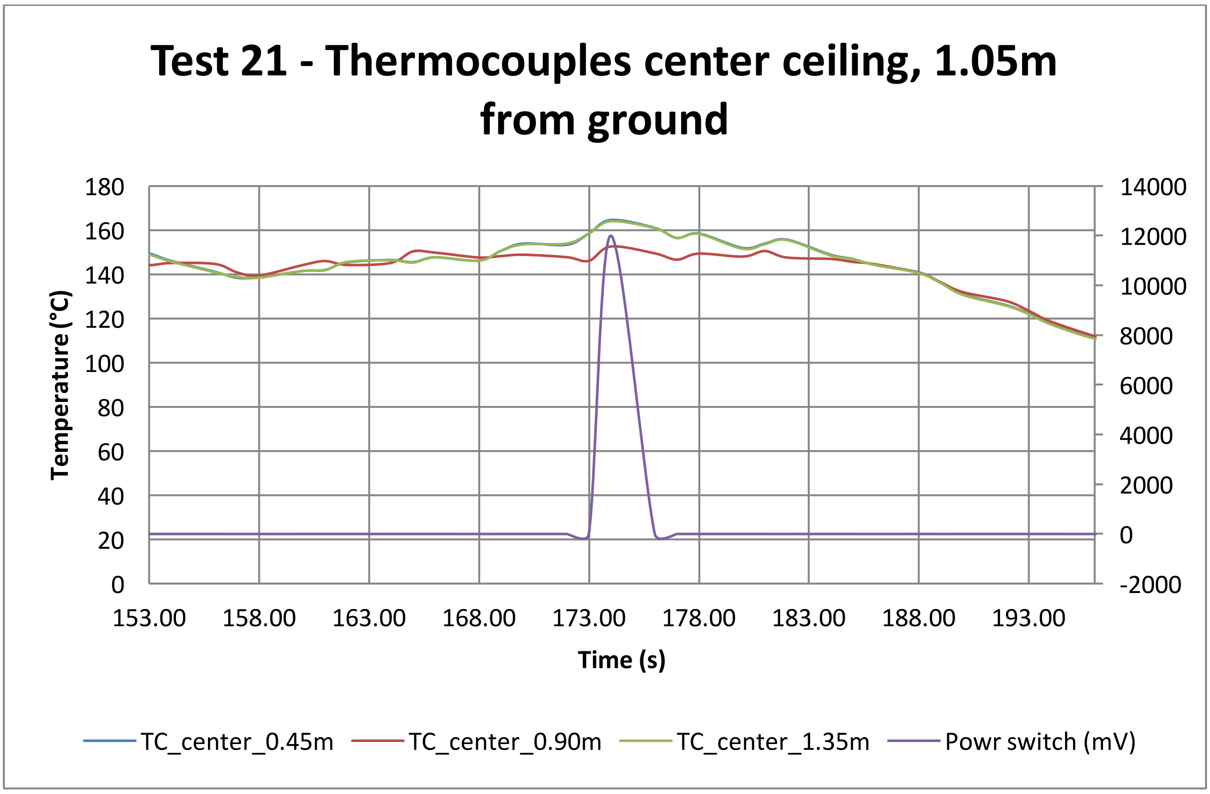
Test 20 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
152.00 157.00 162.00 167.00 172.00 177.00 182.00 187.00 192.00 197.00 202.00
Time (s)
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

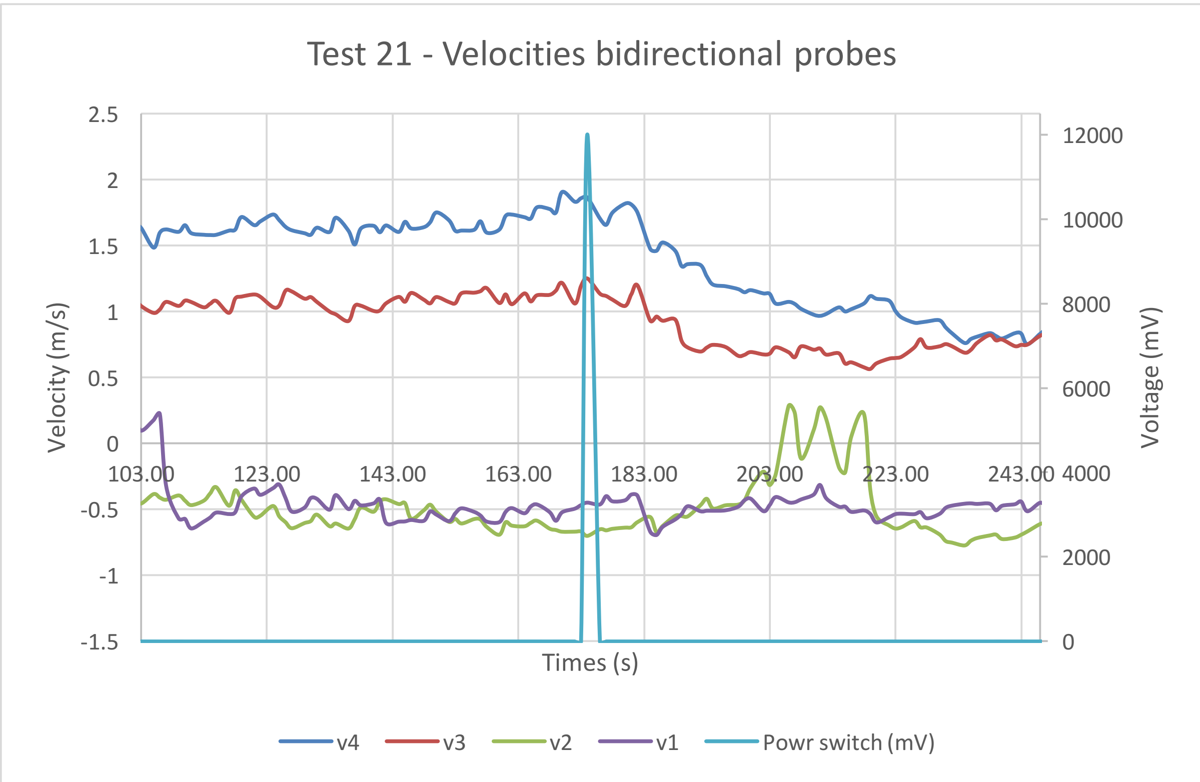


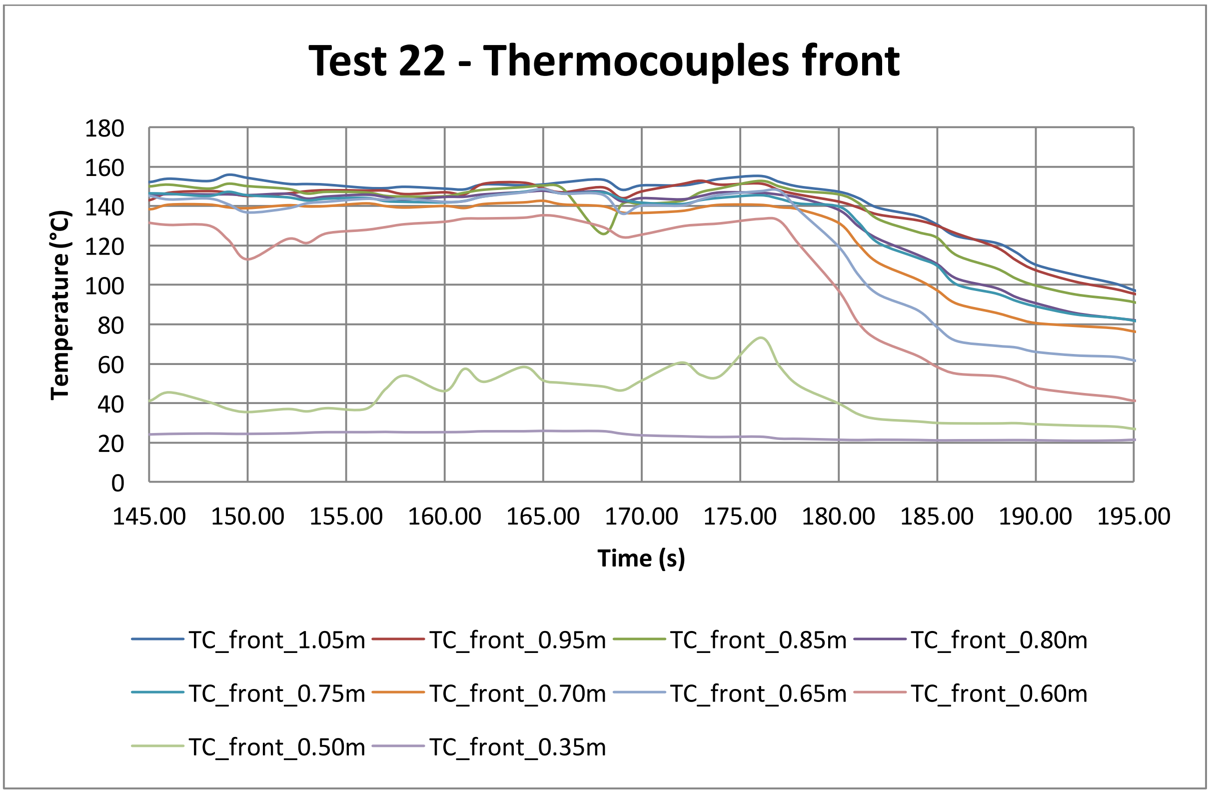
Test 20 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
135.00 155.00 175.00 195.00 215.00 235.00 255.00 275.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

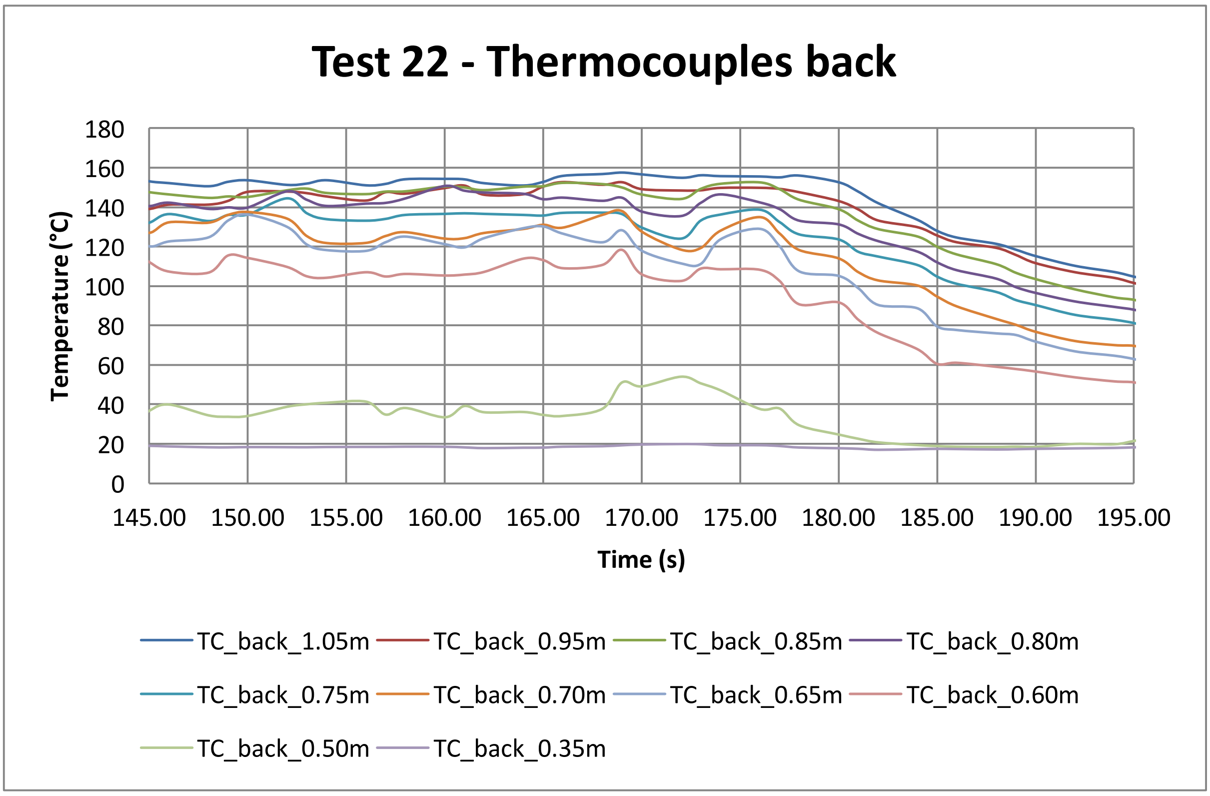

Test 21 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
153.00
158.00
163.00
168.00
173.00
178.00
183.00
188.00
193.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

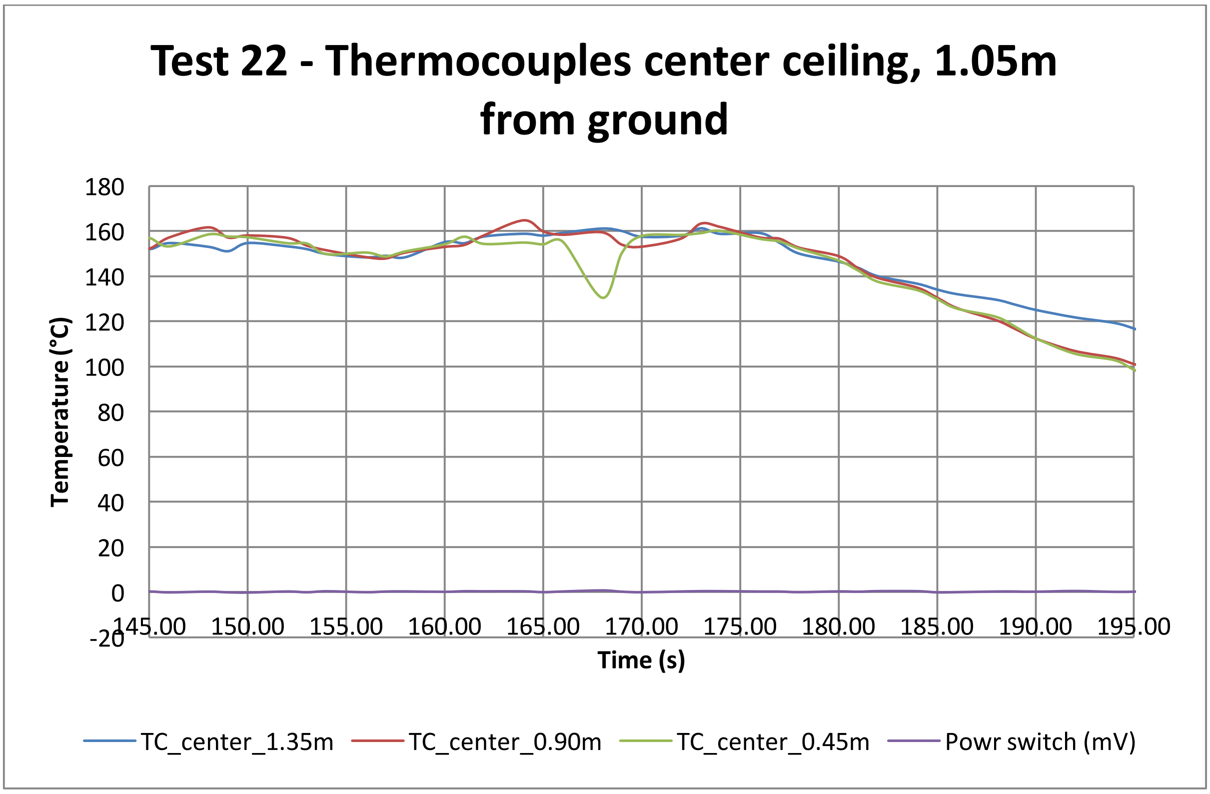

Test 21 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
153.00
158.00
163.00
168.00
173.00
178.00
183.00
188.00
193.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 21 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
153.00
158.00
163.00
168.00
173.00
178.00
183.00
188.00
193.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

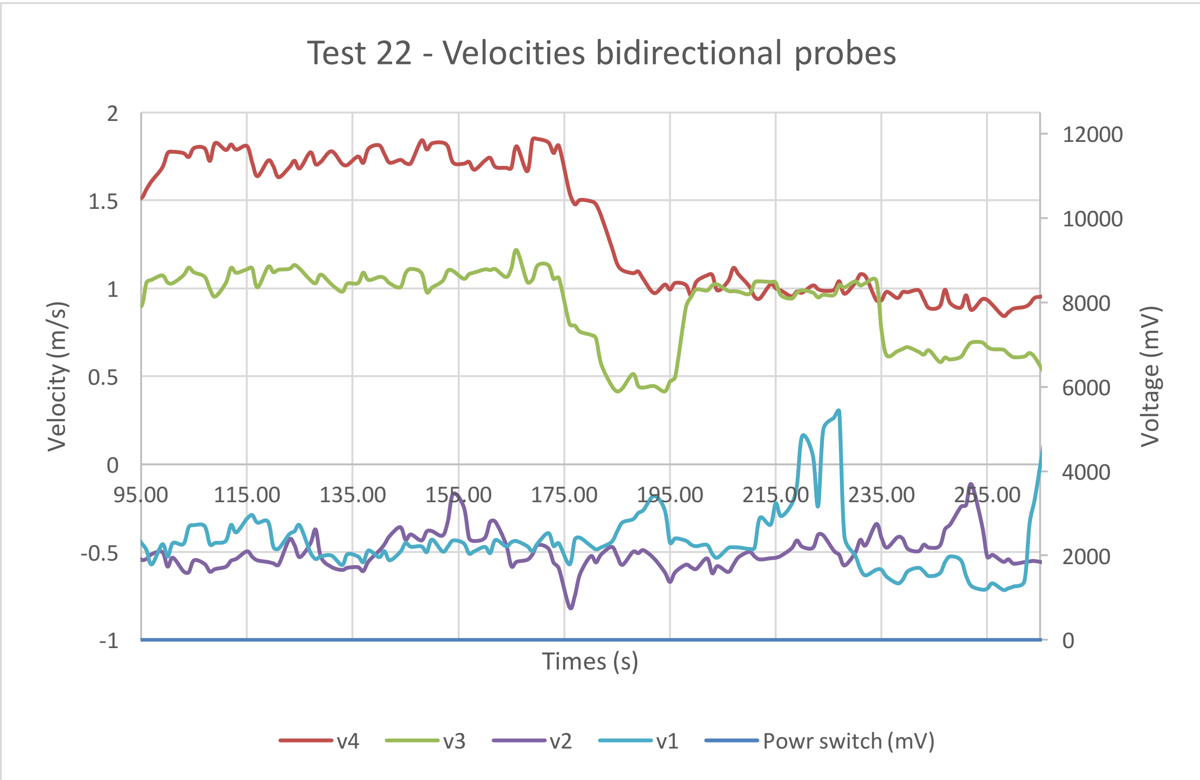

Test 21 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
103.00
123.00
143.00
163.00
183.00
203.00
223.00
243.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 22 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
145.00
150.00
155.00
160.00
165.00
170.00
175.00
180.00
185.00
190.00
195.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m

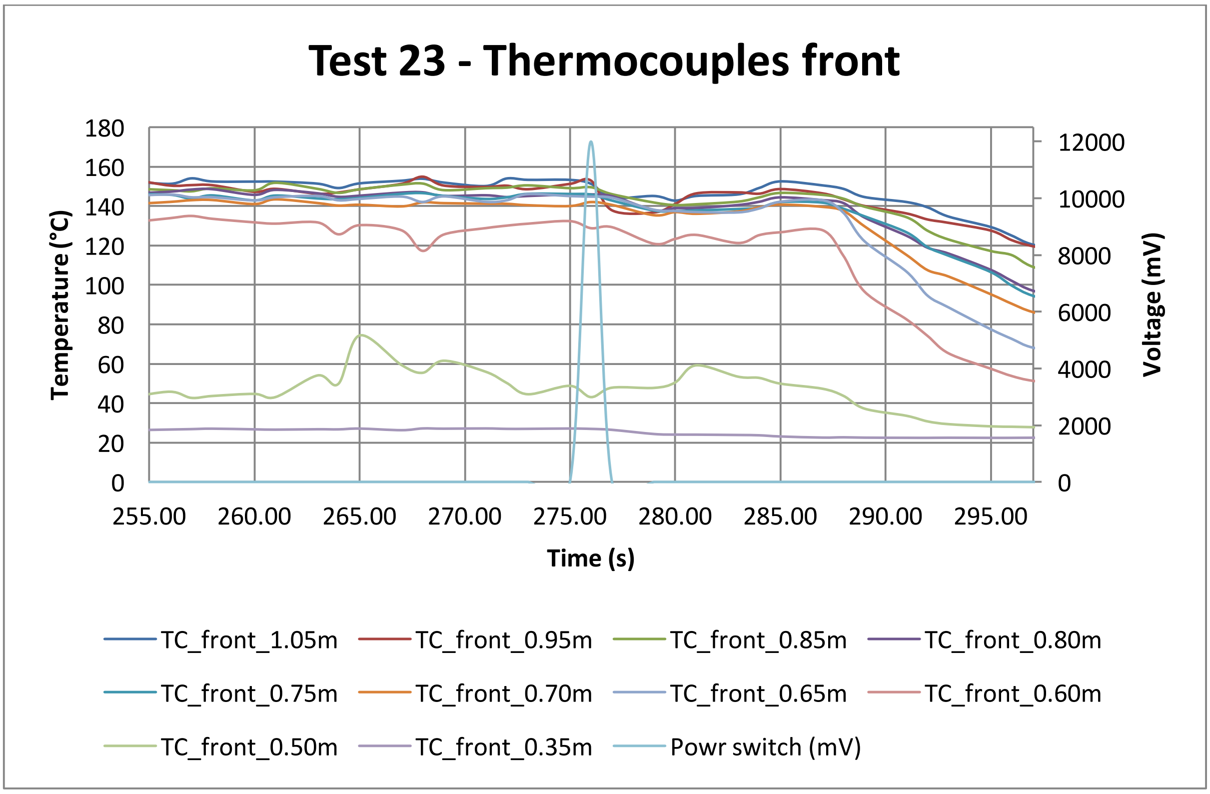

Test 22 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
145.00
150.00
155.00
160.00
165.00
170.00
175.00
180.00
185.00
190.00
195.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m

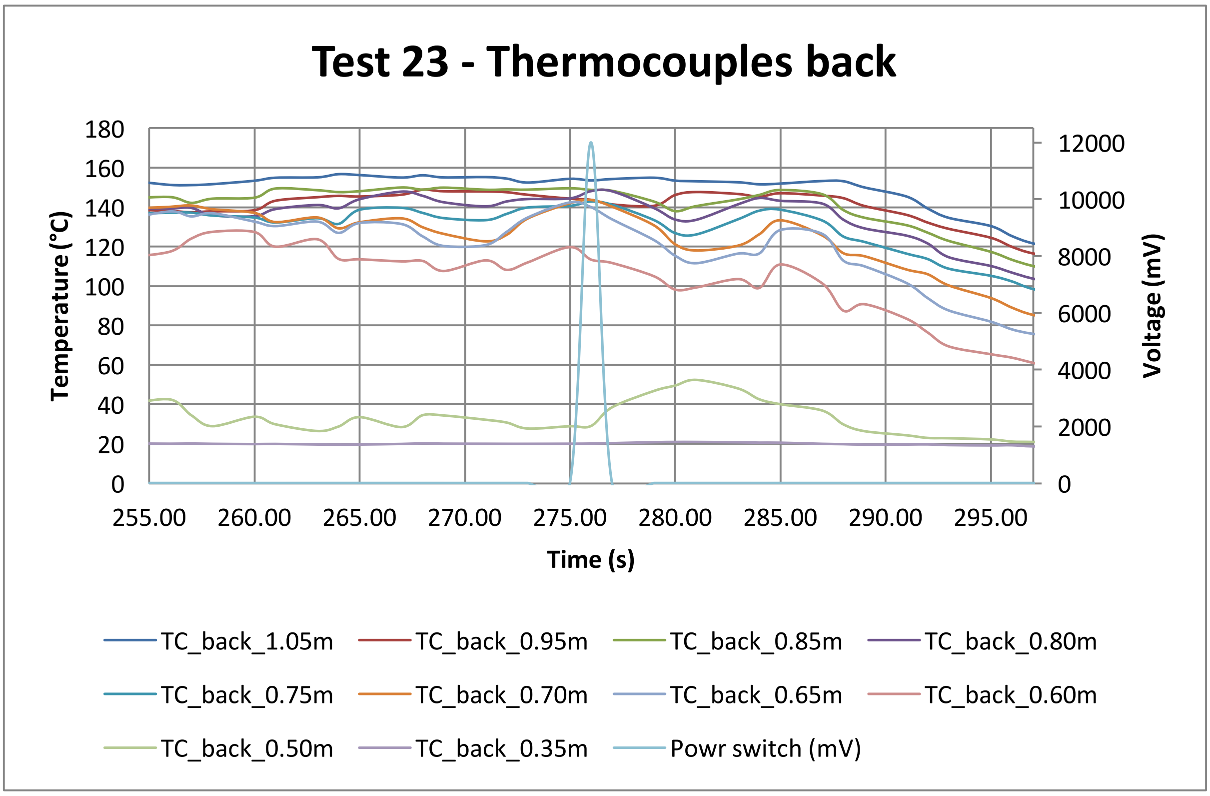


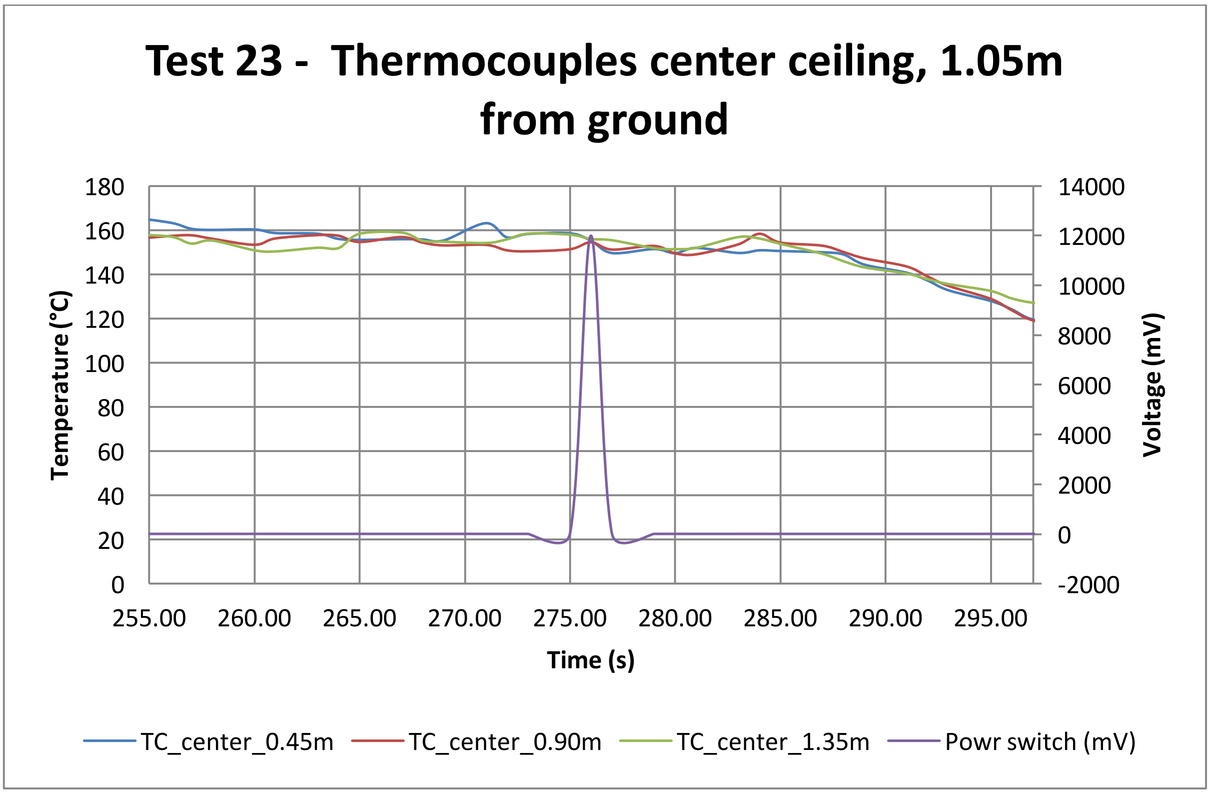
Test 22 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
-20
145.00
150.00
155.00
160.00
165.00
170.00
175.00
180.00
185.00
190.00
195.00
Time (s)
TC_center_1.35m
TC_center_0.90m
TC_center_0.45m
Powr switch (mV)

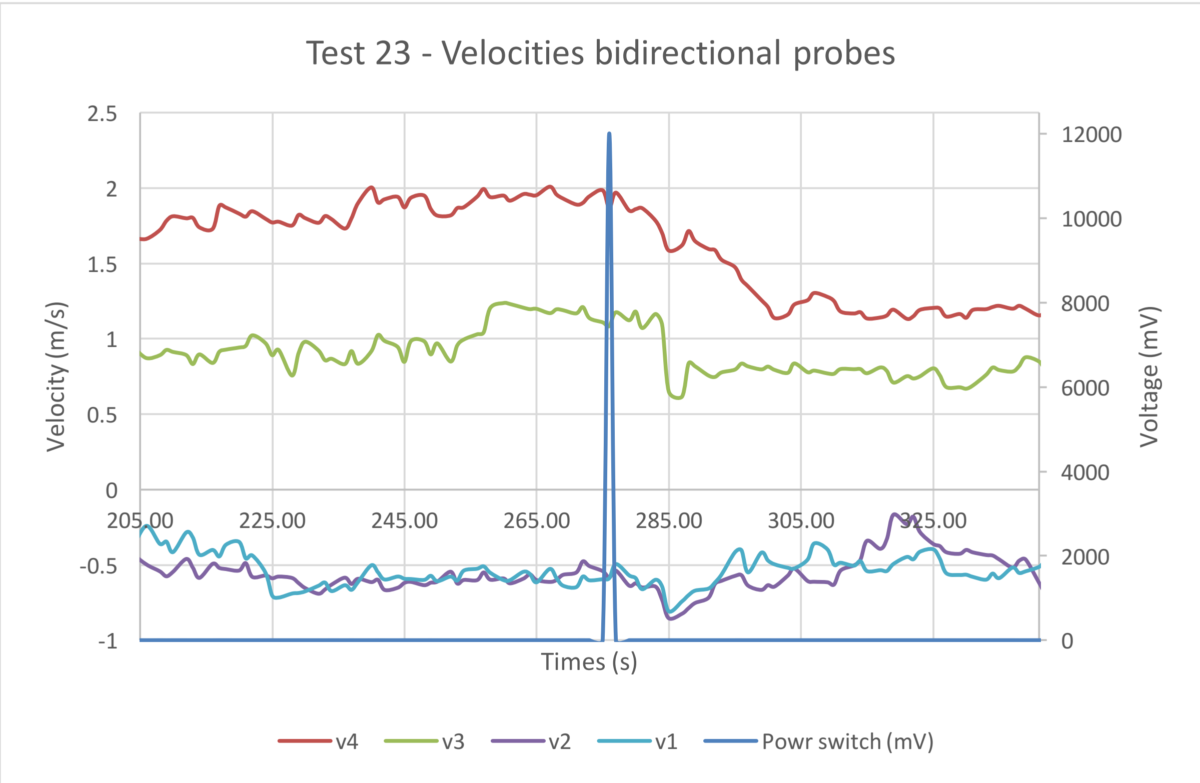


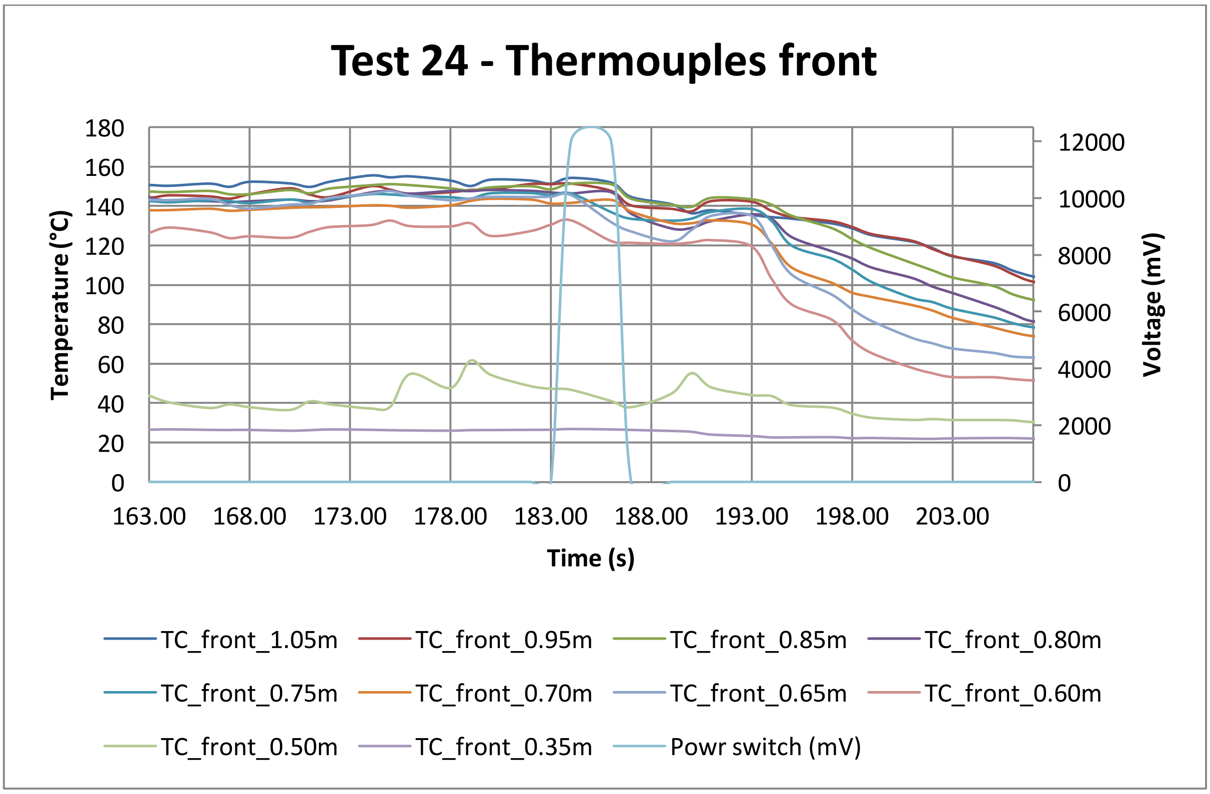
Test 22 - Velocities bidirectional probes
Velocity (m/s)
2
1.5
1
0.5
0
-0.5
-1
95.00
115.00
135.00
155.00
175.00
195.00
215.00
235.00
255.00
Times (s)
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
v4
v3
v2
v1
Powr switch (mV)

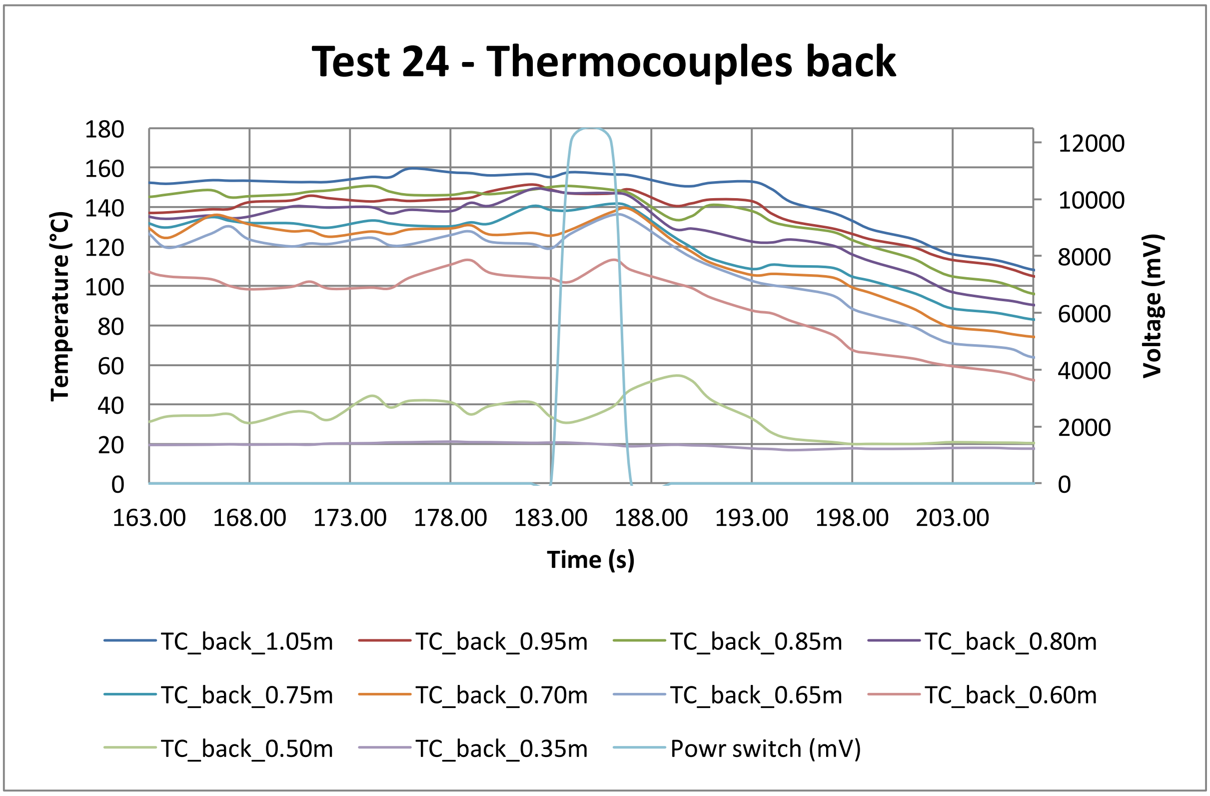

Test 23 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
255.00
260.00
265.00
270.00
275.00
280.00
285.00
290.00
295.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

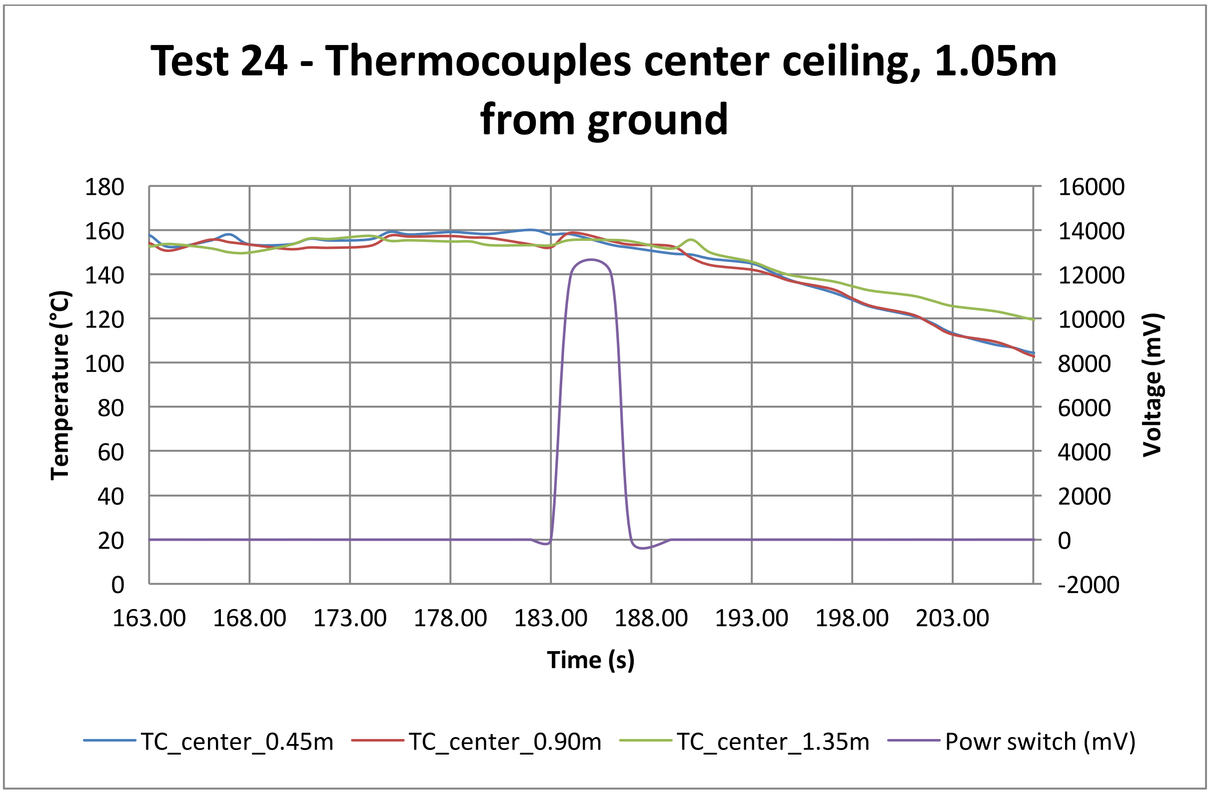

Test 23 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
255.00
260.00
265.00
270.00
275.00
280.00
285.00
290.00
295.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

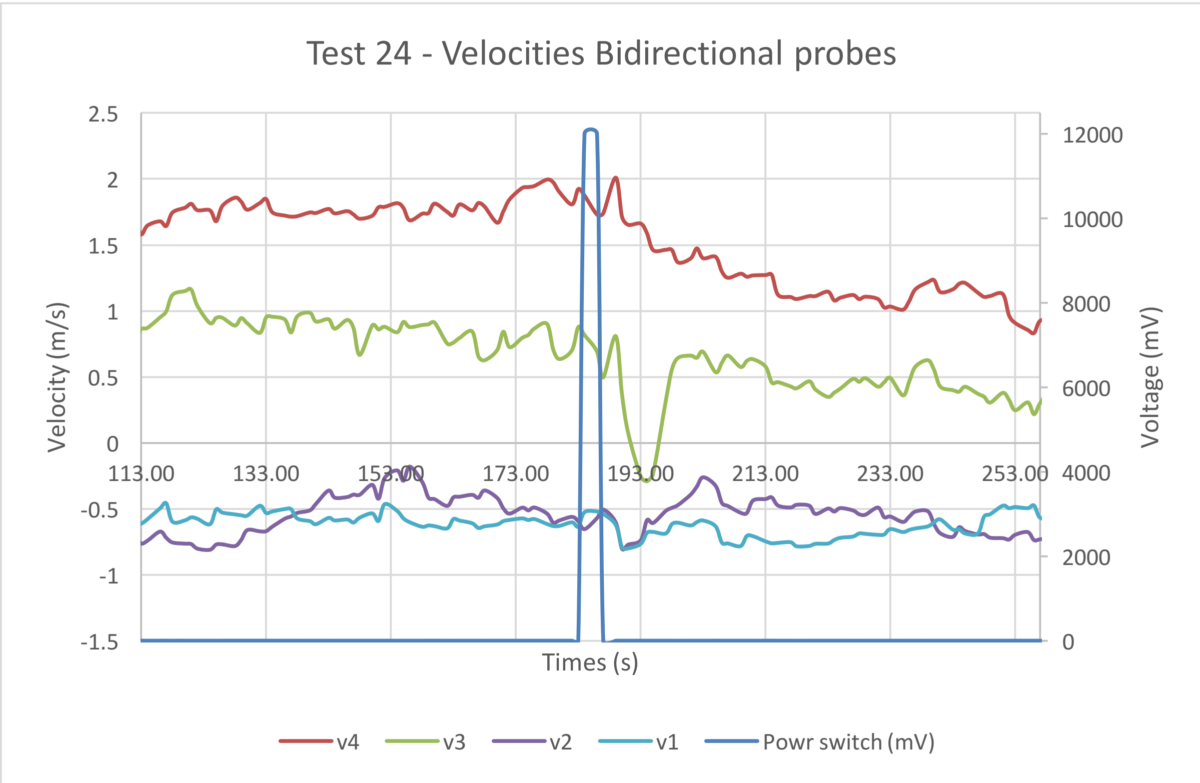

Test 23 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
255.00
260.00
265.00
270.00
275.00
280.00
285.00
290.00
295.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

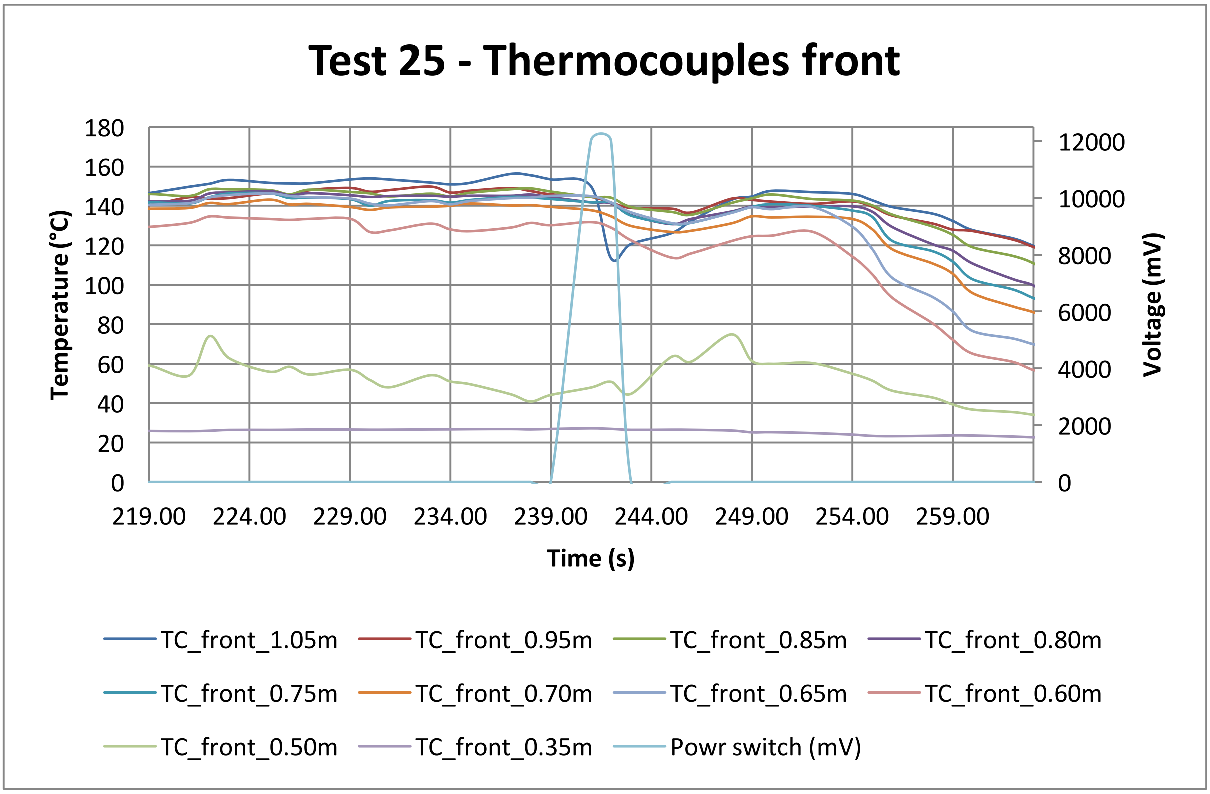

Test 23 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
12000
10000
8000
6000
4000
2000
0
205.00
225.00
245.00
265.00
285.00
305.00
325.00
v4
v3
v2
v1
Powr switch (mV)

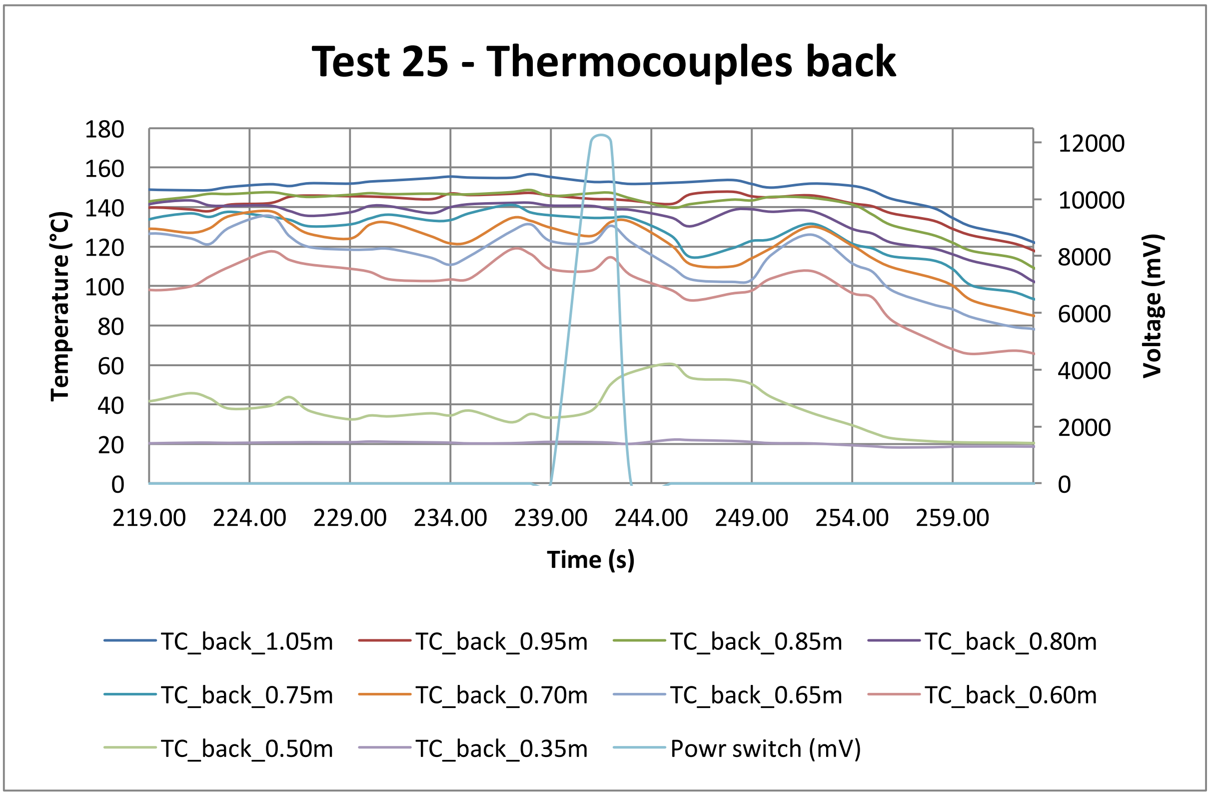

Test 24 - Thermouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
163.00
168.00
173.00
178.00
183.00
188.00
193.00
198.00
203.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

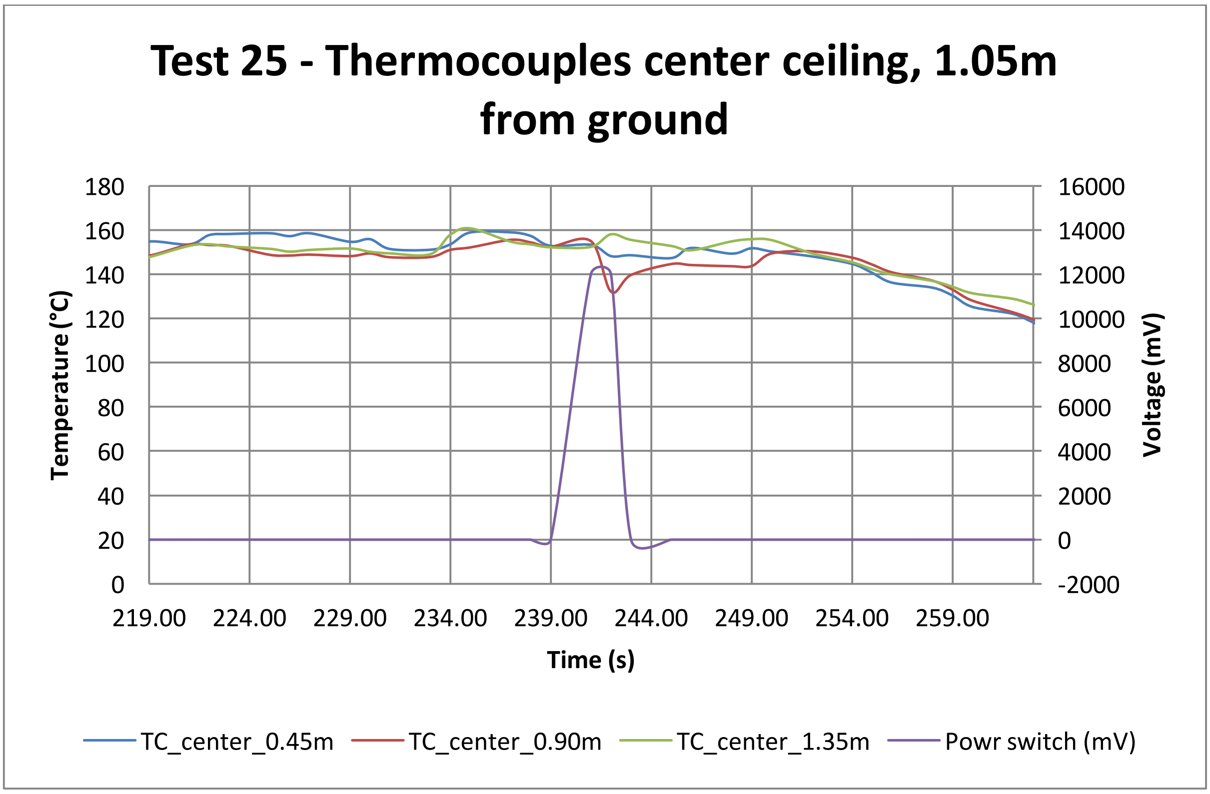

Test 24 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
163.00
168.00
173.00
178.00
183.00
188.00
193.00
198.00
203.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

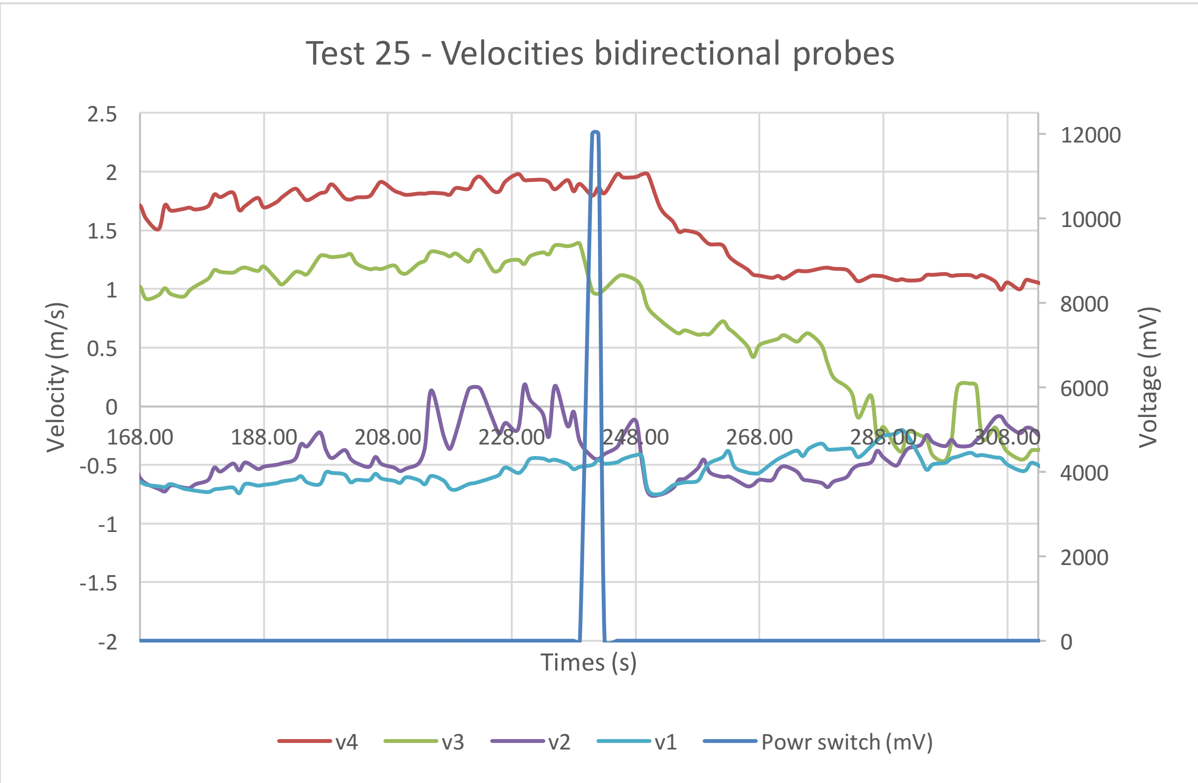

Test 24 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
163.00
168.00
173.00
178.00
183.00
188.00
193.00
198.00
203.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

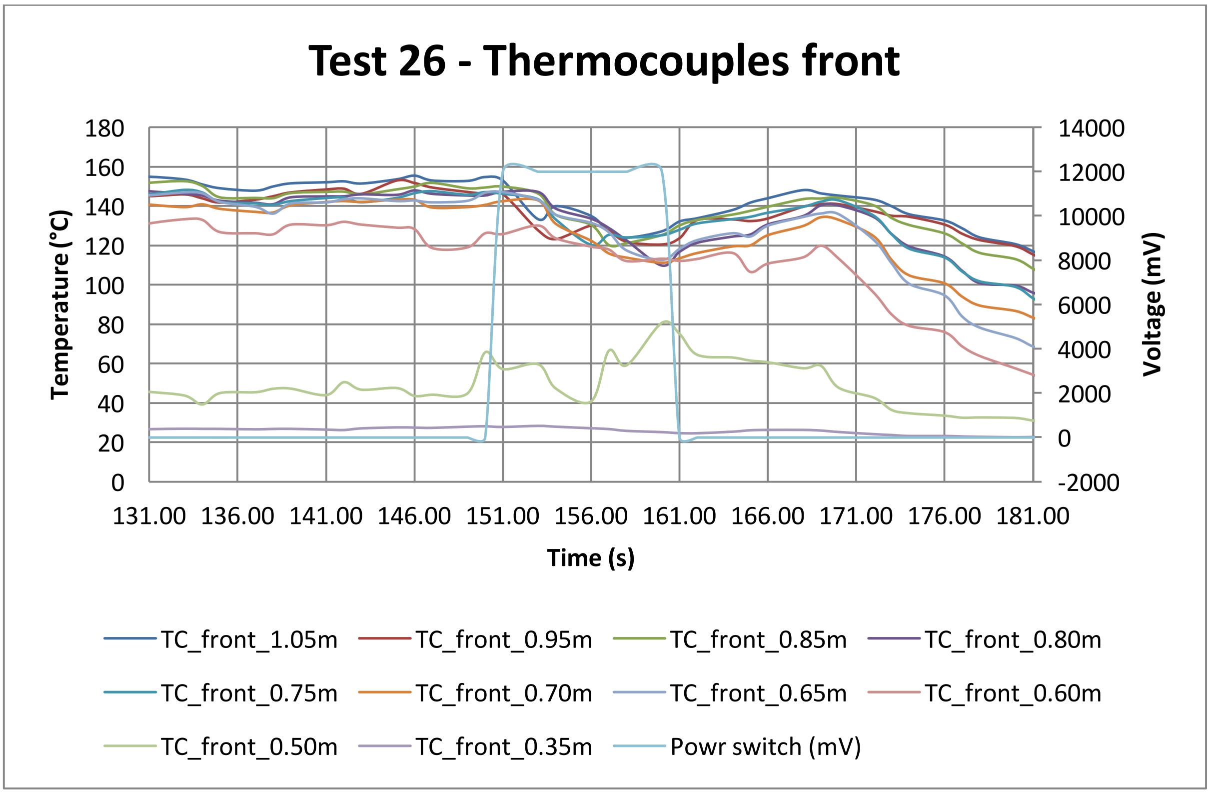

Test 24 - Velocities Bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
113.00
133.00
153.00
173.00
193.00
213.00
233.00
253.00
v4
v3
v2
v1
Powr switch (mV)


Test 25 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

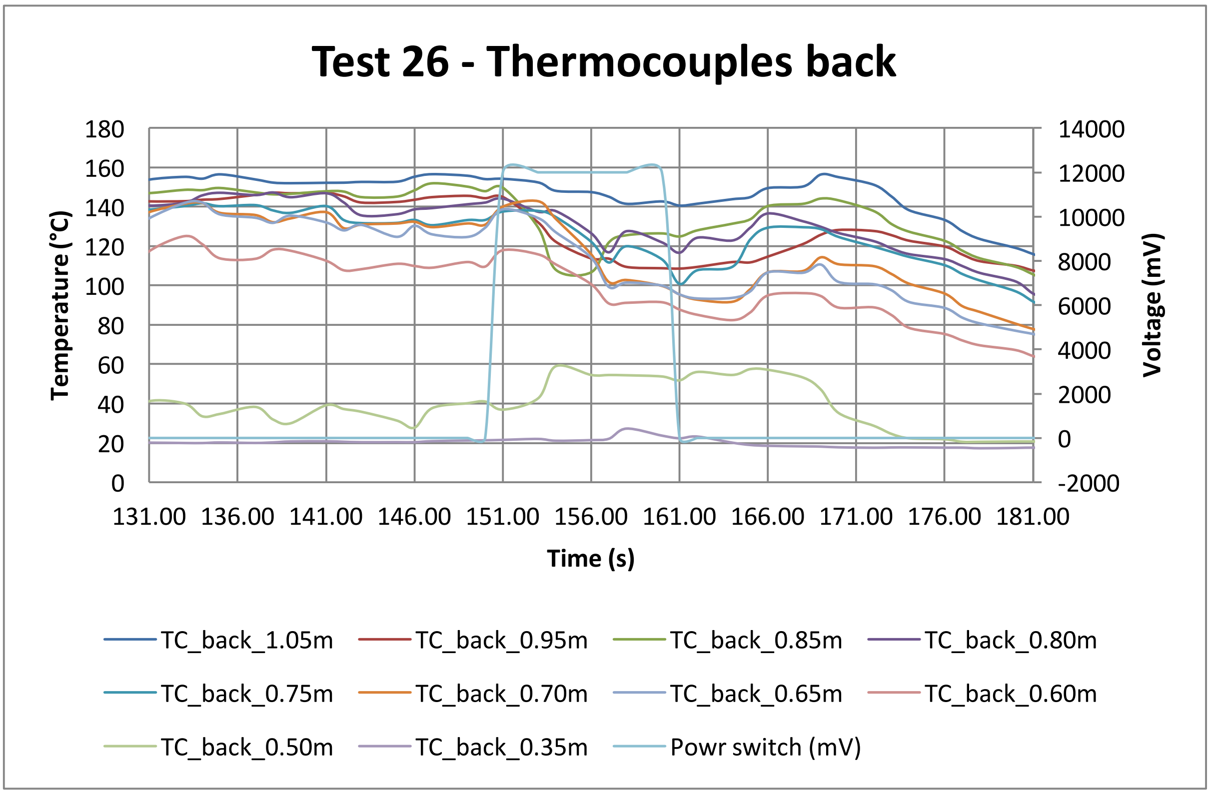

Test 25 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 25 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
Voltage (mV)
219.00
224.00
229.00
234.00
239.00
244.00
249.00
254.00
259.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

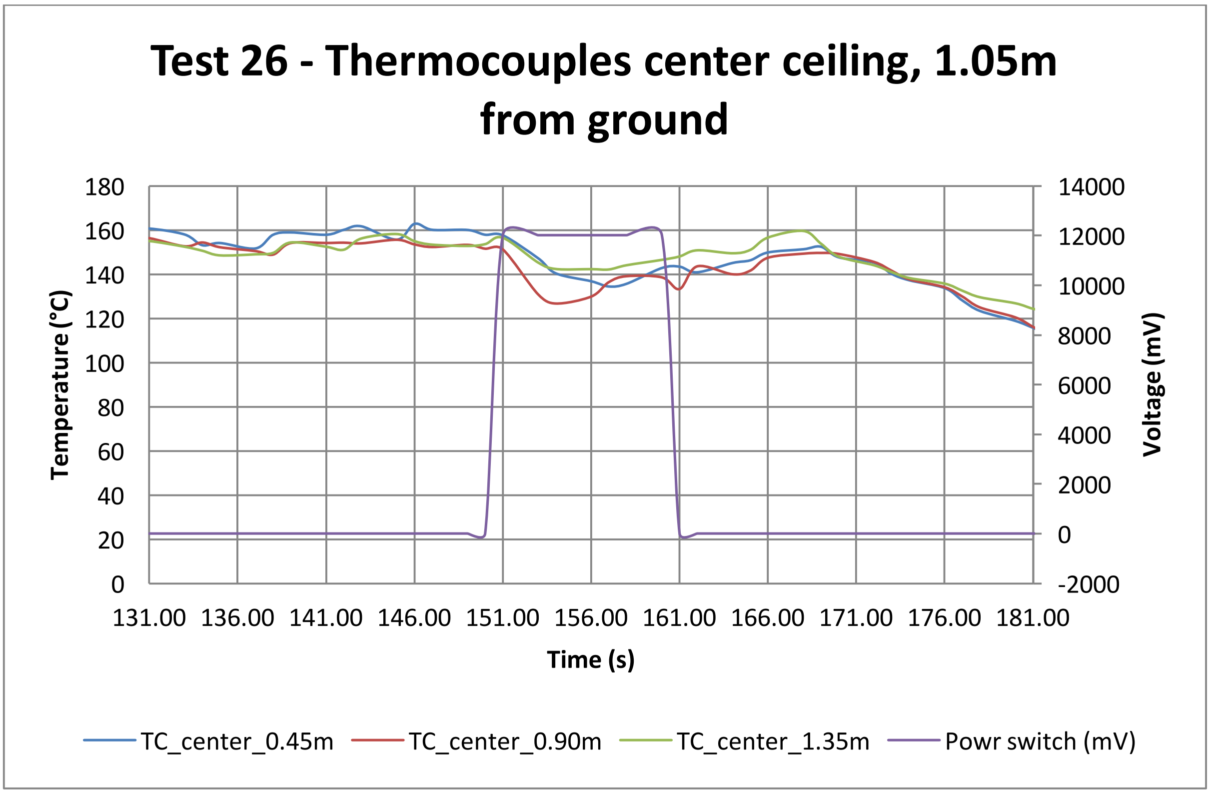

Test 25 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
168.00
188.00
208.00
228.00
248.00
268.00
288.00
308.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)



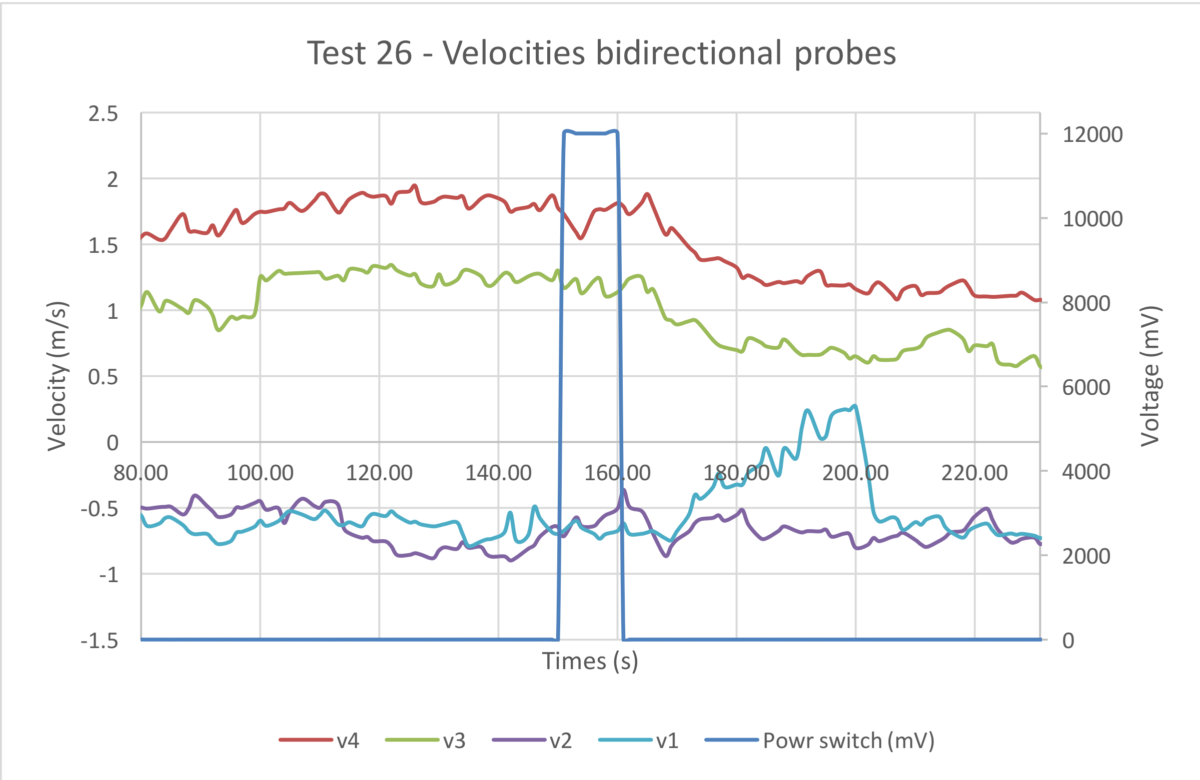
Test 26 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
176.00
181.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)



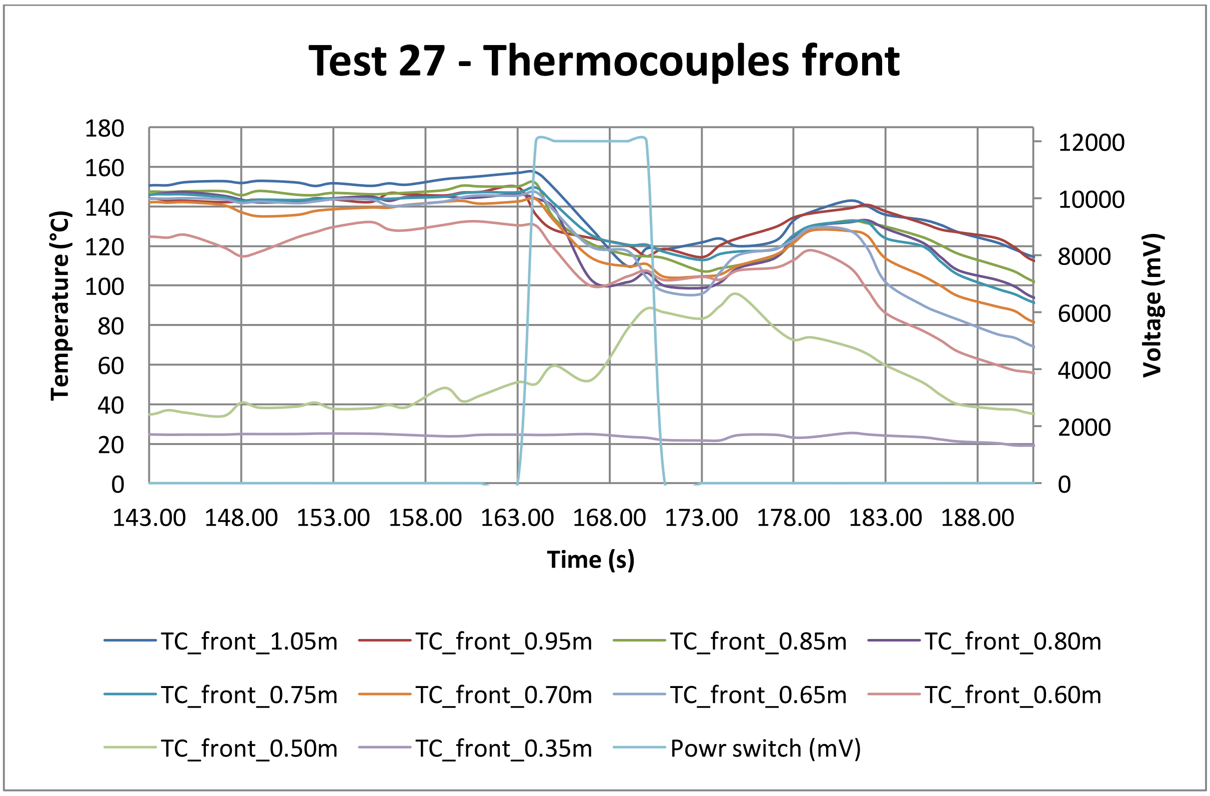
Test 26 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
176.00
181.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

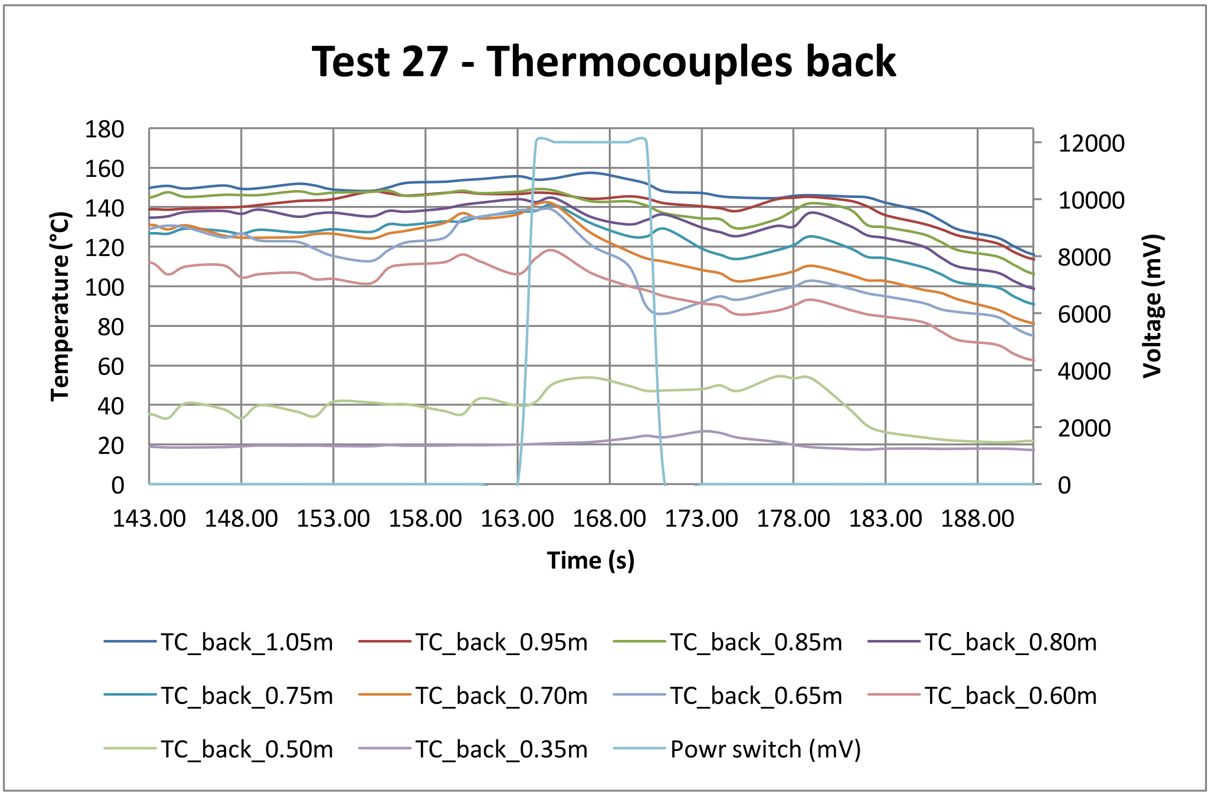


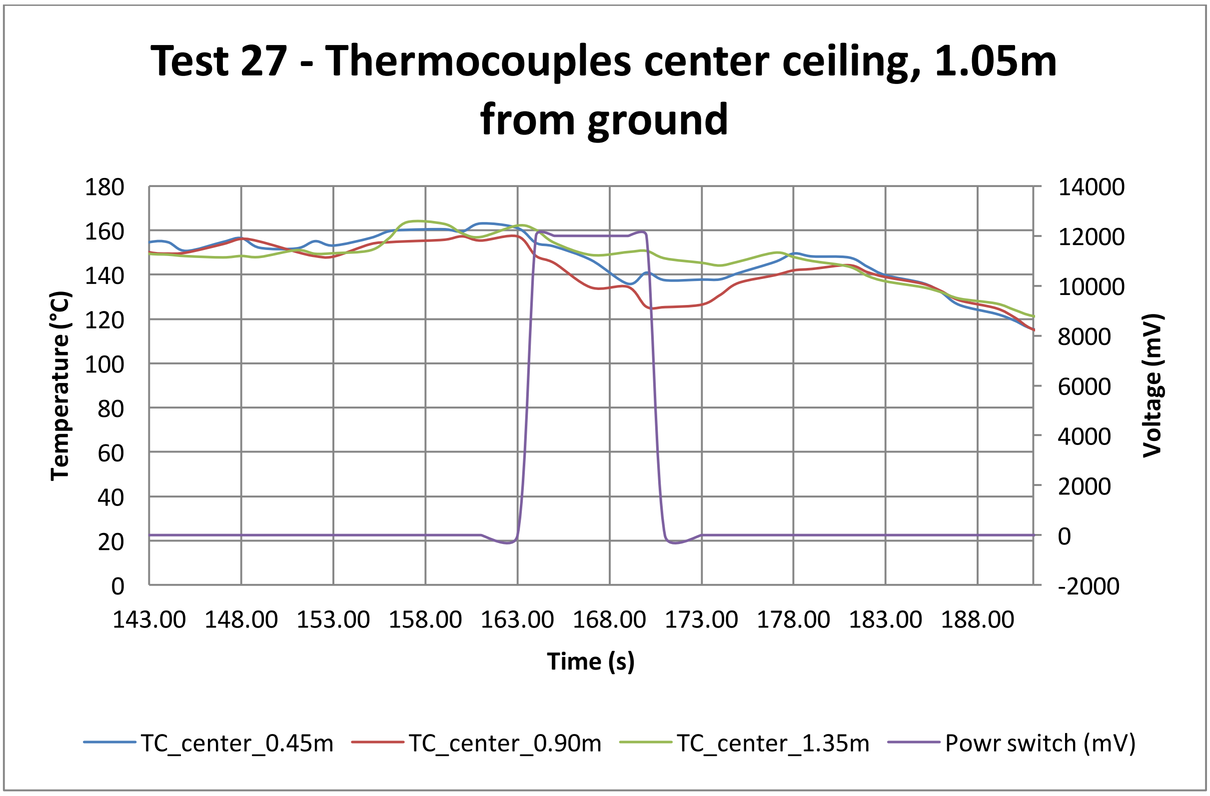
Test 26 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
131.00 136.00 141.00 146.00 151.00 156.00 161.00 166.00 171.00 176.00 181.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

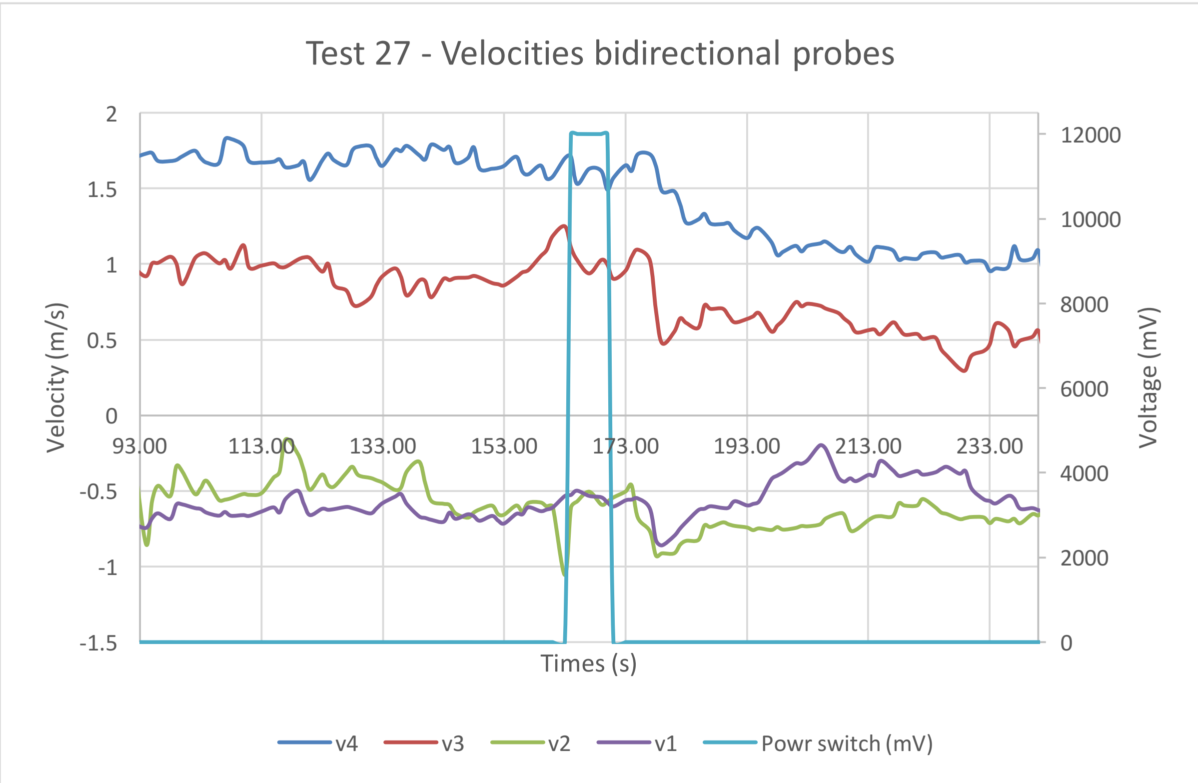


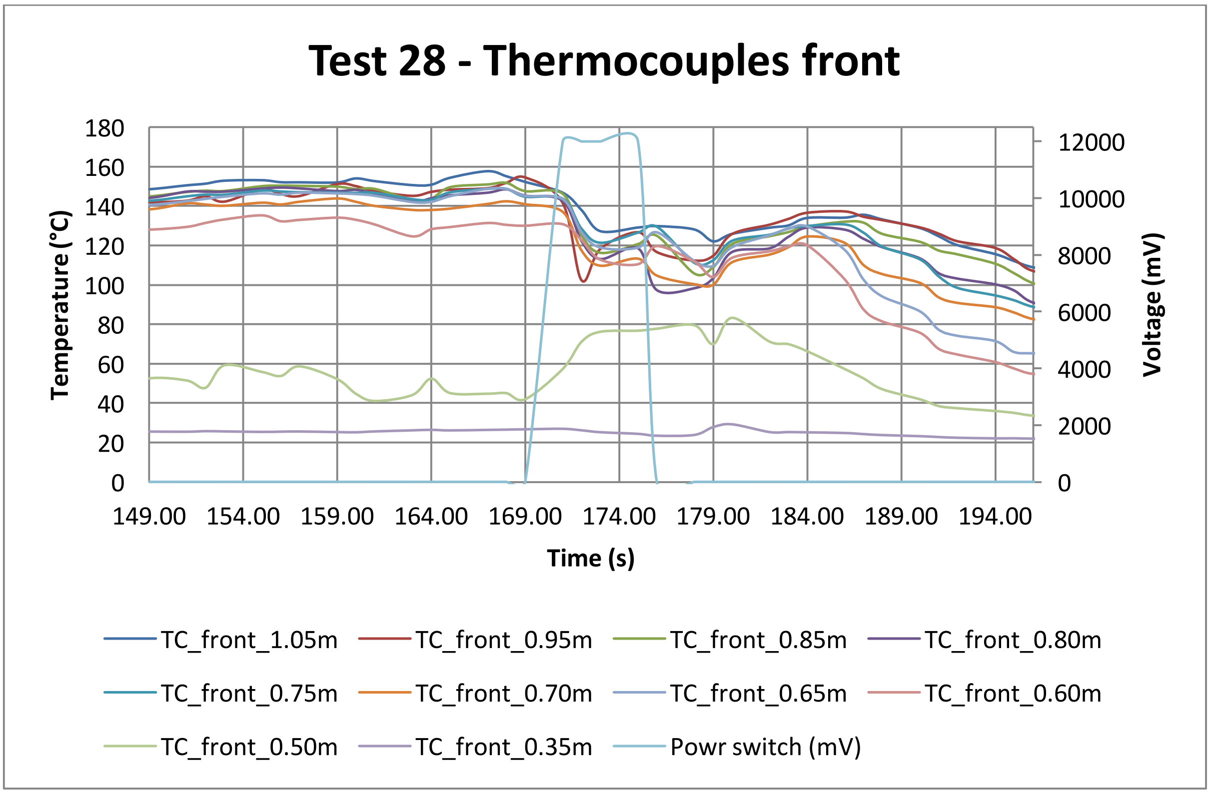
Test 26 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
80.00 100.00 120.00 140.00 160.00 180.00 200.00 220.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

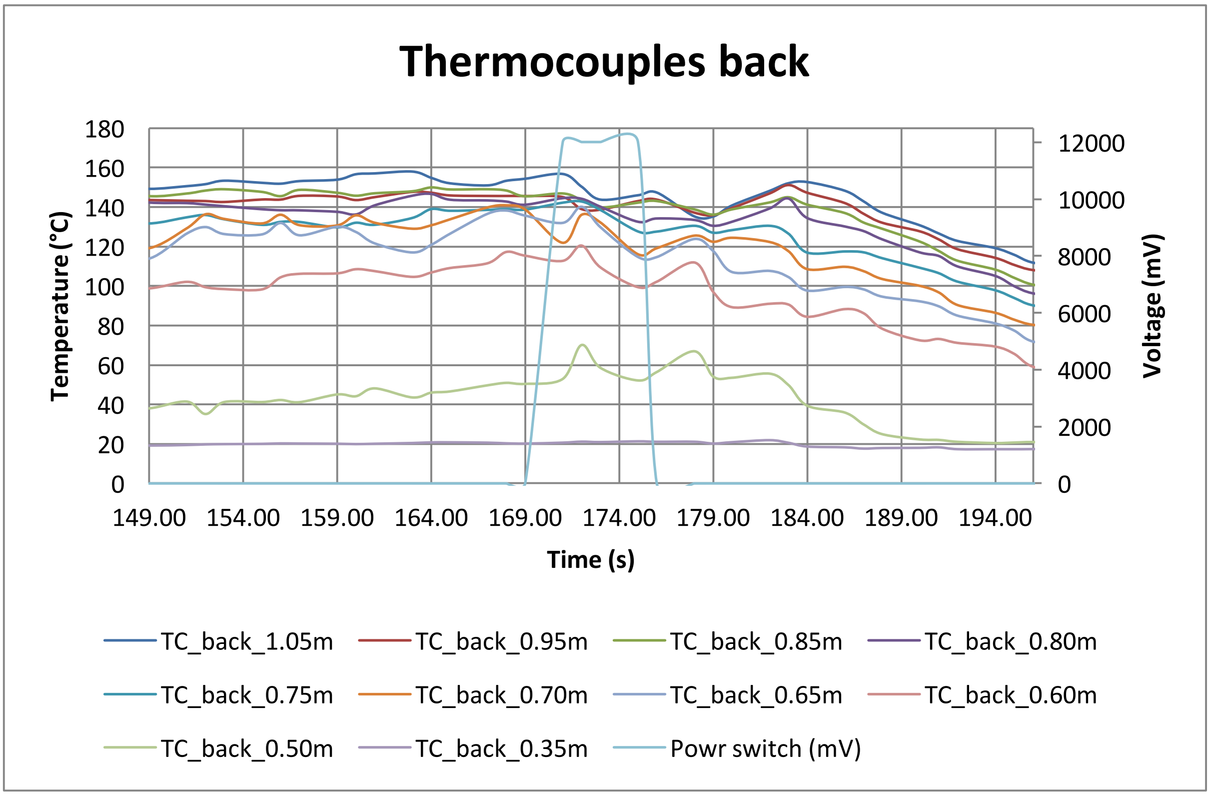

Test 27 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

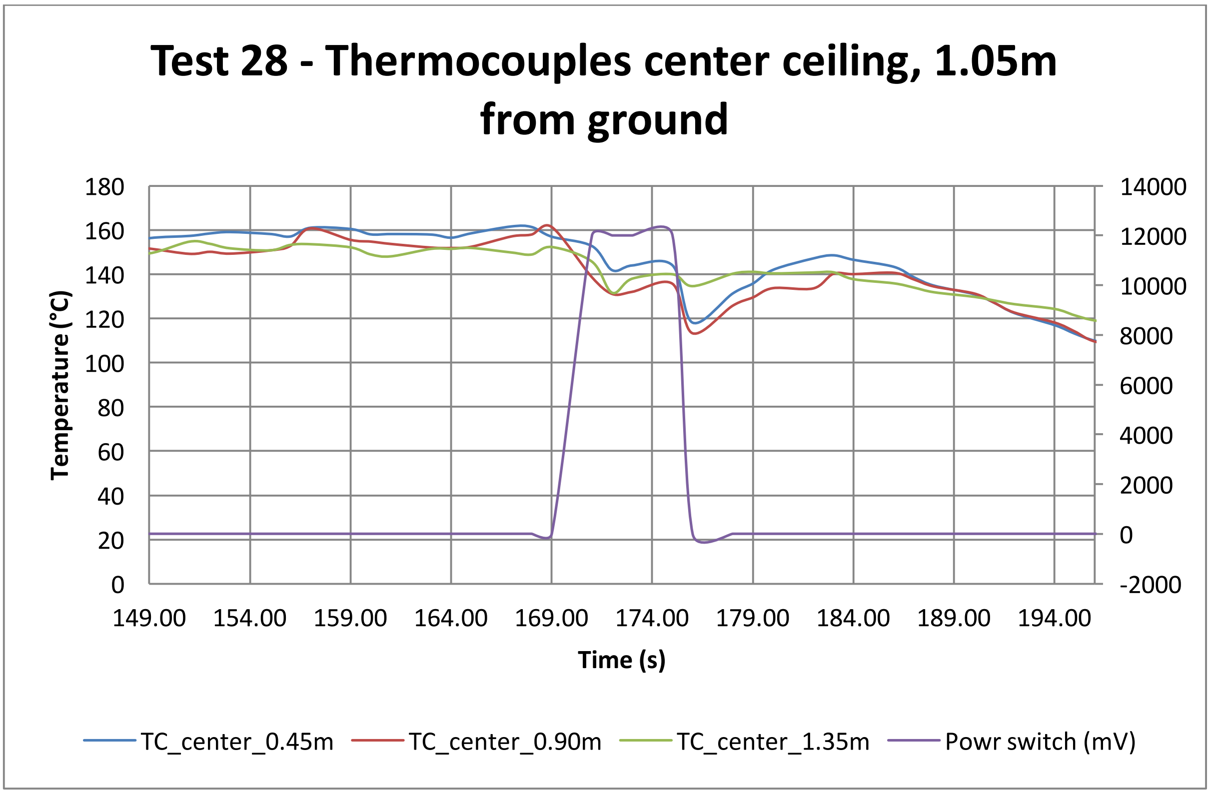

Test 27 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 27 - Thermocouples center ceiling, 1.05m from ground
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
Temperature (°C)
Voltage (mV)
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

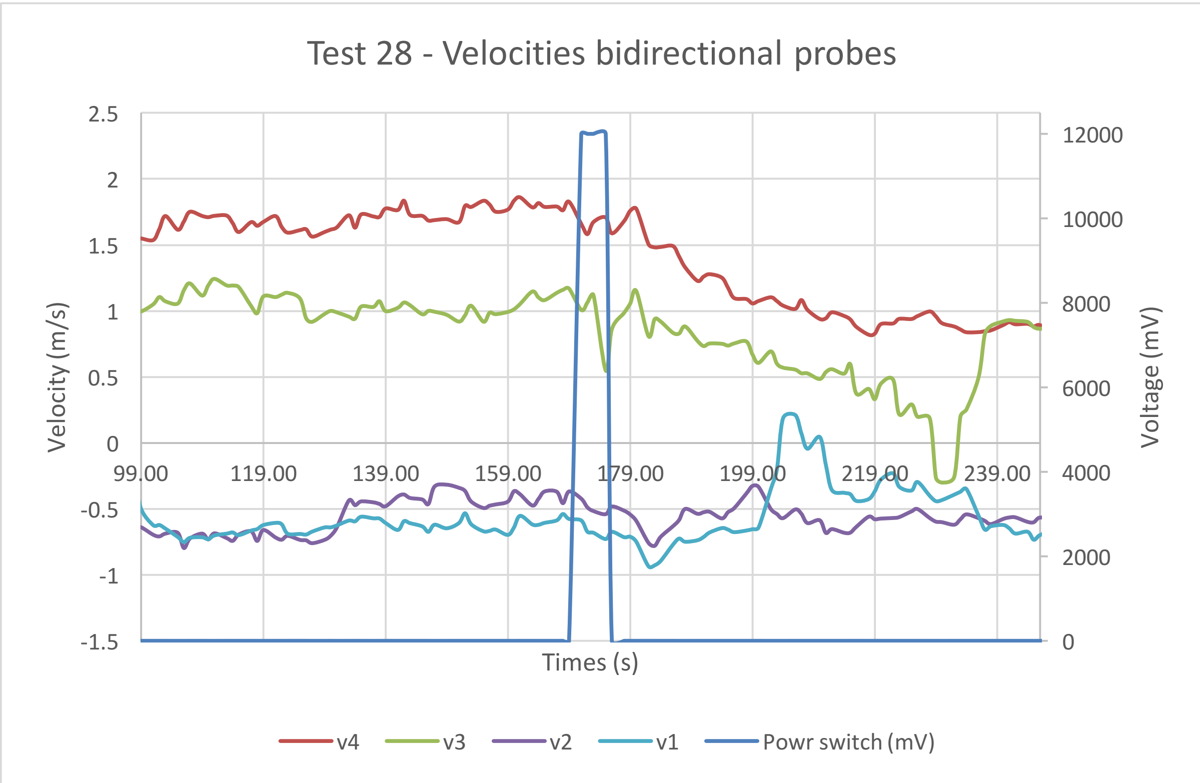

Test 27 - Velocities bidirectional probes
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Velocity (m/s)
Voltage (mV)
93.00 113.00 133.00 153.00 173.00 193.00 213.00 233.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 28 - Thermocouples front
Temperature (°C)
0
20
40
60
80
100
120
140
160
180
Voltage (mV)
0
2000
4000
6000
8000
10000
12000
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
194.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

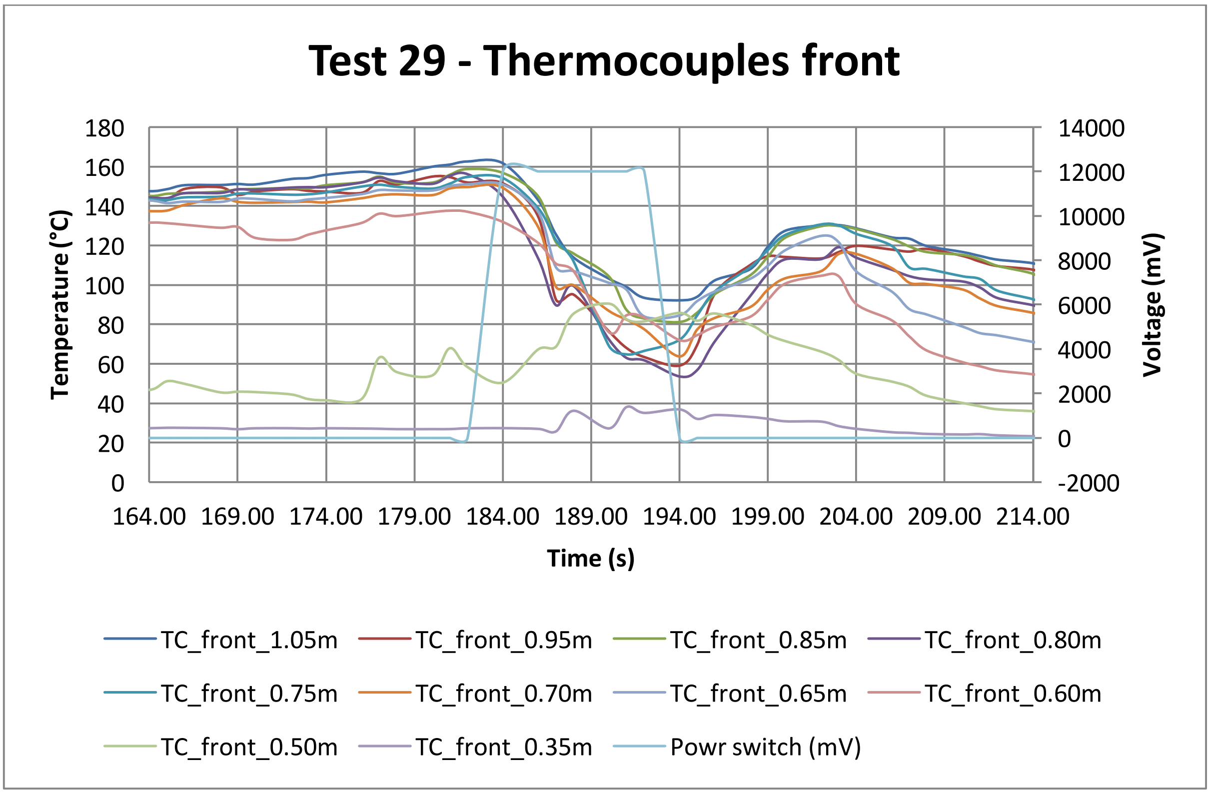

Thermocouples back
Temperature (°C)
0
20
40
60
80
100
120
140
160
180
Voltage (mV)
0
2000
4000
6000
8000
10000
12000
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
194.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

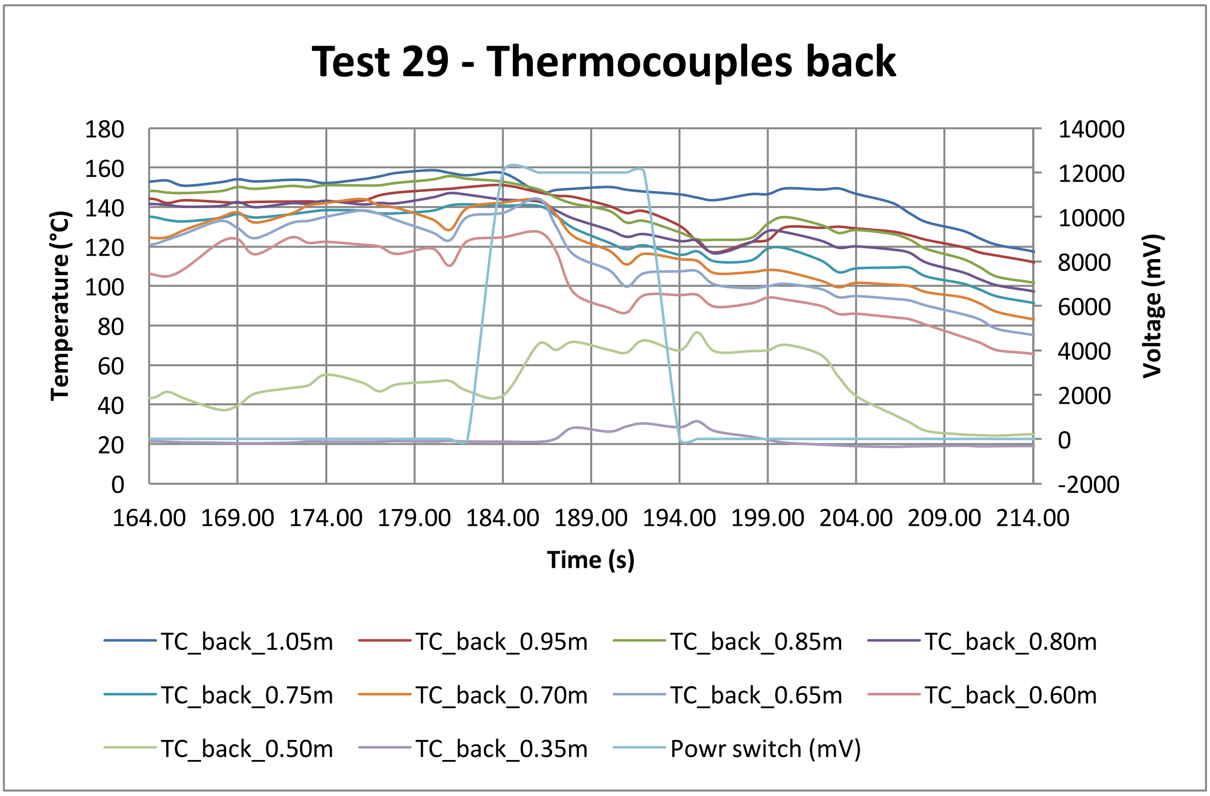


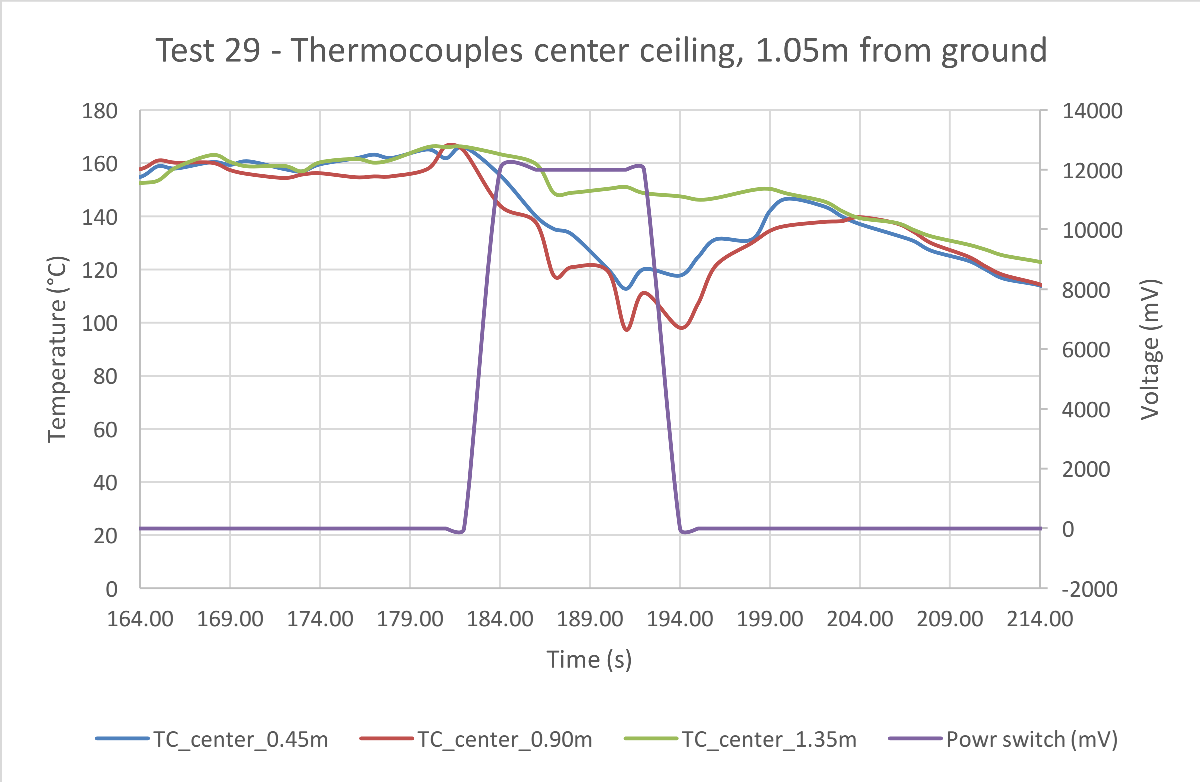
Test 28 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
194.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

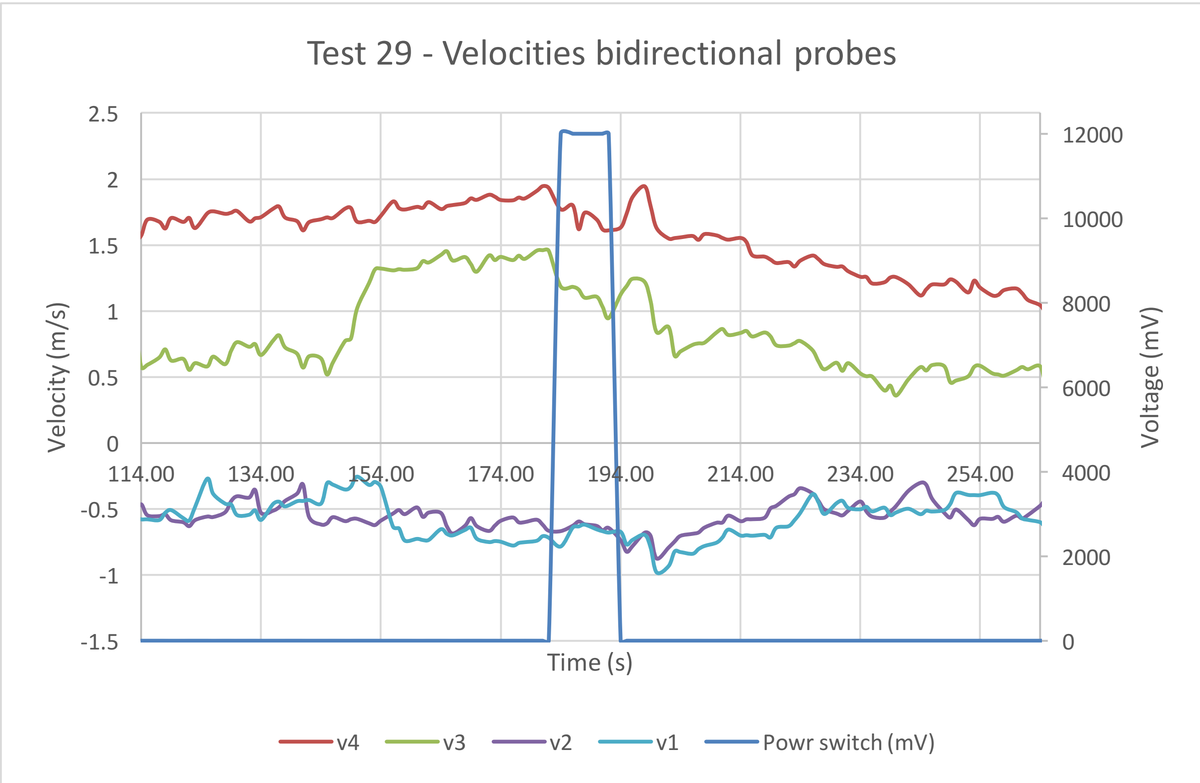


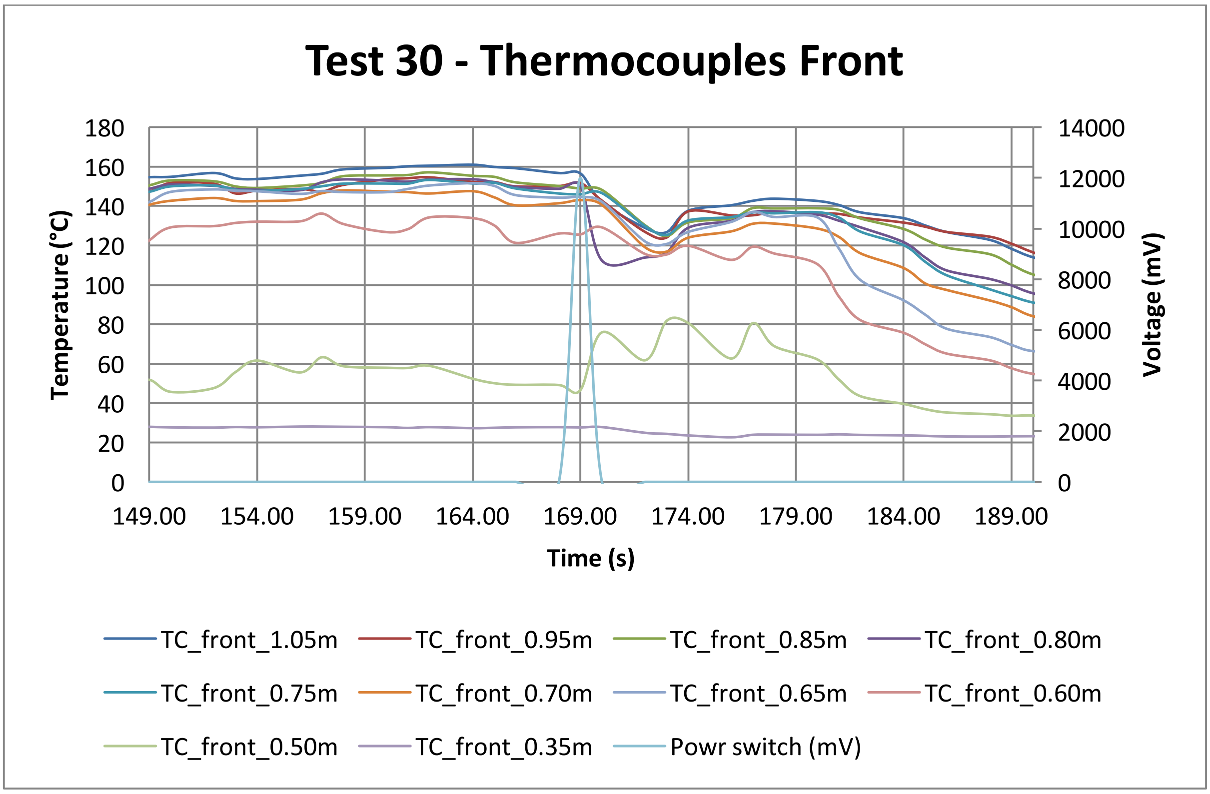
Test 28 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
99.00
119.00
139.00
159.00
179.00
199.00
219.00
239.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

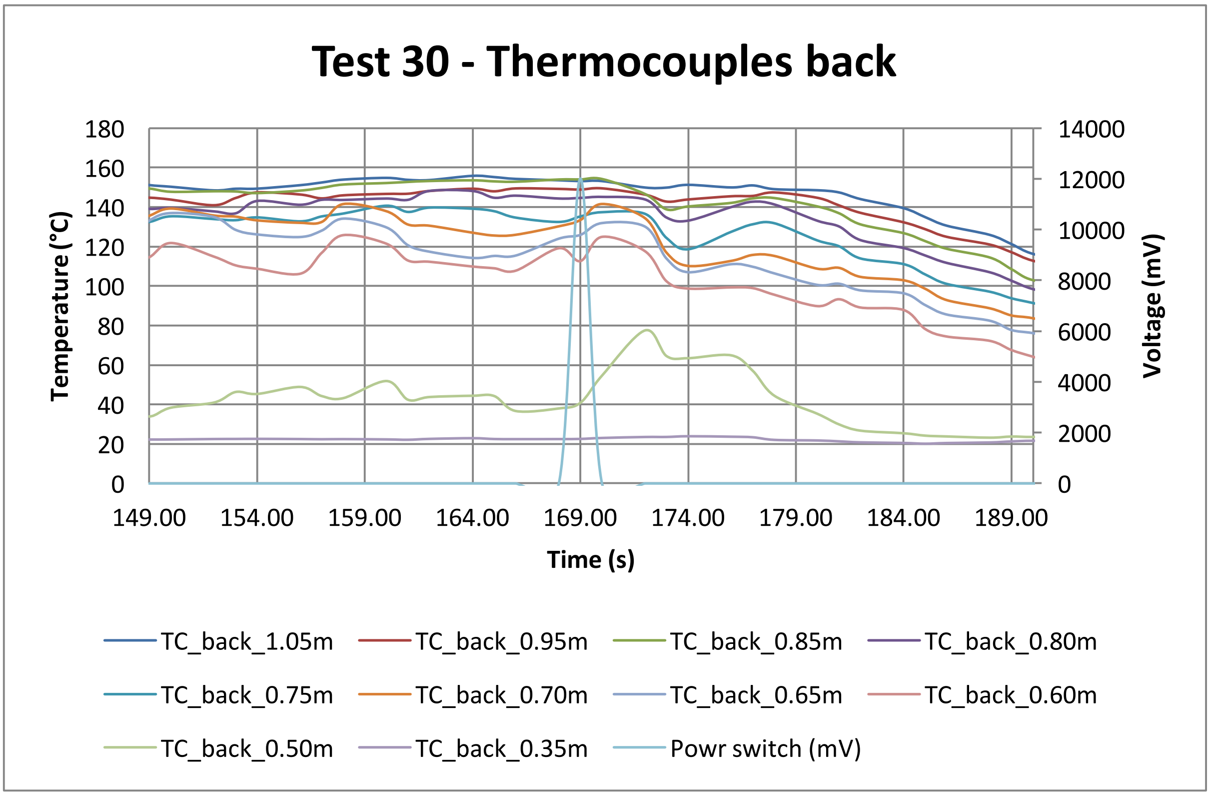

Test 29 - Thermocouples front
Temperature (°C)
Voltage (mV)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
164.00 169.00 174.00 179.00 184.00 189.00 194.00 199.00 204.00 209.00 214.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

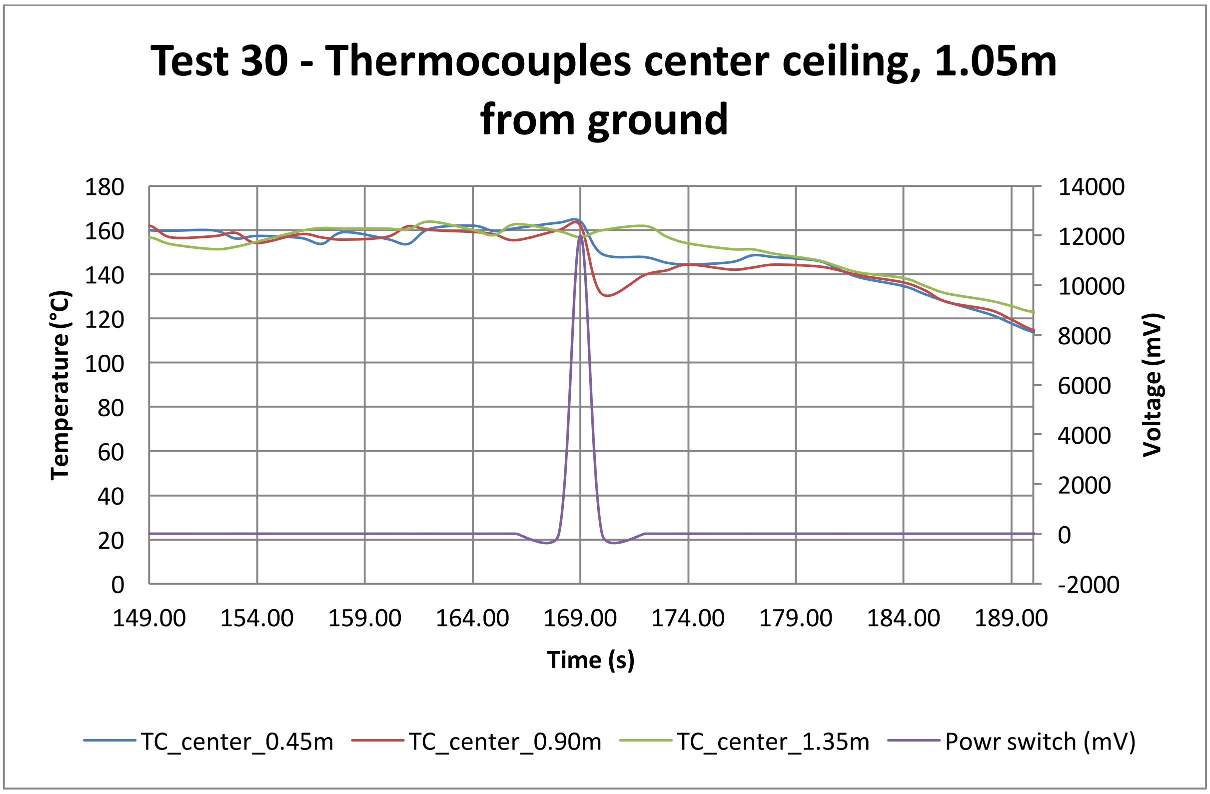

Test 29 - Thermocouples back
Temperature (°C)
Voltage (mV)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
164.00 169.00 174.00 179.00 184.00 189.00 194.00 199.00 204.00 209.00 214.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

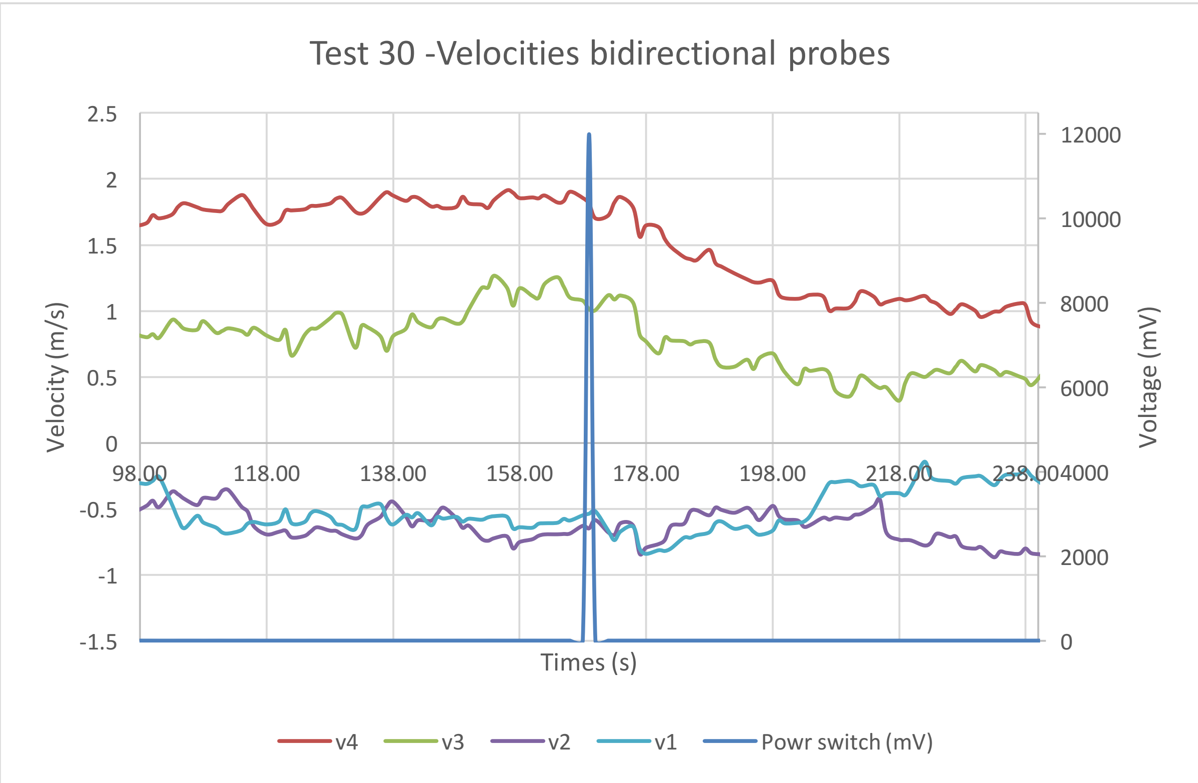

Test 29 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
164.00
169.00
174.00
179.00
184.00
189.00
194.00
199.00
204.00
209.00
214.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

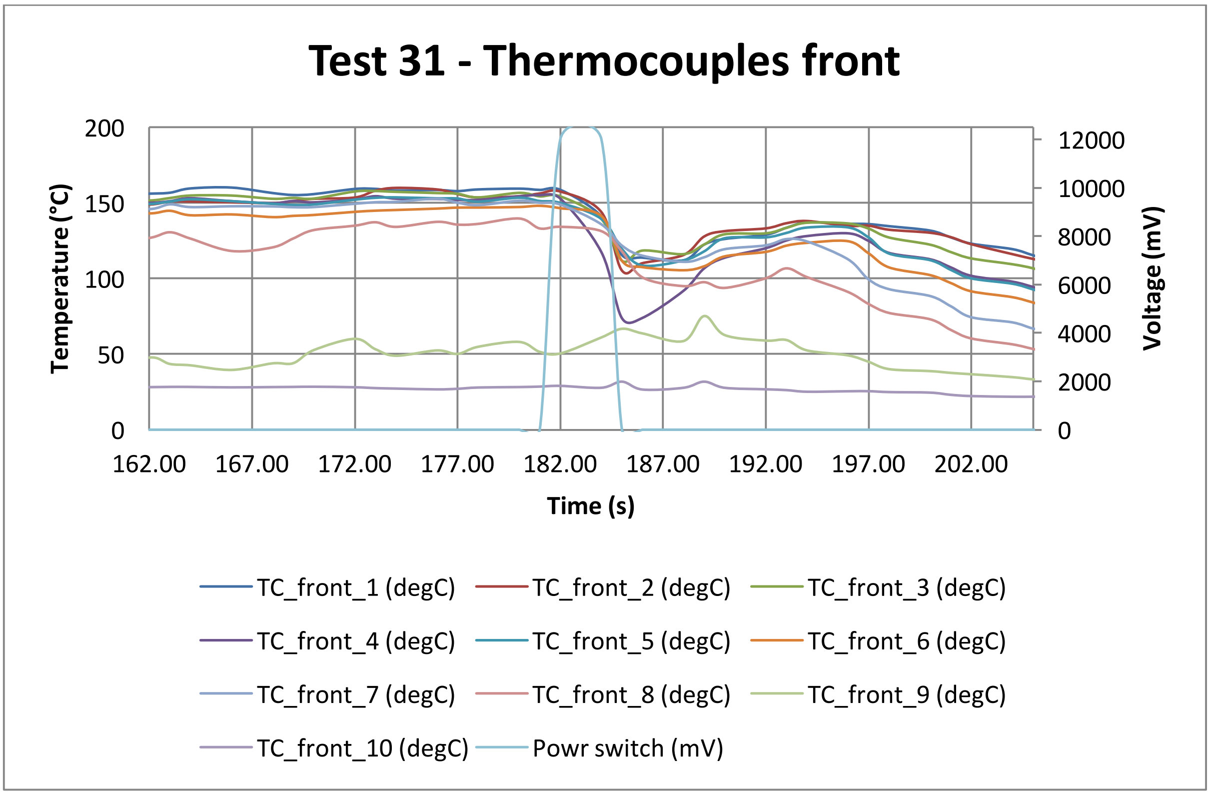

Test 29 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Time (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
114.00
134.00
154.00
174.00
194.00
214.00
234.00
254.00
v4
v3
v2
v1
Powr switch (mV)


Test 30 - Thermocouples Front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

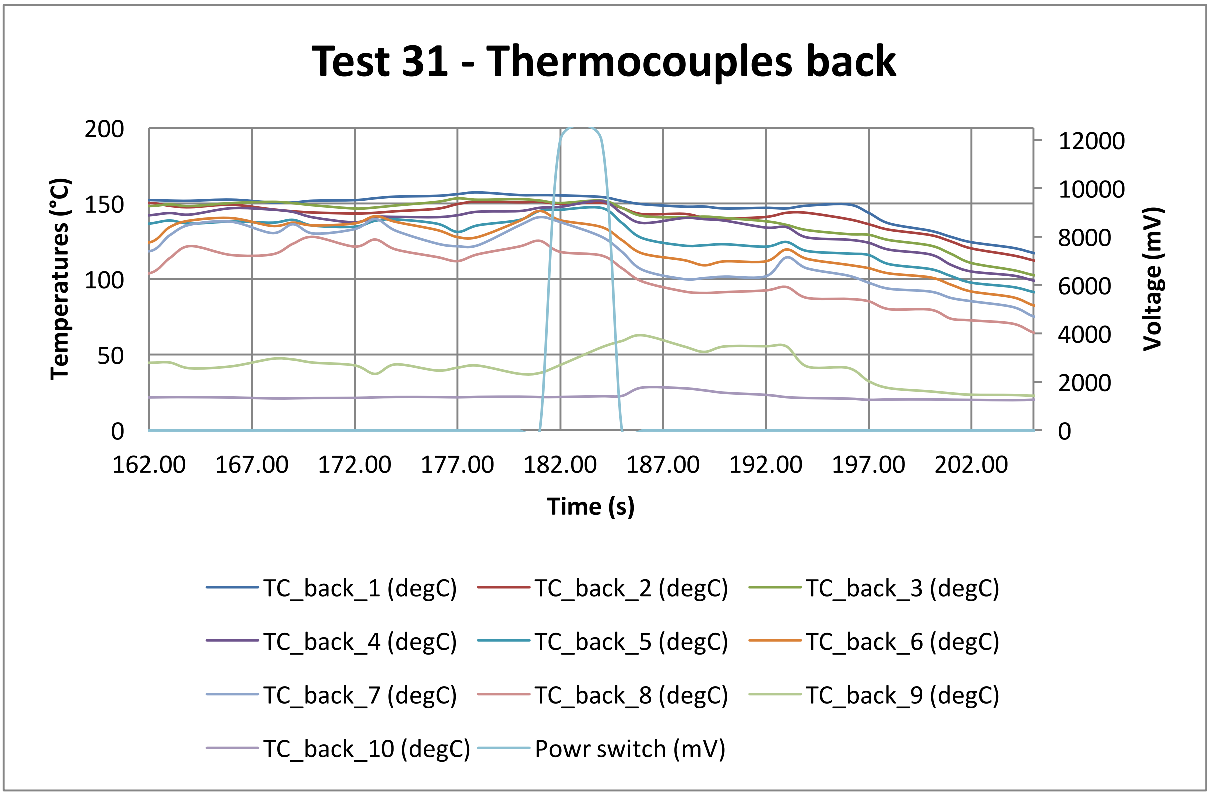

Test 30 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 30 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
149.00
154.00
159.00
164.00
169.00
174.00
179.00
184.00
189.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

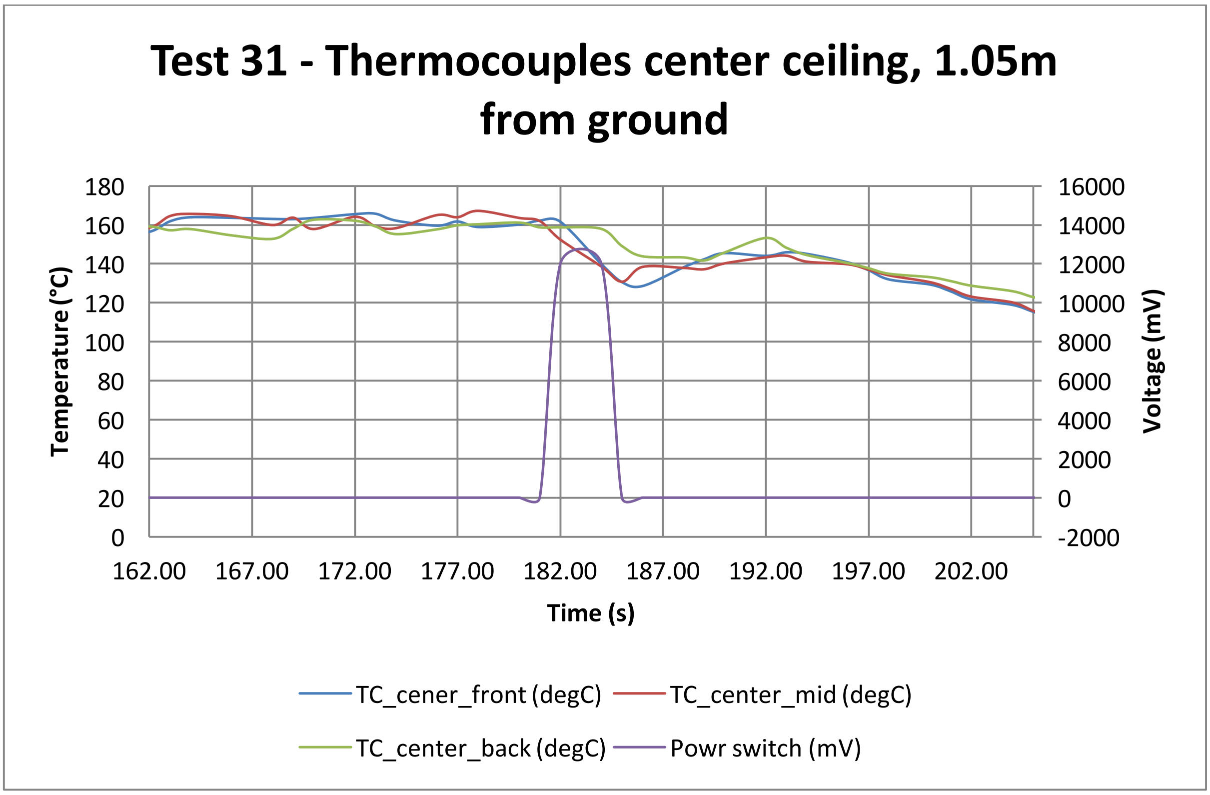

Test 30 -Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
98.00
118.00
138.00
158.00
178.00
198.00
218.00
238.00
v4
v3
v2
v1
Powr switch (mV)

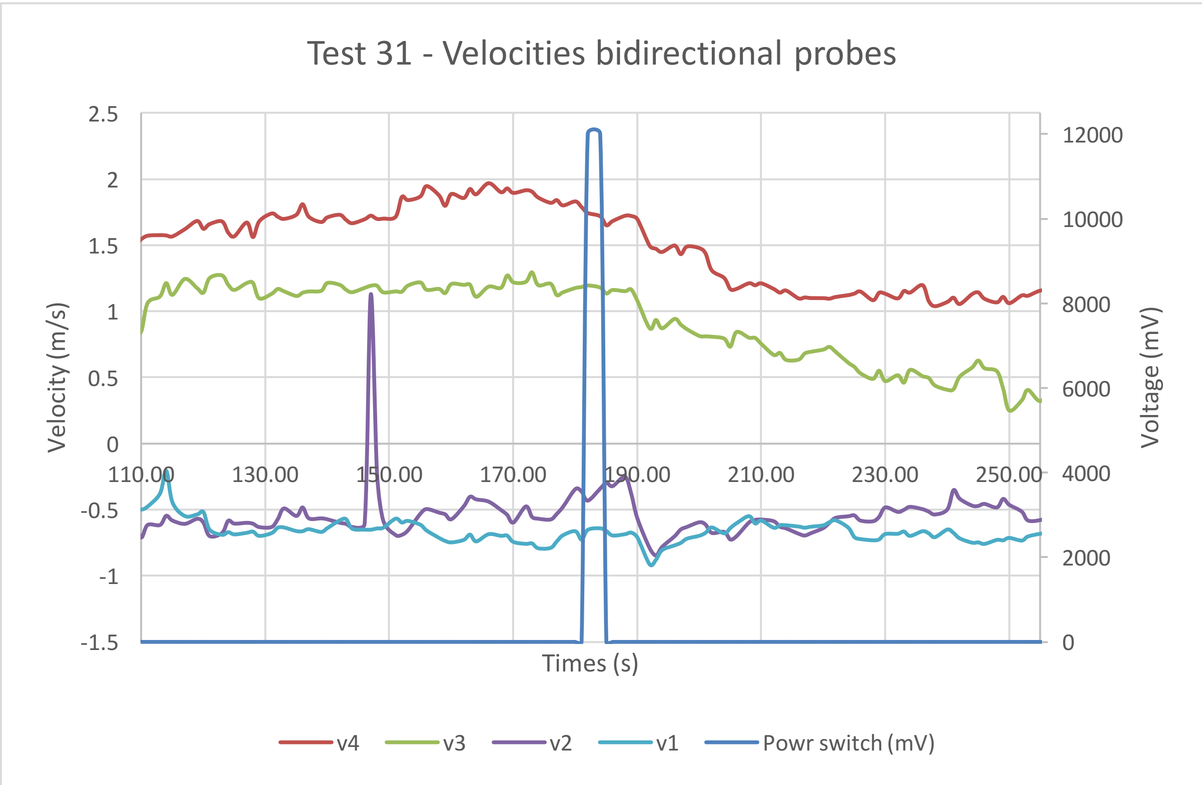


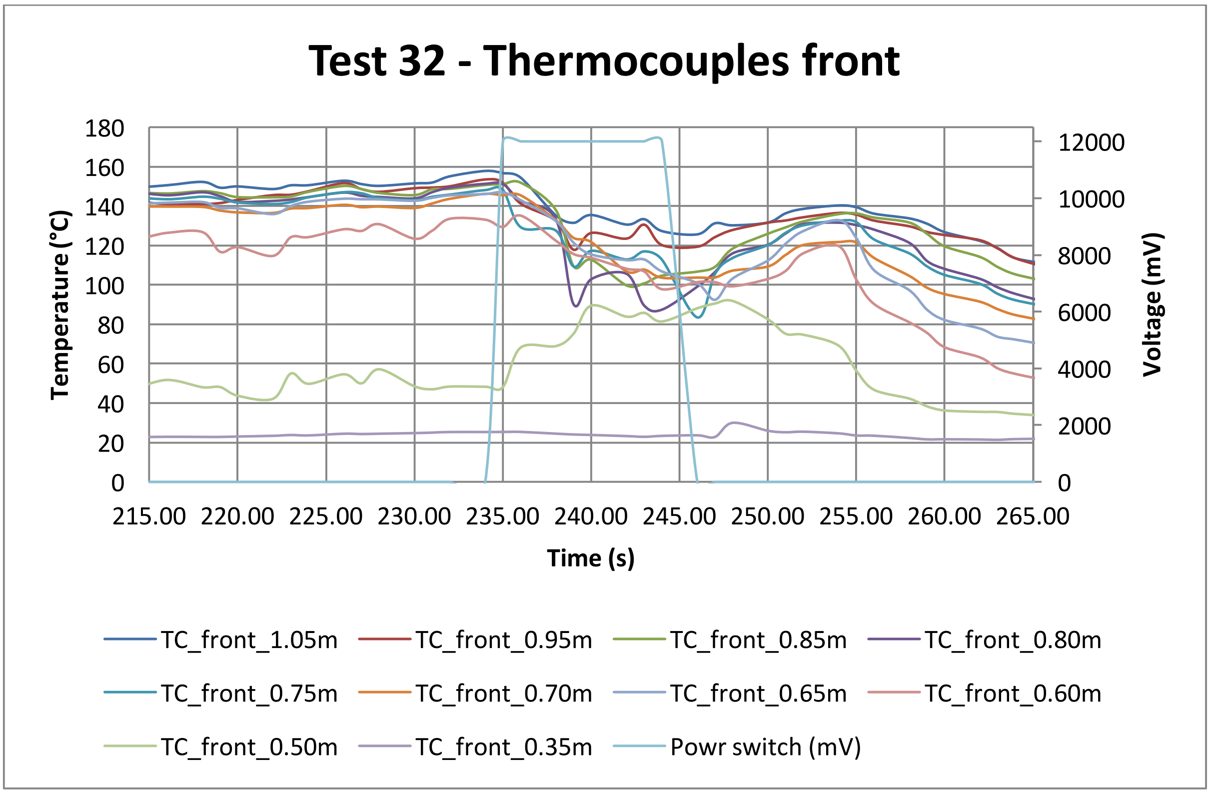
Test 31 - Thermocouples front
Temperature (°C)
200
150
100
50
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
Time (s)
TC_front_1 (degC)
TC_front_2 (degC)
TC_front_3 (degC)
TC_front_4 (degC)
TC_front_5 (degC)
TC_front_6 (degC)
TC_front_7 (degC)
TC_front_8 (degC)
TC_front_9 (degC)
TC_front_10 (degC)
Powr switch (mV)

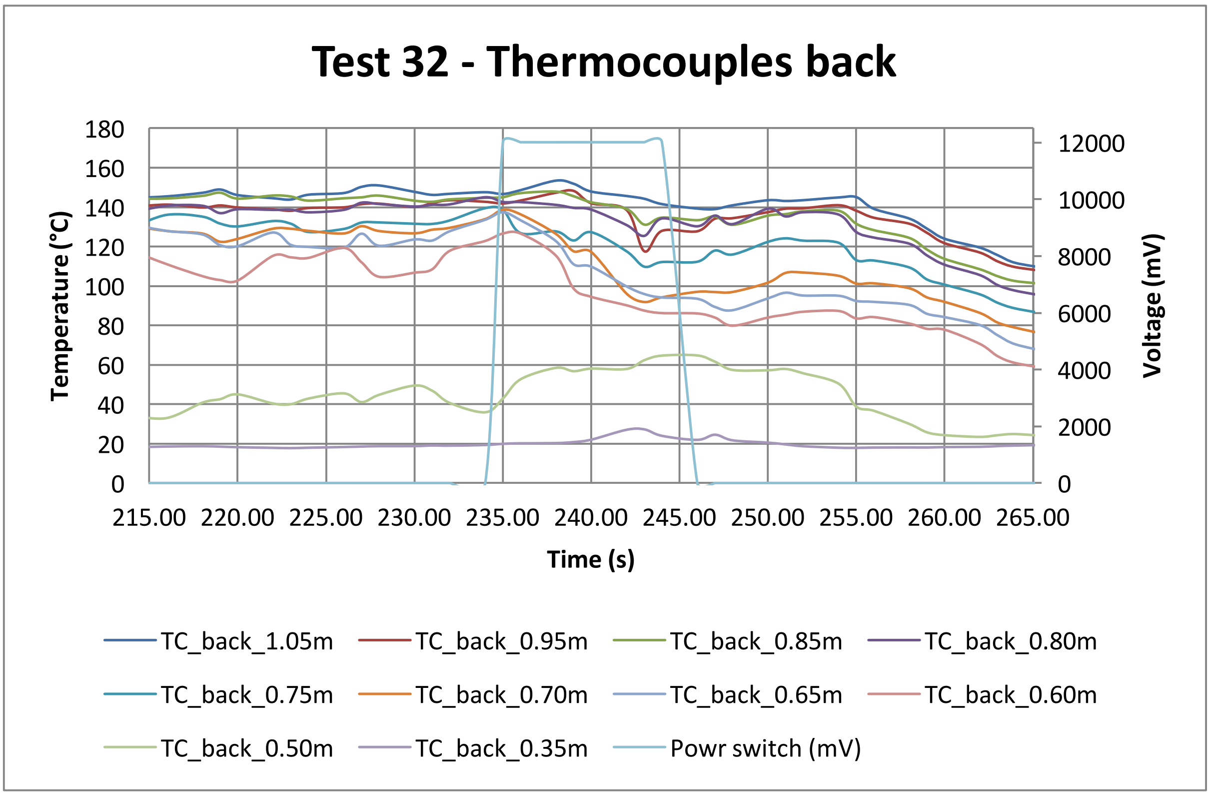


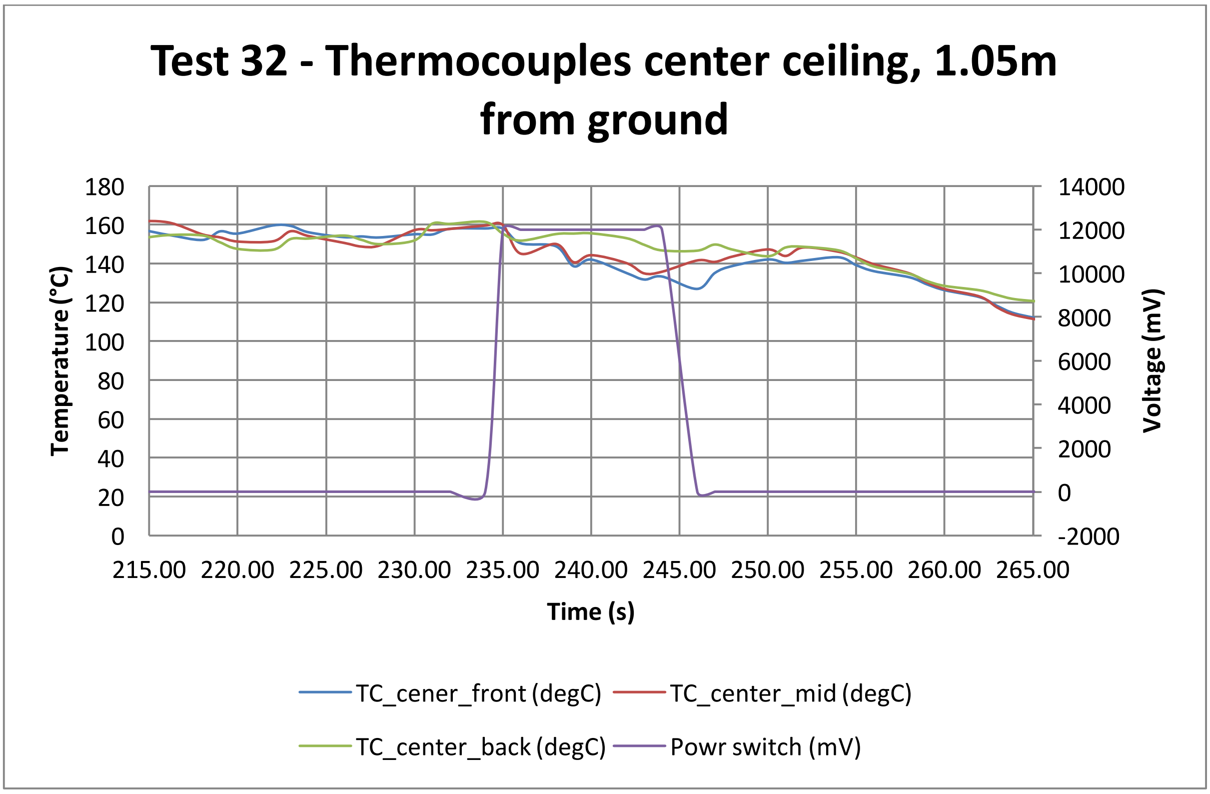
Test 31 - Thermocouples back
Temperatures (°C)
200
150
100
50
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
Time (s)
TC_back_1 (degC)
TC_back_2 (degC)
TC_back_3 (degC)
TC_back_4 (degC)
TC_back_5 (degC)
TC_back_6 (degC)
TC_back_7 (degC)
TC_back_8 (degC)
TC_back_9 (degC)
TC_back_10 (degC)
Powr switch (mV)


Test 31 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
Voltage (mV)
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
Time (s)
TC_cener_front (degC)
TC_center_mid (degC)
TC_center_back (degC)
Powr switch (mV)

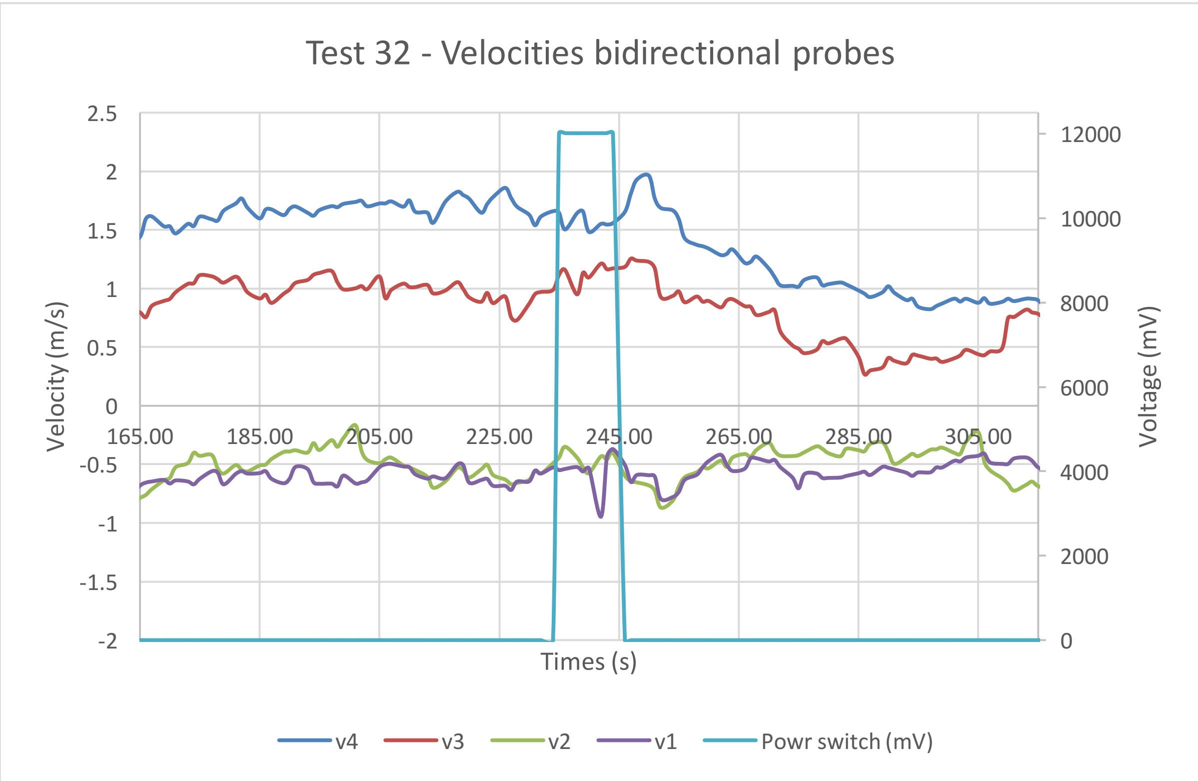

Test 31 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
110.00
130.00
150.00
170.00
190.00
210.00
230.00
250.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 32 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
215.00 220.00 225.00 230.00 235.00 240.00 245.00 250.00 255.00 260.00 265.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

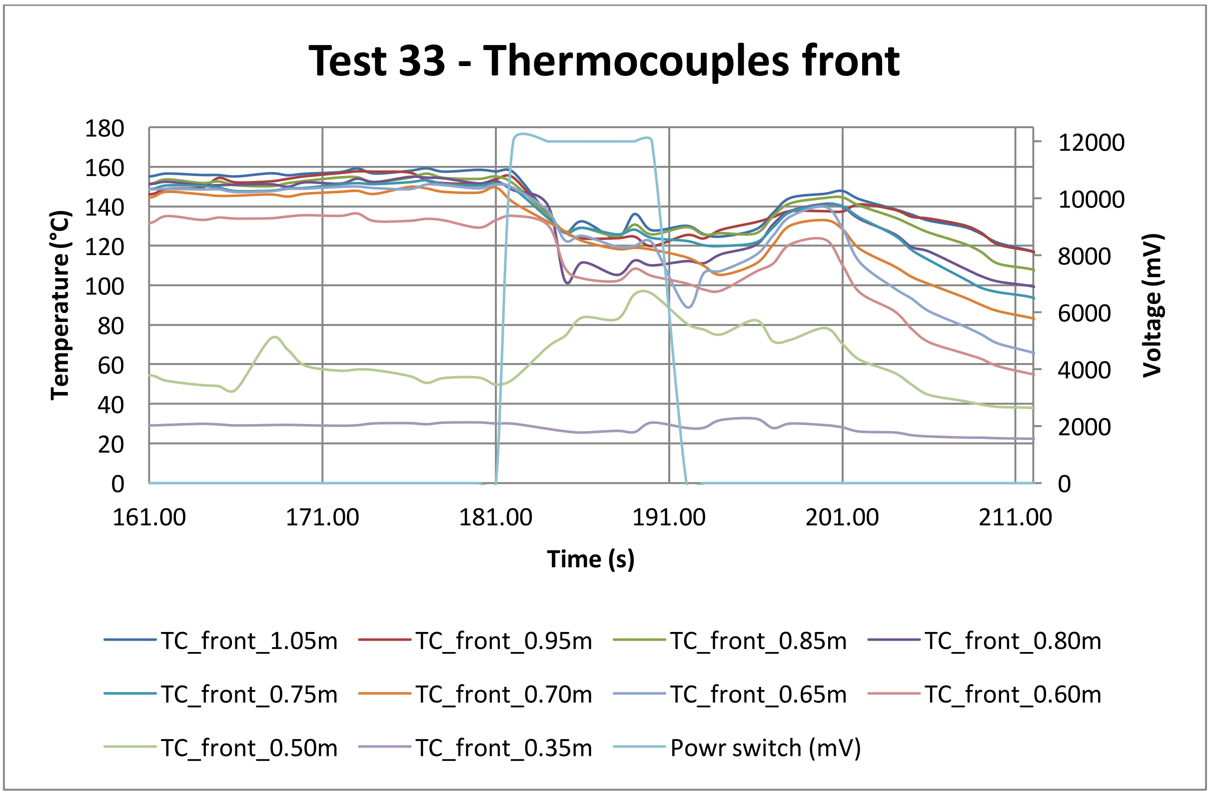

Test 32 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
215.00 220.00 225.00 230.00 235.00 240.00 245.00 250.00 255.00 260.00 265.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

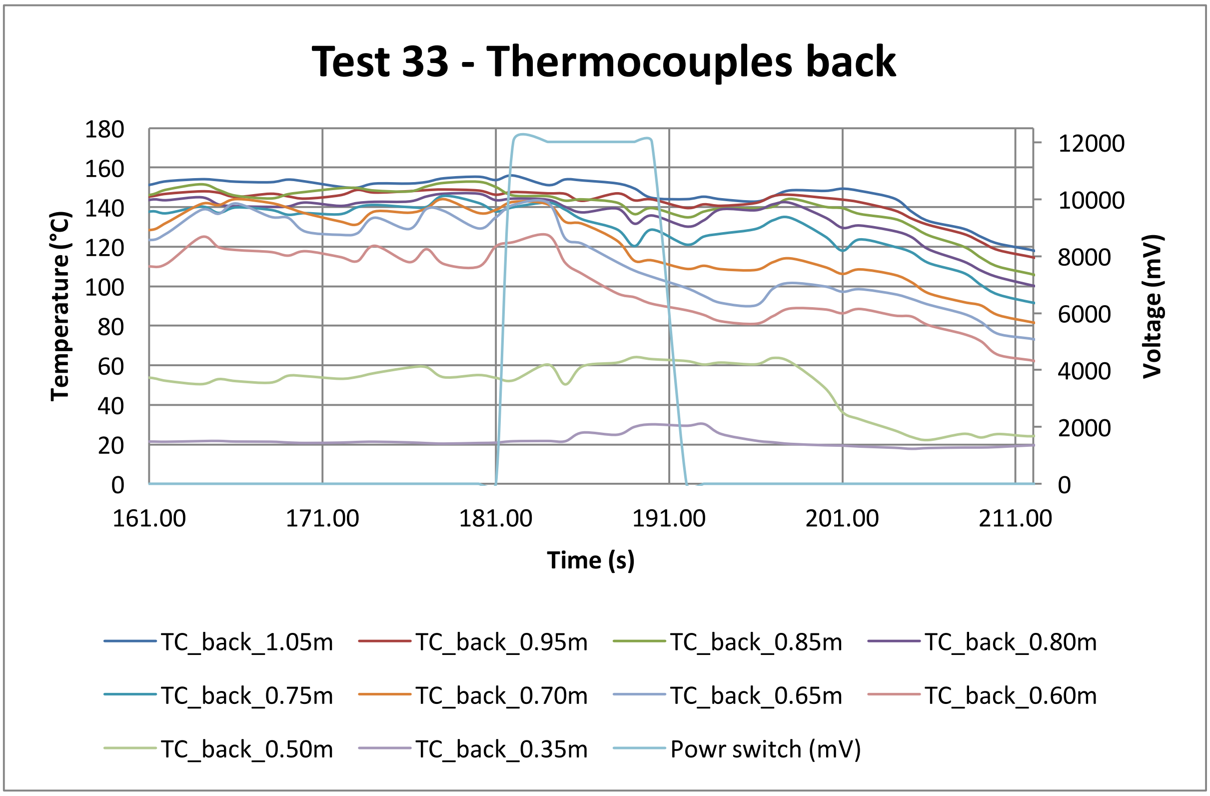


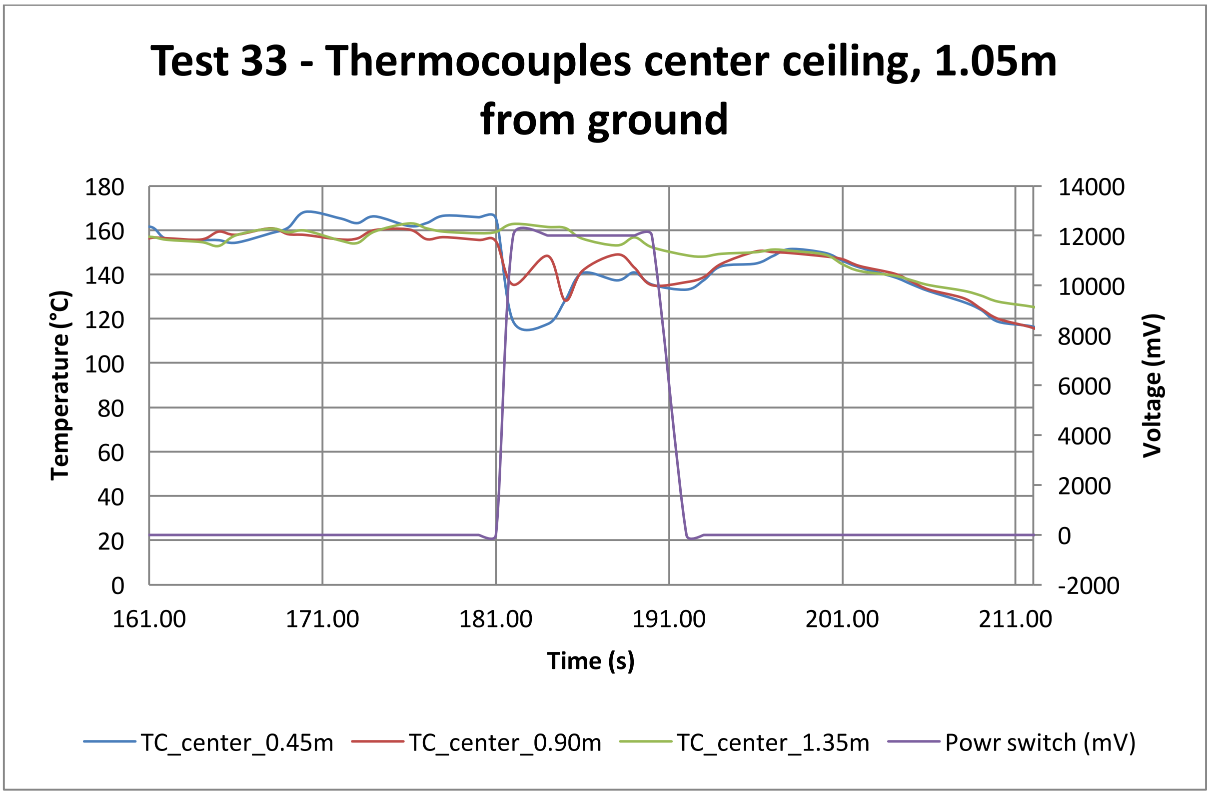
Test 32 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
215.00
220.00
225.00
230.00
235.00
240.00
245.00
250.00
255.00
260.00
265.00
TC_cener_front (degC)
TC_center_mid (degC)
TC_center_back (degC)
Powr switch (mV)

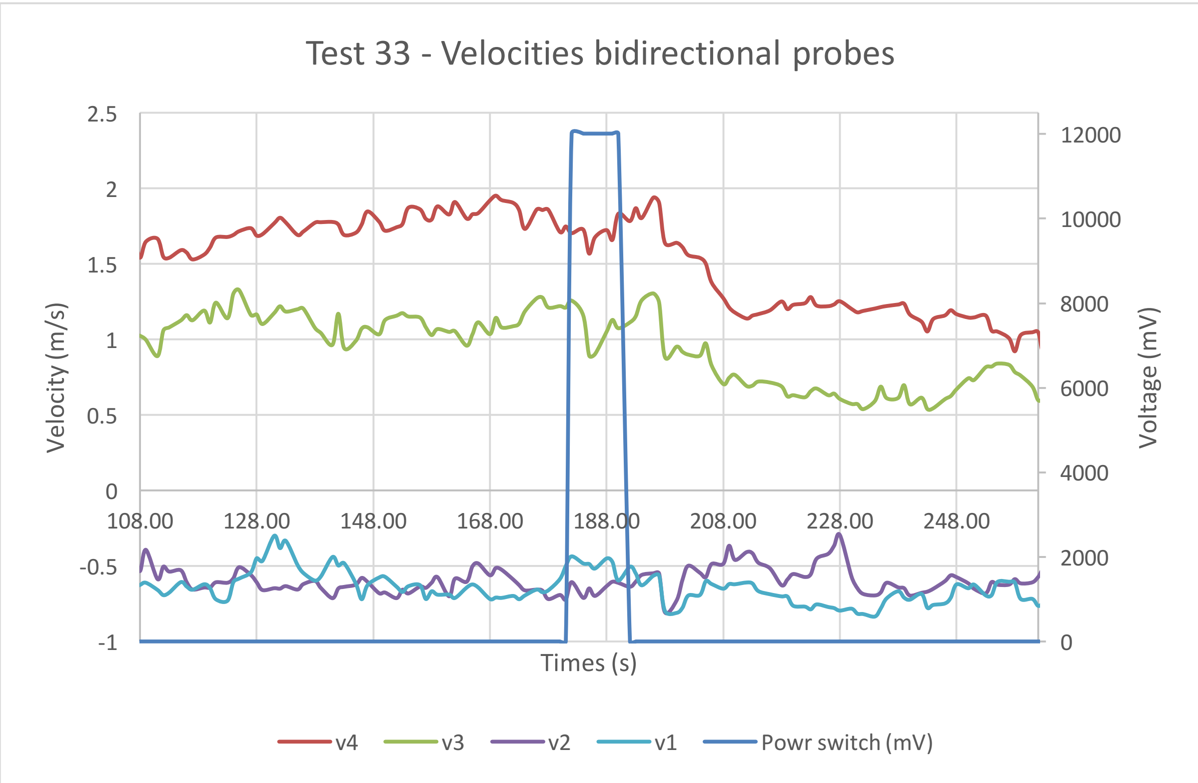


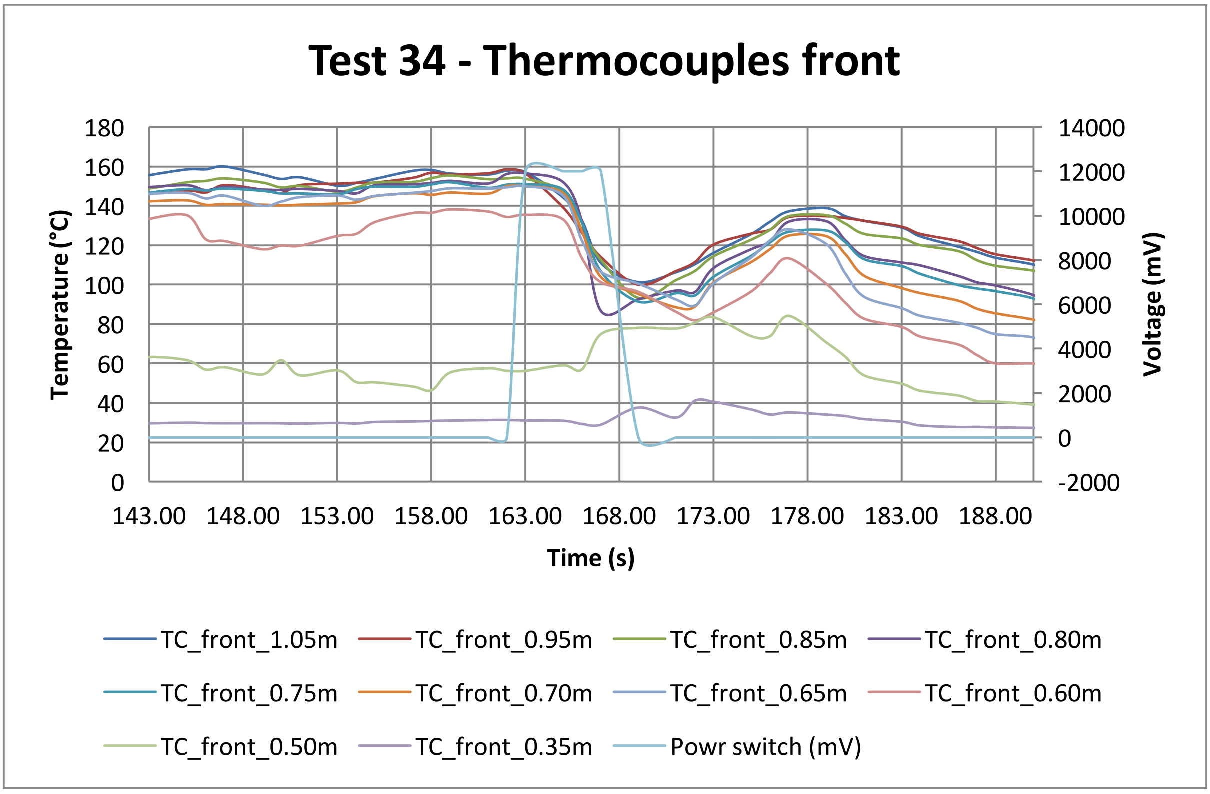
Test 32 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
12000
10000
8000
6000
4000
2000
0
165.00
185.00
205.00
225.00
245.00
265.00
285.00
305.00
v4
v3
v2
v1
Powr switch (mV)


Test 33 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
161.00
171.00
181.00
191.00
201.00
211.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

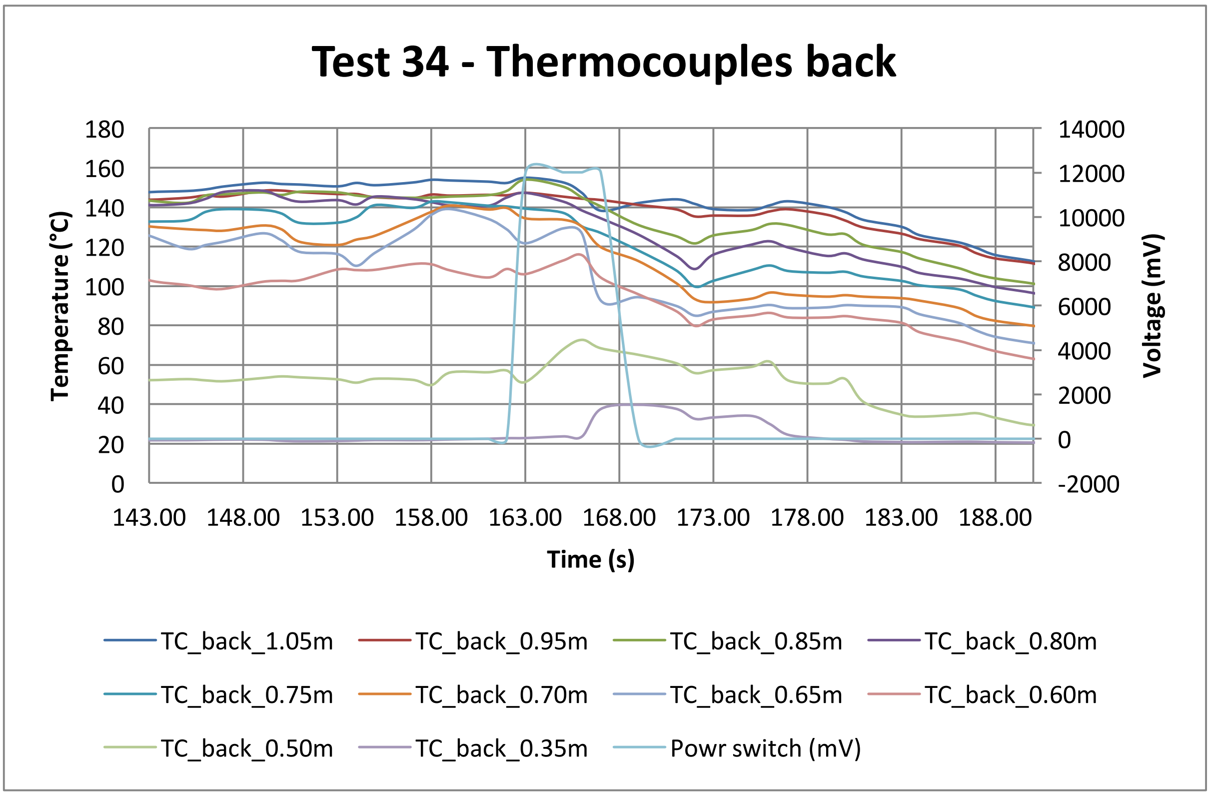

Test 33 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
161.00
171.00
181.00
191.00
201.00
211.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 33 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
Voltage (mV)
161.00
171.00
181.00
191.00
201.00
211.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

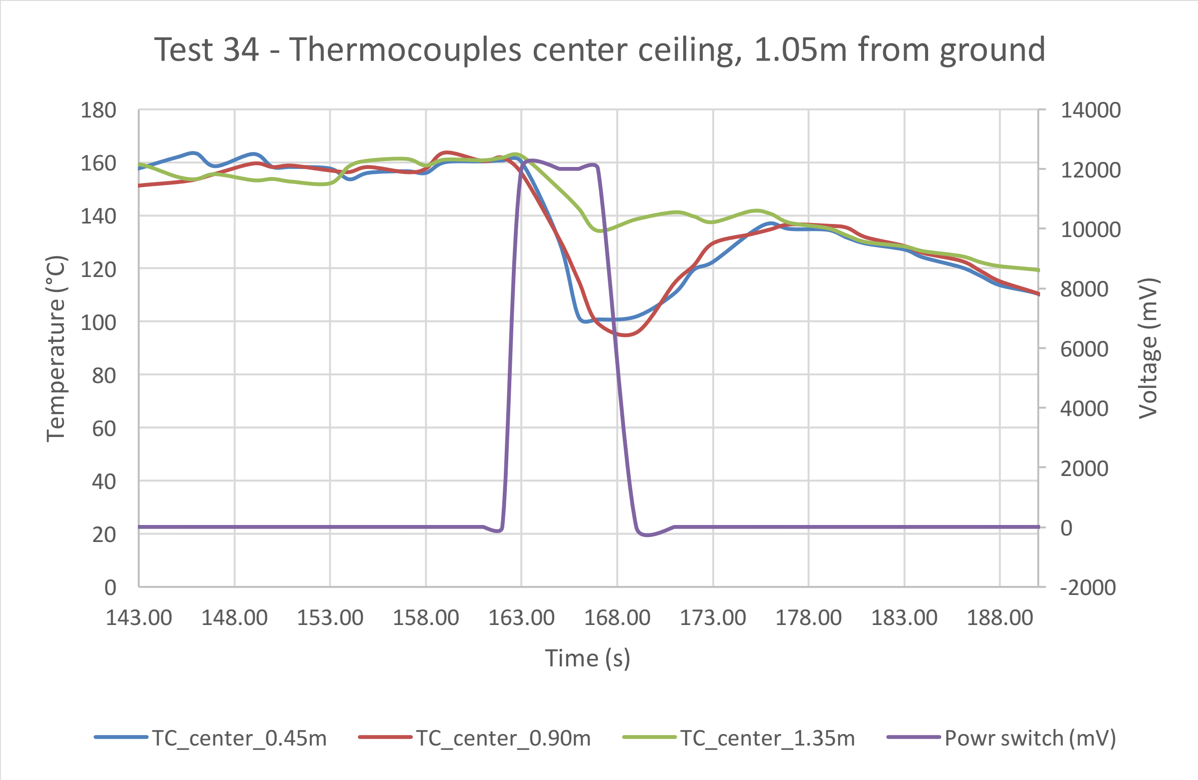

Test 33 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
108.00
128.00
148.00
168.00
188.00
208.00
228.00
248.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

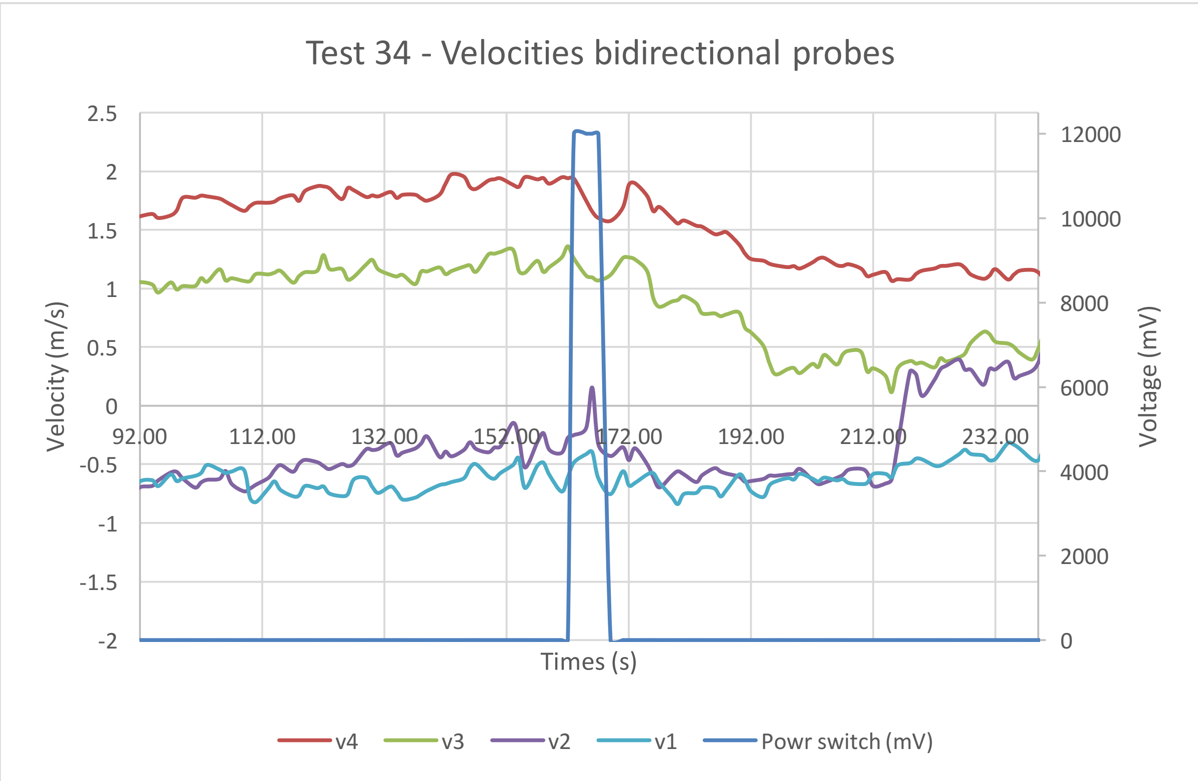


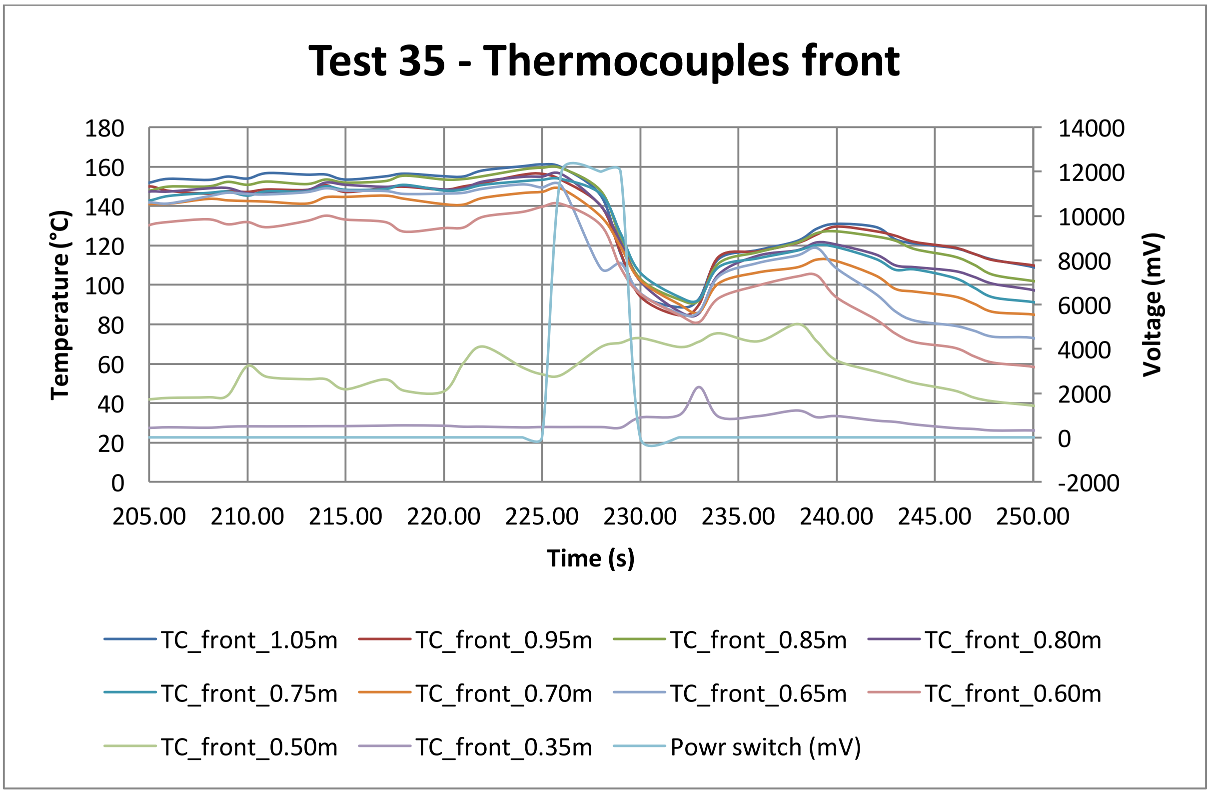
Test 34 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

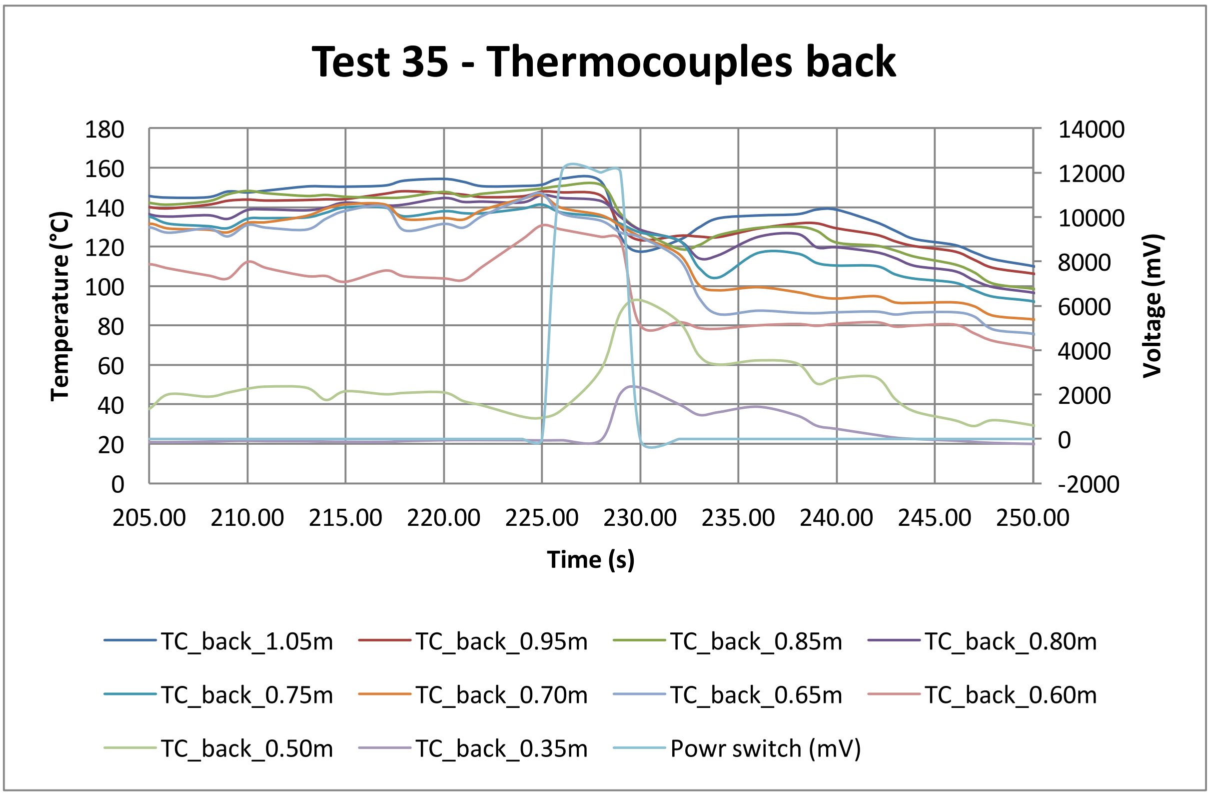


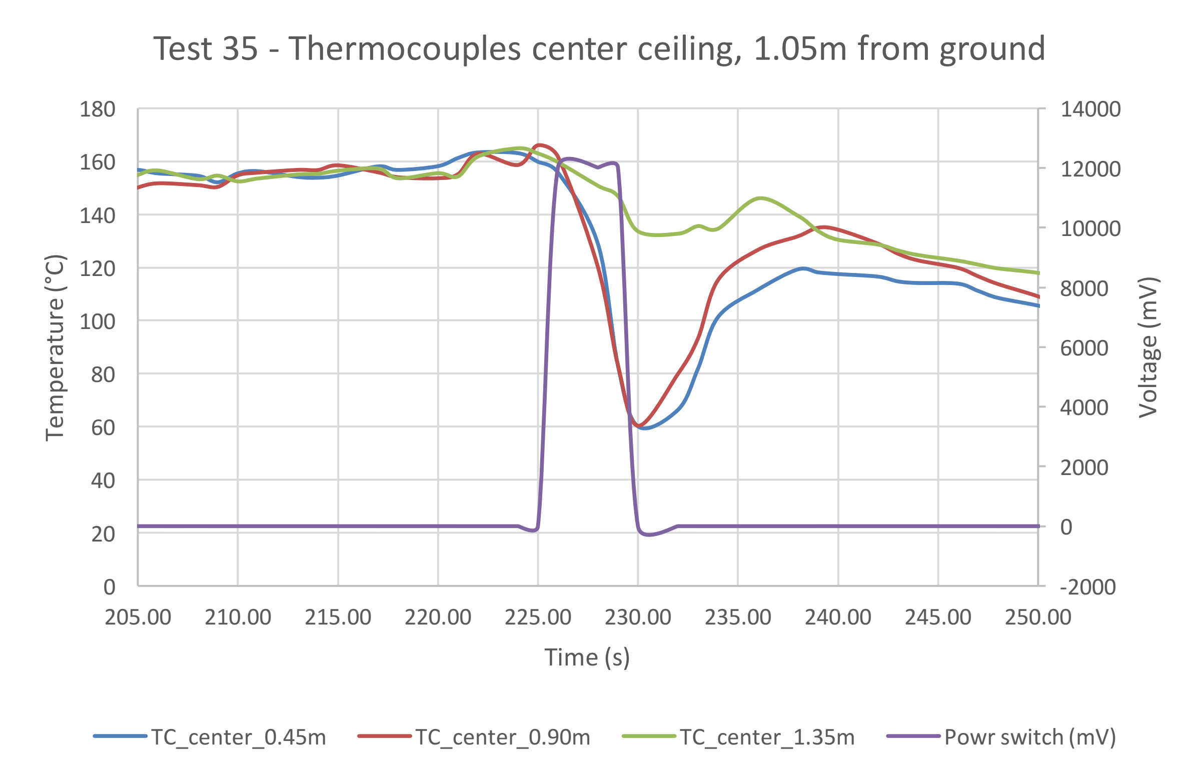
Test 34 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00 148.00 153.00 158.00 163.00 168.00 173.00 178.00 183.00 188.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

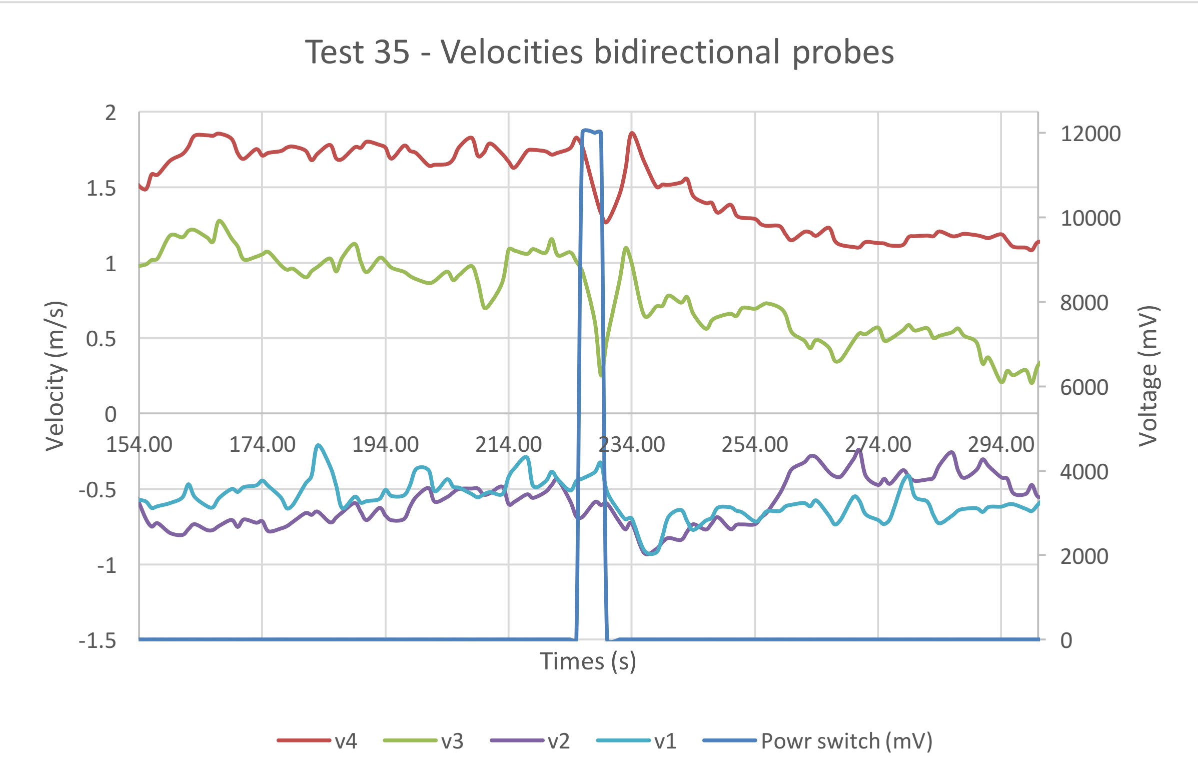

Test 34 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
143.00
148.00
153.00
158.00
163.00
168.00
173.00
178.00
183.00
188.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

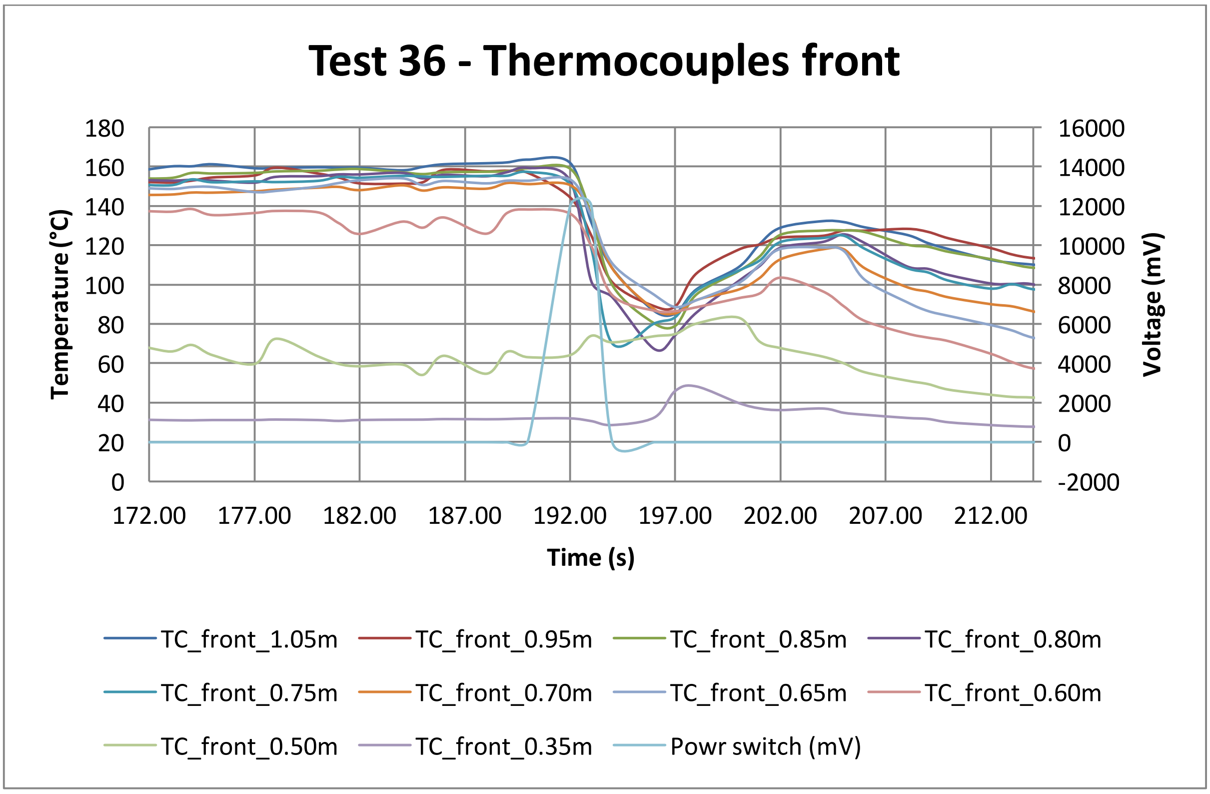

Test 34 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
12000
10000
8000
6000
4000
2000
0
92.00
112.00
132.00
152.00
172.00
192.00
212.00
232.00
v4
v3
v2
v1
Powr switch (mV)

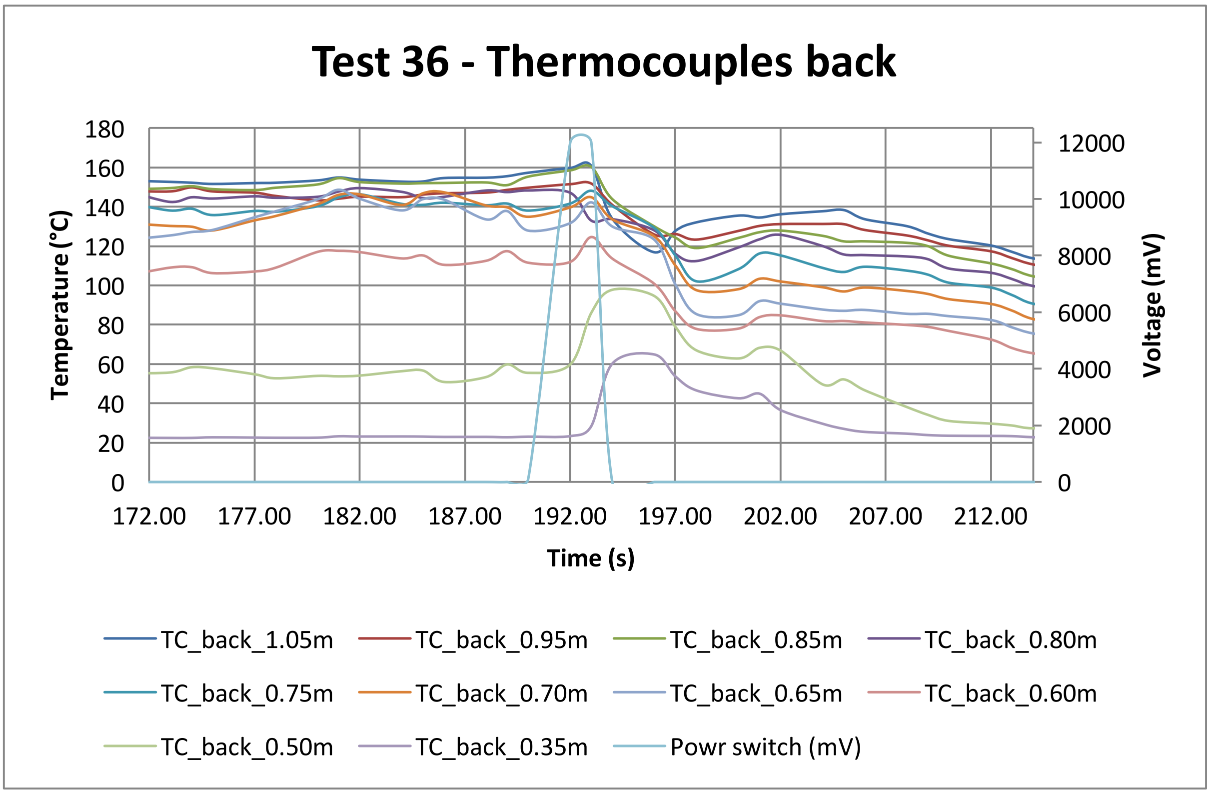

Test 35 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
205.00
210.00
215.00
220.00
225.00
230.00
235.00
240.00
245.00
250.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

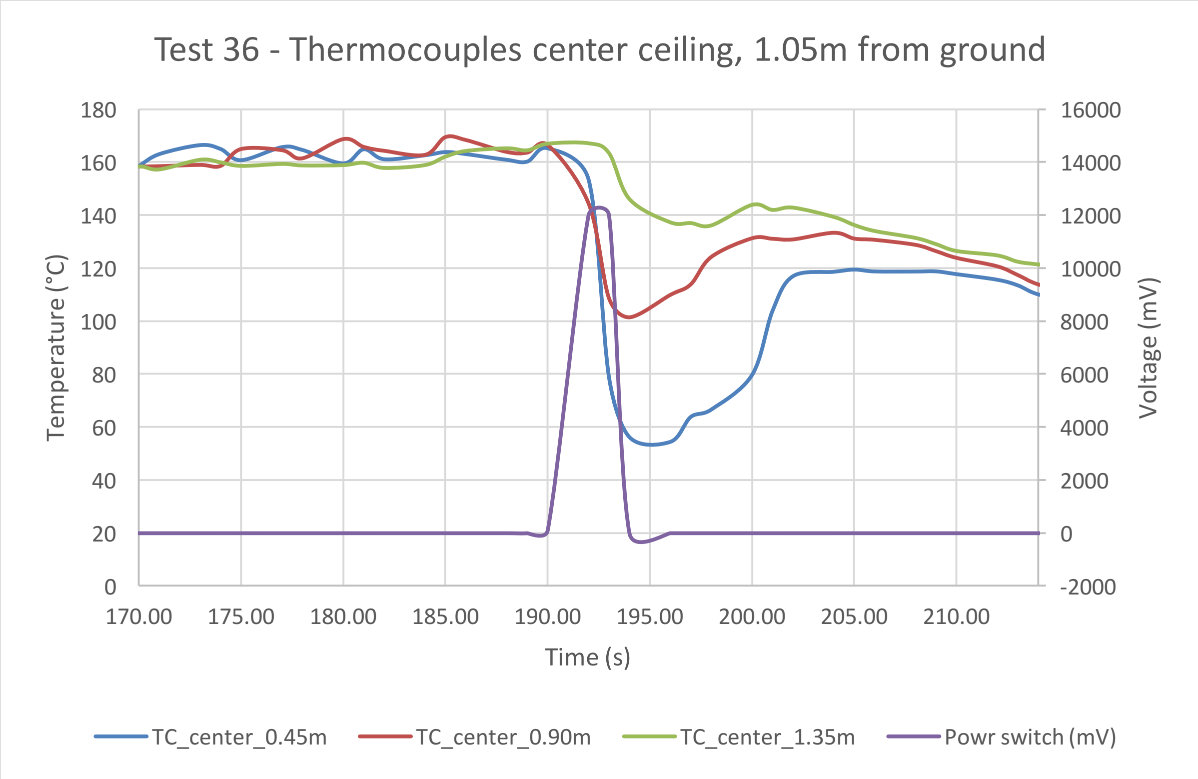

Test 35 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
205.00
210.00
215.00
220.00
225.00
230.00
235.00
240.00
245.00
250.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 35 - Thermocouples center ceiling, 1.05m from ground
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
205.00
210.00
215.00
220.00
225.00
230.00
235.00
240.00
245.00
250.00
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

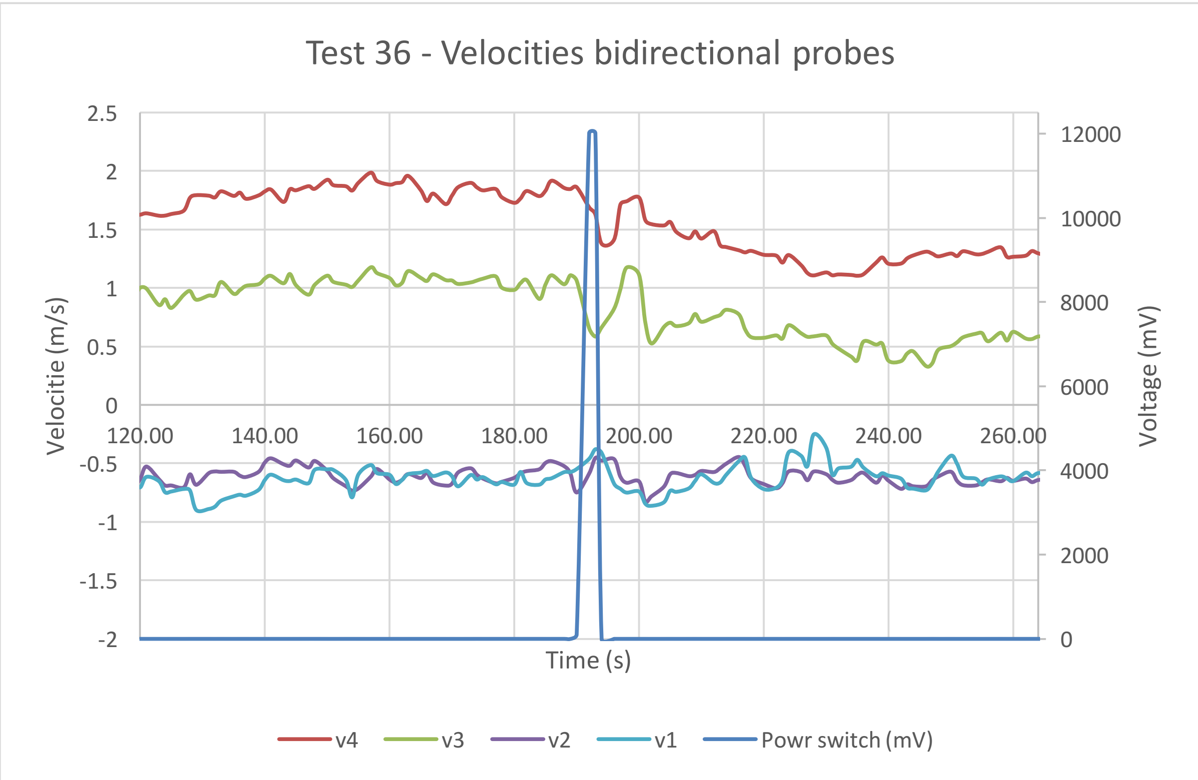

Test 35 - Velocities bidirectional probes
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
154.00
174.00
194.00
214.00
234.00
254.00
274.00
294.00
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 36 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
172.00
177.00
182.00
187.00
192.00
197.00
202.00
207.00
212.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

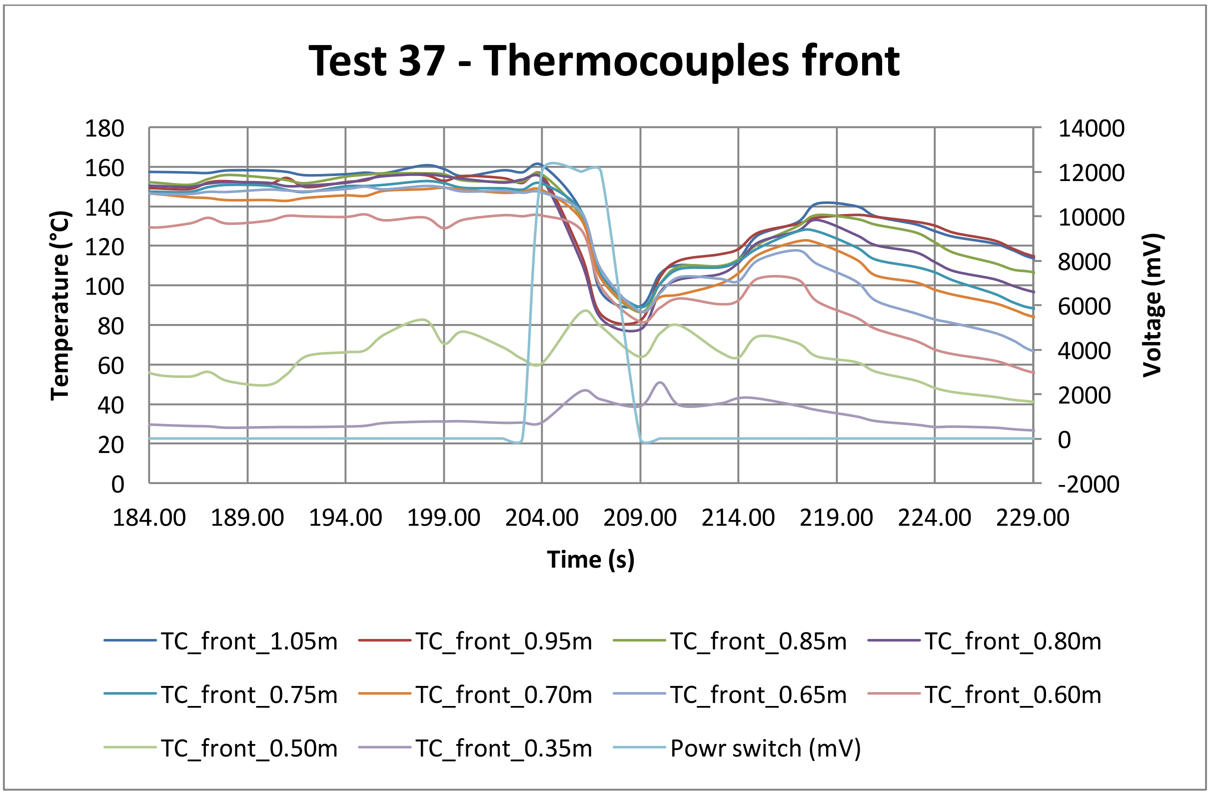

Test 36 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
172.00
177.00
182.00
187.00
192.00
197.00
202.00
207.00
212.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

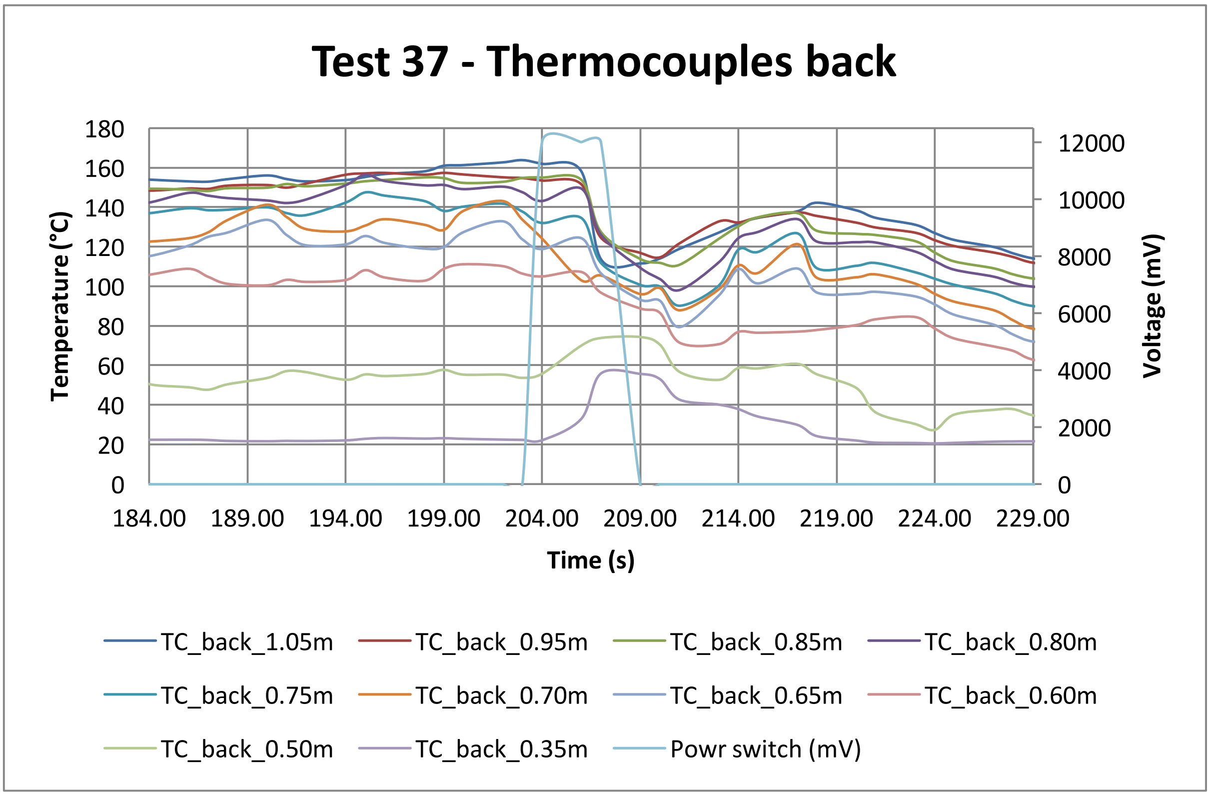


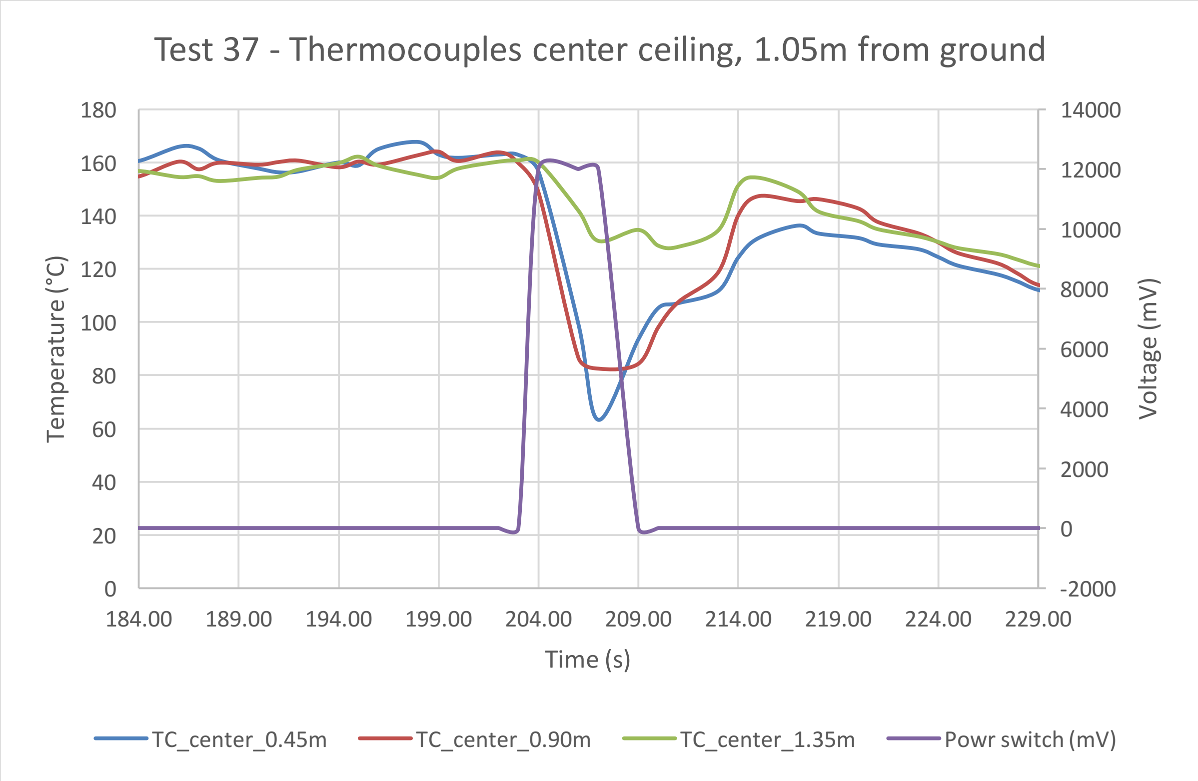
Test 36 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
170.00
175.00
180.00
185.00
190.00
195.00
200.00
205.00
210.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

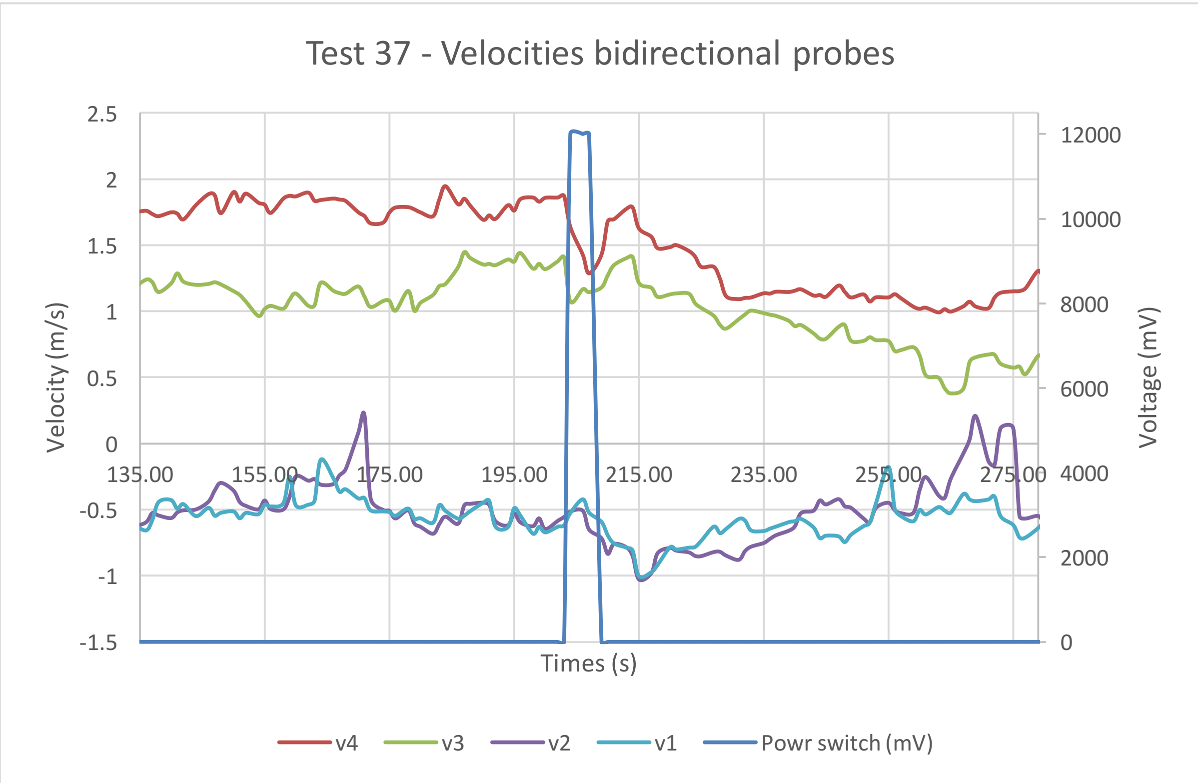


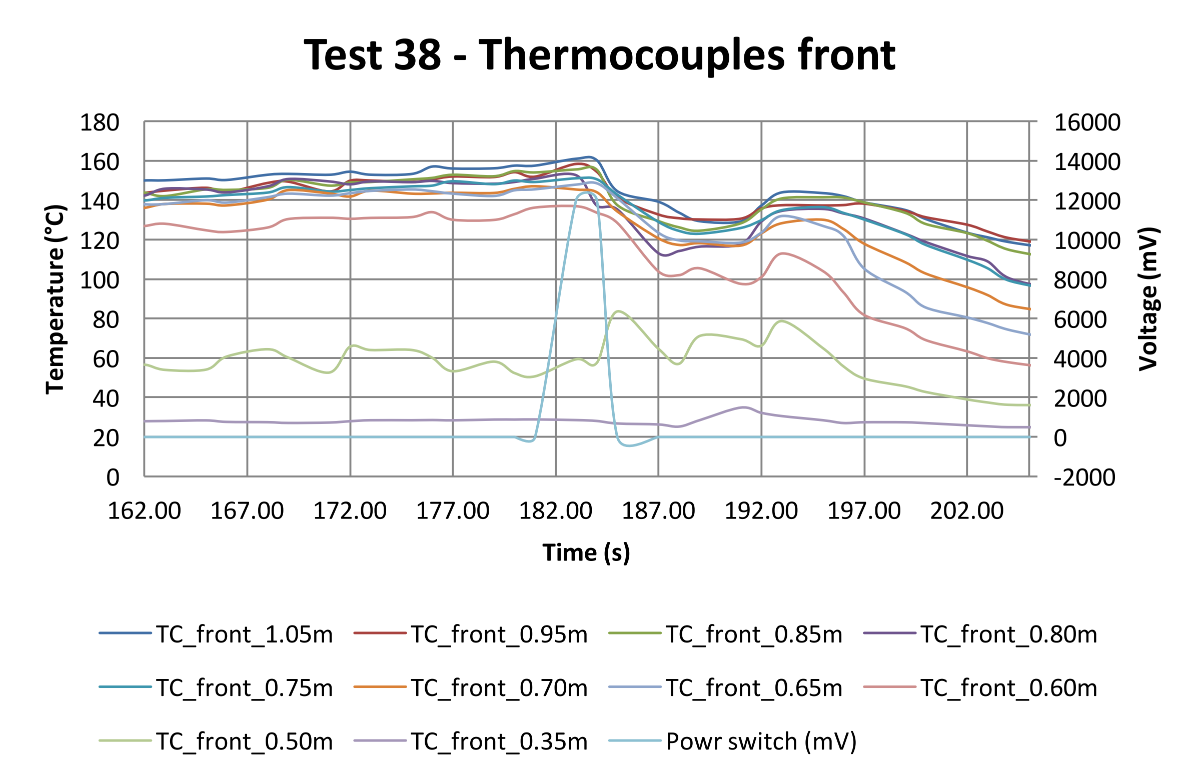
Test 36 - Velocities bidirectional probes
Velocitie (m/s)
Voltage (mV)
Time (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
12000
10000
8000
6000
4000
2000
0
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
v4
v3
v2
v1
Powr switch (mV)

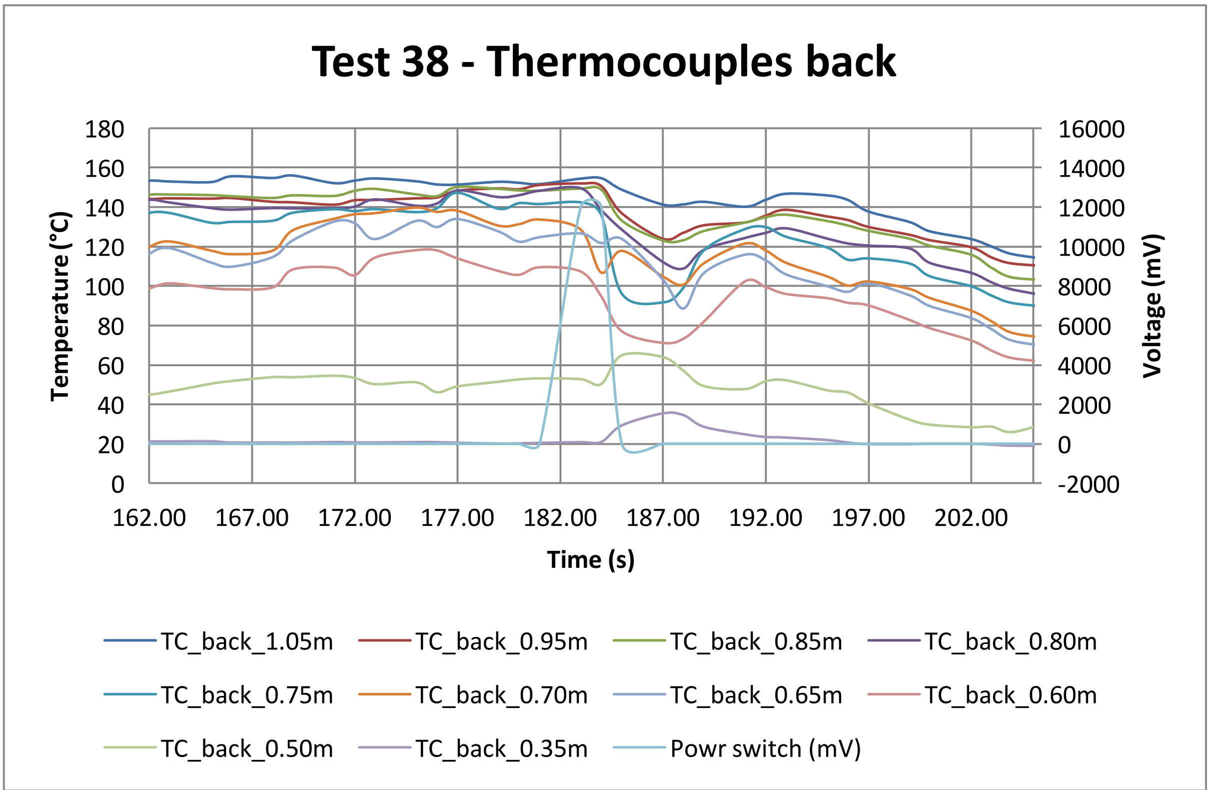

Test 37 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
184.00
189.00
194.00
199.00
204.00
209.00
214.00
219.00
224.00
229.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

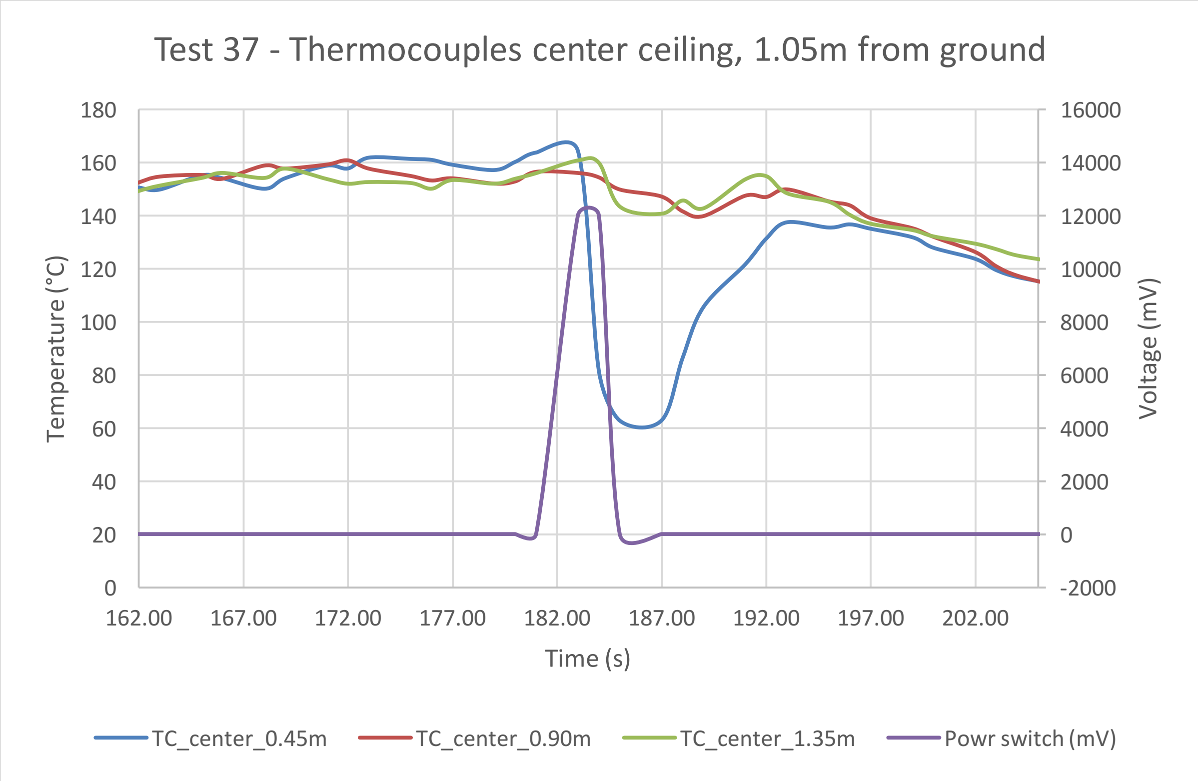

Test 37 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
184.00
189.00
194.00
199.00
204.00
209.00
214.00
219.00
224.00
229.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

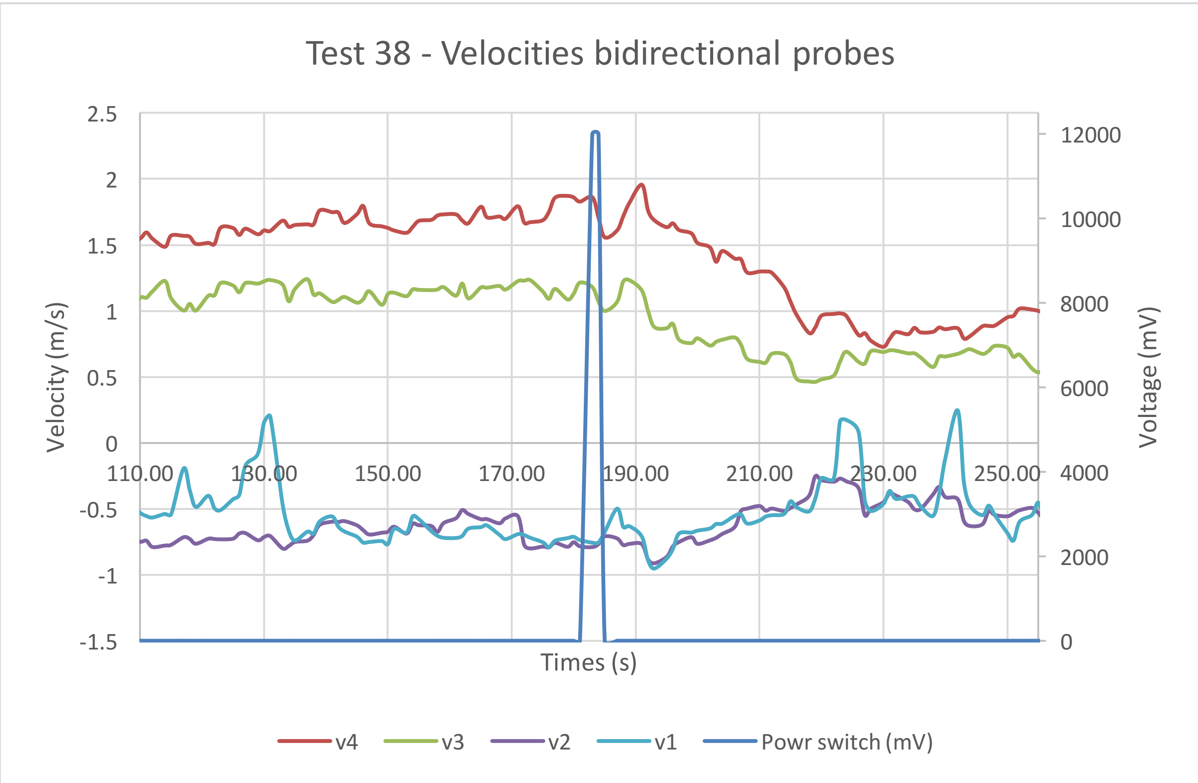

Test 37 - Thermocouples center ceiling, 1.05m from ground
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
184.00
189.00
194.00
199.00
204.00
209.00
214.00
219.00
224.00
229.00
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

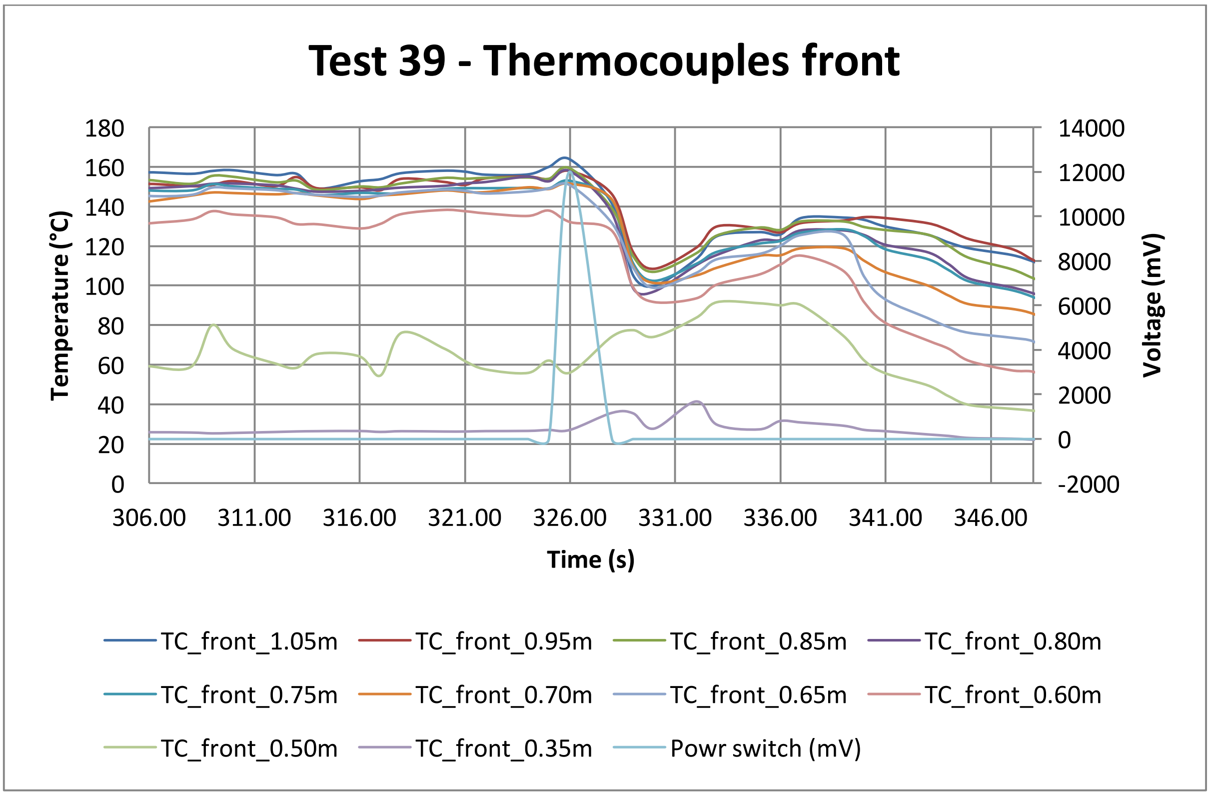

Test 37 - Velocities bidirectional probes
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
135.00
155.00
175.00
195.00
215.00
235.00
255.00
275.00
Velocity (m/s)
Voltage (mV)
Times (s)
v4
v3
v2
v1
Powr switch (mV)


Test 38 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

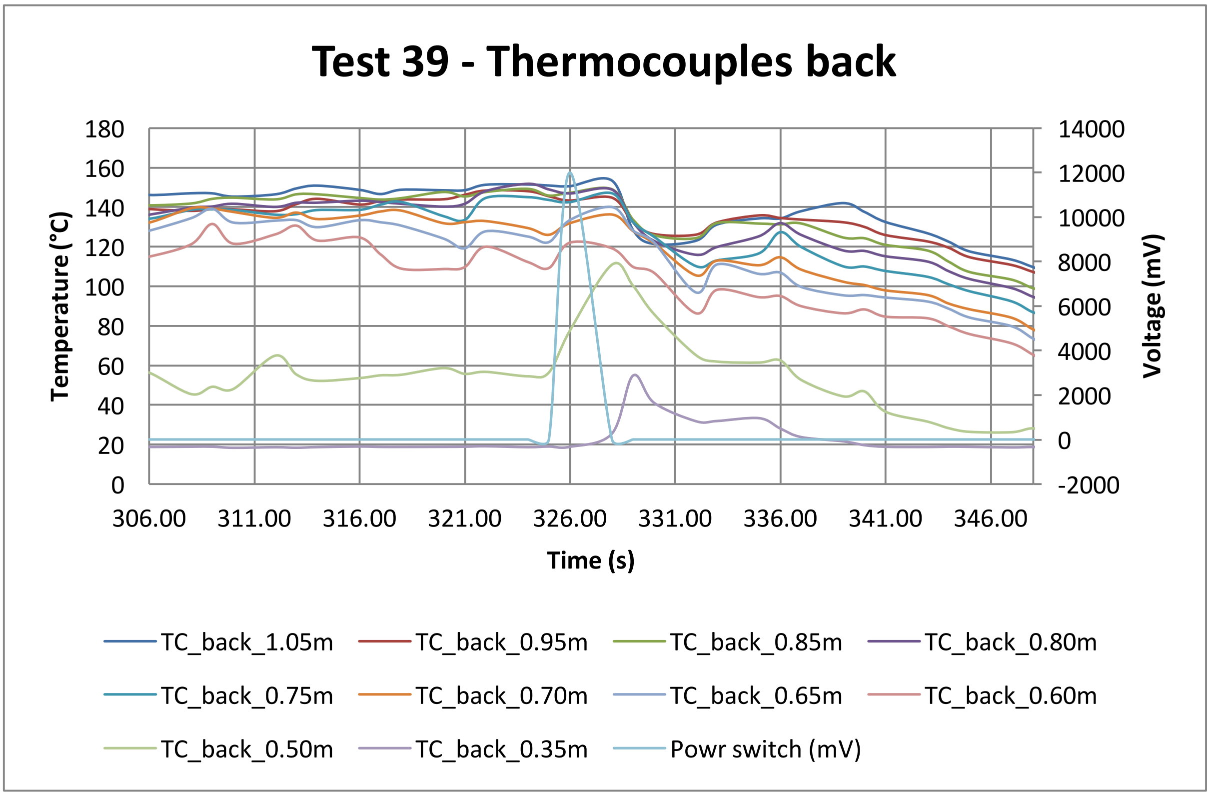

Test 38 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 37 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
202.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

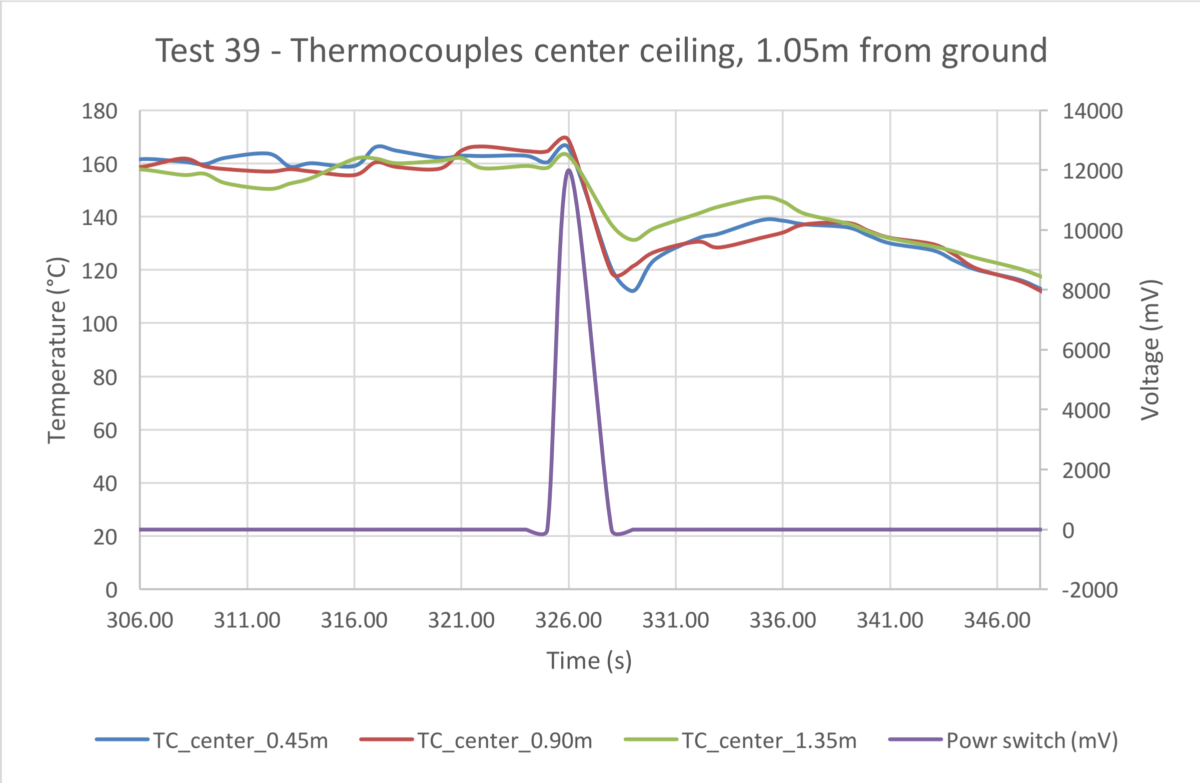

Test 38 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
110.00
130.00
150.00
170.00
190.00
210.00
230.00
250.00
v4
v3
v2
v1
Powr switch (mV)

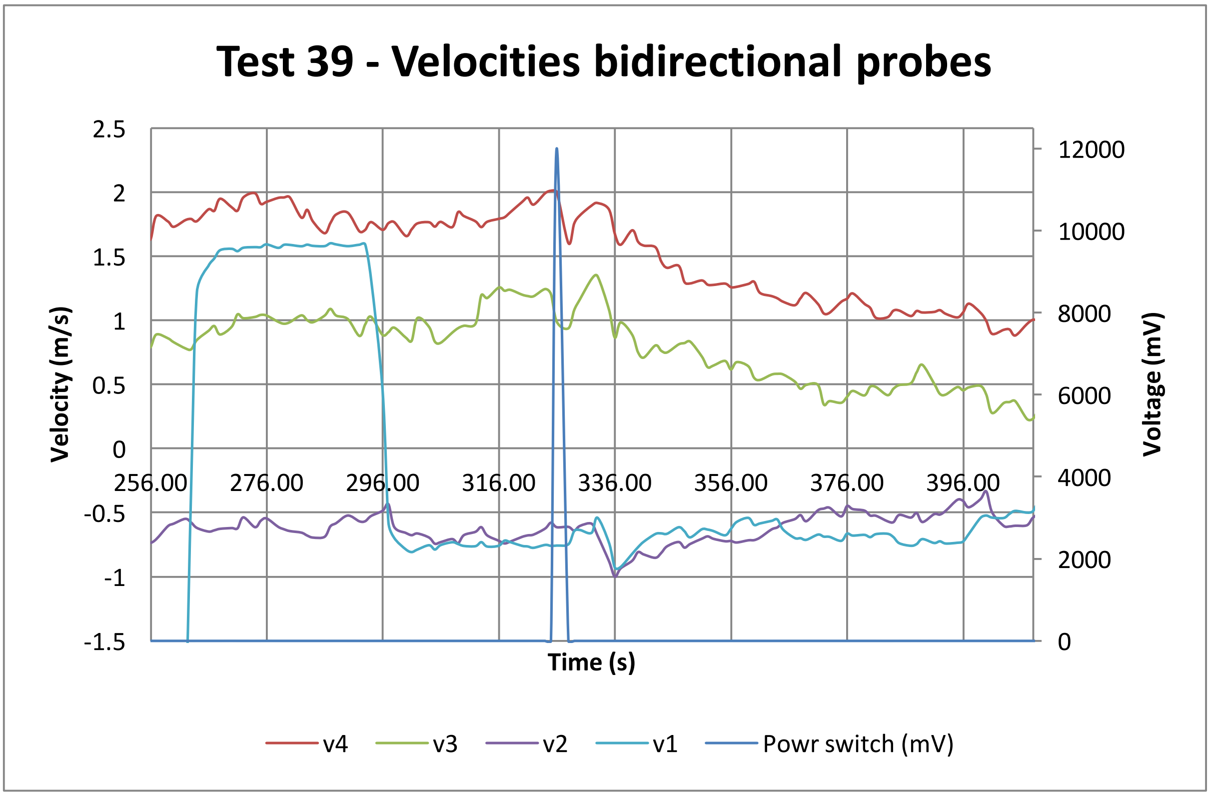


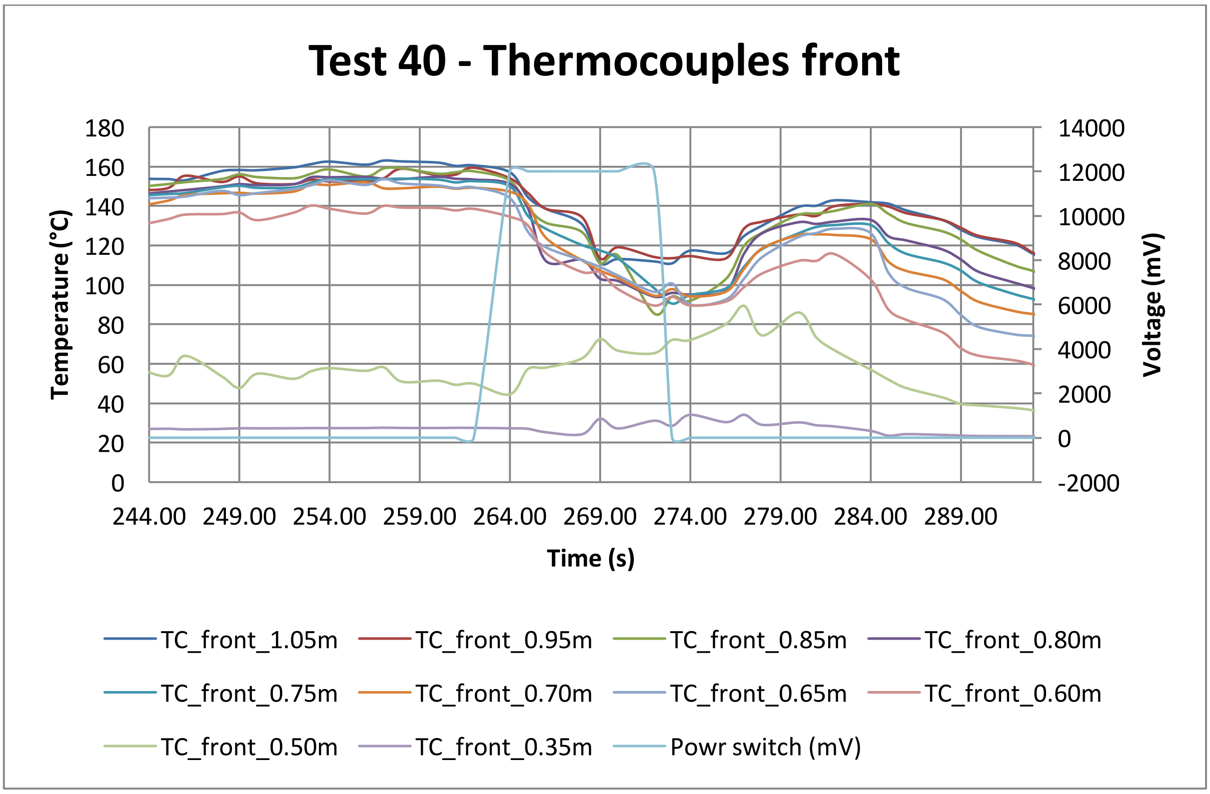
Test 39 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
-2000
0
2000
4000
6000
8000
10000
12000
14000
306.00
311.00
316.00
321.00
326.00
331.00
336.00
341.00
346.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

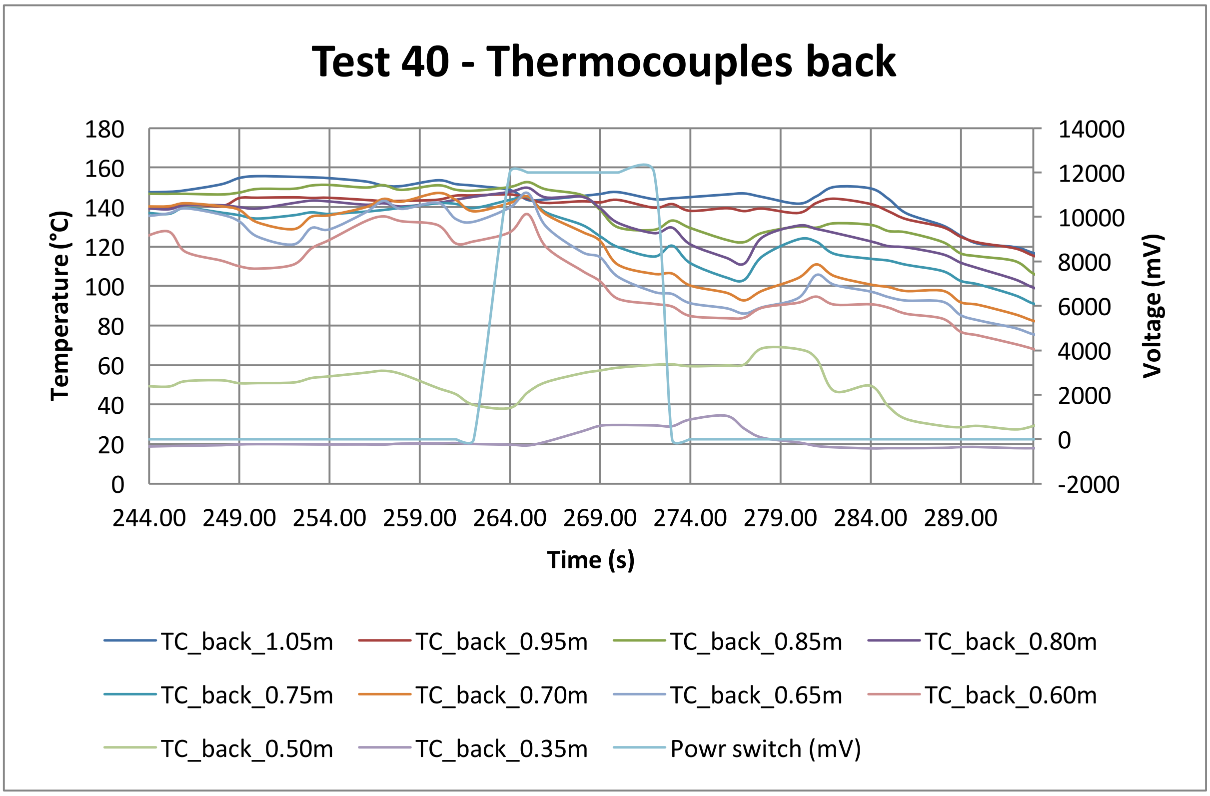


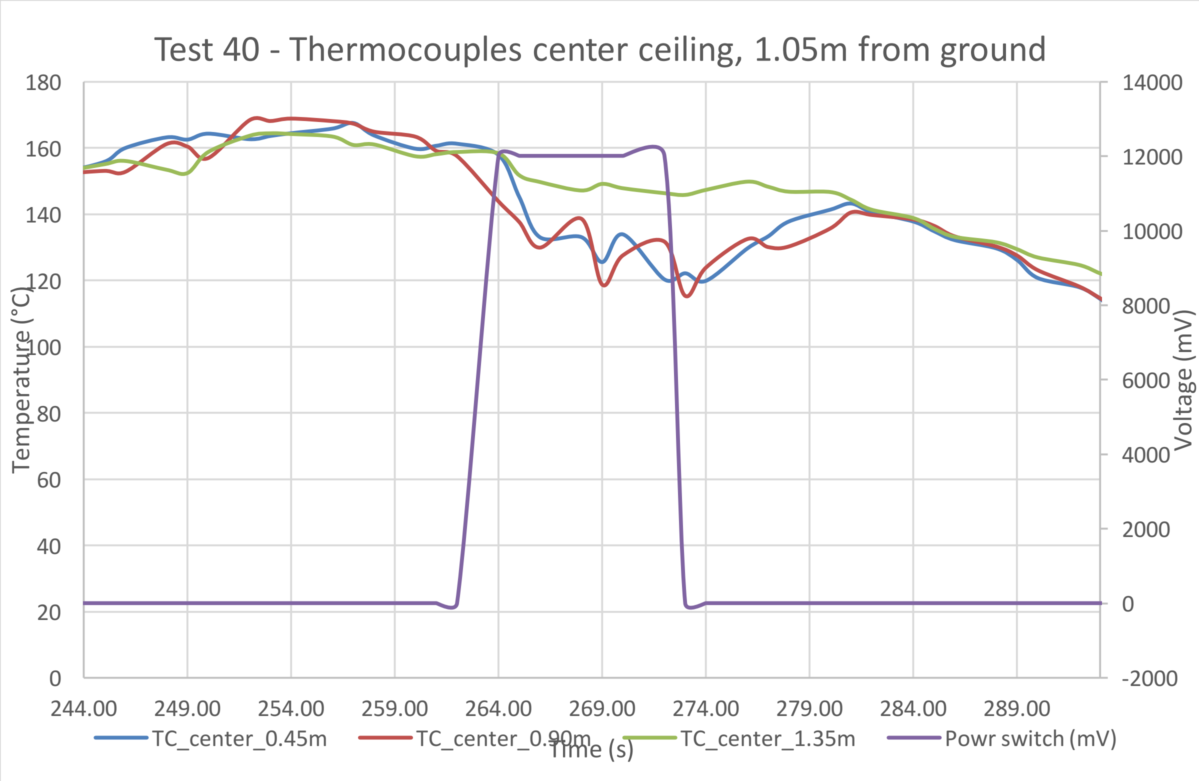
Test 39 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
-2000
0
2000
4000
6000
8000
10000
12000
14000
306.00
311.00
316.00
321.00
326.00
331.00
336.00
341.00
346.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

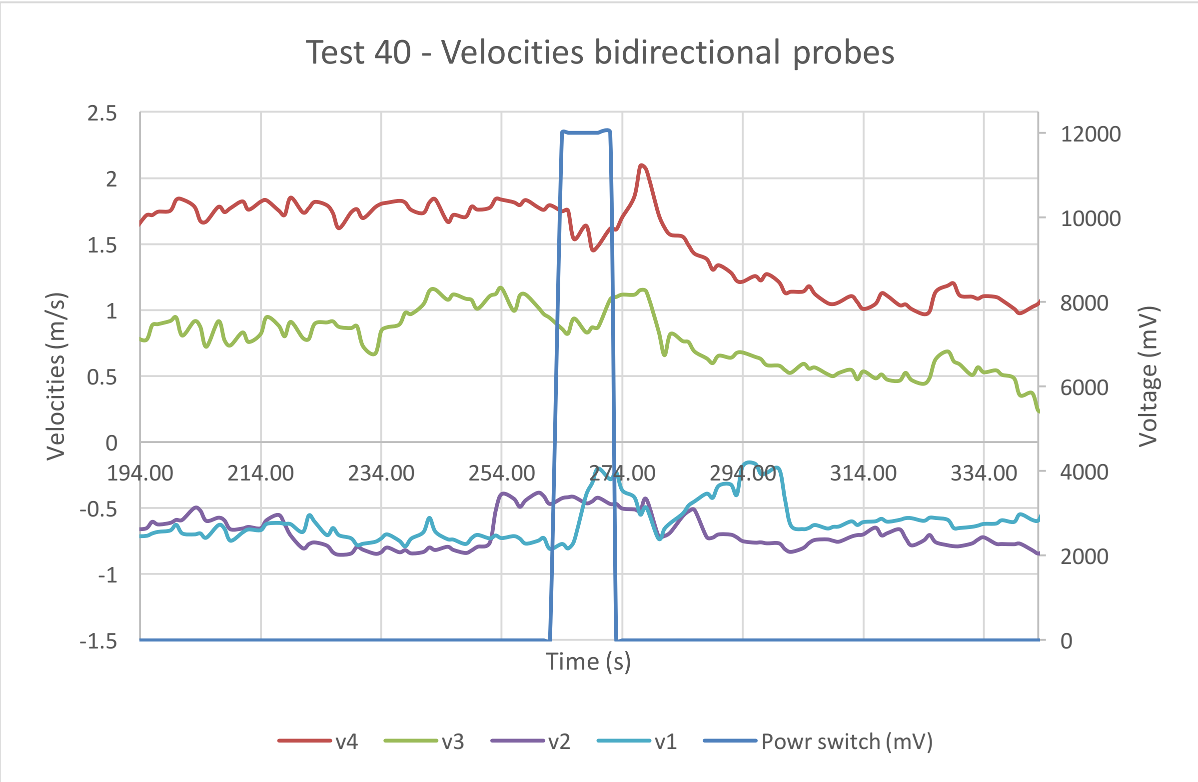

Test 39 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
306.00
311.00
316.00
321.00
326.00
331.00
336.00
341.00
346.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

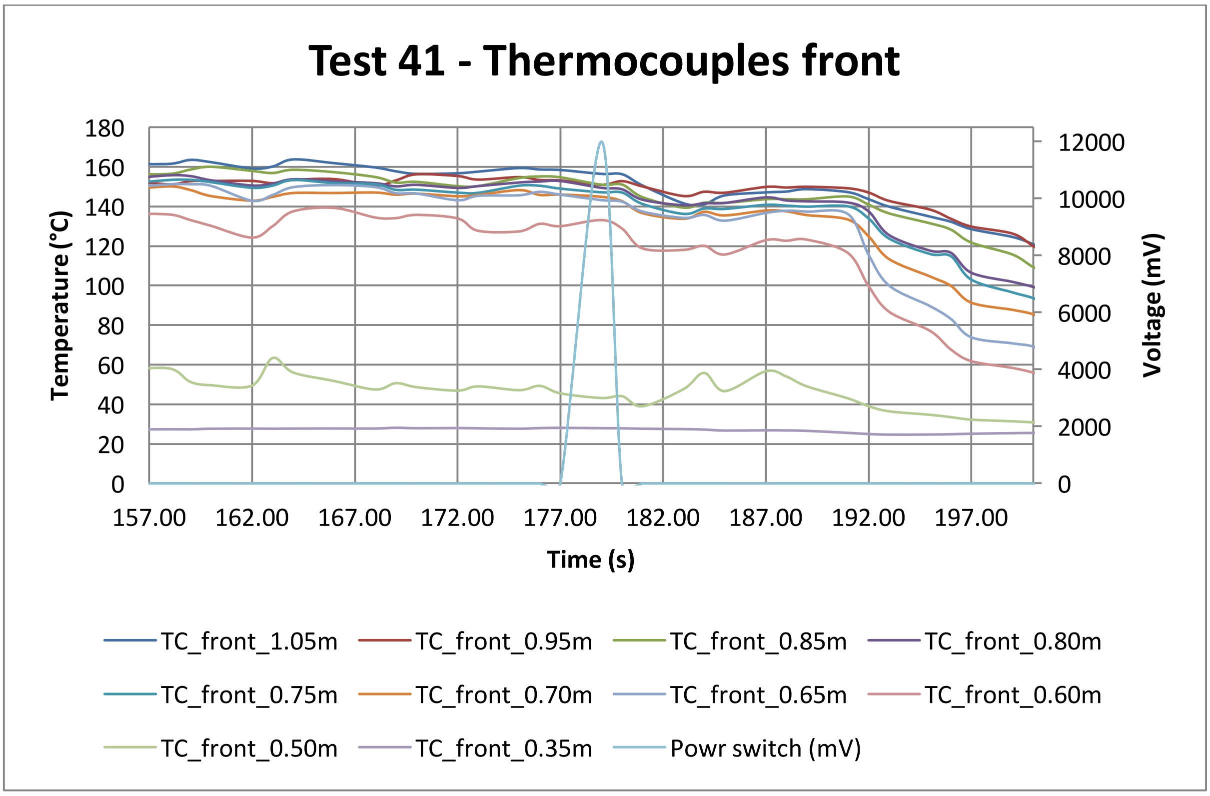

Test 39 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Time (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
256.00
276.00
296.00
316.00
336.00
356.00
376.00
396.00
v4
v3
v2
v1
Powr switch (mV)

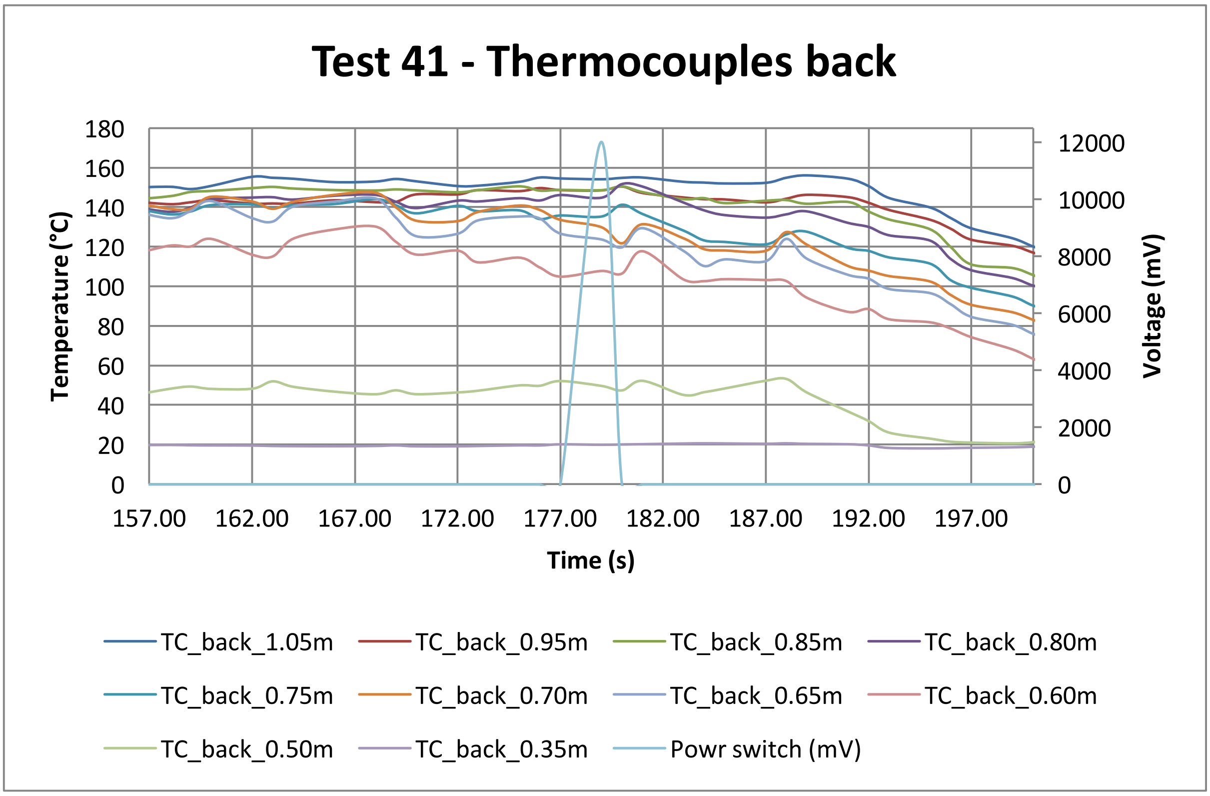

Test 40 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
244.00 249.00 254.00 259.00 264.00 269.00 274.00 279.00 284.00 289.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

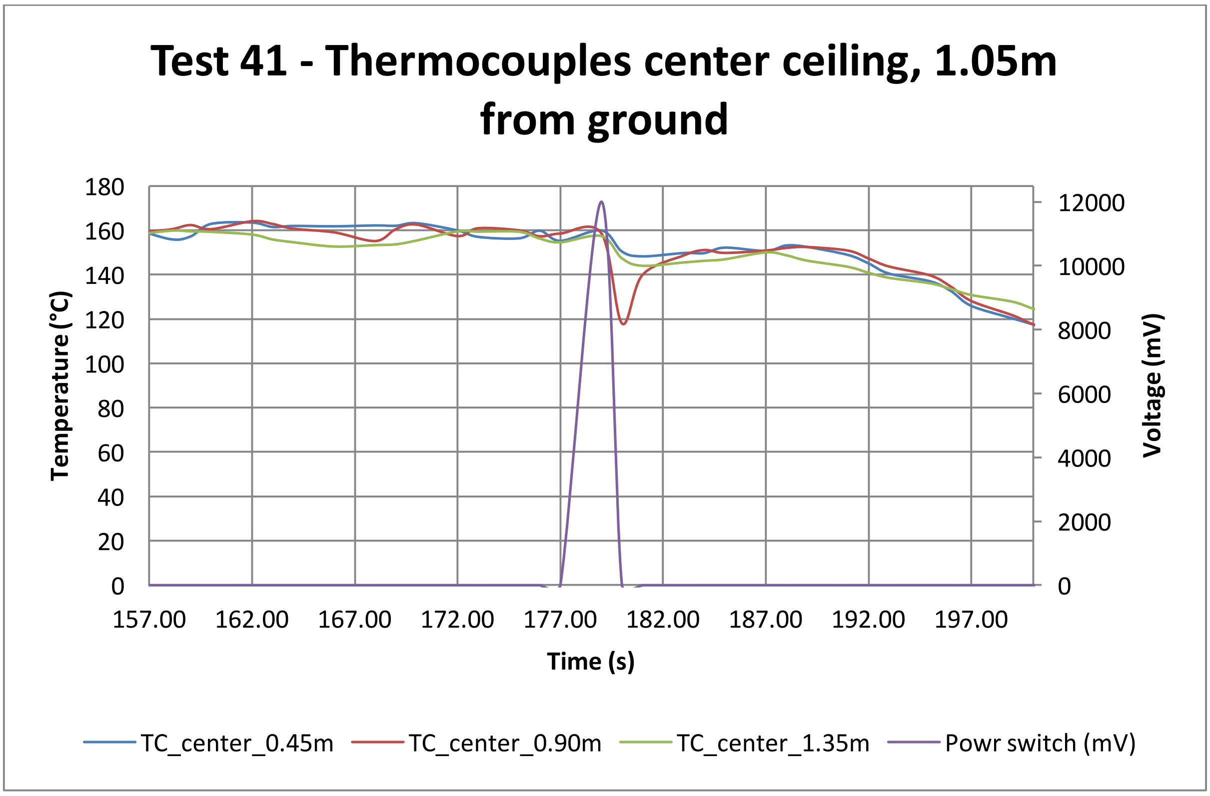

Test 40 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
244.00 249.00 254.00 259.00 264.00 269.00 274.00 279.00 284.00 289.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

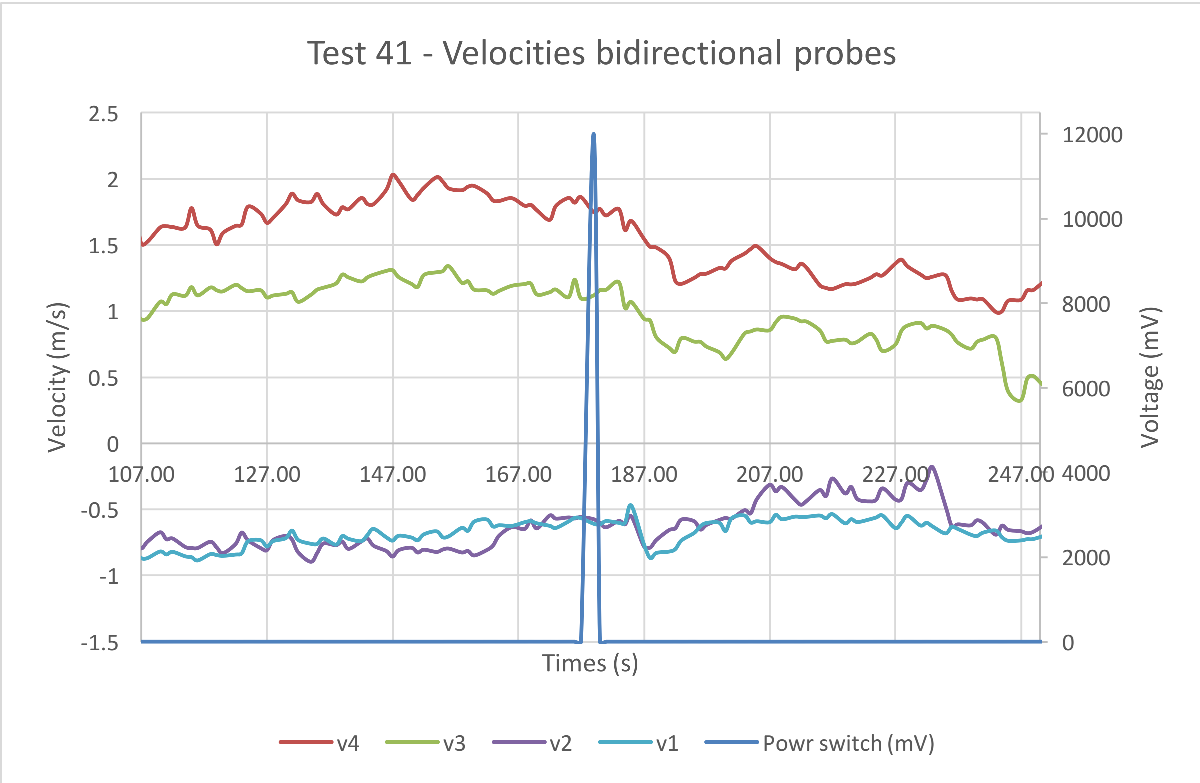

Test 40 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
14000
12000
10000
8000
6000
4000
2000
0
-2000
244.00
249.00
254.00
259.00
264.00
269.00
274.00
279.00
284.00
289.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

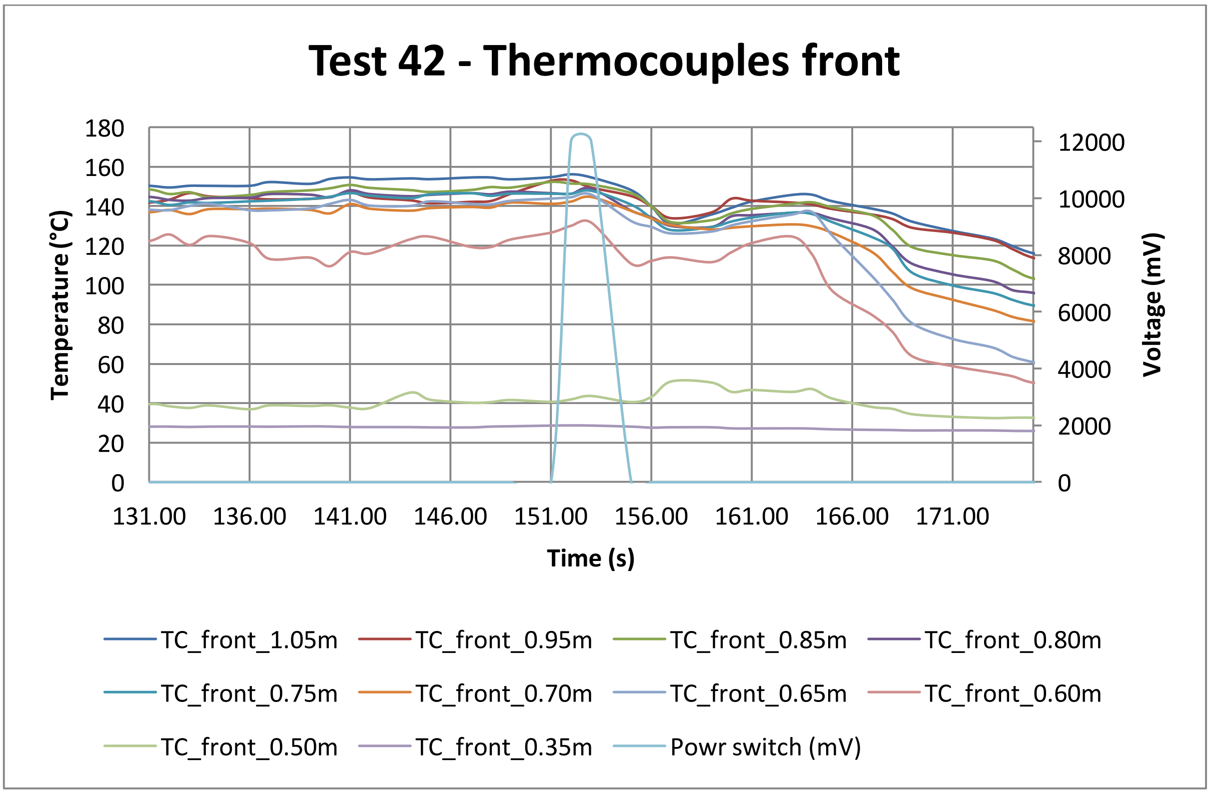

Test 40 - Velocities bidirectional probes
Velocities (m/s)
Voltage (mV)
Time (s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
194.00
214.00
234.00
254.00
274.00
294.00
314.00
334.00
v4
v3
v2
v1
Powr switch (mV)

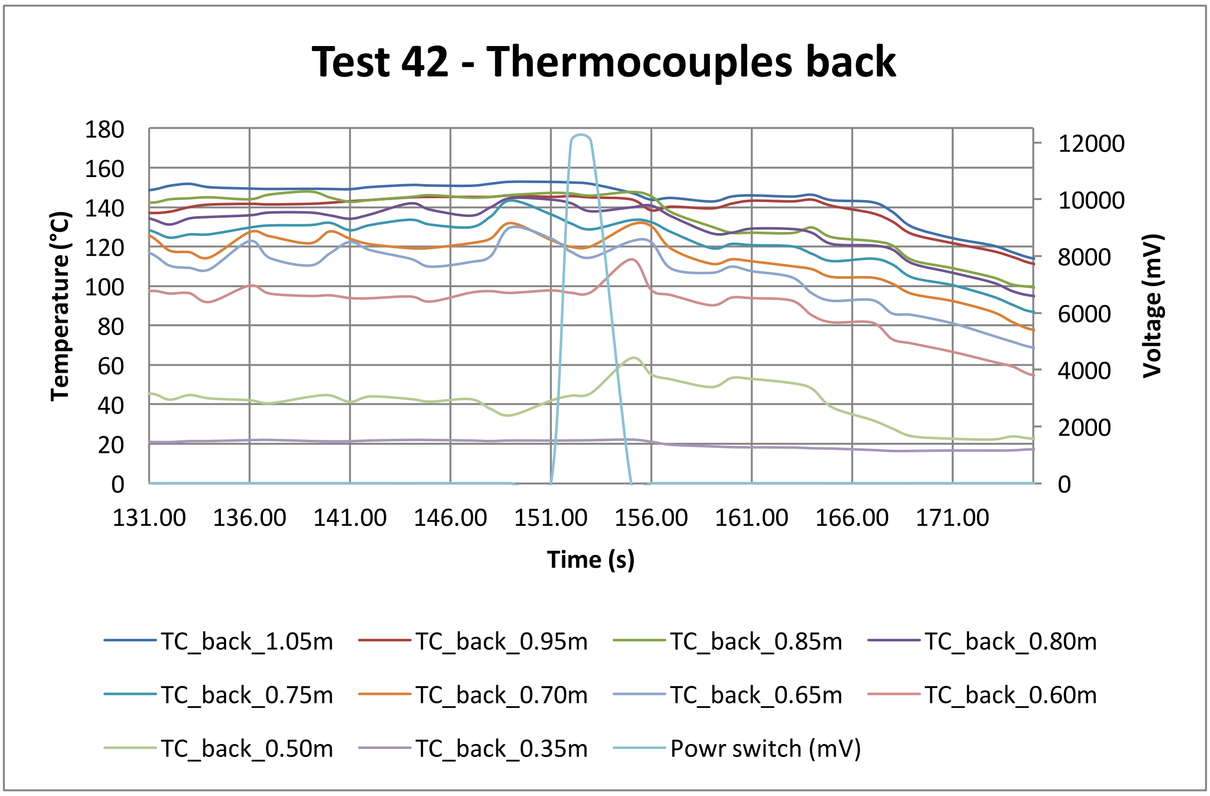

Test 41 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
157.00
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

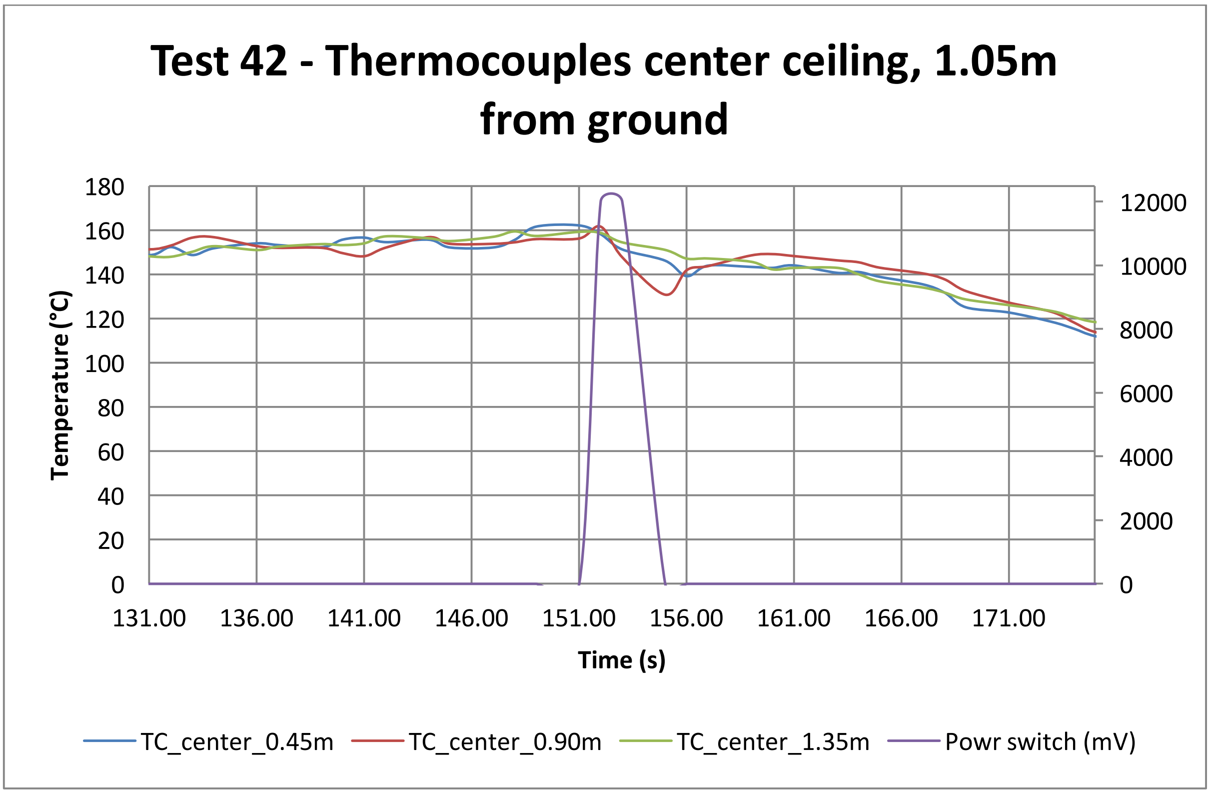

Test 41 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
12000
10000
8000
6000
4000
2000
0
157.00
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

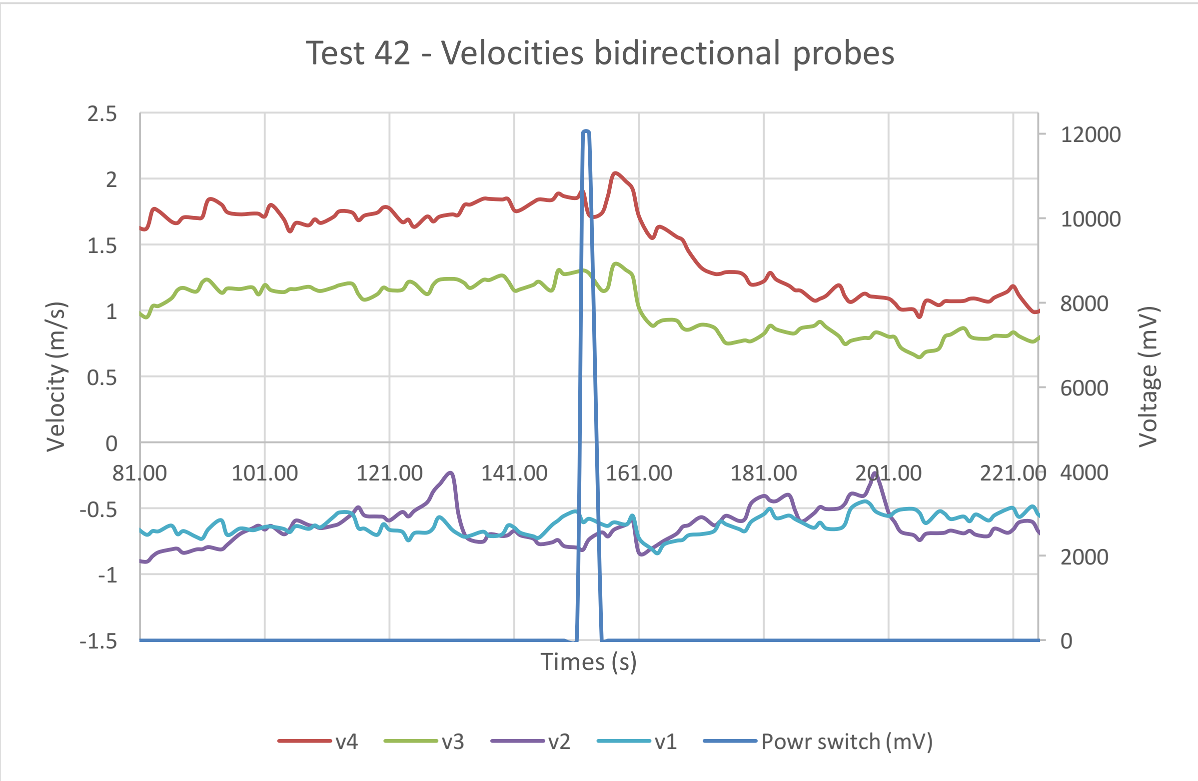

Test 41 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
157.00
162.00
167.00
172.00
177.00
182.00
187.00
192.00
197.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

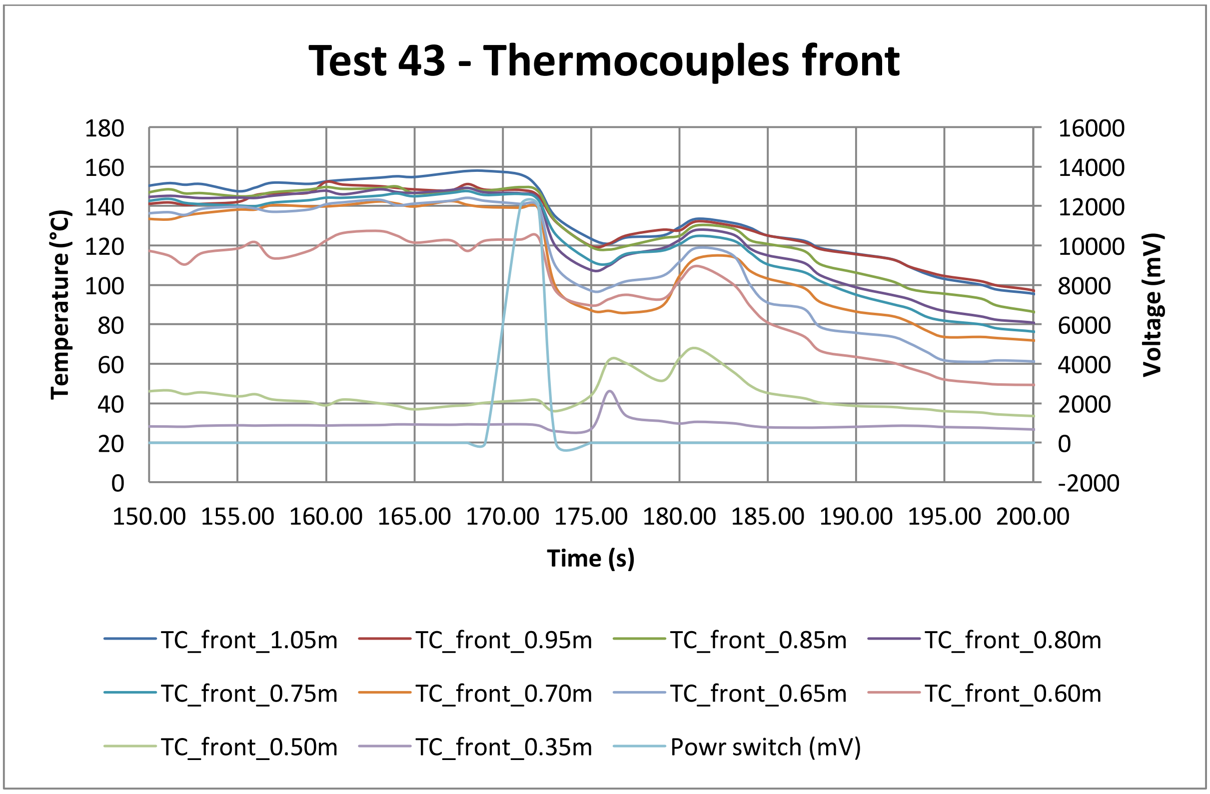

Test 41 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
107.00
127.00
147.00
167.00
187.00
207.00
227.00
247.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

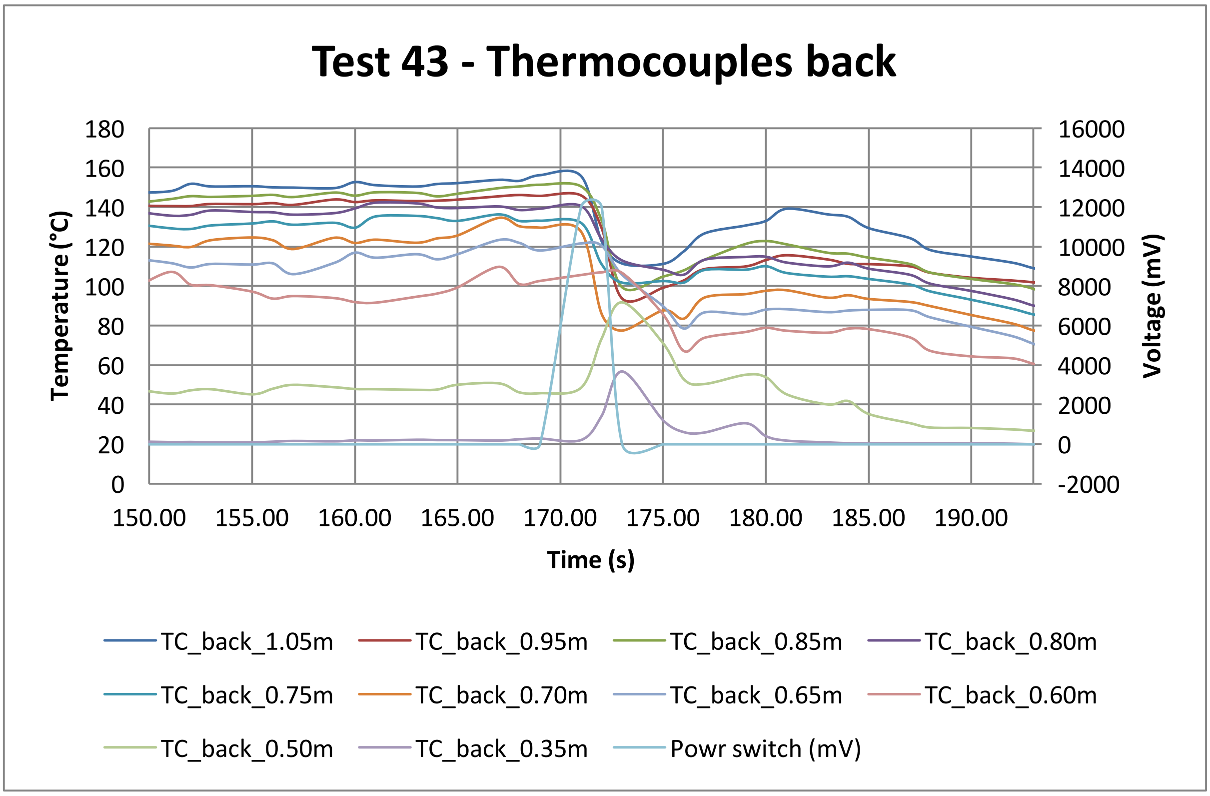

Test 42 - Thermocouples front
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

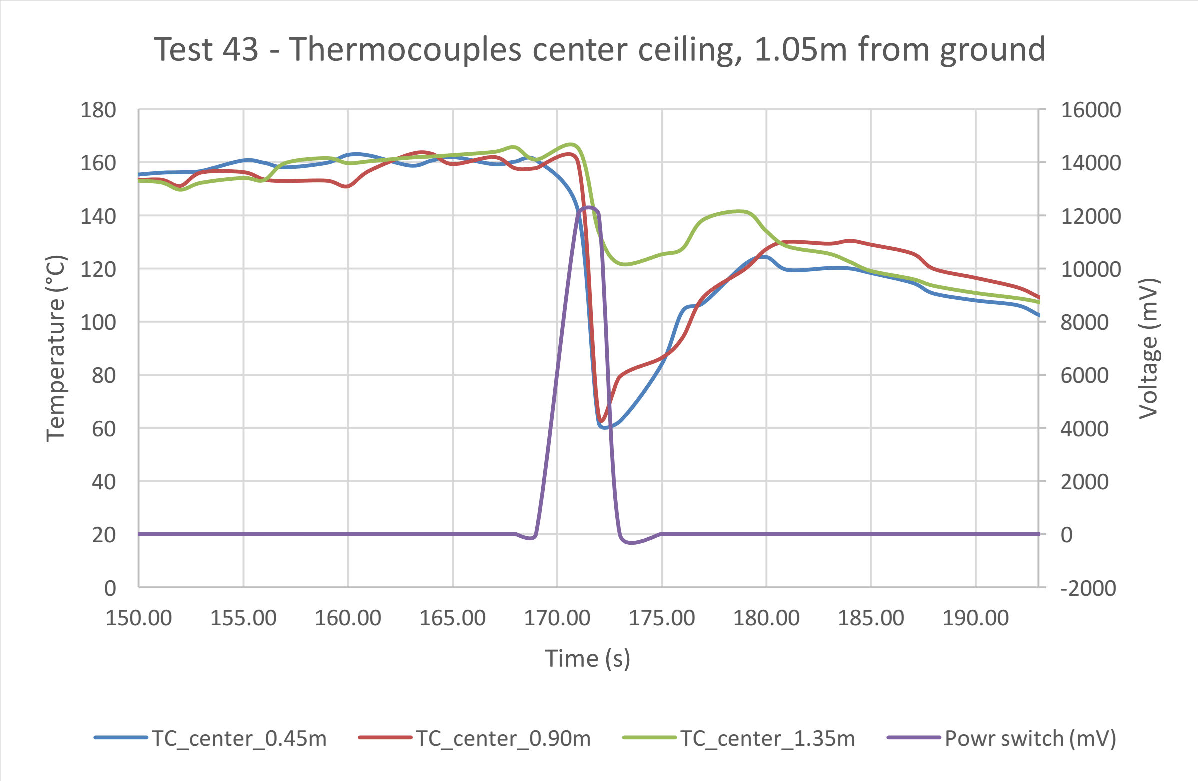

Test 42 - Thermocouples back
Temperature (°C)
Voltage (mV)
Time (s)
0
20
40
60
80
100
120
140
160
180
0
2000
4000
6000
8000
10000
12000
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)

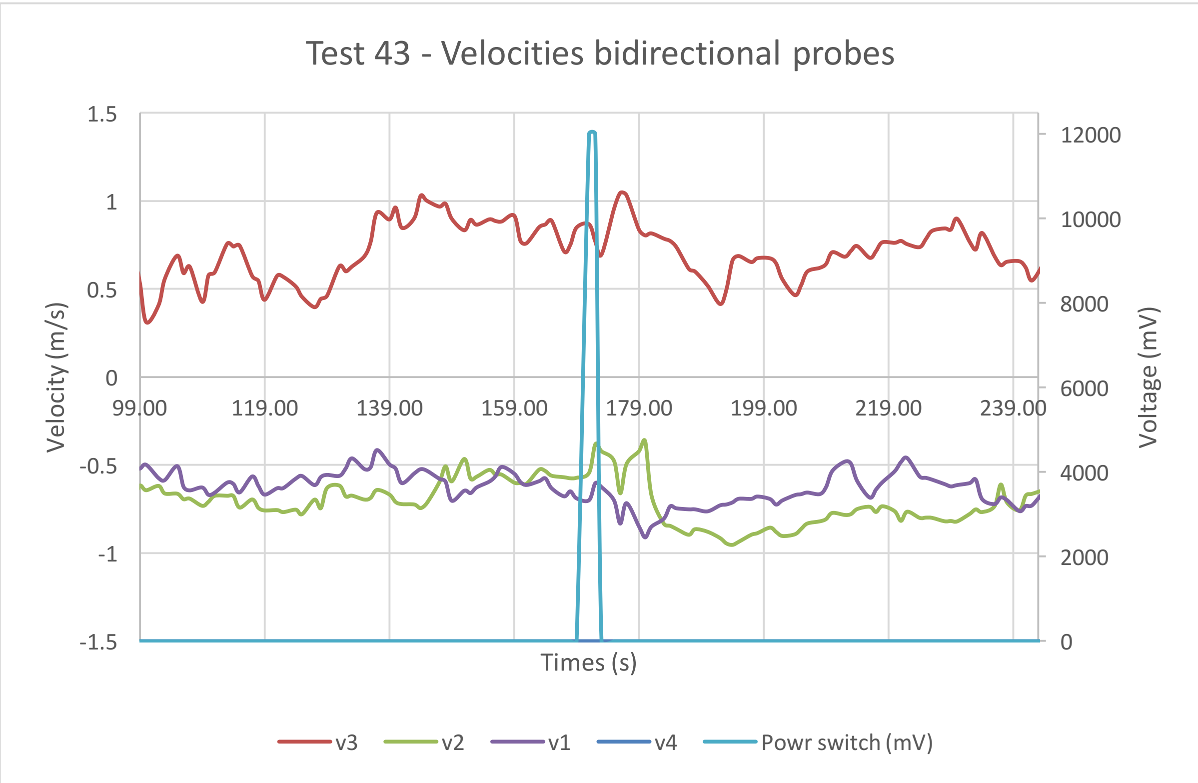

Test 42 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
131.00
136.00
141.00
146.00
151.00
156.00
161.00
166.00
171.00
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

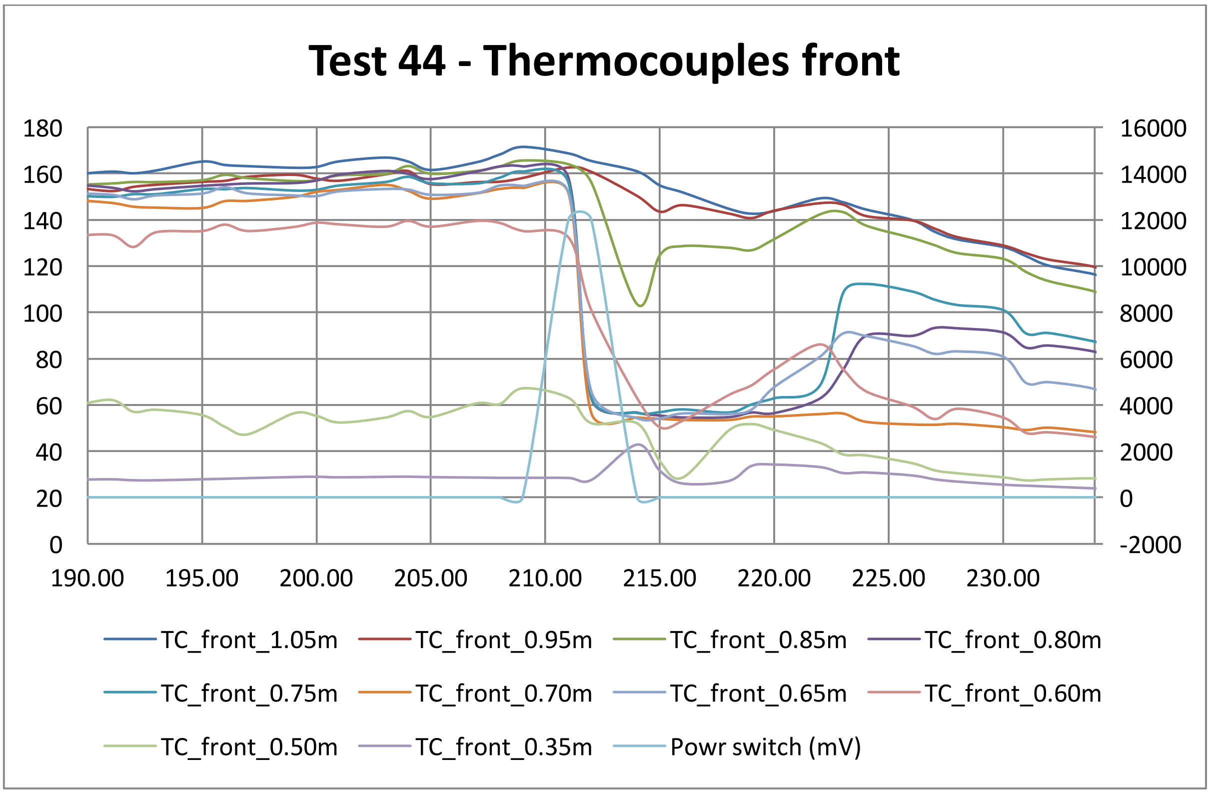

Test 42 - Velocities bidirectional probes
Velocity (m/s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
Voltage (mV)
81.00
101.00
121.00
141.00
161.00
181.00
201.00
221.00
Times (s)
v4
v3
v2
v1
Powr switch (mV)

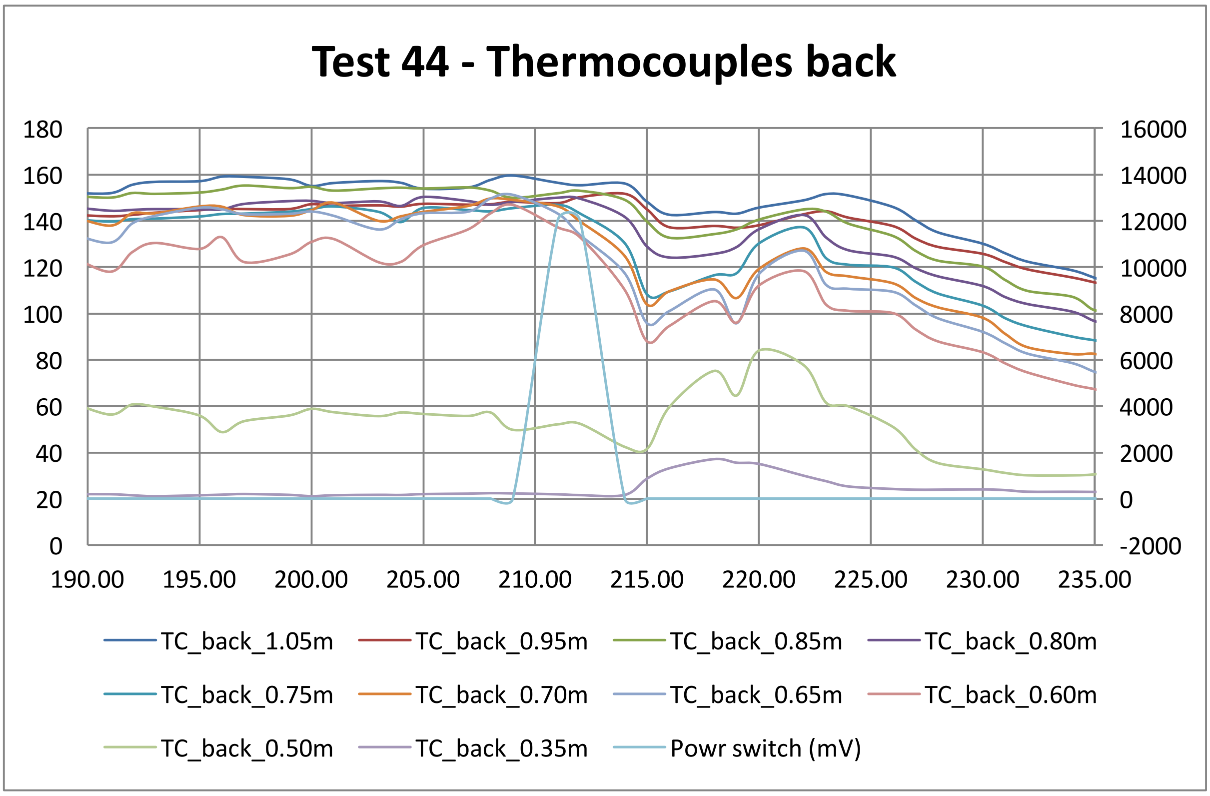

Test 43 - Thermocouples front
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
150.00 155.00 160.00 165.00 170.00 175.00 180.00 185.00 190.00 195.00 200.00
Time (s)
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)

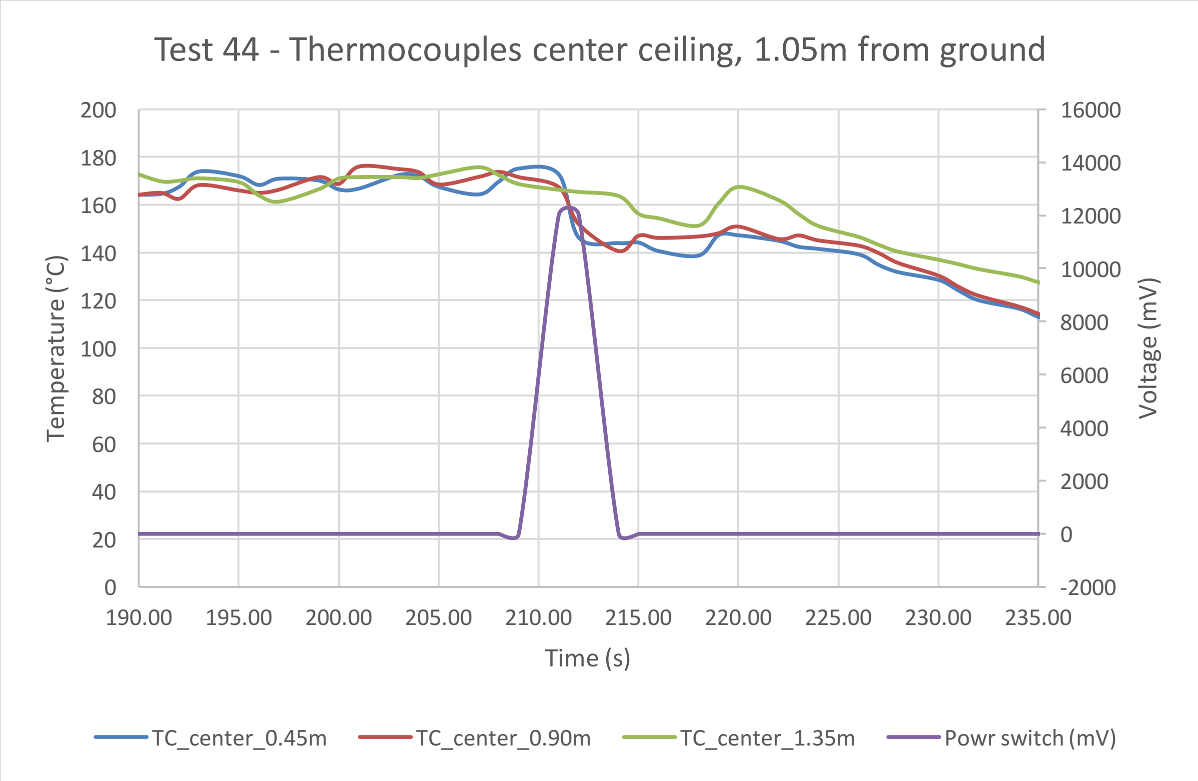

Test 43 - Thermocouples back
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Voltage (mV)
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
150.00 155.00 160.00 165.00 170.00 175.00 180.00 185.00 190.00
Time (s)
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)


Test 43 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
150.00
155.00
160.00
165.00
170.00
175.00
180.00
185.00
190.00
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)

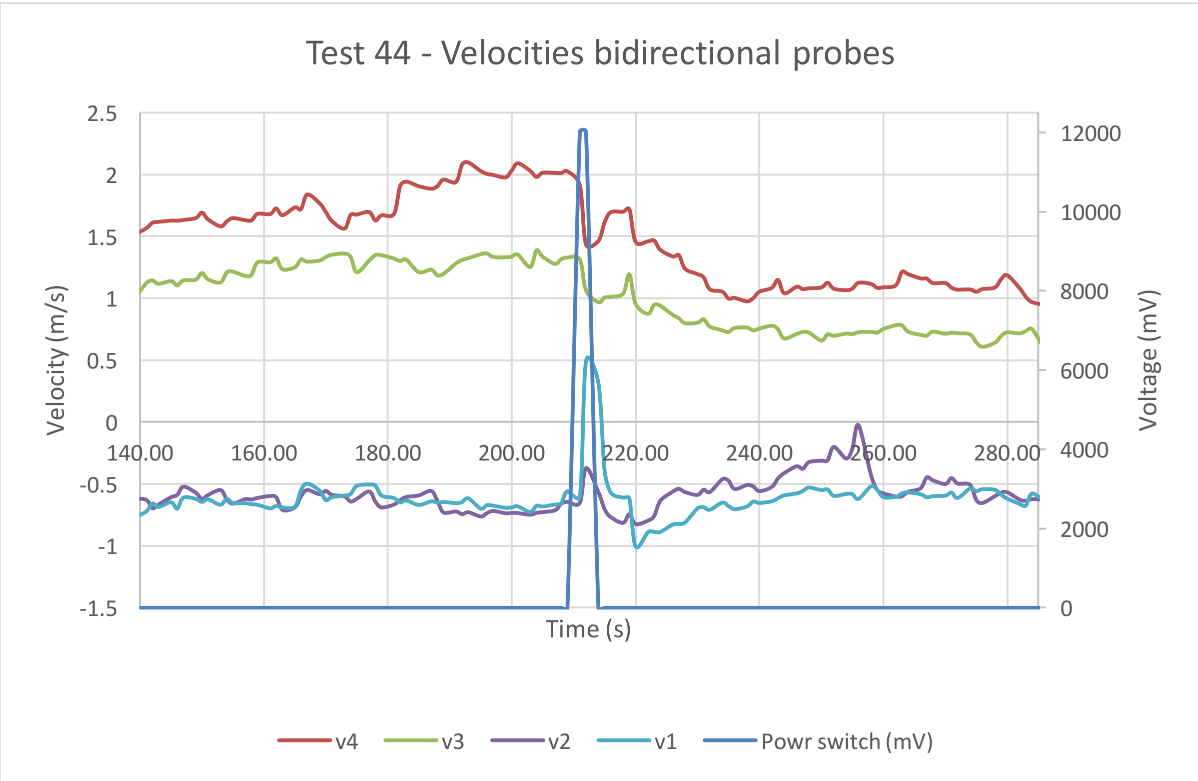

Test 43 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Times (s)
1.5
1
0.5
0
-0.5
-1
-1.5
12000
10000
8000
6000
4000
2000
0
99.00
119.00
139.00
159.00
179.00
199.00
219.00
239.00
v3
v2
v1
v4
Powr switch (mV)


Test 44 - Thermocouples front
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
190.00
195.00
200.00
205.00
210.00
215.00
220.00
225.00
230.00
TC_front_1.05m
TC_front_0.95m
TC_front_0.85m
TC_front_0.80m
TC_front_0.75m
TC_front_0.70m
TC_front_0.65m
TC_front_0.60m
TC_front_0.50m
TC_front_0.35m
Powr switch (mV)


Test 44 - Thermocouples back
180
160
140
120
100
80
60
40
20
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
190.00
195.00
200.00
205.00
210.00
215.00
220.00
225.00
230.00
235.00
TC_back_1.05m
TC_back_0.95m
TC_back_0.85m
TC_back_0.80m
TC_back_0.75m
TC_back_0.70m
TC_back_0.65m
TC_back_0.60m
TC_back_0.50m
TC_back_0.35m
Powr switch (mV)



Test 44 - Thermocouples center ceiling, 1.05m from ground
Temperature (°C)
Voltage (mV)
Time (s)
TC_center_0.45m
TC_center_0.90m
TC_center_1.35m
Powr switch (mV)



Test 44 - Velocities bidirectional probes
Velocity (m/s)
Voltage (mV)
Time (s)
v4
v3
v2
v1
Powr switch (mV)