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High Temperature Fire & Overheat Sensor Elements (FOSE) for aircraft Fire & Overheat Detection System (FODS)

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Abstract

One of the 21st century major challenges is to answer the growing mobility by a carbon saver solution. For aeronautics, improvement of engine architecture (NIPSE European project) permits to reduce its volume and so to get more space for passengers & freight (15%), to save weight and fuel consumption (2-3% i.e. 1% CO_2 emissions). This optimization hinges on integrating the engine and the nacelle into single assembly (Ultra High-Bypass Ratio turbofan engines or UHBR) that means equipment close to engine (calculator, valves, but also sensors and their extension cables…) have to resist higher temperatures. The Fire and Overheat Detection System (FODS) is a critical component for safe working of the aircraft as it controls and prevents from overheat and fire all those electrical equipment and the engine itself. THERMOCOAX, manufacturer of Mineral Insulated Cable (MIC) for over 60 years, is a privileged partner of the aeronautics industry (anti-icing for air inlet, pitot sensor, drain mast and thermal measurement from thermocouples to complete systems such as harnesses). For 25 years THERMOCOAX has manufactured Fire and Overheat Sensor Elements (FOSE) - the sensitive part of FODS - and as a specialist has taken part in this innovative project. The sensing principle of FOSE lies on electrical insulation resistance (IR) drop as the cable is exposed to heat. A wide range of research was made to find technical solutions for the new thermal specification. The difficulty comes from having IR with good sensitivity and linearity at temperature, covering a large temperature range: overheat threshold of either 473K (≈ 200°C) or 873K (≈ 600°C) depending on the location of the sensor. Also, the FOSE has to remain functional after 2 fires at 1453K (≈ 1180°C) during 5 min each, so the sensor sensitive insulant must not be deteriorated. Several solutions based either on thermistor powders or on percolation effect powders have been tested by miscellaneous trials: repeatability, thermal cycling, fire resistance test, local response at different room temperatures (from RT to 723K) and homogeneity along the cable. Finally, a new insulant solution has been selected to be integrated to the FOSE future generation. The other aspect of those new temperature rates is the electrical connectics that should not deteriorate the FOSE response, especially when the aircraft is in overheat or fire situation. So, a new design of 3 contacts ceramic-metal connector has been developed to resist more than 2 fires without generating parasite responses and to fit with aeronautics standards. Severe environment requested by NIPSE project forces THERMOCOAX to develop a new technology of FOSE based on insulant advanced studies and specific connectors to resist high temperature.

Keywords: Fire, safety, engine.

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Nomenclature

ATEX	Explosive Atmosphere
°C	Temperature in degree Celcius with T[K]=T[°C] + 273.15
FODS	Fire and Overheat Detection System
FOSE	Fire and Overheat Sensor Elements
HT	High Temperature
IPPS	Integrated PowerPlant System
IR	Insulation Resistance
$L_{overheat}$	Length exposed to overheat
MIC	Mineral Insulated Cable
NIPSE	Novel Integration of Powerplant System Equipment
NTC	Negative Thermal Coefficient
PTC	Positive Thermal Coefficient
RT	Room Temperature
R_{wire}	Wire electrical resistance
T	Temperature
$T_{nominal}$	Nominal Temperature of detection
UHBR	Ultra High-Bypass Ratio turbofan engines

1. Introduction

NIPSE (Novel Integration of Powerplant System Equipment) project aims at integrating components of future aeronautical engines and nacelle into single equipment and in particular on the next generation of turbojet UHBR (Ultra High Bypass Ratio turbofan engine) that will transport 180 people on flights of 2 hours to 0.78 Mach.

In this context, the NIPSE tends to develop key equipment and capabilities for an efficient integration of future aero-engine architectures (such as UHBR) in view to reduce weight, development time, fuel saving, space gain and optimized maintenance, with these 3 main objectives[1]:

- 15% reduction of the volume required for the Integrated Powerplant Systems (IPPS) equipment and for temperature deduction functions, and the associated weight of the system and connections.
- 10% reduction of the development time of future engine systems, such as UHBR engines, through an optimized equipment integration
- Reduction of the access time for maintenance activities on the systems equipment within the engine nacelle

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Fig. 1 logo of (a) NIPSE project and (b) THERMOCOAX compagnie

THERMOCOAX participated in the NIPSE project because of its aeronautic expertise and its 35 years experience in Fire & Overheat Sensors Elements (FOSE) and Overheat Detectors under the name of Negacoax®. As such, THERMOCOAX is the main European FOSE supplier (Safran, Airbus, Dassault, …) and supplies worldwide to other Original Equipment Manufacturers (Embraer, Bombardier, McDonnell Douglas, …).

THERMOCOAX R&D department has been involved for 3 years in the European project NIPSE aimed at focus on the Fire & Overheat Detection System (FODS), and in particular on its sensitive part, the FOSE. Indeed, one of the direct consequences of this reactor re-architecture is the increase of the ambient temperature of certain

[1] Extract from the official website of NIPSE project: http://www.nipse.eu

equipment that will now be relocated in the hot zone. It is then crucial to control the temperature of the IPPS because its components will be more thermally exposed and potentially subject to critical situations like fire.

2. Mineral Insulated Cable technology

THERMOCOAX is the historically French specialist of shielded Mineral Insulated Cables (MIC) and has developed since 1957 engineered thermal solutions, from customized temperature measurement bench to dedicated heating assemblies. The MIC is the basis to all engineered solutions developed by THERMOCOAX and is manufactured in-house according to proprietary and unique procedures. The most popular example of MIC in laboratory is thermocouple. The MIC is composed of an external metallic sheath insulated from the conductors by a compacted mineral electrical insulant (see Fig. 2).
This configuration permits the conductors to be protected by the sheath from the environment and is resistant to mechanical or chemical aggressions. It also allows the cable to be brazed or welded, coiled with joined spires or immersed into liquid without short-circuits or electrocution risk. The reduction process permits to produce MIC with diameters from Ø 12.5 mm to Ø 0.25 mm, preserving mechanical and electrical properties.

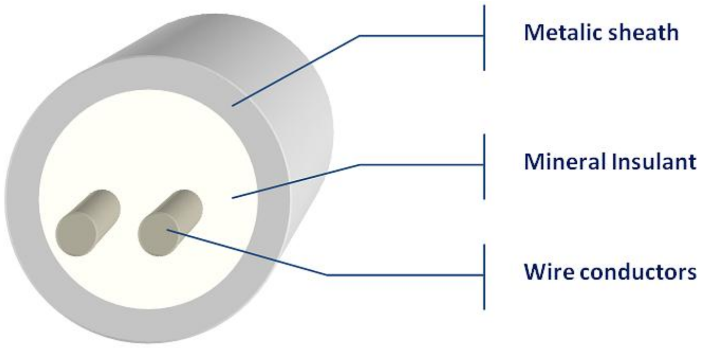

Fig. 2 sectional view of a standard MIC

With regard to the aeronautics sector, MIC presents some specific interests:

- A custom-made cable
- High temperatures withstanding (up to 1573K)
- Fire resistant with no combustive materials
- Low weight / compactness
- Compatible with ATEX areas
- Electrical connections from resin to ceramic-metal technologies
- Ability to be shaped and to keep a twisted shaping (radius down to 3 times MIC diameter or less with specific process)
- Good resistance to vibrations
- Insensitive to electrical disturbance

3. Sensor Principle

Monitoring of temperature is crucial for safety in areas where coexists a source of heat (aircraft, chemical reactors, tank, …) and persons or sensible equipment. In case of overheat or fire, a warning signal is transmitted to the crew and activates cooling or extinguishing systems. This monitoring is made thanks to linear sensor, i.e. sensible to temperature over all length, that passes through the most critical areas and can detect overheat or fire in its path. The particularity of those sensors is they can inspect temperature of large volumes/surface to which we don't know in advance where the overheat will happen, that's why they have to be sensitive over all their length.

A distinction has to be done between a linear overheat detector - that detects overheat above one single specific temperature (ON-OFF behaviour) - and a linear fire & overheat sensor – that can detect several temperature levels.

3.1. Overheat Detector

The principle of detection of linear overheat detector (single level of temperature) is based on melting of a salt inside the insulant of a MIC, that locally drops the Insulation Resistance (IR) until getting a short circuit at the nominal temperature $T_{nominal}$ of the detector. This detector does not permit to evaluate temperature above this $T_{nominal}$ (ON-OFF behaviour). The nature of salts must be adapted every time in order to offer a very precise detection of overheat close to the temperature level desired. This technology is adapted to overheat below 523K (≈ 250°C) and is not usable for fire detection.

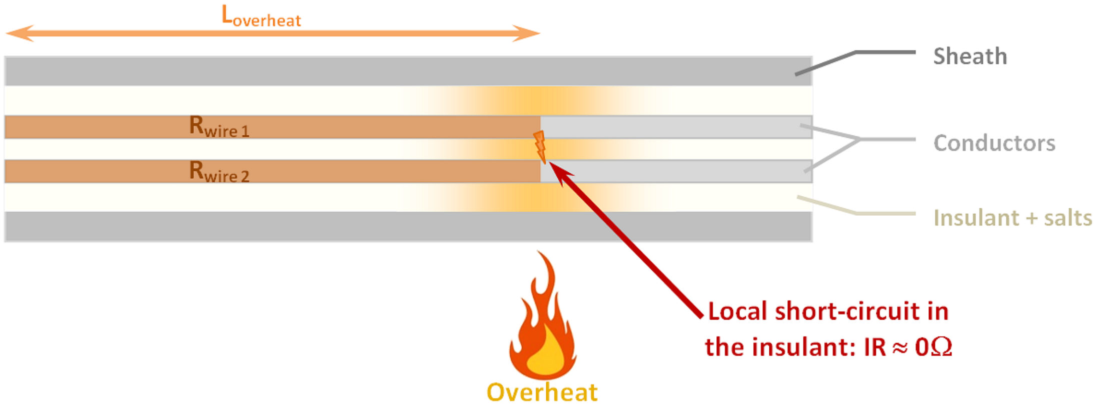

Fig. 3 sectional view of linear overheat detector exposed locally to overheat and repercussions on its response

The Negacoax® standards are NG80, NG104, NG124, NG180, NG204 and NG232; the number corresponding to the nominal temperature of detection in degrees Celsius (see Fig. 4).

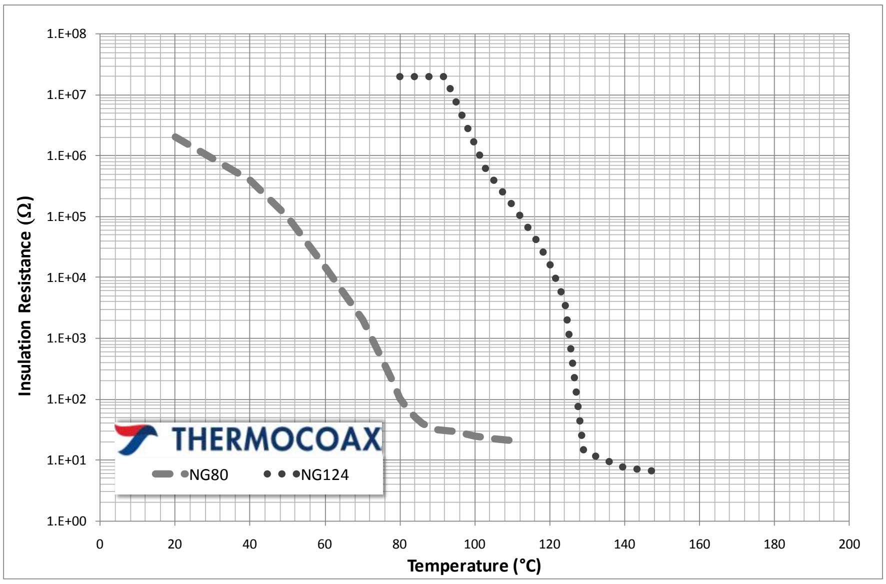

Fig. 4 IR=f(T) response curves of Negacoax® NG80 and NG124 with respective detection temperature of 80°C and 124°C

3.2. Fire & Overheat Sensor Elements

Fire & Overheat Sensor Elements (FOSE) principle can't rest on fusion of a salt into the insulant because it should detect several temperature levels and contrarily to the salts technology should resist to fire without damaging the cable. The monitoring principle is rather based on a thermo-resistive insulant having a linear response IR=f(T) which permits to measure overheat levels by IR evolution and to distinguish 2 nearby levels thanks to the great sensitivity (slope) of the insulant. Also, in case of overheat, there is not a proper short circuit between conductors, but a progressive reduction of IR proportional to the temperature level. The THERMOCOAX reference for this kind of sensor is the Negacoax® NGK that is sensitive up to 673K (≈400°C).

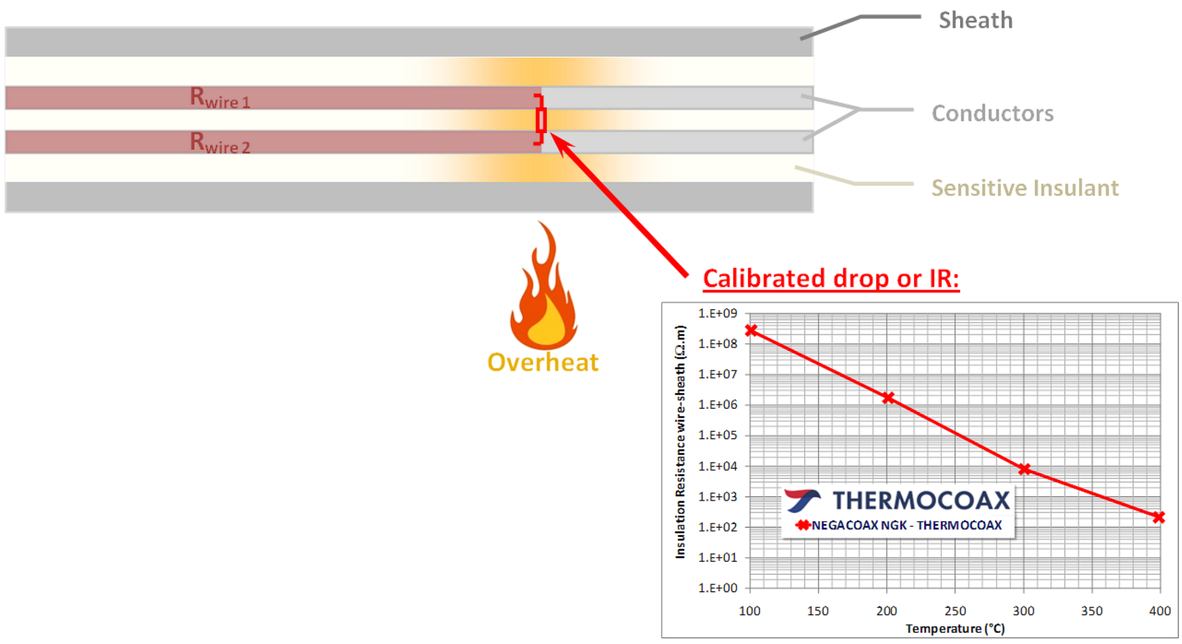

Fig. 5 sectional view of FOSE exposed locally to overheat and repercussions on its response

4. New requirements

NIPSE requirements are based on the following:

- Good sensitivity on large temperature range and multiple discrete alarm signals (see Tab. 1)
- Lower weight
- Easy to replace (maintenance)
- Precision on temperature of ± 17K
- Response time <12s for overheat and < 6s for severe overheat
- No false alarm => that means a single IR for a single temperature and no parasite IR
- Quick fire alert with sensor location and duration of alarm
- Alert if the fire is extinguished or restarted => still functional after 2 fires
- Can resist to chemicals (petrol, water, …), to vibrations, extreme temperatures, maintenance and aeronautics standards

Tab. 1 temperature levels and alarm designations

Overheat conditions	Alarm level	Temperature Levels		
	None	Normal	213K / 473K	*(-60°C / +200°C)*
Global overheat	I	Overheat	> 473K	*(> 200°C)*
	II	Severe overheat	> 573K	*(> 300°C)*
Local overheat	II	Descrete overheat	> 773K	*(> 500°C)*

5. Sensitive Material

When several warning levels are required (different steps of overheating and fires), it is necessary to measure precisely the local temperature with a progressive response (linear), with a sufficient sensibility and without saturation. The use of a “salt technology” overheat detector is no more suitable in these cases. Considering the maximum overheat temperature level, the use of FOSE Negacoax® NGK is not either adapted because of it sensibility range (from 373K to 673K, i.e. from 100°C to 400°C) that does not completely cover the need for NIPSE upper temperatures. That is why THERMOCOAX deployed an ambitious R&D project to find out a new specific sensor Negacoax NGHT, the first to achieve such requirement in the world. Extensive research has particulary concentrated on finding the reactive insulant having adapted thermoresistive behaviour, i.e. having a great variation of IR with temperature.

In the category of thermoresistive materials, there is 2 main families: those with a IR having Negative Temperature Coefficient (NTC) and at the opposite, those with a Positive Temperature Coefficient (PTC). See Fig. 6.

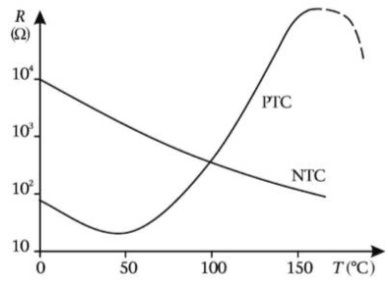

Fig. 6 NTC and PTC standard IR=f(T) evolution

PTC have been immediately rejected because of the risk at high temperature to miss overheat or even fire alarm due to a parasite lower IR on the detection system circuit, that could act as a shunt and simulate lower temperature response of the sensor. For this security reason, the new sensor is based on the MI cable technology including thermoresistive insulants with a NTC behaviour and a progressive IR decreasing with temperature.

6. Performances

Many tests have been performed to evaluate sensor performances, but the most critical are compiled in Tab. 2 and detailed below.

Tab. 2 tests performed on the FOSE new generationNegacoax NG HT with aim and results

Test	**Aim**	**Results**
IR = f(T): from 293K to 873K (≈ 20°C to 600°C) - heating and cooling	Evaluate sensor sensivity and absence of hysteresis	High sensitivity without hysteresis
2 Fire tests: *at 1353K (≈ 1080°C) / 5min*	Capability of the sensor to withstand 2 successive fires and remaining still functional	FOSE has the same response after 2 fires
Thermal cycling: *200 times between 323K and 853K (≈50°C and 580°C)*	Simulating accelerated ageing resulting of engine start & stop	No drift due to thermal cycling
Homogeneity control: *on all the sensor length*	Verify the sensor has the same response independently of the overheat location	FOSE has same response on its whole length
Influence of overheated length: *on 25cm, 1m and 3m*	See if the sensor response is the same for local or global overheat.	Response not affected by the exposed length to overheat
Influence of RT on sensor response: *with RT from 293K to 623K (≈ 20°C to 350°C)*	See if the alarms levels are identical in all configurations of RT	No influence of RT in normal temperature condition. Earlier response for upper temperatures.
Shaping influence**:** *with coiled MIC Ø2mm on Ø12mm*	make sure the response would not be affected by customer shaping	Response not affected by shaping
Response in case of cut sensor	See if the response permits to inform of damage	Cut sensor induce alarm
Weight reduction**:** *compared to standard Ø2,1mm*	Reduce weight drastically	Up to 49% by reducing diameter from Ø 2,1 mm to Ø 1,5 mm

On the Fig. 7, is presented the response of the new Negacoax® HT before and after fire test, without hysteresis effect. The response of the previous version Negacoax® NGK is given as comparison.

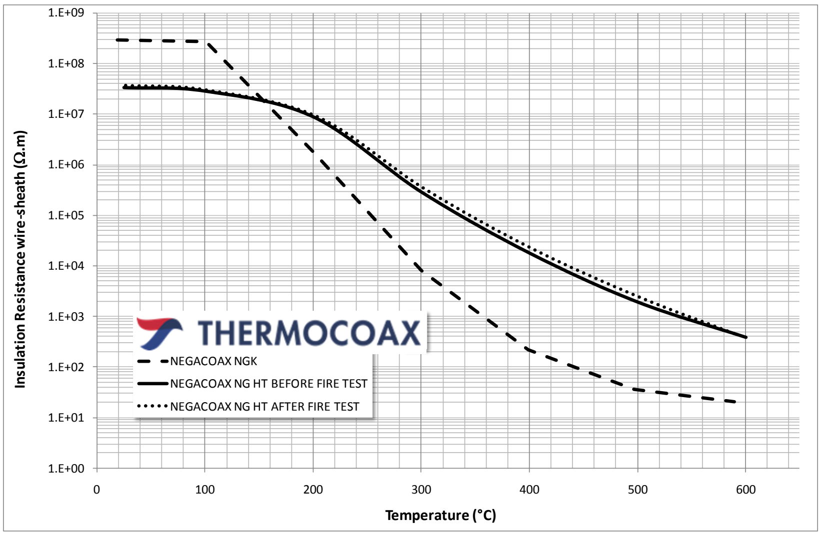

Fig. 7 sensor response of the new Negacoax® HT before and after fire test and in comparison with Negacoax® NGK

Thermal cycling 200 times between 323K and 853K (i.e. 50°C and 580°C) reveals that the sensor has no significant drift. For more clarity, only the IR evolution at 853K (≈ 580°C) is presented on Fig. 8, that corresponds to the upper part of the cycling curve on 200 cycles.

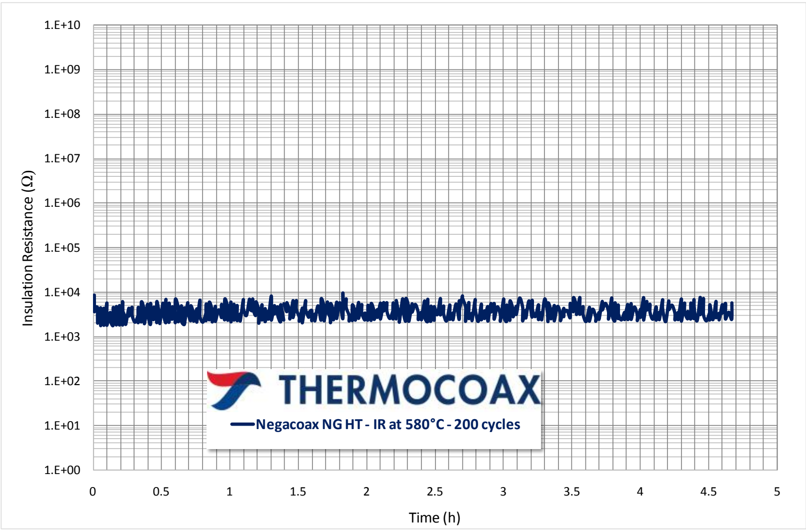

Fig. 8 IR evolution during cycling 200 times between 323K and 853K with only top of cycling curve at 853K (≈ 580°C)

The sensitivity is very high along the whole temperature range needed for NIPSE project (between 473K and 873K) and really stable, even after fire tests.

The cable is homogenous throughout its length, meaning overheat will lead to the same temperature interpretation.

Also, there is no repercussion on the sensor response induced by the exposed length within overheat temperature range, so there is no problem to detect with the same precision local or global overheats (see Fig. 9).

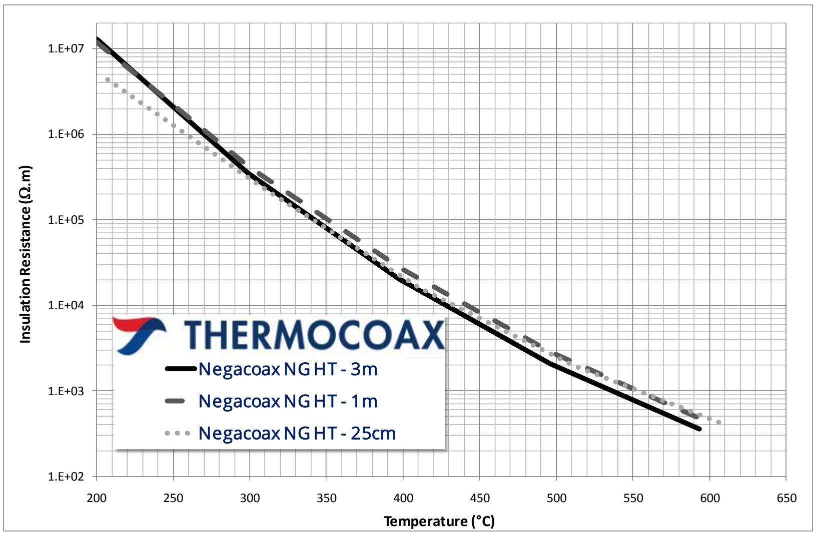

Fig. 9 influence on sensor response of overheated length

The sensor response in variable ambient conditions RT shows that there is no noticeable modification of temperature interpretation of overheats in normal temperature range and it gives an earlier alarm for RT above 523K (≈ 250°C), that is anyway already considered as overheat alarm. It is important for security that the sensor gives an earlier alarm in case of global overheat, because any delay would compromise the chances of intervention. This phenomenon is observable especially for slight overheat temperatures above RT.

There is no significant response variation due to shaping operation, even at very low bend diameter like Ø12mm for a Ø2mm MIC shaped on 50cm.

In case of sensor break, the response at 293K (≈ 20°C) would lead to alarm response. If the break happens during flight, the response would also quickly get in alarm mode. To get a special alarm signal related to sensor break, it is also possible to measure continuously the conductor line resistance to detect any open-circuit.

Lastly, one of the other pillars of NIPSE project is weight reduction. THERMOCOAX having a great expertise in MIC technology and historic experience of FOSE, improvement of the sensor design could permit to reduce linear weight to 49% by using the new insulant and reducing the sensor diameter from Ø2,1mm to Ø1,5mm (weight from 21.10^{-3} kg/m to $10{,}7.10^{-3}$ kg/m).

7. New FOSE Negacoax® NG HT & prospect

A new sensor Negacoax® NG HT based on a specific insulant solution has been developed within NIPSE project and achieves the performance requirements.
For the first time, a FOSE is able to monitor several temperature levels in high temperature range such as 473K - 873K (≈ 200°C - 600°C). This sensor has a high sensitivity on the entire range, without hysteresis effect and is not affected neither by length exposed to overheat, nor by having been exposed to fire twice, nor by cable shaping. Also, the sensor response is not clearly affected by global ambient temperature (RT) to detect overheat, as long as global ambient temperature is below 473K (≈ 200°C). For upper ambient temperature, overheat responses are sent earlier which is still compatible with safety level required in the aircraft. In case the sensor breaks, an alarm is sent in any case. The linear weight can be reduced drastically by 49% by reducing the diameter from Ø2,1mm to Ø1,5mm. The reproducibility has also been proven and permits to launch aeronautical tests (vibration, shocks, fire test, …) and to obtain soon a mature product.

In order to get a complete sensor, THERMOCOAX developed a special high temperature, Helium tight connectors based on Ceramic-Metal technology (see). These connectors are in process of being qualified for aeronautical standards.

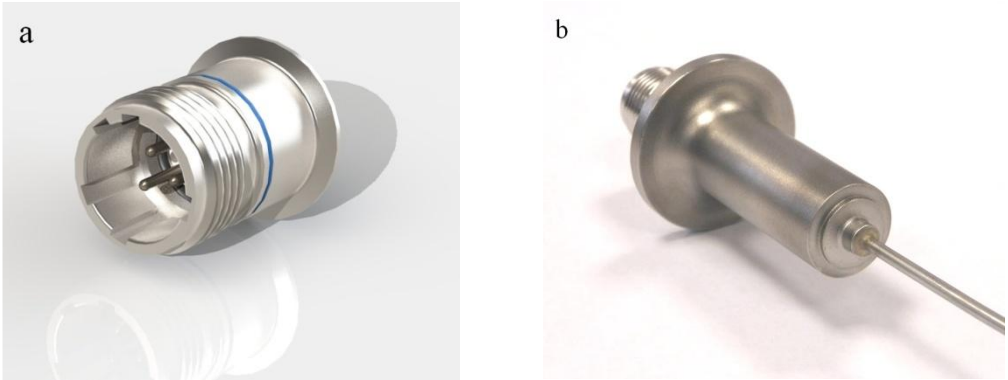

Fig. 10 (a) high temperature Ceramic – Metal connector developed by THERMOCOAX ; (b) aspect of the entire connector