DEVELOPMENT OF DERATING TEST FACILITY FOR SPACE HARNESS DESIGNS

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INTRODUCTION

Now-a-days electrical engineers in the aerospace industry around the world use derating rules from SAE AS50881[1] or ECSS-30-11C[2] when designing wiring bundles for aircraft and space systems without consideration about their validity. However, the derating rules follow the successive series of the military standards MIL–W-5088s that are basically unchanged since the early 50s. The derating rules are based on natural convective cooling of free wires in air and have been updated for load conditions for wires in bundles in the 70s. For space environments derating rules are based on IR cooling and a few tests. As such the derating rules respect *general worst case* conditions indiscriminately to be applied for the whole harness (also where it might not be needed) but at the other hand do not consider *local worst case* environmental conditions as found for harnesses in modern systems to their full extend. Narrow or insulated enclosures, the use of structural composite materials with low thermal conductance, solar radiation and hot surfaces are neglected in the derating rules. This situation leads to large uncertainties and potential failures with respect to the actual wiring temperatures in aerospace systems. Modelling and prediction of wire temperatures could therefore improve bundle designs in terms of weight and safety[3]. The Harness Derating Test facility is developed by NLR (Fig. 1.) for the aircraft industry for wire temperature verification and to validate thermal models for harnesses. This has been done by testing bundle samples to their designed power within a typical worst case enclosure as found in aircraft. The paper describes The Harness Derating Test Facility for *convective environments* by measuring steady state temperatures of wires in bundles at several current levels (0-20A), air pressures between 1 - 10^{-3} bar and sink temperature between -70^{o}C to +100^{o}C. In this paper NLR proposes extension of the Harness Derating Test Facility for simulated *space conditions* by placement inside a Thermal Vacuum (TV) chamber. With this arrangement space harness designs can be tested under full vacuum (<10^{-5} mbar) or low pressure conditions (i.e. simulated Mars CO_2 atmosphere) and sink temperatures between -150^{o}C to +150^{o}C. Derated temperatures of other space components such as connectors, resistors and heaters could also be verified with this facility.

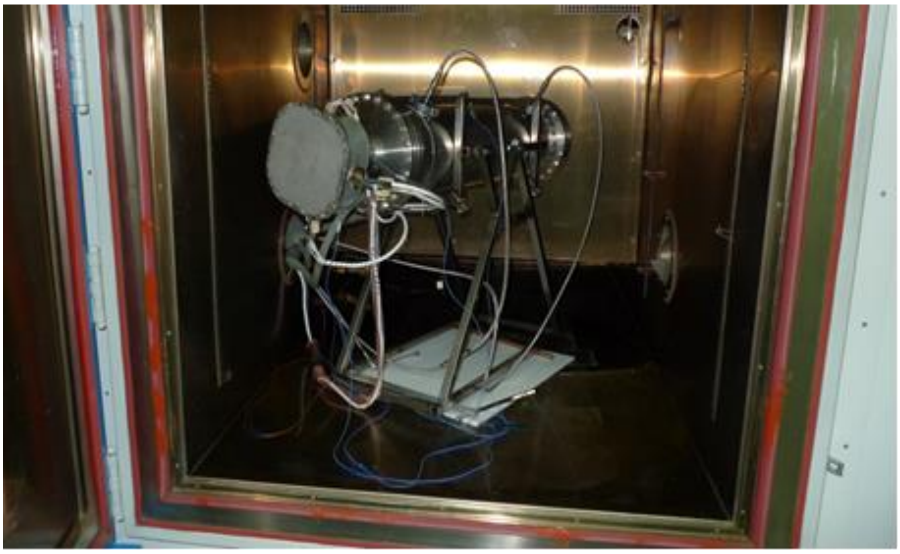

Fig. 1. Photograph of the HDTF for convective environments on a rotatable bench inside NLRs Climate Chamber.

HARNESS DERATING TEST FACILITY FOR CONVECTIVE ENVIRONMENTS

The following facility has been developed by NLR for verification of the derated temperatures of aircraft harness designs in the range of 5-39 mm bundle diameter in 2008.

Facility Description

Climate Chamber

A cylindrical tube (Length 760 mm; ID=200 mm) is placed on a bench in a temperature controlled climate chamber (range -70 to +100°C) (see
Fig. 2.). The bench can be positioned at an angle between the horizontal and about 45°. A sample bundle (effective length ca. 1 m length, tested length 680 mm) with thermocouples is installed inside the cylindrical tube. When applying low pressures a hermetical (air leak tight) sealing is achieved by using connectors for current feed-through of the sample.

Facility equipment

Programmable power units (up to 100A) are available allowing for adjustable current control. A scroll vacuum pump in combination with an electronic valve is applied to control the cylinder internal air pressure (range 15 mBar to 1 Bar). A tubular square shaped copper cold sink is available to simulate convection circulation and heat radiation/conduction. The top and bottom sinks are uniformly cooled down to -40^{o}C with a fluid loop provided by a thermostat bath outside the climatic chamber. The sidewalls are black painted and externally insulated. Guard heaters are additionally applied to minimize any heat flow through the sidewalls by controlling the internal and external temperature gradient to zero.

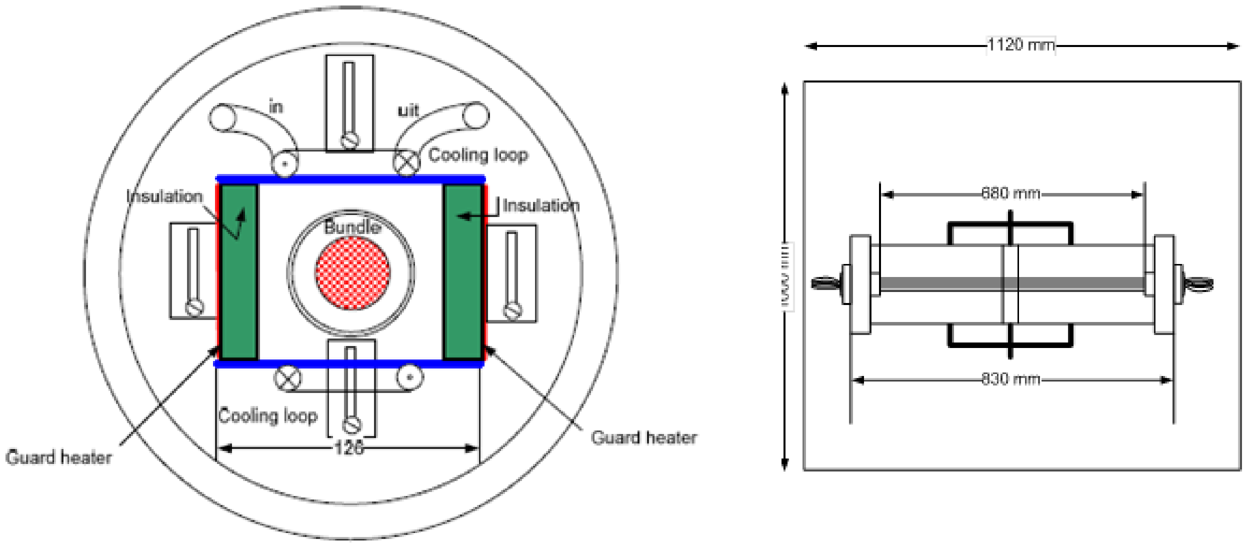

Fig. 2. Cross-section of the HDTF for convective environments in horizontal set-up.

Sample measurements

The cable- / wire bundles are equipped with temperature sensors (thermocouples) to measure the temperatures of the individual wires on several axial locations. Also the temperature of the facility wall is measured. Measurements can be performed on steady state and transient powers. A transient test cases (duty cycle) allow for a temporarily higher current when taking the wire/bundle heat capacity into account. Below (Fig. 3.) an example is given of a D=17.5 mm bundle with AWG 4 (2x), AWG 12 (4x), AWG 16 (6x), AWG 18 (14x) and AWG 20 (18 x) wires in a 25°C air environment The four thick lines at the top of the graph (see Fig. 3) are some measured wire temperatures at 20% above its derated current (44 W) at 1 bar, whereas the four lines in the middle of the graph are the measured wire temperatures at 20% below its derated currents (29 W) at 72 mbar (The ripple is due to the power control equipment). The derated current is specified as the current which rises the inner bundle temperature to 150°C at an ambient temperature of 70°C at 72 mbar.

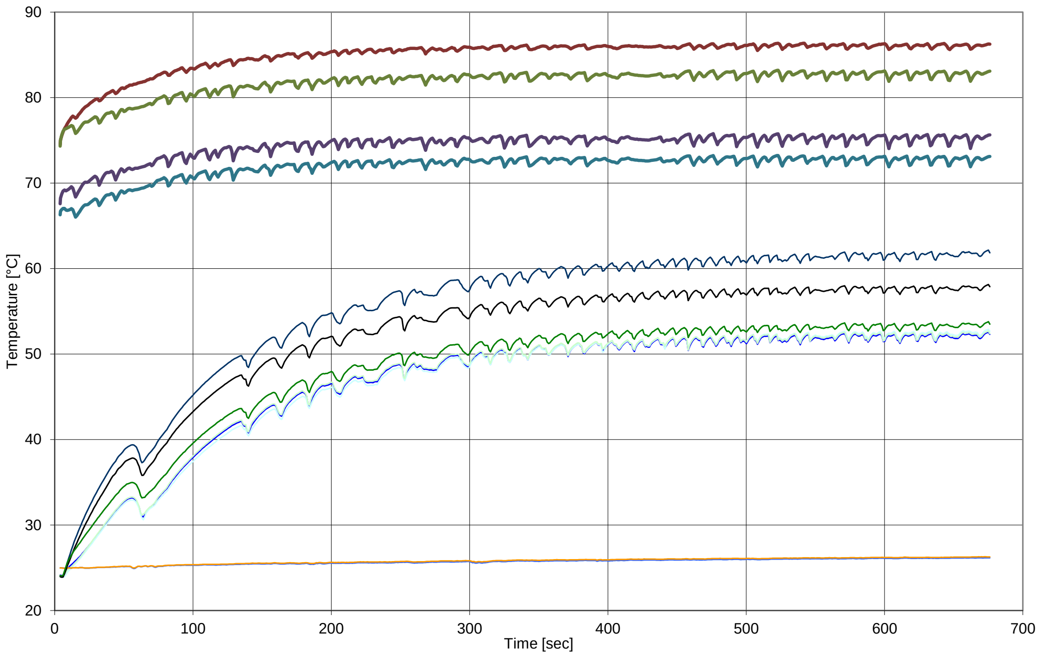

Fig. 2. Measured temperatures of an aircraft cable bundle D=17.5mm (with braid) in 25°C air for a 20% above rated currents at 1 bar (4 thick upper lines) and 20% below rated current at 72 mbar (4 thin lines at the middle) at an ambient temperature of 25°C (lower line).

DESIGN OF HARNESS DERATING TEST FACILITY FOR SPACE ENVIRONMENTS

The following facility is proposed for verification of the derated temperatures for space harnesses. The design has been based on the experiences with the existing facility for convective environments. Major proposed improvements are the low pressure conditions (vacuum), cold sink temperature range down to -150^{o}C and adjustable enclosure dimensions. An overview of the facility specification is given in Table 1.

Facility Description

TV chamber

Samples are placed horizontally in the Thermal Vacuum (TV) chamber at NLR (see Fig. 4.) and surrounded by (up to) six adiabatic walls simulating the desired enclosure dimensions, layout and temperature environment (see Fig. 4.). The enclosure configuration is fixed prior to the closing of the TV chamber door. Cooling of these walls is performed by radiation to the shroud of the TV chamber, which has a temperature range between -150°C to +150°C (without heat load). Heating is performed by electrical heaters on the back of the adiabatic walls. The adiabatic walls are movable so that an enclosure can be created with a fixed length but with an adjustable width and height.

Fig. 3. Photograph of the TV chamber at NLR proposed to be used for the HDTF for space harness designs.

Adiabatic walls

The adiabatic walls are made of two conducting plates separated by a gap. The front plate (as seen from the test sample) is only equipped with temperature sensors. The corresponding back plate is equipped with heaters and temperature sensors. A controller keeps the front plate on the desired temperature or ensures a zero temperature gradient. With these adiabatic walls it is possible to prevent heat to flow through these walls, or to simulate a satellite panel with a pre-defined temperature. The suspension of the adiabatic walls is to be designed, but will be done with stainless steel cables and stand-offs.

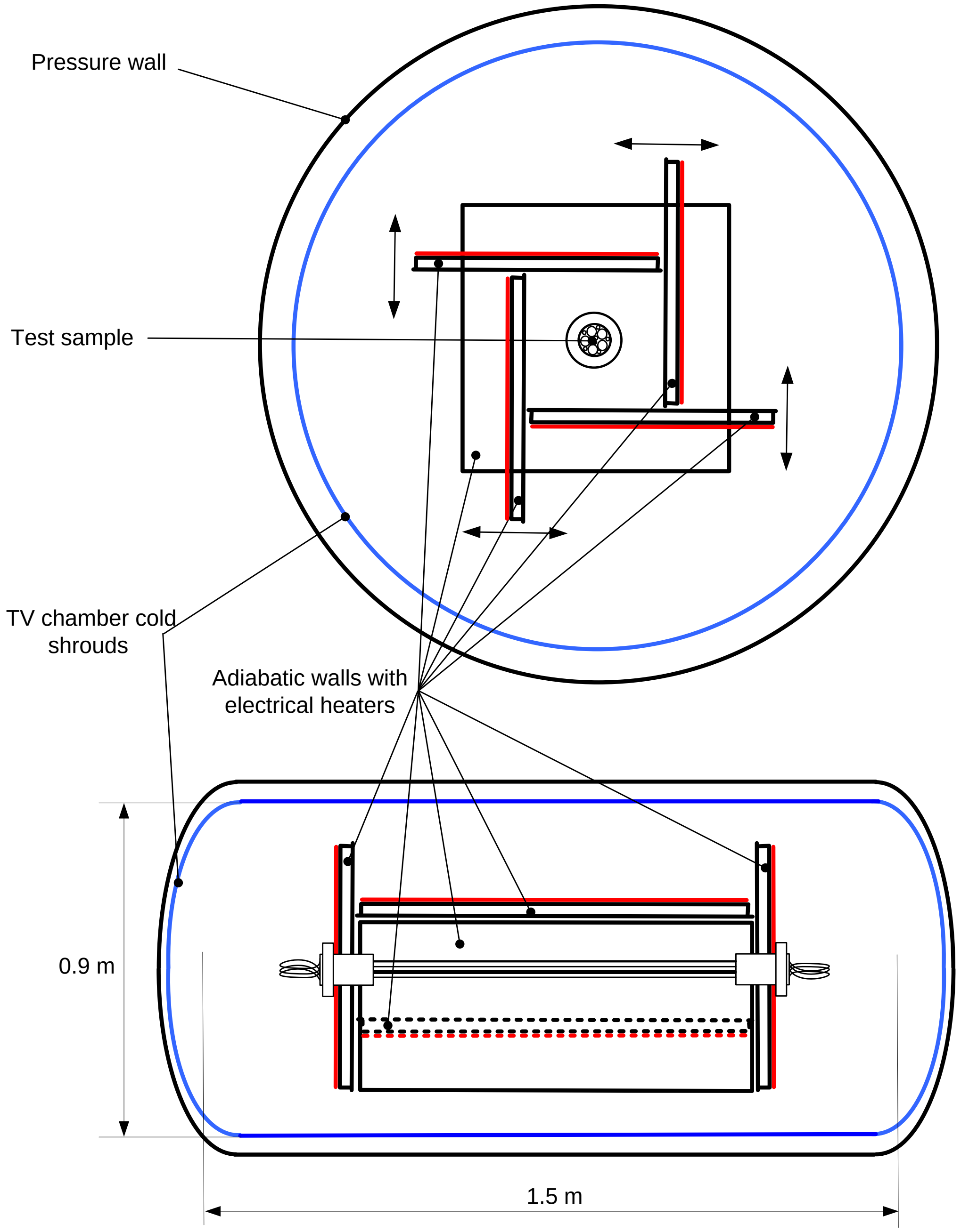

Fig. 4. Cross sections of the proposed HDTF for space environments with a sample bundle suspended in a TV chamber at NLR with adjustable and temperature controlled walls.

Solar heat input
To simulate the solar heat input in earth orbit one of the adiabatic walls can be heated to 170°C, which can provide the sample with a radiation influx equal to one solar power. This way a configuration with a component on the outside of a satellite exposed to solar radiation can be tested.

Samples and interfaces
Samples consist of a wire- or cable bundle, a series of bundle positioned next to each other, connectors, heaters etc. The samples are connected via sub-D through-puts to the power supplies outside the TV chamber. A bundle with at least four different types of wire (with each an adjustable current) will be possible to test, and each wire can be looped numerous times to get the desired test bundle.

Temperature measurements
The test facility is equipped with thermocouples to measure and control the temperatures of the adiabatic walls. The test sample will be equipped with thermocouples to obtain a thorough understanding of the temperatures distribution inside tested sample. For cable bundles for example, on several axial sections multiple thermocouples can be installed throughout the cross-section of the bundle.

Power measurements
The voltage drop over the tested part of the sample is directly measured with cross wires. The current is accurately measured (<1%) by the voltage drop over a calibrated measurement resistance.

Pressure
The pressure inside the TV chamber will be below $1x10^{-5}$ mbar or any other pressure up to 1 bar.

Table 1 Specifications for the Harness Derating Test Facility

	Existing (convective)	**Proposed (space)**
Facility	Temperature controlled climate chamber	Vacuum chamber with temperature controlled shroud
Enclosure envelop (bxh)	Fixed 86 x 84 mm	Variable 100 x 100 to 500 x 500 mm (*TBD*)
Orientation	Horizontal/Vertical	Horizontal
Sample bundle dimensions	L= 1m D=5-40 mm	L=1 m D= 1-40 mm (*TBD*)
Cold sink/shroud temperature range	-60°C to + 100°C	-150°C to + 150°C
Temperature controlled walls	2x adiabatic	4x adiabatic or heated
Pressure range (air)	1 to 1000 mbar	$<10^{-5}$ mbar
Solar heat input	-	Heated wall (*TBD*)
Current sources	5 different currents up to 100 A	5 different currents up to 100 A
Through connectors/number of pins	4 x 28 Deutch	*TBD* x SubD
Current rating pins	4x4 pins 17 A 4x24 pins 5 A	*TBD*
Number of thermocouples (type -T)	48	*TBD*

TBD= To Be Designed

OUTLOOK

With the development of the HDTF for aircraft harness designs doubts about the margins applied in the derating standards could be substantiated. Development of a new facility is proposed for verification of the derating rules for space harness designs. The European Space Agency (ESA) is interested in this development since the new HDTF could lead to an update of the ECSS specifications leading to improved space bundle designs, smaller bend radii and an overall lower harness mass. Realisation of the HDTF for space applications depends on industrial and governmental financial support which is not to be expected before 2014.

REFERENCES

[1] ECSS-Q-30-11C, Space product Assurance, Derating - EEE components
[2] SAE AS50881D, Aerospace Vehicle Wiring
[3] THERMAL ANALYSIS OF WIRING BUNDLES FOR WEIGHT REDUCTION AND IMPROVED SAFETY, Roel van Benthem , Wubbo de Grave, Fennanda Doctor, Simon Taylor , Kees Nuyten , Pierre-Alexis Jacques Dit Routier, 41th International Conference on Environmental Systems (ICES), Portland, USA, 17 - 21 Jul 2011