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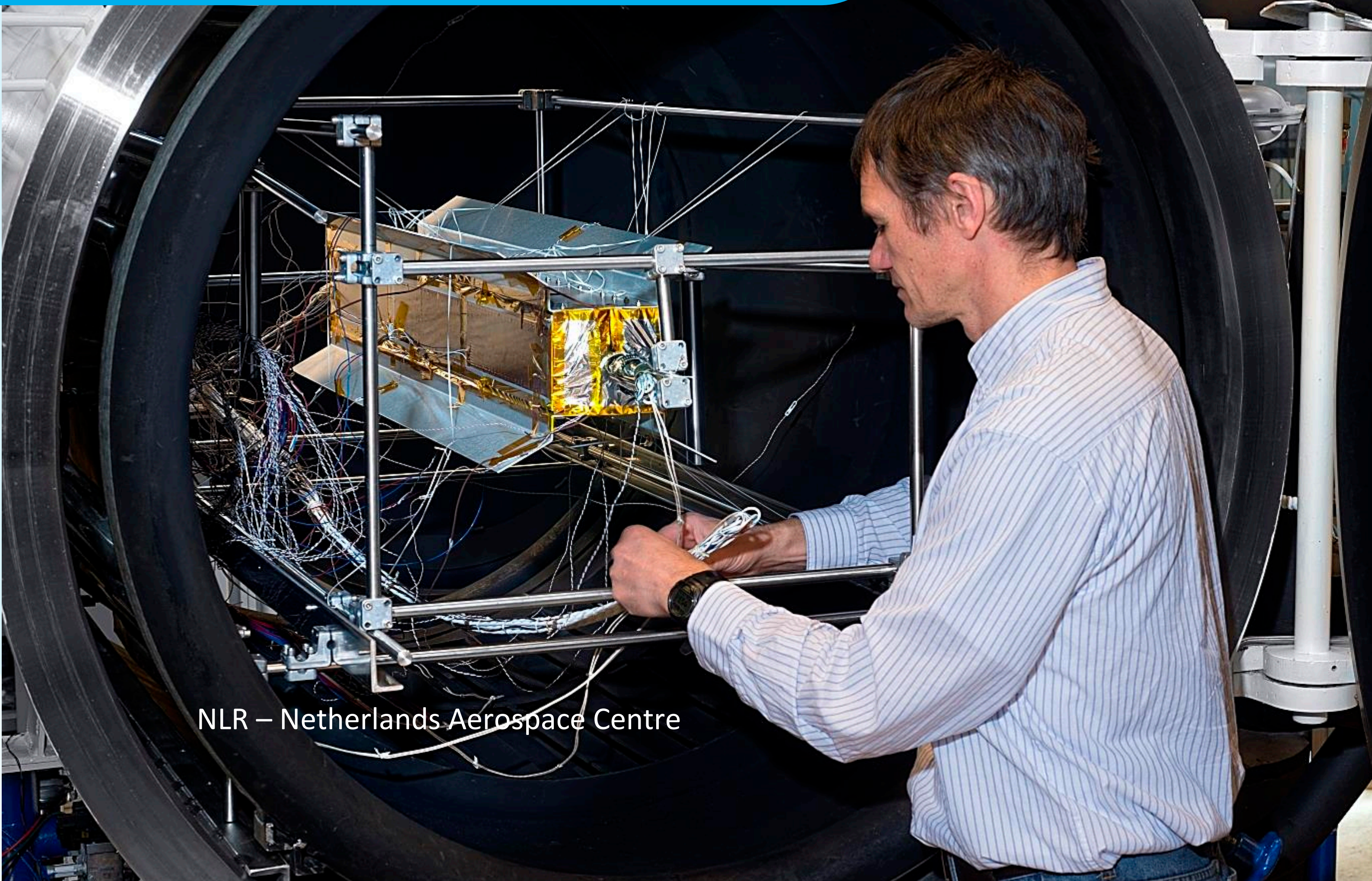
NLR-TP-2016-349 | August 2016

Harness Derating Test Facility for Thermal Testing of Aerospace Harnesses

CUSTOMER: Netherlands Aerospace Centre



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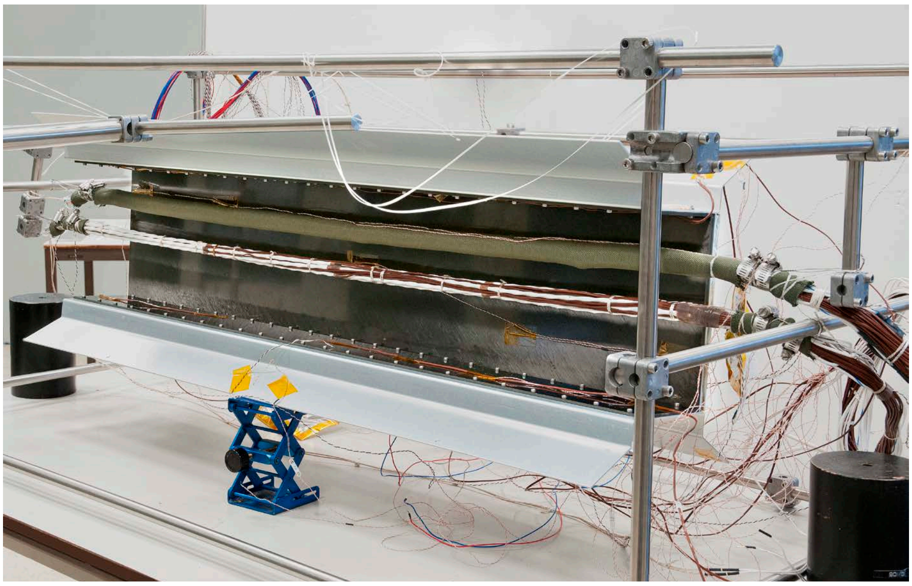
Harness Derating Test Facility for Thermal Testing of Aerospace Harnesses



Harness Deration Test Facility (HDTF) in preparation for the double bundle test inside a wing representative enclosure with composite (CFRP) walls. The left wall has been removed for the photograph.

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The derating rules in the aerospace standards are unchanged since the 1950s and are a combination of the Single Wire Current (i.e. the rating as function of temperature) and subsequently a derating factor to be applied indiscriminately for the whole harness which could lead to significant design margins. It is considered that experimental verification of the derating rules and improvement of thermal analysis could lead to a relaxation of derating rules and an optimization of aerospace electrical powered systems.

Description of work

To support these developments, the Netherlands Aerospace Centre (NLR) developed a dedicated Harness Derating Test Facility (HDTF) for accurate measurement of single wire and bundle temperatures at different currents inside pre-defined enclosures, both in air as well in vacuum. The HDTF has been successfully used for testing of aircraft harnesses inside representative wing enclosures with the objective to verify if the volume occupied by the harness can be reduced and is currently prepared for single wire rating and bundle derating test in vacuum with the objective to improve the ECSS derating standard.

GENERAL NOTE

This report is used for a poster session at the Space Passive Components Days ESA/ESTEC, October 12-14, 2016.

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Harness Derating Test Facility for Thermal Testing of Aerospace Harnesses

12-14 October 2016
ESA/ESTEC, Noordwijk, The Netherlands

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INTRODUCTION

For the sizing of aerospace harness designs worst cases generalized derating rules are usually applied from the aerospace standards [6]-[12]. However thermal testing of actual wire and bundle temperatures leads to improved harness designs in terms of weight and safety. The Netherlands Aerospace Centre (NLR) developed a dedicated test facility for accurate measurement of single wire and bundle temperatures at different electrical currents inside a predefined enclosure both in air as well in vacuum. The Harness Derating Test facility (HDTF [3]) is a modified thermal vacuum chamber that is used as altitude chamber by controlling the air pressure between ambient, high altitude (low pressures and low temperatures) and vacuum (deep space) conditions. Rectangular shaped enclosures are available for convective circulation of air and IR heat transfer as relevant for enclosed aerospace systems. Baseline setup is that the top and bottom plates are cooled. The HDTF (**Fig 1**) is specially designed for validation of thermal models of single wires and bundles. Other components such as connectors, resistors and heaters can also be tested using the HDTF. The development of the HDTF has been partly funded by the EU- Clean Sky JTI project[1] [5] for testing of aircraft harnesses inside a representative wing boxes and is currently being prepared for ESA [4] for single wire rating and bundle derating tests in vacuum.

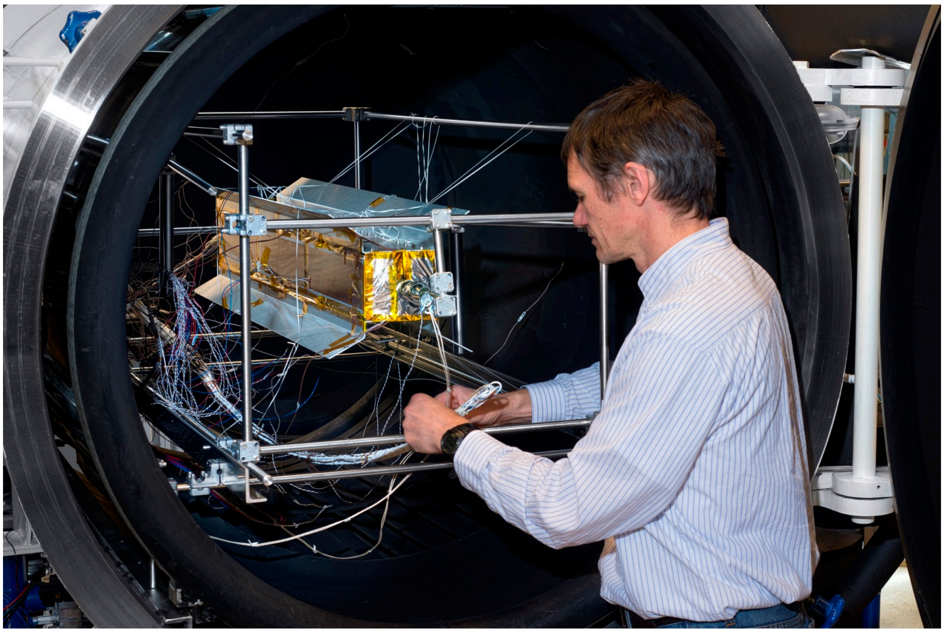

Fig 1 The Harness Derating Test Facility at NLR preparing for a bundle sample inside a wing box enclosure [5].

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[1] The research leading to these results has received funding from the European Union's Seventh Framework Program (FP7/2007-2013) for the Clean Sky Joint Technology Initiative under grant agreement number CSJU-GAM-SFWA-2008-001. Because aircrafts are increasingly more electric, the Electrical Wiring Interconnection System of Aircraft becomes more complex and larger while the available space is more constrained especially in wing areas. Technologies demonstrated in Clean Sky JTI to reduce size and weight are: (1) Fluidic Actuator System, (2) Electro-Mechanical Actuation and (3) Compact Wiring. The Fluidic Actuated System blows air to increase laminar flow over the flap during takeoff and landing, reducing flaps size at the same lift. Electro-Mechanical Actuation replaces hydraulic actuation to move flaps and slats. The third technology demonstrated is Compact Wiring. Separation distance between wiring bundles and adjacent structures is reduced to minimize the space occupied.

BACKGROUND

The derating rules in the standards [6]-[12] are combination of the Single Wire Current (i.e. the rating as function of temperature) and subsequently a derating factor to be applied indiscriminately for the whole harness. Besides the surprisingly ambiguous definition in the standards, this coarse approach does not respect local environmental constrains for modern aerospace harness to their full extent [2]. For example narrow or insulated enclosures, solar radiation and hot surfaces are fully neglected in the standards leaving this for the judgment of the harness engineers. This situation leads to large uncertainties and potential failures for harness designs with respect to the actual wire temperatures in aerospace systems. It is considered that experimental verification of the derating rules and thermal analysis of harness designs could lead to a relaxation/optimization of electrical systems which in turn could:

- Save a significant mass of both the harness and connectors
- Facilitate integration with smaller diameters and lower bend radii wiring
- Support miniaturization of electrical interfaces
- Improve design robustness
- Improve reliability and safety

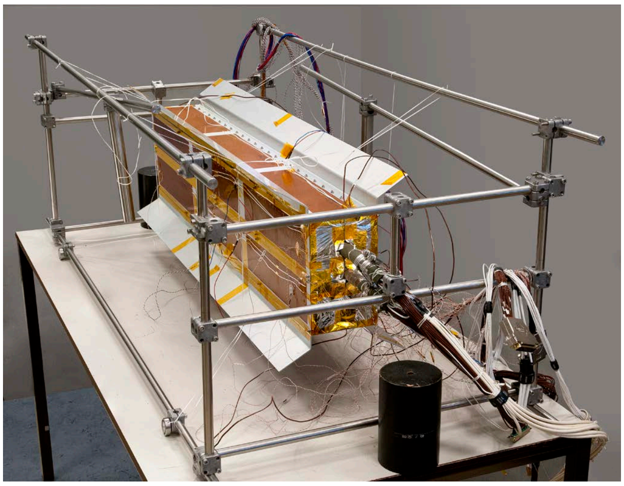
To support these developments, the Netherlands Aerospace Centre (NLR) developed a dedicated test facility for accurate measurement of single wire and bundle temperatures at different currents inside pre-defined enclosures, both in air as well in vacuum. The HDTF has been used for testing of aircraft harnesses inside representative wing enclosures with the objective to verify if the volume occupied by the harness can be reduced [5] and is currently prepared for single wire rating and bundle derating test in vacuum with the objective to improve the ECSS derating standard [4].

TEST FACILITY DESCRIPTION

An existing TV facility (Thermal Vacuum Chamber, Ø90cm) at NLR has been upgraded towards an Altitude Chamber to allow testing of items under low temperature and low pressure conditions. Instead of ambient air, dry nitrogen gas is applied to prevent water condensation. Since ambient air already contains 80% nitrogen this does not affects convective patterns. One or multiples wires or bundles will be tested in the facility for an ESA project [4] and two enclosure boxes have been applied for an EU project [5]. An adjustment of the enclosure dimensions and replacement of internal surface materials are possible. The following configurations are available for testing of multiple wires and bundles:

- Wire or bundle sample lengths of 1 meter[2]
- Variable options for attachment using springs or counter balancing weights to prevent bending of samples.
- Direct exposure to the shroud (Fig 4)
- Variable sink temperature (-60°C to + 110°C)
- Variable pressure conditions (<10^{-5}mbar (high vacuum) and 10mbar to 950mbar. At ambient pressure the facility door opens)
- Variable enclosure cross sections from 4”x 4” to 4”x 8” (Fig 2 and Fig 3)
- Variable bundle positions within enclosure box (Fig 3)
- Exchange of enclosure wall materials (Aluminium or CFRP)
- MLI covers at both ends of the enclosure to supress air movements in axial direction.

Fig 2. One bundle within a nominal enclosure (4”x4”) for tests in air.
Top and bottom fins are applied for radiative cooling of the enclosure [5].



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[2] Theoretically 19 single wires or 3 bundles (Fig 4) can be simultaneously accommodated in the facility maintaining a distance of 20 cm and 50 cm respectively supressing the view factors between the wires or bundles to less than 1%. In practice the in number of samples is limited by the capacity of the feedthroughs of the facility.

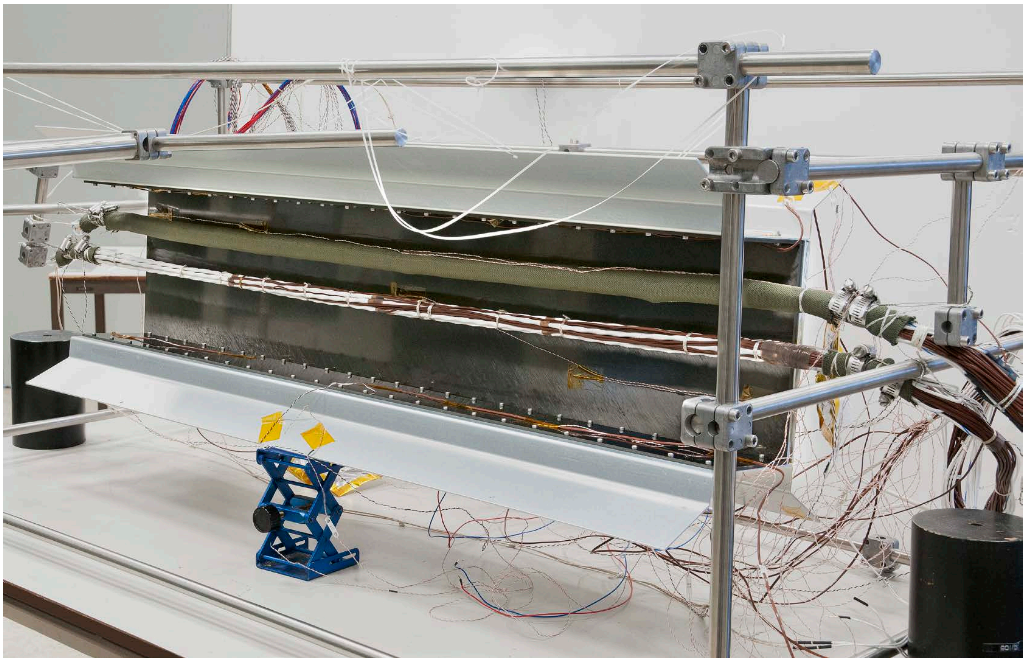
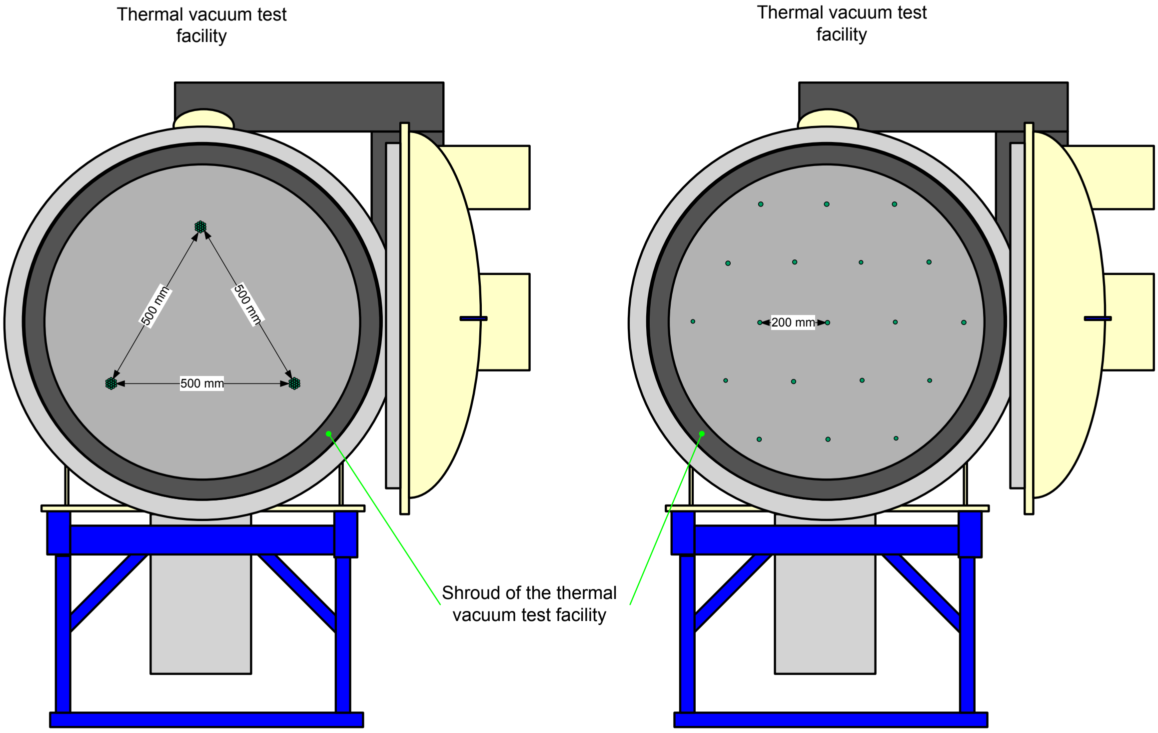


Fig 3. Two bundles within an enlarged enclosure (4”x8”) with CFRP walls for tests in air
The bundle positions can be adjusted within the enclosure [5].



Setup with three sample bundles up to 15 mm each.

Setup with nineteen sample wires up to 1.5 mm each.

Fig **4.** Cross-section for the testing of 19 single wires and 3 bundles for tests in vacuum [4]

SAMPLE INSTRUMENTATION

See Fig 5 for an example for the instrumentation that is required for the testing of a bundle sample having current injection into several wire groups, sense wires for four point power measurements and thermocouples for temperature measurements.

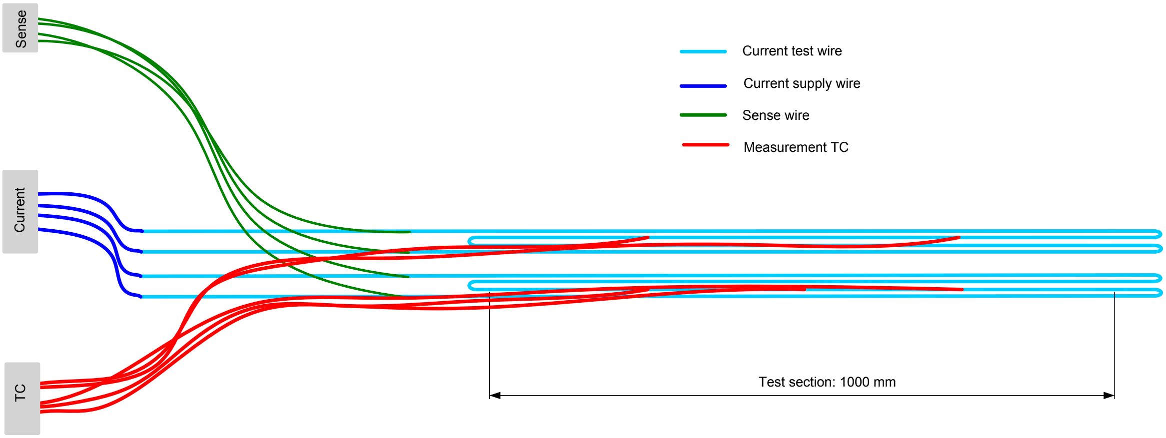


Fig 5 Example of the instrumentation required for a bundle sample

The following instrumentation is discussed in the section below for single wires and bundle samples.

- Thermocouples (type T) for conductor and dielectric temperature measurements.
- Four points voltage drop for measurements of the electrical resistance and power
- Dielectric emissivity measurement from the equilibrium temperature of single wires
- Infrared (IR) camera

Thermocouples (type T)

Calibrated and carefully installed thermocouples have an accuracy of better ±0.5°C between -50°C up to 250°C. The thermocouples are applied onto the core or the dielectric surface of a wire and fixated with tape. For the single wires tests in vacuum the thermocouples are heated using a small heater (Fig 6) in order to minimize the heat leak from the wire to the thermocouples.

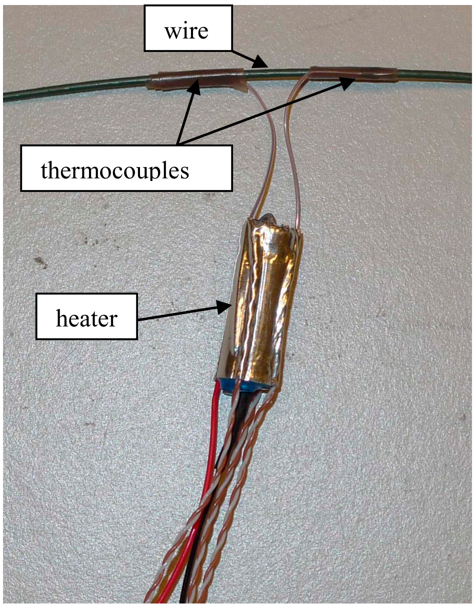


Fig 6 Example of the thermocouple instrumentation for a single wire using a heater measuring both the core and dielectric surface temperature [4]

Electrical Resistance

The electrical resistance and power dissipation as function of temperature of a wire (see Fig 7) is measured by applying a four point's measurement for voltage drop and current. Vice versa after calibration temperatures can be calculated from the resistance. An advantage is that the conductor temperature is directly measured without disturbing the heat balance due to instrumentation. The electrical resistance (R) of a conductor is a linear function of the temperature difference.

$$R(T) = R_o\,[1 + \alpha(T - T_0)] \tag{1}$$

With R_o the wire resistance at room temperature and α, the temperature coefficient of the conductor material such as copper (α =.00386 K-1) or aluminium (α =.00429 K-1). The thermal coefficient and R_o of each wire is calibrated in a temperature controlled environment applying a small current to minimize self-heating. While the voltage drops are quite small, temperature measurement accuracies between ± 2.5°C have been demonstrated in initial experiments (Fig 8). However in some cases differences up to ± 10°C were measured which could not be fully explained. Additional investigation is ongoing to improve the method such that implementation in future tests will be possible.

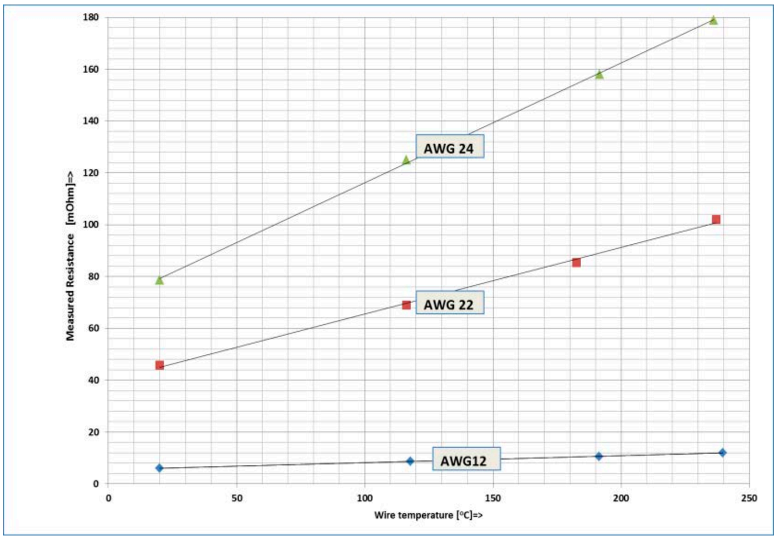


Fig 7. Example of electrical resistance measurements of single wires (AWG12, 22 and 24) as function of temperature.

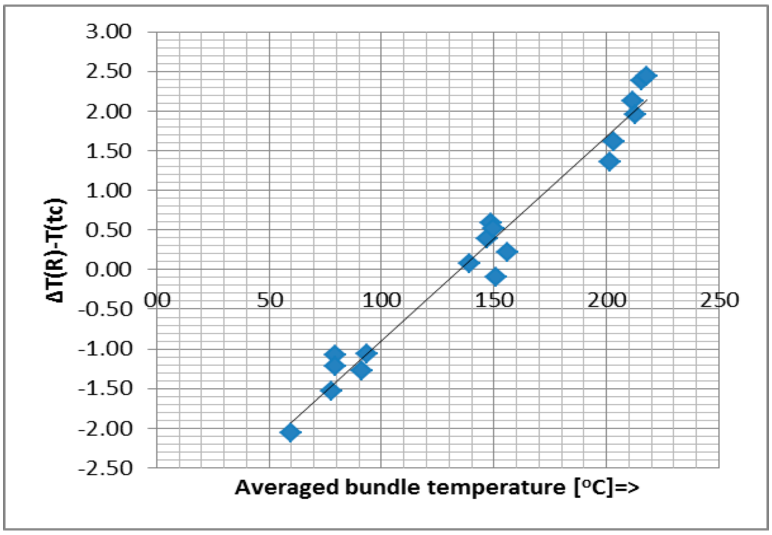


Fig 8. Example of the difference (up to ±2.5°C) between both temperature measurement methods based on resistance T(R) and thermocouples T(tc) as function of averaged bundle temperature [5]

Emissivity measurements

The external emissivity (ε) of a wire is usually between 0.7-0.9 related to the dielectric insulation and can be taken from the radiative heat balance equation of a wire in vacuum neglecting axial conduction and convection:

$$I^2 R(T) = \sigma \varepsilon A_{ext} (T_{ext}{}^4 - T_{env}{}^4) \quad (2)$$

With I the current load, R the electrical resistance (*per meter*) of a piece of wire, A_{ext} the external dielectric surface area ($A=\frac{1}{4}\pi L d^2$, d is the external wire diameter) and T_{ext} the temperature of the outer surface and T_{env} the environmental temperature to the fourth power and $\sigma=5.67E\text{-}8 Wm^{-2}K^{-4}$. Note that the wire length (L) for both the resistance and the surface area cancels out of the equation. By correlation with the steady state test results measurement accuracy for emissivity measurements of the external surface of a wire of better than ±0.1 is expected. Verification and improvement of the emissivity measurement of wires is ongoing [4].

Infrared (IR) camera

The conductor and dielectric surface temperatures can also be observed with an infrared camera for contactless verification of the temperature differences between the conductor core and outer surface. By removing a part of the dielectric insulation of wire, both the outer surface and the conductor core can be observed simultaneously. A test done in ambient air on a heated wire (by applying a current) to ca 100°C showing a temperature difference up to 16°C between the conductor and the outer surface as can be seen in Fig 9. A relative measurement accuracy of ±2°C has been demonstrated for these initial experiments. Similar tests can be conducted in vacuum. However this requires either an IR transparent window or an IR camera prepared for use inside a vacuum chamber.

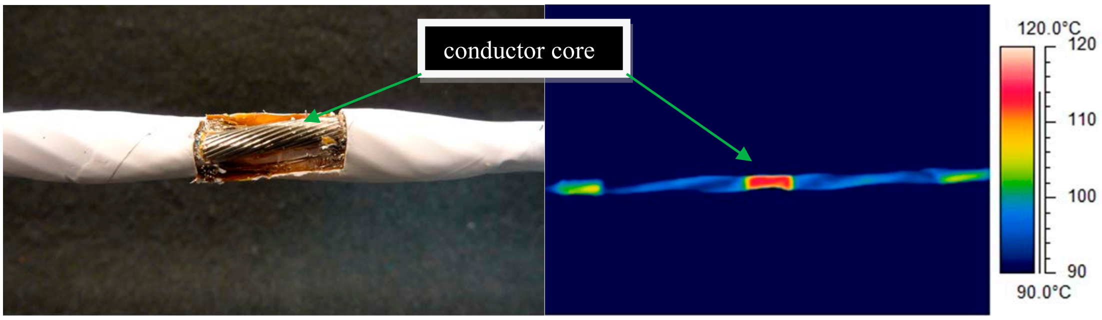


Fig 9. Example of a piece of wire with a small part of the insulation removed such that the conductor and dielectric surface are observable in the visual (left) and infrared (right) to demonstrate IR temperature measurements [4]

TEST RESULTS

Several test campaigns have already been conducted with the HTDF for testing of aircraft harness samples in low pressure air and enclosure conditions representative for a wing box environment. See Table 1 for an example of the test results for a bundle (OD=12mm) with a metallic braid in a 4"x 4" aluminium enclosure [5]. The bundle temperature is obtained from the unweighted averaged of the installed thermocouples. Similar tests (without enclosures) are currently being prepared in vacuum for testing of single wires and bundle samples [4]. The first results are being expected end-off this year (2016).

Table 1 Example test results for an aircraft bundle in a wing box environment in air at different pressures, temperatures and power conditions [5]

	Pressure	**T_{sink}**	**Current**	**Power**	**T_{bundle}**
Test case T2.1c	mbar	°C	Amps	Watt	°C
C1	43.9	-47.7	15.98	37.79	91.0
C10	300.6	24.8	19.09	63.92	148.9
C18	950.3	98.2	20.90	89.69	212.9

References

[1] Roel van Benthem, Simon Taylor, Kees Nuyten e.a "Thermal Analysis Of Wiring Bundles For Weight Reduction And Improved Safety", *41st International Conference on Environmental Systems*, AIAA 2011-5111

[2] Roel C van Benthem, Marc Malagoli, Bastien Bonafous at all, "Derating Standards And Thermal Modelling Tools For Space Harness Designs", *45th International Conference on Environmental Systems*, ICES-2015-59

[3] Wubbo de Grave, Roel van Benthem, Marc Malagoli, "Development Of Derating Test Facility For Space Harness Designs*", Space Passive Component Days 1st International Symposium 2013 ESA/ESTEC*

[4] ESA project "Improved design and use of electrical harnesses", ITT AO/1-8329/15/NL/SW.

[5] European Project "CleanSky1 - Smart Fixed Wing Aircraft - Integrated Components Demonstrator (SFWA-ITD) – Thermal testing.

[6] ECSS-Q-ST-30-11C Rev 1 (ESA, 2011) European Cooperation for Space Standardization, "Space Product Assurance, Derating - EEE Components", Chapter 6.32 Wires and cables -

[7] EEE-INST002 3/05 (NASA/TP—2003–212242) "Instructions for EEE Parts Selection, Screening, Qualification and Derating"

[8] SAE-AS50881 D (SAE, 2010) SAE Aerospace, "Aerospace Standard, Wiring Aerospace Vehicle"

[9] SMC-S-020 (USAF, 2004) Air Force Space Command Space and Missile Systems Center Standard, "Technical Requirements for Wring Harness, Space Vehicle"

[10] JERG-2-212 N1 (JAXA, 2008), Japanese's Space Agency "Design Standard Wire Derating"

[11] DOD-W-W83575A (1977), USAF, "Military Specification Wiring Harness, Space Vehicle, Design And Testing"

[12] MIL-STD-975M (NASA, 1994) Military Standard, "NASA Standard Electrical, Electronic and Electromechanical (EEE) Parts List"

AUTHORS

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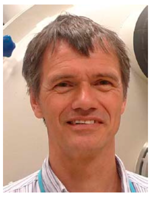
Roel graduated at Twente University in 1990 where he studied applied physics. Is employed for 26 years in the aerospace industry (Fokker Space and NLR) as thermal engineer and R&D project manager. Since 2008 he was involved in reviewing the industrial standards about derating analysis of harness designs and validation testing of thermal modeling for the aerospace industry. He wrote three papers [1], [2] and [3] about the subject in which he discusses margins in the aerospace derating standards indicating that improvement of the aerospace derating standards could lead to significant weight saving and improved safety.

Wubbo de Grave B. Eng.



Wubbo graduated from Haarlem Technical College in 1988 where he studied aeronautical engineering. Is an application engineer employed for 27 years at NLR with 20 years of experience in space projects. He was responsible for the instrumentation and assembly of the third Dutch satellite SloshSat and build several single and two phase cooling systems. Since 2008 he performed environmental tests to validate hardware and thermal models of wires and wire harnesses for the aerospace industry He wrote a paper about the development of the HDTF [3].

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