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DEFENCE AND SPACE

Harness Optimization by Improvement of the Derating Standard ECSS-Q-ST-30-11C

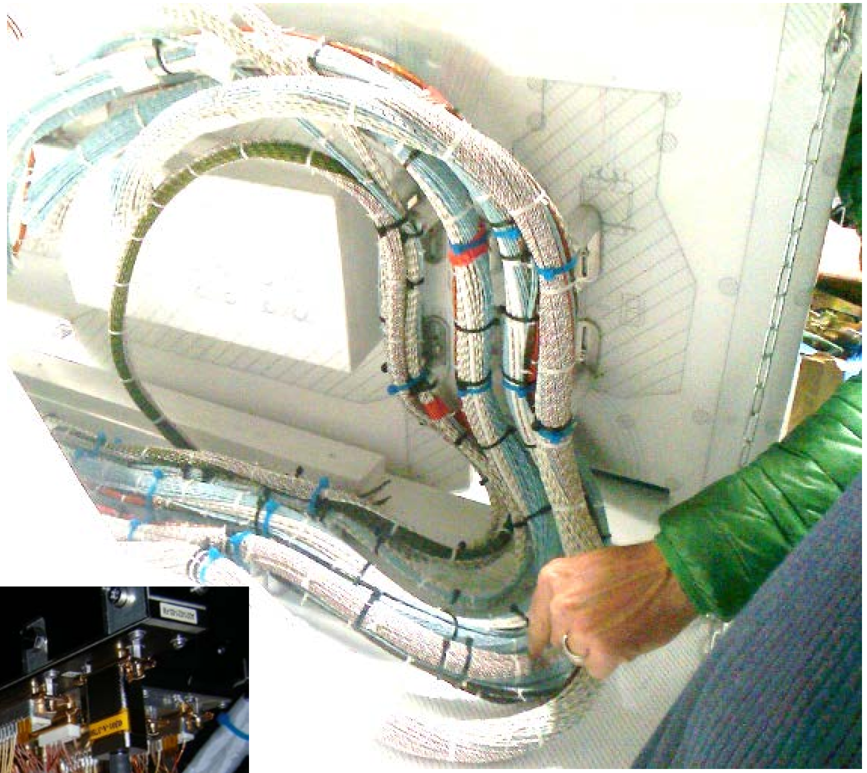
Space Passive Component Days
ESA/ESTEC, Noordwijk, The Netherlands

Marc MALAGOLI
10 October 2018

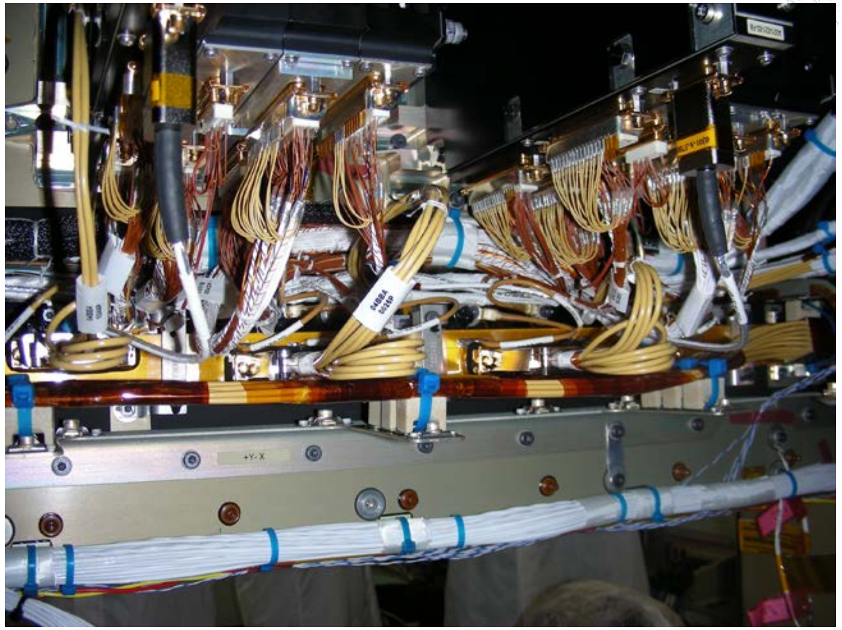
Space Harness Optimization

Mass and Volume are critical in Space.

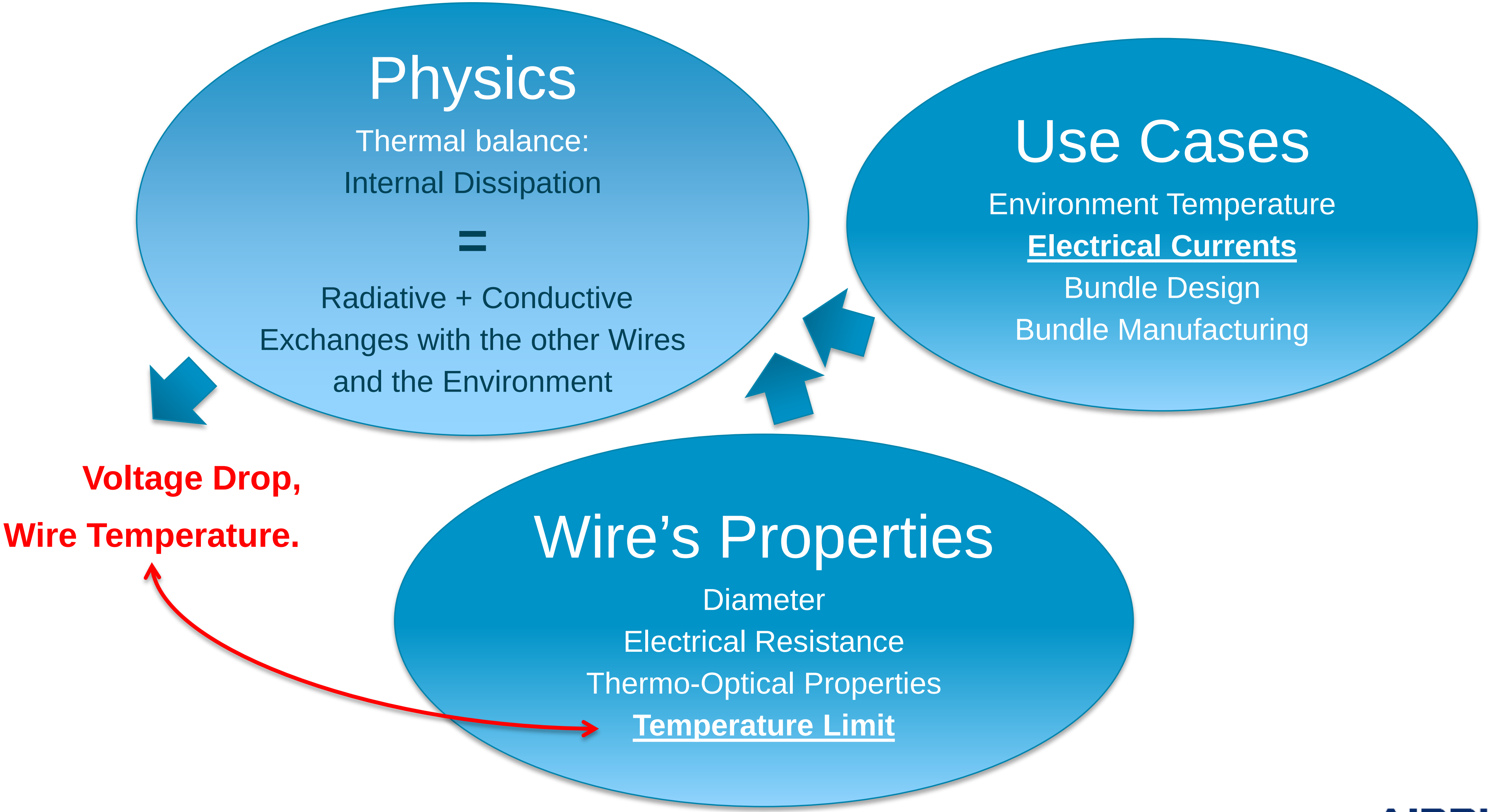
The Harness mass can exceed 250kg.
Bundles can gather hundreds of wires
with total diameters exceeding 5cm



The Harness MUST BE optimized



Harness Sizing Drivers



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Current Sizing Rules: Derating Standards for Wires & Cables

ECSS-Q-ST-30-11C Rev 1

(ESA, 2011) European Cooperation for Space Standardization, "Space Product Assurance, Derating - EEE Components".

NASA - EEE-INST002 3/05

(NASA/TP—2003–212242) "Instructions for EEE Parts Selection, Screening, Qualification and Derating"

JAXA - JERG-2-212 N1

(JAXA, 2008), Japanese's Space Agency "Design Standard Wire Derating"

However, the standards are limited to specific conditions of environment and they differ significantly between the agencies. (e.g.: 70°C for Nasa & JAXA, 40°C for ESA).

An ESA-funded review of main standards concluded in 2015:

"Experimental and theoretical verification of the wire rating and bundle derating is recommended" *(*)*

(*) 45th International Conference on Environmental Systems ICE2015, 12-16 July 2015, Bellevue Washington, « Derating Standards and Thermal Modelling Tools for Space Harness Designs », Roel C van Benthem, Fennanda Doctor, Marc Malagoli, Bastien Bonnafous.

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New Test & Simulation Study – Technology & Research Program

A new ESA-funded 2-year project was started in 2016 with the following goals:

- To define sizing rules taking into account most of the sizing drivers with easy methods and clear justifications.
- To make possible further harness design optimization through simulation for complex use cases (e.g. partially loaded or flat shaped bundles).

The European Space Agency selected Airbus Defence and Space and the NLR to conduct this study.

It was completed this year. The work performed and the main findings are described in the paper and summarized hereafter.

General Approach

1) Define and implement a test campaign in vacuum for single wires and bundles.

2) Propose a thermal model for single wires and a simulation software for bundle thermal analysis.

3) Correlate the model and the software parameters with the test results.

4) Use the model and the simulation software to define new optimized sizing rules.

5) Propose an update to the ECSS derating rules.

Intensive Test Campaign

Hundreds of test cases have been performed at NLR, covering:

Single wires:

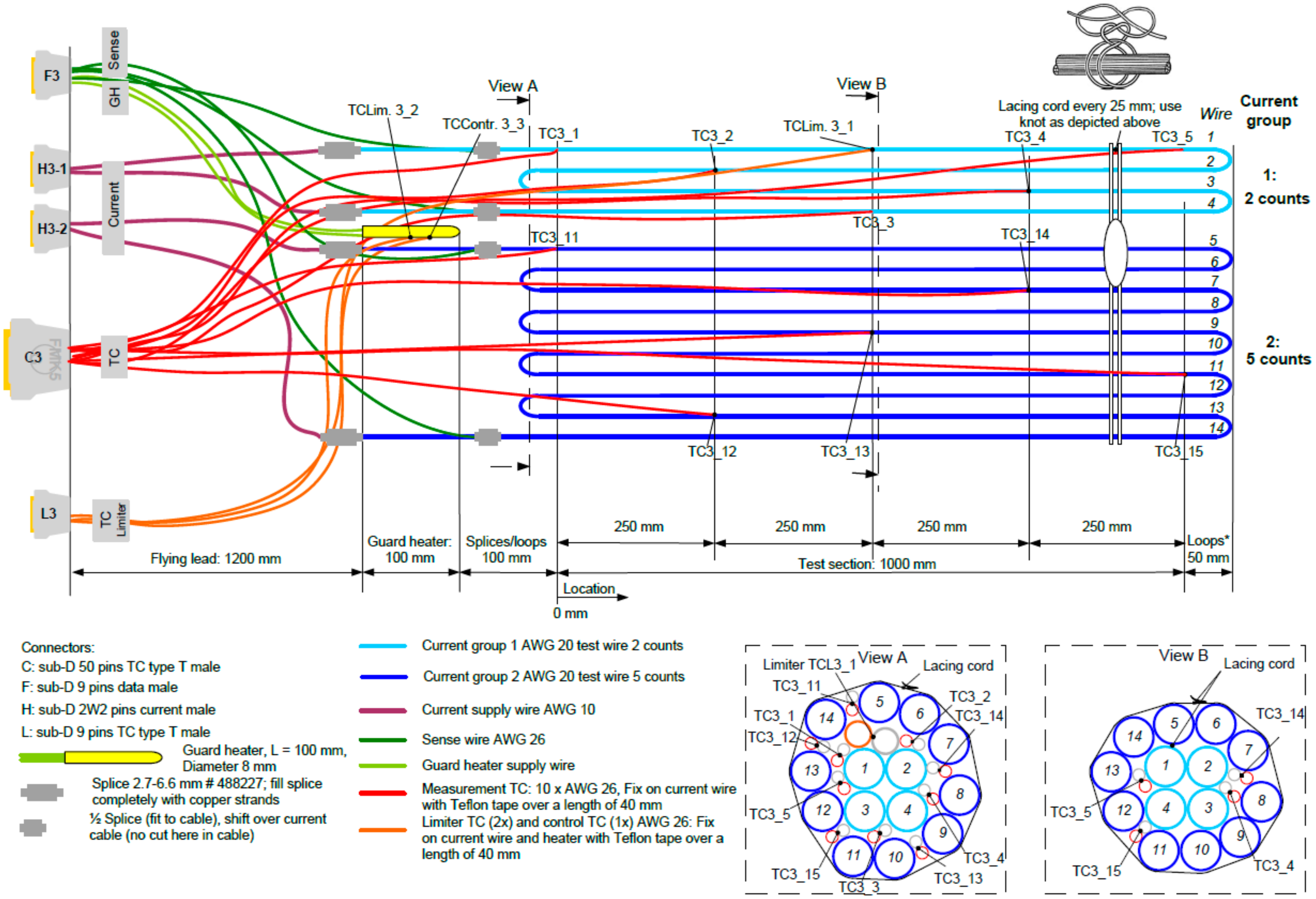
- 20 different wires samples (AWG 10 to 28, copper, aluminum and steel, with various insulation material).
- 3 different environment temperatures : -50°C, 25°C and 100°C
- Multiple current load conditions.

Bundles:

- 8 samples, from 6 to 200 wires, made of single gauge or mixed gauges wires.
- 3 different environment temperatures : -50°C, 25°C and 100°C
- Multiple loads, homogeneously applied in groups of wires.

The measurements included the wire’s physical parameters, the core and surface temperature at several locations on single wires and inside bundles, the electrical resistance, and the injected power.

Example of Test Set-up for Bundles



Test set-up in the NLR Harness Derating (TV) Test Facility

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Thermal Formulation for Single Wires

Main assumptions:

- The thermal exchanges between the wire and the vacuum chamber environment are predominantly based on radiative exchanges.
- The environment is considered as a black body with absorptivity = 1, and no solar flux is applied on the wire.
- The wire is assumed to be of infinite length.

With these hypotheses, the physical model can be formulated as:

$$I = \sqrt{\frac{\varepsilon . D . \pi}{R_{Tref}}} \times \sqrt{\frac{\sigma({T_{wire}}^4 - {T_{env}}^4)}{1 + C_t(T_{wire} - T_{ref})}}$$

With:

C_t = Coefficient of temperature for the wire resistance [K-1]

I = Direct current [A]

ε = Thermal Emissivity of the wire's surface [-]

D = Wire's external diameter [m]

σ = Stephan-Boltzman constant = 5.67 E10-8; [Wm-2K-4];

T_{wire} = Wire temperature [K] neglecting the small gradient between the dielectric and the conductor

T_{ref} = Reference temperature for the resistance (293.15K was considered in this paper) [K]

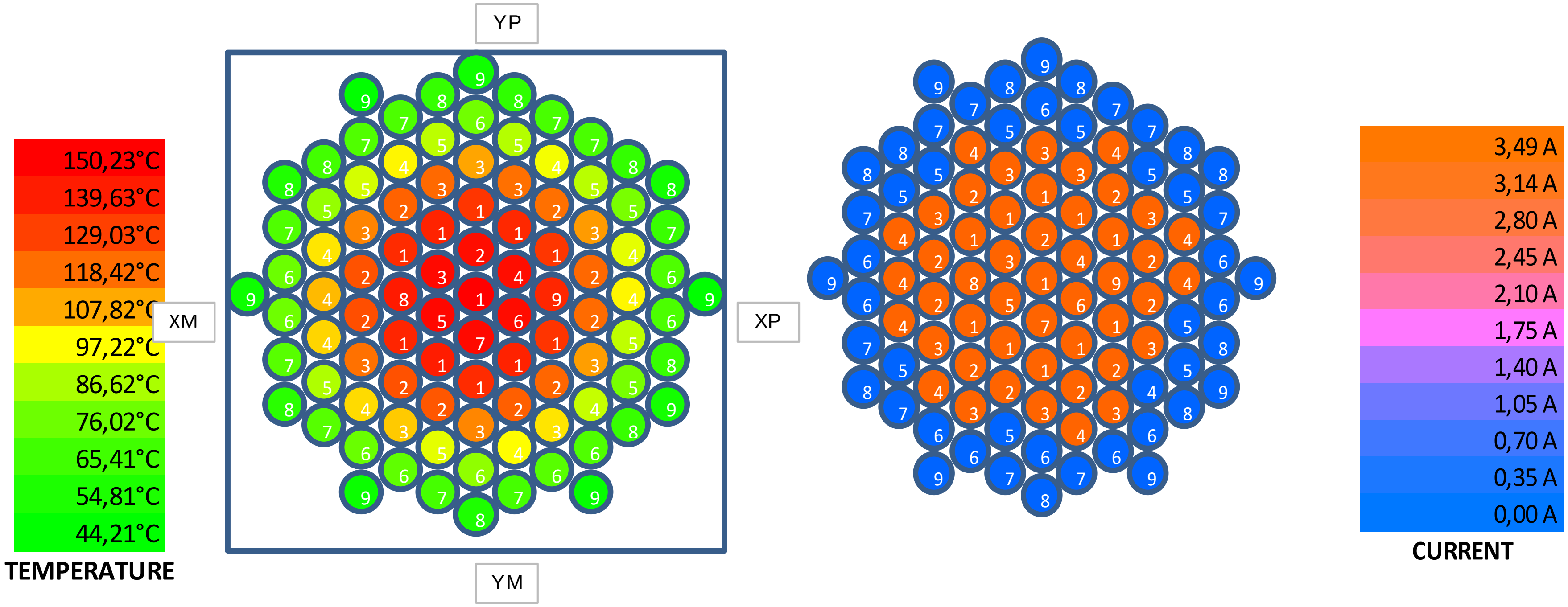
T_{env} = Temperatures of the environment considered as a black body [K].

$R_{T_{ref}}$ = Ohmic resistance (ohm/m) at T_{ref} [Ω/m]

Simulation Software for Bundle Thermal Analysis

Software : TTC / BundleTemp :

- Was developed by Airbus Defence and Space several years ago, and currently used for satellite design.
- Successfully evaluated during the previous ESA study in 2015.
- Able to generate and simulate bundle configurations quickly and easily.



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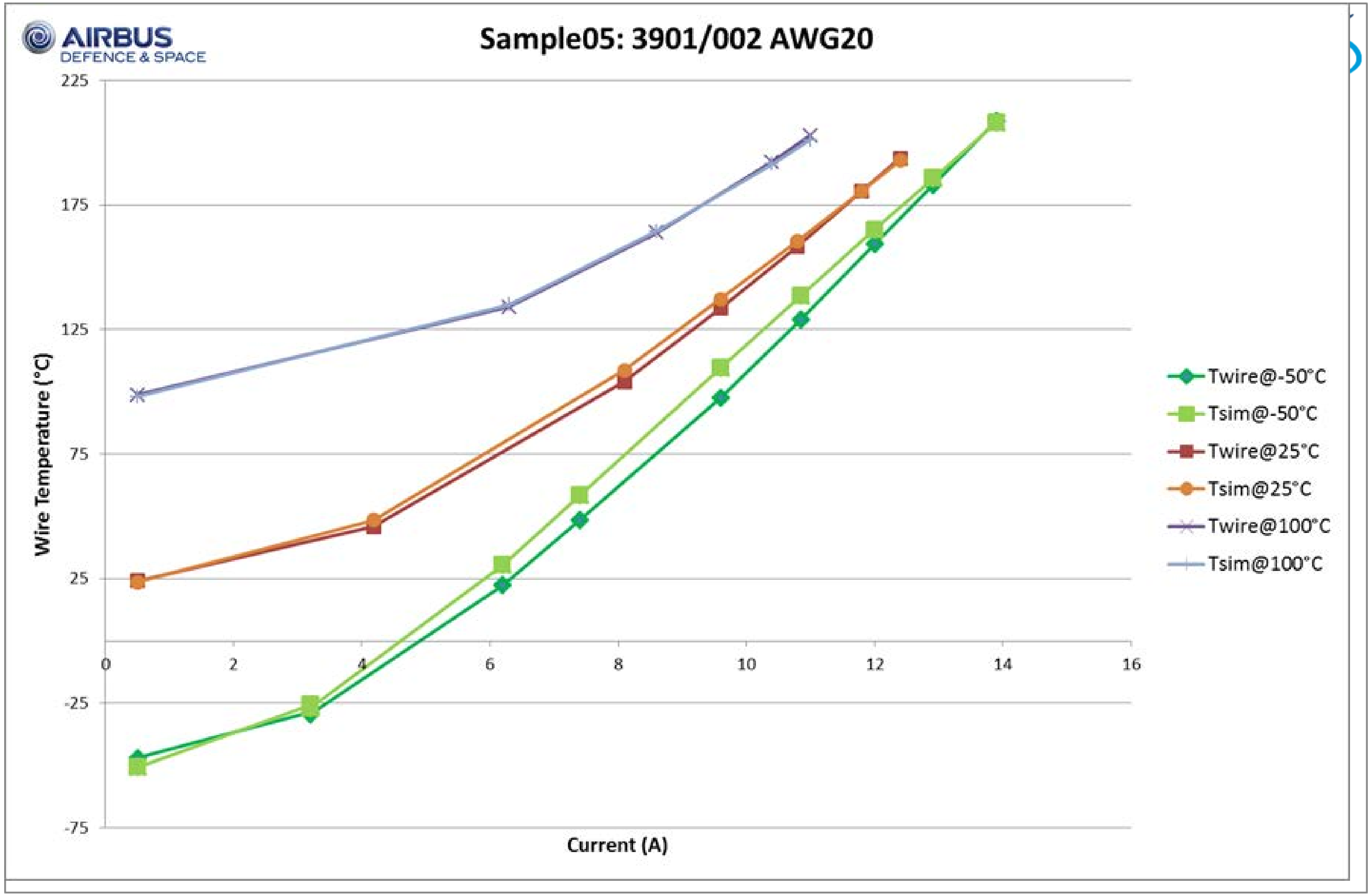
Correlation with the test results – Single Wires

All of the test results have been compared to the thermal model and have shown a good correlation.

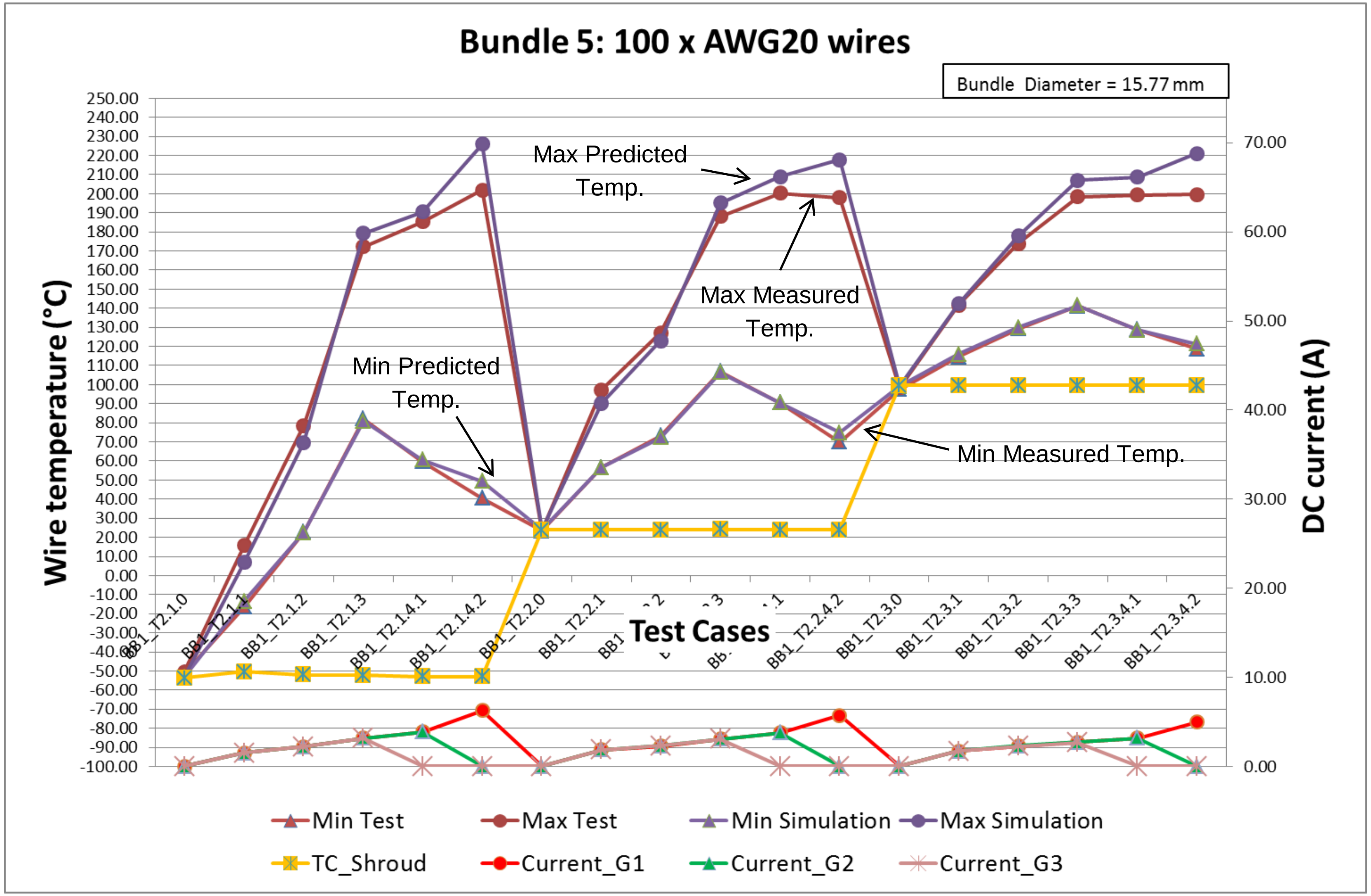
The Emissivity was evaluated around 0.85 to predict the temperatures slightly worst case, but probably higher in practice.



Correlation with the test results – Bundles

All of the bundle test cases have been simulated and correlated with the experiment.

The correlation shows that the thermal conduction factor within the bundle depends on the size of the bundle.



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Thermal Model vs. Derating Standards

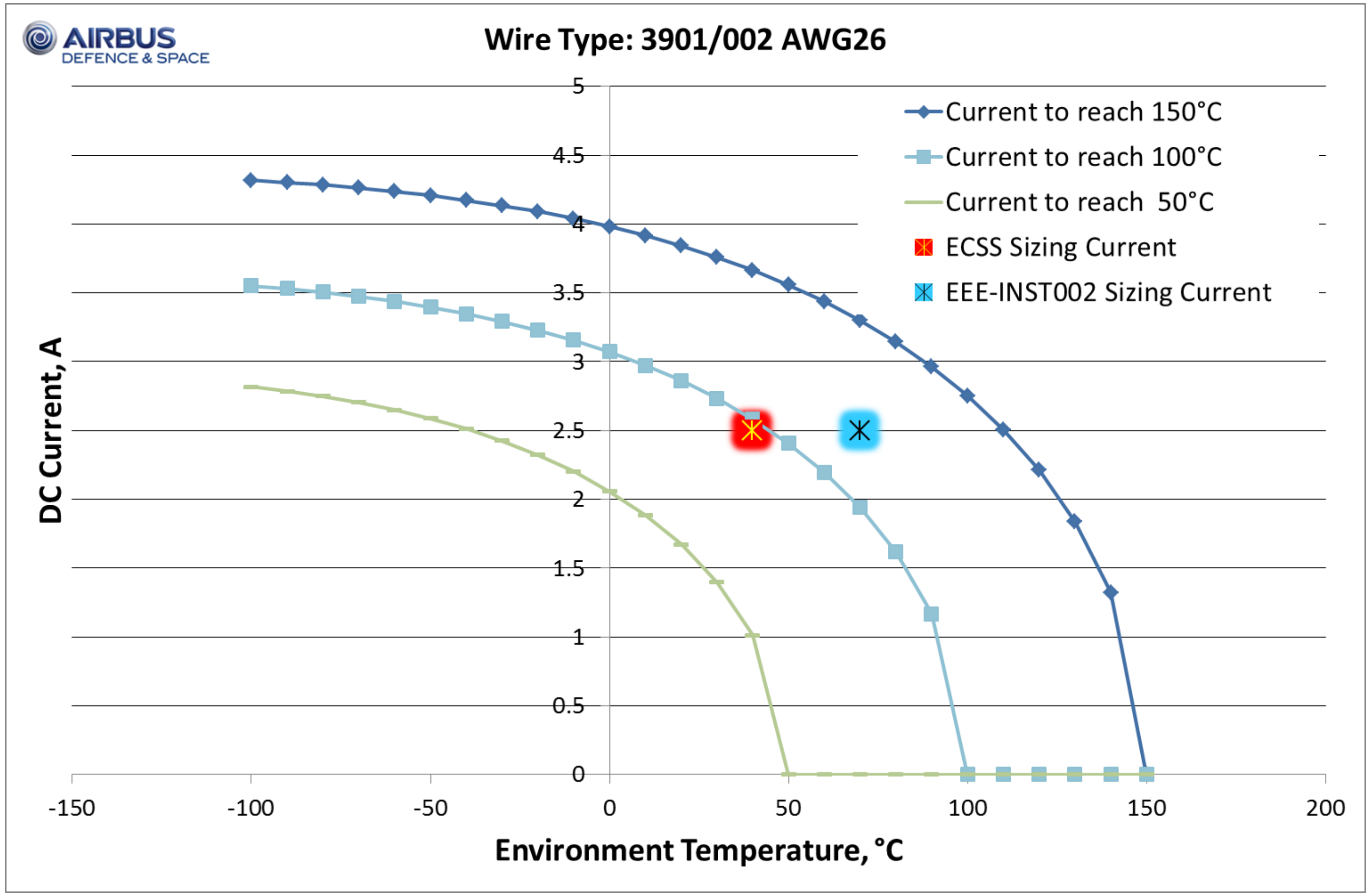
More than 3 000 additional use-cases have been simulated to evaluate the actual electrical current-carrying capacity (ampacity) of single wires and bundles, varying:

- The environment temperature (from -50°C to 150°C).
- The maximum temperatures of the wire (100°C, 150°C, 200°C)
- The gauges and bundle diameters (from AWG10 to AWG28 and from 2 to 400 wires)
- The location of the power within the bundle, including partial loads.

Thermal Model vs. Derating Standards – Single wires

Example:
Values of Current to reach 150°C, 100°C or 50°C depending on the environment temperature.

These curves show the large room for improvement of the standards for the sizing current in this wire.
(The wire operating temperature is 150°C)



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ECSS-Q-ST-30-11C Single Wire sizing currents compared to the thermal model

Rating values have been computed using conservative parameters in the thermal formulation.

AWG	ECSS-Q-ST-30-11C [A] Environment Temperature= 40°C	Thermal Formulation [A]	Delta (%)
28	1.5	2.2	+48%
26	2.5	3.1	+22%
24	3.5	3.8	+11%
22	5	6.2	+25%
20	7.5	8.6	+15%
18	10	11.8	+18%
16	13	15.6	+20%
14	17	20.1	+18%
12	25	29.7	+19%

Thermal Model vs. Derating Standards - Bundles

The derating of the Single Wire current (I_{SW}) for bundles with N wires (I_{BW}) shall be calculated as:

$$I_{BW} = I_{SW} \times K(N)$$

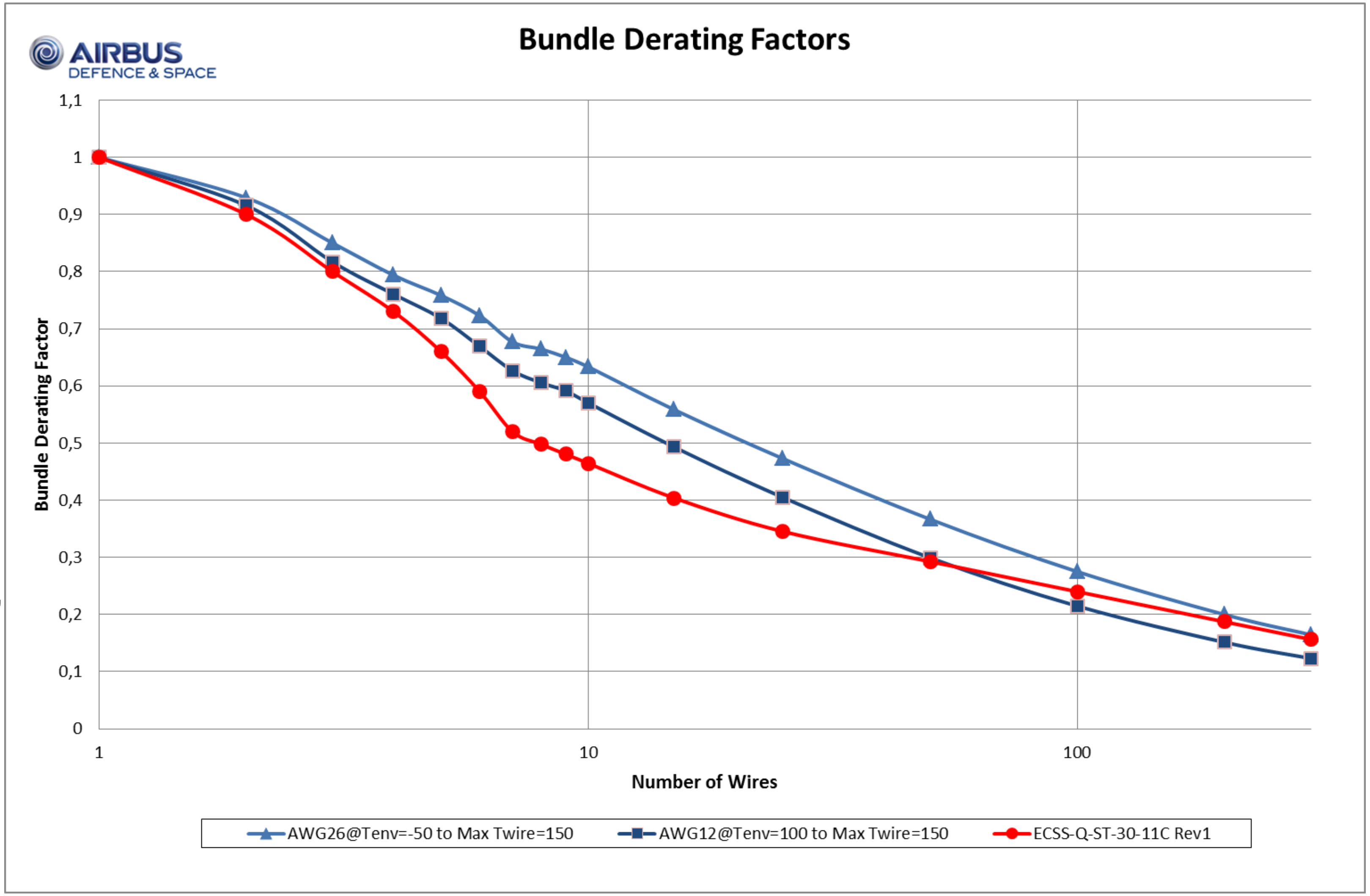
K(N) is the derating factor for wires in bundles. It’s value is between 0 and 1.

It represents the reduction factor to apply to the single wire current to reach the same “worst case” temperature in a bundle of N wires.

Thermal Model vs. Derating Standards – Bundles

The comparison between ECSS and simulations shows that:

- The ECSS is pessimistic for small bundles, but slightly optimistic for very large bundles
- The bundle derating factor is related to the wire count but does not heavily dependent of the wire gauge, environment temperature or wire’s temperature.



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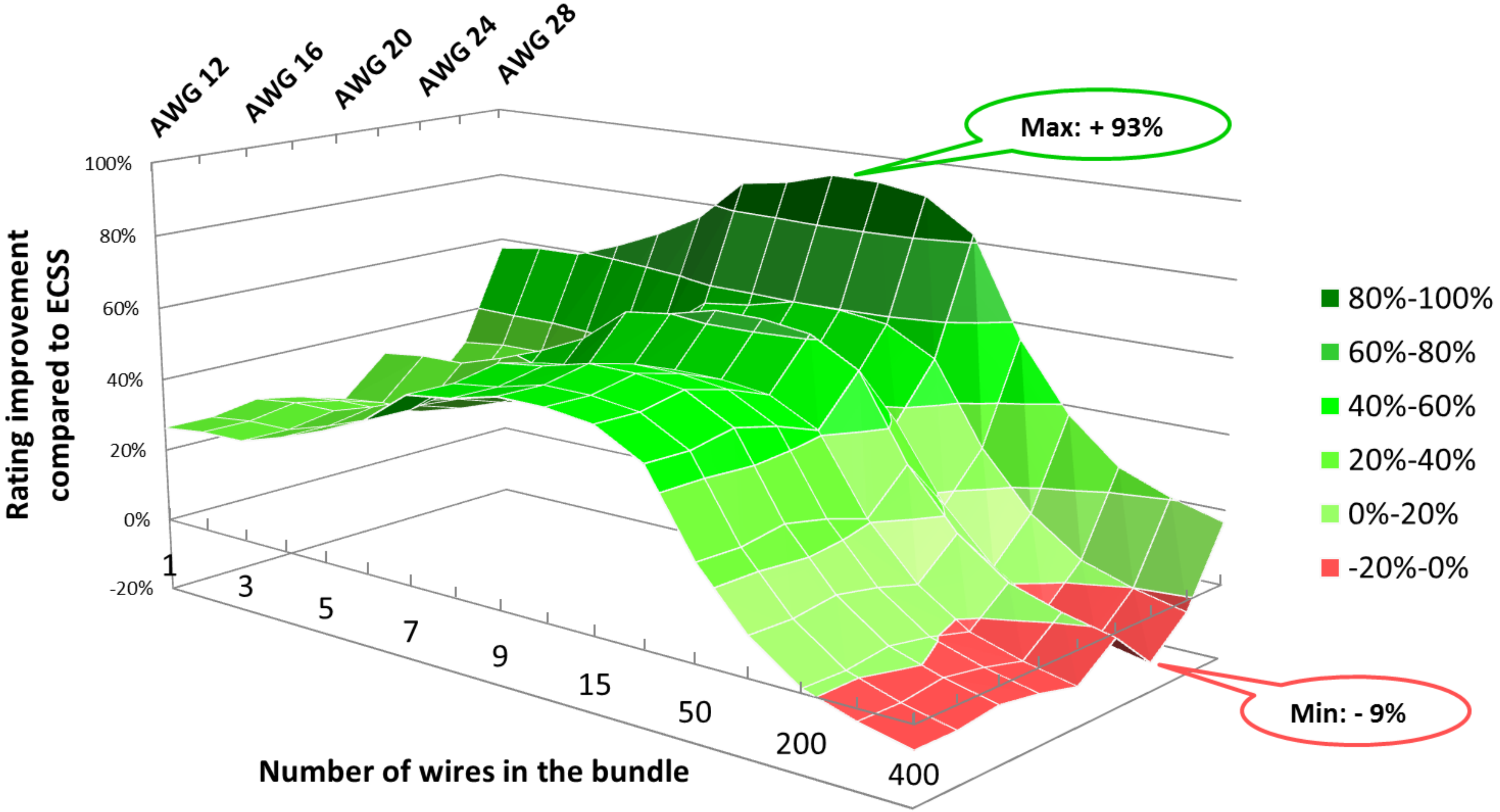
Overall Improvement for bundles compared to ECSS



Expected Mass Savings

The resulting mass saving for harnesses can only be evaluated for use cases, because it depends on conditions such as:

- The exact environment temperature.
- The total electrical power of the spacecraft (i.e. the payload mission).
- The architecture of the power distribution.
- The location of the electrical sources and loads.
- Many other factors…

On Airbus DS Telecom satellites, the mass saving could exceed 10% (~15kg) thanks to:

- The differences between the ECSS standard sizing rules and the thermal model.
- The ability to take into account the use cases, instead of a worst case environment temperature.
- The reduction of the number of wires in the bundles, thanks to the two above factors.
- The thermal simulation on critical power bundles with the actual currents.

Conclusion

- This study proposed a new approach for harness sizing based on well-known physical laws and thermal simulations algorithms. It is validated by tests in conditions representative of flight cases.

- It allows to optimize the harness mass with respect to the environment temperature and to the maximum allowed wire temperature.

- Except for very large bundles, it significantly increases the DC current that is accepted in a wire, compared to the ECSS and other standards. Expected mass saving could be tens of kilograms per spacecraft.

- An upgrade to the European Derating Standard for Wire and Cables (ECSS-Q-ST-30-11C) is proposed this year.

Thank you very much for your attention !

Questions ?