Thermal Modelling Studies of the ATLAS ITk Strip Barrel Staves Using ANSYS

Position Sensitive Detectors 14 (PSD14)
Queen Mary University of London, London, UK

Ali Awais*, Graham Beck, Adrian J Bevan, Ian Dawson, Aled Horner, Paul S Miyagawa, Seth Zenz

*a.awais@qmul.ac.uk

Abstract

The Phase-II upgrade of the ATLAS Inner Tracker (ITk) is being developed to operate in the high-luminosity phase of the LHC, where increased occupancy, radiation levels, and power dissipation place stringent requirements on detector performance. The upgraded system employs a fully silicon-based tracker with enhanced granularity and a two-phase CO_2 cooling system to ensure stable operation under these conditions.

This work presents finite element thermal models of the ITk barrel strip staves in both short-strip and long-strip configurations, developed using ANSYS. The models are used to study the thermal behaviour of the staves under nominal operating conditions and to evaluate their response under conditions approaching thermal instability. The analysis focuses on temperature distribution along the End-of-Substructure (EoS) regions and the associated thermal margins, as well as the sensitivity of the system to small variations introduced during assembly and construction.

Comparison with earlier ABAQUS models shows good agreement, with temperature differences of 0.3 – 1°C at module level, and maximum differences of 1.3°C and 1.7°C for the long-strip and short-strip staves, respectively. At stave level, the module sensor temperatures agree within 0.4°C, while the largest deviations are observed in the EoS regions, supporting the validity of the ANSYS thermal model.

ATLAS ITk Phase-II Upgrade

- **Designed for HL-LHC:** Handles higher luminosity and particle rates
- **High Granularity:** ~10 x more readout channels in the same volume
- **Advanced Electronics:** Faster and radiation-tolerant readout systems
- **All-Silicon Tracker**
  - **Inner Region:** Pixel Detector
  - **Outer Region:** Strip Detector
    - 4 Barrel Layers + 6 Endcap Layers

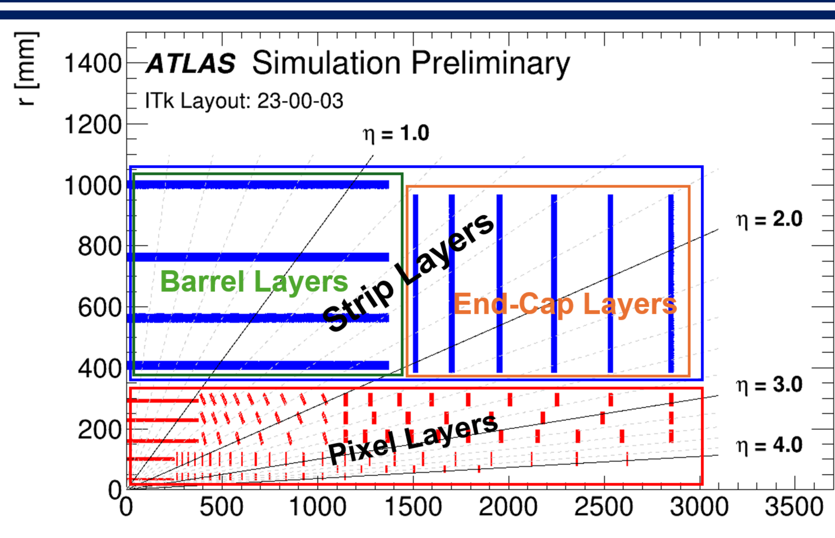
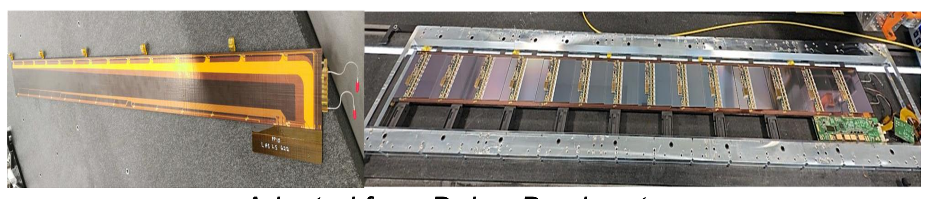


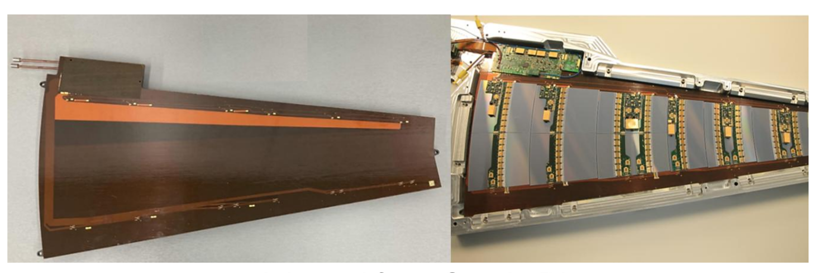
Figure Reference: "The ATLAS ITk strip local support structures"

Local Support Structures for Strip Detector



Adapted from Debra Dewhurst

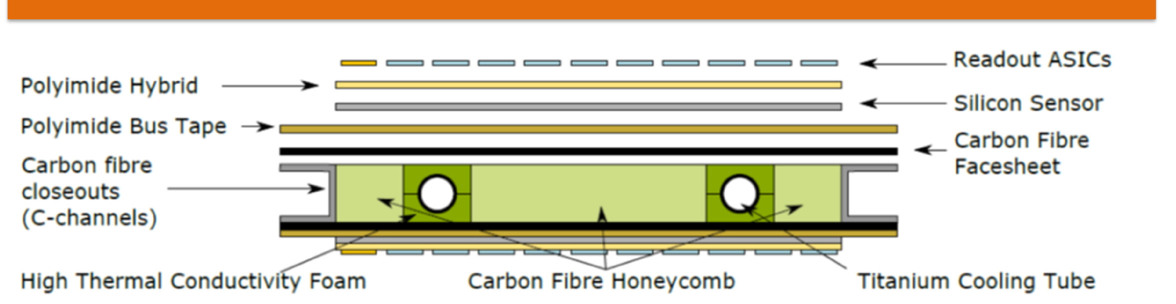
- **Petals (Endcap Region)**
  - Support structure for endcap modules
    - **12 modules per petal** (6 modules per side)
    - **One unique petal flavour** for the full tracker
  - **384 petals** installed in total
- **Staves (Barrel Region)**
  - Support structure for barrel modules
    - **28 modules per stave** (14 modules per side)
    - **4 stave flavours**
      - **LS-A, LS-C** (Long Strip Module Staves)
      - **SS-A, SS-C** (Short Strip Module Staves)
  - **392 staves** in total



Adapted from Sergio Diez

Stave Thermal Model

Stave Core Cross-Section



Module Design

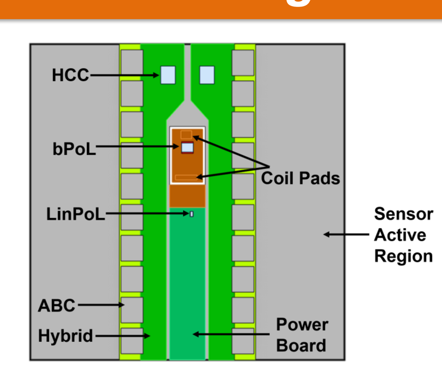
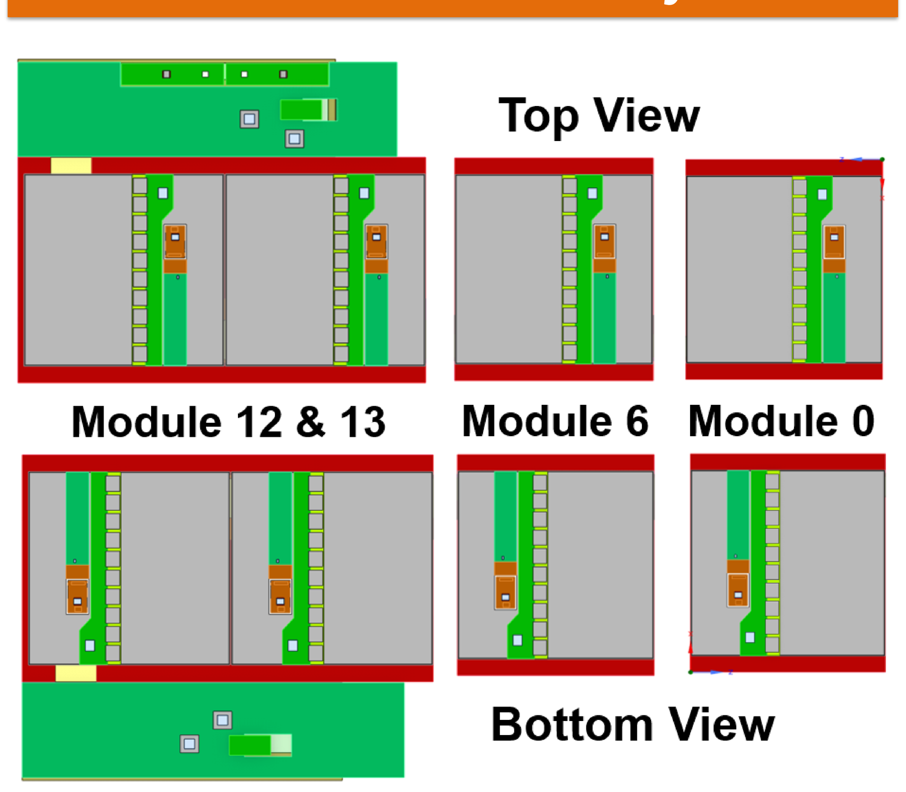
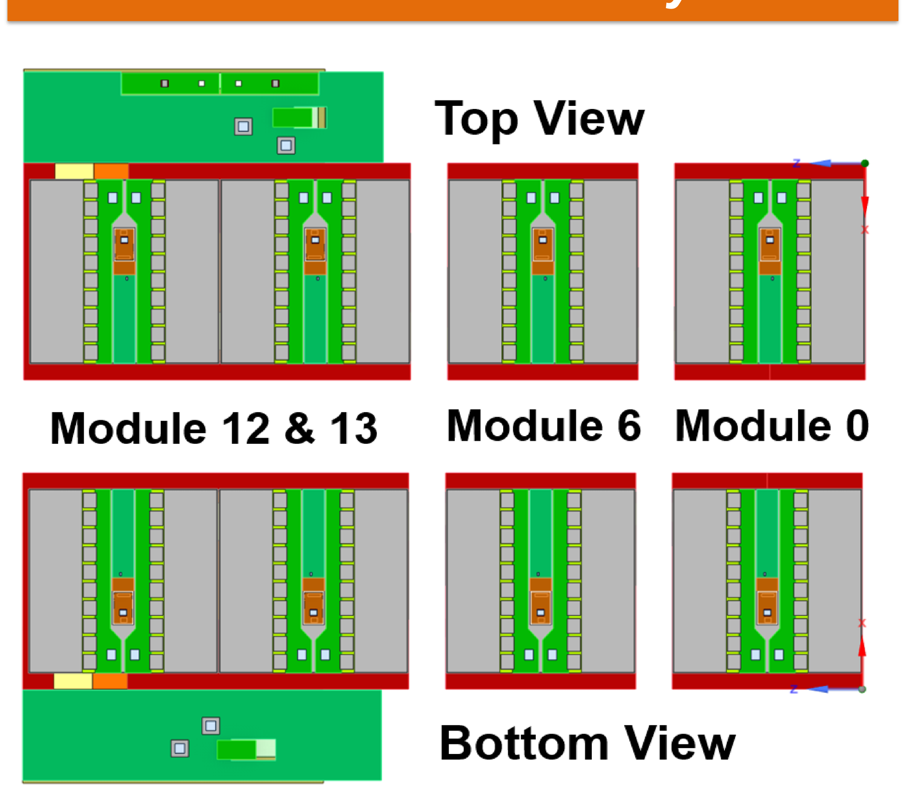


Figure Reference: "ATLAS Inner Tracker Strip Detector, ATL-TDR-025 LHCC-2017-005"

LS Stave Geometry



SS Stave Geometry

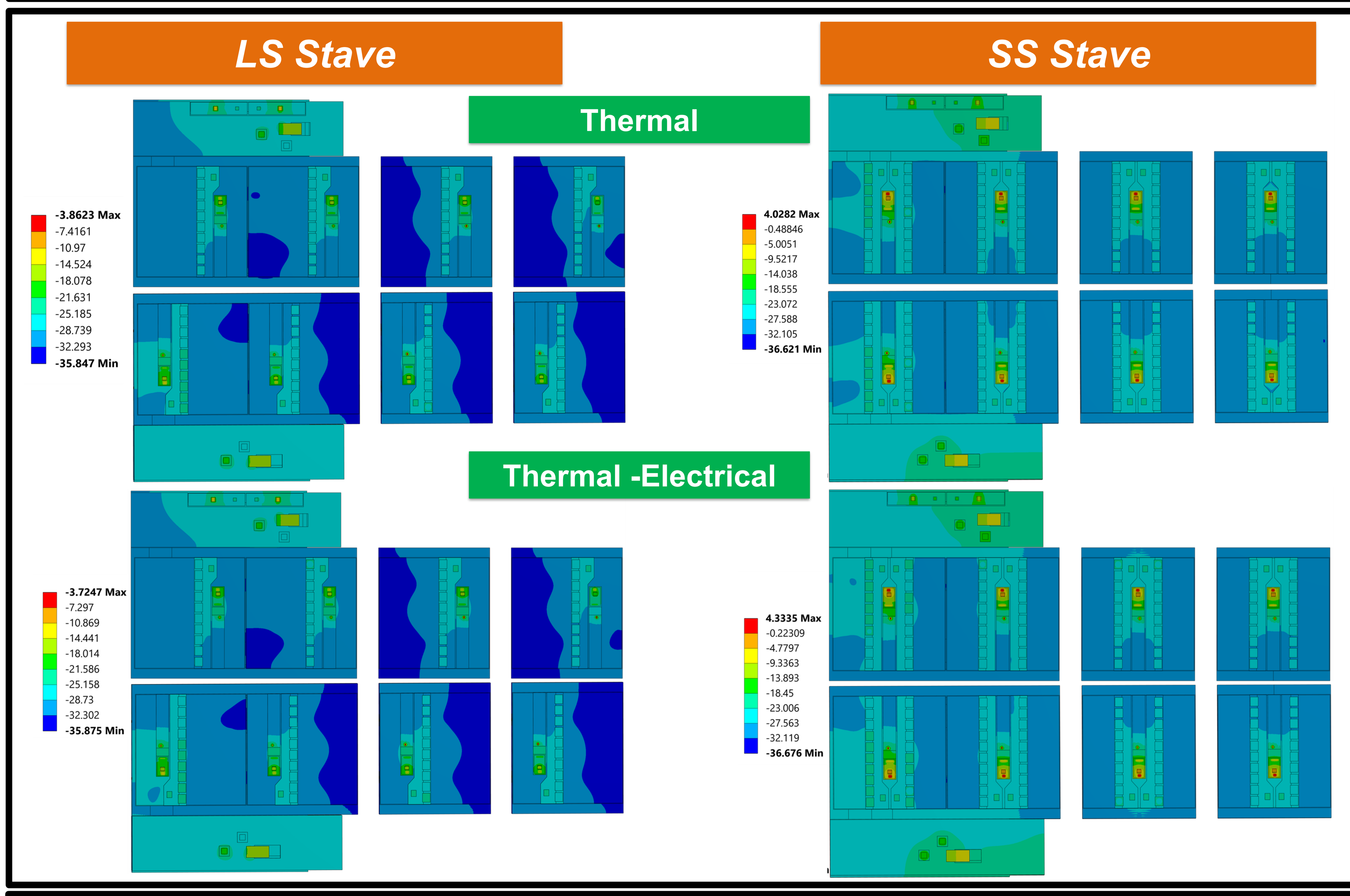


Thermal Boundary Conditions

- **Steady-state simulations under nominal operating conditions**
  - **Thermal:** Electrical power dissipation from the chips, coil, and VTRx included
  - **Thermal–Electrical:** Additionally, models temperature-dependent electrical power in the sensors
- **Sensor conditions**
  - Active region biased at 500 V
  - Temperature-dependent resistivity for the ultimate HL-LHC scenario (4 ab⁻¹)
- **Radiation fluence**
  - SS (Barrel 0): 7.31×1014 neq/cm^2
  - LS (Barrel 2): 3.71×1014 neq/cm^2

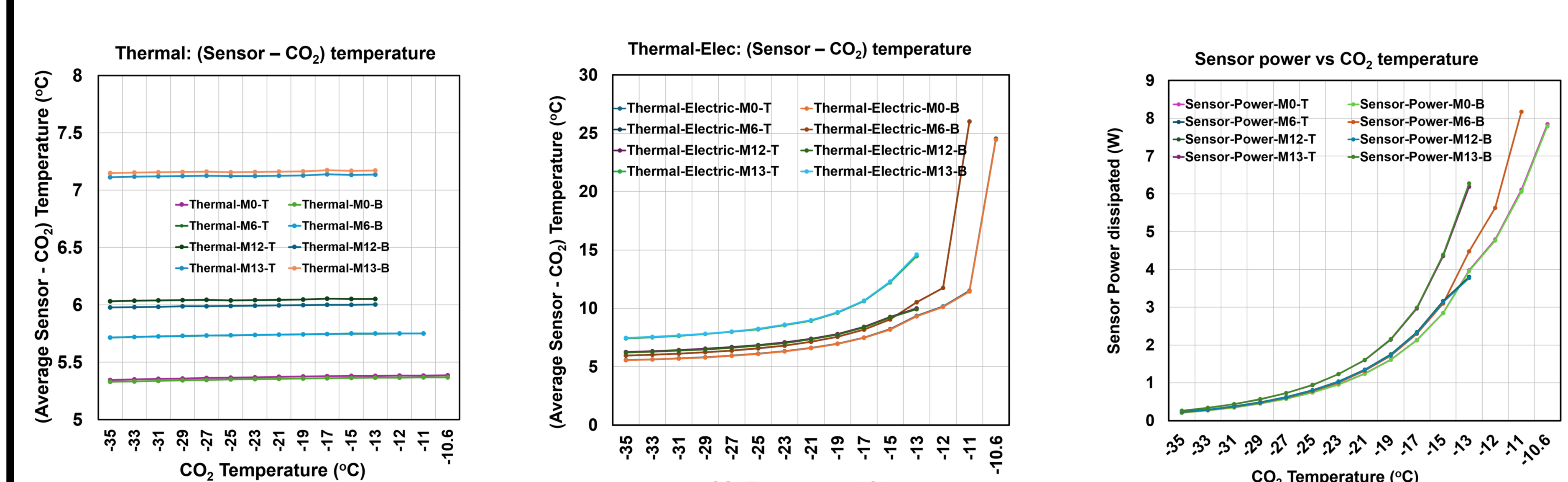
Component	SS (Power per component)	LS (Power per component)
ABC	0.1485 W × 20	0.1485 W × 10
HCC	0.2565 W × 2	0.2565 W × 1
bPOL	1.045 W	0.523 W
Coil	0.448 W (0.224 W on each pad)	0.224 W (0.112 W on each pad)
LinPOL	0.48 W	0.48 W

Temperature Distribution Results



Thermal Stability Analysis

- **SS Stave**
  Thermal runaway conditions vary with module position along the stave
  - ✓ **Module 0:** runaway observed above **−10.6 °C**
  - ✓ **Module 6:** runaway observed above **−11.6 °C**
  - ✓ **Module 13:** runaway observed above **−14 °C**
- **LS Stave**
  Similar position-dependent thermal runaway behaviour is observed
  - ✓ **Module 0:** runaway observed above **−3.5 °C**
  - ✓ **Module 6:** runaway observed above **−5 °C**
  - ✓ **Module 13:** runaway observed above **−7.5 °C**



ANSYS vs. Abaqus: Thermal Simulation Comparison

- **Validation Against Abaqus Results:** ANSYS thermal results compared with existing Abaqus simulations results for
  - ✓ **Single-module case:** module mounted on a chuck maintained at 20 °C
  - ✓ **Stave-level comparison:** Temperature results were compared for individual modules and different components for both LS and SS staves under CO_2 cooling at −35 °C

Module Components	ABAQUS (°C)	ANSYS (°C)	ΔT (°C)
bPOL	42.5	42.8	0.3
LinPOL	46	47	1
Coil (Pad1)	50	49	1
ABC	23.7	24.1	0.4
HCC	26.1	26.8	0.7

LS Stave	ABAQUS (°C)	ANSYS (°C)	ΔT (°C)
Module 0T – Sensor	-32.1	-31.8	0.3
Module 6T – Sensor	-31.6	-31.4	0.2
Module 12T – Sensor	-30.9	-31.0	0.1
Module 13T – Sensor	-30.6	-30.7	0.1
Module 13B – Sensor	-30.1	-30.1	0
EoS – bPoL12V Master	-17.7	-16.4	1.3
EoS – bPOL12V Slave	-16.8	-15.7	1.1
EoS – LpGbT1 Master	-21.2	-20.8	0.5
EoS – VTRx Master	-17.3	-17.4	0.2

SS Stave	ABAQUS (°C)	ANSYS (°C)	ΔT (°C)
Module 0T – Sensor	-29.8	-29.4	0.4
Module 6T – Sensor	-29.4	-29.0	0.4
Module 12T – Sensor	-28.7	-28.7	0
Module 13T – Sensor	-27.7	-27.6	0.1
Module 13B – Sensor	-27.9	-27.5	0.4
EoS – bPoL12V Master	-13.4	-11.7	1.7
EoS – bPOL12V Slave	-11.9	-10.4	1.5
EoS – LpGbT1 Master	-17.0	-16.5	0.5
EoS – VTRx Master	-9.3	-9.3	0

Summary

- Steady-state thermal–electrical models of the LS and SS staves were developed in ANSYS to assess their thermal performance and stability
- No thermal runaway was observed under the nominal operating conditions investigated
- Thermal stability depends on module position along the stave; the Module 13 sensor exhibits a ~3.5°C lower runaway threshold than the Module 0 sensor
- ANSYS shows good agreement with Abaqus, with temperature differences generally below 1°C
- The validated ANSYS model provides a reliable framework for future thermal performance and stability studies of the ATLAS ITk staves