Appendix S

Mathematical models for the Columbus engineering support team

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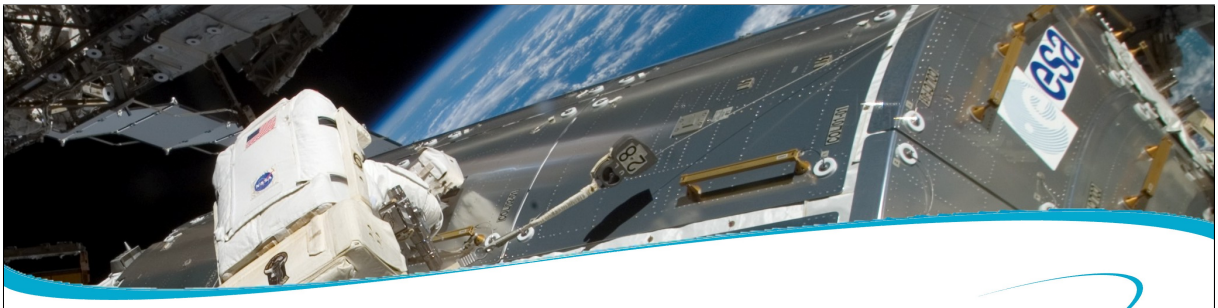
Abstract

Columbus module started its operations on early 2008 as European element of the ISS. Mathematical models originally developed for CDR/FAR phases and fitted to current flight configuration play a key role for the engineers supporting the on-orbit operations.
This presentation provides an overview of the Thermal-Hydraulic Mathematical Models (THMM) running in TAS-I Torino by thermal control team, focusing then on the water loop Active Thermal Control System (ATCS) element, by comparing flight telemetries with models outcome for some relevant cases. Conclusions summarize this first year of experience covering also s/w needs and expectation for next future.



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MATHEMATICAL MODELS FOR THE COLUMBUS ENGINEERING SUPPORT TEAM

Savino DE PALO, Gaetana BUFANO, Albino QUARANTA - ThalesAlenia Space
Marco BRUNO - Sofiter System Engineering

Template reference : 100181685K-EN

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INTRODUCTION

Page 3

- Columbus module started its operations on early 2008 as European element of the ISS
- TAS-I as part of the industrial team supporting the mission provides engineering support to on-orbit operations
- Mathematical models originally developed for CDR / FAR phases fitted to flight configuration

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MODELS OVERVIEW

Page 4

The TMMs / THMMs used to predict the thermal-hydraulic behavior of Columbus and P/Ls during on orbit operations are:

1. IOTMM (Integrated Overall THMM)
2. ECTMM (External Complement TMM)
3. PCTMM (Pressurized Complement THMM)
4. ATCS THMM

All models have been developed in ESARAD and ESATAN software tools

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IOTMM

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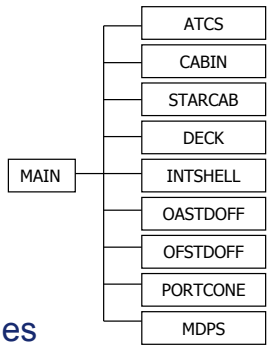
IOTMM has one main model and nine sub-models and simulates the interactions between:

- water loop
- cabin environment and air loop
- external environment



Model size = 2714 Thermal Nodes + 378 Fluidic Nodes

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IOTMM

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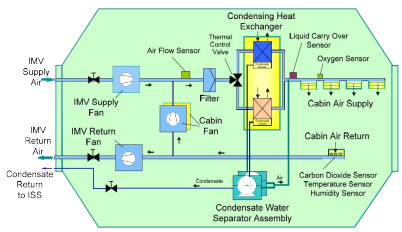
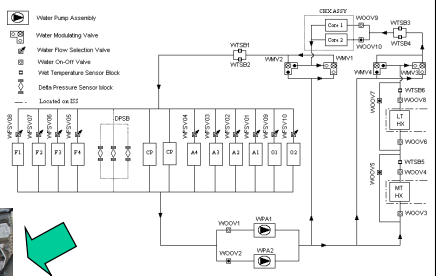
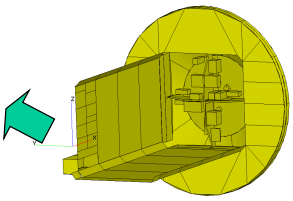
Used to:

- analyze risky deviations from nominal functioning
- responding to E-Chits, SPRs requests
- provide inputs for Flight Rules / Procedures







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ECTMM

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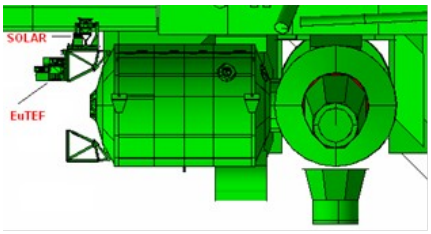
ECTMM → thermal behavior of Columbus + external P/Ls (e.g., SOLAR, EuTEF)

- ECTMM = simplified IOTMM (ATCS FHTS → GF) + external P/Ls detailed models
- External P/Ls are sub-models both at ESARAD and ESATAN level

Model size = 5107 Thermal Nodes



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ECTMM

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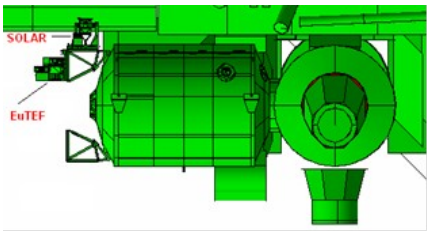
Used during 1E Mission to provide the Columbus Thermal Clock (time window in which the Columbus Module could survive without any risk of condensation without any heaters power) for a dedicated Flight Rule

Currently used to complete the thermal Flight Rule related to the Payloads behavior in contingency situation during EVA activities or in case of loss of power to the External Payloads to provide thermal clock for each equipment and experiments



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PCTMM

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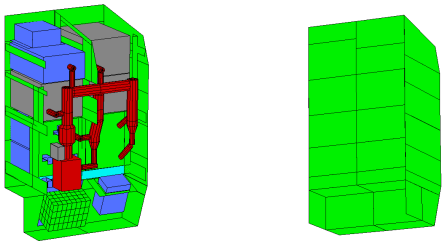
PCTMM → thermal behavior of Columbus + internal P/Ls

- PCTMM = IOTMM + reduced models of EDR, FSL, EPM with experiments (according to the relevant stages)
- Internal P/Ls are sub-models both at ESARAD and ESATAN level

Model size = 3174 Thermal Nodes + 568 Fluidic Nodes



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PCTMM

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Some convergence issues due to integration of sub-models into IOTMM with simultaneous hydraulic loops (water, air)

Currently used for the Stage Analyses to:

- demonstrate the compliance of the payload complement with requirements
- define operational guidelines where necessary
- define constraints if element level conflicts are identified

Used for stages 1E, 1JA, 1J, 2JA, ULF2, 15A, 17A, ULF3 & 20A

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ATCS

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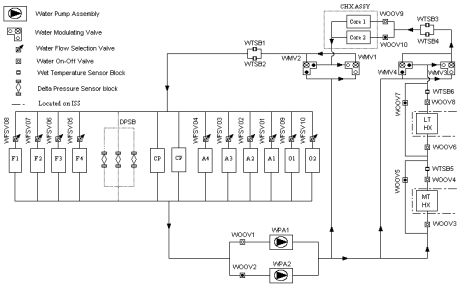
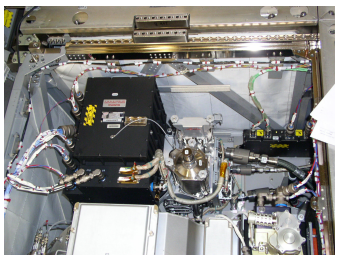
ATCS → thermal-hydraulic behavior of Columbus water loop (feedback controls included)

- ATCS can run stand-alone or as part of the IOTMM
- Water cooled P/Ls can be included to ATCS

Model size = 99 Thermal Nodes + 410 Fluidic Nodes





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ATCS

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Currently used for the Stage Analyses to:

- demonstrate the compliance of the payload complement with requirements, provide WFSV positions
- define operational guidelines (where necessary)
- define constraints if element level conflicts are identified

Used for stages 1E, 1JA, 1J, 2JA, ULF2, 15A, ULF3 and 17A

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CHX DRYOUT

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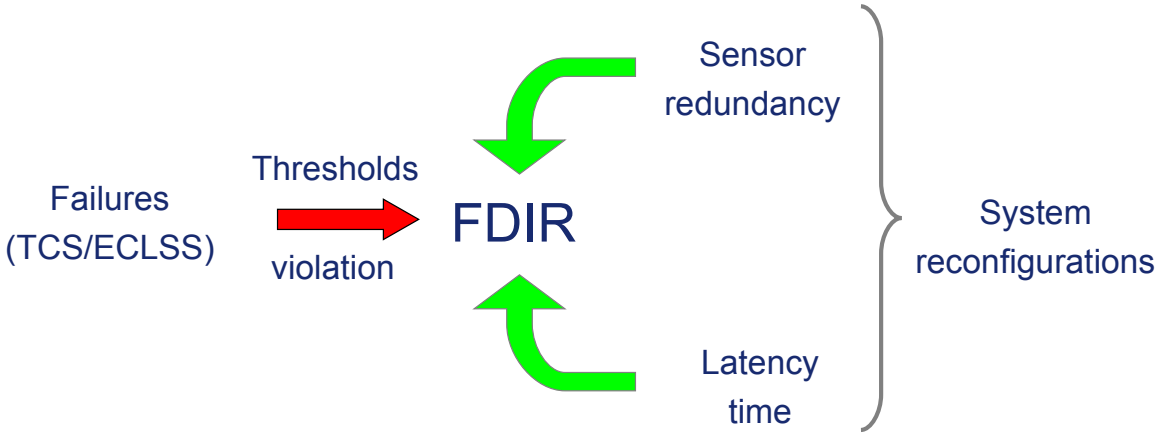

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CHX DRYOUT

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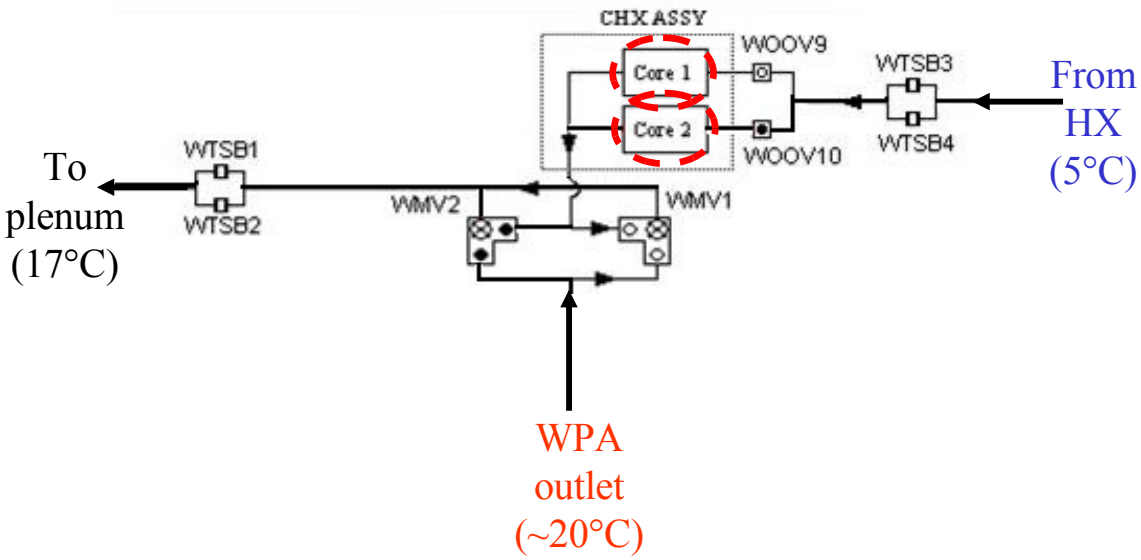

CHX DRYOUT

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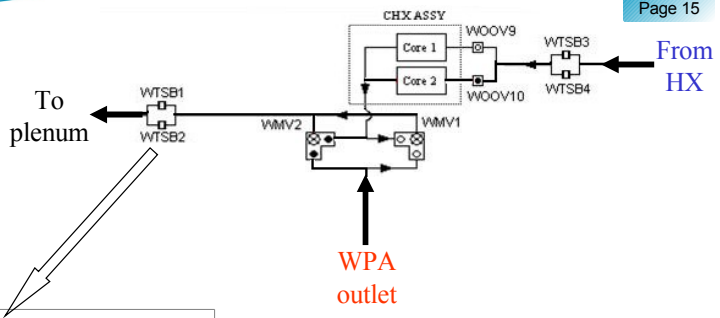
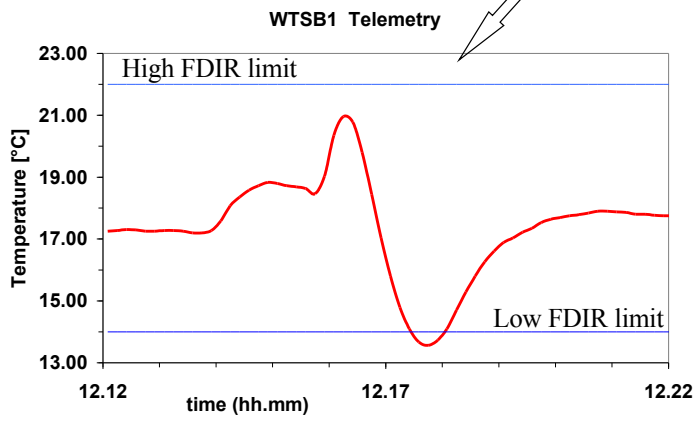
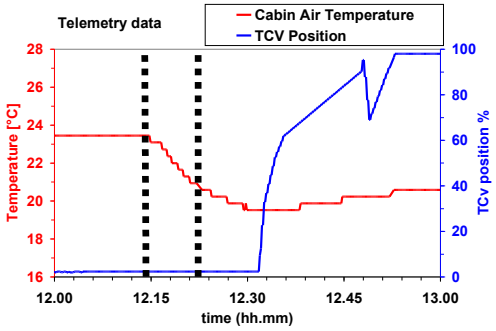
Telemetry data







CHX DRYOUT

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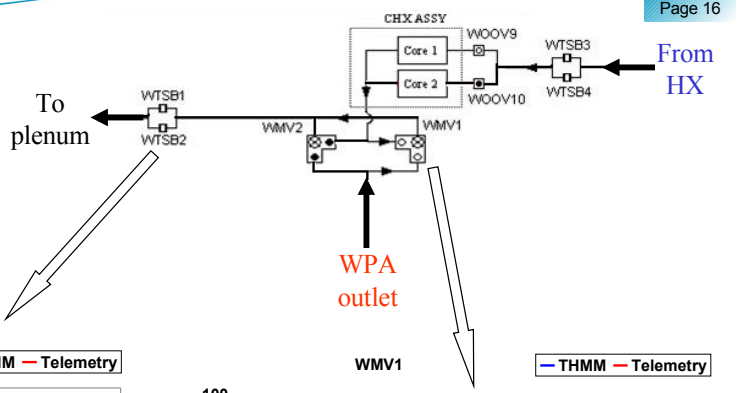
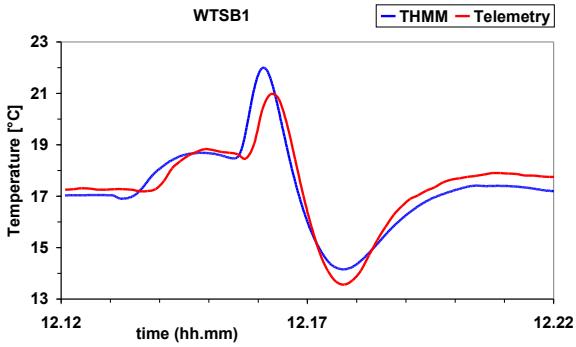
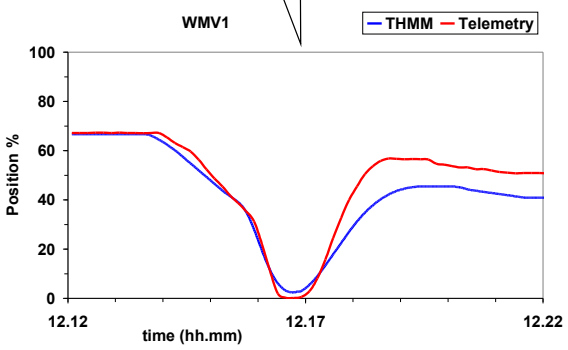
THMM analysis for:

- correlation
- data extrapolation
- telemetry analysis
- problem solving







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CHX DRYOUT

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THMM analysis for:

- correlation
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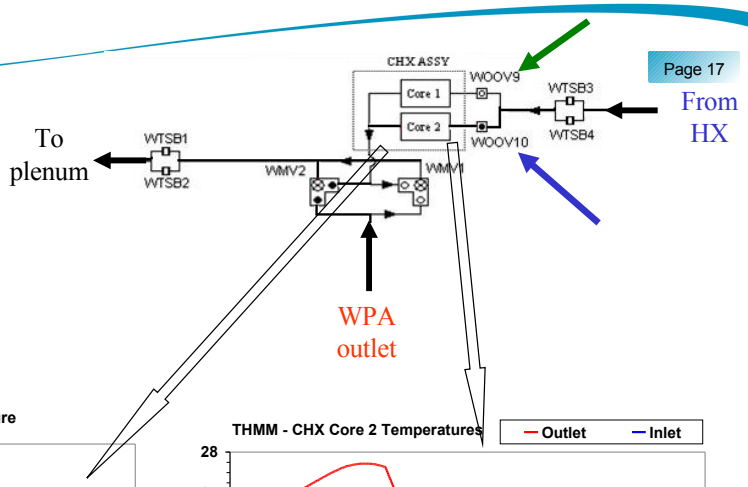
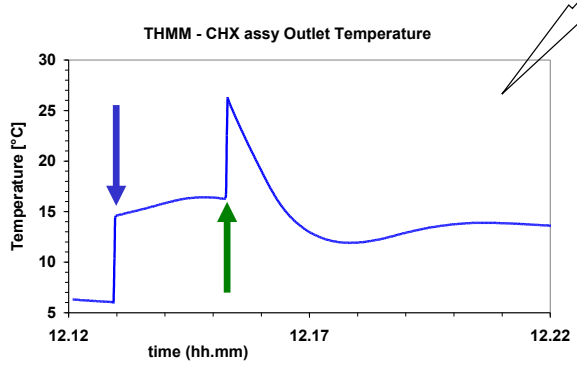
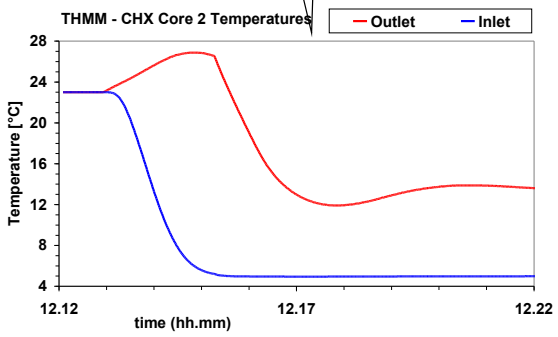
- problem solving







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THMM analysis for:

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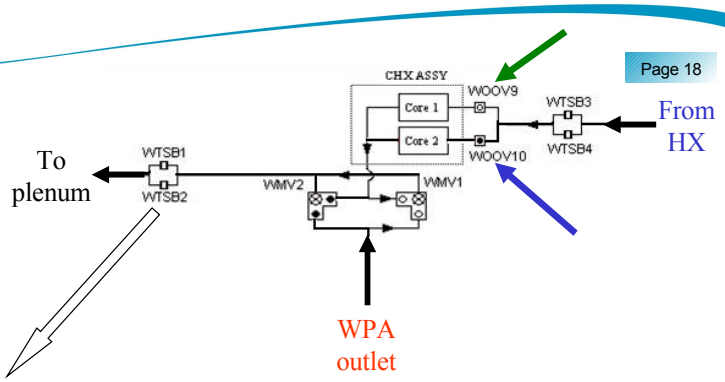
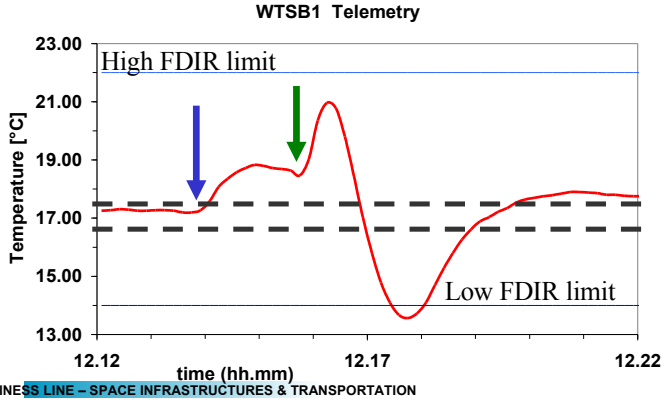
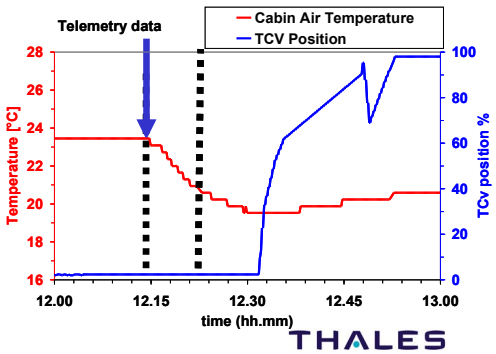
- telemetry analysis
- problem solving







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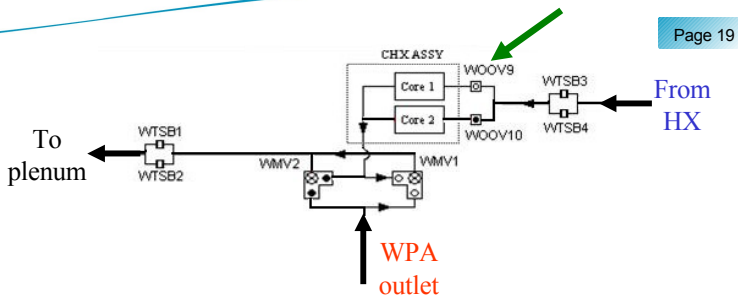
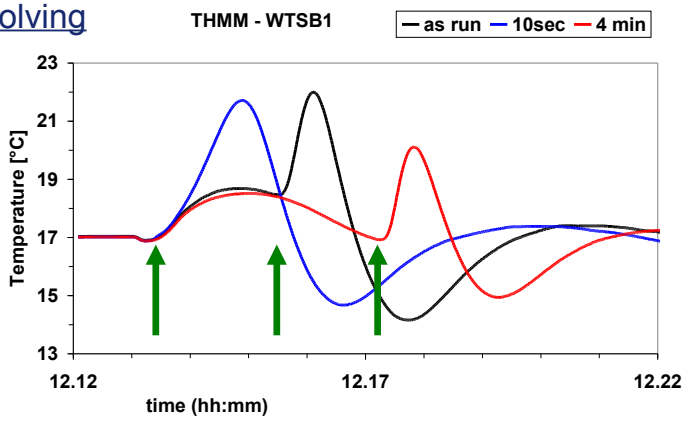
THMM analysis for:

- correlation
- data extrapolation
- telemetry analysis
- problem solving





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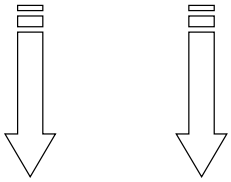
IOTMM



Verify Tcabin ≥ 21°C

TCV position = 50%

Wait 7 minutes before swapping CHX cores

Wait further 12 minutes before re-enabling TCV CL

FDIR temporary limits ➔ 23°C & 12°C

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CHX DRYOUT

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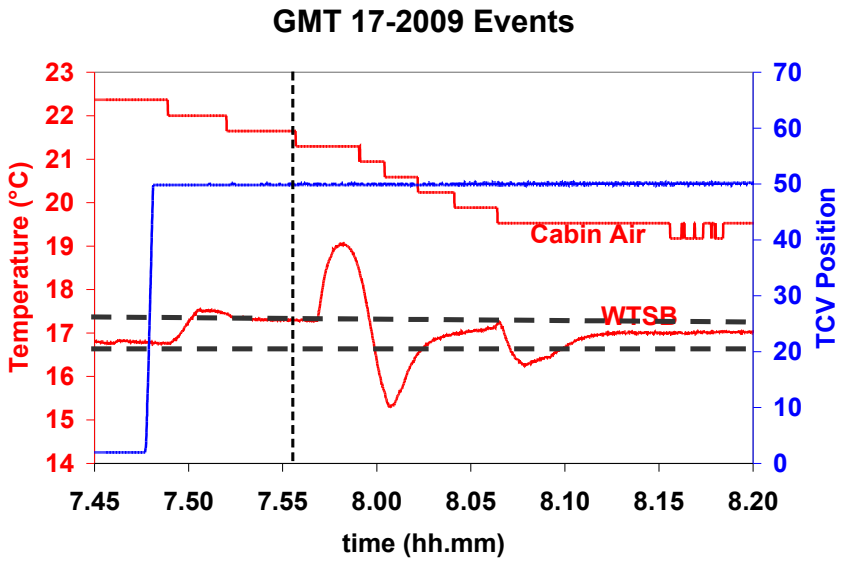

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CONCLUSIONS

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- TMM / THMMs provide insight of system behaviour
- Models correlation with telemetry necessary but time consuming (huge amount of data)
- Flight conditions vs CDR / FAR assumptions → real loads vs design margin (e.g. crew heat load)
- Need for rapid evaluation is sometime requested vs huge/complex models
- Real time simulations ?