Appendix L

LHP MODULE SOFTWARE

Application at System Level

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Abstract

Loop Heat Pipes (LHPs) are more and more used for spacecraft thermal control thanks to its performances and ability to transport heat load on a long distance.
In the frame of CSO program, LHPs are implemented on Visible and Infra-Red Detection Sub-assemblies.
In order to simulate LHPs behaviour at system level, specific software was developed by Astrium / Thales Alenia Space under CNES and ESA fundings. The LHP Module is compatible with many thermal softwares and works as a sub-model of ESATAN-TMS Thermal Mathematical Model (TMM).
The objectives of the presentation are to describe briefly the LHP Module inputs/outputs and functional blocks. Main performances of Visible and Infra-Red Assemblies are simulated using the LHP Module. Breadboard test exploitations are compared with predictions in order to validate the LHP Module accuracy. The software limits and constraints will also be presented.

Summary

2

- Introduction
- LHP operating principles
- LHP Module Software
- LHP Module application
- Validation with breadboard tests
- Limits and constraints
- Conclusion

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Introduction

3

- Tool development to simulate biphasic product at system level
- Development made by Astrium / Thales Alenia Space under CNES and ESA fundings
  - « Simplified » thermal model
  - Interface as a sub-model with ESATAN-TMS Thermal Mathematical Model
- LHP Module Software version V2.4 firstly used on CSO program

LHP Module Software developed for use at System Level

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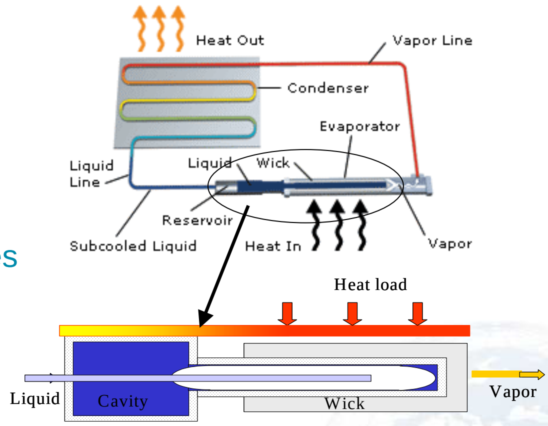
LHP operating principles

4

- LHP : two-phase (vapor and liquid) heat transfer device, using the evaporation and condensation of a working fluid (ammonia), and the capillary forces developed by evaporator wick
- Main elements :
  - Reservoir,
  - Evaporator,
  - Condenser,
  - Vapor and Liquid transport lines



Main Elements involved in LHP Performances

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LHP Module Software (1/6)

5

- Simulating the LHP functioning by computing the main parameters:
  - Heat transfers through the LHP (fluid heat transported, heat flux at evaporator,flux exchanged at condenser level…)
  - Temperatures of LHP elements
  - Conductances (evaporator, condenser and total LHP conductances)
  - Sub-cooling (Tsat-Toutlet condenser)
  - Front position in condenser
  - LHP status (ON or OFF)
  - Thermo-hydraulic parameters (pressure losses, mass flow, fluid speed…)

Access to thermal and thermo-hydraulic Inputs/Outputs at System Level

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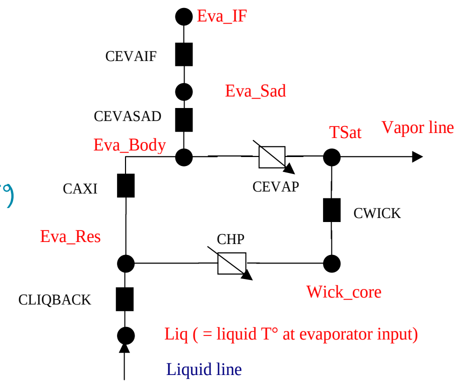
LHP Module Software (2/6)

6

- Insertion in an ESATAN program
  - LHP Module Software used as sub-model
  - Sub-model modeling
    - Evaporator : 3 nodes or 5 nodes (**baseline**)
    - Vapor line : 1 node (adiabatic at saturation T°)
    - Condenser : N nodes
    - Liquid line : N nodes
    - LHP parameters



  - System modeling
    - Radiative and conductive couplings between the model and the LHP sub-model
    - Reservoir and liquid line regulation

Sharing functionalities between LHP Module and System Model

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LHP Module Software (3/6)

7

- An elemuser.dat file : file with computing algorithms and subroutines
- System inputs (power, temperature initialization, nodal breakdown, modeling and numerical parameters) in the specific data file (XXX.LHP)
- Loop heat pipe inputs, describing the hardware of elements of the loop in generic data files:
  - XXX.EVAPHW for evaporator (capacitances, stop/start criteria, conductances)
  - XXX.CONDHW for condenser (number of branches, tubing properties)
  - XXX.VAPLHW for vapor line (number of sections, properties of branch)
  - XXX.LIQLHW for liquid line (number of sections, properties of branch)
  - XXX.PPTY for working fluid (thermodynamic properties)

LHP Module generic algorithms and input files

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LHP Module Software (4/6)

8

System model

$MODEL SATELLITE, GLOBALFILE=ELEMUSER.DAT

$ ELEMENT LHP
Call of the specific data file "LHP"

$NODES
Definition of system and LHP I/F nodes

$CONDUCTORS
Definition of the link between system I/F nodes and LHP nodes
...

$END MODEL

→

LHP specific data file

$FLUID
Call of the generic data file

$EVAPORATOR
Call of the generic data file

$VAPOR LINE
Call of the generic data file

$CONDENSER
Call of the generic data file

$LIQUID LINE
Call of the generic data file

$NUMERICAL PARAMETER
Definition of the numerical & modelling parameter

FLUID generic data file Definition of the fluid property	**EVAP generic data file** Definition of the evaporator	**COND generic data file** Definition of the condenser	**LIQ generic data file** Definition of the liquid line	**VAP generic data file** Definition of the vapor line

Input data implementation in an ESATAN TMM

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LHP Module Software (5/6)

9

- Main subroutines
  - Calch : diphasic and monophasic heat transfer coefficients (HTC) computation for each cell
  - ComputeLHP : permanent and transient temperatures computation
  - DeltaP : pressure losses computation in vapor, liquid lines and condenser
- Main function
  - Glfluid : heat transfers between tubing and fluid

LHP Module subroutines and functions

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LHP Module Software (6/6)

10

1. Fluid transported heat computation → mass flow computation
2. Pressure losses computation in LHP (DeltaP subroutine) → Tsat computation, using the Clausius-Clapeyron curve dP/dT
   - Pressure losses=f(mass flow, tubing geometrical parameters)
3. Heat transfer coefficients computation at cell level (Calch subroutine)
   - HTC=f(mass flow, tubing geometrical parameters)
4. Exchanged power computation at cell level (Glfluid function)
   - Exchanged power=f(HTC, fluid input temperature, tubing temperature)
5. Enthalpy and fluid output temperature of each cell (ComputeLHP subroutine)

LHP Module computation sequences

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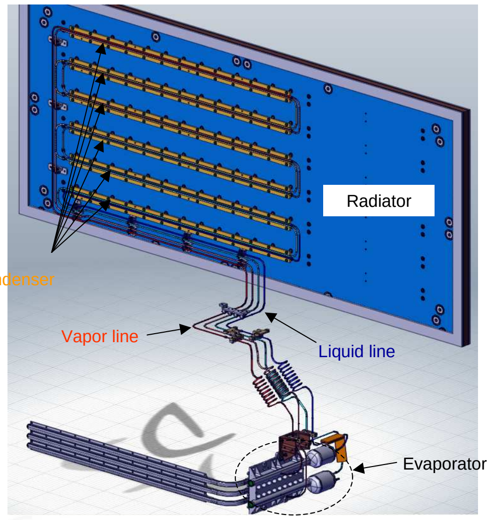
LHP Module Application (1/3)

11



- LEO Mission
- Cold Redundancy (1 LHP ON – 1 LHP OFF)
- LHP requirements
  - Transported heat power range : [50W,80W]
  - LHP conductance CLHP : 3W/K@min power, 7.5W/K@max power
  - Sub-cooling : >10℃
  - 1W < Operating reservoir heating power < 7W (Operating reservoir regulated @12℃)

Implementation of LHP to control electronic box (Visible assembly)

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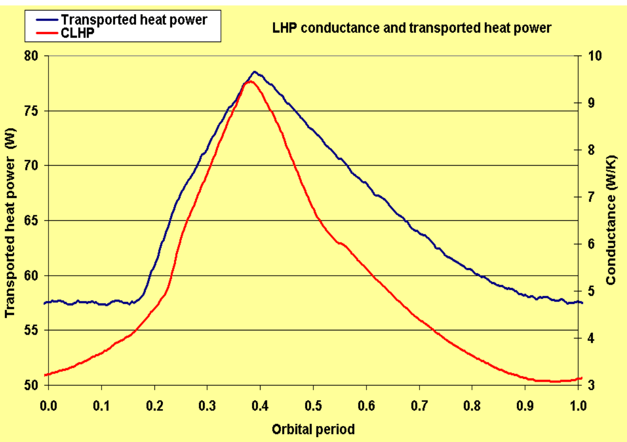
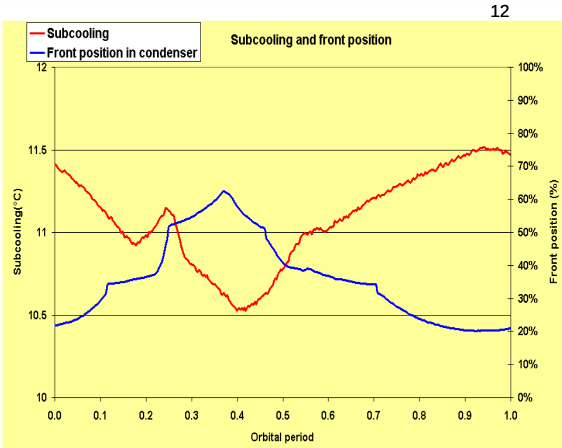
LHP Module Application (2/3)

12





- Access to thermo-hydraulic outputs and LHP performances simulation
- LHP design optimization : evaporator length = 182 mm / max CLHP≈ 10 W/K / sub-cooling >10℃

LHP design compliant with thermal requirements

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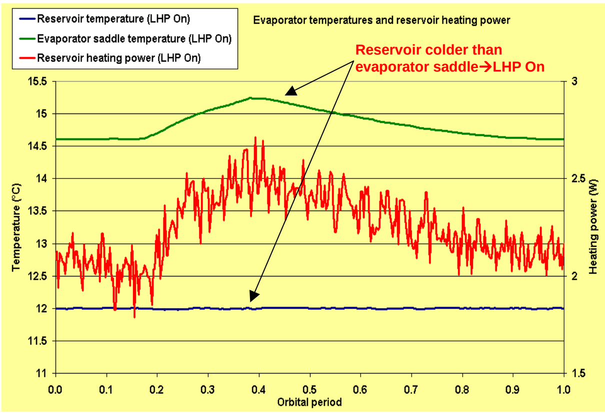
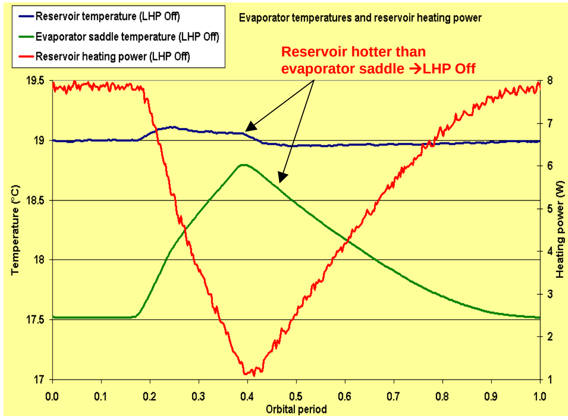
LHP Module Application (3/3)

13





- Electronic TRP stability along the orbit < 20℃ tha nks to CLHP variation
- Verification of LHPs behavior (ON and OFF)

Design optimization to fulfill system budget (power consumption,…)

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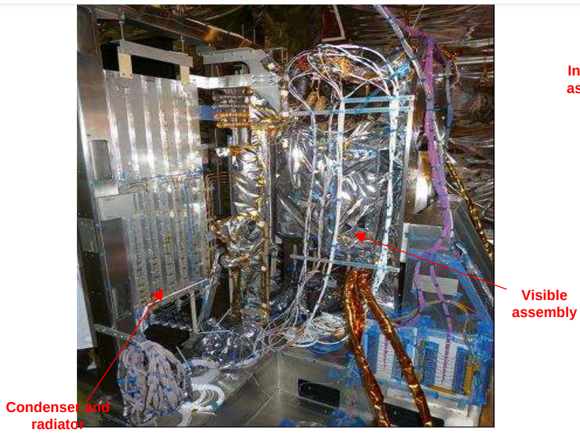
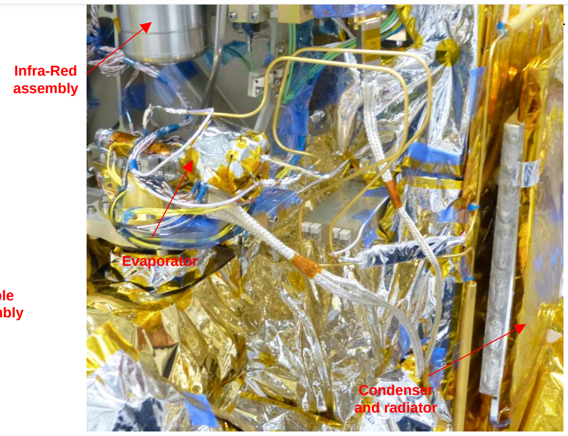
Validation with breadboard tests (1/4)





Visible Sub-Assembly breadboard tests Infra-Red Sub-Assembly breadboard tests

- Breadboard tests objectives
  - Verification of LHP performances under 0g or 1g configuration
  - Vacuum test condition (<5.10 $^{-5}$ mbar)
  - TBT duration (10 days)

Breadboard Thermal Balance Test configuration

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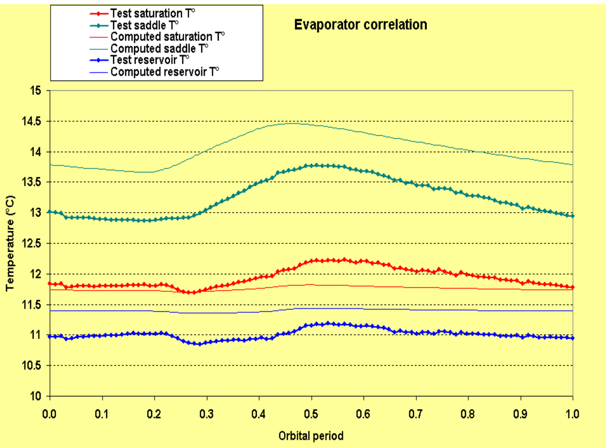
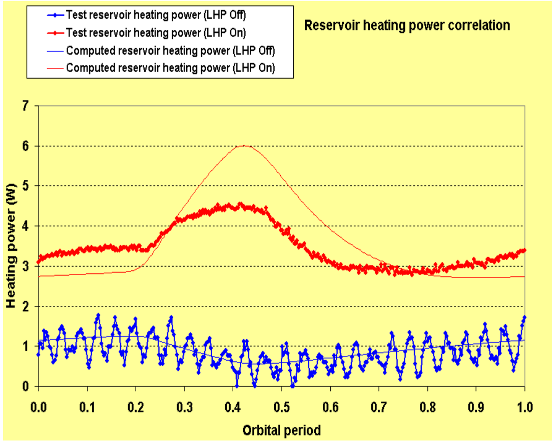
Validation with breadboard tests (2/4)





- Comparison between Visible Sub-Assembly TBT and correlated results
  - Less than 1°C of difference on evaporator temperatu res
  - Less than 10% of difference on average power consumption
  - Equivalent thermal behavior along the orbit in hot and cold cases

LHP Module validation and thermal model correlation

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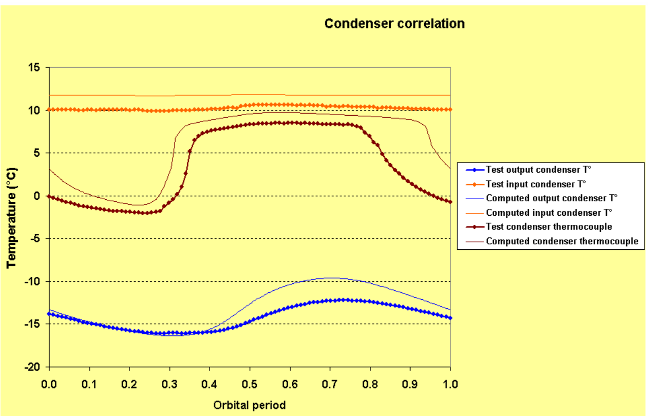
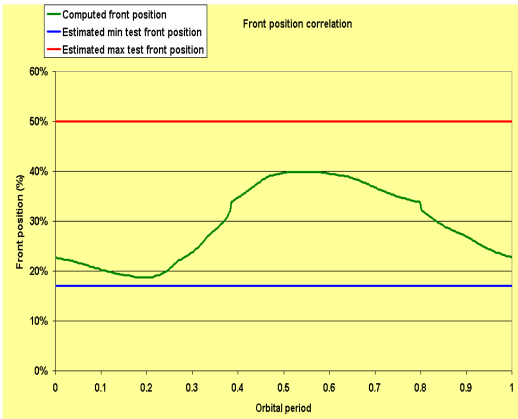
Validation with breadboard tests (3/4)





- Comparison between Visible Sub-Assembly TBT and correlated results
  - Front position correlated less than 5% at minimum transported heat power
  - Front position correlated less than 10% at maximum transported heat power

LHP Module validation and thermal model correlation

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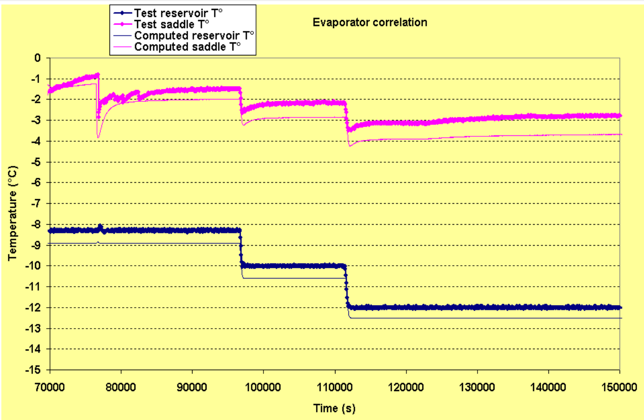
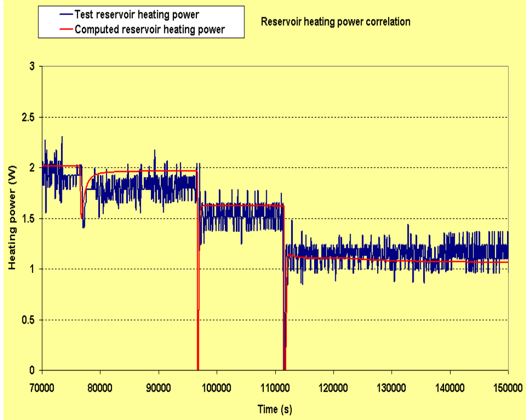
Validation with breadboard tests (4/4)





- Comparison between Infra-Red Sub-Assembly TBT and correlated results
  - Less than 1℃ of difference on evaporator temperatu res
  - Less than 10% of difference on average power consumption

LHP Module validation and thermal model correlation

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Limits and constraints

18

- Long computation time
  - Small time step required for convergence (dt<2s)
- Permanent case
  - Steady state computations not available
- Vapor line nodal breakdown
  - Vapor line should be considered adiabatic and simulated by 1 single thermal node (otherwise convergence problem occurs)
- Evaporator saddle modeling
  - 1 node could not be sufficient for a large evaporator length due to gradient along the saddle
- Condenser modeling
  - Fine nodal breakdown must be made to simulate the front position and gradients in condenser

Constraints identified without impact on the presented application

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Conclusion

19

- LHP Module Software allows to :
  - Simulate the behavior of biphasic LHP within a system model
  - Optimize a thermal design
  - Necessary to characterize performances (LHP module input) at sub-contractor level (0g and 1g configurations)
- Simulation results validated by thermal tests
- Discussion on-going with CNES/ESA to update LHP Module Software :
  - New technologies (Pressure Regulation Valve, Multi-condensors,…)
  - Gravity effect

Benefit to use LHP Module at System Level

Update of software functionalities identified

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20

Thank you for your attention

Any questions?

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