

DECOM VALIDATION

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ABSTRACT

Deepak Condenser Model (DeCoM) was validated in a two-step process. The first step validated DeCoM/TTH/FloCAD against a simplified 1D (1D fluid flow and 1D heat flow) scenario. Through this simplification the fluid calculations were simple enough that the results were comparable to hand calculations. Once a method was compared against 1D case, the next step was the verification against a 2D test case. 2D is only for heat flow, while the fluid flow is still 1D. The test data was obtained from the project Geoscience Laser Altimeter System (GLAS) which performed a Looped Heat Pipe (LHP) test and contained necessary condenser information; such as a test point and condenser configuration. From the GLAS LHP test report, the construction of the LHP condenser and correlation was roughly possible. The assumptions and limitations are discussed, within this paper, of the 2D correlation. The success of DeCoM is illustrated by the results after correlation to the test data. Results show the differences between the model and the test setup, as well as explaining the probable cause for the differences; another set of results were produced after taking into account these differences, such as parasitic heat leak. Substantial effort has been made in listing the possibilities to further develop DECOM, thus to make it more reliable, user-friendly, and better integrated with generic SINDA models. The comparison of DeCoM to FloCAD and TTH LHP should not be taken as a definite answer to choosing DeCoM as a condenser modeler, rather as an alternate to obtaining preliminary results without the complexity of TTH LHP and license of FloCAD.

INTRODUCTION

A method to analyze the performance of the Advanced Topographic Laser Altimeter System (ATLAS) laser radiator with a LHP condenser embedded was required. The requirement for this method includes a simplified method which does not use much CPU time; it does not require many parameters which might act as constraints; and most importantly the method should be correlated against test data. Three methods were taken into consideration for comparison to DeCoM : EXCEL (very much like DeCoM), Triem t. Hoang (TTH) LHP condenser, and FloCAD. EXCEL has been generated solely to verify the hand calculations with steady state results, while the other methods can perform transient analysis as well as steady state analysis. The first step of verification in 1D scenario compares all three methods. The 1D scenario does not take into account the heat leak due to a serpentine routing, which makes it easy to hand calculate the length at which the phase change will occur from two-phase to subcooled liquid. Once each method has met the “length” comparison in 1D scenario, the methods that closely match the length will then be compared to a 2D test case. A 2D case consists of 2D heat

flow and 1D fluid flow. Using test data obtained from the GLAS LHP test setup, the LHP condenser exit temperature was compared against selected methods. The compared methods that met ΔT within the acceptable range were then integrated into the ATLAS laser radiator.

1D Case(s) = 1D Heat Flow, 1D Fluid Flow

2D Case(s) = 2D Heat Flow, 1D Fluid Flow

DECOM/EXCEL IMPLEMENTATION

DeCoM/EXCEL Implementation:

DeCoM/EXCEL is the first of three condenser simulation techniques to be discussed. Equations derived in the paper “Analytical Approach in DeCoM¹” were used in order to develop the DeCoM method. The EXCEL approach is only used for the 1D scenario because of its limitations; it calculates LHP condenser performance off-line (not connected to any thermal analysis platform) using boundary conditions. The GLAS project also used an EXCEL based model to predict its LHP condenser performance. The EXCEL method is limited to steady state and 1D case only due to its methodology of calculations.

DeCoM is a code written in the FORTRAN language. Figure 1 summarizes the calculations steps of DeCoM/EXCEL for both two-phase and subcooled liquid. It was developed to perform calculations for transient as well as steady state analysis.

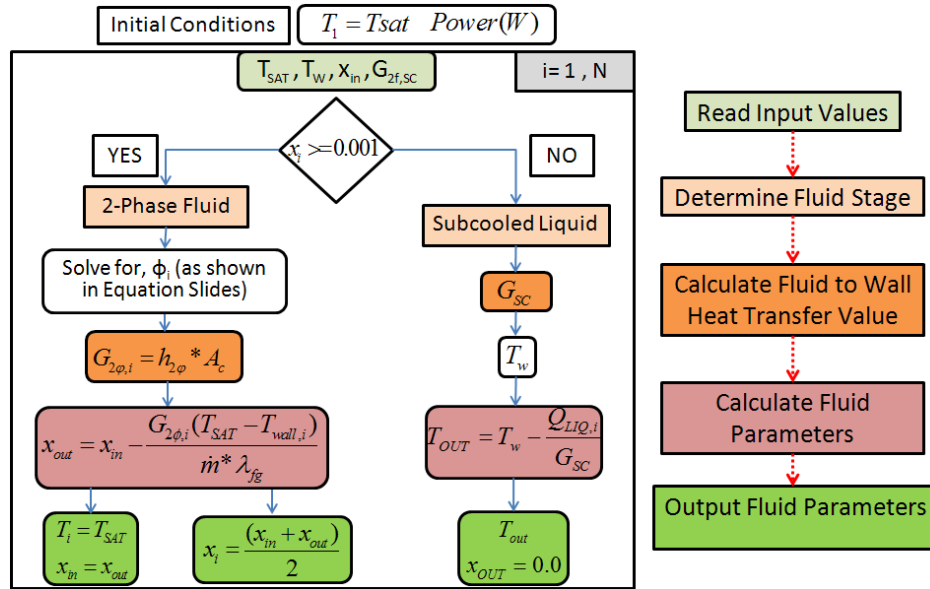


Figure 1: DeCoM/EXCEL Calculations flow chart

The results produced by DeCoM for the 1D case were compared with steady state results so that the methodology can be consistent with EXCEL. This code computes the fluid to wall interactions using Lockhart-Martinelli for the two phase correlation method. The benefits of DeCoM are that it can be merged with SINDA in order to map temperatures in Thermal Desktop (a C&R Tech product), print fluid parameters depending on the user's request, as well as calculate fluid/wall temperatures, fluid quality and its properties. DeCoM is both distributable and validated; the validity is confirmed in the 2D correlation section of this paper. The input of

this code is done under the “VARIABLES 1” logic block of SINDA so that DeCoM can be executed at every time-step.

TTH Implementation:

The TTH LHP routine was developed under a NASA Small Business Innovation Research (SBIR) program. It is a LHP system solver consisting of all the components of a loop heat pipe (condenser, evaporator, liquid/vapor transport lines, and the compensation chamber). TTH, similar to DeCoM, is written in the FORTRAN language and can be integrated with SINDA to perform thermal analysis. For this project, the condenser section of TTH LHP code was executed independently of all the other components (with the permission of TTH). This was done in order to compare its results to the DeCoM/EXCEL models, which are also independent condenser implementations. The TTH condenser code calculates all the fluid parameters as well as performing transient and steady state analysis with multiple or single condenser lines. It is important to keep in mind that TTH LHP code was only executed with its condenser section and was not designed for this isolated usage. The entire LHP method although has shown robustness with multiple test data².

FloCAD Implementation:

FloCAD was the third tool that was used as verification against DeCoM and TTH. FloCAD is a graphical user interface in Thermal Desktop to generate the FLUINT constructs used to solve for the interactions between the fluid lumps and node thermal states. For this project FloCAD was constrained with all the factors that DeCoM and TTH had, without these constraints FloCAD is capable of performing detailed LHP analysis, similar to TTH. Constraints imposed on FloCAD included keeping the methodology similar to previous implementations. The two phase correlation used was Lockhart-Martinelli and the run-time settings were not adjusted from those used in the DeCoM runs. The results produced by FloCAD display only the steady state results but as described before, transient analysis can be performed if needed. The FloCAD network is shown in Figure 2. Within Figure 2 the plenum is the fluid lump consisting of boundary conditions, which regulates the temperature, pressure and quality of the network; MFRSET is the component that keeps the mass-flowrate of the system at a constant rate; fluid lumps are modeled as junction nodes, so that no energy is stored within the lumps, and Ties are the convective heat transfer coefficient connections between the fluid and the wall.

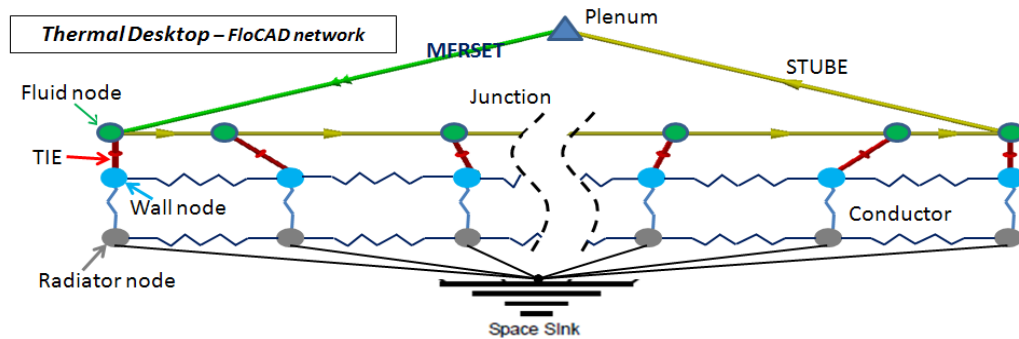


Figure 2: FloCAD nodal network

DISCUSSION ON 1D RESULTS

1D heat flow analysis was performed by comparing the lengths at which the fluid changes phase from two-phase to liquid. The calculation of this length is simple if it's assumed that the length of the condenser and the radiator are identical and one dimensional. Figure 3 displays the geometry implemented for this case. Also shown in Figure 3 is the ATLAS laser radiator which was “unfolded” in order to create a straight line (1D) radiator and a condenser with the same radiating area.

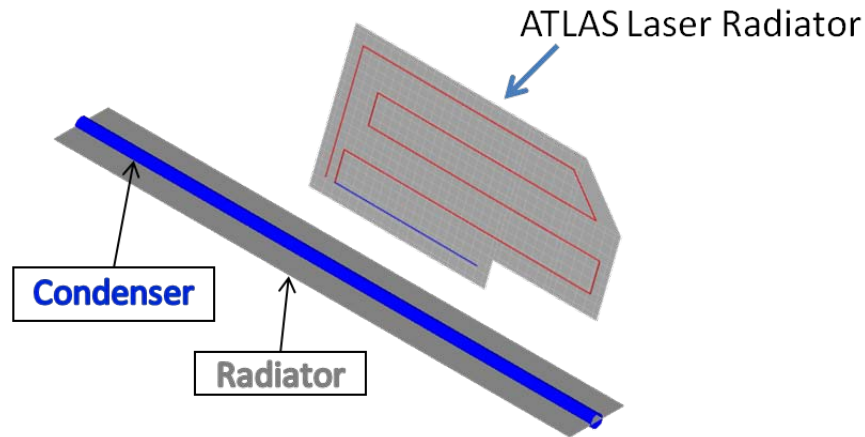


Figure 3: 2D to 1D radiator and condenser

The implementation of DeCoM and this construction was fairly simple, if the user is knowledgeable with Thermal Desktop. The fluid nodes created within the condenser code interact with the wall nodes created by SINDA; after which the wall nodes interact with the radiator nodes with a conduction value applied between the radiator and the condenser wall. Similar approach was taken for TTH implementation, where the geometry was similar but the calculation routine was different. For FloCAD, new geometry had to be created while using similar conduction values and similar two-phase correlation method (Lockhart-Martinelli method).

The cases taken into account to investigate the implementations are listed in Table 1.

Table 1: Input power and operating temperature settings

Evaporator Input Power (W)	Operating Temperature (°C)
216	-4
216	16
142	23

Each of these cases are likely scenarios that the ATLAS laser will experience. These three cases are chosen for specific reasons which will be explained in the method integration section of this paper. For the first case (216W and saturation temperature at -4°C), the results are displayed in Figure 4 showing the quality and temperature as a function of pipe location.

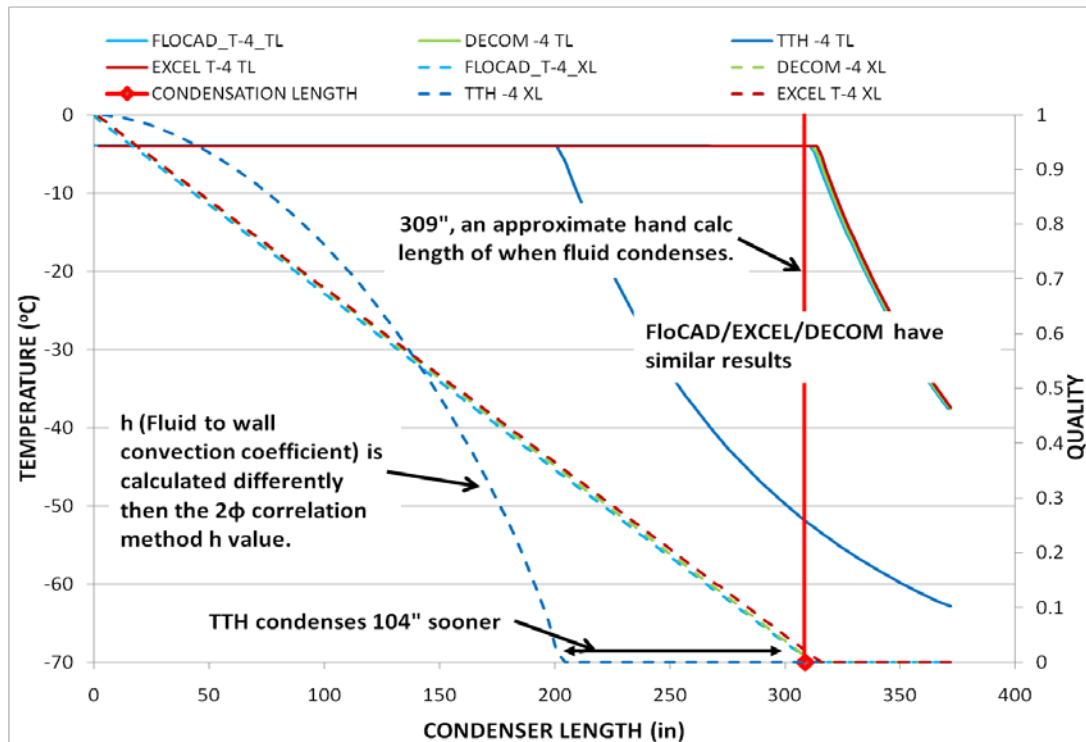


Figure 4: Power & Tsaturation @ 216W / -4°C

The first case results are distinctive in terms of only one method stands out in comparison to others. FloCAD and DeCoM are very close to the steady state results from EXCEL and are in good agreement with the hand calculated length of the two-phase region. As a reminder, the hand calculated length is estimated from the length of radiator necessary to reject the heat input to the sink at the saturation temperature. Beyond this location, subcooling of the working fluid occurs. TTH is the only method which predicts subcooling much sooner than the rest of the methods. *One thing that the reader should keep in mind is that this method was not developed to perform an exclusive condenser analysis.* Results discussed here are for a simple scenario and therefore more data is needed to prove the robustness of each implementation for condenser simulation. The TTH method is currently under investigation for why there is a large length difference predicted for where subcooling is reached.

The other cases: 16C and 23C all have similar outcomes where the TTH implementation predicts subcooling much sooner than DeCoM or FloCAD. The trend for TTH is consistent among all three cases. The summary for all three cases which includes the length comparison and CPU time comparison is presented in Table 2.

Table 2: 1D Analysis summary table

Implementation	Power (W)	Tsat (°C)	CPU Time (sec)	Condensation Length (in)
Hand Calc	216	-4	N/A	309
DECOM			7.0	312
FloCAD			30.0	285
TTH Condenser			8.0	197
Hand Calc	216	16	N/A	213
DECOM			7.0	220
FloCAD			26.0	201
TTH Condenser			6.0	108
Hand Calc	142	23	N/A	124
DECOM			11.0	130
FloCAD			7200.0 (8.0)*	119
TTH Condenser			13.0	52

- ❖ The timestep calculated by FLUINT was much smaller than the timestep needed by SINDA; therefore, the overall solution time with FLUINT was much longer. Manually setting the fluid timestep equal to the thermal timestep resulted in reducing the total solution time from 7200 seconds to 8 seconds.

The summary indicated should not be taken as solid data which might shows that the methods are reliable or not, as the results are done on a simple hand calculated length comparison. If the results match the simple case, then it will be investigated further with test correlation and be compared once more. The first comparison is of the CPU time which shows that all the methods in all cases are within reasonable time range except FloCAD for 23C case. The higher CPU time for FloCAD was due to the fact that DeCoM/TTH analyses were run with default run-time settings, allowing FLUINT to compute the timestep. This resulted in a much smaller timestep than was needed thermally and consequently a longer run time. While the user could control this and produce results in the reduced run-time, it does require knowledge of the software and understanding of FLUINT to configure the model to do so.

The only other difference that stands out is the length difference for the TTH method. As mentioned earlier, the reason for the result difference is currently under investigation. The parameters being investigated are the G (W/K) conduction values between the fluid and wall, as this value is calculated using the heat transfer convection coefficient (h - W/m²K). The fluid, wall and radiator temperatures are also being compared to show how much heat is being rejected by TTH and DeCoM method under the same situations. As seen from Figure 5, the heat transfer rate of DeCoM method is much lower than of TTH.

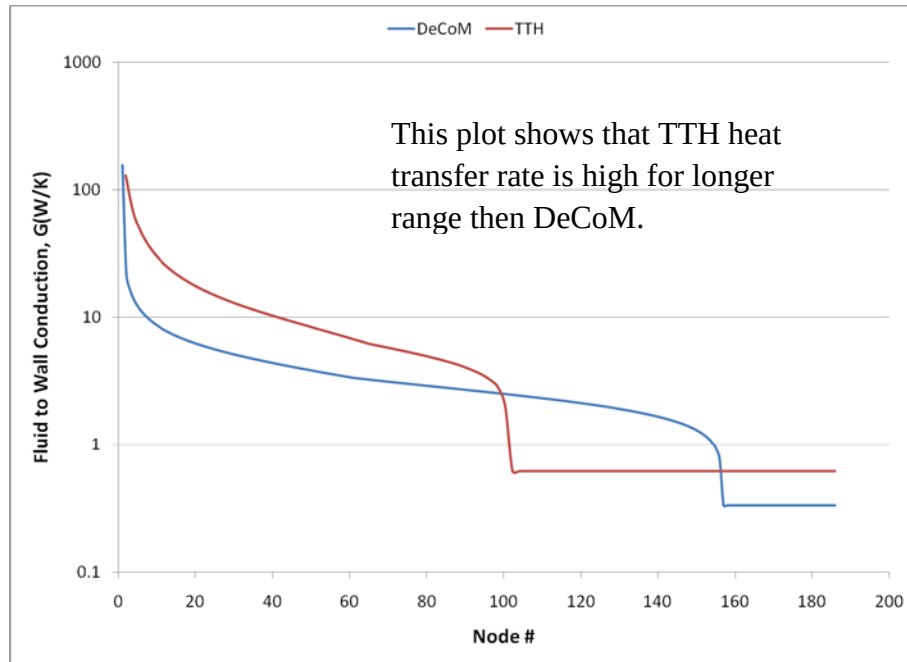


Figure 5: DeCoM vs. TTH heat transfer value (log scale)

VALIDATE 1D VERIFIED METHOD AGAINST 2D TEST CASE

The reliability of any method is only satisfied by direct correlation to actual test data. The test data obtained for correlation was from GLAS LHP test³. While the only test data that could be extracted from the test report was the temperature at the interface between the condenser exit and the liquid return line, this does represent a crucial point for characterizing the location of the subcooling, since this is the location at which the fluid remains at its subcooled liquid state and at a constant temperature throughout the liquid line. Another limiting factor to obtaining accurate correlation results was the modeling of the condenser, since exact dimensions and routing were not available in the test report; therefore, the routing and the temperature sensor location were approximated as shown in Figure 6. Also shown in Figure 6 is the table with test parameters. The two chosen test cases simulated the environment that the loop heat pipe observed during the test. The gray rectangle represents the radiator and the red and green lines are the condenser and flange setup. The figure on the right is the actual drawing of the condenser with the radiator in the background. The single test data point indicated on the drawing is the temperature sensor location which is shown on the right and mocked on the left within the thermal model. The radiator is modeled as 1/8" aluminum with 3mil Kapton (coating material) on the front and blankets on the back. The condenser fluid, diameter, liquid line starting position, and test inputs are displayed in Figure 6 as well.

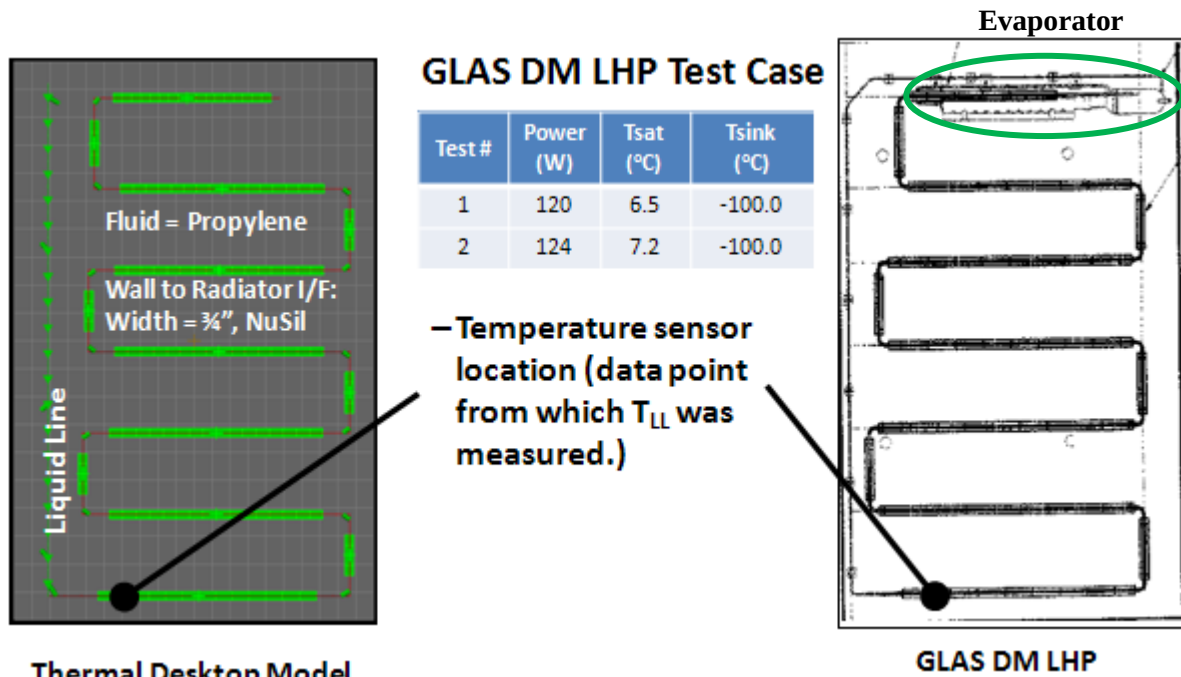


Figure 6: Thermal Model on the left, test cases in center, and GLAS LHP condenser model on the right

The test cases were analyzed in SINDA/Thermal Desktop using both DeCoM and FloCAD integration. Table 3 displays the results of the two test cases, as well as a “modified” labeled column. As observed from the DeCoM results, the average temperature difference is approximately 2.6°C for both test cases; concluding that the method DeCoM can predict the test data in an acceptable temperature range. The FloCAD method was also taken into account as a part of 2D test correlation and the results for FloCAD produced were -18.79°C for the first case resulting in a ΔT of 4.2°C. The differences between FloCAD and DeCoM may be geometry modeling differences of FloCAD to DeCoM, fluid to wall convection value differences, or the calculation routine of fluid lump to another lump or nodes to nodes.

Table 3: 2D GLAS LHP Test correlation results for DeCoM

GLAS Condenser Test Results vs. DeCoM Results					Modified (W) °C
Power (W)	Tsat (C)	Tsink (C)	TEST LL TEMP (C)	DeCoM LL TEMP (C)	
120	6.5	-100.0	-23.0	-20.49	(118)-22.23
124	7.2	-100.0	-20.0	-17.38	(122)-19.05

$$\Delta T_{avg} = \sim 2.6C$$

The column “Modified” is formulated in order to understand the effect of taking into account the parasitic heat leaks from the system. These results presented are solely for DeCoM and not for TTH or FloCAD; this is because FloCAD and TTH have already been correlated with other test data. While modeling the condenser for this correlation, possible heat leak contributors such as weak insulation and conductive heat leaks to the mechanical support structure were not

taken into consideration. Converting this ΔT of approximately 2.6°C into power using $Q = m_{\text{FLOW}} \cdot C_p \cdot \Delta T_{\text{avg}}$ results in 1.9W, which can be subtracted from the test cases and re-analyze the cases to estimate the magnitude of the “missing” leaks. The results after taking this 1.9W or heat leak into account are shown in the “Modified” column of Table 3 with DeCoM predicting within 1°C of the test data point.

INTEGRATION INTO ATLAS INSTRUMENT MODEL

The three main purposes of analyzing the ATLAS laser radiator are the following: 1) Size the radiator, 2) size the radiator heater power and 3) to provide temperature gradients for Structural, Thermal, and Optical (STOP) analysis. Sizing the radiator will help ensure that the condenser has enough area to reject instrument power with extra length for subcooling the working fluid. Sizing the radiator heater is crucial to ensure that the subcooled liquid does not reach the fluid freezing point. And finally, the STOP analysis ensures that the radiator/condenser system can withstand large temperature gradients without critical deformation. For maximum flexibility, the simulation of the condenser should:

- Have Source code available for distribution and/or modification
- Not be detrimental to model runtime
- Be validated against test data and hand calculations.

The TTH code is removed from consideration since it is a proprietary code and; therefore, the distribution of it would be unfavorable. TTH is also developed to function as a loop heat pipe code with all its components working together to take into account the changing variables (i.e mass flowrate) which might be dependent upon another component of the loop heat pipe for which design details are not yet determined (e.g. wick pore size). Since the TTH condenser portion is also under investigation for its discrepancies with hand calculations in the 1D case and it was not validated against the 2D cases, it was not selected for further use on current ATLAS work.

The next method to consider is the FloCAD approach. FloCAD has met all limitations that were put on it, with the exception of user being knowledgeable to be able to edit the run time settings to decrease CPU time. FloCAD satisfied both 1D analysis as well as 2D test case, but it is a method that requires licenses which may be unfavorable for distribution to a vendor without access to such software. The final method for consideration is DeCoM, which has an advantage of distribution and/or modification of the code, has performed calculations at a fast CPU time, and has been validated against both hand calculations and test data. The selection of DeCoM over FloCAD is mainly for the licensing capability. While DeCoM does not require a license to perform its calculations, it is limited to a single condenser as opposed to parallel or multiple condensers lines. FloCAD has the capability of performing analyses with more complex systems and may be reconsidered if the design evolution leads away from a single condenser. Because of its simplicity, reliability, and allowing of distribution without restriction, DeCoM was chosen to be integrated into ATLAS laser radiator.

Figure 7 shows the ATLAS laser radiator, with its preliminary condenser routing design. The three cases that the radiator will be analyzed are presented in Table 4. The first case with power at 212W and saturation temperature at -4°C is used to size the radiator to reject all the heat at the lowest temperature. This would be considered the worst case environment/scenario in

which the sized radiator must reject all heat. The second and third cases are performed to size the heater power to prevent freezing of the working fluid. Sizing the heater power requires both cold case with high power and hot case with low power.

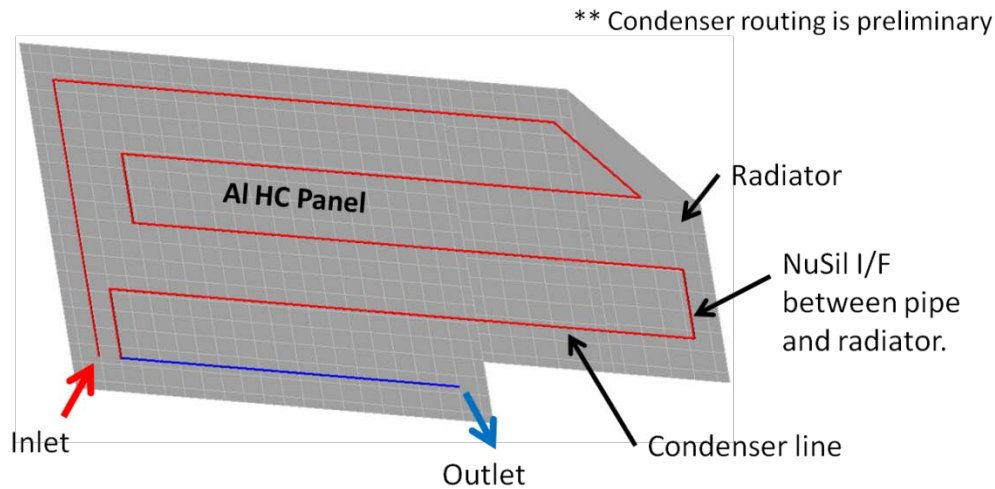


Figure 7: ATLAS Laser radiator construction, with condenser embedded

Table 4: ATLAS Laser radiator scenarios

Evaporator Input Power (W)	Operating Temperature (°C)
212	-4
212	16
142	23

Once these cases were applied to the ATLAS Laser radiator and condenser thermal model, the first case results were produced as summarized in Figure 9. The term “subcooling-cancellation” refers to the heat leak from colder section to the two-phase section. This is an important temperature point as it helps reduce the amount of heater power required to keep the condenser fluid from freezing. Points A and A’ in Figure 8 are the phase change locations while 1A, 2A, and 1A’ are the subcooling cancellation points. Figure 8 also shows that there is still room for the subcooled section, concluding that the radiator has been sized sufficiently.

To understand the temperature maps graphically, Figure 9 displays the phase change locations as well as subcooling cancellation points; and its effects on temperature variations. For this case there are two plots presented for the HB00 (hot beta 0) orbit. This orbit is also displayed within Figure 9 and it’s seen that the radiator experiences both shadow and sun environments. Subcooling cancellation points and phase change locations also occur for the next two cases as displayed in Figure 10 and Figure 11. These figures show that the temperature of the fluid drop much lower than in the first case; therefore, these cases were chosen to size the heater on the radiator. The comparison of CPU time (analysis time) of DeCoM before and after the integration was negligible (less than 1 second). The next comparison is done of the minimum liquid return temperature. Minimum liquid return temperature is observed between the points when the fluid starts subcooling, within the condenser, until the exit. Along the subcooled length, the minimum liquid return temperatures were recorded for all three cases and are summarized in Table 5. After obtaining the minimum liquid return temperatures from all three

cases, the next step was to calculate the heat required to bring the subcooled temperature up to its respective saturation temperature. The bounding case to size the heater is the 23°C case with the lowest liquid return temperature at -60°C. The approximate power required in order to bring the fluid, from its lowest liquid return temperature, up to its saturation point is 48W.

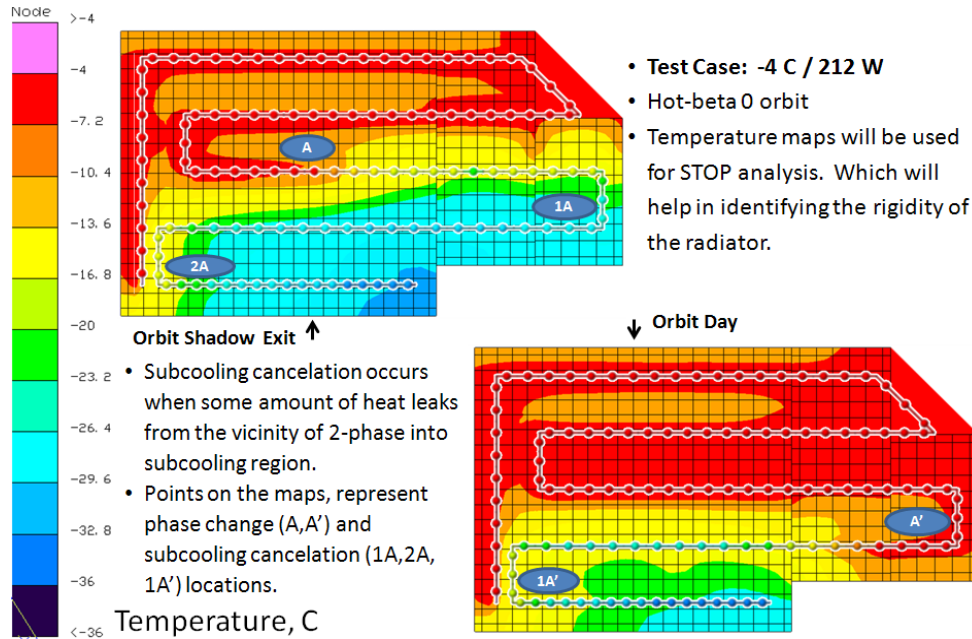


Figure 8: Temperature maps for Test case: 212W/-4 degC, HB00 Orbit

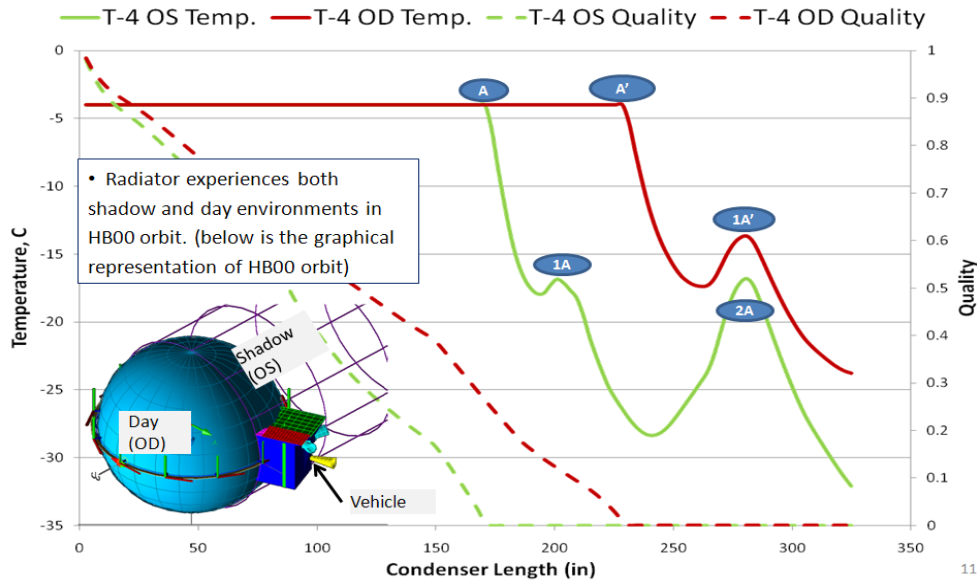


Figure 9: Test case: 212W/-4 degC, HB00 Orbit

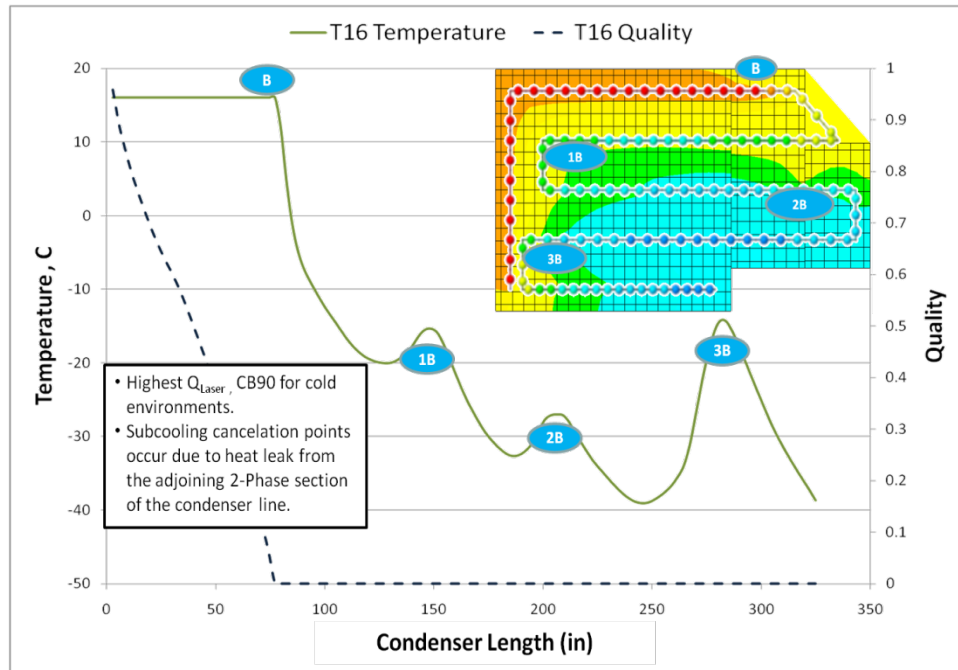


Figure 10: Test case: 212W/16 °C, HB00 Orbit

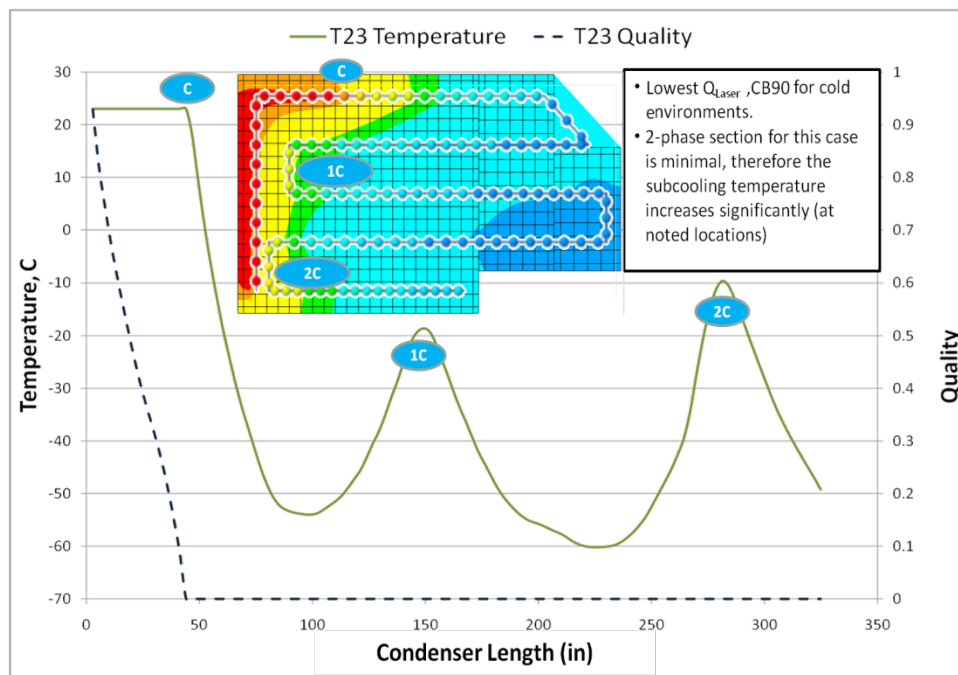


Figure 11: Test case: 142W/23 °C, HB00 Orbit

Table 5: Liquid line return temperature

Temperature Case	Liquid return Temperature (°C)	Q (W)
-4.0 C (least condensed length)	-32.00	21.00
-4.0 C (most condensed length)	-24.00	15.00
16.0 C	-39.00	46.00
23.0 C	-60.00	48.00

CONCLUSION

The steps that finalized the condenser method and analyze the radiator were:

1. verify three possible condenser simulating methods (DeCoM/TTH/FloCAD), for 1D analysis which validated against hand calculations
2. correlated the test data against validated method (DeCoM/FloCAD)
3. DeCoM, as selected method, was integrated into the ATLAS laser radiator.

The integration of DeCoM helped in verifying the ability of the radiator to reject the laser heat, size the heater power required to keep the condenser fluid from freezing and finally reduce gradients over the radiator. These temperature results were then used to map temperatures to the structural model for STOP analysis to analyze the rigidity of the radiator. DeCoM was verified against two other condenser modeling methods and hand calculations for a simplistic scenario. After showing that DeCoM was accurate compared to hand calculations, it was then verified against test data. Test data from GLAS LHP helped in verifying the robustness and reliability of DeCoM, with an average error of $\sim 2.6^{\circ}\text{C}$. DeCoM was then integrated into the ATLAS thermal model and used to generate radiator performance predictions.

ACKNOWLEDGEMENT

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CONTACT

For more information on DeCoM code or the development of analytical methods for modeling simple two-phase heat transfer LHP condensers please contact Deepak Patel at Deepak.Patel@nasa.gov or (301)-286-1549.

NOMENCLATURE

μ:	Dynamic viscosity, kg/in*sec
2Φ:	Two Phase
ATLAS:	Advanced Topographic Laser Altimeter
CC:	Compensation Chamber
Cp:	Specific heat capacity of liquid, J/kg*K
DeCoM:	Deepak Condenser Model
FLUINT:	Fluid Integrator
$G_{2\Phi}$:	Conduction in two phase, between the fluid and the wall, W/K
GLAS:	Geoscience Laser Altimeter System
h:	Heat transfer convection coefficient, W/m ² K
ICESat-II:	Ice Cloud Elevation Satellite II
LHP:	Loop Heat Pipe
LM:	Lockhart-Martinelli
mflow:	mass flowrate, kg/sec
°C:	Degree Celsius
Q:	Heat load, W
SBIR:	Small Business Innovation Research
SC:	Subcooled
SINDA:	Systems Integrated Numerical Differencing Analyzer
STOP:	Structural Thermal & Optical
TD:	Thermal Desktop
TTH LHP:	Triem T. Hoang Loop Heat Pipe
W:	Watts, W
X:	Lockhart-Martinelli parameter
x:	quality
ΔT:	Temperature difference, °C
λ:	Latent heat of vaporization, J/kg
Φ:	Lockhart-Martinelli Two phase multiplier

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