DEVELOPMENT OF INSTRUMENT SPECIFIC ENVIRONMENTAL HEAT RATES IN THERMAL DESKTOP AND SINDA FORMATS

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ABSTRACT

The Aerospace industry utilizes numerous methods allowing instrument teams to create instrument thermal designs that maintain their sensitive components with the proper temperature ranges when exposed to a wide variety of thermal environments. Some organizations produce a detailed document describing all the orbital and spacecraft conditions and then it's up to the instrument developer to create their own thermal models replicating these environments. Others exchange detailed thermal models between the spacecraft developer and the instrument teams and then the spacecraft developer provides the instrument developer a set of tables representing the sink temperatures to which the external surfaces of the instrument will be exposed. It's then up to the instrument developer to interpret and apply these sink temperatures correctly to the instrument model. This paper discusses the process that has been developed by the author to create instrument specific environmental heat rates that can be used by an instrument developer to create an instrument thermal control design independent of the spacecraft. This technique provides the instrument team heat rates in either Thermal Desktop or SINDA compatible formats that can be included directly into their thermal model with little or no modification. Furthermore, this technique is streamlined to a level such that a one to two day turn around is typical between receiving an instrument geometry model and the return of the instrument specific heat rates.

INTRODUCTION

How do you create a thermal design for a scientific instrument on board a spacecraft, when different teams are building their models in different thermal software codes? Each organization or program must handle this situation in order allow the instrument teams to develop the instruments relatively independent of the spacecraft team. The APL thermal engineer on the NASA-sponsored Radiation Belt Storm Probes (RBSP) mission has developed a process that utilizes first simple geometry model transfers between the spacecraft and instrument thermal engineers and then the full detailed models. The process provides the instrument thermal engineer heat rates that can be applied to a stand alone instrument model that contains almost no spacecraft nodes. The supplied heat rates take into account the external thermal environments (Solar and planetary heating), along with the thermal interaction with the local spacecraft surfaces, all as a function of time.

There are several direct benefits to this technique. The heat rates are provided to the instrument developer in Thermal Desktop (TD) or SINDA compatible formats, which allows them to easily integrate the heat rates directly into their model with little or no modifications. Each external surface in the instrument model has its own unique heat

rate that accurately represents the external environment. There is no complicated interpretation of sink temperatures necessary. The process has been streamlined to a very quick turn around time. The instrument developer can provide a new external geometry model to the spacecraft thermal engineer and within one to two days, receive their new heat rates, allowing them to continue with the thermal design. Finally, the instrument thermal engineer does not need the spacecraft geometry or thermal models. The instrument thermal engineer just builds the instrument geometry model of the instrument that is exposed directly to space, with nothing else in the model. The resulting radiation conductors (radks) connect the instrument to space and to itself, should there be instrument external surfaces that view each other. With the instrument only radks and the provided heat rates, the instrument thermal engineer has everything they need to develop the instrument thermal control design.

PROCESS DESCRIPTION

The process can be split up into two phases totaling 7 steps; the Geometry Math Model (GMM) section and the Thermal Math Model (TMM) section, as shown in Table 1. The first step describes the transfer of a simple external only GMM developed by the instrument team and sent to the spacecraft thermal engineer in the spacecraft specified format. APL currently uses Thermal Synthesis System (TSS) to create the spacecraft GMM. Thermal desktop (TD) has a feature to output TSS compatible files in different units. Most instrument teams are using TD. The spacecraft thermal engineer integrates the instrument GMM into the spacecraft GMM (step 2). The spacecraft thermal engineer is responsible for developing a detailed spacecraft GMM and TMM. The TMM should contain enough detail to properly predict the temperature of the spacecraft. Thus, a preliminary thermal control design for the spacecraft should be in place prior to the start of this process. This is important, since part of the environmental heat rates provided to the instruments includes the connections to the spacecraft. Thus, to get the heat rates as accurate as possible, the spacecraft temperatures need to be fairly accurate. Step 3 entails the generation of the needed environmental heat rate cases and providing them to the instrument teams.

Table 1
Steps in Process

GMM				TMM			PDR	CDR	Final
1	2	3	4	5	6	7	8	9	10
Receive Instrument GMM	Integrate into S/C GMM	Provide Instrument Heat Rate Files	Compare Massless Temperatures	Receive Full-up Instrument TMM	Integrate into S/C TMM	Compare Full-up Temperatures	Repeat Cycle before PDR	Repeat Cycle before CDR	Repeat Cycle with Correlated Instrument Model

RBSP uses 6 cases as the baseline to design the instruments and spacecraft thermal systems; 3 hot and 3 cold cases. Beta angles of 0, 24 and -33 where selected as the extreme environmental cases based on a 10 degree inclination, highly elliptical, 9 hour orbit. Beta 0 is the condition with the perigee close to the sub-solar point resulting in a 112 minute eclipse. Beta 24 is a full sun orbit and Beta -33 is an intermediate case with the apogee close to the sub-solar point and a 24 minute eclipse.

To complete the first phase of the process (Step 4), the instrument develop uses the spacecraft provided heat rates and their stand alone TMM to predict temperatures. The spacecraft thermal engineer computes the temperatures for the instrument nodes (all are massless) and sends both steady state orbit average and transient temperature predictions to the instrument team. The instrument thermal engineer compares these temperature to the ones created from the instrument stand alone model with the supplied heat rates. At this point the two thermal engineers jointly debug any differences between the two temperature predicts. The models should be updated and rerun until the temperatures compare within +/- 3 C.

Figures 1A to 1C show the process that the instrument thermal engineer should follow in order to provide the spacecraft thermal engineer with the necessary information and complete the process. The steps listed in Table 1 are indicated in the figures to help the reader keep track of the process. Figures 2A to 2C show the more complicated flow that the spacecraft thermal engineer follows in order to produce the necessary heat rates and temperatures. Further note that there are specific pieces of software used to allow several block in the flow to be efficiently completed, also indicated in the figures.

Now that phase 1 is complete, the process can continue with the Full-up TMM's. The instrument thermal engineer adds the masses, internal heats, heaters and any other internal feature of the instrument that is required to accurately predict the thermal behavior of the instrument. Once the instrument model is completed and a preliminary thermal control design has been established for the instrument, the instrument TMM is sent to the spacecraft thermal engineer (Step 5). The instrument TMM is incorporated into the spacecraft TMM (Step 6) and temperatures are again predicted by the spacecraft thermal engineer and sent back to the instrument developer for comparison to the stand alone model results (Step 7). Once any discrepancies are resolved, both the spacecraft and instrument thermal engineers now have fully functioning thermal models.

Table 1 indicates that this process should be repeated just before the instrument PDR, again before the instrument CDR and finally after the instrument team has complete the instrument flight thermal balance test and the TMM has be correlated to the thermal balance data.

BENEFITS

There are several notable benefits to this detailed process. The instrument teams can proceed with their designs with very little interaction with the spacecraft since the instrument is provided heat rates that are independent of the spacecraft model. These heat rates are applied directly to the instrument-provided nodes and thus no additional manipulation of the provided information is required. The instrument developer can include the heat rates directly into the TD model.

The process has been streamlined such that less than a 2 day turn around time occurs between when the instrument developer provides a new GMM to the spacecraft

thermal lead and when the new heat rates are provided back to the instrument developer. This fast turn around allows the instrument team to continue with their thermal design with the best environmental conditions possible.

As a result of this process the spacecraft thermal lead has a good insight into how the instrument teams are developing their thermal models. For programs where the spacecraft thermal lead has an oversight role, the transfer and integration of models allows for a very detailed look into the thermal designs of the instruments.

When the process is complete, the spacecraft lead has a full-up model of all the instruments in the spacecraft TMM. The interaction between all the instruments and the spacecraft can be assessed to determine if the agreed upon interface requirements are still in compliance. Furthermore, the spacecraft thermal lead can now perform a wide variety of additional thermal analyses to verify that instruments and spacecraft will survive and operate properly. For example, a launch analysis needs to be performed to verify that all the hardware will work property when exposed to the expected environmental conditions, which include, ground operations, boost phase, post-fairing ejection aero-heating, possible third stage burn conditions, launch vehicle separation sequences and post separation conditions. The spacecraft thermal lead can check all the instrument temperatures to see if any limits have been exceeded.

TEMPERATURE COMPARISONS

Figure 3A shows a plot of two of the RBSP instrument temperatures predictions as produced in step 4. Figure 3B shows the same set of temperatures generated from the full-up spacecraft thermal model, with the simplified external-only instrument models. The temperatures predictions are very close to each other. Figure 4 compares the maximum and minimum differences between the instrument and spacecraft model for all the arithmetic nodes in the model. Note that all the differences are between +/- 2 C. When then step has been finished, the first phase on the process is complete.

Figure 5A shows the same two temperatures illustrated in Figure 3A, but now the nodes are from the full-up instrument model, which have mass, internal power and all the internal conduction and radiation connections. By comparing 5A and 3A, the overall temperature range has reduced, as expected with mass added to the system. Figure 5B shows transient response of the same two nodes, but as computed in the spacecraft model. The temperature responses from the instrument stand alone model and the spacecraft generated temperatures again compare very well. Figure 6 shows the maximum and minimum temperatures differences between all of the nodes. Once again, the results show the differences to be less than the requirement of +/-3 C. Further note that there are now 46 nodes in the instrument model, compared to the 19 nodes found in Figure 4. This illustrates that the internal components of the instrument are now included in the model with proper connections to the external surfaces.

METHOD LIMITATIONS

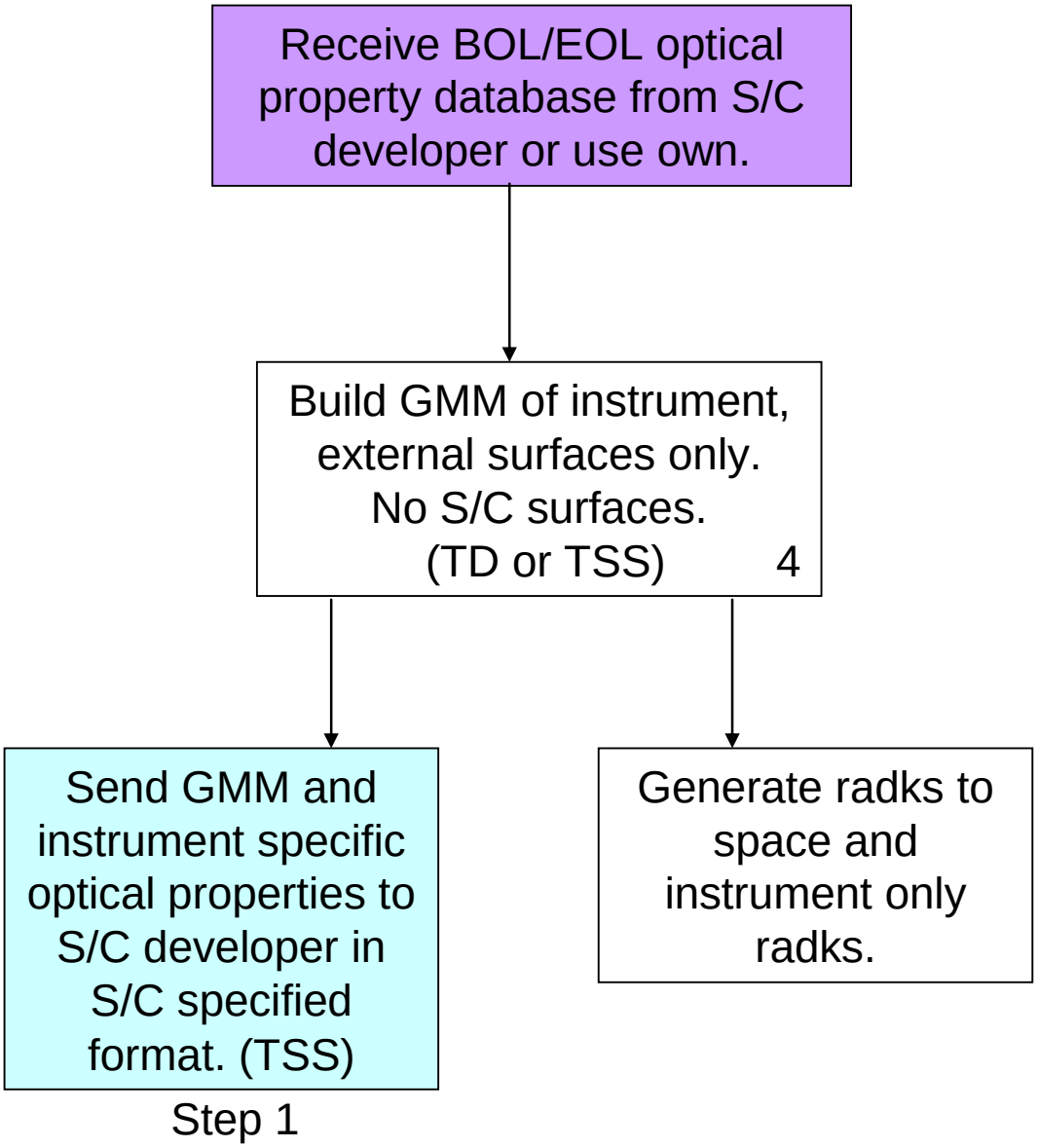
The process documented here works very well for all external surfaces that see external heat loads, like the Sun and Earth, as well as other spacecraft surfaces, like solar arrays. All high emissivity surfaces, both externally and internally work fine. There is one limitation that has been discovered during the development of this process. Low emissivity surfaces, like bare aluminum, that see into a near cavity don't appear to work correctly. Low emissivity surface that see externally work fine, just ones that look into a small cavity don't. This limitation has not hampered the design process since most surfaces are high emissivity surfaces and/or the cavities are large. Luckily, the 7 step process outline in this paper guards against this possibility and will find this one condition should it occur.

CONCLUSION

The process outlined above has been followed during the development of the eleven scientific instruments that are planning to fly on each of the 2 RBSP spacecraft. Eight different instrument thermal engineers from 7 different institutions employed this method to create their thermal designs and so for two of them have verified their designs via thermal vacuum testing. This process has shown to be easy to use for both the spacecraft and instrument thermal engineers, as well as, provide a consistent method for verifying thermal models. Ultimately the spacecraft thermal engineer ends up with a fully integrated thermal model that closely matches the thermal behavior of all the instruments on-board the spacecraft.

Figure 1A

Instrument Developer Flow Diagram



4: Instrument developers who are using Thermal Desktop (TD) will probably build the full-up GMM and TMM at the same time with masses and internal heats. The external nodes may be a separate layer that can be output and sent.

Figure 1B

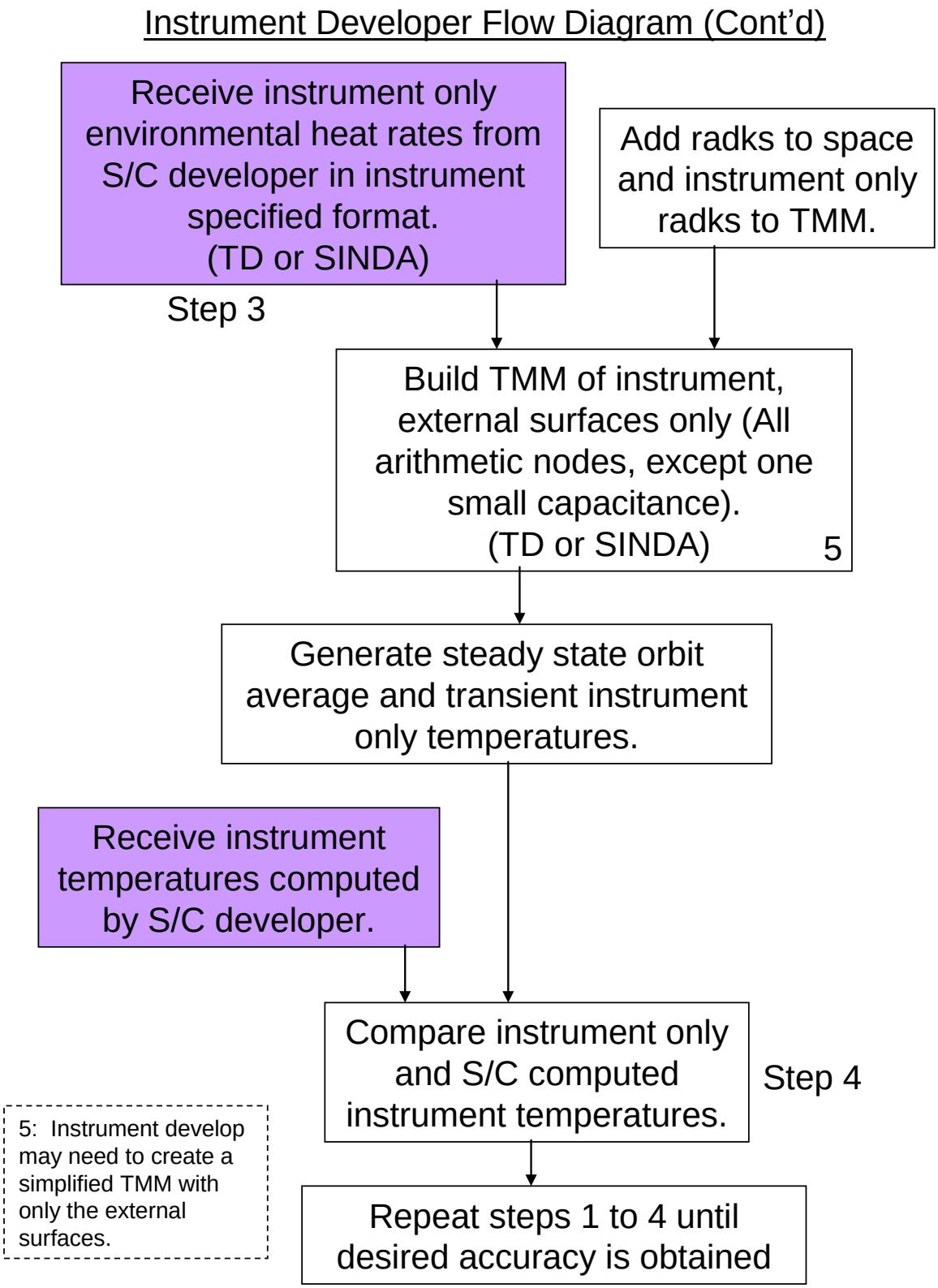

Instrument Developer Flow Diagram (Cont'd)
Receive instrument only environmental heat rates from S/C developer in instrument specified format. (TD or SINDA)
Step 3
Add radks to space and instrument only radks to TMM.
Build TMM of instrument, external surfaces only (All arithmetic nodes, except one small capacitance). (TD or SINDA)
5
Generate steady state orbit average and transient instrument only temperatures.
Receive instrument temperatures computed by S/C developer.
Compare instrument only and S/C computed instrument temperatures.
Step 4
5: Instrument develop may need to create a simplified TMM with only the external surfaces.
Repeat steps 1 to 4 until desired accuracy is obtained

Figure 1C

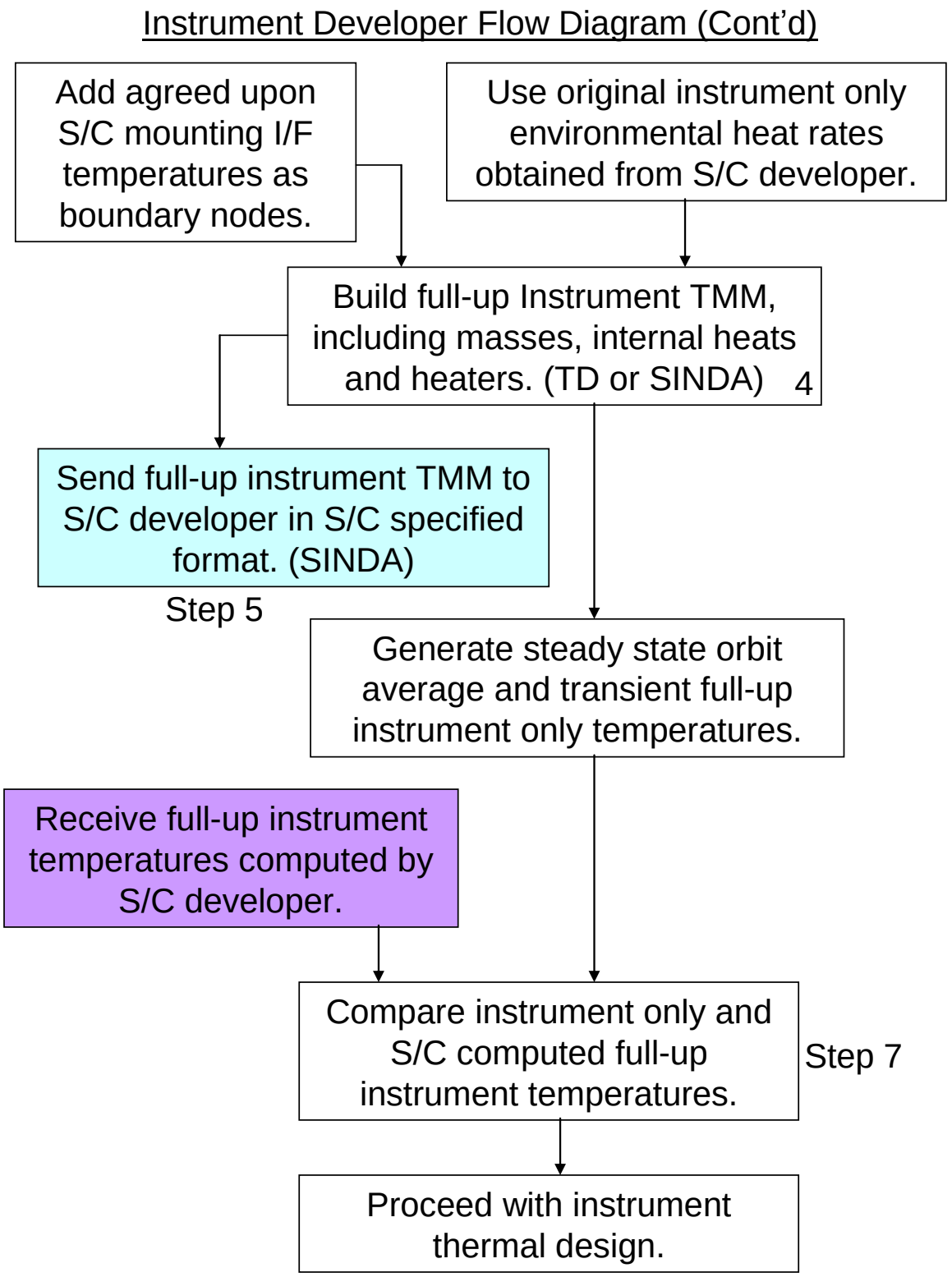

Instrument Developer Flow Diagram (Cont'd)
Add agreed upon S/C mounting I/F temperatures as boundary nodes.
Use original instrument only environmental heat rates obtained from S/C developer.
Build full-up Instrument TMM, including masses, internal heats and heaters. (TD or SINDA)
4
Send full-up instrument TMM to S/C developer in S/C specified format. (SINDA)
Step 5
Generate steady state orbit average and transient full-up instrument only temperatures.
Receive full-up instrument temperatures computed by S/C developer.
Compare instrument only and S/C computed full-up instrument temperatures.
Step 7
Proceed with instrument thermal design.

Figure 2A

Spacecraft Developer Flow Diagram

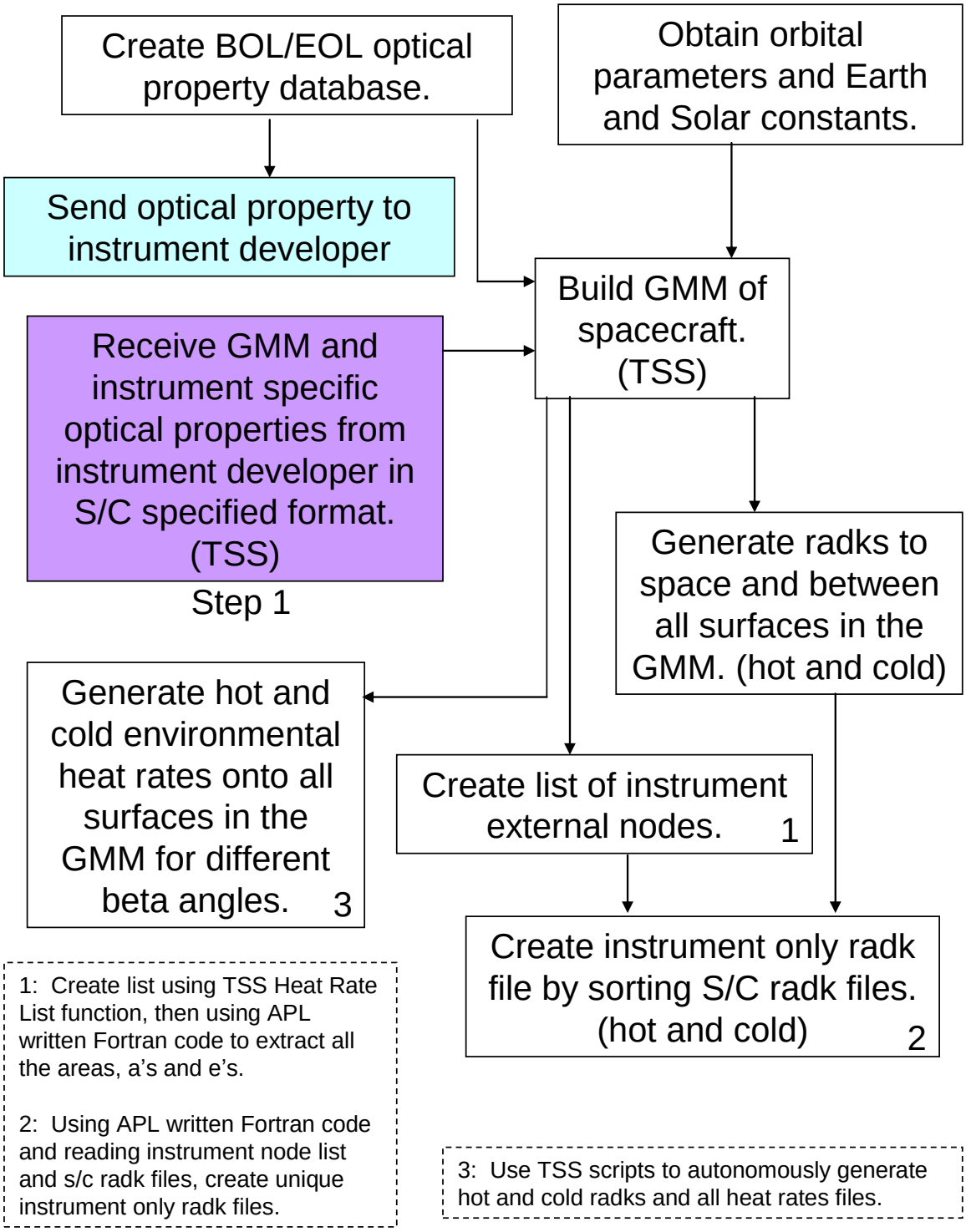


Figure 2B

Spacecraft Developer Flow Diagram (Cont'd)

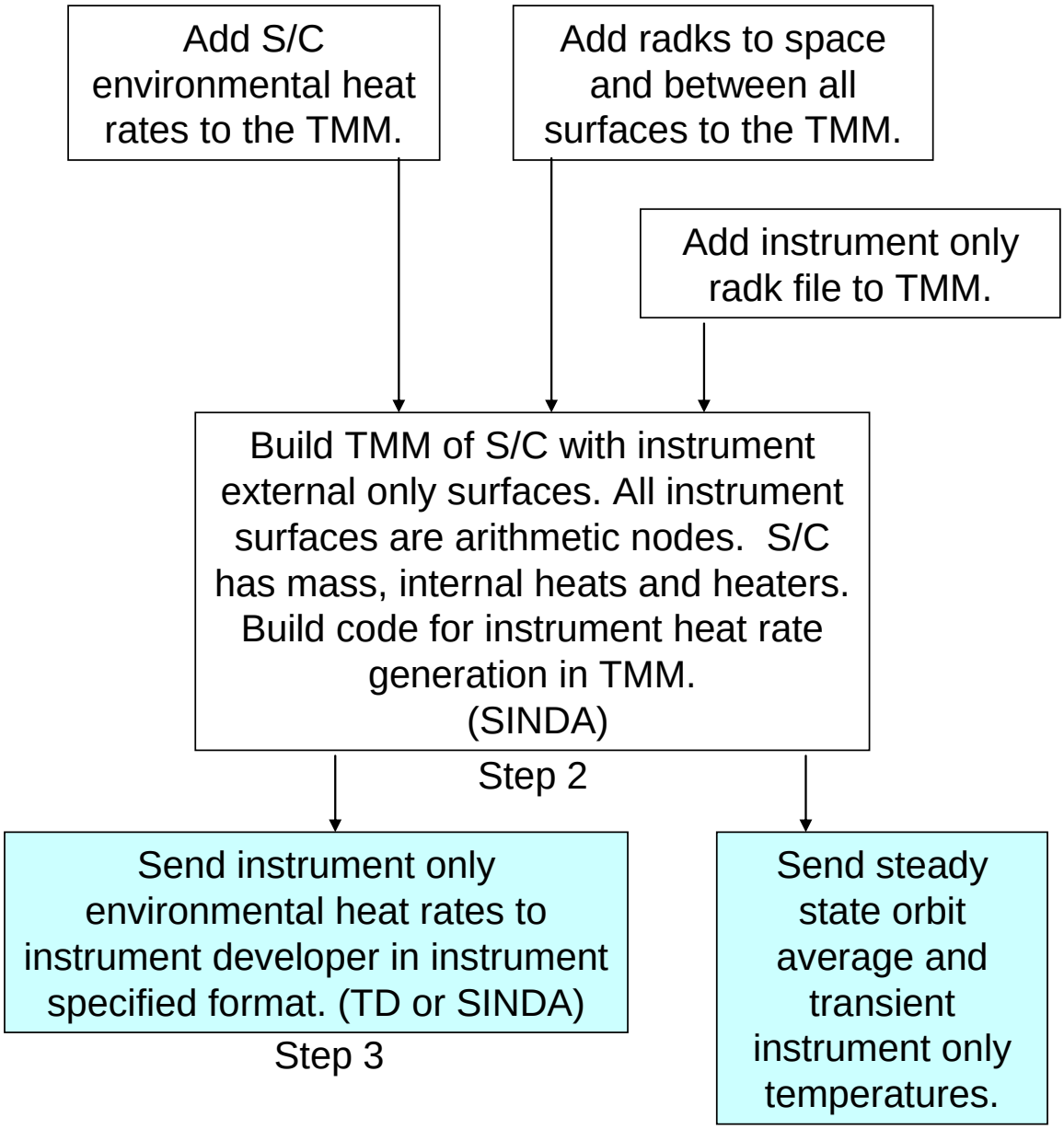


Figure 2C

Spacecraft Developer Flow Diagram (Cont'd)

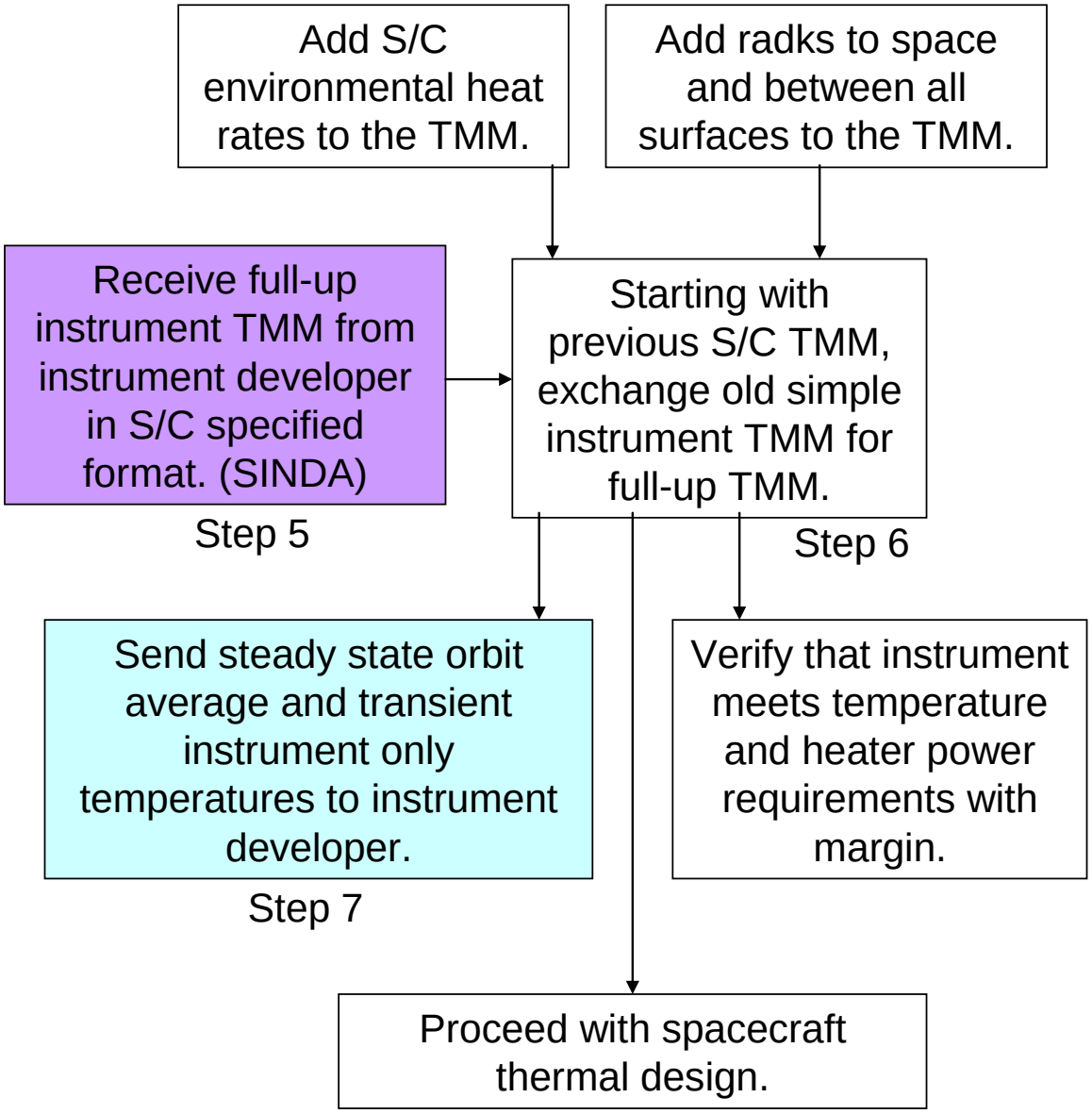


Figure 3A (Step 4)

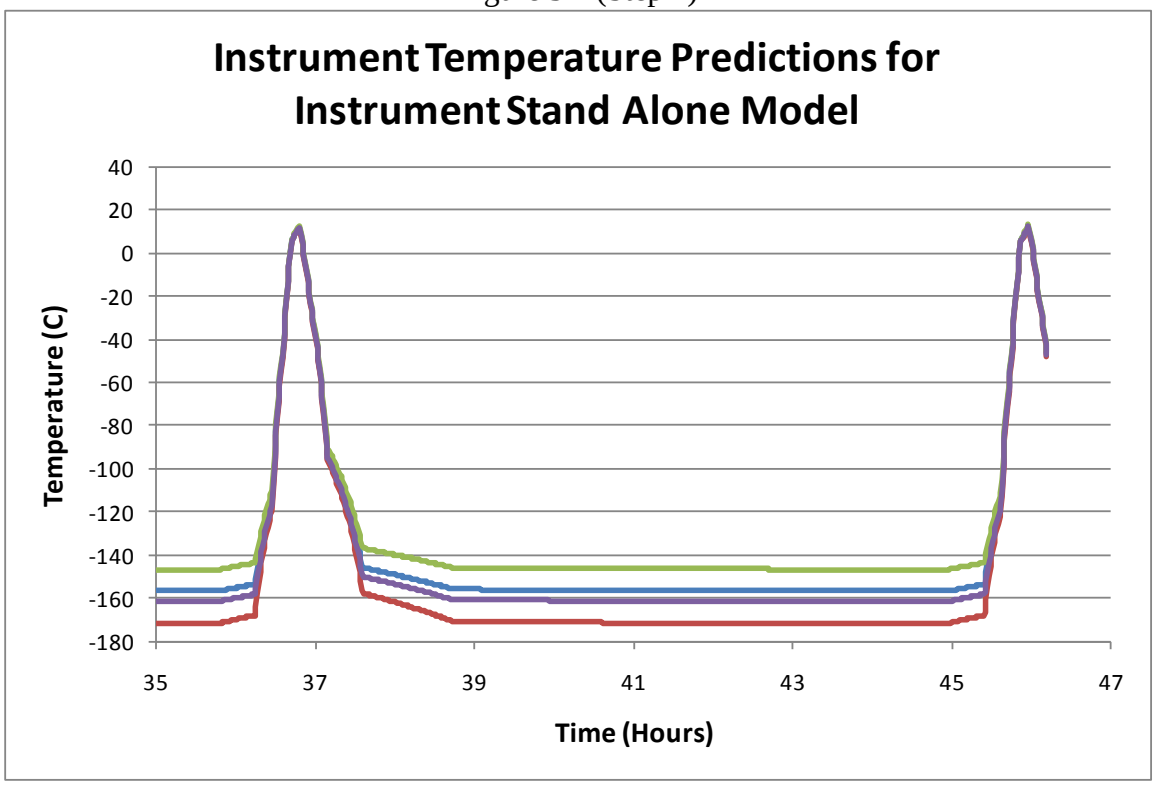


Figure 3B (Step 4)

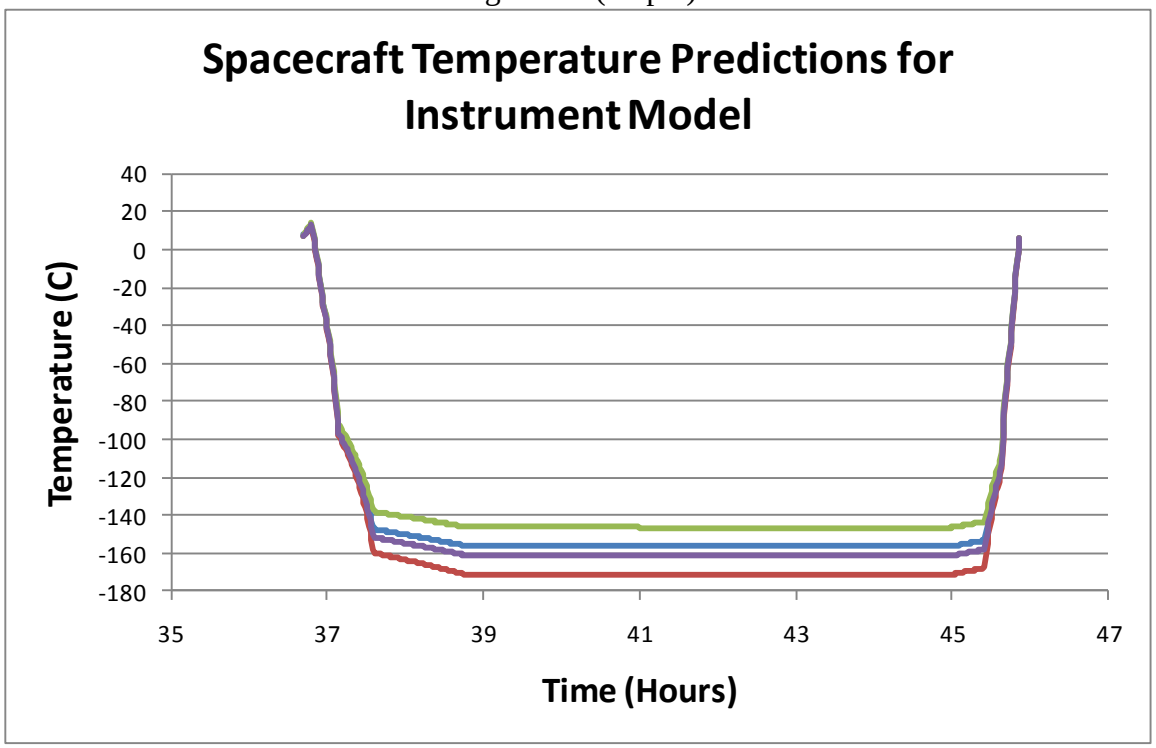


Figure 4 (Step 4)

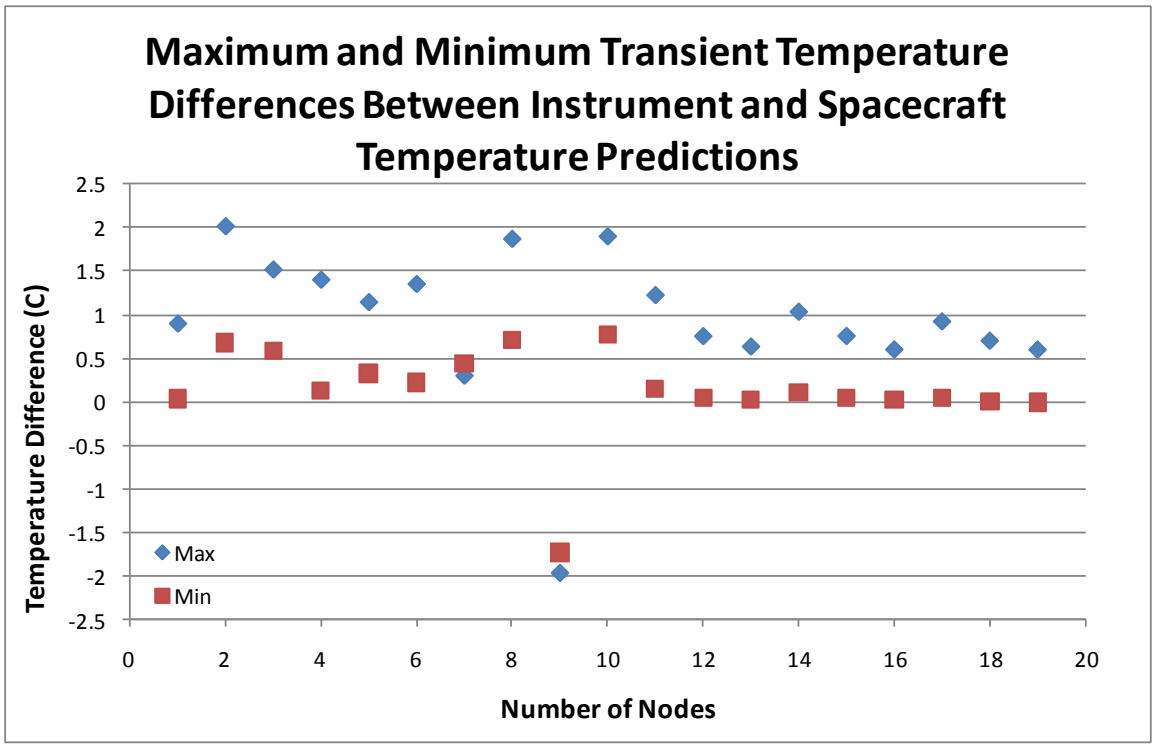


Figure 5A (Step 7)

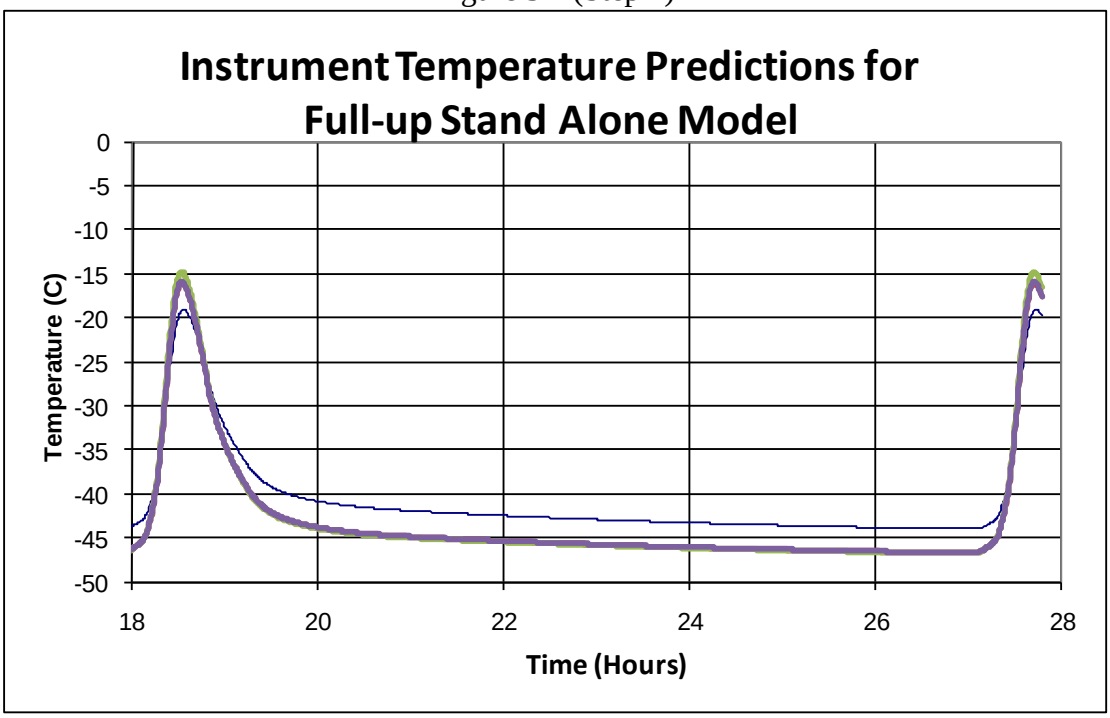


Figure 5B (Step 7)

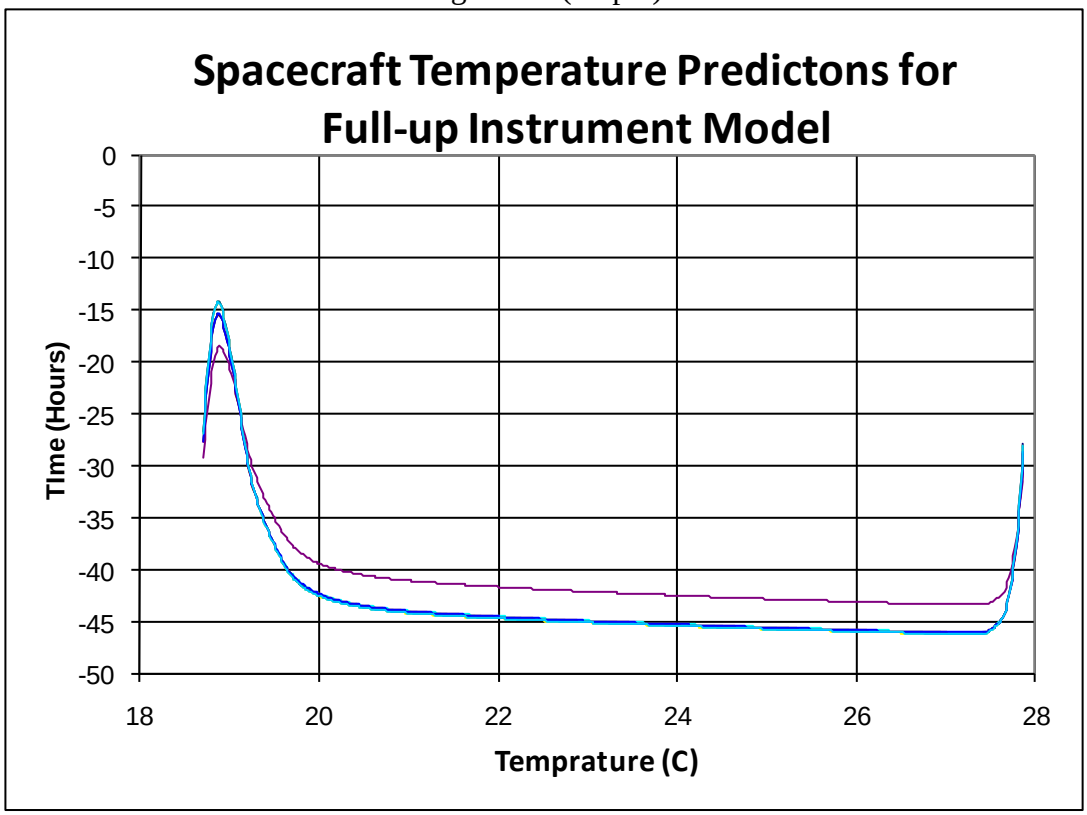
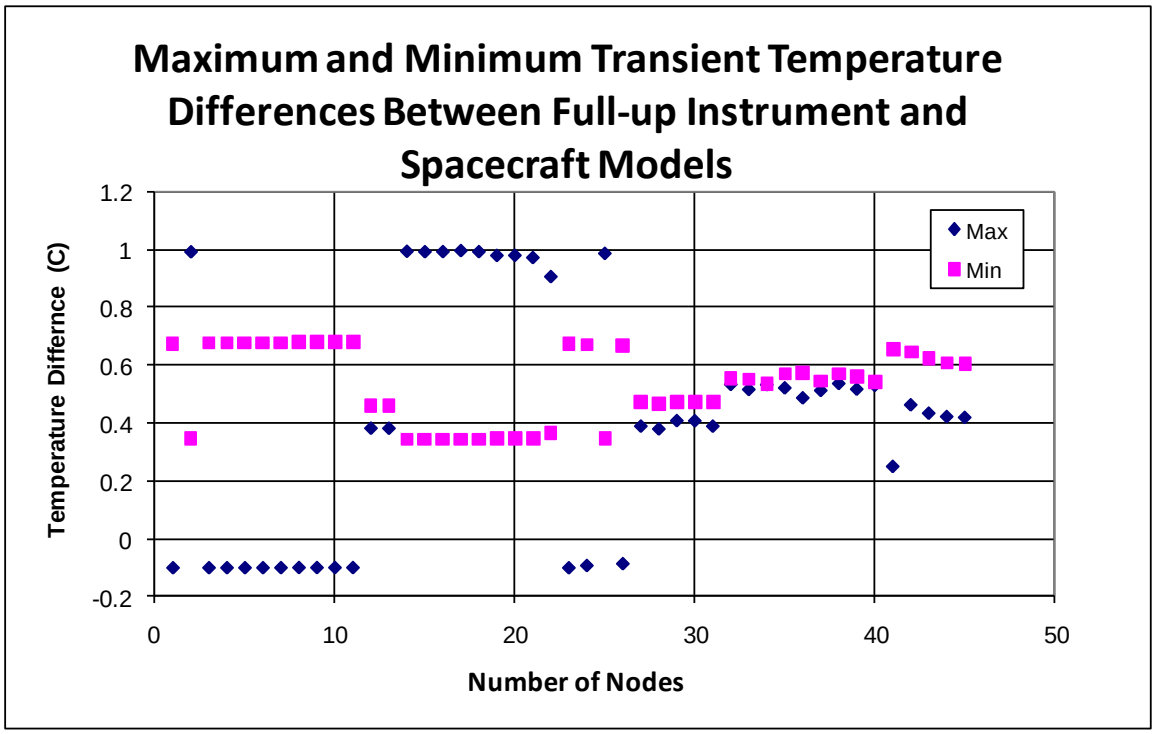



Figure 6 (Step 7)