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Mission **Lunar Reconnaissance Orbiter (LRO)**	**Date** **May 15, 2006**
Report Title **Instrument Thermal Balance and Thermal Vacuum Direction**	**Revision** **Rev. – (Initial)**
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Scope/Purpose:

The purpose of this engineering report is to document LRO's expected approach for instrument thermal balance and thermal vacuum cycling testing.

1 Purpose

Thermal Balance and Thermal Vacuum testing philosophies amongst LRO flight instrument builders are diverse enough that LRO thermal feels it needs to develop a policy statement to give philosophical and practical direction for Thermal Balance and Thermal Vacuum testing of LRO instruments. Working with the LRO Thermal Lead to develop a complete thermal balance and thermal vacuum test plan is paramount for the success of the LRO instrument level thermal vacuum test. The fidelity of the test and realism of thermal targets shall ensure a functional instrument thermal model and mitigates the chance that thermal surprises are discovered in-orbit.

2 Thermal Balance

Thermal balance's primary purpose is to validate the thermal design by for verifying radiator size, evaluating thermal isolators coupling and MLI blanket e*, and sizing of heaters. Analytically, thermal models are only as good as the assumptions put into them. Balancing a hot, cold, and survival case show that the component can perform in all expected flight environments independent of the model. Significant couplings can only be adequately evaluated if all 3 cases are run, because internal temperature differences and heat flows will be different in all three cases providing three independent points to correlate with. Heaters are typically enabled for all cases during thermal balance and the quasi-steady state results are used for cold and survival cases. Duty cycles on operational and survival heaters shall be measured and reported in the thermal test correlation report.

Thermal balance portion of the test shall be performed first. The thermal balance test purpose is to insure an adequate instrument thermal design in the bounding thermal cases and instrument configurations. Thermal balance is done at predicted end of life environment for hot cases, beginning of life for cold cases. Protoflight margins are applied only during thermal cycling. The results of the thermal balance testing shall be used to correlate the instrument flight thermal model.

2.1 Thermal Balance Cases

The thermal balance targets shall be set to achieve flight like temperatures and heat flows during thermal balance testing in hot operational, cold operational, and survival environments. Since the hot case is primarily a transient case, certain simplifications must be made to establish a steady state condition necessary for thermal balance. In order to ensure that radiator sizing is adequate and the instrument stays below the hot operational limits two things must be tested: orbit average hot environments thermal balance and thermal transient testing which will be discussed later. The cold case is essentially a steady state condition which is used to ensure that the operational heaters are adequately sized and the instrument stays above the cold operational limits. The survival case is a steady state condition for all instruments except the Diviner Instrument and Mini-RF Antenna where the lunar eclipse case will be simulated. The survival case is used to ensure that the survival heaters are adequately sized and the instrument stays above the survival operational limits. The cold operational startup shall be done following the cold survival balance prior to completing the thermal balance test.

There can be multiple separate hot and cold cases run under thermal balance. All bounding power, instrument configurations, and thermal cases shall be thermally balanced. Operational voltage for heaters shall be as follows for the balance cases: 27 V for survival, 31 V for operational cold and hot.

2.2 Thermal Balance Target Test Design

Thermal balance test setups are instrument specific. The overall driving requirement of thermal balance is to set up targets that simulate the flight-like hot operational case, cold operational case and survival case of the LRO mission specific to the instrument being tested so that the model can be adequately correlated. The baseline set of targets shall be as specified in Table 2-1 or as negotiated by the LRO Payload Systems Manager and LRO Thermal Lead:

Figure 2-1 Thermal Balance Target Baseline

Instrument/Component	S/C I/F Conductive and Radiative	Radiative Sinks
CRaTER	Portion of Deck that CRaTER bolts to shall be simulated conductively and radiatively	Zenith Face Nadir Face
Diviner	Portion of Deck that Diviner bolts to shall be simulated conductively and radiatively	Nadir Face +Y Face -Y Face +X Face -X Face
DREB	ITP cold plate	None
LAMP	Portion of OB that LAMP bolts to shall be simulated conductively and radiatively with the ability to drive gradients	Aperture Face (Nadir) Radiator Face (Zenith) MLI Sink
LEND	Portion of Deck that LEND bolts to shall be simulated conductively and radiatively	MLI sink
LOLA OTA	Portion of OB that LOLA OTA bolts to shall be simulated conductively and radiatively	Nadir Face Radiator Face MLI Sink
LOLA MEB	Portion of OB that LOLA MEB bolts to shall be simulated conductively and radiatively	Radiator Face MLI Sink
LROC NACs	Portion of OB that LROC NACs bolts to shall be simulated conductively and radiatively	Aperture Face Radiator Face Back of Cone of Silence Internal IM Simulator
LROC SCS	Portion of OB that LROC	Radiator Face

	SCS bolts to shall be simulated conductively and radiatively	MLI Sink
LROC WAC	Portion of OB that LROC WAC bolts to shall be simulated conductively and radiatively	Aperture Face Radiator Face MLI Sink
Mini-RF Electronics	Heat Pipe Cold Plate simulator shall be simulated conductively	None
Mini-RF Antenna	Portion of Deck that Mini-RF Antenna bolts to shall be simulated conductively and radiatively	Antenna Face -Y Face +X Face -X Face
Star Trackers	Portion of OB that Star Trackers bolts to shall be simulated conductively and radiatively	Aperture Face MLI Sink

All thermal balance test fixtures shall be approved by the LRO Thermal Lead as part of the instrument thermal test plan. The test plan shall also include a thermocouple diagram.

2.3 Setting Target Temperatures

Target design and temperatures in test design analysis shall match flight model temperature and heat flow predictions to the extent practicable. The measure of flight-like is by matching the reference temperatures to within 5 C when comparing the thermal test model to flight predictions using nominal emissivity and end of life absorptivity.

After the temperatures between test and flight are matched, the major heat flows are matched. This means the amount of heat leaving the radiator for a target or amount of heat gained or lost from a baffle is matched within 5% between test and flight. There is a natural focus to get the predicted temperatures, instrument internal spatial gradients, and heat flows the closest in areas of the component that are most sensitive to temperature and gradients.

2.4 Testing for Thermal Transience

Thermal transience is complex to test for, but tends to be one of the most uncertain predictions in a thermal model. It is up to the lead instrument thermal engineer to examine a portion of the thermal balance test during transitions or during a thermal transient simulation to verify thermal transients are as the model predicts. Each instrument shall verify that the thermal model predicts reasonable transient behavior thru thermal transient simulation or thermal transitions.

If orbital transient cases are simulated (such as Beta 0), they shall be done for enough orbits so that it can be demonstrated that orbit to orbit measured test temperature follow a predictable trend (i.e. the driving structural temperatures from cycle to cycle are roughly the same (orbit trends on reference points become predictable.)

2.5 Thermal Stability during Testing

Stability in thermal balance shall be achieved when the bulk temperature of the instrument varies less than 0.1 C/hr or better or when the amount of energy change (entering or leaving the instrument thermal mass) per hour is less than 3% of the power dissipated in the instrument. Q(thermal mass) = (mass of instrument x specific heat x delta Temperature max in 1 hour)/1 hour such that Q(thermal mass = 0.03 Q(instrument dissipation). The temperature stability shall be maintained for at least three consecutive hours. For cold and survival cases, an average temperature may be used if the cycling of operational or survival heaters render absolute temperature stability impossible.

2.6 Test Correlation

Correlation of the flight article in the test model shall be based on physically possible differences in conductances and e* blanket values. This is best done by plotting all thermocouples with their corresponding nodes and changing one conductance or coupling at a time and viewing how the entire test model results change. Therefore a large spreadsheet traces the difference between measured test thermocouples and the model predicts as each conductance in the model is changed. Statistically, the thermocouples can then be correlated to 2 C on average with a standard deviation at about the same level. The uncertainty residual to 2 standard deviations between the model and the test and the variation between Beginning of Life and End of Life properties will be maintained in the final flight predicts.

Flight models shall be updated based on the correlated test model and delivered to LRO. LRO needs the updated models and correlated test model as soon as they are available. It is preferred that a draft report be provided to the LRO thermal lead so it can be reviewed for content. The updated report and thermal model shall be provided two weeks prior to the instrument pre-ship review.

3 Thermal Vacuum Cycling Testing

Thermal balancing shall be completed prior to starting the 8 thermal vacuum cycles in order to adjust temperatue cycling extremes based on what was observed during thermal balance testing. Thermal vacuum cycling testing is intended to demonstrate 10 C of margin on the expected on-orbit thermal performance of the instrument based on thermal balance test results folded into a flight model plus modeling uncertainties of 5 C resulting in a 15 C of margin versus raw flight predicts (3 sigma number.) This is done to qualify the instrument for the LRO mission lifetime and test overall thermal workmanship under temperature vacuum cycling. There may be a simplification of the thermal targets, but instrument performance shall be measured during all plateaus and during some of the transitions between the temperature extremes. In that there may be multiple key parameters, the first one bounding on the system (first one to reach 10 C) limits protoflight qualification margin. A predict before the test and an as-run summary of key parameter qualification margin shall be put in the Test Readiness Review and Correlation

Summary Reports respectively. All thermal cycle test fixtures shall be approved by the LRO Thermal Lead as part of the instrument thermal test plan.

3.1 Thermal Cycling Temperature limits

During the cold vacuum cycles, the operational heaters are typically lowered in power and or turned off carefully to allow the bulk temperature of the instrument to drop at least 5 to 10 C below the close setpoint of the heater. During all instrument vacuum cycles, instrument performance shall be verified. It is also expected that the Instruments will vary power configurations and voltage cycle to cycle to demonstrate other LRO requirements such as operational over the full mission voltage range per the Electrical System Spec. Heaters shall be varied from 27 V to 35 V survival to 31 to 35 V operational.

3.2 Hot and Cold Startups and Bakeout

The instrument shall also have one warm turn on (within the operational temperature range during cycling) and one cold turn on from the survival temperature range (if not performed during thermal balance. The final activity that typically occurs during thermal cycling is an elevated temperature bakeout (where the instrument is typically turned off). This is done to verify the Instrument contamination requirements in the LRO Contamination Control Plan.

3.3 Thermal Testing Profile

The thermal testing profile is a way of expressing the overall thermal test plan for instrument testing.

As is stated in the Thermal System Specification (431-SPEC-000091), all instruments shall have 8 thermal cycles under vacuum. Our orbiter four cycle thermal vacuum and thermal balance profile is shown below for reference.