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MARTIAN MOONS EXPLORATION (MMX) MISSION

COMPONENT THERMAL DESIGN CRITERIA

REVISION AND HISTORY PAGE

Status	Revision Number	Change Number	Description	Release Date

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1. INTRODUCTION

1.1. Purpose and scope of this document

This document (MMX-C-TDC) describes the criteria on thermal interface designs for Martian Moons Exploration (MMX) on-board components.

In case of conflict, the MMX-I-IRD will take precedence over this document.

For any component that raises issues in satisfying the requirements, coordinate with the MMX system team.

1.2. Reference documents

See Section 6.

1.3. Notation

[TBD-Sys] [TBC-Sys]

The results of previous study for MMX or other projects are described as reference information for systems and the PI instrument. They will be established by system design in Phase A or beyond.

[TBD-Sys/PI] [TBC-Sys/PI]

The results of previous study for MMX or other projects are described as reference information for systems and the PI instrument. They will be established through coordination between the PI instrument and systems in Phase A or beyond.

[TBD-Doc] [TBC-Doc]

Information that can be described through coordination with design standards and other documents. (Phase A or beyond)

[TBD-Plan] [TBC-Plan]

Information determined after government approval of the project plan.

2. DESIGN CRITERIA

2.1. General Information

2.1.1. Standard Metric System

Drawings, specifications, and engineering data shall use the International System (SI) metric standard.

- Dimensions in meters [m]
- Angles in degrees
- Temperatures in degrees Celsius [°C]
- Power / Heat in watts [W]
- Energy in joules [J]
- Mass in kilograms [kg]
- Magnetic field in tesla [T]
- Time in seconds [s]
- Electric current in amperes [A]

2.1.2. Classification of Equipment

This document broadly classifies components into the following two types:

(1) Internal on-board component

Internal on-board component is defined as component installed into a spacecraft and is not exposed to the space environment.

(2) Exposed on-board component

Exposed on-board component is defined as component installed outside of a spacecraft or component installed in a spacecraft, but has an opening for observation or is partially exposed to the space environment.

2.1.3. General Requirements

Thermal designs shall be made to spacecraft systems and components, so that on-board components will operate normally under specified thermal interface conditions.

Specified thermal interface conditions is defined as thermal environments or component temperatures, as specified in the following documents:

(1) Thermal Interface Condition Document

(2) ICD

2.2. Thermal Design Requirements for On-board Equipment

2.2.1. Internal On-board Equipment

Internal on-board component shall be designed to meet the following requirements:

2.2.1.1. Interpretation of Heat Radiation and Requirement for Uniform Temperature

There are two aspects for heat radiation in the self-heating of internal on-board component: heat radiation elements through conductive heat transfer from the mounting surfaces of component and radiative heat transfer from the surface of component casings. Equipments shall be designed to consider that temperatures become uniform at mounting surfaces of component as well as various sections of component casings, including their mounting surfaces, as much as possible. In principle, components shall be designed so that a temperature difference (between the highest temperature and the lowest temperature) should be within 5°C for temperature distribution on component cases including the mounting surfaces.

2.2.1.2. Mounting Method

In principle, components are connected to a body by screws. Flanges or tabs shall be basically provided in longitudinal direction of the component. Since contact thermal resistance depends on a mounting hole pitch, the pitch of heat generating component shall be determined in consideration of not only mechanical environmental conditions but also the amount the component's heating generation. In particular, if the thermo density exceeds the value specified in Section 4.2.1.4, the pitch shall be basically 100 mm or less. Also, since components may be coated with thermal fillers when mounted, there shall be no holes or gaps on mounting surfaces to avoid penetration of thermal fillers. Note that MMX System Team will decide on which component should be coated with thermal fillers.

2.2.1.3. Surface Roughness and Flatness

Surface roughness and flatness rate of mounting surfaces shall satisfy the following conditions:

(1) Surface roughness: better than 6.3S

(2) Flatness rate: 0.001 mm/1 mm or less

2.2.1.4. Average Heat Generation Density

Average heat generation density of respective components shall be 0.06 W/cm2 or less in relation with the contact area of a mounting surface.

Note that average heat generation density shall be defined as follows:

(Average heat generation density) = (Maximum heat generation amount: Note 1) / (Contact area of a mounting surface: Note 2)

Note 1: Excluding the maximum heat generation amount within five minutes,

Note 2: Plate thickness of the mounting surface shall be 1 mm or more.

Any components failing to satisfy these specifications shall be coordinated through MMX System

Team and described in the ICD.

2.2.1.5. Shapes of Mounting Surfaces

Since thermal fillers may be coated on to the mounting surfaces when the component is mounted, there shall be no holes or gaps on the mounting surfaces, to avoid penetration of thermal fillers that will impair the component performance.

2.2.1.6. Surface Treatment of Mounting Surfaces

Surface treatments, such as coatings that prevent thermal conduction, shall not be applied to mounting surfaces of respective component.

2.2.1.7. Surfaces Surface Treatment of External Surfaces Except for Mounting Surfaces

Regarding thermal emissivities of external surfaces, treatment shall be applied so that, in principle, the total hemispherical emissivity will be 0.8 or more.

In particular, if any section is restricted in surface treatment, such area, surface treatment of such area, and total hemispherical emissivity shall be indicated in advance in the ICD and the Interface Thermal Mathematical Model User's Manual.

Note that MMX System Team shall separately provide its requirements on components, having systems requiring a total hemispherical emissivity, which is different from the above value. Therefore, PI Instrument Team shall apply surface treatment, which will conform to this requirement.

If it is necessary to apply thermal control to surfaces, except for the above section with some restriction on surface treatment, it shall be possible for MMX System Team to change the thermal emissivity, for example, by means of taping, according to the agreement with PI Instrument Team.

2.2.2. Exposed On-board Equipment

Exposed on-board component is characterized by its necessity to be exposed, due to its performance. In general, it has sections such as openings for observation and has areas that cannot be freely used for thermal control. In addition, it has relatively small flexibility for mounting positions. In many cases, appropriate arrangements for thermal control are not appropriate for observation. What is more important is direct exposure to severe thermal environments of space.

Thermal control of exposed on-board component needs to be performed on the basis of balance between space thermal environments and self-heating. One of the most important aspects is, first of all, to arrange appropriate external shapes or positions of main thermal control surfaces. For this purpose, it is necessary to start with the design of internal structures of exposed on-board component.

In many cases, exposed on-board component cannot be thermal-controlled simply by adjusting mounting surface specifications or thermal-optical characteristics, as in the case of internal on-board component. In other words, exposed on-board component itself is required to be designed to fit to surrounding thermal environment conditions.

The “Thermal Interface Condition Document” specifies thermal environment conditions for the purpose of thermal designs of exposed on-board component.

While the “Thermal Interface Condition Document” specifies general information on thermal interfaces in addition to thermal environment conditions, thermal designs of exposed on-board component shall basically follow the criteria below:

(1) Thermal exchange amount relative to a system body

A large thermal exchange amount between exposed on-board component and a system body may impede the thermal control of an entire spacecraft. In principle, therefore, exposed on-board component shall be designed so that the thermal exchange amount relative to the body will be 5 W or less in combined total of radiative elements and conductive elements.

Therefore, if a thermal exchange amount relative to the system body deviates from this value, radiative insulation and conductive insulation from the body shall be applied to on-board component.

(2) Surface Refection Characteristics

For surfaces where sunlight, Mars albedo light, Mars infrared rays, Phobos/Deimos albedo light, or Phobos/Deimos infrared rays may enter, a diffusion surface shall be applied as much as possible, except for thermal radiation treatment using OSR, etc.

(3) Temperature Control Heater

If temperature of exposed on-board component is controlled using an electric resistance heater, the component shall basically have its own heater or control circuit for this purpose. In particular, if temperature is directly related to component performance (for example, if performance heavily depends on temperature and if component without its own control circuit causes difficulty in a unit performance tests), the component shall have its own control circuit.

However, if it is judged from an overall perspective that there will be no difficulty in temperature control or operation of the component, a “heater control equipment (HCE)” belonging to a thermal control system can be used. Specifications for HCE will be provided separately.

In addition, MMX System Team may require, according to necessity, that a survival heater (including a thermostat thermistor) or a replacement heater (a heater that generates heat, to obtain a condition equivalent when component is turned off) should be mounted on component.

2.3. Temperature

2.3.1. Temperature Specified Points

Specific locations on components, specified for design, testing or temperature monitoring while in orbit are called “temperature specified points.” Temperature specified points shall be as shown below, depending on how thermal radiation is controlled. However, if the following concepts are not applicable to the temperature specified points of externally exposed component or mission component, such matter shall be coordinated separately.

(1) If conductive thermal coupling of a mounting surface controls heat radiation A mounting flange of the component or its proximity

(2) If radiative thermal coupling of a casing surface controls heat radiation

A location which is the geometric center of a surface of a casing and which does not cause a heat spot

(3) If a component-specific radiator controls heat radiation

The following two locations shall be applicable. Note that the interface with the system shall be (a).

(a) A mounting flange of the component or its proximity

(b) In proximity to a radiator surface

(4) Others

A mounting flange of the component or its proximity shall be one of the temperature specified points. Other temperature specified points will be coordinated separately when necessary.

Note that, if a measured temperature point is different from a temperature specified point, the difference in temperature shall be clarified and be specified in the ICD together with the position of the measured temperature point and the position of the temperature specified point.

2.3.2. Design Temperatures

Equipment shall be designed in taking into account factors such as, thermal environment fluctuations or analytical errors, as follows:

2.3.2.1. Factors to Be Considered in Temperature Predictions

Temperature predictions shall incorporate the following (1) to (8) factors as thermal analysis conditions:

(1) Seasonal fluctuations and short-term fluctuations of external thermal source intensity
(2) Thermal input fluctuations due to changes in attitude
(3) Changes in self-heating due to component’s operating conditions
(4) Tolerances, temperature dependence and aging of component’s self-heating mechanism
(5) Uneven thermal characteristics due to tolerances in the component fabrication stage and lot-based uneven thermal-optical characteristics of thermal control materials
(6) Temperature dependence and degradation of thermal characteristics
(7) Changes in radiative boundary temperatures (temperatures of the component and objects related to radiative thermal exchanges) and conductive interface temperatures (temperatures of the component and objects related to conductive thermal exchanges)
(8) Accuracy of thermal analysis modeling and uncertainty of analyses of analytical tools

2.3.2.2. Temperature Prediction Calculations

Temperature predictions of the component shall be calculated by taking the factors of 2.3.2.1. (1) to (8) into account.

2.3.2.3. Classification of Temperature Range

The temperature range of component is classified below.

<1> design estimated temperature range

<2> maximum estimated temperature range

<3> allowable temperature range

Figure 2.3.2.3-1 shows mutual relationship of temperature range above mentioned. The details are described hereafter.

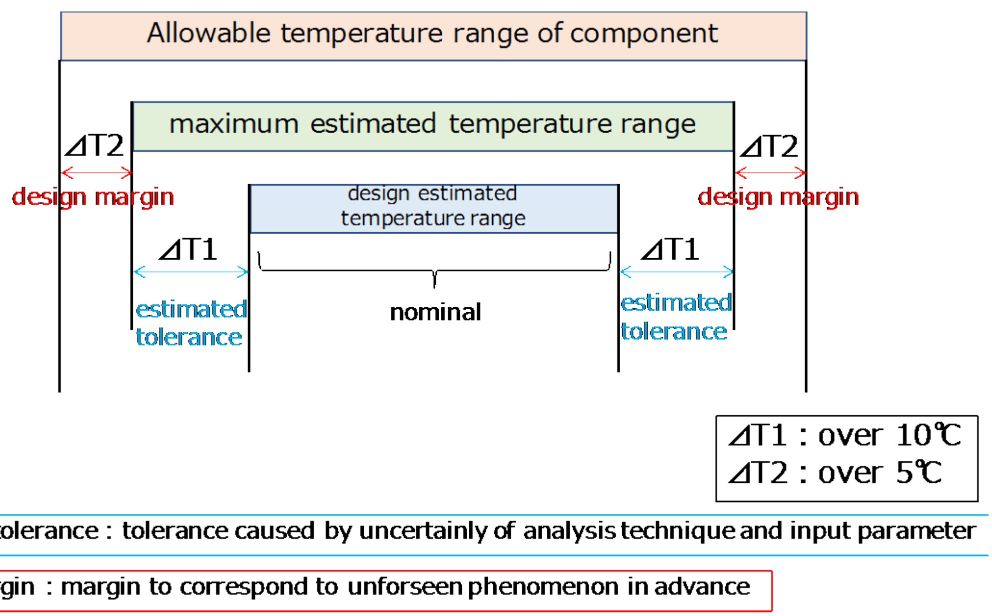

Figure 2.3.2.3-1 Mutual relationship of allowable temperature range and estimated temperature range

2.3.2.4. Design Estimated Temperature Range

The design estimated temperature range is the nominal temperature range considering the heat input fluctuation etc. caused by seasonal variation, operation and degradation of thermal control devices. Specifically, it means the temperature range obtained by thermal analysis considering the following factors.

(a) The seasonal variation and short-range variation of external heat source strength.

(b) The variation of heat input by the change of the spacecraft's posture

(c) The changes in the operating condition of component which brings about changes in the output of heat (including degradation of a component's heating element)

(d) The deterioration of thermal control devices through age

(e) The temperature changes to the thermal properties of materials uncertainties as a result of contamination etc. which must be addressed using results from flight testing

(f) The change of the radiation boundary temperature (i.e. the temperature of a body while releasing radiation which is exchanged with a component) and the conductive interface temperature (i.e. the temperature of a body while releasing conducted heat which is exchanged with a component)

2.3.2.5. Maximum Estimated Temperature Range

The maximum estimated temperature range means the in-orbit maximum estimated temperature range which includes a predicted error of ΔT1 to become the "design estimated temperature range".

2.3.2.6. Allowable temperature ranges

The allowable temperature range is classified below according to the operating condition and service condition of the component.

(a) The operational temperature range (i.e. temperature range for maintaining a component's efficiency). This is also the temperature range to satisfy its specifications and performance.

(b) The temperature range for maintaining a component's function. This temperature range may result in decreases in performance below specifications, but the component still functions and satisfies its performance requirements without any malfunction nor degradation during operation.

(c) Inactive temperature range (preserved temperature range). The temperature range that does not create a malfunction or permanent degradation during inactivity while in orbit.

(d) Turn-on temperature range. The temperature range over which the components may be turned on and which does not create a non-recoverable degradation while in orbit.

These allowable temperature ranges shall be specified in the ICD for respective components. They shall be specified rationally on the basis of temperature specified points.

2.4. Heater Control Authority Margin

2.4.1. ΔT1 and ΔT2 of Components Subject to Active Thermal Control

2.4.1.1. Approach to Thermal Control

This section describes the standards for defining ΔT1 and ΔT2 of components subject to active and passive thermal control.

Concerning the heat input Q (including self-heating) to a component in orbit, the temperature of the component must be maintained within the allowable temperature range by installing a thermal coupling that conducts heat between the component and its surroundings.

In the following formula, T is set within the specified temperature range within the variable range of Q by appropriately selecting a fixed value for G. Here, T_0 is the temperature of the boundary, which is also variable.

$Q = G\Delta T = G(T-T_0)$ Equation 2-1

Figure 2.4.1.1-1 shows a conceptual diagram of passive thermal control.

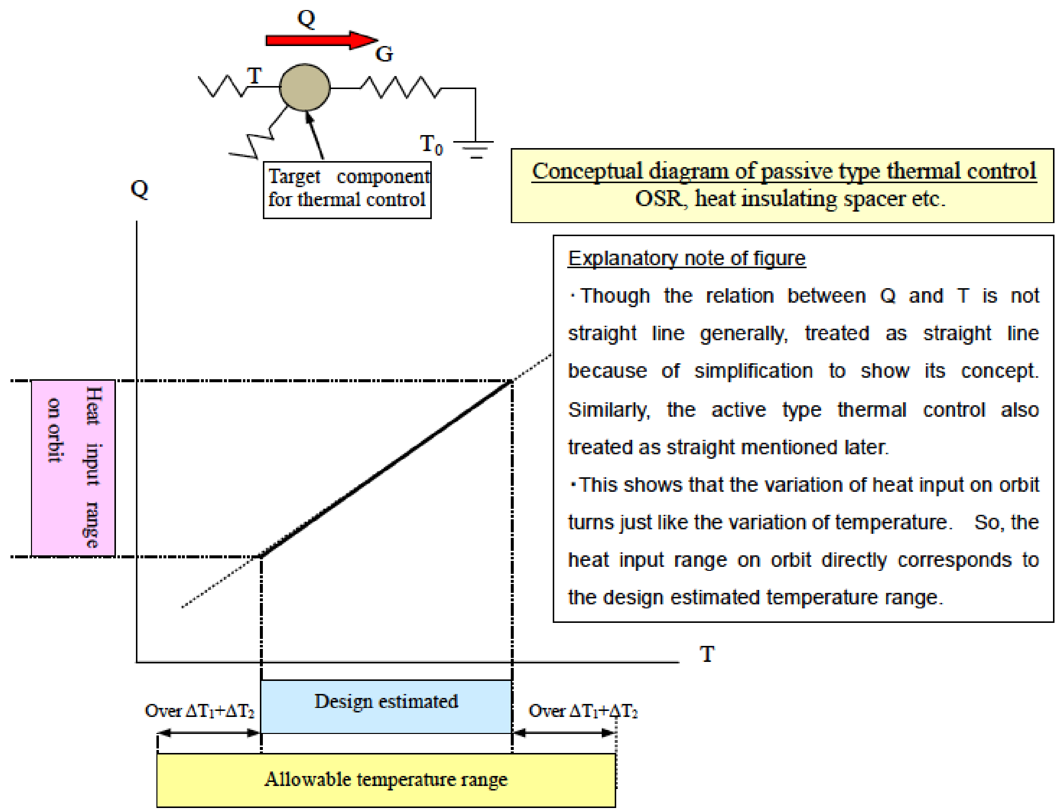

Figure 2.4.1.1-1 Conceptual diagram and design margin of passive thermal control

2.4.1.2. Requirements for ΔT1 and ΔT2

In Equation 2-1, T must be within the designated temperature range by regarding Q, G, or both as variable.

The sample of variable G is set for a thermal louver, a variable conductance heat pipe (VCHP), and other components, with variable Q controlled by the heater and so on.

The following diagram shows the concept of active thermal control and its design requirements.

(1) Conceptual diagram of active thermal control (the case where Q is variable, part 1)
When spare control power is available only to the lower limit of the estimated design temperature range.

The sample diagram below is a thermal control heater that maintains the lower temperature limit.

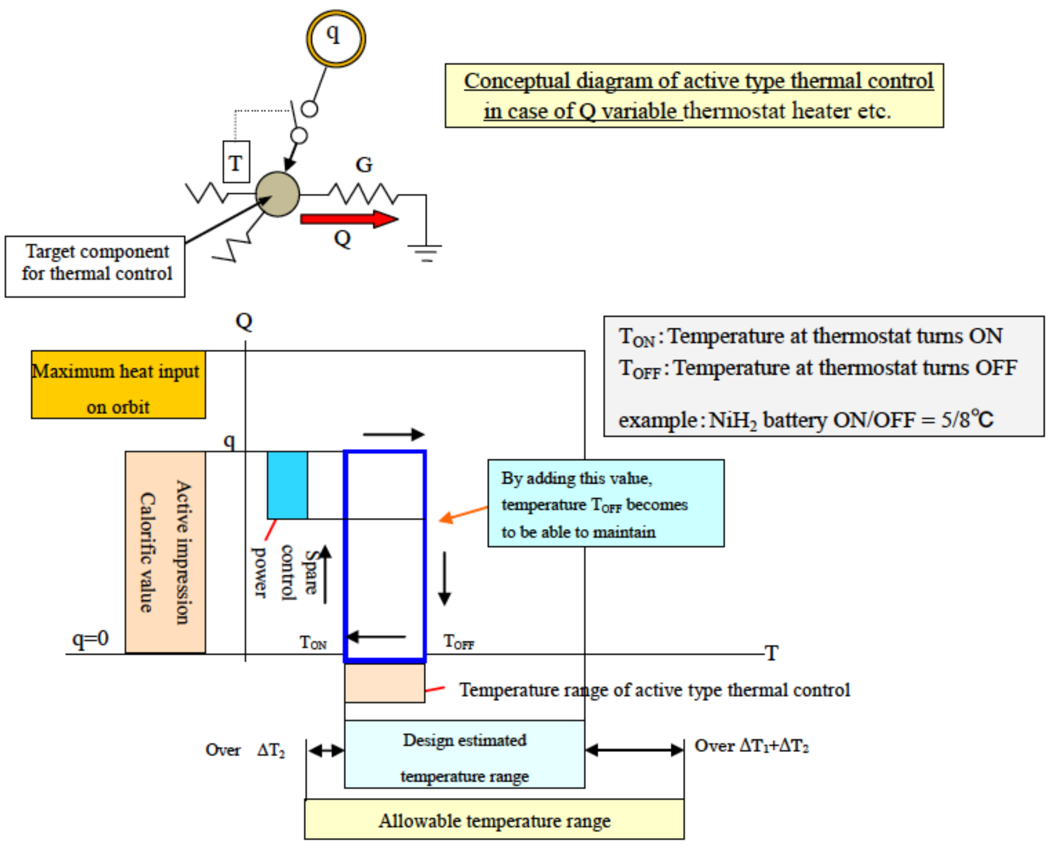

Figure 2.4.1.2-1 Conceptual diagram and design margin of active thermal control

(Q is variable)

Figure notes:
[1] This is a conceptual diagram for thermal control at the lower limit of the allowable temperature

range by active thermal control. Specifically, this case corresponds to the thermal control of a battery mounted in a high-capacity geostationary satellite and propulsion system (tank and piping) with a relatively high allowable lower limit as compared with other components.

[2] For such a component, the area of the radiating surface is usually measured based on the case of maximum heat generation (maximum heat input) at the upper limit temperature. Conversely, the lower limit temperature requires keeping a minimum level of heat generation using a heater.

Design requirements

While the upper temperature limit is designed as passive thermal control, the following describes the lower temperature limit.

[1] Heater capacity should be larger either than the heat for keeping the temperature containing the margin of ΔT1 (°C) or than the heat multiplied by the safety factor when the heater is OFF.

[2] At the lower temperature limit with active thermal control, the designed estimated temperature range should be secured within a margin over ΔT2 (°C) of the allowable temperature range. In some cases, ΔT2 (°C) secures its margin through the heater capacity.

Reference example

DRTS NiH_2 battery

・Allowable temperature (–10 to 25 [35(*1)] °C) thermostat: ON/OFF = 5/8 (±1 °C)

(*1) At electric discharge and 3 hours after the start of charging

・On-orbit data

・ During trickle charging, temperature shall be maintained within the thermostat control temperature range [5 to 8 °C]

・During discharge, the temperature increases above the temperature at thermostat OFF (all heaters OFF)

[Approximately 18 °C at DC arc jet operation, and approximately 10 °C at maximum shade at equinox]

(2) Conceptual diagram of active thermal control (the case where Q is variable, part 2)
When spare control power is available for both the lower and upper limit of the estimated design temperature range.

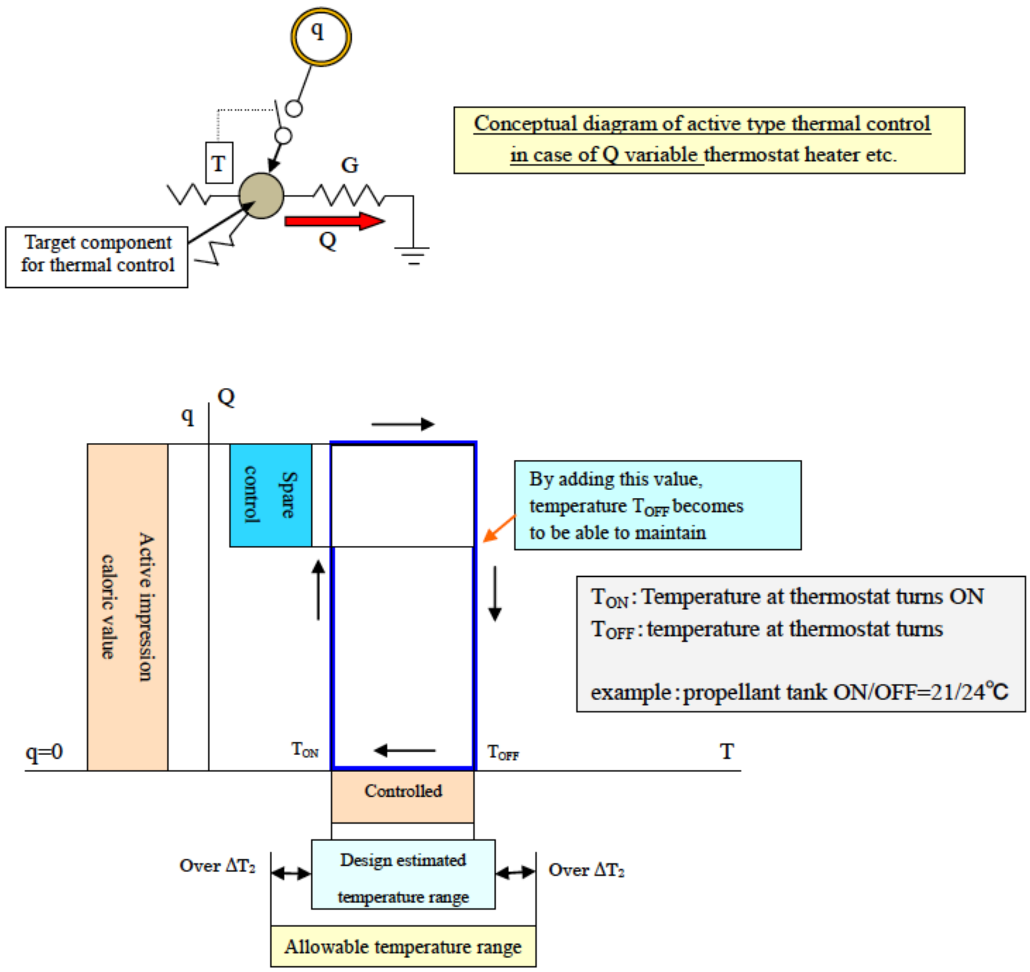

Figure 2.4.1.2-2 Conceptual diagram and design margin of active thermal control

(Q is variable)

Figure notes
[3] This is a conceptual diagram for when there is thermal control to the upper and lower limit of the allowable temperature range by active thermal control. This example is the case of a thermal control for a battery and optical sensor with a narrow allowable temperature range.

Design requirements

The upper temperature limit, principally values ΔT1 + ΔT2 (°C) over the upper design temperature limit, should be secured (secure the radiating surface) when the active thermal control of the heater, etc., is OFF.

The design margin for the lower temperature limit is set as follows:

[1] The heater capacity should, in principle, be larger either than the heat output from the heater OFF temperature to over ΔT1 °C, or than the value multiplied to account for the safety factor and heater capacity necessary to maintain the heater OFF position temperature.

[2] At the lower temperature limit with active thermal control, the design-estimated temperature range should be the secured to a margin of ΔT2 (°C) over the allowable temperature range. (In some cases, ΔT2 (°C) secures this margin through heater capacity.)

(3) Conceptual diagram of active thermal control (the case of G as variable, part 1)

When spare control power is available for both the lower and the upper limit of the estimated design temperature range.

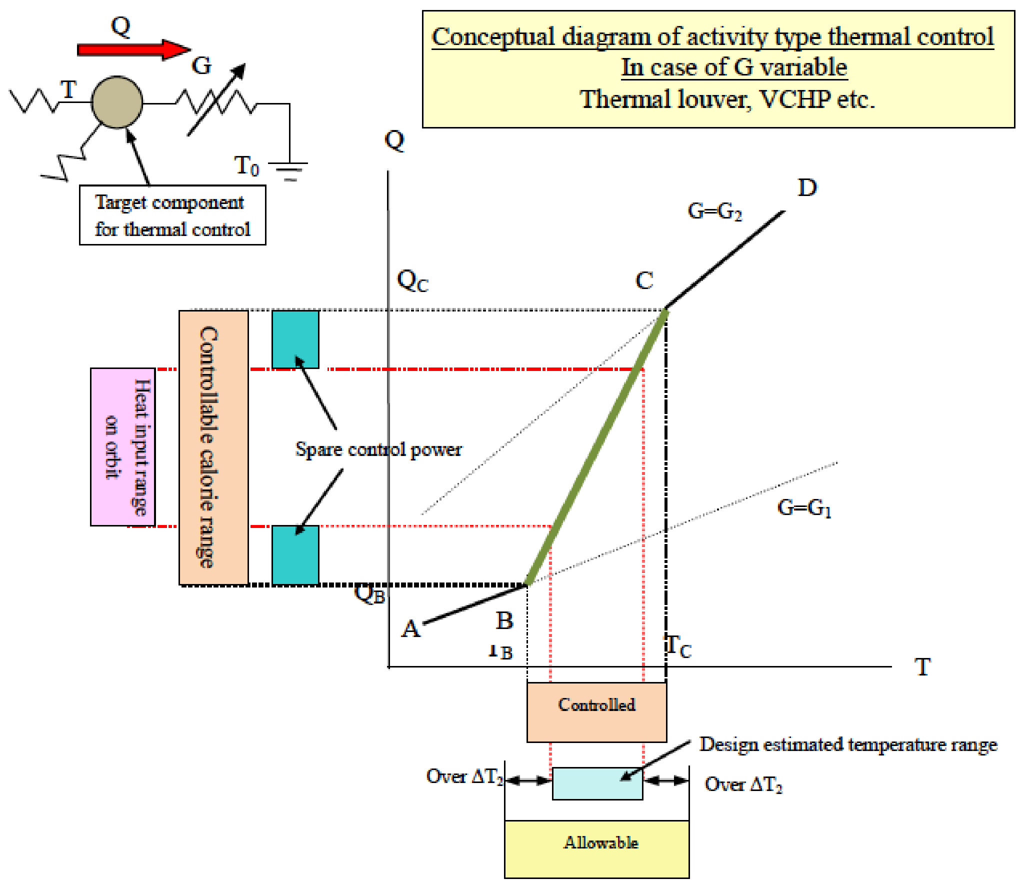

Figure 2.4.1.2-3 Conceptual diagram and design margin of active thermal control

(G is variable)

Figure notes

・The following is an explanation, in principle, of the figure using the example of a thermal louver.

・In the range of line segment AB, the blade is closed and the radiating surface is constant with minimum emissivity (for example ε = 0.1).

・In the range of line segment CD, the blade is open and the radiating surface is constant with maximum emissivity (for example ε = 0.8).

・In the range of line segment BC, ε changes from 0.1 to 0.8 according to the temperature of the radiating surface.

・When variation of the heat amount is from Q_B to Q_C, the radiating surface is maintained within the controlled temperature range from TB to TC.

・In the above figure, as the heat input range in orbit is between Q_B and Q_C, it indicates being maintained within the controlled temperature range.

・Because of factors such as differences between the temperature-specified point and control-sensing point or the temperature tolerance of the radiating surface and divergence angle of the blade, the design estimated temperature range of the component does not necessarily correspond to the heat-input range in orbit.

Design requirements

[1] In principle, the margin of the control power (heat flow) should be heat needed to raise the temperature over ΔT1 (°C), within the upper and lower limits of the design-estimated range.

[2] The estimated design temperature range should be a secured margin over ΔT2 (°C) from the allowable temperature range.

(4) Conceptual diagram of active thermal control (the case of variable G, part 2)
When spare control power is not available for both the lower and upper limit of the estimated design temperature range.

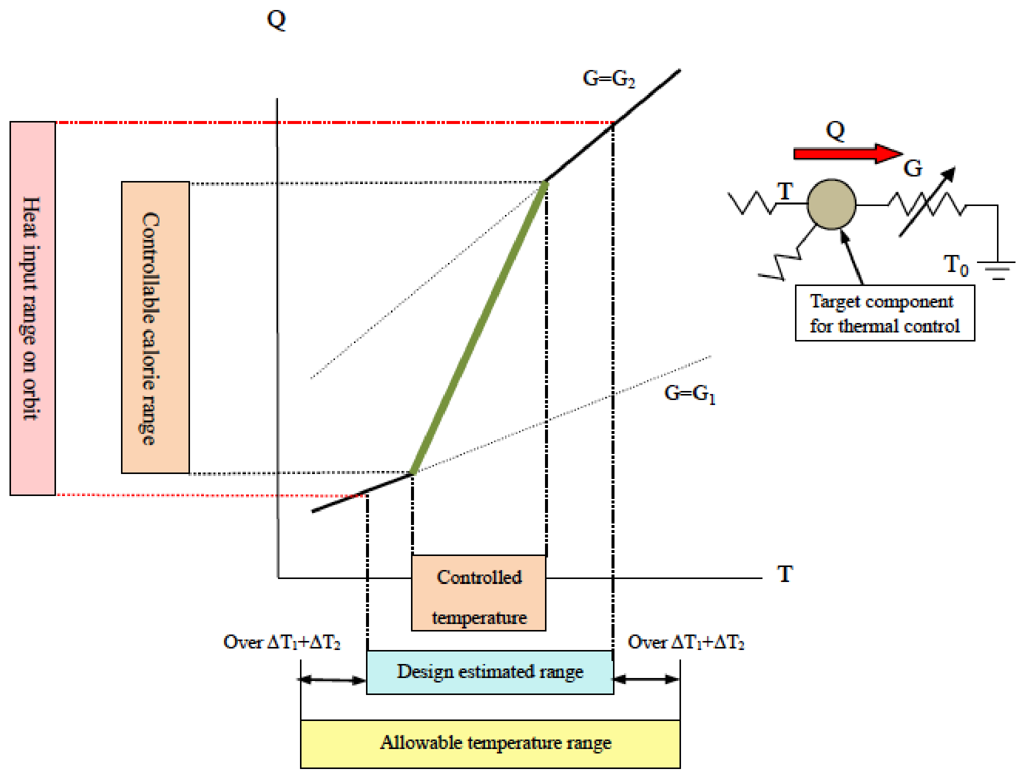

Figure 2.4.1.2-4 Conceptual diagram and design margin of active thermal control

(G is variable)

Figure notes
・As in Figure 2.4.1.2-3, the figure shows, in principle, the example of a thermal louver.
・In the previous figure, the heat-input range on orbit was within the range of controllable heat dissipation by the louver. This is over the range in this figure.
・The upper temperature limit is thus passively thermal controlled under a fixed value of ε = 0.8 with the blade full open, and the lower temperature limit is passively thermal controlled under a fixed value of ε = 0.1 with the blade closed.
・At the upper and lower limits, there is thus similarity in the procedure for securing the temperature margin using passive thermal control.

Design requirements

[1] Because the heat input range on orbit exceeds the controllable heat input range, the procedure using the passive type thermal control is applied. That is, the estimated design temperature range shall be secured over the temperature margin from the allowable temperature range with a prediction error of ΔT1 (°C) and temperature margin of ΔT2 (°C).

[2] When there exists spare control power at the upper or lower limits of the estimated temperatures shown in Figure 2.4.1.2-3, the active thermal control shall be applied on that side.

2.4.2. Thermal Control of Thermally Critical Components

Because thermal-control components are sensitive to temperature, it is necessary to pay special attention to their thermal control design (e.g., battery, propellant piping of the attitude control system), which are defined as “thermally critical components.”

Normally, the following items are considered thermally critical components:

・Components with narrow allowable temperature ranges

・ Components with wider allowable temperature ranges that diverge significantly from the average temperature level of a usual spacecraft

As thermally critical components are difficult to secure within the temperature margin (ΔT1 + ΔT2) as a general component, it is required that they satisfy one of the following:

(1) Apply active thermal control

(To retain margins not of temperature, but of control ability, refer to 2.4.1.)

(2) Design for small prediction error (adopt validated and proven control systems, maintain thermal separation from other parts, and isolate the influence of uncertainty from other parts of the spacecraft)

2.5. Thermal Analyses

2.5.1. Thermal Analyses of On-board Equipment

PI Instrument Team shall perform internal thermal analyses of exposed on-board component and internal on-board component.
MMX System Team shall present thermal interface conditions, which the on-board component management group requires to perform thermal analyses, in the “Thermal Interface Condition Document.” Note that MMX System Team shall decide whether thermal interface conditions will

be presented or not and whether interface thermal mathematical models for the component will be required or not.

2.5.2. Handling of On-board Equipment in System Thermal Analyses

On-board component for the main body of a spacecraft is classified into the following five types:

(1) Internal on-board component whose average heat generation density does not satisfy the specifications in 2.2.1.4.
(2) Internal on-board component whose mounting surface shapes do not satisfy the specifications in 2.2.1.5.
(3) Internal on-board component with restriction on surface treatment
(4) On-board component to be exposed to space
(5) Equipment other than (1) to (4)

Regarding the above (5), MMX System Team shall create a thermal mathematical model for system thermal analyses according to the ICD presented by PI Instrument Team. Note that, if necessary, MMX System Team can request PI Instrument Team to present thermal characteristics data in addition to the one in the ICD.
Regarding the component in the above (1) to (4) as well as the component that MMX System Team considers necessary, PI Instrument Team shall create an interface thermal mathematical model for system thermal analyses and present the model to MMX System Team.
The interface thermal mathematical model shall be created according to the “Thermal Mathematical Model Preparation Manual” presented by MMX System Team.
MMX System Team shall perform system thermal analyses by incorporating the above-mentioned thermal mathematical model, and validate a thermal interface between the component and the system as well as system thermal designs.

2.5.3. Interface Thermal Mathematical Models

The on-board component management group using tests, analyses, etc. shall validate each of the interface thermal mathematical models, which are created by the on-board component management group according to 2.5.2.

3. TEMPERATURE SENSORS

3.1. Temperature Sensor Mounting Criteria

Temperature sensors shall be mounted to appropriate locations in order to acquire temperature information that is necessary for spacecraft operations and evaluations of experimental data.

Note, however, that mounting positions of temperature sensors shall be decided according to consultation between PI Instrument Team and MMX System Team.

Interfaces with telemetry command systems shall be based on the telemetry/command interface rules in the Electric Design Criteria (MMX-C-EDC).

Temperature measurement ranges and temperature measurement accuracies that are required by on-board component shall be fully taken into account in selecting temperature sensor types and temperature sensor circuits.

3.2. Temperature Sensor Mounting Positions

Temperature sensor mounting points shall be indicated in the ICD.

4. THERMAL INTERFACE PRINCIPLES

4.1. General Information

4.1.1. Equipment Design and Testing

Drawings, specifications, and engineering data shall use the International System (SI) metric standard.

(1) Internal On-board Equipment

Internal on-board component shall be designed to satisfy the specifications in this document.
If self-heating of internal on-board component is substantial or if it is considered to be impossible to satisfy the requirement for uniform temperature in Section 4.2.2.1 due to restrictions of materials for use, etc., such information shall be provided to MMX System Team. If PI Instrument Team and MMX System Team consider it important, MMX System Team shall establish design conditions in the "Thermal Interface Condition Document. Based on this document, PI Instrument Team shall design component and perform design validation through testing.
In addition, since the allowable temperature range of BAT is narrow and temperature of a cell itself is important, an interface thermal mathematical model enabling the cell temperature prediction shall be presented to MMX System Team.

(2) Exposed On-board Equipment

Exposed on-board component shall be designed according to this document and the "Thermal Interface Condition Document." Also, design of exposed on-board component shall be validated through testing.
In addition, an interface thermal mathematical model for exposed on-board component shall be presented to MMX System Team.

4.1.2. Roles of System Team

MMX System Team shall validate designs of thermal characteristics of surfaces and mounting surfaces of internal on-board component and designs of exposed on-board component from the viewpoint of the entire spacecraft, and evaluate conformity through thermal analyses and tests. In addition, MMX System Team shall create the "Thermal Interface Condition Document" for exposed on-board component to clarify thermal design conditions for such component.

MMX System Team shall verify/evaluate analytical results of a thermal mathematical model that are reported by subsystem management groups. MMX System Team shall also evaluate those coupled results on the system level. MMX System Team shall finally confirm the consistency of those evaluated issues.

4.2. Thermal Interface Points

4.2.1. Definitions of Thermal Interface (Demarcation)

In order to design and fabricate component conforming to a spacecraft system, it is necessary to take account of the specifications of other related hardware and environments. For this purpose, we set forth boundary conditions, which can be considered to be most appropriate for specifying thermal design conditions for component, and adopt a method to carry out designs smoothly by specifying various conditions for this area.

This boundary area is called “a thermal interface demarcation point.” In principle, the following areas shall be applicable.

4.2.1.1. Thermal Interface for Conductive Thermo Coupling

(1) Internal on-board component

Equipment mounting surface of a body

(2) Exposed on-board component

Equipment mounting surface of a body

4.2.1.2. Thermal Interface for Radiative Thermo Coupling

(1) Internal on-board component

Although, strictly speaking, body surfaces of a bus section around the component or surfaces of other component become thermal interface demarcation points, MMX System Team shall set simplified virtual surfaces.

(2) Exposed on-board component

Body surfaces around the component or surfaces of other component shall be thermal interface demarcation points. However, if the component has radiative thermo coupling with interiors of a spacecraft, MMX System Team shall set simplified virtual surfaces for this area.

In addition, regarding the areas in which a body around the component or other component is covered with Multi-layer insulation(MLI), temperature amplitudes or thermal-optical characteristics of MLI surfaces need to be taken into account. Since MLI surface temperatures also depend on heat radiation of the component that faces MLI, MMX System Team shall specify temperatures for MLI’s mounting sections and MLI thermal characteristics.

In performing temperature predictions, PI Instrument Team shall perform thermal analyses, where MLI surface temperatures are also calculated, according to the conditions presented by MMX System Team.

4.2.2. Items Specified for Thermal Interface

(1) Thermal Interface Demarcation Points for Conductive Thermo Coupling

A temperature for a thermal Interface demarcation point is specified. This temperature is called “a conductive interface temperature.”

(2) Thermal Interface Demarcation Points for Radiative Thermo Coupling

The following items are specified for thermal Interface demarcation points for radiative thermo coupling.

① Shapes and dimensions

② Thermal-optical characteristics

③ Temperature (which is called “radiative boundary temperature”)

④ Thermal characteristics for MLI (only for an area to be used)

4.2.3. Thermal Interface and Applicable Objects for Specifying Their Conditions

In principle, the following objects shall be applicable to specify thermal Interface demarcation points and set thermal interface conditions.

(1) Exposed on-board component specified in Section 2.1.2. (2)

(2) Internal on-board component that cannot satisfy a requirement for uniform temperature in 2.2.1.1.

4.3. Thermal Interface Condition Document and Interface Thermal Mathematical Models

MMX System Team shall submit the Thermal Interface Condition Document for applicable objects specified in 4.2.3.

In addition, MMX System Team shall design the objects specified in 4.2.3. according to the Thermal Interface Condition Document, reflect the design results in the ICD, and create and submit interface thermal mathematical models and their user manual.

Moreover, MMX System Team shall generate the Interface Thermal Mathematical Model Preparation Manual.

4.4. Scope of Thermal Design for Equipment

Thermal designs within the thermal interface shown in Section 6.2 shall be implemented for the component.

4.5. Fabrication of Thermal Control Hardware for Equipment

Hardware necessary for these thermal controls shall be procured or fabricated for the component.

4.6. Precautions for Thermal Control Hardware Designs

(1) Precautions for MLI design

Regarding the MLI, both MMX System Team and PI Instrument Team shall perform their designs in such a way that interfaces can be adjusted as least as possible.
If it becomes necessary to equip the MLI beyond a thermal interface point, the issue shall be coordinated with the counterpart as early as possible because the coordination work is complicated and time-consuming. Then, coordinated results shall be described in the ICD.
In addition, ground treatment between MLI layers shall be performed as necessity arises.
MLI should be selected and designed not to cause any harmful deformation and degradation of the performance on orbit. For example, MLI shall have enough perforation to vent remaining gas in layers during accent phase. Also, MLI shall be fastened by proper pitch and method to the spacecraft surface with enough margins to eliminate the possibility of separation.

(2) Precautions for materials to be used

Materials with the small amount of outgas shall be selected.
(3) Precautions for surface treatment
Electric requirements such as electric bonding and EMC shall be taken into account.
(4) Values common to systems and subsystems shall be used for thermal-optical characteristics (α, εH) for thermal control materials.

4.7. Design and Manufacturing Validation for Equipment

PI Instrument Team shall validate conformity with this document and the Thermal Interface Condition Document through tests, analyses, etc.

4.8. Handling of MLI for Equipment in System Integrations

(1) Attachment and Detachment
PI Instrument Team shall attach or detach the MLI fabricated by PI Instrument Team during system integrations and system integration tests.
An MLI to be equipped beyond a thermal interface demarcation point shall be attached or detached by the party who has fabricated the relevant MLI when the counterpart is witnessing.
(2) Taping
If taping is necessary after MLI is equipped, the party who has fabricated the relevant MLI shall perform taping. Note that, if taping is applied across the boundary between the MLI fabricate by MMX System Team and the MLI fabricated by PI Instrument Team, taping shall be performed by MMX System Team when PI Instrument Team is witnessing.

5. VERIFICATION REQUIREMENTS

5.1. Definitions

The following definitions (in alphabetical order) are recommended:

Acceptance verification or certification:

Tests intended to demonstrate that hardware is acceptable for flight. These also serve as a quality control screen to detect deficiencies, and normally to provide the basis for delivery of an item under the terms of a contract or agreement.

Design qualification verification:

Tests and analyses intended to demonstrate that the item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations. The purpose is to uncover deficiencies in design and method of manufacture and is not intended to exceed design safety margins or to introduce unrealistic modes of failure.

Environmental tests

Environmental tests shall be conducted on the flight or flight-configured hardware to assure that the flight hardware will satisfactorily perform in one or more of its flight environments. This class of test includes random, thermal balance (TB)/thermal vacuum (TV) (or temperature), and EMC tests. They are normally combined with functional testing to a degree depending on the objectives of the test.

TB test:

A test conducted to verify the adequacy of the thermal model, the adequacy of the thermal design, and the capability of the thermal control system to maintain thermal conditions within established mission limits.

TV test:

A test to demonstrate the validity of the design in meeting functional goals. It also demonstrates the capability of the test item to operate satisfactorily in vacuum at temperatures expected for the mission.

The test can also uncover latent defects in design, parts, and workmanship.

Note: This test shall be performed only for the instrument when thermally isolated from the spacecraft or designed with a special thermal concept.

Temperature test:

A test to demonstrate the validity of the design with operability in a specified temperature range and thermal cycle environment. This test will be performed for the instrument as designed.

Verification by analysis:

The compliance to a requirement is analytically verified. The typical method is by using mathematical models, which may be supplemented or supported by hardware simulations.

5.2. Analysis

5.2.1. Thermal analysis

5.2.1.1. General

A thermal analysis of payload units shall be performed by the unit responsible, with the following objectives:

1. Verifying that internal parts and materials are below their maximum allowed temperatures under acceptance and qualification testing
2. Verifying the ability of the thermal design to maintain the internal required temperatures and intended heat flow patterns to ensure performance requirements under the worst flight cases
3. Verifying compliance with the spacecraft interface requirements under the worst flight cases

5.2.1.2. Units

SI units are mandatory for all documentation exchanged with JAXA. Temperatures can be presented either in kelvin or degrees Celsius.

5.2.1.3. Thermal design cases

A Flight Hot and Cold Case described by the following conditions shall be analyzed:

- Conditions: The unit is coupled by contact conduction to the spacecraft structure and by radiation to the spacecraft radiation environment. The structure and the radiation environment are at a temperature equal to the System Interface Temperature Point (STP) temperature.
- Dissipation: Maximum EOL dissipation.
- STP temperature level: The STP temperature level is assumed equal to the Thermal Control Subsystem (TCS) design temperature at the Temperature Reference Point (TRP).
- External fluxes load: The Q_{IR} flux is obtained by computing the incident planetary and solar fluxes on the area of the instrument aperture. The effect of an Infrared Rejection Device (IRRD) or heated baffle must be evaluated if used.

The Flight Cold Operational Cases described by the following conditions shall be analyzed:

- Conditions: As above.
- Dissipation: Minimum BOL dissipation.
- STP temperature level: The STP temperature level is such to give the minimum TCS design temperature at the TRP. The actual value of the STP temperature must be obtained by an iterative process.
- External flux load: No loads.

The Flight Non-Operational Case described by the following conditions shall be analyzed:

- These cases can be obtained from the operational ones by considering no electronics dissipation.

Acceptance and Qualification Testing Cases described by the following conditions shall be analyzed:

- Conditions: The unit is coupled by conduction to the test cold plate and by radiation to the test chamber walls. The cold plate and the chamber walls are at a temperature equal to the STP temperature. These cases are considered as steady-state cases.
- Dissipation: Maximum and minimum dissipation.
- STP temperature level: The STP temperature level is varied to give the maximum and minimum acceptance or qualification temperature at the TRP. The actual value of the STP temperature must be obtained by an iterative process.

External fluxes load: TBD-Sys/PI.

5.2.1.4. Thermal mathematical models

Unit thermal analyses shall be performed by the responsible unit using a Detailed Thermal Mathematical Model (DTMM). The unit ITMM for thermal spacecraft system analysis shall be derived from the DTMM.

5.2.1.5. Software codes

TBD-Sys/PI

5.2.1.6. Deliverable models

The ITMM shall be regularly updated and delivered according to the unit design maturity. At a minimum, the following model updates shall be delivered for each unit:

- Preliminary model of the flight unit
- Models of the flight unit updated after any major design modification and after thermal verification tests
- Structural thermal model (STM) unit if this is required by the spacecraft verification program

- Final model of the flight unit with measured dissipations

5.2.1.7. Thermal analysis uncertainties

The temperature of the unit internal parts shall be predicted by adding the thermal analysis uncertainty to the computed temperatures. In the hot cases, the absolute value of the uncertainty will be added while, in the cold cases, the absolute value of the uncertainty will be subtracted.

5.2.1.8. Thermal control design documentation

PIs shall deliver to ISAS/JAXA the following reports:

- A Unit Thermal Design Description Report in the format described in the Document Template
- A Unit Thermal Analysis Report in the format described in the Document Template
- A Unit Thermal Tests Report in the format described in the Document Template
- A Unit Thermal Model Correlation Report (following thermal tests) in the format described in the Document Template
- A Unit ITMM Description Report in the format described in the Document Template

Each Document Template is TBD-Doc.

5.3. Testing

5.3.1. Thermal tests requirements

5.3.1.1. Thermal design verification

The thermal design of a payload unit shall be verified by a dedicated thermal balance test according to the guidelines and requirements in Section 5.4.6.2.

The thermal balance test will consist of at least a hot and a cold steady state and several transient phases that simulate boundary conditions experienced during the mission.

The test shall be designed on a case-by-case basis by the unit responsible and approved by ISAS/JAXA.

For an ordinary electronic box, the thermal verification can be derived from the unit qualification test, if the unit is adequately internally equipped with thermal sensors and proper steady-state phases are included in the test.

5.3.1.2. Test methods

The component shall be mounted in a vacuum chamber in a thermally controlled environment (See Figure 5.3.1.2-1).

Temperatures shall be controlled, measured, and selected to guarantee that the test item experiences actual temperatures equal to or beyond the minimum and maximum acceptance temperatures in the test environment.

This is achieved by adopting one of the following test methods, as appropriate:

1) Non-special component, internally mounted

- The component shall be bolted to a mounting panel, using the correct bolts and bolt torques as specified in the component interface specification.
- The mounting panel shall be painted black (except for the mounting contact area) and have the following dimensions as a guideline (TBD-Sys/PI):
  - Thickness representing standard platforms and sidewalls,
  - Length and breadth approximately equal to at least twice the nominal base dimensions of the component.
- The mounting panel is temperature controlled.
- During the test, shrouds and panels shall be exposed to a fixed temperature to provide the spacecraft internal environment to give the qualification temperature level on the component itself.

2) Special component, internally mounted

Certain internally mounted component will require special test provisions. Examples of such component would be:

- sensors having space-viewing apertures, or
- highly dissipating, direct-radiator-cooled component.

In such cases, the required approach is to modify the test method for internally mounted component, to the extent needed to give a reasonable representative test environment.

3) All components, externally mounted

Any instrument mounted outside the main spacecraft body will have special test requirements. The test arrangement must be designed to give the required qualification temperatures on the component, with approximately representative heat flows to and from the environment.

The following minimum test requirements shall be satisfied:

- Equipment shall be tested in a thermal vacuum environment having a pressure of 0.0013 Pa (10^{-5} Torr) or less. The test may be commenced when the pressure falls below 0.013 Pa (10^{-4} Torr), and a pressure of 0.0013 Pa or less shall be achieved prior to start-up of units not operating during the first ascent.

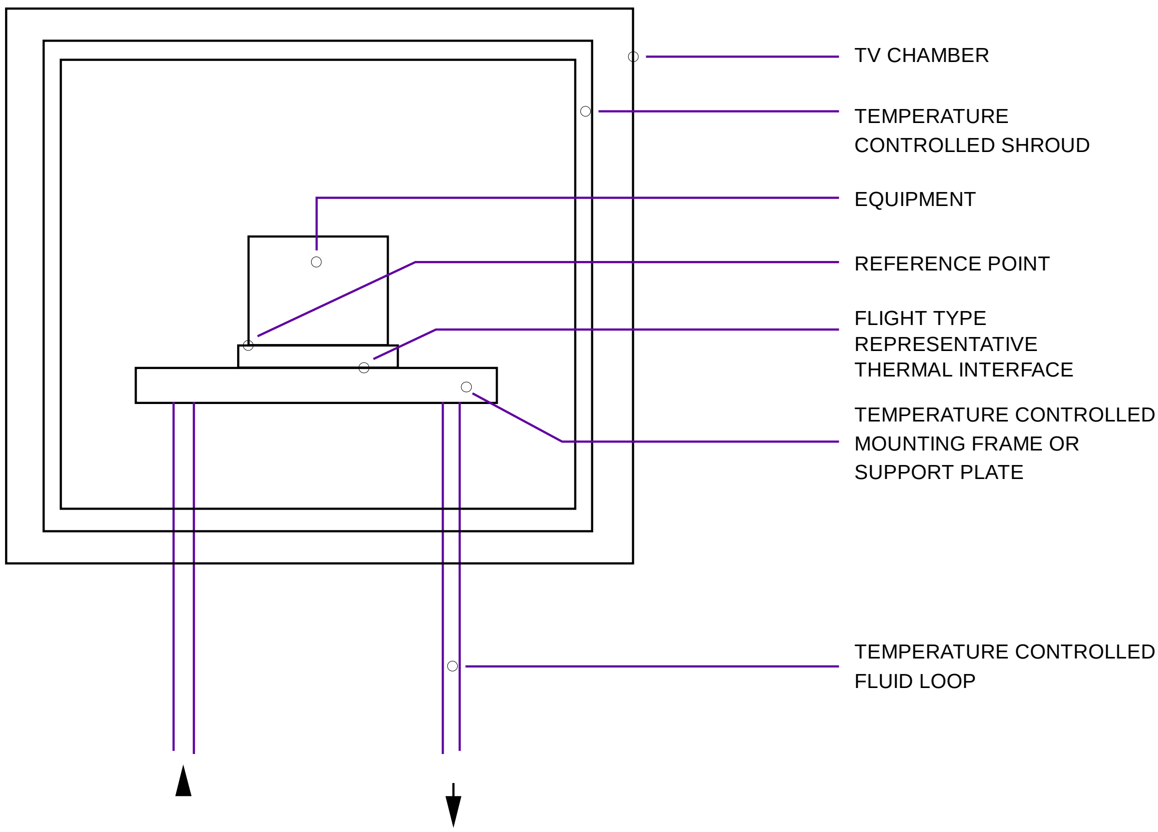

Figure 5.3.1.2-1 Thermal Vacuum Test Arrangement

5.3.1.3. Temperatures and thermal cycles

See MMX Environmental Design Data & Test Conditions (MMX-EDDTC).

6. DOCUMENTS

6.1. Applicable documents

(1) JAXA-RPR-MX##### [to be issued]

Thermal Interface Condition Document

(2) JAXA-RPR-MX##### [to be issued]

Interface Thermal Mathematical Model Preparation Manual

(3) JAXA-RPR-MX##### [to be issued]

Interface Thermal Mathematical Model User's Manual

(4) JAXA-RPR-MX16307

MMX Environmental Design Data & Test Conditions (MMX-EDDTC)

6.2. Reference documents

6.2.1. System design reference documents

(1) JAXA-RPR-MX16301

MMX Instrument Interface Requirement Document (MMX-I-IRD)

(2) JAXA-RPR-MX##### [to be issued]

MMX Interface Control Document (ICD)

7. ACRONYMS

BAT	Battery
DTMM	Detailed thermal mathematical model
HCE	Heater control electronics
IRRD	Infrared rejection device
ISAS	Institute of Space and Astronautical Science
ITMM	Interface thermal mathematical model
JAXA	Japan Aerospace Exploration Agency
MLI	Multi-layer insulation
MMX	Martian Moons Exploration
PI	Principal investigator
STM	Structural thermal model
STP	System interface temperature point
TCS	Thermal control sub-system
TRP	Temperature reference point