Thermal control: radiators, insulation, heaters and heat pipes

Essential answer

Thermal control: radiators, insulation, heaters and heat pipes. The question to solve is: Why does the cold of space not automatically cool a computer? In vacuum there is essentially no external air to carry heat by convection. Internal heat must be conducted, transported and radiated. The rest of the course turns that idea into an auditable line of reasoning: explicit units, stated assumptions, reproducible calculations, order-of-magnitude checks and interpretation limits. A result is useful only when the reader can explain what it measures, where every input came from and which engineering decision it can support.

Reasoning map

1. 1 — The concrete scene
2. 2 — Essential words, explained before using them
3. 3 — See the architecture before calculating
4. 4 — Formulas, only when they answer a question
5. 5 — What units and margins mean

In vacuum there is essentially no external air to carry heat by convection. Internal heat must be conducted, transported and radiated.

Transfer through matter or contact.

Before calculating

Quantity:	Thermal control: radiators, insulation, heaters and heat pipes
Check:	units + order of magnitude + assumptions
Decision:	state what the result actually supports

Thermal control: radiators, insulation, heaters and heat pipes

2 — Essential words, explained before using them

Transfer through matter or contact.

Electromagnetic emission related to temperature.

Surface rejecting heat by radiation.

Multi-layer insulation limiting radiative exchange.

3 — See the architecture before calculating

Electronics, batteries and people dissipate heat.

Insulating does not mean cooling.

Straps, heat pipes or fluids move heat.

Radiators exchange by radiation with the environment.

4 — Formulas, only when they answer a question

How to read it : Q equals mass times heat capacity times temperature change

Estimates energy to change a mass temperature.

How to read it : approximate radiated power

T must be in kelvins; a real balance includes absorbed radiation.

5 — What units and margins mean

K for absolute temperature, W for thermal power, J for energy.

6 — Three concrete demonstrations, calculated step by step

10 kg, c=900 J/kg/K, ΔT=20 K.

At ideal 200 W: 900 s=15 min

Input 500 W, output 460 W.

7 — Deepening: what the simplified diagram hides

Active reading

Sections:	2 — Essential words, explained before using them ; 3 — See the architecture before calculating
Verification:	A value is usable only with its unit and calculation boundary.
Exercise:	change one assumption and predict the direction of change before recalculating

Thermal control: radiators, insulation, heaters and heat pipes

Coatings, MLI, straps, heat pipes, radiators.

Heaters, pumps, cryocoolers or thermoelectrics.

A radiator can also absorb Sun or planet energy.

Control avoids unnecessary cycling and excursions.

It correlates model, temperatures and interfaces.

8 — Application to an Earth-Mars spacecraft

9 — Reference dossier: what a real project must still consider

Outside a spacecraft, convection through air is essentially absent. Heat moves internally by conduction and is ultimately radiated to space. Radiator equilibrium therefore depends on rejected power, area, surface properties and what the surface sees: cold space, Sun, Earth, Mars or another warm vehicle surface.

Coatings, multilayer insulation, heat pipes, thermal straps, conductive interfaces, sunshields and radiators can manage heat with little continuous control power. Their performance still depends strongly on orientation, ageing, contamination, contact conductance and geometry.

Heaters protect batteries, fluid lines and mechanisms; pumps move coolant; cryocoolers reach very low temperatures. These devices consume power, depend on sensors and control logic, may vibrate and may fail. A survivable passive or degraded state is therefore valuable.

A heat-rejection surface can absorb heat if it sees the Sun or a warm planet. View factors and spacecraft attitude therefore matter. A communications pointing change can alter radiator illumination, coupling GNC , communications and thermal design.

Temperature has inertia. Steady-state analysis asks where temperature eventually settles; transient analysis asks how long it takes to reach a limit. For short manoeuvres or eclipses, time-to-limit can be more useful than final equilibrium.

Thermal models contain conductances, dissipation, radiative properties and geometry. Thermal-vacuum tests measure actual temperatures and response so the model can be correlated. Hot-cold cycling can also expose workmanship and material problems.

Mars surface thermal control is not deep-space thermal control. Thin atmosphere, soil coupling, daily and seasonal temperature cycles and dust modify the environment. Habitats, external equipment, fluid lines and power systems form a distributed thermal infrastructure that must be maintained.

Active reading

Sections:	8 — Application to an Earth-Mars spacecraft ; 9 — Reference dossier: what a real project must still consider
Verification:	A value is usable only with its unit and calculation boundary.
Exercise:	change one assumption and predict the direction of change before recalculating

Thermal control: radiators, insulation, heaters and heat pipes

10 — Common traps and bad intuitions

Thinking vacuum cools like cold air.

In vacuum, heat still has to go somewhere

A spacecraft moves heat by internal conduction and by radiation to and from the environment; there is no external air convection. Electronics can overheat in very cold space if waste heat lacks a path to a radiator.

Surface absorptivity and emissivity play different roles in the thermal balance. MLI, coatings, heat pipes, conductive straps, heaters and radiators are combined to keep equipment inside qualification limits.

The hottest sunlit case is not always limiting. A long eclipse can drive batteries or propellants too cold. Thermal design is therefore transient: heat capacity, mode duration and heater power determine time to a limit.

11 — Guided exercises

Question : What question comes before choosing hardware?

Question : Why is a nominal result insufficient?

12 — What to remember

Explain the topic in simple words before symbols.

Connect at least four interfaces with other subsystems.

Redo the three numerical examples without reasoning gaps.

13 — NASA sources for further study

NASA - 2026 State-of-the-Art: Thermal Control

NASA - 2026 State-of-the-Art: Complete Spacecraft Platforms

Active reading

Sections:	10 — Common traps and bad intuitions ; In vacuum, heat still has to go somewhere
Verification:	NASA - 2026 State-of-the-Art: Thermal Control | NASA - 2026 State-of-the-Art: Complete Spacecraft Platforms | NASA Systems Engineering Handbook
Exercise:	change one assumption and predict the direction of change before recalculating