RAL DESIGN & DISCOVERY
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THERMAL CONTROL

Thermal Requirements

There are several reasons why spacecraft subsystems may have temperature limits outside of which excursions are not permitted. The most obvious is to avoid failure - certain types of battery for example can actually explode at temperatures in excess of 35°C! Another reason is to give better scientific performance - certain detectors need to be operated at about -50°C, others as cold as -200°C. Temperature gradients can cause deformation of instrument structures causing stresses at mechanical interfaces and other problems. These will often require careful control, sometimes to within 1°C over lengths of several feet.

Limits on heat exchange across certain interfaces are often applied for various reasons. For example the thermal decoupling of scientific instruments from the main spacecraft greatly simplifies the thermal design and analysis of each, with consequent implications for design reliability. Other important thermal interfaces are those between cooled components and their surroundings - it is important to maintain the heat load on such components (at the desired temperature) to that which can be rejected by the cooling system .

Thermal Design

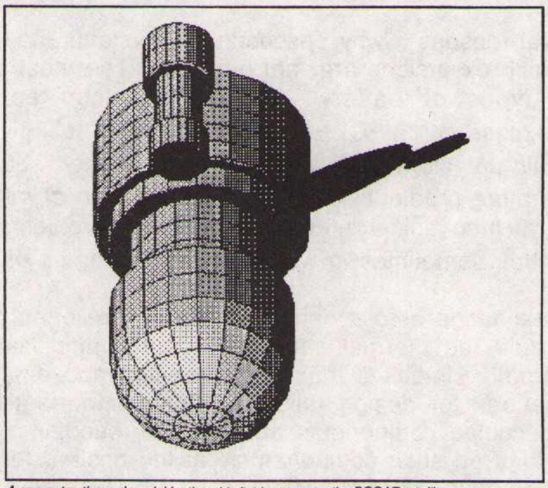
The thermal control subsystem has interfaces with most of the other spacecraft subsystems resulting in a large number of design drivers. These range from equipment thermal requirements (temperatures, gradients etc) to system requirements (reliability, cost, safety, mass , power etc) and those mission constraints which affect the overall thermal balance (stabilisation, acceptable materials, configuration, spacecraft operations and orbit/attitude parameters).

Two basic approaches to thermal design exist : passive and active control systems. Passive systems require no moving parts or power consumption and include Multi-Layer Insulation (MLI), thermal control surfaces (black or white paints, second surface mirrors, aluminium etc), radiators and heat links of high or low conductance (including heat pipes). Active systems may require both mechanisms and power consumption and include heaters, louvres, fluid loops and Stirling Cycle Coolers.

In general the overall thermal control subsystem tends to be mainly passive with certain active elements , but sometimes a choice may be required between the two approaches for a specific application. For example in order to cool a detector to 80 K a dewar filled with expendable liquid nitrogen could be used or a Stirling Cycle Cooler. A trade-off analysis would be performed weighing up the relative merits of each approach and including aspects such as thermal performance, mass, cost, reliability, lifetime, degradation and power consumption.

Thermal Analysis

The spacecraft thermal balance is a non-linear distributed parameter problem and is solved with the aid of computer-based mathematical models. The most widely adopted method is the lumped-parameter approximation solved using an iterative process such as the Newton-Raphson technique. The instrument is split into a number of isothermal elements which are then linked together by radiation and conduction links to give a thermal network; for transient analyses each node also requires a thermal capacity. Setting up this network is a lengthy process - radiation links are a function of view factors which describe the view that one surface has of another taking into account shading by other surfaces. In most cases these can only be calculated numerically from a database which describes the overall system geometry as shown below.



A computer-thermal model for the wide field camera on the ROSAT satellite.

Having established the thermal network the loading which results from electronics dissipation and external influences is calculated . The first of these should be well defined but the heat input resulting from the sun and earth is a function of many variables including the spacecraft geometry and its surface properties, the orbit size and orientation, spacecraft attitude, solar declination etc. An orbital simulation is carried out to determine these loads, usually for different modes of spacecraft operation and including allowance for uncertainties in the less well-defined parameters such as the effective black body temperature of the earth and its albedo.

Once these heating effects have been introduced into the thermal mathematical model (TMM) of the spacecraft the resulting set of equations is solved to predict temperature and heat fluxes for each element. The TMM will be calibrated against test data following thermal balance tests and the thermal design judged acceptable or not depending on whether the requirements are met.

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