6. Spacecraft Thermal Design.

The purpose of the thermal control design is to maintain all of the elements of the spacecraft system within their temperature limits for all mission phases. From this viewpoint, the IUE spacecraft may be conveniently divided into five separate and distinguishable sections, which are delimited referring to figure 6-1: the HAPS bay from station 0 to station 45.5, the main equipment bay from station 45.5 to station 87.5, the spectrograph which is mounted in its canister within the main equipment bay, the telescope from station 87.5 to station 164.5, and the solar array. The station numbers refer to the position in inches from the separation plane from the Delta launch vehicle.

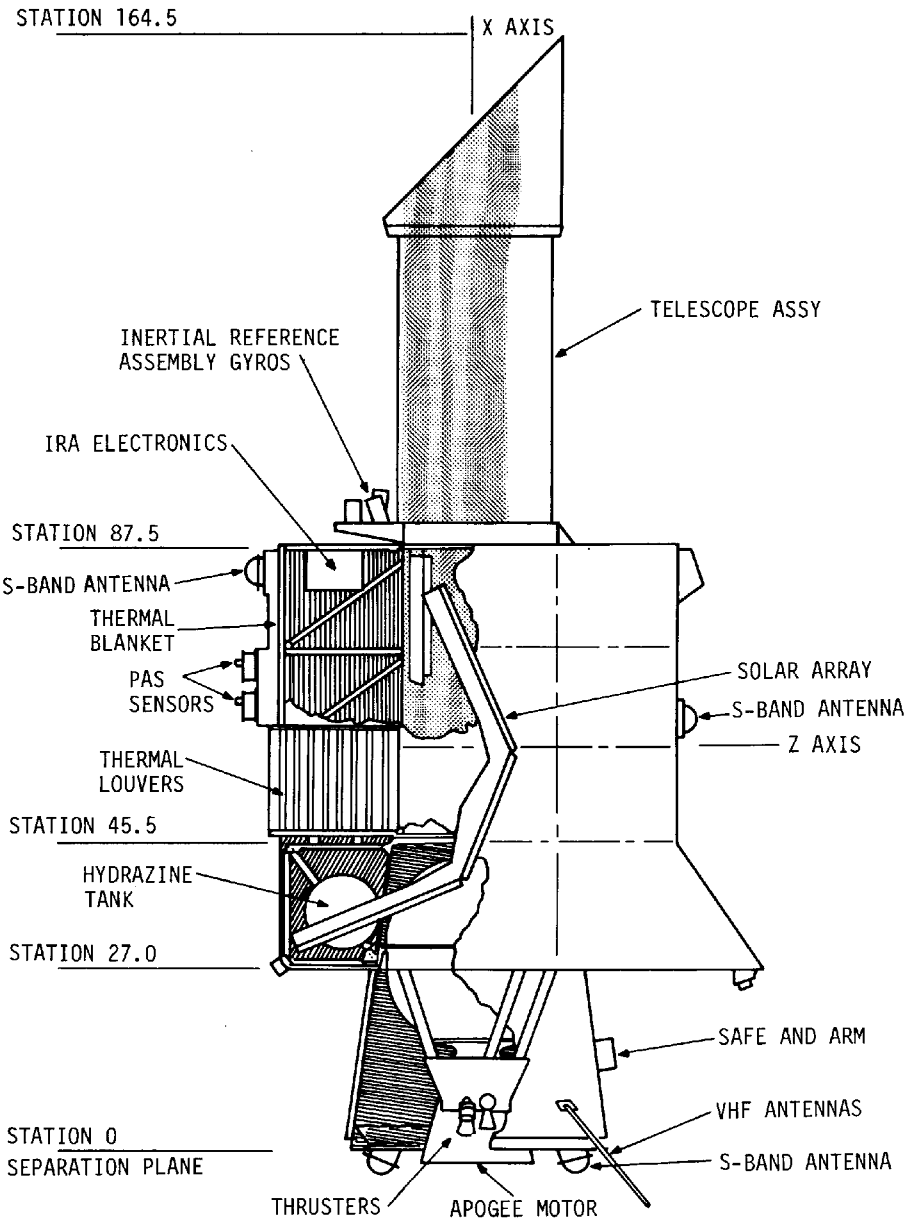

Figure 6-1. IUE Interior and Exterior Features.

The HAPS bay.

The HAPS bay consists of the apogee boost motor, the HAPS and the surrounding spacecraft structure.

The only thermal requirement on the ABM was to maintain its temperature between -15°C and +38°C prior to ABM ignition. The HAPS was kept between +5°C and +65°C at the beginning of the mission. Due to the HAPS heater group 1 failure (section 5.5.9.1), the temperature upper limit was raised to +85°C (except +ZLN and -ZLN which had an upper limit of +90°C).

Since the hydrazine system could withstand rather wide temperature limits, it was decided to make use of solar energy to reduce the dependence on heaters. The canted side (“sun catcher”) of the HAPS bay is a single layer of kapton with a VDA-SiO-SiO_x coating having an absorptance (α) of 0.25 and an emittance (ε) of 0.23. This surface provides a solar input of approximately 20 watts at a 135° beta angle solar aspect and aids in maintaining a more uniform energy balance over all solar aspects. The sides of the HAPS bay are covered with multilayer insulation with an external surface of Vapor Deposited Aluminum (VDA). The remainder of the propulsion area is covered with multilayer insulation with a black exterior layer. The propulsion area is radiatively isolated from the main equipment platform by a multilayer blanket.

The apogee motor is covered with multilayer insulation to prevent heat leaks to the main equipment bay during firing and to prevent heat leaks to space during orbital flight. In addition, a heat shield covers the nozzle exit plane during the transitional phase of the flight to keep the ABM warm before firing.

The main equipment bay.

The main equipment bay was intended to be maintained between 0°C and +40°C. The batteries were an exception as were the gyros in the IRA. The batteries were not to exceed +25°C (see section 5.1.1.) while the gyros contain their own thermal controller to maintain the temperature in the IRA.

The main equipment bay which surrounds the spectrograph is covered with multilayer insulation to reduce the effect of solar input. The spectrograph is further decoupled from the main equipment bay by utilizing low emittance surfaces. As a further reduction of the solar effect, the outer layer of the insulation is silverized teflon.

To achieve the required temperatures at a minimum power dissipation of about 130 watts, approximately 0.55 m^2 of radiating area is required. Since this power dissipation is not constant and the spacecraft must operate over a wide range of solar aspects, this radiating area is provided by thermal louvers. Three sets of louvers consisting of nine blades each are located on the anti-sun side of the spacecraft. Each louver blade is individually controlled by its own bimetallic spring within the honeycomb of the main equipment platform. The louvers provide approximately 0.6 m^2 of radiating area in the fully open position and are calibrated to move from fully closed at 0°C to fully open at +10°C. To further reduce thermal gradients, two circular heat pipes are mounted to the underside of the main equipment platform. These pipes are ammonia-filled grooved heat pipes, which are capable of transporting 75 watt-metres. It was calculated that the heat pipes reduce the gradients on the platform to less than 5°C.

The spectrograph.

The objectives of the spectrograph thermal design were to maintain the environment between 0°C and 15°C and the secondary mirror/focus drive mechanism below 30°C and above -20°C with minimum heater power.

The spectrograph is enclosed by a single dust cover. All surfaces (except for optical components) internal to the dust cover are either painted black with Chemglaze Z306 or anodized. These surface finishes minimize temperature gradients by enhancing radiative exchange. The dust cover is made of aluminum and is conductively coupled to the strong ring. Heat dissipated in the spectrograph is radiatively transferred to the primary mirror, the strong ring, and the dust cover. The primary mirror was maintained above a temperature of -15°C at all times using heaters attached to the back surface of the mirror (see section 5.7.). The strong ring is covered with a 20 layer insulation blanket with the external layer 5 mil FEP Teflon/Ag. Some heat transfer takes place between the strong ring and the spacecraft and IRA package, but the principal path for heat dissipation is through conduction to the telescope tube.

The telescope.

The objective of the telescope thermal design was to minimize the peripheral and longitudinal temperature gradients in the main structure of the telescope.

The telescope and sunshade have a 20 layer blanket of insulation on the external surface maintaining the circumferential temperature gradients of the telescope within a few degrees Celsius and minimizing temperature variation with sun angle. Again, the external layer of the blanket is 5 mil FEP Teflon/Silver.

The primary mirror is conductively isolated from the telescope's structure to minimize axial and circumferential gradients, and is held above -15°C by turning on one of the two heaters (one heater provides 3 W of power and the other provides about 4.5 W) attached to the back surface. Heaters using about 1.5 W of power each are attached to the back of the secondary mirror to keep it and the focus drive mechanism above -20°C. The focus drive mechanism is covered with a 20 layer insulation blanket and dissipates about 1.0 W continuously to help maintain the temperature above its lower limit. Low conductivity material is utilized between the sunshade and the secondary support ring to limit the conductive the interaction with the cold sunshade.

The solar array.

A thermal analysis of the IUE solar arrays showed that the array had to be deployed within five minutes of completion of the despin maneuver. When the satellite is spinning and the arrays are in the stowed configuration with a beta angle of 90°, the highest cell junction temperature is 20.5°C. Under the same circumstances as above but with the satellite not spinning and one paddle directly facing the sun, the hot paddle would reach temperatures as high as 93°C in spots. The cold paddle could see temperatures as low as -183°C. This condition could be serious for two reasons. First, the power from the array would be small because the hot paddle's cells would have a greatly reduced voltage output. Secondly, the cold paddle's deployment mechanism may not function at such cold temperatures. Thus, it was necessary to deploy the array immediately after the despin.

The solar array experienced very large temperature gradients, from -180°C to +80°C. The solar array temperature sensors failed soon after launch, so, the only available data is from the first three years in orbit (see section 5.1.1.).

Thermal factors.

Fluctuations in the spacecraft temperatures result from a number of factors. The thermal effects caused by these factors have a range in duration from hours or days to long term of months or years.

Short Term Factors.

- **The spacecraft's beta angle.**
  During typical operations, the beta angle varied a large amount (up to 60° in the last IUE year, the operational beta range was decreasing during the IUE life, see section 5.1.1.) within an hour or it could remain constant for up to 24 hours or more. The significance of the beta angle on the warming or cooling of individual pieces of equipment depended on the location, the thermal insulation, and the thermal isolation of each item.

- **Onboard heater configurations.**
  There are several heaters onboard IUE that were used to maintain a specific thermal environment for the scientific instruments. Since the DKSP and DKLP thermistors are part of the scientific instrument, they are greatly influenced by the setting of these heaters. With the selective use of the scientific instrument heaters, the thermal environment about these thermistors was controlled so that the heating and cooling effects due to other factors was minimized.

  Another heater routinely controlled by ground command was HAPS heater group 2. The status of this heater affected the temperatures of EV#2 and EV#7. During the winter months, this heater was cycled more often than in the summer months; however, it normally remained on unless a low beta angle (less than approximately 50°) was maintained for an extended time.

- **Lunar and daily earth shadows.**
  During shadow seasons, the spacecraft's view of the sun was eclipsed by the earth on a daily basis. This resulted in the solar radiation that normally impinges on the spacecraft being completely blocked from the spacecraft. The thermal effect of a shadow season were observed on a daily basis as well as a monthly basis. On a daily basis, the temperature of the spacecraft as a whole was reduced during the eclipse period. Following the eclipse period the spacecraft began to warm and re-establish its pre-shadow thermal balance. This sequence of cooling and warming occurred each day of the shadow season.

  During the daily earth shadow periods, all scientific heaters and HAPS heater group 2 were commanded off to save power. Therefore, the thermal stability provided by these heaters was not in effect during the eclipse periods. This might have the effect of lowering the daily average temperatures for these points through the shadow season.

Lunar shadows occurred several times throughout any given year. However, significant lunar shadows only occurred approximately twice a year. During a lunar shadow the solar radiation was partially blocked from the spacecraft; therefore, the cooling effect on the spacecraft was not as drastic as an earth shadow.

Intermediate Term Factors.

- **Earth Shadows.**
  Earth shadows not only resulted in a daily cycle of cooling the spacecraft, as mentioned above, but also affected certain spacecraft temperatures for an extended period following the shadow season. This extended period might last from a few days to more than a week. During earth shadow seasons, the overall temperature of the spacecraft was reduced. Those onboard components really influenced by the beta angle or heaters recovered fairly quickly after each daily eclipse period as well as at the completion of the shadow season. However, those components that were isolated from their surroundings by a high thermal resistance required a longer time to re-establish their pre shadow thermal balance.

- **Mean distance to the sun.**
  The solar radiation flux varies with the distance from the sun as $1/r^2$. Therefore, during the summer months when the earth is farthest from the sun, temperatures on the spacecraft generally run slightly lower than during the winter months. This factor was most noticeable in those components that were greatly influenced by the beta angle.

Long Term Factors.

- **Decreased equipment power dissipation.**
  When IUE was launched, its nominal power requirement was listed as 186 watts. At the end of the mission, its nominal power was approximately 148 watts. This reduction in the power requirements resulted from the failure of various instruments onboard the spacecraft. This decrease in equipment power dissipation mainly affected those components internal to or on the back side of the spacecraft that received heat from the failed components.

- **Red line temperature limits.**
  Specific maximum and/or minimum temperatures were set for a large portion of the instruments onboard IUE (Red Line Limits). The temperature of these instruments was either influenced by the beta angle or a heater or both. Components that had an associated Red Line Limit for their temperature might show a false maximum or minimum temperature equal to the Red Line Limit value, since ground intervention to change the beta angle or heater configuration occurred when this limit was reached.

  The thermal balance of the spacecraft was also effected by occasional changes to the Red Line Limits. Such changes were made to reduce the effect of an imposed temperature limit on normal operations when other constraining factors were involved or to excessive cycling of a heater when deemed necessary. Such changes to a Red Line Limit were not made in haste but were only permitted after close examination and a trial period was passed. Such changes to a Red Line Limit, when it was a maximum limit, might cause the historical data to give a false indication of an increase in the temperature; when in fact the temperature would have reached this new maximum value in previous years if it were permitted to do so. A similar effect would apply if a minimum temperature Red Line Limit were decreased.

- **Deterioration of thermal controls.**
  The IUE thermal control system included several temperature control techniques: reflective covers, coatings, insulation, heat sinks and thermal louvers. Deterioration of the covers, coatings and insulation was expected and was cumulative with time. The extent of deterioration for various components of the thermal control system, as well as different portions of the same component might vary. This general deterioration of the thermal control system might be observed in the long term increase or decrease of specific temperatures, depending on the intended purpose of the thermal control.

Average temperatures on the spacecraft.

The figures present the history of average temperatures for several component and general areas.

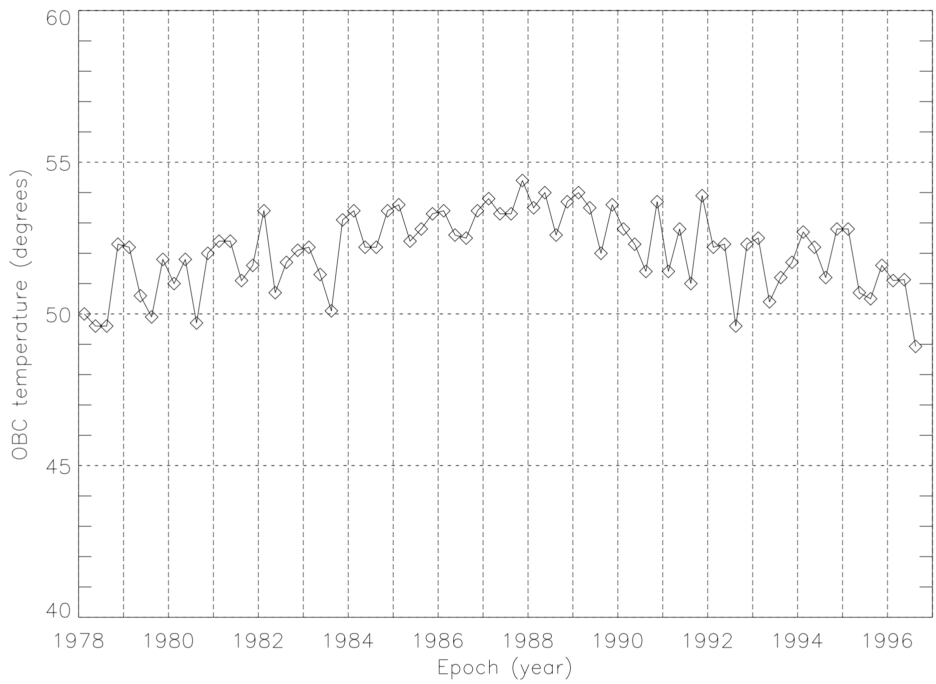

Figure 6-2. History of average onboard processor 1 temperatures.

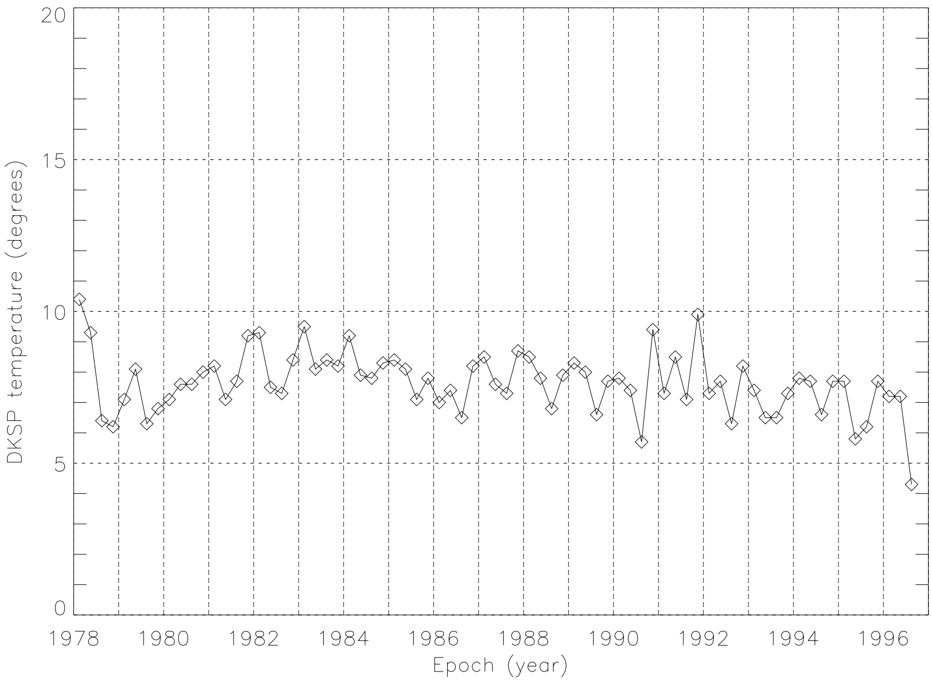

Figure 6-3. History of average camera deck temperatures near SWP.

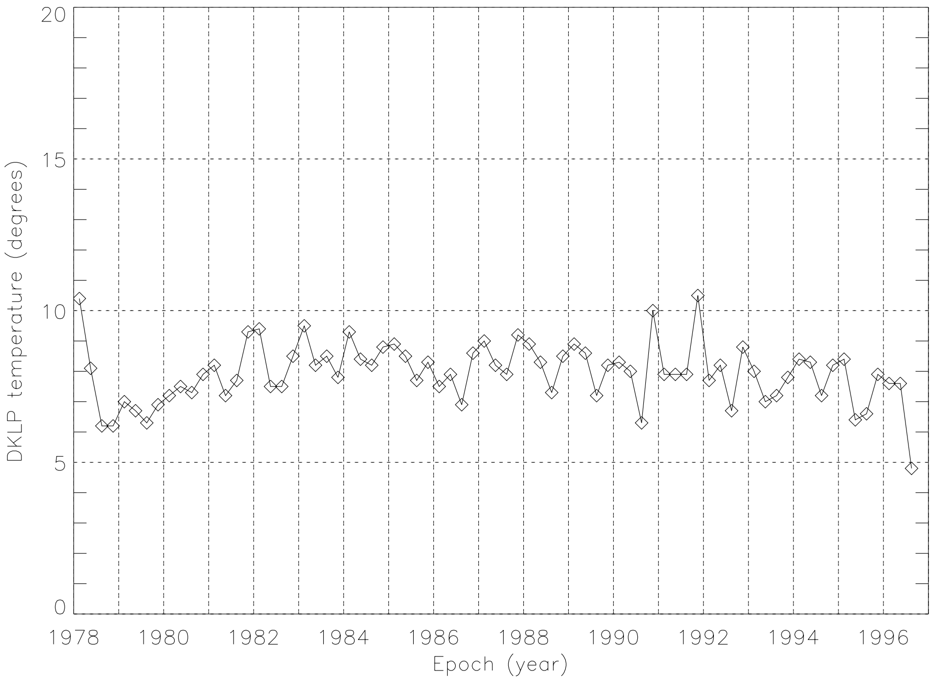

Figure 6-4. History of average camera deck temperatures near LWP.

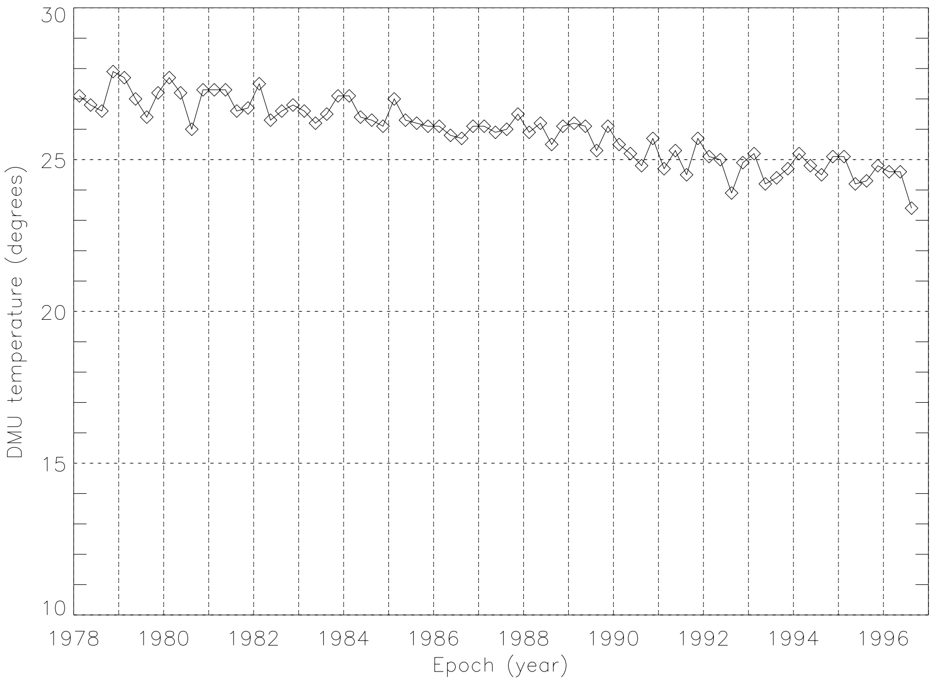

Figure 6-5. History of average data multiplexer 1 temperatures.

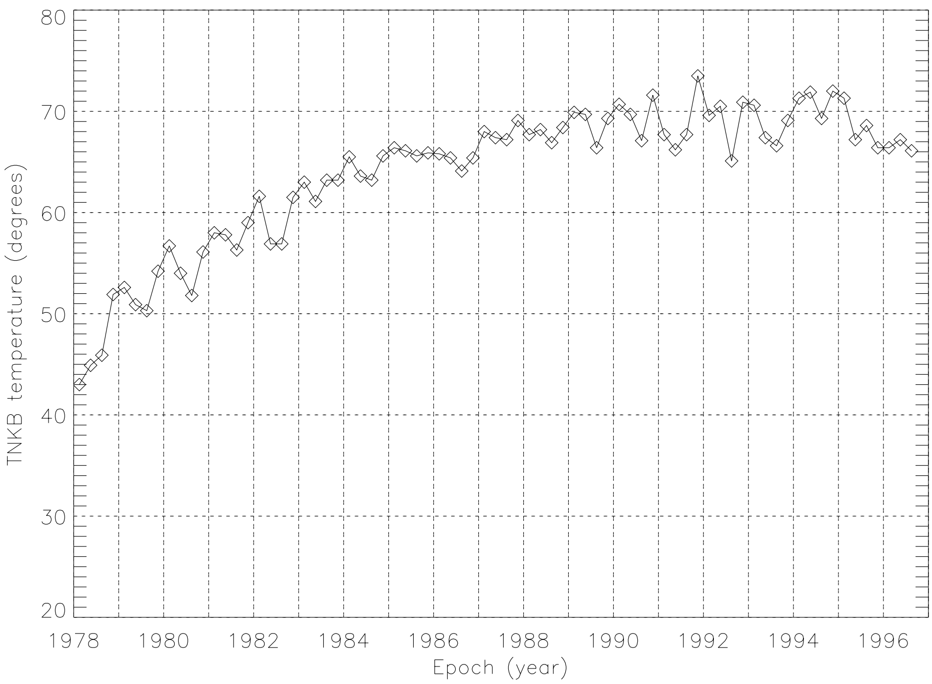

Figure 6-6. History of average hydrazine tank B temperatures.

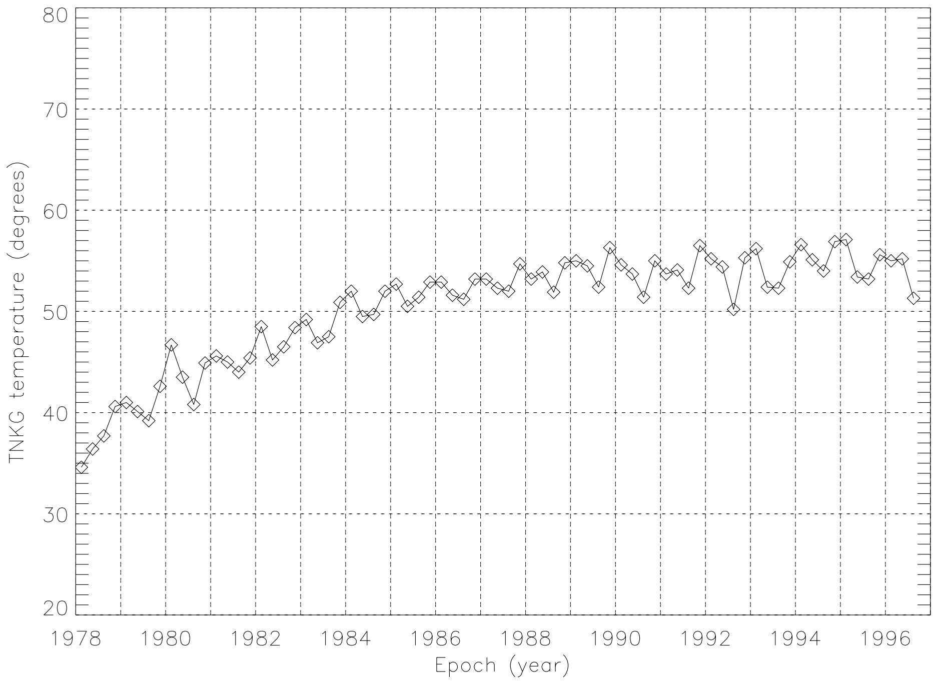

Figure 6-7. History of average hydrazine tank G temperatures.

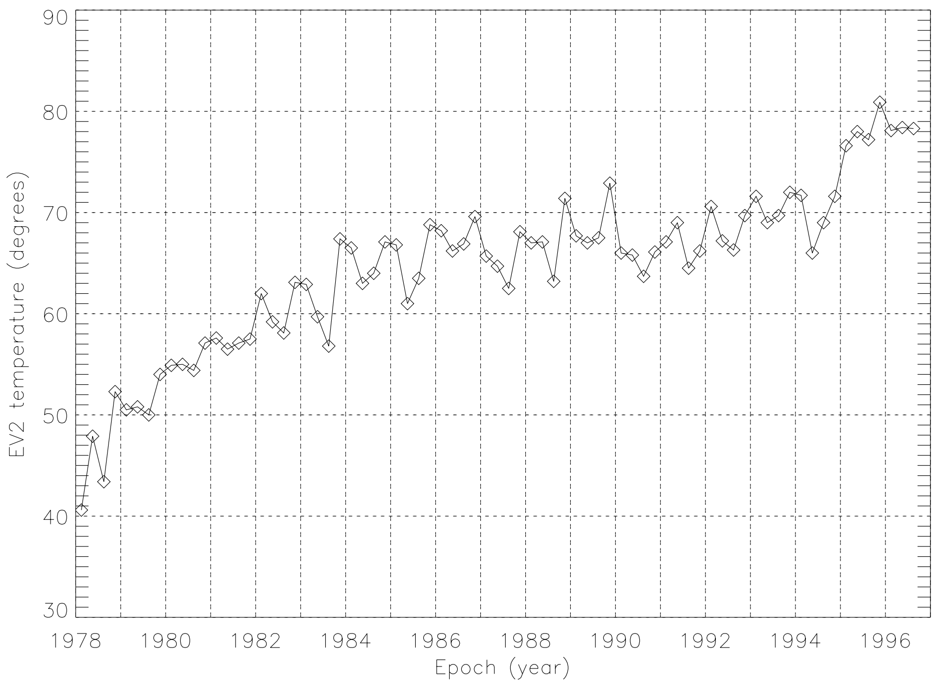

Figure 6-8. History of average engine valve 2 temperatures.

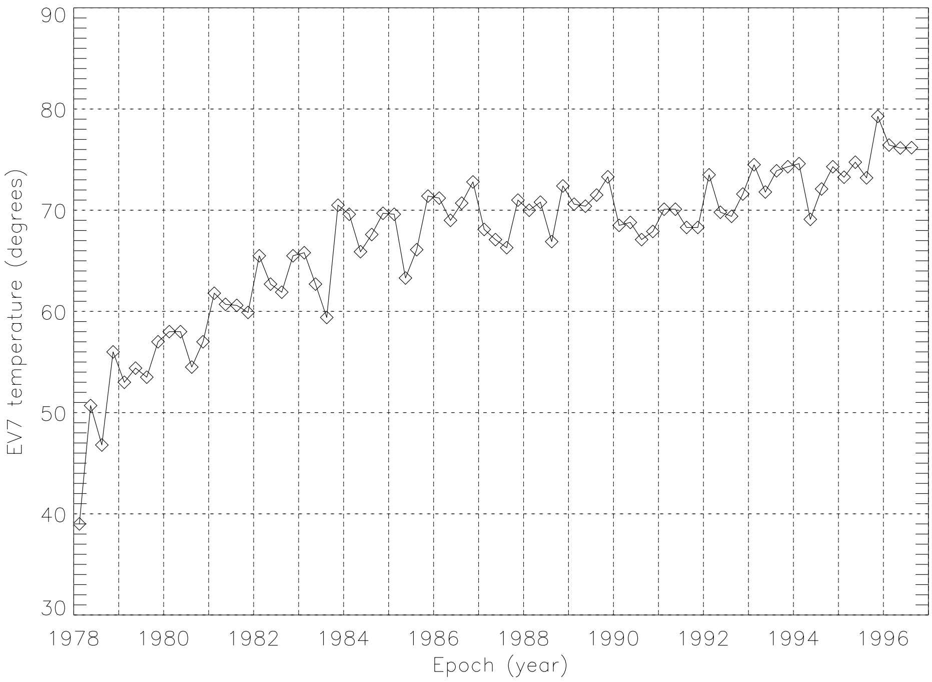

Figure 6-9. History of average engine valve 7 temperatures.

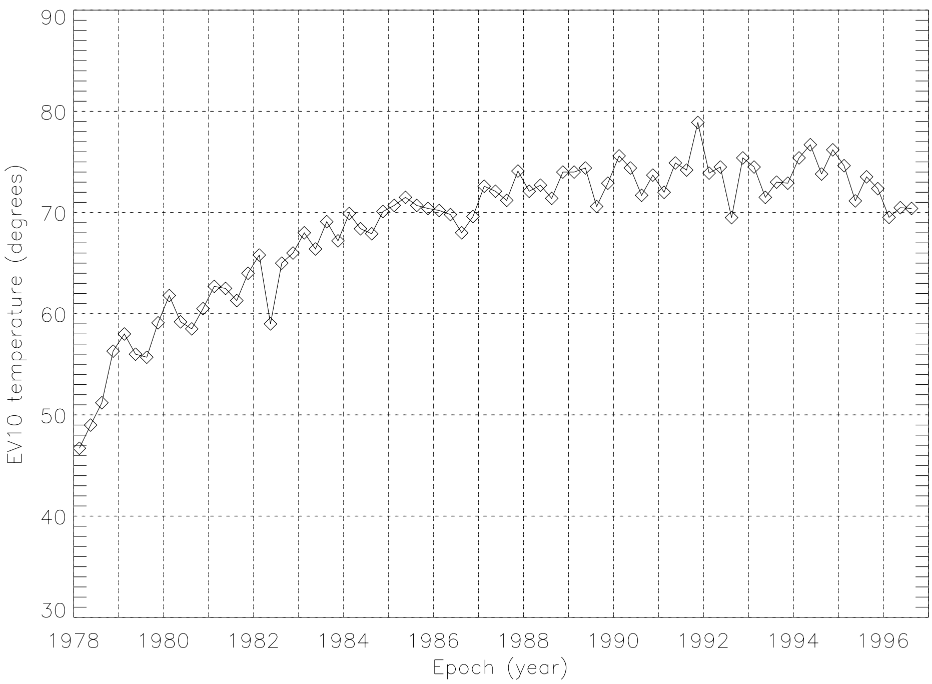

Figure 6-10. History of average engine valve 10 temperatures.

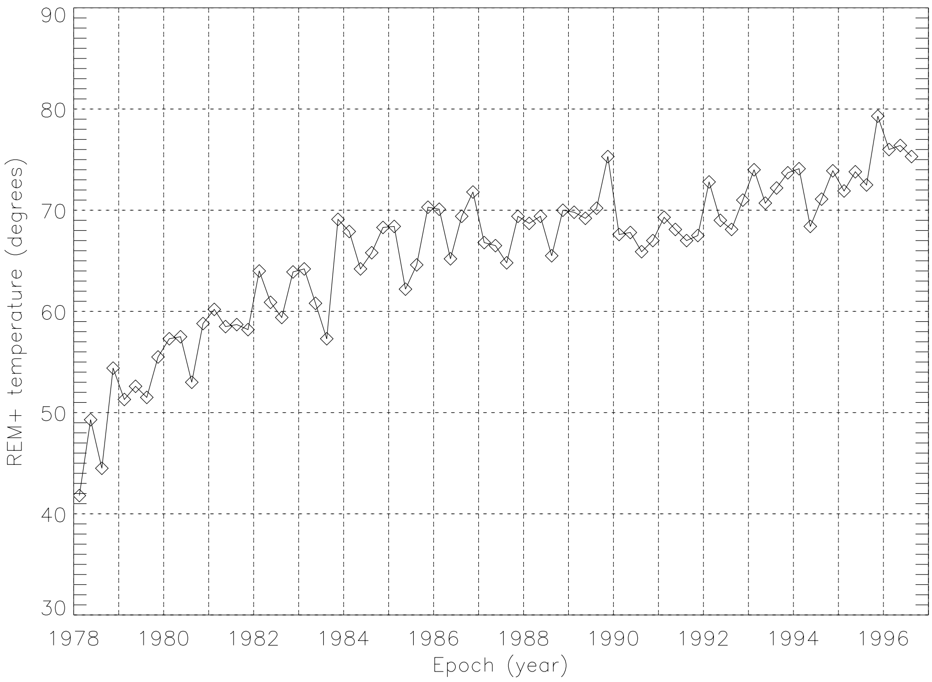

Figure 6-11. History of average remote engine module temperatures.

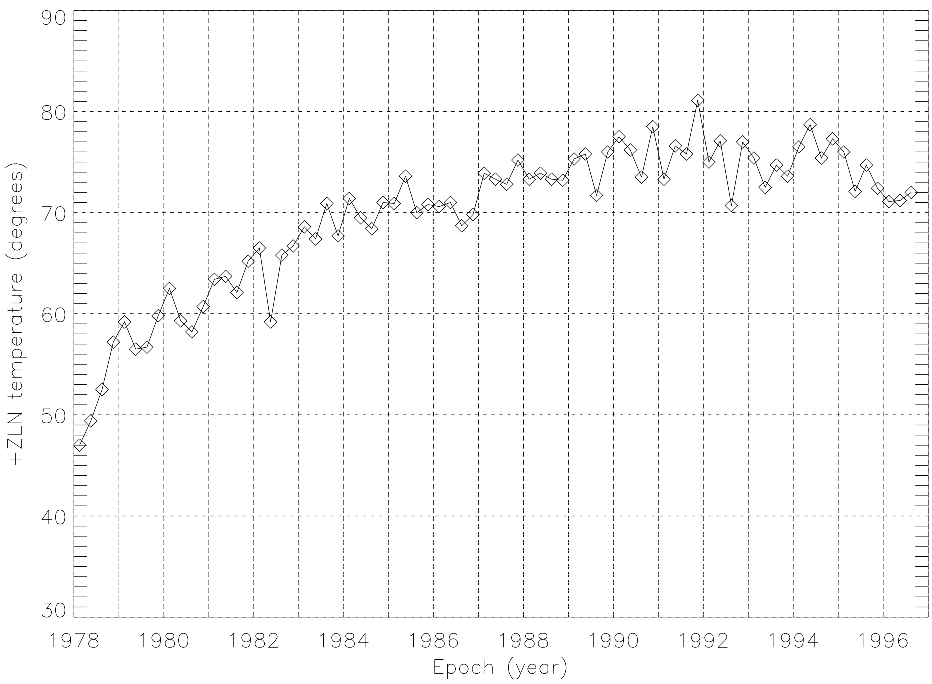

Figure 6-12. History of average +Z line temperatures.

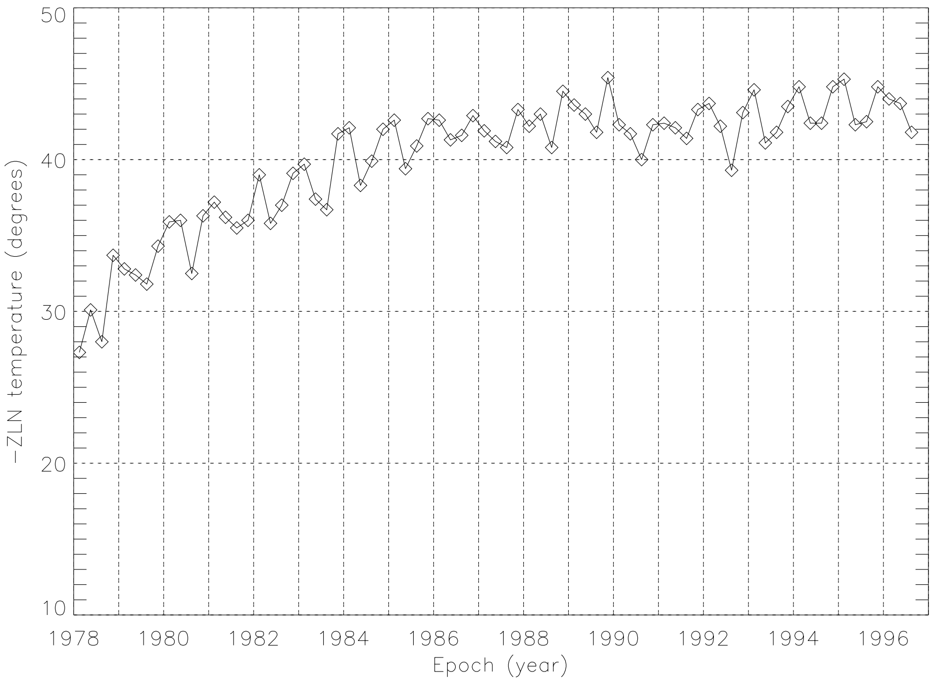

Figure 6-13. History of average -Z line temperatures.

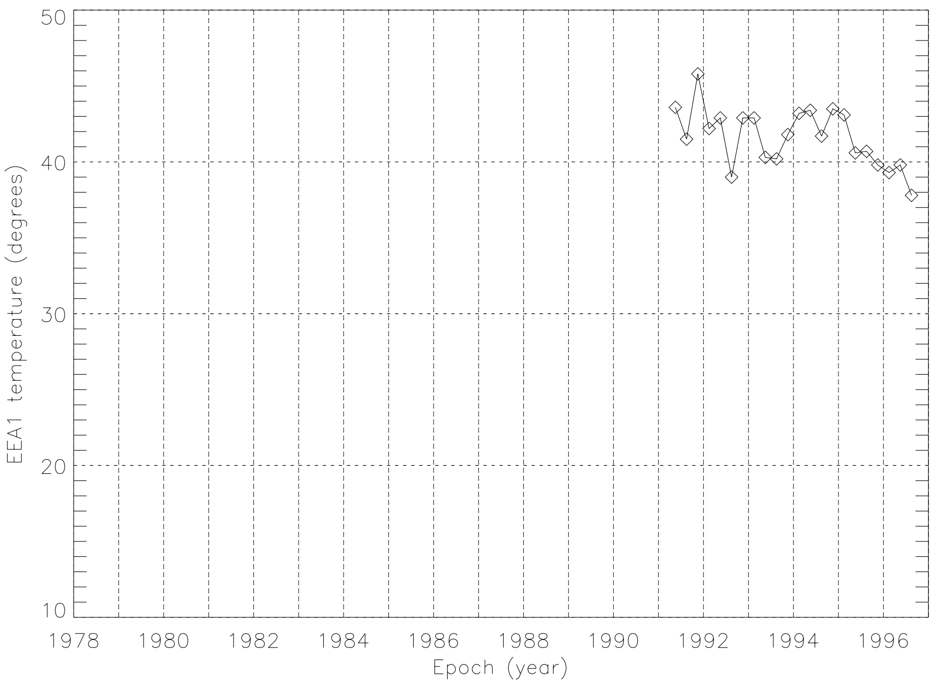

Figure 6-14. History of average EEA1 temperatures.