BIRD 9 years microsatellite mission –
the experience of passive thermal control in space

F. Lura, B. Biering, H. G. Lötzke
German Aerospace Center, Berlin, Rutherfordstr. 2, D-12484, Berlin, Germany
Phone:+4930 670 55 600, Fax:+ 49 30 670 55 602, email: Franz.Lura@dlr.de

H. Studemund
Astro- und Feinwerktechnik Adlershof GmbH, Berlin, Albert-Einstein-Str. 12
D-12489 Berlin, Germany, Fax: +49 30 639 21 002, email: Hartwig.Studemund@dlr.de

V. Baturkin
National Technical University of Ukraine "Kyiv Polytechnic Institute", Kyiv, Ukraine
Pr. Peremogy, 37, 03056, Kyiv, Ukraine, Phone/Fax: +380 44 406 80 97,
email: baturkinvm@mail.ru

ABSTRACT

The microsatellite BIRD (**B**ispectral **I**nfra**R**ed **D**etection) with mass 92 kg and overall sizes 0,55x 0,61x 0,62 m operates on a low Earth sun-synchronous orbit more than 9 years. The temperature range -10…+30 ^{o}C for payload and housekeeping equipment with average power of about 35 W and peak power of 200 W in the observation mode, continuing 10…20 min, is provided by a passive thermal control system (TCS). The TCS supports a thermal stability of the payload structure by use of heat transfer elements – grooved heat pipes, thermally jointing the satellites segments. Two radiators, multilayer insulation (MLI) and low-conductive stand-offs provide the required temperature level. An analysis of TCS performance includes the definition of minimal, maximal and average temperatures of satellite units and their comparison with the designed parameters. The passive TCS successfully supports the nominal temperature level of satellite components during one-year designed period of exploitation and sequent 8 years.

INTRODUCTION

The main features of BIRD (**B**ispectral **I**nfra**R**ed **D**etection), having launched on 22 October 2001 by PSLV-C3 are presented in [1], the description of the thermal control system and some summaries of operation – in [2, 3]. This satellite is intended to demonstrate in space new compact infrared imaging sensor technologies and the approach to modular design of microsatellites. BIRD is a cubic shaped, 3-axis stabilized microsatellite without a propulsion system. The satellite bus is designed as a three-box body, and consists of the service segment (SS), the electronic segment (ES) and the payload segment (PS). The satellite external surface is covered with MLI except the instruments windows, antennas and 2 radiators.

The payload is mounted to the special payload platform, which makes about 1/2 of the body volume and accommodates 30 kg of equipment. To keep the line of sights of the instruments very stable the payload platform is connected deformation free with the bottom located satellite segments. The heat transfer from (or to) the payload platform to (from) the main radiator, located in SS, is realized by two heat pipes [4], fig. 1.

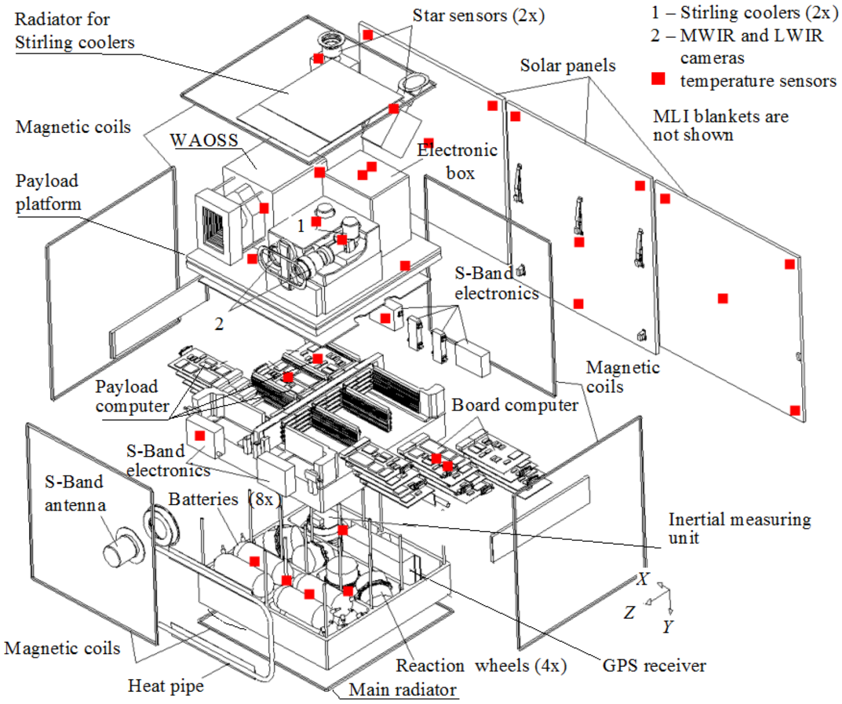
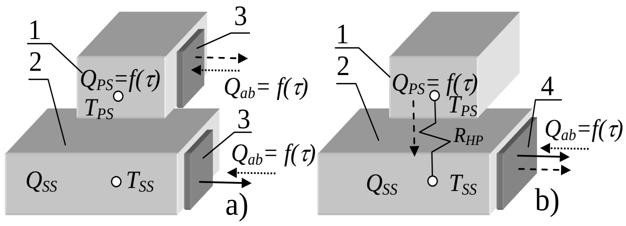


Fig. 1: Scheme of temperature sensors layout on satellite BIRD

The heat removal from the IR instrumentation is realized to the separate radiator, positioned in –Y direction. The BIRD TCS is designed as a passive, when a heat rejected by radiator through MLI and devices windows is compensated by inner heat generation. The temperature limits of major satellite units are typical for space components [3].

The selected thermal scheme combines the autonomous thermal control system for IR Stirling coolers (which provide 80 K for CCD matrix of MWIR and LWIR cameras) and centralized thermal control system for all other satellite components. The centralized concept has the following advantages:

- increasing of thermal mass of assembly by thermal connection of payload instrumentation and service segment reduces the variation of temperature of units with lower thermal capacity (C_{SS} = 40 kJ/K, $C_{PS}/ C_{SS} < 0{,}25$) in the case of periodical power generation and periodical external heat loads on radiators (fig. 2);



- if Q_{PS} goes to minimum, heat transfer from service segment to payload prevents PS overcooling and reduces the temperature gradient between satellite segments by 2…4 K.

BIRD THERMAL REGIME IN FLIGHT

During 9 years the satellite orbit has changed from intended sun-synchronous orbit. The orbit inclination *i* has minimum $i = 97{,}7°$ in the range of day of mission (DOM) 1000…1500, the orbit period was reduced from 96 to 95 min, the semi axis value – from 6945 to 6901 km, decrease of eccentricity – from 0,0019244 to 0,0014283. Due to drift of orbit plane, right ascension of ascending node (RAAN) is changed by ~81°, and stable shaded orbits with shadow duration about 35 min at DOM < 2200 has changed at DOM 3245 to un-shadow orbits during September 2010 (fig. 3).

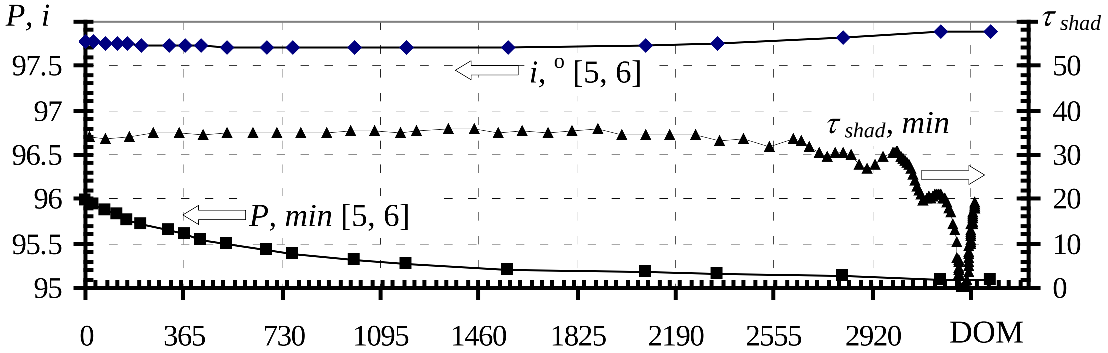


Fig.3: Variation of orbit inclination *i*, orbit period *P* on the base of [5, 6]. *S*hadow time τ_{shad} was complied on the base of sun sensor telemetry

The on-board temperature measurements are performed by 33 temperature sensors of the type AD590. The sensors have been spread over the satellite structure, payload, housekeeping equipments and solar panels (fig. 1) and are interrogated every 30 s.

The on-orbit temperature variation for the main radiator is inside of ΔT = 1…4 ^{o}C, for payload platform – less than ΔT = 2 ^{o}C. Sometimes the radiator has the more essential rise of temperature due to satellite manoeuvres. The increasing of S-band transmitter temperature during operation (7 min) makes ΔT= 10…14 ^{o}C. The solar panels have considerably lower thermal mass and are directly illumined by sun, therefore they have the widest range of temperature excursions. The central panel, cooled from one side only, has the maximal temperature +75…+90 ^{o}C and minimal -25…-60 ^{o}C in shadow. The panels -X and +X (two sides radiate) have the maximal temperature +60…+70 ^{o}C and minimal temperature less than -70 ^{o}C .

There is a certain interest to review the satellite temperatures during the whole period of its exploitation. In order to reduce the volume of summarized file, having saved the most important features during every day, the following algorithm was proposed for temperature and power data processing: to find the maximal $T_{max} = max(T_{\tau 1} : T_{\tau 2})$, minimal $T_{min} = min(T_{\tau 1} : T_{\tau 2})$ and mean integral values for certain period of processing $\tau_2 : \tau_1$. The interval $\tau_2 : \tau_1$ = 24 hours has been accepted as it coincided with telemetry timing output interval. After processing of telemetric data every temperature is presented by three values (min, max, mean integral) at the same time.

Figure 4 presents the overview of several important temperatures for the period till DOM 3300. Nominal BIRD operation took placed during DOM 1…846 with average daily power within the range of 40…50 W, and the main radiator temperature is inside of 0…20 °C. Reducing of power to 20 W and the rise of the main radiator temperature up to 25 °C within DOM 846…1037 deals with the loss of sun-pointed orientation due to the failure of altitude hardware. After new attitude control algorithm with use of magnetic coils for orientation has been introduced (DOM 1039), the orientation on sun was recovered but was not stable. Nevertheless, power consumption was recovered to the level of 25…30 W from DOM 1040 till now.

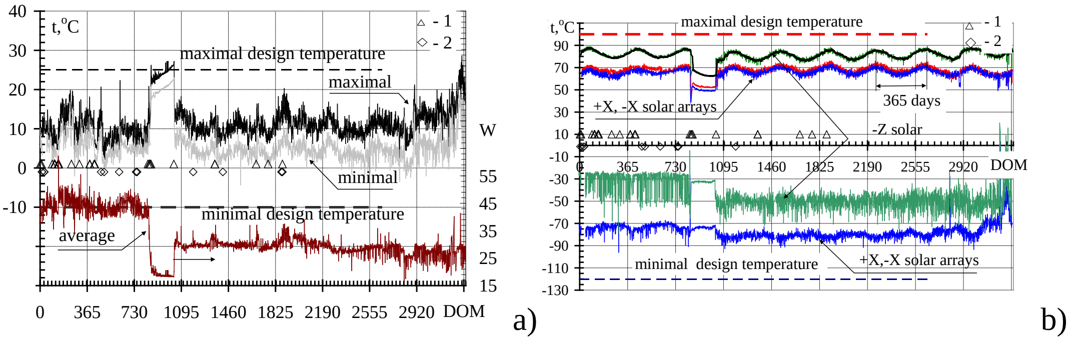


Fig. 4. Overview of temperatures for the main radiator and consumed power (a) and solar arrays (b) within DOM 1…3300: 1, 2 – solar storms and events on satellite

The main radiator temperature is always inside of the planned limits -10...+25 °C, except DOM 1000…1037 and its rise within 3230 < DOM < 3273 is connected with un-shadow orbits. This temperature is the reference for other units due to selected centralized TCS concept. The electronics maximal temperature was less than 40 °C, the temperature of NH_2 batteries is inside of -2…25 °C. The solar arrays maximal temperature has an evident oscillation with the period of 365 days with peak on 2-5 January that deals with variation of solar constant during the year.

Comparison of thermal specification with the results obtained on the basis of telemetry has shown that minimal and maximal temperatures, which were met during the flight, lay inside of the design temperature limits. Collected database is intended to be applied for thermal performance forecasting for future missions realized by microsatellites.

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