SESSION IX: Infrared Radiation I

9.6: Temperature Control in a Bio-Satellite

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SINCE SMALL laboratory mammals (such as rats) cannot tolerate large extremes of temperature without deterioration of performance of learned behavior, the temperature of the life cell of an orbiting satellite carrying such animals must be actively controlled, if absence of gravity is to be the only condition whose effect on behavior is to be investigated. The *Bio-Satellite* prototype, now being built for the Aero-Medical Acceleration Laboratory (NADC, Johnsville), is designed to achieve such active control without internal heat sources or sinks by automatic regulation of the rate of rejection of internally generated and absorption of incident heat from both the sun and the earth. Sources of heat generation are the metabolism of the two rats, the exothermic reaction of water and carbon dioxide with the lithium hydroxide used to absorb both, and the electronic equipment, air circulation pump, etc. Calculated rates of heat production range between 21 and 80 BTU/hr.

While the configuration of the proposed satellite was not primarily determined by the temperature control problem, it was possible to adapt the structural components to serve as appropriate conductors, heat reservoirs and radiators. The roughly cylindrical life cell is shielded by a pair of frustated conical shields which are supported by thermal insulators on four pairs of ribs radiating from the center of the cylinder. An inner layer of reflective foil in each conical shield provides additional thermal insulation and permits neglect of heat transfer between the life cell and space in a preliminary analysis.

Between the cones, and supported by the ribs, is a cylindrical shield with alternating stripes of high and low ratios of solar absorptivity to emissivity. This cylindrical shield is

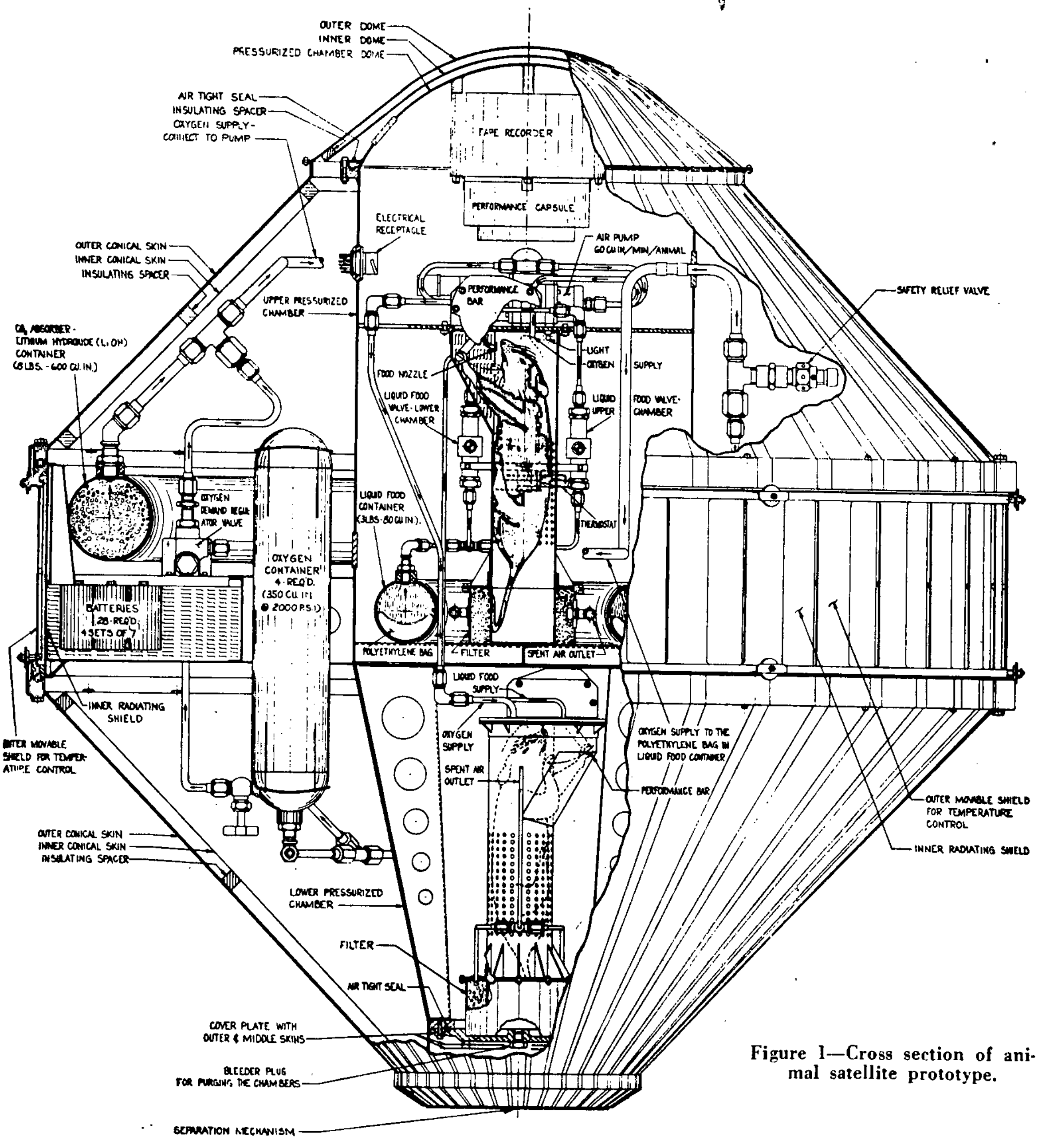

Figure 1—Cross section of animal satellite prototype.

covered by an outer shield having windows which may be aligned with either set of stripes, as determined by the temperature inside the life cell.

One advantage of the proposed configuration is that equipment which must be protected from temperature extremes such as the batteries, the oxygen, tanks, and the lithium hydroxide (where freezing of water would cause blocking of the air supply) may be located within the outer shell, but need not be pressurized, which results in a saving in weight and elimination of large airtight joints. Also the outer cones may serve as meteor shields, thus reducing the chances of puncture of the life cell. Finally, location of heavy equipment close to the "equatorial" plane of the satellite makes for a large moment of inertia about the body axis of the animals, thus increasing the stability of spin which is considered essential for maintaining the rats as closely as possible in a zero-*g* condition.

Since battery power is required to change the position of the outer shield, it was important to determine how frequently such shifting would be required under the expected conditions of internal heat generation, and external heat input.

The two extreme conditions explored were: *I*—Satellite between sun and earth, with maximum area of the adjustable shield exposed to radiation and *II*—zero heat input (i.e., Satellite completely surrounded by a perfect heat sink at absolute zero). For each of these conditions three different rates of heat generation were assumed constant per one hour, (*A*—maximum *B*—average, *C*—minimum) and the temperature change of the life cell was computed for the two settings of the shield.

The assumption of a residual rate of spin eliminates the necessity for calculating lateral temperature gradients in the skin.

Three simultaneous, linearized, first-order, non-homogeneous differential equations of the idealized thermal system were solved by the *Laplace transform* method, using a desk calculator. Results indicate that, for the assumed conditions, and surface properties of the radiators, fairly close control of life cell temperature can be achieved with only occasional shifting of the outer movable shield. However, before the proposed scheme may be considered acceptable, step-by-step calculations for a variety of possible conditions must be carried out.

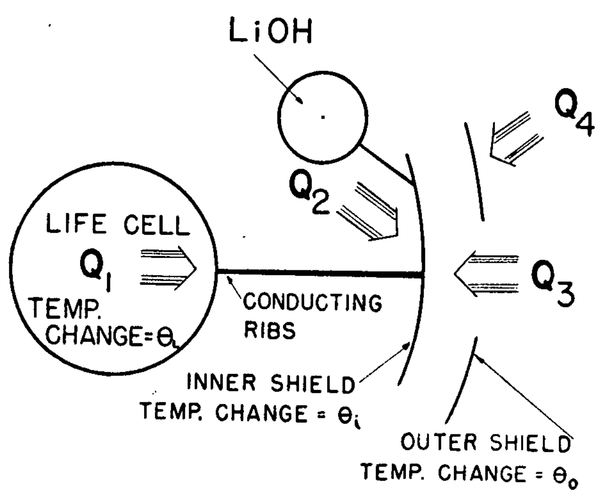

Figure 2—The Bio-Satellite represented as an idealized thermal system, with main sources of heat gain: C_1—from animals; C_2—exothermic reactions in LiOH; C_3 *and* C_4—heat absorbed by inner and outer shields.

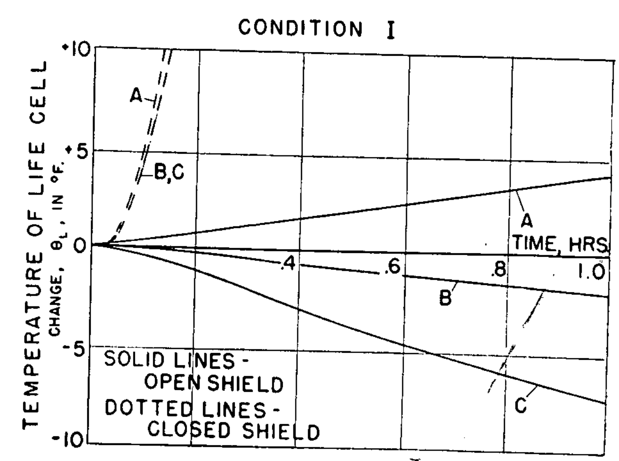

Figure 4—Temperature changes in life cell of Bio-Satellite, with thermal control shield of satellite receiving maximum amounts of radiation from sun and earth, and maximum (*A*), average (*B*) and minimum (*C*) internal heat generation.

$$\dot{\Theta}_L = \frac{Q_1}{C_L} - \frac{KA'}{C_L L}(\Theta_L - \Theta_i) - \frac{KA'}{C_L L}(T_L - T_i) \qquad (1)$$

$$\dot{\Theta}_i = \frac{Q_2 + Q_3}{C_i} + \frac{KA'}{C_i L}(T_L - T_i) + \frac{KA'}{C_i L}(\Theta_L - \Theta_i) - \frac{\sigma A \epsilon_i}{C_i} T_i^4 - \frac{4\sigma}{C_i}(A\epsilon_i + A_c\epsilon_c) T_i^3 \Theta_i + \frac{4\sigma A_c \epsilon_c T_o^3}{C_i}\Theta_o - \frac{\sigma A_c \epsilon_c}{C_i}(T_i^4 - T_o^4) \qquad (2)$$

$$\dot{\Theta}_o = \frac{Q_4}{C_o} + \frac{4\sigma A_c \epsilon_c T_i^3}{C_o}\Theta_i - \frac{4\sigma A_c(\epsilon_c + \epsilon_o) T_o^3}{C_o}\Theta_o + \frac{\sigma A_c \epsilon_c T_i^4}{C_o} - \frac{\sigma A_c(\epsilon_o + \epsilon_c) T_o^4}{C_o} \qquad (3)$$

Figure 3—Equations expressing change in temperature (Θ) from assumed base temperature (*T*) in life cell, inner and outer shields. Emissivity of inner shields (ϵ_i) is changed by displacement of outer shield.

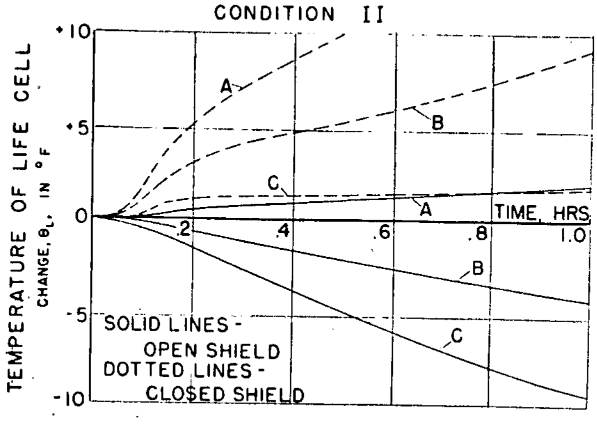

Figure 5—Temperature changes in life cell of Bio-Satellite, without external heat inputs, and with same rates of internal heat generation as in Figure 4.