INTRODUCTION

Certain in-orbit experiments, which are presently in the planning stage, have stringent low-temperature environmental requirements. In the case to be considered here, it is necessary to maintain a cylindrical interior having a volume of several cubic feet at a spatially uniform temperature. The magnitude of the temperature should not exceed 30°K. In addition, small electronic components must be kept at a constant temperature of 5°K or less. The required lifetime of these environments is approximately one week in orbit. This paper discusses some of the problems encountered in designing systems to meet these requirements in low gravity and proposes tentative solutions to the problems.

PROBLEMS ASSOCIATED WITH A LOW-GRAVITY ENVIRONMENT

For convenience, a cooling system can be thought of in terms of its major functions. For a single-pass system such as is being considered here, these functions are to provide storage for the coolant, to transport the coolant from storage through areas of heat exchange to waste disposal, and to make provision for the transfer of heat from the high-temperature areas being cooled to the heat-exchange areas. Each of these functions has to be approached somewhat differently for a space environment from that required for ground systems.

The absence of gravity complicates the problem of coolant storage because there is no body force present to positively position the liquid with respect to the vapor in the cryogenic container. Positive separation and positioning of the two phases is essential to prevent wasteful venting of liquid coolant overboard and to insure that a constant quality liquid coolant is in contact with the heat exchange surfaces. Alternate passage of liquid and vapor over such surfaces would cause undesirable temperature fluctuations. Thus, a well-designed system must employ some means to fix definitely the liquid–vapor interface.

There are several ways in which the force necessary to position the liquid–vapor interface could be provided. Most frequently discussed at the present are (1) inertia forces produced by vehicle rotation, (2) dielectrophoretic forces, or the forces on an inhomogeneous dielectric medium in the presence of a space-varying electric field, and (3) surface tension or capillary forces. Depending on the application, one of these methods will have certain advantages which will dictate its use.

For applications involving in-orbit scientific experiments, rotation of the space vehicle, or of the cryogen container, is undesirable because it will usually affect the...
experimental environment. Settling impulses have the same disadvantage. Dielectrophoresis, as a means of controlling or positioning propellants and coolants in low gravity, is still in the developmental stage. For these reasons, the most practical approach for the present application is the use of capillary forces. The advantages of this approach are simplicity of design and the fact that their use affects only the stored cryogen, not the spacecraft as a whole. The added weight should not exceed that which would be required by rotational or other systems. Capillary forces can be applied by using a honeycomb arrangement of standing tubes in the coolant container. Concentric baffles standing parallel to the reservoir longitudinal axis are also practical. The initial positioning of the liquid and vapor in the desired position can be assured by providing that this configuration corresponds to the equilibrium prelaunch configuration on earth.

A convenient ratio for indicating the relative effectiveness of capillary forces is the Bond number, or the ratio of gravity or body forces to surface tension forces. It is given by

$$Bo = \frac{\rho gr^2}{\sigma}$$

where $\rho$ is the density, $r$ is the capillary radius, $\sigma$ is the surface tension force per unit length, and $g$ denotes the magnitude of the local gravity. With the use of (1), an estimate of the required radius of the honeycomb can be obtained. If the Bond number is $10^{-1}$ or smaller, the surface tension forces will completely dominate inertia forces. The gravity forces which will be experienced due to spacecraft maneuver are usually no larger than $10^{-3}g_e$ where $g_e$ is the gravitational acceleration at the surface of the earth. Then for neon, for which $\sigma = 5.5$ dynes/cm and $\rho = 1.2$ g/cm$^3$, the required radius is 0.7 cm. Thus, a positive positioning of the liquid in the capillary tubes requires a tube diameter no larger than about 1.5 cm for acceleration forces of this magnitude. If the expected inertia or disturbance forces for a particular mission are smaller, then, of course, the capillary diameter can be increased.

Consideration must also be given to the effect of low gravity on the processes of heat transfer. The free-convection process is, of course, no longer available, so that care must be taken that heat-transfer surfaces are not in contact with cooling liquid when there is no provision for its removal. Otherwise, vapor bubbles are formed when the coolant locally exceeds the saturation temperature and poor heat transfer results, with consequent surface overheating. Due to these and other complications, it is advisable, wherever possible, to transport heat by processes independent of gravity, that is, by conduction, forced convection, and radiation.

The conduction process is particularly attractive at cryogenic temperatures due to the large values of the thermal conductivity of certain nearly pure metals in this range, notably aluminum and silver. In the remainder of this paper, the general considerations discussed above will be applied to the problem of creating the environments described in the introduction.

**UNIFORM TEMPERATURE ENCLOSURE**

A cylindrical enclosure (see Fig. 1) with length and ID of about 4 ft and 2 ft, respectively, must be maintained at a uniform temperature not exceeding 30°K. The enclosure is open on one end, through which its interior exchanges heat by radiation with the space vehicle and space. The net heat gained by the interior in this manner does not exceed 50 Btu/hr. It can be assumed to be distributed uniformly over the interior surface.