PERFORMANCE MODEL FOR REVERSIBLE FLUID BALLOONS

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A detailed analytical model has been produced that can predict the motion of balloon systems that use the phase change of a fluid to control altitude. Although the model is specialized, it is also believed to be more accurate than all previous thermal/motion predictive models for lighter-than-air balloon systems.

The principle of using reversible phase change fluids to control balloon altitude on Earth was originally developed at JPL in 1993 with confirmation testing occurring in 1993 and 1994. The principle itself is that in the warmer lower atmosphere, a fluid evaporates and fills a balloon, thereby displacing more air and creating a net gain in buoyancy, allowing the balloon to rise. In the cooler upper atmosphere, the fluid condenses, thereby creating a net decrease in buoyancy that allows the balloon system to descend.

A comprehensive test program known as the ALtItude Control Experiment (ALICE) was initiated in July of 1993 to prove the basic principles. After careful considerations of industrial safety and environmental concerns, freon R114 was selected as the controlling fluid. However, since freon gas is heavier than air, the addition of a helium balloon was necessary to provide the necessary lifting force,

The decision to use R114 as the controlling fluid posed a technical challenge, Since R1 14 gas is very heavy (molecular weight = 170,9), it cannot displace a large volume of air, and therefore cannot produce a large lifting force for a given weight. Therefore, for a balloon system to float at a neutrally buoyant altitude with 1 kg of partially liquefied R1 14, the helium balloon must provide a lift in the narrow range of 0.83 to 1 kg. This margin must be maintained regardless of the dry weight of the system. Therefore, this margin will be a smaller percentage compared to the helium lift as the dry weight of the system increases.

The control margin, expressed in terms of the ratio of the control force due to phase change or R1 14 to the net lift of the helium gas is generally on the order of 10% or less for the ALICE flights. Since the control margins are small, a variety of factors can easily upset the delicate force balance of the balloon system and prevent a successful flight, These factors include the effect of thermal radiative and convective heat transfer on balloon fluid temperatures, leakage of the balloon fluids, and the rates of freon condensation and evaporation, Since the condensation and vaporization of RI 14 cannot produce a dominant control force, other related parameters that can alter the dynamics of the balloon system has to be carefully accounted for. Analytical studies on a helium balloon that were previously performed by Carlson and Horn provided an excellent starting point for the present investigation.

This present paper contains details of the updated equations governing balloon motion including a modified equation of motion, total enthalpy heat content of the balloon system, heat balance equations (solar, radiation, convection, phase change), and heat flux equations. The computer code was written in Microsoft Excel 4.0 and is usable by both the Windows and Macintosh versions. The code is in the public domain and will be available through NASA.

The code is presently being varied to allow mission designs for balloon systems on other gaseous planetary bodies such as Venus, Jupiter, Saturn, Uranus, Neptune, and Saturn's gas-covered moon, Titan, In particular, the code is now being used to design a mission known as Balloon Experiment at Venus (BEV), in which a Venetian balloon system would repeatedly travel to the lower hot altitudes or surface of venus for imaging and science experiments and then float higher in order to cool the electronics.