RE-ENTRY PROBLEMS

This article, outlining some of the many problems involved in the safe recovery and landing of a vehicle from a satellite orbit or deep-space mission, is a shortened version of the paper "Re-entry and Landing" presented by L. F. Crabtree and D. H. Peckham of the Royal Aircraft Establishment, Farnborough, at the symposium on aerospace vehicles held by the British Interplanetary Society in London on November 13.

There are many problems involved in the safe recovery and landing of a vehicle from a satellite orbit or space mission. Since a large part of the deceleration is provided by the atmosphere, a re-entry vehicle must be designed to withstand enormous heat loads as well as to control the actual deceleration loads. There are two principal methods of achieving recovery from satellite orbits:

(a) a pure ballistic re-entry as typified by the Mercury capsule, and
(b) a glide re-entry in which aerodynamic lift provides manoeuvrability, and in which the peak heating rates are less than in (a), but the total heat load is greater due to the longer time involved in the re-entry manoeuvre.

A typical value of maximum lift/drag ratio for a winged vehicle of this latter class is 2 at hypersonic speeds. (This would yield a value of max L/D of about 4 at low speeds.) Trimable ballistic trajectories are visualized for Gemini and Apollo with a maximum L/D ratio of about 0.5, so in this case only minor trajectory corrections will be possible. Again, a lifting body of somewhat boat-like shape with a maximum L/D ratio of about unity has been suggested. With such a vehicle the heating and deceleration problems are greatly eased, but of course the actual landing manoeuvre would not be so easy as with the winged vehicle.

Up to the present only ballistic re-entry with final recovery (or "landing") by parachute has been employed, for the main reason that the weight is thereby kept to a minimum. This has been unavoidable since available booster rockets were limited in thrust.

For the future, however, with the ever-increasing scale of orbital debris operations, water accessability in the choice of the final landing area will be necessary and this means controlled lifting re-entry. For military operations this feature will be imperative if orbiting satellites are to be re-used.

So far we have been discussing only re-entry from satellite orbits. For re-entry from space missions where the speeds are much higher, then all the problems are magnified. For instance, at speeds above escape speed, heating of the vehicle by radiation from the hot gas atmosphere dominates and affects the whole design philosophy. Guidance problems also become more acute in that the "corridor" depth for safe re-entry becomes smaller.

Lifting Re-entry

Up to now recovery from orbit has been along a ballistic trajectory. For future systems, however, the characteristics of ballistic re-entry appear altogether too restrictive, and some degree of manoeuvrability will be needed during re-entry to give control over range, deceleration and heating rates. This means the ability to generate lift. In this way a relatively deep corridor (compared with the ballistic case) is obtained within which a safe re-entry can be accomplished. The boundaries of this re-entry corridor have been termed "undershoot" and "overshoot," and correspond to steeper and shallower initial flight path angles respectively. The overshoot boundary corresponds to the smallest angle at which re-entry can be made without the vehicle passing through the atmosphere before the opposite boundary of the atmosphere is reached, but a lifting vehicle can use negative lift to hold itself in the atmosphere at greater than orbital speeds while decelerating; it can therefore re-enter at a shallower angle. The undershoot boundary corresponds to the steepest re-entry angle for which the deceleration or heating are kept within prescribed limits.

A typical lifting re-entry from greater than orbital speed is illustrated in the diagram (overleaf). The first stage involves lifting away from the Earth at or near the C_l max of the vehicle, keeping the acceleration normal to the flight path within a prescribed limit (say 8-10g). This then is the undershoot boundary as just described, where the use of positive lift is to avoid penetrating to too low an altitude at too high speed. Modulation of the lift during this phase can be used to obtain the steepest possible re-entry angle. Thus initially the vehicle would be at the angle of attack for maximum lift and high drag, and the angle of attack would be reduced as the vehicle penetrated deeper into the atmosphere so as to maintain accelerations and lower surface heating within acceptable limits. Thus the maximum pull-up and deceleration forces are generated at the highest possible altitude and the heating at the bottom of the pull-up is minimized. The end of this initial phase of re-entry occurs when the flight path angle becomes zero.