Human Factors in Space Vehicles and Space Stations

The past few days have been devoted to the discussion of new and sophisticated ways of exploring and utilising the space environment. But in spite of the technological advances that will make it possible to carry more payload more effectively and more cheaply, the most useful and delicate items of equipment will conform to design criteria established for a different purpose millions of years ago, and a crash program to update them appears to have a low probability of success. In fact, the human problems associated with space flight threaten to become more severe as the scale of operations expands, because the small pool of highly-selected and exhaustively-trained astronauts must be widened and stocked with frailer mortals. It is likely that the first generation of space shuttles and space stations will be operated and manned by professional spacemen, but if the concept of a permanently-orbiting laboratory is to have full scientific value, its occupants must eventually be chosen for their specialist skills rather than for their stamina. In this respect, the evolution of space flight is likely to be different from that of conventional aviation. The latter became available to the masses because over the course of many years both the machinery and the environment of flight grew simpler and safer; the physical stresses were reduced by clever engineering design. Space vehicles, however, are not yet tailored for passenger travel (much less for owner-operation), and design is primarily "mission-oriented".

The main responsibility of the human factors expert is to set forth the requirements for the safety, comfort, and working efficiency of passengers and crews during all phases of the flight. A related, but different, duty is to specify the environmental limits that they can tolerate. This is by no means as easy as it may appear, partly because it is often impossible to estimate hazards in numerical or statistical terms, and partly because too little is known about the interaction between different stresses when they act together. (For example, the average human tolerance for the patterns of acceleration encountered during re-entry is fairly well established, though only for a population of fit young men; the dose of ionising radiation that will give rise to radiation sickness is known, though only approximately; the extent of the presumably deleterious effect of acute radiation sickness on acceleration tolerance is strictly a matter for "guesstimates"). In situations such as this, there is a strong temptation to be unduly conservative, and a compromise must eventually be reached between the ideal and the expedient. This paper outlines some of the basic stresses that are inherent in all space flights, and considers some of the new problems that may arise when the establishment of space stations changes both the nature of the mission and the characteristics of the population at risk.

Acceleration

The effects of acceleration upon the body depend not only upon the magnitude of the applied force, but also upon its duration, and upon the direction in which it acts. The ejection seat of a fighter aircraft may apply 15G for about one-tenth of a second along an axis parallel to the spine. The same force acting in the same direction for five seconds would result in unconsciousness, even in the hardiest of astronauts. However, a force of 15G applied transversely to the body from front to back is tolerable for 15 seconds or more, although it is extremely uncomfortable, and breathing is difficult or impossible. The reason for this great variation in the directional effect of accelerative force lies in the anatomical arrangement of the major blood vessels, and in the distressing tendency of blood to obey the laws of hydrostatics. For a man in the erect position, there is a column of blood about 30 cms long between the heart and the brain, and the pressure difference between the two ends of this column is, accordingly, about 22 mm.Hg. If the effective gravitational force is increased from 1G to 5G, the pressure drop is also increased fivefold, to reach about 110 mm.Hg. This figure is close to the pressure developed by the heart (which does not alter greatly with acceleration) and it follows that blood cannot be propelled to the brain in these circumstances. The result is the well-known sequence of loss of vision and unconsciousness that can afflict the unwary and unprotected fighter pilot during aerobatic maneuvers.

It is not difficult to select a posture in which the gravitational force is at right angles to the heart/brain axis, so that no hydrostatic pressure difference exists. In this position the tolerance for accelerative forces is, theoretically, extremely high, and the limit