THE JOURNAL OF
AVIATION MEDICINE
Official Publication of the Aero Medical Association

VOLUME 27 OCTOBER, 1956 NUMBER 5

Environmental Considerations of Space Travel from the Engineering Viewpoint

BY ALFRED M. MAYO

NEW problems are being generated by man's increasingly active encroachment toward the fringes of space. None of these new problems or resulting new information requirements, however, indicate that there will be any lessening of the need to apply primary effort toward achieving an optimum man-machine combination for maximum overall efficiency.

An effective approach toward better over-all efficiency must increasingly make use of the best available aeromedical, scientific and engineering data in order that the necessary working compromises can be achieved. Some of these data, already available, indicate that problems peculiar to flight in space will radically change much of the equipment and crew spaces. Flight speed and altitude records are currently being shattered with increasing regularity. It is no coincidence that both speed and altitude records are falling together, since the increasing drag and heat problems of the lower atmosphere are both attenuated by flight at higher altitudes.

CREW SPACE DESIGN

Flight in space will impose new physiologic and psychologic stresses on the expected operational demands of the crew members. Evolution in man being a rather slow process, the rapid strides being made in the machine systems must for practical purposes be balanced by improvements in aids for and education of the crew members.

An effective set of requirements for accommodational aids for the crew must take into account the fundamental limitations and strengths of the human being as its foundation. The location and size of the occupied area should be determined with full cognizance of the functional and environmental requirements of the crew. These relatively fixed human requirements must by necessity take priority over the comparatively flexible requirements of equipment. Careful consideration must be given to the operational and control

---

From the Engineering Section, Douglas Aircraft Company, El Segundo, California. tion, Chicago, Illinois.

Presented April 16, 1956, at the 27th annual meeting of the Aero Medical Association, Chicago.

requirements in order that each piece of equipment will perform effectively as a part of the over-all system and provide the human operator with information in the form and time sequence suited to his capacities. The same set of requirements that dictate the design and function of equipment will, if properly arrived at, direct the location and arrangement of the equipment in the crew compartment.

VISION

As the speed increases it is necessary to make decisions resulting from visual information from increasing distances, in order for the man's time constant to be satisfied. Increased altitude also dictates the reception of visual stimuli from greater distances. These fundamental visual problems immediately generate a requirement for improved electronic aids to provide information over great enough distances to allow the human operator time to make effective decisions.

While progressively less of the required visual information can be obtained from direct outside observation, man's past psychologic conditioning will probably for a long time dictate the incorporation of transparent areas in manned aircraft. The direct transparent areas will continue to have important observation uses, even though less of the total required visual information will be available from direct observation. The psychologic conditioning of man to direct vision will probably also tend substantially to effect the design of primary transparent areas.

Problems related to proper interior illumination and vision with respect to generated displays will continue to be of primary importance.

TIME-DISTANCE PROBLEM

Time must be increasingly recognized as a fundamental quantity and distance a subordinate variable, if we are to realize the maximum potential of the man in the system.

Figure 1 shows that it is man's time constant and not distances *per se* which dictate the extent to which aids must be provided to supplement the man's sense and computational speed.[1,16,17] Since these data represent the simplest case of direct visual stimuli and a single bit of information, they further emphasize the fact that certain types of control functions must be handled by devices capable of sensing and reacting to changes in much less time than can a human being. Even so computational equipment can be developed to present the human operator with the necessary information so scaled in time that he can make those decisions too complex for man-made computers.

TEMPERATURES

In heavier-than-air craft, there has been a consistent trend toward rapidly increasing speed along with increasing altitude. The fact that the same airplane currently holds both the world's speed and altitude records is an example of this trend. Since the temperature rise of a molecule of gas, on becoming rapidly accelerated to the speed of the aircraft, is proportional to the square of the speed, it is not too hard to understand why temperature problems already solved in present day aircraft can become serious unsolved problems for higher speed flight within the atmosphere. The fire path of a meteor is but one example of the devastating effect very high velocity within the earth's atmosphere can have on materials normally considered heat resistant. Fortunately, temperatures encountered at extremely high altitudes cease to have the same meaning in terms of actual heat transfer as the same temperatures at sea level, even though each particle has energy equal to that at sea level. As altitude increases the number of particles decrease so greatly that the normally felt heat transfer by means of conduction and convection becomes negligible with radiation assuming the predominant role in the outer fringes of the atmosphere.

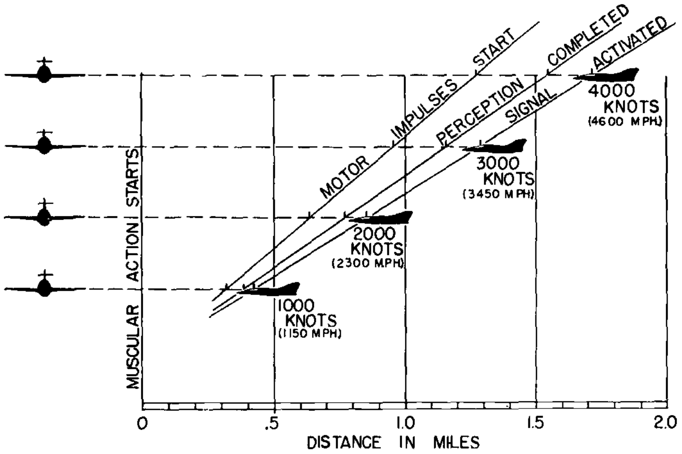

Fig. 1. The distance traveled after the perception of a visual signal until the onset of muscular action.

Figure 2, based on data reported by Kaplan,[8] Newell and Kallmann,[10] and Roberts,[11] shows that the primary temperature control of a flight above the atmosphere becomes a function of stored energy and of radiant heat transfer. For flights in which re-entry to the atmosphere is required, structure temperature control becomes extremely critical. The external portions of the aircraft will need to be designed in such a manner that substantially all of the heat generated on the craft's surface, in using up the terrific kinetic energy and gravitational potential energy of the craft, can be dissipated by radiation and molecular rebound. The aerodynamics of this craft must be such that this heat transfer will be accomplished within the temperature limitations of the structure to prevent the craft from falling into the category of a vaporizing meteor.

For flights up to roughly 70,000 feet, various modifications of the air cycle and ram air cycle refrigeration system will probably be usable with the ram cycle systems finding their applications mostly with ram jet engines where a source of high compression ratio air will not be available. At altitudes substantially above 70,000 feet,[2,3,12,19] the air cycle refrigeration systems are so ineffective that storage or radiant temperature control systems will become necessary. Cooling by means of the evaporation of liquid oxygen in conjunction with the use of substantial thermal insulation may be practical for short flights. Radiant heat transfer for temperature stabilization may be visualized by considering the fact that greater or lesser proportions of dull (high emissivity) surface can be presented to the direct rays of the sun as against the proportion of shiny (low emissivity) surface. With greater portions of dull surface toward the sun and the shiny surface away from the sun, the temperatures of the craft will tend to increase. The temperatures will tend to decrease when the shiny surface is presented to the sun.

PRESSURE

Mountain climbers and later the early balloonists experienced some of the problems involved in performing physical tasks under conditions of reduced pressure. Here the important physiological result was that of hypoxia. At increasing altitudes the continuous reduction of pressure gives rise to additional physical problems such as "bends" and "chokes" and eventually to excessive swelling due to evaporation of liquids within the body. These later troubles occur even in event of proper compensation of oxygen. At very high altitude counter pressure is also required to maintain a sufficient partial pressure of oxygen in the lungs in order that oxygen can be transferred through the lung tissues to the red blood cells then to the using cells.

These problems together with those of maintaining proper air composition, by elimination of impurities and toxic gases, can and are being effectively handled in pressurized cockpits by compressing outside air to ratios sufficiently high to allow both for cooling and workable cockpit pressures. This approach appears practical only to roughly an altitude of 70,000 feet. For short duration flights above 70,000 feet, a simple storage system utilizing liquid oxygen can probably do a satisfactory job of both cooling and pressurization. The presence of such small amounts of carbon dioxide, water vapor and excreted body gases as would occur could undoubtedly be tolerated for short periods of time.

Self-contained pressurizing and air purification systems needed for extended flight above the atmosphere will become increasingly difficult to provide. The techniques developed for use in submarines will probably be useful for flights of intermediate duration. For very long duration flights, much more work on the chemistry of air regeneration to provide, essentially, a hermetically sealed balanced environment will be necessary. As the outside ambient pressures become very low compared to cockpit pressures, an explosive loss of pressure, as in the case of a damaged cabin or even a slow loss, would present a very serious problem. Until the cockpit structure and pressurization system can be developed to a point of reliability equal to that of the basic structure components, some sort of a pressure safety equipment will be needed. One approach to this type of equipment would be the provision of a pressure suit designed to be as light and comfortable as possible for use in its normal unpressurized condition, even to the point of allowing for substantial loss of comfort and mobility during the emergency. Such equipment would be comparable to a parachute, the actual use of which may never occur during the entire flying career of a pilot but which would be highly essential in case of a pressure emergency. In the case of a commercial transport flying at altitudes so high that it is impractical to dive to a safe altitude upon accidental decompression, the safety of the passengers would rest primarily with the design engineer who must provide pressurization of an order of reliability consistent with that of the basic aircraft structure.

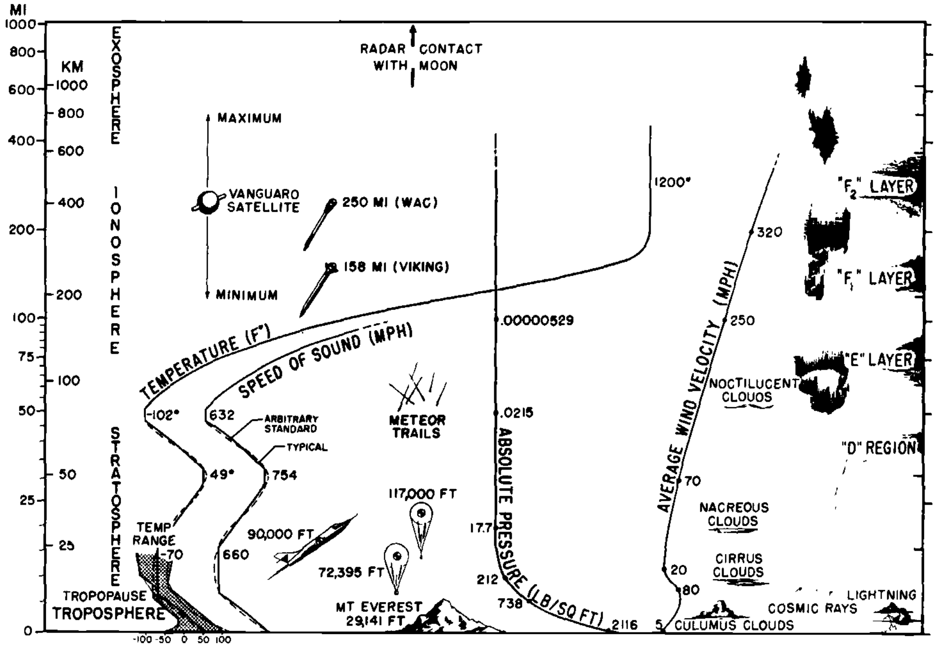

Fig. 2. The characteristics of the earth's atmosphere summarized from information available in 1956.

ACCELERATION

As the present type of aircraft is improved for higher altitude flight, it is probable that the turning and maneuvering accelerations of a relatively low order of magnitude but of substantial duration will become important to the engineer.

As the extremely high thrust rocket engines are utilized for manned vehicles, it is likely that conditions will arise where the acceleration tolerances of man will be an important limitation. During the take-off phase, thrust-time relationships must be controlled to values allowing the crew to perform the assigned tasks. The problem of re-entry into the atmosphere will be even more demanding with respect to acceleration control. Present studies indicate that relatively small errors in control during re-entry can impose very large acceleration loads on the craft and the crew.

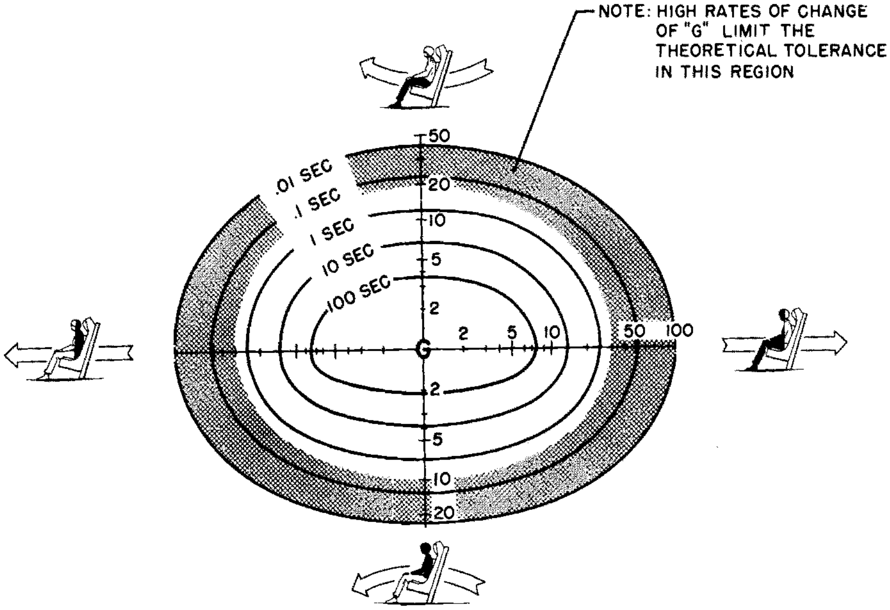

Fig. 3. Schema of acceleration tolerance.

Another area of important acceleration studies includes those conditions in which either the direction or magnitude of acceleration is changing at a rate faster than the reflexes of the human being. It is likely in certain emergency conditions that such changing directions and magnitudes of acceleration might introduce problems under which control and even operation of emergency systems would become virtually impossible. Good work in these areas has been done by the Navy's Aviation Medical Acceleration Laboratory. Even so, additional work is necessary to define man's limitations thoroughly under these conditions.

Once in orbital flight the problem of weightlessness or zero gravity state will be of considerable interest to the designer. While it appears relatively easy to provide a certain level of artificial gravity, much remains to be learned about the detail effects of the weightlessness state on a human being. While Haber[5] and others have done much very clear thinking on the subject of the weightless state, very few data are available based on prolonged experimentation at or near the zero gravity condition. Much conjecture exists concerning the levels of g and/or time of indoctrination necessary to overcome the disorientation effects of the removal of our normal gravitational environment.

Figure 3[9] gives an indication of acceleration-time tolerances without being sufficiently precise to show possible changes caused by the difference in fundamental body systems affected by the stress at different levels. This curve does not indicate reductions in tolerances as a function of the rate of change of application of the acceleration. While a substantial amount of good work has been done giving certain combined values of time at *g* and rate[7,13] of change of *g* limitations, work still remains to be done in indicating the effects of high rate of onset of acceleration at various levels of *g* and time. It seems logical, for example, that low levels of *g* could be applied at fantastically high rates without serious effect and that the rate of onset could be sharply limiting at higher values of *g*. Additional aeromedical data and physical studies are needed to provide usable objective information covering conditions of rapidly changing acceleration.

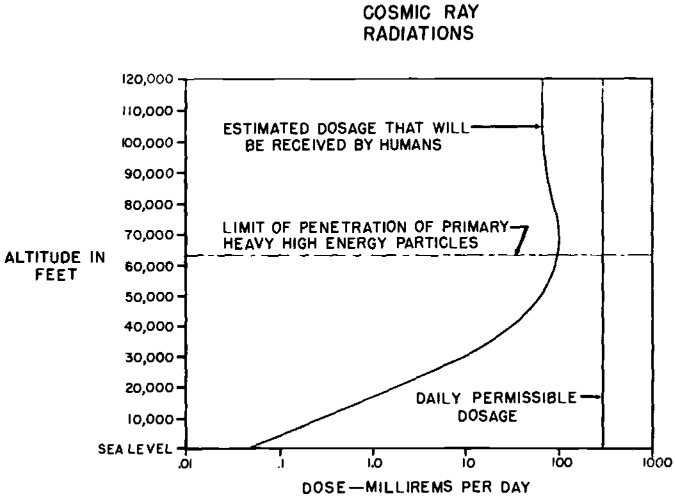

Fig. 4. Cosmic ray radiations at high altitudes.

NOISE AND VIBRATION

At high subsonic speeds it has been observed that there is a very rapid increase in the intensity of the aerodynamic noise with velocity. As the speed of sound is exceeded, much of this externally generated energy is left behind the aircraft, in some cases to the dismay of local populaces subjected to sonic booms, but to the definite relief of the pilot. As the craft moves out of the atmosphere, the importance of aerodynamically generated noise will tend to decrease to negligible values. The problem of extremely high order internally generated noise together with shocks and vibrations transmitted as a result of irregular burning in rocket engines will require much future attention.

RADIATION

Many data concerning intensities and biologic effects of a wide range of solar and cosmic radiations are becoming available. Even though many of our best informed physicists and biologists now tend to be optimistic, no one can state categorically that serious biological radiation damage will not result from extended flight in free space. Solar ultraviolet radiation without the atmosphere's protective influences would in itself be a primary hazard, except for the fortunate fact that it can be easily excluded by relatively thin layers of protective material. Present indications are that solar x-rays also will present a relatively unimportant problem, but the cosmic particles and other heavy ionizing radiations are major worries. No practical approach toward shielding against these particles is yet available. Present test data show that ionization from certain heavy particles is still increasing after penetrating to the center of a lead sphere two ft. in diameter. Insofar as any known techniques are concerned, the possibility of deflecting these particles by high energy magnetic fields appears to be even less practical than extremely heavy mass shielding. As the most likely approach, shielding against only the ultraviolet, soft x-ray and other low penetrating power radiations leaves relatively unimpeded the path of high energy particles, thus keeping the width of the high energy ionizing tracks to a minimum. Figure 4[14,18] shows the values of present and permissible radiation doses and expected intensities versus altitude. Recent data are among the best now available, but do not cover all possible effects of heavy cosmic particles and their secondary reaction.[14,15]

METEOR-COLLISION

With probable meteor velocities in the order of magnitude of 150,000 to 250,000 feet per second, it can be seen that energies, per unit mass, approximately 10,000 times that of ordinary gun fire projectiles, will be probable. This would be an unfortunate situation except for the fact that the vast majority of meteor particles are extremely small. Curves, plotted from rather meager data mostly collected by Whipple,[20] with calculation methods of Grimminger,[4] and not including the effect of meteor showers, indicate that an aircraft presenting 1,000 square feet of area projected normal to the earth might fly for approximately 100 years before having its three-eighth inch simple dural skin penetrated by a meteor. Whipple[20] has suggested that a structure designed for better utilization of material might provide a thin outer buffer skin to cause an explosion of the meteor particles (explosion is likely on hitting a thin member because of the extremely high ratio of kinetic energy to momentum), and thus spread out the resulting smaller particles over a larger area of the primary skin structure. Thus more skin area would be brought into the function of resisting penetration and the resulting weight of this double skin structure could be considerably less than that of a single skin structure.

With this in mind, it can be seen that even though no reasonable method for protection against a direct hit by a large meteor exists, the problem is not one of excessive concern because it is in the same probability category as being struck by lightning. A more real problem is the sand blasting, or erosion effects, of numerous but fantastically small meteorite particles on observation windows or other transparent surfaces. To preserve the transparency of observation ports some type of cover will be a requirement.

ESCAPE

The question of how much emphasis should be placed on getting crew and passengers safely out of damaged or burning aircraft has presented itself since the beginning of flight. There is no reason to expect that this problem will suddenly solve itself. The means of accomplishing emergency escape are possible from the engineering standpoint provided the over-all cost, considering moral, military and economic factors, is properly justified in light of statistical probabilities. An escape capsule of the type shown in Figure 5 appears capable of performing the required functions of environmental and acceleration protection at coming intermediate altitudes.

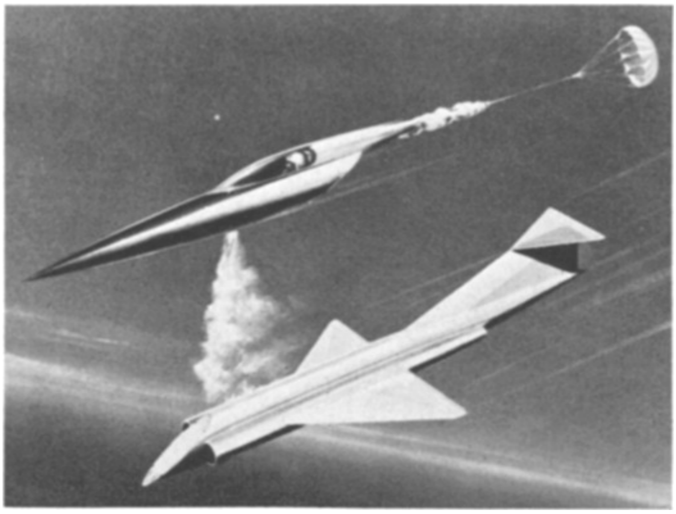

Fig. 5. Artist's conception of proposed escape capsule.

In certain types of space craft it is likely that the final stage of the craft, devoid of its fuel and other fire hazards, might well be designed to serve the combined function of normal flight and escape vehicle.

COMBINED STRESSES

The difficulty of gathering and cataloging physiologic data has made it necessary to concentrate on getting information on the effect of single stresses on subjects rather than trying to evaluate the complex interactions of the more realistic conditions of combined physiologic stresses. Because of the way in which these data have been made available to engineers, it has not been uncommon for the engineer to make the error of assuming that a man should be able to withstand the maximum values of several individual stresses simultaneously. This dangerous assumption can be illustrated by noting that some of these stresses have a direct additive effect on the same body system, and others individually affect more than one body system. One example[6] of this problem is illustrated by combining a condition of 10,000 ft. cockpit altitude with the carbon monoxide concentration of 0.1 per cent (both permissible under current flying regulations). This simple combination can reduce the oxygen saturation of the arterial hemoglobin to a value as low as 77 per cent and thus cause a very substantial reduction in efficiency. When simple combinations of stresses such as this can show substantial effects, it is not surprising that these conditions, with such additional effects as repeated accelerations from pullouts from dives and "morning after," together with the normal psychologic and physiologic stresses of flying, can at times end in fatal accidents. More study of combined stress effects is needed in order to insure progress in reduction of the type of accidents caused by such vague causes as "pilot error" or "target fixation."

ECONOMIC CONSIDERATIONS

In order to engineer aircraft with performance characteristics necessary for continued progress in higher altitude flight, added emphasis must be placed on the control of weight. Because of the necessity of carrying a much larger percentage of the aircraft weight in fuel, at least until the advent of suitably developed "atomic power plants," the percentage of useful weight of the craft will be reduced and the value of removing each excess pound of weight will continue to increase. In many present military aircraft, the useful load is approximately one-tenth of the total weight of the aircraft; consequently, if performance is to be maintained, each pound of added weight must be supported by an additional ten pounds of fuel, engine, structure and equipment. To look at it differently, an increase in the weight of equipment or pay load equal to 10 per cent of the total weight of certain aircraft doubles the weight of the aircraft if performance is held constant. For extremely high altitude flight, the percentage of useful load will be much less than 10 per cent and the cost value of weight will accordingly be greatly magnified.

CONCLUSIONS

The basic medical, physical and engineering data for manned flight in free space, while still inadequate, are rapidly being assembled. Progress to date has been made possible by the combined effort of workers in almost every branch of science. As the day of manned space flight is more closely approached, a drastic increase in the amount of effort will be needed to answer the increasingly detailed questions incident to actual design fabrications and operation of the manned space craft.

REFERENCES

1. Canfield, A. A.; Comrey, A. L., and Wilson, R. G.: A study of reaction time to light and sound as related to increased positive radial acceleration. *J. Av. Med.,* 20:350, 1949.
2. Cornwall, E. W.: Aircraft structure temperatures in high speed high altitude flight. *Douglas El Segundo* Report No. ES-15917, 1951.
3. DuBois, R. G., and Kelley, J., Jr.: A design manual for determining the thermo characteristics of high speed aircraft. AAF Technical Report 5632, 1947.
4. Grimminger, G.: Probability that a meteorite will hit or penetrate a body situated in the vicinity of the earth. *J. Applied Physics,* 19:1947, 1948.
5. Haber, Heinz: *Man in Space.* Indianapolis: Bobbs, Merrill, 1953.
6. Heim, J.: The toxicity of carbon monoxide at high altitudes. *J. Av. Med.,* 10:211, 1939.
7. Henry, J. P.: Studies of the physiology of negative acceleration. *USAF*

Aero Med. Lab. Tech. Report No. 5953, 1950.

8. Kaplan, J.: The Chemosphere. In *Physics and Medicine of the Upper Atmosphere.* Albuquerque: Uni. of New Mexico Press, pp. 99-108, 1952.
9. Lombard, C. F.: Human tolerances to forces produced by acceleration. *Douglas El Segundo* Report No. ES-21072, 1948.
10. Newell, D., Jr.; Kallmann, H. K., and White, W. B.: Physical properties of the speculative standard atmosphere. (In press).
11. Roberts, H. E.: The earth's atmosphere. *Aeronaut. Eng. Rev.,* 8:18, 1949.
12. Stalder, J. R., and Jukoff, D.: Heat transfer to bodies traveling at high speed in the upper atmosphere. *NACA* Technical Report No. 944. Washington: Superintendent of Documents, 1949.
13. Stapp, J. P.: Effects of mechanical force on living tissues. I. Abrupt deceleration and wind blast. *J. Av. Med.,* 26:268, 1955.
14. Schaefer, H. J.: The cross section for thin-downhits from heavy nuclei of the primary cosmic radiation in biological experimentation. *USN Sch. Av. Med.* Res. Report No. NM 001 059.13.07, 1954.
15. Schaefer, H. J.: Theory of protection of man in the region of the primary cosmic radiation. *J. Av. Med.,* 25:338, 1954.
16. Strughold, H.: The human time factor in flight. I. The latent period of optical perception and its significance in high speed flying. *J. Av. Med.,* 20:300, 1949.
17. Strughold, H.: The human time factor in flight. II. Chains of latencies in vision. *J. Av. Med.,* 22:100, 1951.
18. Tobias, C. A.: Radiation hazards in high altitude aviation. *J. Ac. Med.,* 23:345, 1952.
19. Tribus, M., and Boelter, L. M. K.: An investigation of aircraft heaters. II. Properties of gases. *NACA* Advance Restricted Report 601, Wartime W-9, 1942.
20. Whipple, Fred L.: The contents of interplanetary space meteoritic phenomena and meteorites. In *Physics and Medicine of the Upper Atmosphere.* Albuquerque: Univ. of New Mexico Press, pp. 137-170, 1952.

The Safety Belt Comes Down to Earth

The safety belt came into use in airplanes as long ago as 1913, and became universal shortly thereafter. It is probably impossible to find anywhere in the world today an airplane seat without a safety belt, and yet the need for the same in the motorcar is probably greater than in airplane. In the field of military aviation the problem has been met with boldness and originality. When the B-47 has made a landing and is going too fast for safety, a parachute at the tail is released, a simple and effective device for rapid deceleration. In a paper in 1956 Hugh De-Haven stated, "Up to the present, aircraft have been built solely to fly, not to crash. This single approach and design has been costly in the past and is no longer acceptable in military aircraft where a few pounds of extra weight to give crash protection has been an important concession." It is possibly about time that we build the motorcar to crash. We need something to hold us in place when we apply our modern brakes, and for years we have needed something to hold us in place when we "make a forced landing," as it were.—H. E. Campbell: *Surgery,* December, 1954.