Atmospheric Space Equivalence

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IN ALL FIELDS of science, a clear definition or concept is sometimes just as valuable as a successful experiment, for both research and teaching. This is especially true in scientific fields which are apt to invite wild speculation from the outside—such as that of space flight. In this field, the concept of the functional borders between atmosphere and space, which was developed by members of the department of Space Medicine, USAF School of Aviation Medicine, Randolph Field, Texas, in 1950, has proven to be very fruitful and enlightening.

It is based upon consideration of the various functions of the atmosphere as a whole with respect to manned rocket flight.[10] At the altitudes where these various functions cease, we meet the respective functional borders of space. They are not found on a single topographical line at the outer limits of the atmosphere as defined by astrophysics (about 600 miles),[15] but rather at various altitude levels.

The concept of these functional borders also led to the term "aeropause" (K. Buettner).[3,4] This comprises the entire area of the atmosphere within which the functional borders of space are found, starting above 50,000 feet. The value of an approach of this kind lies in the fact that it clarifies the belief that in the upper atmosphere we deal with a radically different environment, compared with the familiar one encountered in the conventional flight zones including the lower part of the stratosphere.[6,19]

In this paper the term "space equivalent" will be used to denote the conditions found in the stratosphere and the upper atmosphere.[20] The applicability of this concept partially overlaps that of the functional borders of space. For the most part, however, it is broader. We can associate the term "space-equivalent" with certain levels within the atmosphere that are identical with the functional borders. Also we can apply it to the entire region above the functional borders of space. Further, it can be applied to conditions which are not confined to any specific level or border—such as the zero-gravity state. And finally, because the term "equivalent" is found in many languages, it is well understood internationally. (French: équivalent à l'espace; German: Weltraum äquivalent; Italian: equivalente allo spazio; Spanish: equivalente á los espacios.)

In this broad range of applicability the concept of space-equivalence is especially apt in showing how far we have actually come toward the conquest of space. In the discussion that

Condensed from a speech given at the Fifth Congress of the International Astronautical Federation at Innsbruck, Austria, August 2-8 1954.

follows, emphasis will be given to those space-equivalent conditions which are physiologically of decisive importance.

Oxygen: As has been explained in several papers,[19,21] the atmospheric function of contributing to respiration ceases when air pressure drops to 87 mm Hg, because of the peculiar chemical composition of the alveolar air.[1] This is further supported by the fact that the time of useful consciousness (of man)[12] and the survival time (of animals),[7,13] after an explosive decompression to or below this air pressure, show a constant minimal value. At the corresponding altitude of 50,000 feet, therefore, we are beyond the range in which atmospheric oxygen contributes to respiration. We have reached the physiological zero-point in tne oxygen pressure of the atmosphere, even though oxygen physically is still found there. The situation is the same as if we were surrounded by no oxygen at all, as in space. Therefore, at 50,000 feet or above, we face a space-equivalent condition physiologically with regard to oxygen.[19]

Liquid State of Body Fluids: It has been shown experimentally that the body fluids of warm-blooded animals start to boil at an air pressure of 47 mm Hg.[1] When this happens, the barometric pressure is equal to the saturated vapor pressure of body fluids at 37°C. At the corresponding altitude of 63,000 feet, then, we are beyond the range of air pressure which is necessary to keep our body fluids in the liquid state. Here we have reached the physiological zero of air pressure even though physically there is still some pressure left. It is the same as if we were surrounded by no pressure at all, as in space. Thus, at 63,000 feet and beyond, we are under space-equivalent conditions physiologically with regard to barometric pressure. For more detail, especially concerning variations, see Reference 1 and Reference 5.

Necessity of a Sealed Cabin: At an altitude of about 80,000 feet we require a kind of cabin which is the prototype for future space ships or artificial satellites. This is the sealed cabin. It becomes necessary for the following reasons:

1. Technical. Due to the low air density, compressing the ambient air with present-day equipment is technically prohibitive.
2. Thermodynamic. Compressing the rarified ambient air to a physiologically useful range would produce a temperature of about 400°F in the cabin, and such temperature would be intolerable for the occupants.[14]
3. Toxicological. Ozone, and possibly other irritating chemicals, would be drawn into the cabin by an ordinary compressor at these levels of the atmosphere.

For all of these reasons, the conventional cabin, pressurized with air from outside, must be replaced by a sealed cabin, pressurized entirely from within. The need for such a cabin is itself a space-equivalent condition. For, above the level where it becomes necessary, the atmosphere is just as useless for pressurization purposes as is the vacuum of space.

The three space-equivalent conditions which we have discussed so far are caused by the loss of properties intrinsic to the atmosphere. Now let us consider some space-equivalent conditions which are the result of extraterrestrial factors originating in space itself: radiation and meteors.

In the lower regions of the atmosphere these extra-terrestrial factors either are not found at all or have changed their original form by interaction with the atmosphere itself. However, at higher altitudes they approach increasingly toward the full force of their solar or cosmic origin and finally create space-equivalent conditions of their own, still within the atmosphere.

Cosmic Rays and Meteors: Most frequently discussed among these extra-terrestrial factors, are the primary cosmic rays (especially their heavy components) and meteors. The upper absorption limit for the heavy primaries of cosmic radiation lies at 120,000 feet.[17] The same limit for meteors is at 400,000 feet.[11,22]

In the vicinity of the earth, however, we are protected from half the total of both kinds of matter by the bulk of the Earth itself. Under these circumstances we may better speak of *semi-space equivalent conditions.* Other variations in their intensity should be noted. Among these is the effect of the earth's magnetic field on cosmic rays below a certain magnetic rigidity. Another is the effect of the Earth's speed on the collision energy of meteors. These effects have been discussed elsewhere.

Ultra Violet Radiation. The space-equivalent altitude for the sunburn producing ultra violet band of solar radiation (3,000 to 2,100 Å) lies above the ozonosphere at 140,000 feet.

Scattering of Visible Light. More important physiologically may be the loss of the atmosphere's power to scatter visible light, resulting in the so-called twilight or darkness of Space. This space-equivalent level is reached at about 400,000 feet.

Propagation of Sound Waves. It may be noted here that, at about this same level, propagation of sound waves becomes impossible. This silence of space is reached when the free pathway of molecules in the air becomes of the order of the wave-length of sound.[2,16]

All the space-equivalent conditions which we have discussed so far, with their variations, have one thing in common. They are found at certain topographically fixed levels of the atmosphere. Their effects would occur even in a vehicle floating freely or at rest—if such a thing were possible—at the respective altitudes where they are found. Hence, these may be called *static space-equivalent conditions.*

The Gravity Free State. One important space-equivalent condition occurs within the atmosphere, however, as a direct result of the vehicle's own movement. This is the phenomenon of weightlessness, or the gravity-free state.[8,10]

It is true that the force of gravity decreases with the inverse square of the distance from the earth's center.

At a height of 4,000 miles above the earth's surface, or twice the earth's radius, it is only ¼ what it is on the ground; at 8,000 miles it is only 1/9, and so on. At a distance of 36,000 miles it is reduced to a mere 1/100. The near gravity-free state at this altitude is indeed a static condition. But it could only be valid for a supported body—one lying, for example, on a tower 36,000 miles above one of the Earth's poles, if such a thing were conceivable. In practice, no one could ever experience this condition.

With a vehicle in flight, however, the situation is quite different.[9,19] Subgravity and zero gravity can then be produced at any height. The effect is produced by the motion of the vehicle itself when the force of inertia, or centrifugal force, counterbalances the gravitational force of the earth. Examples are found in certain parabolic flight maneuvers, in the orbit of an artificial satellite, or in a free fall.

In all these cases, diminished weight is a dynamic phenomenon, not a static one resulting from a topographical location. In an aircraft near the earth's surface it can be produced for a few seconds. In the upper atmosphere it can be produced for several minutes. Above 120 miles where atmospheric drag is insignificant, it can be produced almost indefinitely.[16] This is the nearest feasible orbit of an artificial satellite. In space, zero gravity is the typical gravitational condition of any moving body. Since it is produced by motion, it is a *dynamic space-equivalent condition.*

No object in space is ever at rest. Perpetual motion is the normal state of the physical universe. Nor is there any point in space where the gravitational field of the earth—or of any other matter—ceases to exert some force, however small. Hence, the concept of static gravitational space-equivalence is purely theoretical, and of no significance for us.

But the concept of dynamic gravitational space-equivalence, which opposes one motion and one force against another motion and another force, is of the utmost importance to us. For it demonstrates that, in flight, we may undergo an experience which is typical of space at any altitude, if only for a brief interval.

The concept of space-equivalence shows us where we stand today in the advancement of flight. In the area where we encounter one or several—but not all—factors typical of space, we deal with a *partial space equivalence.* This region begins at 50,000 feet. Above 120 miles all the factors characteristic of space are met. Thus, if we ignore some minor variations, we face here a *total space equivalence* within the earth's atmosphere.

Today's manned rocket-powered craft have already advanced well into the area of partial space-equivalence, passing beyond at least three important space-equivalent levels. Animal-carrying rockets have left nearly all of them behind. Unmanned two-stage rockets have penetrated deep into the region of total space equivalence. It will not be too long before piloted rockets enter that region too. Then the age of true flight in space will be before us.

SUMMARY

Within the astronomically defined extension of the atmosphere (600 mi.), conditions are found that are physiologically and/or technically equivalent to those existing in free interplanetary space. Those that occur at certain topographically fixed levels of the atmosphere are termed *static space equivalent conditions.* The levels where they begin are identical with the "functional borders" of the atmosphere. Some of these space equivalent conditions are caused by the loss of certain vitally important atmospheric factors, which loss results in anoxia, boiling of body fluids, and the impossibility of utilizing the ambient air for pressurization of the cabin.

Other static space equivalent conditions are the result of the appearance, in full force, of certain extraterrestrial factors such as cosmic rays, meteors, etc. These space equivalent conditions in the vicinity of the earth are affected by the solid body of the earth, its speed, and its magnetic field.

The state of zero-gravity as it is encountered in flight is defined as a *dynamic space equivalent condition.* This condition is not associated with any height or distance from the earth. Only its permanency requires a certain level above the earth's surface.

The concept of space equivalence clearly shows us, where we stand today in the advancement of flight. With regard to manned rocket-powered craft, we are in the phase of *partial space equivalence,* where one or several—but not yet all—space equivalent conditions are encountered. Unmanned rockets have penetrated deep into the region of *total space equivalence* which for all practical purposes begins above 120 miles, if we ignore some minor variations caused by the vicinity of the earth.

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