Possible Methods of Producing the Gravity-free State for Medical Research

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MODERN AIRCRAFT may soon fly at velocities of over 2,000 miles per hour in stratospheric altitudes. Such data remind the flight surgeon of medical problems which chiefly center around acceleration during maneuvers, pressurized cabins and explosive decompression.

Yet, these data also form the source of another problem, however less obvious, for the flight surgeon, namely, the occurrence of reduced gravity. Let us consider an aircraft of the above-mentioned type which flies parallel to the ground at a velocity of one kilometer per second, i.e., 3 Mach. Then we see that this craft travels around the center of the earth in a circular course, and, a brief calculation shows that about one sixtieth of the aircraft's weight is counteracted by the centrifugal force arising from this "rotatory" movement of the aircraft. The same holds true for the pilot: his original 150 pounds, for instance, are reduced to 147½ pounds. If the aircraft's velocity would be tripled, the amount of this reduction of weight would become noticeable; it would amount to not less than 15 per cent. Figure 1 shows the relationship between velocity of the aircraft and the prevailing gravity under these circumstances.

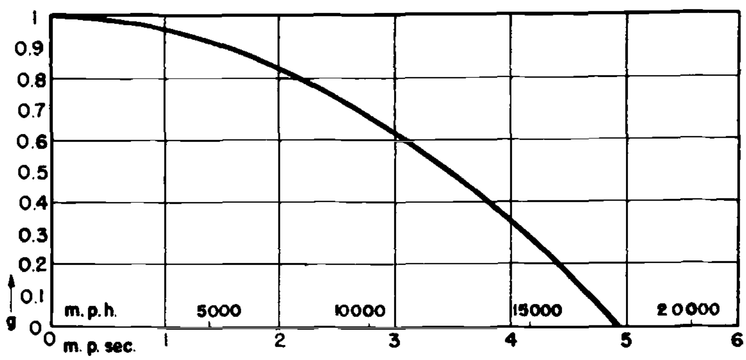

Fig. 1.

It further becomes evident that the occurrence of reduced gravity in modern aircraft is favored also by the extreme altitudes in which these crafts cruise. This effect is not produced by the decrease of terrestrial gravitation with increasing altitude, as one might be led to believe. At an altitude of 100,000 feet, for instance, terrestrial gravity still amounts to more than 99

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per cent of its value at sea level. It is the density of the air at this altitude which is responsible for the effect now under consideration; for, at that height, the density of the air is only one hundredth of the corresponding value at sea level. As a consequence, an aircraft cruising at 100,000 feet will negligibly be disturbed in its free motion as soon as the drive is throttled. This means that the pilot will find himself in an almost ideal state of free fall in all maneuvers involving throttling of the drive. The state of free fall, however, is mechanically characterized by the fact that the resultant of all forces acting on the pilot vanishes. Consequently, the pilot is put into the gravity-free state, or at least into a state of sharply reduced gravity as soon as he dares throttle his engine.

The duration of such states of reduced or eliminated gravity are still short: They are of the order of one-half to one minute. But one must consider this phenomenon as a medical problem, chiefly for two reasons:

1. Gravity as a physical factor of environment has the outstanding property of being omnipresent and everlasting. Not a single individual has as yet been away from its influence for more than one to two seconds.

2. Zero-gravity and sub-gravity will greatly gain importance as environmental factors of man, since the development of rocket craft points toward a rapid increase of velocities and altitudes in the not too distant future.

In view of this development we must not fail to direct our attention to possible effects of sub-gravity and zero-gravity on man. It is the purpose of this paper to present some theoretical considerations as to the procurement of means suitable for studying the medical phenomena associated with the lack of weight.

In medical research, the principle of simulation is almost exclusively applied for studies related to influences of physical environmental factors on the living organism. For this, the low pressure chamber and the human centrifuge are the most outstanding examples in aviation medicine. However, confronted with the necessity of producing states of sub-gravity and zero-gravity we must concede that all tricks of simulation fail. The means required for the elimination of gravity are quite involved, and, it is for this reason that no experiments have as yet been attempted to eliminate or even reduce gravity for the purpose of medical research.

Before entering the discussion on the possibilities of the elimination of gravity we are to concern ourselves with the various aspects of the phenomenon of weight. Within the gravitational field of the earth, a body derives its weight from the mechanical support that prevents it from falling freely. A body is weightless as soon as it is allowed to move freely under the influence of gravitation and of its own inertia. Every fashion of support, including frictional forces from the ambient air and propelling forces from an engine, restores the body's weight either partly or entirely. As a consequence, within the gravitational field of the earth, gravity can be reduced or removed by kinematic means only.

The simplest means to this end consists of the realization of the state of vertical free fall. If a body moves vertically downward at an acceleration of 1 g, an upward acting force of inertia becomes effective which exactly compensates the body's weight. It is true, owing to the velocities soon to be reached by a free falling body, strong frictional forces from the air will arise, so that the body's weight will soon be restored because of the support from these frictional forces. Speaking in terms of kinematics, the acceleration of 1 g cannot be maintained for any appreciable length of time and the velocity of the falling body approaches a certain constant value. With the vanishing acceleration the force of inertia pulling upward expires also, so that the body's weight will be restored.

From these conditions it can be derived that friction from the air makes the exploitation of a free-fall-missile difficult for our purposes. At the least, it would be required to drop the missile from a balloon; for, the initial translatory motion of the missile, if dropped from an aircraft, would give rise to considerable frictional forces from the air resulting in considerable deceleration from the start. There are a score of other problems which stem from the necessity of braking the missile's fall by means of parachutes; the difficulties involved in the recovery of the missile; and the considerable preparations required for a single experiment.

The possibilities of utilizing the vertical motion, for our purpose, however, are not exhausted with the failure of the free-fall-missile. There is a means which permits reduction of a body's support by a constant amount for a certain period of time, namely, the elevator. If the elevator is at rest, the weight of the elevator car is exactly equal to the tension of the rope. If the tension of the rope is decreased by a certain fraction of the suspended weight, the elevator car will be deprived of that same fraction of its support. According to the mechanical principles outlined above, the car and everything it contains will then be transposed into a state of sub-gravity. Speaking in terms of kinematics, the elevator car will move downward at a certain acceleration a, whence $a < g$. As long as these kinematic and dynamic conditions can be maintained, the passengers of the elevator car will find themselves in a state of sub-gravity of the amount g-a. The durations of such states of sub-gravity which can be attained in this manner, depend chiefly upon the maximum permissible velocity of the elevator car. Furthermore, the height of the elevator shaft will be of importance, since longer braking distances and consequently higher velocities are permissible in long-shaft-elevators.

From the laws of kinematics it can be followed that the acceleration only must be kept constant in experiments of this kind, i.e., one is free to begin the motion of the elevator with any initial velocity desired. Consequently one is able to double the duration of the various states of sub-gravity by starting the experiment with the largest velocity the elevator car can attain in an upward motion. A state of sub-gravity characterized by the value g-a is produced by superimposing a downward acceleration "a" on the motion of the elevator car. This is done by decreasing the tension of the rope by a proper amount, and the passengers of the elevator remain in this state of sub-gravity as long as these conditions of the rope's tension can be maintained. Under these conditions the motion of the elevator car is such that the upward velocity will gradually be consumed by the superimposed downward acceleration; after having reached the peak, the car starts to drop and reverses the pattern of motion in its downward course.

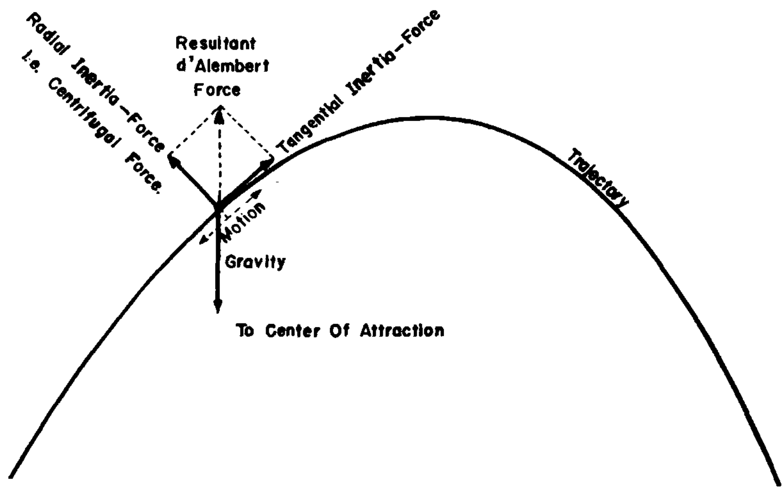

Fig. 2.

By applying this method states of sub-gravity between 0.9 g and 0.7 g can be produced for five to twenty-five seconds using long-shaft-elevators of skyscrapers. The durations obtainable with this means are short; yet, the elevator method appears to be worth while for a selected number of medical problems under sub-gravity conditions. This is especially true in view of the ease of access to elevators, the ease of operation and the number of experiments that can be carried out within a short time.

In directing our attention to the entire elimination of gravity we can state the following requirements a means to this end must fulfill:

1. The means must be equipped with a controllable force in order to make it capable of overcoming and eliminating the support originating in friction from the air.

2. The means must be able to cope with high velocities which it must attain and subsequently break down.

The modern aircraft is such a means.

The aircraft, in contrast to the elevator, is not limited to a single dimension, namely the vertical, in its motion. Consequently, the initial component of velocity which can be superimposed to the component of acceleration, may assume any value regarding size and direction. A close examination of all factors involved shows that it is most profitable to select an initial velocity as large as possible at a large angle of climb. In order to eliminate gravity during such a flight, care must be taken that a constant downward acceleration of 1 g prevails during the entire flight. Similar to the case of the elevator, the upward vertical component of the aircraft's velocity will gradually be consumed by the downward acceleration; the vertical component of velocity vanishes at the peak of the trajectory and subsequently reverses its pattern. The horizontal component of velocity remains constant during the entire zero-gravity flight; it equals the aircraft's velocity at the start multiplied by the cosine of the angle of climb at that point.

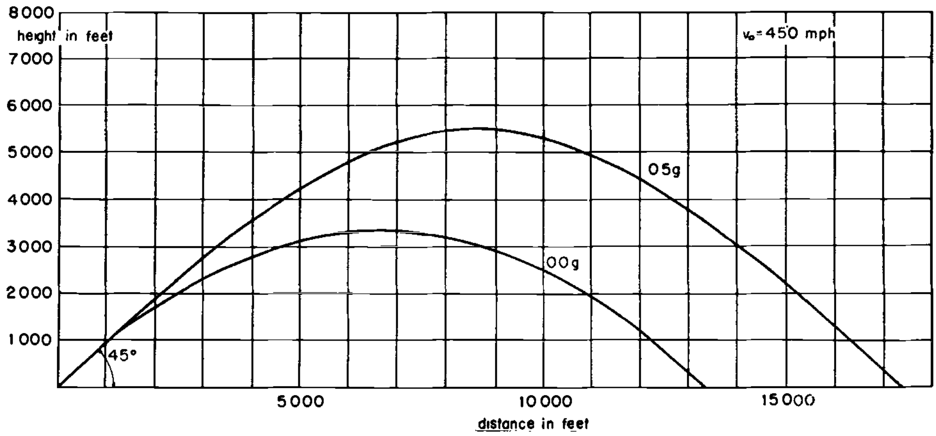

Fig. 3.

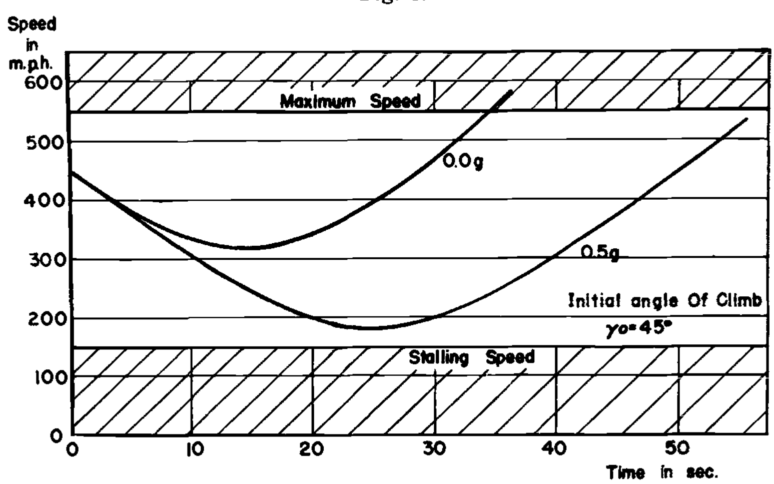

Fig. 4.

The aforementioned characteristics of the trajectory reveal that it is a parabola with vertical axis. In other words, the aircraft simulates the motion of a body hurled obliquely upward, if there would be no friction from the air. These are exactly the requirements for producing the gravity-free state. The body would move under the influence of terrestrial gravitation

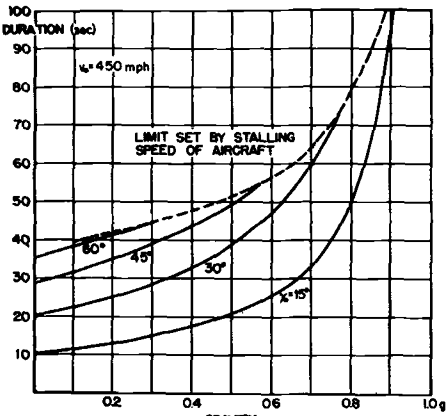

Fig. 5.

and of its own inertia only, undisturbed from any other outer force, it is then that it is weightless. In the case of the aircraft, the supporting force of friction from the air is eliminated by the power of the engines. Figure 2 demonstrates a scheme how the weight of a body moving along a vertical parabola is eliminated by the resultant of the forces of inertia.

Theoretically, the velocity of the aircraft has no part in the formation of sub-gravity and zero-gravity states; in our practical case, however, it plays a dominant role. Both the maximum permissible speed and the minimum stalling speed of the aircraft impose certain limitations on the duration of these states. The trajectories must be such that the velocities at the beginning and the end of the trajectory are not too large, and that the velocity at the peak of the trajectory is not too small.

The aircraft-method also affords the possibility of producing certain values of sub-gravity. As with the elevator, the motion of the aircraft must be characterized by a certain downward acceleration a, so that the passengers of the aircraft are exposed to an acceleration g-a. With this method, states of sub-gravity can be maintained for correspondingly longer periods of time.

The following figures demonstrate a number of numerical details as to zero-gravity and sub-gravity flights. Figure 3 shows the trajectories resulting from values of 0.0 g and 0.5 g, with a maximum velocity of 450 m.p.h., and an initial angle of climb of 45°. Figure 4 shows the corresponding velocities as a function of time exhibiting the limitations of the method caused by the maximum and minimum velocities. Figure 5 shows the duration obtainable as a function of the amount of sub-gravity desired for various initial angles of climb.

The last figure demonstrates that gravity can be removed, exploiting present means, for about ten to thirty-five seconds. The durations obtainable for states of sub-gravity are correspondingly longer. Admittedly, as in the elevator, the periods are still short, but we may consider these periods long enough for investigations concerning selected medical problems, since any other method, such as a parachute jump from a balloon, does not remove gravity for more than one or one and one-half seconds. In contrast to this, the zero-g-aircraft affords durations of the gravity free state more than twenty times as long.