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Multi-directional G Protection in Space Flight and during Escape

A Theoretical Approach

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IN THE LAST DECADE the radial G tolerance of high performance aircraft was not appreciably higher than the average operator could withstand if he was protected by anti-G garments. For this reason protection achieved through transverse positioning of the pilot lost some of its urgency. Now, however, we are confronted with vehicle designs which will be capable of producing appreciable G loads for extended durations. This applies especially to the re-entry phase of orbital and space projects as well as to changes of direction of the flight path of supersonic atmospheric crafts at multiple Mach number velocities. Because protection by anti-G suits certainly cannot be increased appreciably, a solution must be found by adequate transverse positioning of the operator.

In the device described herein multi-directional G-protection by automatic positioning is possible so that the resultant of all acting accelerations, during flight as well as during escape, would be presented at right angles to the heart-head line of the operator.

REVIEW OF LITERATURE

Buehrlen[2,3] in 1937 reported centrifuge runs with humans in supine position with peaks up to 17 G. Later Wiesehoefer[22] recognized that the continuous prone or supine position achieves protection only against radial G loads, but leaves the pilot unprotected against the linear loads in direction of the flight path, which are especially high in catapult take-off and in arrested landings. He installed a backward tilting seat in the second cockpit of a dive bomber version of a Heinkel He-50 fighter aircraft. This seat allowed the operator the control of the craft in conventional position and tilted him backwards to a supine position when the acceleration reached values of 3 G. In sixteen flights, five differ-

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ent subjects resisted 7 G during 15 seconds without having reached their limits of tolerance. As usual in acceleration test flights, the control pilot with and without combination of anti-G garments and straining.[1,5,9,12,20] It was demonstrated that only a backward tilt beyond 77° exceeded the pro-

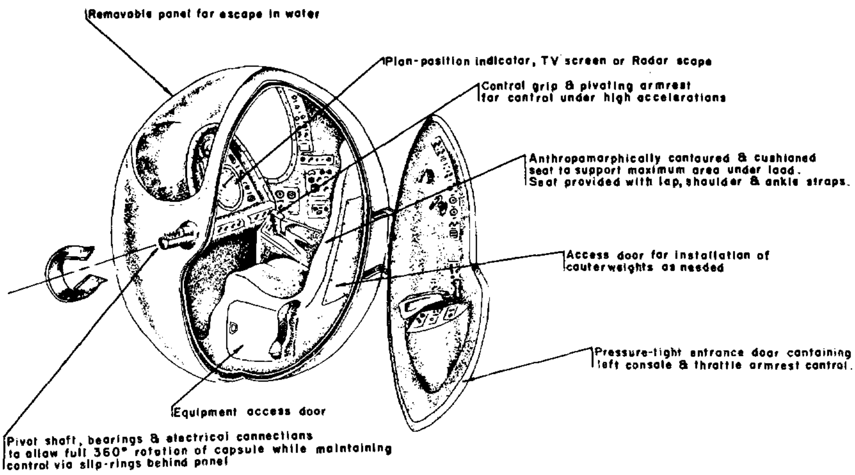

Fig. 1. Schema of anti-G ejection capsule showing details of operator's seat.

flew in the "crouch" position. Although the backward tilting took place after the acceleratory stress had begun, no vertigo or other labyrinthine troubles were observed.

Since that time intensive investigations of the tolerance to transverse G have been performed. Stauffer[17,18] exposed humans for 5 to 8 seconds to 12 G and Duane, Beckman, Ziegler and Hunter[6] exposed themselves for 5 seconds to 15 G, which these authors considered as a "voluntary endpoint." Strughold and Ruff,[20,21] and Clark and his associates[4] considered human tolerance to be 12 G during 60 seconds.

Because the transverse position of the pilot in the plane presents operational and engineering difficulties, extensive efforts were made to study the protective effect of partial supination tection afforded by anti-G garments and that maximum protection was reached only at 85°.

Gell[8] accomplished remarkable flight experiments with a supinating seat in the second cockpit of an F7F-2N *Tigercat* fighter aircraft. The pilot withstood high radial G loads during pull outs from steep dives and during spirals for 30 seconds, using an autopilot "P1-K" when supinated. Gell also corraborated the experiment of Wiesehoefer by demonstrating that backward tilting within a G field does *not* cause vestibular troubles.

Following the principle of the supinating seat, this report describes a conceptual device, which could grant a "multi-directional" G protection by automatic supine positioning. This device is termed the "anti-G ejection capsule."

DESCRIPTION OF ANTI-G EJECTION CAPSULE

In the anti-G ejection capsule the operator's seat is integrated for escape purposes in an oblatespheroid, pressurized cell (Fig. 1), which is pivoted in the lateral axis of the craft allowing free rotation through 360°. The center of gravity, determined by the eccentric location of pilot and part of the equipment, is located such that within the plane of symmetry the line from the axis of rotation to the center of gravity is perpendicular to the line between heart and head of the operator. If the direction of the resultant of acting accelerations changes, the capsule assumes the new adequate position either directly by the acceleratory stress itself, or indirectly through remote sensing and external power. Thus G loads act again transversely and press the operator in his anthropomorphologically-designed and energy-absorbing seat, and seat-back. Adequate damping of the axis avoids oscillatory movements.

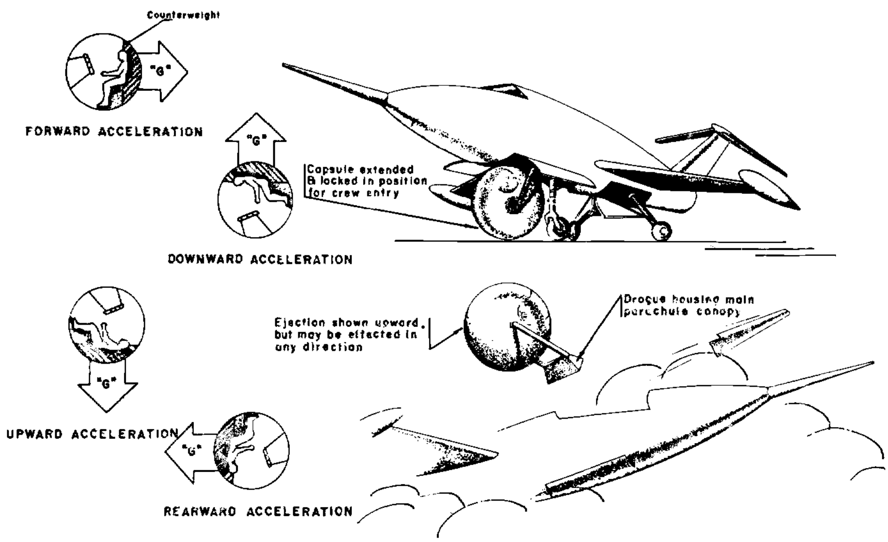

Fig. 2. Schema of anti-G ejection capsule showing acceleration forces during escape.

Operational controls, such as, control stick, rudder pedals, throttle and emergency controls, are constructed to be handled in supine position under action of high G loads—the control stick is integral with the armrest and its axis of neutral position coincides with the resultant of G forces. Displays are integrated in the cabin and turn with the operator. They are connected via slip rings with the pivot shaft of the capsule. Provisions are made for direct vision, or, indirectly through displays, for control from any position of the capsule.

It is foreseen that the pilot can lock the capsule in the conventional position, which allows him direct vision during that part of the flight path when high radial accelerations are not expected. This could be, for instance, during take-off, landing, and eventually as an emergency procedure if malfunctioning of indirect vision displays occurs. During and after ejection the capsule functions similarly, as in flight, because the ejection mechanism acts upon the pivot axis. The pivot shaft is fixed on both ends to a fork-shaped device which in turn is attached to a drogue housing the main chute canopy (Fig. 2). This prevents post-ejection tumbling and places the pilot transverse to the decelerative stress. The main chute system and energy absorbing and buoyant qualities of the capsule allow landing on either earth or water (Fig. 3).

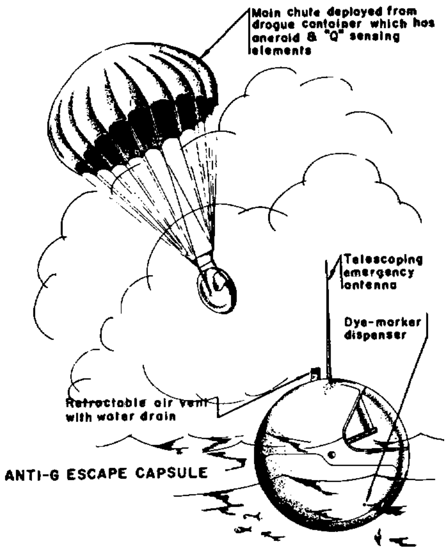

Fig. 3. This drawing shows the anti-G capsule in descent by parachute, and after a landing in the water.

FUNCTION OF THE CAPSULE IN FLIGHT AND DURING ESCAPE

In Flight.—The capsule will be locked in the conventional position for entry of the operator and take-off. As soon as the capsule is unlocked the pilot's position will be always perpendicular to the resultant G-load—in supine position (Fig. 4). Lateral accelerations would not cause rotation of the capsule but, because they already act in a transverse direction (right-left or left-right), protection would be necessary only against traumatic injuries caused by collision with the inner structure or side walls of the capsule. These lateral movements of the operator can be avoided by the anthropomorphic configuration of the seat and an adequate restraint. In zero gravity conditions, the capsule remains in any position at rest. The restraint prevents separation of the pilot from his seat, and he remains protected if a G field is again produced.

During Escape.—Theoretically the capsule can be ejected in any direction, but upward ejection seems the most desirable for facilitating escape at low altitudes and "off the deck." If experimentation shows that positioning by the ejection stress itself produces too high angular accelerations, the operator could be positioned immediately before ejection by external power (cartridge). Entering the airstream, the operator would be positioned by the deceleratory stress itself. Another possibility would be to eject with the capsule locked in its telescopically extensible fork. In this case the aerodynamically designed drogue housing would act primarily as stabilizer without adding appreciably to the drag of the capsule, as in the former case. Both solutions would position the pilot transversely to the deceleratory stress. In the same position he would confront the opening shock of the main parachute system and would descend in a horizontal position. The energy-absorbing qualities of the seat and lower structure of the capsule would allow the pilot to tolerate the landing impact (Fig. 4). After landing the pilot would exit by the entrance door or by the removable panel. In a water landing he has at his disposal a survival kit, dyemarker dispenser, telescoping emergency antenna, and retractable air vent with water drain, and when rescued can exit through the removable panel.

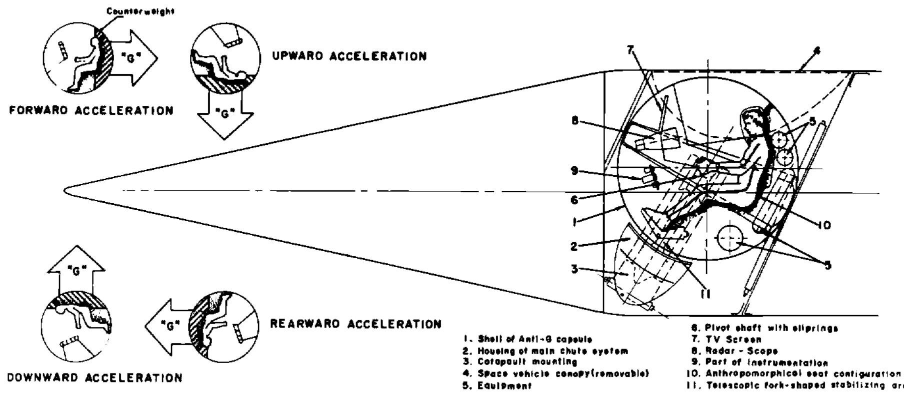

Fig. 4. Schematic details of installation of anti-G ejection capsule in a space vehicle.

DISCUSSION

Ballinger[1] as well as Preston-Thomas and his associates[14] reported valuable data concerning the tolerance to accelerations to be expected in multi-stage manned rocket crafts. Assuming exhaust velocities between 2.5 and 4 km./sec. they used the human centrifuge to demonstrate that men in the supine position and undergoing a typical series of G loads with peaks of 8, 5.8 and 5.8 G in the same run, could perform a dual pursuit task satisfactorily. This would indicate that selected crewmen could assist in the control of such a vehicle, especially if they were helped by adequate computer devices.

Rocket craft, during typical escape trajectories, would produce only insignificant radial loads except in the re-entry phase, but rocket interceptors could produce high radial loads in their curved trajectories. At a velocity of 3000 m/sec. (10,800 km./h) a very small deviation from the linear flightpath, corresponding to a circle of 200 km. diameter, would in conventional position produce the intolerable longitudinal load of 9.17 G. If it is assumed that the thrust of the vehicle simultaneously produces 5 linear G, the resultant G load reaches 10.3 G. Both accelerations are intolerable in longitudinal direction at longer duration and only "multi-directional" G protection by continuous positioning transverse to the resultant force could make survival feasible.

The physiologic end points and

symptoms produced by transverse G have been studied in detail and defined by numerous investigators.[2,6,12,19] It was reported that stiffness and weariness was noted by all subjects, but no appreciable recovery time was required and no black-out or impending unconsciousness occurred. Vertigo, however, which persisted for 24 to 48 hours, was a common finding and could be interpreted as probably caused by edema within the vestibular apparatus. No permanent damage was reported.[6]

A special problem concerning the function of the capsule should be mentioned: the backward-forward rotation within a G field. Both Gell[8] and Wiesehoefer[22] found that backward tilting during the acceleratory stress did *not* cause discomfort or diminution of the operator's capability to control the craft. In the anti-G capsule much larger excursions will take place. In transition from positive to negative acceleration the rotatory movement would be through 180°. Therefore, the incidence of labyrinthine and other symptoms should be studied with suitable devices. The valuable results of Weiss and his co-workers,[21] obtained from experiments with spin tables, are only of partial application for the described device, for this type of movement would be experienced only to a small extent in the capsule.

The human centrifuge could serve for studying prolonged G conditions during the flight when the capsule is pivoted with its axis perpendicular to the centrifuge arm. However, angular and coriolis accelerations have to be considered. For reproducing the escape conditions of the capsule, a rocket sled, and a Northrop "bopper" device will be used. The capsule model will be mounted with the pivot shaft in vertical position. The test animal could be positioned before the run with his head-heart line in direction of movement, would swing 90° backwards during the acceleration phase, and finally 180° forwards during the deceleration phase.

In escape from aircraft at supersonic speeds, it is noted that with increasing speed the linear ejection force must be increased in order that the pilot might clear the tail structure. In conventional ejection systems, this linear stress acts from head to foot, and jeopardizes the structural integrity of the vertebral column. This induced Lombard[11] to consider ejection from a jack-knifed position and Mohrlock[13] to experiment with a torso harness-vest. This device consists of a vest which is attached to the upper part of the seat-back and diminishes appreciably the G load to the lumbar vertebrae. This torso harness is postulated to increase the tolerance by 50 per cent.

A more radical solution utilizes the bobsled seat, developed by Convair and the Stanley[7] ejection capsule. Both bring the pilot in a nearly supine position prior to ejection, so that he receives the ejection load transversely.

It is necessary, however, to consider that this problem is twofold because supine ejection will not protect the pilot against the linear G encountered during deceleration of the capsule, which will now act in longitudinal direction. In spite of the advantage of a smaller frontal area and additional forward thrust, this stress could become intolerable at extreme speeds and high altitudes, especially as the latter prolongs the decelerative phase of escape.[10]

CONCLUSIONS

The author is aware of the numerous technical difficulties involved in the realization of the device described, such as the weight ratio, the transmission of all connections via slip rings, the adequate damping to avoid oscillatory movements, and the maintenance of the environment of the sealed capsule. It appears, however, that the principle of the anti-G capsule could be tested before these problems are completely solved, for instance, as a capsule carrying an animal in orbital and space flights. In this case, the complicated slip ring-transmission problem would be lessened because only a reduced number of connections would be necessary for registering the physiologic reactions of the animal.

In the first attempts at orbital flights a multi-directional G-protection seems important because of the possibility that imperfections of the automatic guidance system could produce much higher G loads than foreseen, especially in the re-entry phase. Survival of the test animals then, would depend to a high degree on adequate positioning devices, which at the same time protect the animal after ejection and bring it back to the ground alive.

Another modification of the capsule could also be installed in nose cones of rockets that are spin-stablized. Although animal compartments could be stabilized by gimbaling devices it would be a simpler solution to place the animals in an anti-G capsule, located at some distance from the axis of the cone. In this case the animal could tolerate, in continuous supine position, the resultant of the centrifugal load produced by the spinning of the cone and the linear acceleration of the trajectory.

SUMMARY

It is known that maximum human tolerance to G-loads is obtained if the accelerations are acting at right angles to the long axis of the body. This report describes a device, termed the "anti-G capsule," which is pivoted about the lateral axis of the craft and automatically assumes a position, such that the resultant of all acting accelerations is perpendicular to the heart-head line of the subject. The ejection and stabilization mechanism of this capsule would also afford an analogous G protection during and after escape from a disabled aircraft or space vehicle within the lower layers of the atmosphere.

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Out of This World

The aim of space medicine is essentially to aid engineers in creating approximately the same environmental conditions for man in space that prevail near the earth's surface. In addition, protection of his normal physiologic processes and normal psyche in the "aloneness" of a strange environment will be necessary. Since man will probably not be able to improvise "out there," all vital precautions will have to be taken before he goes "out of this world." We as yet do not have the answer to the question—what on earth can we do about it?—HOMO SPACEIENS: *Physician's Bulletin*, April, 1958.