Preston-Thomas H, Edelberg R, Henry JP, Miller J, Salzman EW, Zuidema GD. ***Human tolerance to multi-stage rocket acceleration curves.*** **J Aviat Med 1955; 26:390–8.**

The acceleration associated with launch was a critical concern in the early medical planning for human spaceflight. This Classic paper was the first report of data from human subjects exposed to a realistic launch profile.

The paper began with a mathematical analysis of the forces needed to accelerate a human to orbital velocity and pointed out that a multi-stage rocket would produce a series of acceleration peaks rather than a uniform level as had been assumed earlier. The authors then used a human centrifuge that was capable of producing high peak accelerations and rapid rates of change to simulate the launch profile for a three-stage rocket with peaks of 8, 5.8, and 5.8 G over a 6-min period. Subjects were placed in a semi-reclined position with legs elevated (similar to current launch configurations) and their performance was measured using a dual-pursuit task. Although mean performance values for the nine subjects deteriorated during peak G, problems were greatest for inexperienced subjects who were reporting simultaneous oculogyral effects from the changing motion of the centrifuge, while two of the more experienced subjects showed no performance deviation at all. The authors concluded that manual control of a three-stage rocket was possible, but that preflight centrifuge training would be valuable.

Background

Earlier centrifuge profiles for launch were based on a constant G level imposed for the time needed to achieve orbital velocity (i.e., lower G required longer duration). In 1952, Ballinger studied profiles ranging from 3 G for 9.5 min to to 10.0 G for 2 min. He found that a semi-reclined position (20° from horizontal) allowed short-duration tolerances up to 10 G, but none of his nine subjects could complete profiles above 8 G for 2.5 min (1).

Dr. James Henry and colleagues were involved in the sub-orbital Aerobee primate flights in 1951-52, previously discussed as a Classic paper (2). In Aerobee III (45 s at 3–4 G) they found no difference in response between an animal oriented in +Gz and one in +Gx, and that launch acceleration forces were well tolerated physiologically. Several other sub-orbital animal flights were performed between 1958 and 1960 following publication of this classic, notably the 1958 sub-orbital flight of Able (rhesus monkey) and Baker (squirrel monkey) demonstrating physiological tolerance to launch forces, but no performance studies were performed until the 1961 sub-orbital Mercury-Redstone flight of the chimpanzee Ham, who performed normally at operant-conditioned tasks except for missing one required lever-pull when he experienced 18 G during premature firing of his escape tower (3).

Other trained chimpanzees were then tested on simulated Mercury-Atlas launch and reentry acceleration profiles. The animals showed the greatest impairment of performance during the peak G of the launch profile (58% of lever pulls missed) and only mild impairment (20% of pulls missed) during reentry. Most importantly, performance following launch and reentry was back to normal after 4 min. Acceleration combined with noise and vibration and repeated exposure to acceleration produced similar results, leading to the conclusion that there might be impaired performance during launch and reentry, but it would be followed by rapid recovery (4). In fact, operational experience with Project Mercury showed no performance degradation among the astronauts during launch and validated the use of preflight centrifuge training (6).

Comment by James T. Webb, Ph.D, Research Physiologist, Brooks AFB, TX

Although the Space Shuttle has a relatively benign launch profile (peak 3.0 +Gx), the data in this Classic identified several factors of importance in the early years of orbital flight that may also prove relevant to future, post-Shuttle launches. Seat-back angle determines the effective head-to-heart distance and thereby influences G tolerance, and these trials showed the advantage of using an angle 15° from horizontal. They also showed that control panel tasks can be continued when only minor hand movements are required

Shuttle launches use a fully horizontal seatback angle (pure Gx) with legs elevated and a slight head-down orientation during transition to orbit, so that launch produces cephalad fluid shifts rather than lower-body venous pooling. This cephalad shift was demonstrated using impedence plethysmography during simulated Shuttle launch profiles on the centrifuge at Brooks AFB in the 1980s (5).

The vertical nystagmus that interfered with performance in this study is an unavoidable consequence when centrifuge velocity changes, and it remains a major problem for centrifuge training and research. Although statistical analysis with only nine subjects is problematic, this Classic provided valuable information on performance during what amounted to a multi-tasking effort. In their conclusions, the authors appropriately emphasized the ability of crewmembers to provide input to simulated vehicle control despite changing acceleration levels.

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