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G-TOLERANCE STANDARDS FOR AIRCREW TRAINING AND SELECTION

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G tolerance varies widely among individuals. It stands to reason that aircrew with higher G tolerance are less likely to experience symptoms of G stress in flight than are those with lower G tolerance, and that they can fly highly maneuverable aircraft with greater safety and effectiveness. To assure that aircrew with abnormally low G tolerance are not assigned to aircraft that operate in the high-G environment, a G-tolerance standard and the means to implement that standard are necessary. Since 1977 the USAF School of Aerospace Medicine has used in human centrifuge operations an informal G-tolerance standard for selecting experimental subjects, evaluating medically disqualified aircrew, and ensuring efficacy of high-G training for aircrew. That standard consists of the subject's being able to sustain for 15 s a rapidly applied $+7\text{-}G_z$ load, without totally losing peripheral vision or losing consciousness, while wearing a functioning anti-G suit, performing an anti-G straining maneuver, and sitting in a conventionally configured fighter aircraft seat. Inability to tolerate a 7-G, 15-s, rapid-onset G profile in a centrifuge is also the basis of

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internationally recognized (NATO, ASCC) definitions of low G tolerance. The rationale for choosing the 7-G, 15-s standard is discussed. Experience with use of this standard and the equivalent standard of 8 G for 15 s when the F-16-configured seat is used reveals that fewer than 1% of actively flying fighter aircrew are unable to meet the standard. Eventually a formal, more stringent, G-tolerance standard may become a valuable component of the means of selecting and training aircrew for high-performance fighter aircraft.

G-TOLERANCE STANDARDS FOR AIRCREW TRAINING AND SELECTION

BACKGROUND

As is the case with other human physical characteristics, G tolerance varies among individuals. It has an approximately normal distribution and ranges from +2.2 G_z to +7.1 G_z for unprotected young males on rapid-onset G profiles to greyout (1, 2). G tolerance also varies within individuals (i.e., from day to day) (3), but not nearly to the same extent as among individuals. It is obvious that one way to reduce the probability of symptoms of G intolerance in flight--specifically, greyout, blackout, and G-induced loss of consciousness (GLC)--is to avoid exposing to the high-G environment those individuals with low G tolerance. This idea is not new: the Japanese used a centrifuge during World War II to select fighter pilot candidates (4), and the Republic of Korea Air Forc- has used a centrifuge for pilot selection since the late 1970s. Some Warsaw Pact air forces are also believed to use G tolerance as one of their fighter pilot selection criteria. Until very recently, however, the U.S. Air Force has regarded as anathema the concept of pilot selection on the basis of G-tolerance testing.

Since about 1977, medical personnel involved in G-tolerance testing and high-G training at the USAF School of Aerospace Medicine (USAFSAM) have adopted an informal "G-tolerance standard" of +7.0 G_z, applied at a rate of 1 G/s or greater and sustained for 15 s, for subjects seated in an upright seat (13° seatback angle), wearing a functioning anti-G suit, and performing an anti-G straining maneuver. Experimental subjects, aeromedical patients, and aircrew trainees unable to sustain 7 G for 15 s under those conditions without losing 100% of peripheral vision or without losing consciousness are considered to have low G tolerance. The rationale for this G-tolerance criterion was based on analyses of G-tolerance distribution data available in the USAFSAM Acceleration Stress Data Repository in 1977 and upon reports of subsequent GLC in flight occurring in patients not tested to the 7-G, 15-s tolerance level (5). In 1977 G tolerances below about one standard deviation below the mean (i.e., the bottom 15%) on standard medical-evaluation G profiles were arbitrarily classified as "low." In addition, experience showed that 10 to 20% of non-aircrew and currently non-flying aircrew could not complete the 7-G, 15-s profile. Failure to tolerate this profile was thus also considered indicative of low G tolerance, even though 7 G for 15 s was not at that time one of the standard medical evaluation profiles. The most recent analysis of non-flyers' performance on the 7-G, 15-s profile shows that 80% of 213 men and 88% of 24 women successfully completed the profile (6). Furthermore, of 11 patients referred to USAFSAM between 1973 and 1977 for evaluation of unexplained loss of consciousness in flight (most likely GLC), the first seven were tested to 6 G, and the last four were tested to 7 G. Of the seven who were tested with a 6-G, 15-s exposure, four passed and three failed. Two of those who passed subsequently experienced GLC in flight, forcing the conclusion that a 6-G tolerance standard was insufficiently stringent, and resulting in use of the 7-G standard thereafter (5). Thus far no reports have been received of anyone passing the 7-G, 15-s standard on the centrifuge and subsequently experiencing GLC in flight.

As a result of experience with G-tolerance testing at USAFSAM and elsewhere in the 1970s, two documents published by international organizations have defined low G tolerance in relation to a 7-G standard. NATO Standardization Agreement (STANAG) 3827 AMD, Minimum Requirements for Selection, Training and Employment of Aircrew in High Sustained G Environments, states that aircrew who do not successfully complete a rapid-onset, $+7\text{-}G_z$, 15-s centrifuge profile with anti-G suit and straining maneuver will be considered to have low G tolerance (7). Similarly, the Air Standardization Coordinating Committee (ASCC) has issued Advisory Publication (ADV PUB) 61/26A, Standardized Centrifuge G-Stress Profiles for Medical Evaluation of Aircrew Members, in which it is stated that aircrew unable to pass a 7-G, 15-s rapid-onset run while wearing an anti-G suit and performing an anti-G straining maneuver should be considered to have low G tolerance (8). The NATO STANAG has been ratified by the majority (eight) of the participating nations, but not by the United States. The basis of the U.S. objection to the STANAG was that U.S. aircrew candidates presently are not subjected to G-tolerance testing and that the proposed standard therefore cannot be implemented. ASCC ADV PUB 61/26A, on the other hand, has been approved by all five participating countries; and while the ADV PUB is not a standard per se, its issuance confers multinational official recognition on its contents.

RECENT EXPERIENCE

Experience at USAFSAM with actively flying aircrew reveals that a 7-G, 15-s G-tolerance standard would be an extremely lenient standard for this population. In the spring of 1983, 73 Tactical Air Command (TAC) pilots, mostly F-15 and F-16 pilots, were given high-G centrifuge training at USAFSAM. Eleven were trained in the conventionally configured seat (13° seatback angle), and 62 were trained in the F-16-configured seat (30° seatback angle with elevated rudder pedals). As G tolerance was thought to be about 1 G higher in the F-16-configured seat, G training of the pilots riding in that seat was conducted at 1-G higher levels than those employed in the training when the conventional seat was used. All 11 pilots trained in the conventional seat completed the 7-G, 15-s G profile, and all 62 trained in the F-16-configured seat completed the corresponding 8-G, 15-s profile. Furthermore, 90% of those pilots went on to complete a G training profile 1 G higher than, and twice as long as, the "G-tolerance standard" profile (9). Since the 1983-84 modification of the USAFSAM centrifuge to provide high G-onset rates and subject-in-the-loop control, another 741 TAC aircrew have received high-G centrifuge training at USAFSAM, all in the F-16-configured seat. Only two of the 741 did not complete the 8-G, 15-s G profile during the scheduled training session, and only 44 did not complete an additional 9-G, 15-s profile (99.7 and 94.1% success rates, respectively). One of the two initially unsuccessful trainees was an F-15 pilot who repeated the training on the following day and met the informal 8-G, 15-s G-tolerance standard, and the other was a non-pilot crewmember whose inability to meet the standard caused relatively little concern.

Reports from U.S. Air Forces in Europe (USAFE) regarding performance of their aircrew during high-G training on the Dutch centrifuge at Sjoesterberg indicate that only three out of 330 USAFE pilots trained to date have been unsuccessful in completing the 7-G, 15-s G profile in the upright seat, or the 8-G, 15-s profile in the F-16-configured seat, on the day of the scheduled training session. One of these unsuccessful pilots was retrained and completed the 8-G, 15-s profile on the following day. Another was allowed several weeks to recover from the flu-like illness that compromised his performance on the training day, and then successfully completed the 7-G, 15-s profile. The third pilot was advised to undertake appropriate physical conditioning and was able to complete the 7-G, 15-s profile during retraining four weeks later.

CONCLUSIONS AND RECOMMENDATIONS

We must conclude from our current experience with G-tolerance testing and high-G training within the U.S. Air Force that a G-tolerance standard of $+7\ G_z$ for 15 s would certainly not be overly stringent, at least not for trained fighter pilots who are actively flying. Whether use of the Holloman AFB centrifuge for high-G training of Lead-In Fighter Training (LIFT) students will yield a similar experience is unknown at this time. I estimate that 3 to 5% of the LIFT students--no less than 0.5-1% (based on experience with fully trained, actively flying fighter aircrew) and no more than 10-20% (based on experience with non-aircrew and currently non-flying aircrew)--will be unable to complete the $+7$-G_z, 15-s centrifuge profile on their first day of exposure.

What, then, should be the disposition of those LIFT students who cannot complete the $+7$-G_z, 15-s profile? First, the student should be retested on another day--ideally the following day, to take advantage of both the recency of instruction on the straining maneuver and the acute adaptation to motion-sickness-producing stimuli resulting from the centrifuge exposure. If the student is unable to complete the 7-G profile during retesting, he should be evaluated medically. An essential part of the evaluation would be a relatively thorough cardiovascular examination, including echocardiogram, exercise stress testing, and certainly centrifuge stress testing with electrocardiographic monitoring. Although most of the students subjected to the medical examination as a result of their demonstrated low G tolerance will be found not to have any medically disqualifying condition, some will not be so fortunate. At this point recommendations for the further disposition of those students failing the medical evaluation will be the responsibility of the aeromedical authorities who recommend waivers for continued flying duty. Given that all LIFT students have already completed Undergraduate Pilot Training (UPT), I would expect a large fraction of the medically disqualified students to be granted categorical waivers, i.e., medical clearance to fly tanker, transport, and bomber aircraft but not fighter, attack, and reconnaissance aircraft. Those students who pass the medical evaluation should be allowed to continue their flying training but be required to undertake a physical conditioning (strength training) program. At the end of their LIFT course they should be retested on the centrifuge. If a student who has completed LIFT is still unable to tolerate $+7\ G_z$ for 15 s, his safety and effectiveness in high-performance aircraft must be seriously questioned. It seems reasonable that at this point the demonstrated deficiency in G tolerance should be treated as a type of flying deficiency, like consistently inadequate situational awareness or poor gunnery scores, and be taken into account by line (as opposed to medical) personnel when deciding how best to assign their resources.

Eventually the experience gained in conducting high-G training with the Holloman AFB centrifuge will allow TAC to set its own G-tolerance standards. Such experience will reveal to TAC commanders that there are, in fact, some medically and physically fit individuals whose G tolerance is too low to justify spending time and money training them to be fighter pilots. As fighter aircraft capable of generating even more stressful G environments than are encountered today become available, that fact will become all the more evident. While presently a G-tolerance standard of +7 G_z for 15 s would serve adequately both to identify students who have not learned an effective anti-G straining technique and to screen for medical conditions that lower G tolerance, eventually higher standards, designed to optimize the match between G-load-generating capability of a particular aircraft and G tolerance of the pilot selected to fly that aircraft, will probably be indicated. It will be up to the operational TAC community to decide which G level is the appropriate selection standard for any particular purpose, and that decision should be based not only on aircraft performance but also on factors that determine what percentage of pilots can be rendered ineligible to fly that aircraft because of too low G tolerance. To illustrate this point, we might hypothesize that the Advanced Tactical Fighter (ATF), for example, could have a sustained 10-G capability under certain conditions, and that the fighter mix is such during a given year that TAC can assign only 20% of LIFT graduates to fly the ATF. Under these circumstances it might be reasonable to select only those graduates who fall in the top 50% of the G-tolerance distribution to fly the ATF. A G tolerance of 10 G for 15 s, with anti-G suit and straining maneuver in an ATF-configured centrifuge seat, might then be the appropriate standard, as it would be commensurate with a worst-case G environment for that aircraft, and would be attainable by only about half of the LIFT graduates.

In conclusion, let me suggest that an observation made by Group Captain Ruffell-Smith about British fighter pilots in World War II is particularly pertinent today (4): "Successful British fighter pilots were not interested in anti-G suits because they had a high G tolerance anyway; those who were not successful [because of low G tolerance] were shot down!" In contrast, the performance of today's fighter aircraft makes the anti-G suit an undisputed necessity, whereas the value of a G-tolerance standard is debated. I submit that the time has come to implement a G-tolerance standard for use in pilot selection. To do so will help prevent a natural selection, through attrition, due to superior enemy G tolerance during wartime and avoidable GLC mishaps during peacetime.

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