ANALYSIS OF 'G' LEVELS ASSOCIATED WITH THE C-5A ACCIDENT NEAR SAIGON APRIL 4, 1975

by

James W. Turnbow, Ph.D.

Consultant - Aviation Safety

LOCKHEED-GEORGIA COMPANY
A DIVISION OF LOCKHEED CORPORATION

INTERDEPARTMENTAL COMMUNICATION

TO R. P. Barton DEPT. 85-03 ZONE 35 DATE 29 July 1981

E-05-665-81

FROM J. W. Edwards DEPT. 72-05 ZONE 240 EXT. 4004

SUBJECT: C-5A SIAGON ACCIDENT FIRST IMPACT G LOADS

An analysis of all available data relevant to subject impact loads resulted in a range of loads based on the following data:

a) Engineering Analysis of Data From AF 68-218 - Second page states "The MADAR data for a period of 3.6 seconds prior to initial impact was lost due to power interruption at impact. At this point the airspeed was approximately 270 knots and the altitude trend information available indicates a probable sink rate at initial touchdown on the order of 16 ft/sec, however, it must be emphasized that no data exists for approximately 3.6 seconds prior to touchdown and ground effect should have produced a reduction in sink rate prior to ground contact."

b) Captain Harp's Court Testimony - Page 174, "The first landing, I would classify as a relatively smooth landing under the conditions, quite honestly. I have made firmer landings since then on a normal runway, I have seen firmer landings, both by military and commercial aircraft. I was prepared for a much firmer impact than what we had on the first landing."

c) Page 2141, "The first landing, I would describe as relatively smooth, considering the conditions we were landing in. I guess some people would probably call it a firm landing or something. I have seen worse landings. I personally have made worse landings."

d) Major Traynor's Court Testimony - Page 2213, "And the cushioning affect of the wings, against the ground made the airplane flare. And I remember looking at the vertical velocity and it was reading about 500 feet per minute, which is even less than a normal touchdown. So, I touched down the first time and was quite releived because of the non-severity of the touchdown."

e) Page 89, "The ground effect flared the airplane. We touched down in normal, or less than normal, rate of descent, so it was a very smooth initial touch." "One of the standard cross-check items is your rate of descent indicator, and I did notice that it was right at 500 to 600 feet per minute, which is the preferred normal rate of descent for touchdown."

f) My own personal observation at the accident site was that the aircraft initial touchdown caused failure of both aft main gears due to aft drag loads caused by the gears plowing into the soft dirt. There was no evidence of failure of the aft main gears due to vertical loads which indicates a normal descent rate and since the forward main gears and the nose gear stayed with the airplane until after the second touchdown, the initial touchdown was probably made at a tail down angle.

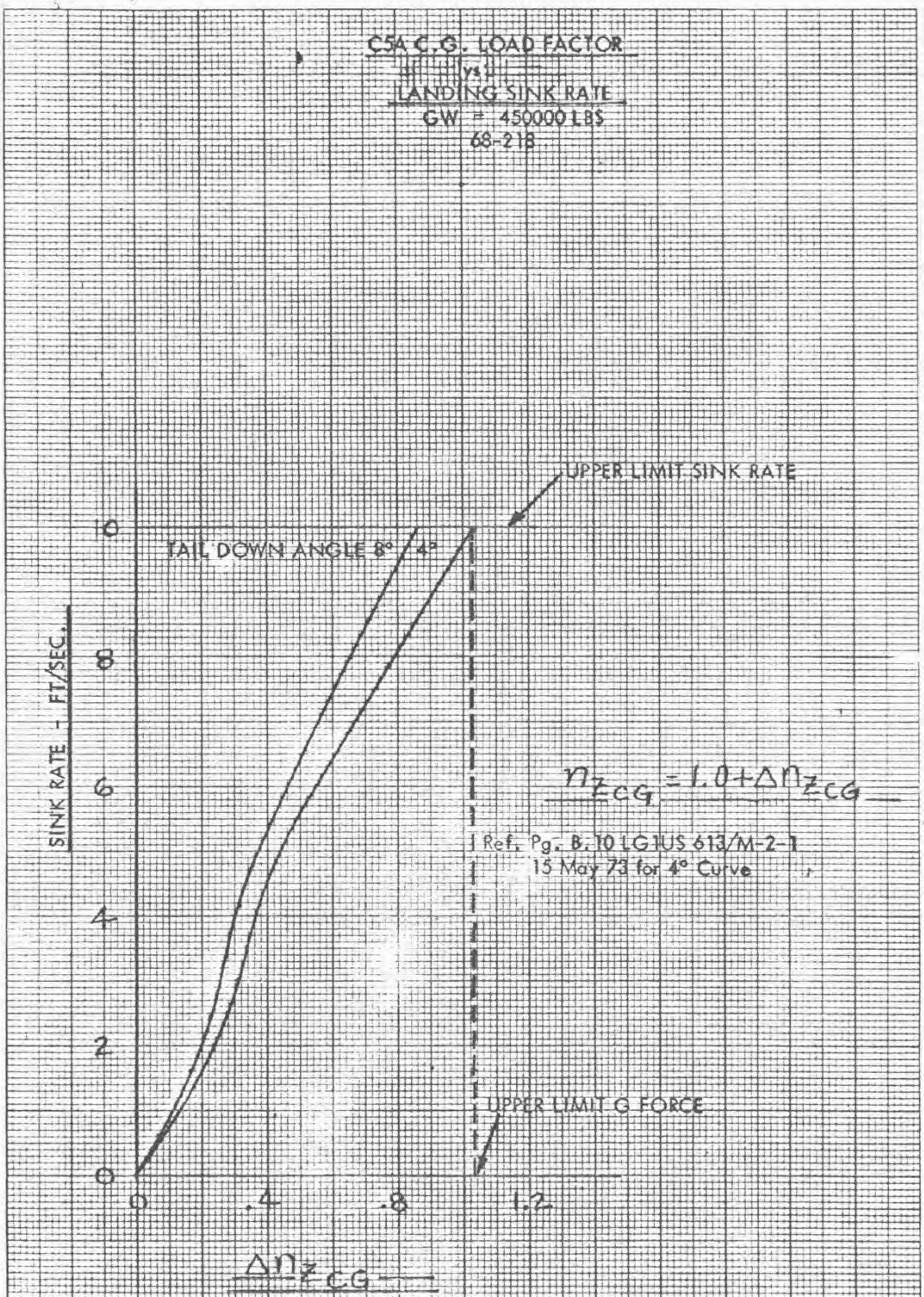
Attached is a graph of C-5A C.G. LOAD FACTOR VS LANDING SINK RATE prepared by the structures department. Given a sink rate of 600 fpm (10 fps) and a tail down angle of 4°, the g loading at the airplane CG is 1.025 which is considered to be the highest probable go force. Given a sink rate of 500 fpm (8.33 fps) and a tail down angle of 8°, the g loading at the airplane CG is .7. The g force on a person would be one plus the airplane g force or 2.025 and 1.7 respectively.

Therefore, the vertical g forces were either equal to or less than 1.7 g's or 2.025 g's depending on the tail down angle and these values would have been reduced further by the ground effects.

The vertical g loads at the second impact were essentially negligible since the aircraft crossed the river and dragged the two forward main gear through the vegetation (with the nose gear above the vegetation since no nose gear track was evident) for some fifty feet indicating a very level trajectory.

J. W. Edwards
Chief Project Engineer
Project Engineering Division

JWE:bg



C5A C.G. LOAD FACTOR
vs
LANDING SINK RATE
GW = 450000 LBS
68-218
UPPER LIMIT SINK RATE
TAIL DOWN ANGLE 8° / 4°
SINK RATE - FT/SEC.
10
8
6
4
2
0
0
.4
.8
1.2
$n_{z_{CG}} = 1.0 + \Delta n_{z_{CG}}$
Ref. Pg. B.10 LG1US 613/M-2-1
15 May 73 for 4° Curve
UPPER LIMIT G FORCE
$\Delta n_{z_{CG}}$

Analysis of 'G' Levels Associated
With the C-5A Accident Near Saigon
April 4, 1975

by

James W. Turnbow, Ph.D.
Consultant - Aviation Safety

References Used:

The following analyses and conclusions are based in part, but are not limited to, a review of the following documents:

1. USAF Collateral Report, Vols. I, II, III.

2. Photographs of the aircraft prior to and following the accident.

3. Photographs of the accident site.

4. Miscellaneous drawings of the C-5A aircraft.

5. Sworn statements of:

   Regina Aune
   Tilford Harp
   Christine Lieverman
   Keith Malone
   Marcia Tate

6. Depositions and/or trial testimony of the following:

   Regina Aune
   Tilford Harp (co-pilot)
   Christine Lieverman
   Harriett Neill
   Merritt Stark
   Marcia Tate
   Dennis Traynor (pilot)
   William Timm
   John Edwards

7. Wreckage Distribution Diagram.

8. Cutaway view of C-5A troop compartment.

9. NASA Technical Report SP-3006 'Bioastronautics Data Book,' 1964.

10. USAF Technical Report No. 5915 Part 2, 1961, 'Human Exposures to Linear Deceleration,' 1951.

11. USAAMRDL Technical Report 71-22, 'Crash Survival Design Guide,' 1971.

12. Plots of the Data Obtained from the onboard recorder (MADAR).

13. The author also draws on some 20 years of experience in aircraft accident reconstruction and full scale crash testing of aircraft. A vitae is attached for convenience of the reader.

ACCIDENT SYNOPSIS

The crash of this aircraft consisted of two ground contacts separated by approximately 875 yards of free flight. The analysis of the data available shows the following concerning these two contacts:

Contact No. 1

This contact has been characterized by several of those aboard the aircraft as 'a near normal touch down' or 'no more than a hard landing typical of military or commercial aircraft.' The sink rate was reported to be 500 to 600 feet per minute by one of the cockpit crew (Mayor Traynor), a fact in agreement with:

a) Extrapolation of the MADAR data.

b) The aircraft attitude and speed, i.e., nose up at touchdown. (It is noted that the nose gear did not contact the ground at this point).

c) The aircraft would have been in 'ground effect' as it approached the surface with resulting tendency to reduce any existing sink rate.

d) Statements of other crew, for example: Capt. Harp said in the Schneider Trial, page 2143, line 4: 'I would say there were hardly any G forces on the first landing.'

The primary structural failure at this first contact was removal of the rear sets of landing gears, probably due to the landing on a less than normally firm runway and to the above normal touchdown speed of 270 knots, both of which could be expected to increase the drag forces on the gear.

Since the ultimate design load for each gear does not exceed 240,000 lbs, and assumption of full design load being developed on the rearmost gears, plus a limit load of 160,000 lbs on each of the forward main gears, gives a total load of 800,000 lbs. This would load the 450,000 lb aircraft to no more than 1.78g's along the longitudinal axis of the aircraft. The vertical loads would have been very consistent with those occuring for a landing at near or lower than normal sink rate. Vibratory oscillations would have been induced into the structure due to failure of the gear, however these, being of high frequency, would have been more of an 'audible' nature to passengers of the troop compartment rather than of a nature such as to produce a displacement or impact type response of those passengers.

No hazard to the occupants of either the cockpit or troop compartments can thus be expected from this contact.

Contact No. 2

This ground contact occurred after the aircraft became airborne following the initial touchdown and crossed the Saigon River. Observation of the forward main gear tire marks relative to a small dike on the far bank of the river shows (together with the absence of nose gear marks) that the aircraft again touched down in level or slightly nose up attitude. The extended nose gear and extended main gear permitted the aircraft to pass over this dike, allowing failure of all of these remaining gears with little or no contact of the bottom of the fuselage with the dike. The decelerations here would again be no more than the values occurring in the first contact. Upon passage over the dike the bottom of the aircraft began a skidding and plowing run through wet and soft rice fields to the final points of rest. Observation of the accident photos and other evidence shows the following:

a) The troop compartment and the crew compartments remained essentially intact, maintaining living space for those occupants.

b) All seats remained attached to the floor and there were no seat belt or harness failures.

c) Seats in the troop compartment are 16g seats attached to the floor with a 9g restraint. All were rearward facing.

d) Skid tracks through the wet/soft marsh-like terrain are strongly indicative of long-duration, low-level, constant deceleration for the cockpit and troop compartments.

e) Break-up of the lower fuselage occurred in many relatively small pieces consistent with many successive failures, again indicative of continued and hence low level continuous deceleration.

f) The failure of the side walls of the lower (cargo) compartment ultimately resulted in the formation of two skids or runners for the troop compartment which guided that compartment in almost a straight track, reducing lateral loads to only those of vibratory nature and allowing the floor to remain intact.

g) Adult occupants seated or kneeling on the floor between rows of seats, without any kind of restraint other than holding by hand were able to stay in place throughout the complete impact sequence without serious injury. Cuts and bruises were reported. Only those occupants in line with an isle and holding by hand appear to have been unable to retain position. These occupants would have been in a condition similar to a 'free fall' at a somewhat elevated 'g' value of about 1.5 to 2.0g as they 'fell' longitudinally along the isle to impact at or near the front bulkhead. Their injuries thus occurred in this mode.

The 'Wreckage Diagram' for C-5A SN 68-218 shows a deceleration distance for the troop compartment of about 650 yards or 1950 feet as scaled from the diagram. For an initial speed of 270 knots or 456 ft/sec the average deceleration over this distance is 1.66g.* In view of the nature of this accident it is the opinion of the author that the peak decelerations which occurred are probably not more than three (3) times this value or about 5g's. The reader should observe carefully the fact that such peaks cannot physically be applied for any appreciable period of time otherwise the aircraft would have to stop in much less than 1950 feet. [The value would be 646 feet at 5g's constant deceleration].

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* See Appendix I.

HUMAN TOLERANCE TO DECELERATION

The voluntary tolerance of the whole human body for short duration pulses with forward facing seat and shoulder harness is at least 40g's or eight times the 5g value mentioned above. For rearward facing seats the voluntary tolerance level is well in excess of 40g. At least one 80g test has been conducted on a voluntary human subject without serious injury.

The tolerance to head impact alone, as established by a Wayne State University research group, indicates that peak accelerations of 15 milliseconds duration would have to be of the order of 140g just to produce unconsciousness. For a 2ms pulse the corresponding value would have to be about 400g.

It should be noted that in the C-5A accident in question many of the children were not even awakened by the crash. In view of: 1) The visually observed response of the children in the troop compartment to the crash (or the lack thereof) and 2) to the extremely large disparity between the probable actual decelerations (both peak and average values) and the limits of voluntary human tolerance to such loads, it appears clear that no hazard to life or health existed due the deceleration environment alone in the Saigon C-5A accident of April 1975.

For the convenience of the reader, copies of several human tolerance charts taken from reference No. 10 are included in the appendix.

CONCLUSIONS

It is the opinion of this author that it is a scientific certainty that the decelerations occurring in the April 4, 1975 Saigon C-5A accident did not provide a direct hazard to the life or health of the children or adults located in troop compartment of that aircraft. More specifically it is not possible that the magnitude of the crash decelerations were such as to result in brain damage for the seated occupants or to those adult occupants who remained in position throughout the crash.

APPENDIX I

For uniform (constant) deceleration the governing equation is:

$$G = \frac{V^2}{64.4S}$$

<u>where</u>:

V = Velocity in ft/sec
= 270 knots = 456 ft/sec

S = Deceleration distance = 1950 feet

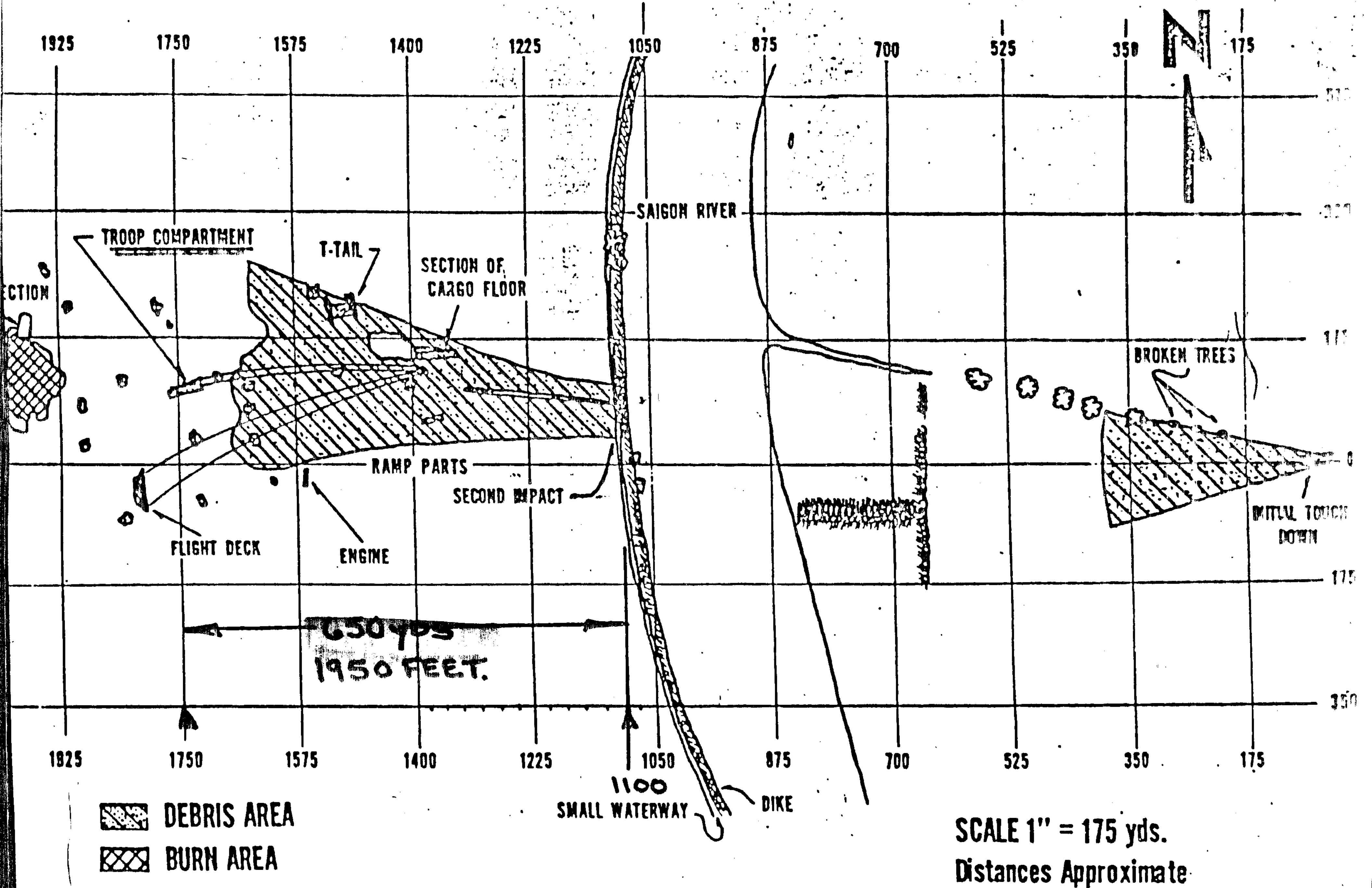
The constant 64.4 is twice the acceleration due to gravity or $2g = 2 \times 32.2 = 64.4$ ft/sec^2.

<u>Then</u>:

$$G = \frac{(456)^2}{64.4\ (1950)} = 1.66$$

APPENDIX II

C-5A SN 68-218 4 APRIL 1975



APPENDIX III

USAAMRDL TECHNICAL REPORT 71-22

CRASH SURVIVAL DESIGN GUIDE

REVISED OCTOBER 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-69-C-0030

DYNAMIC SCIENCE (THE AvSER FACILITY)
A DIVISION OF MARSHALL INDUSTRIES
PHOENIX, ARIZONA

head velocity was that value of initial velocity which resulted in the impact material's being crushed to a predetermined value of strain. This strain value was dependent on the properties of the impact material chosen. The restriction on head deceleration was defined by human tolerance limitations. The head tolerance to impact is a function of pulse duration and average head decelerations as shown in Figure 5-7. In combination, these limitations define a maximum velocity curve as a function of original material thickness, above which absence of concussion (as defined by the tolerance limit of Figure 5-7) was doubtful, regardless of impact material characteristics. This curve is presented as Figure 5-8.

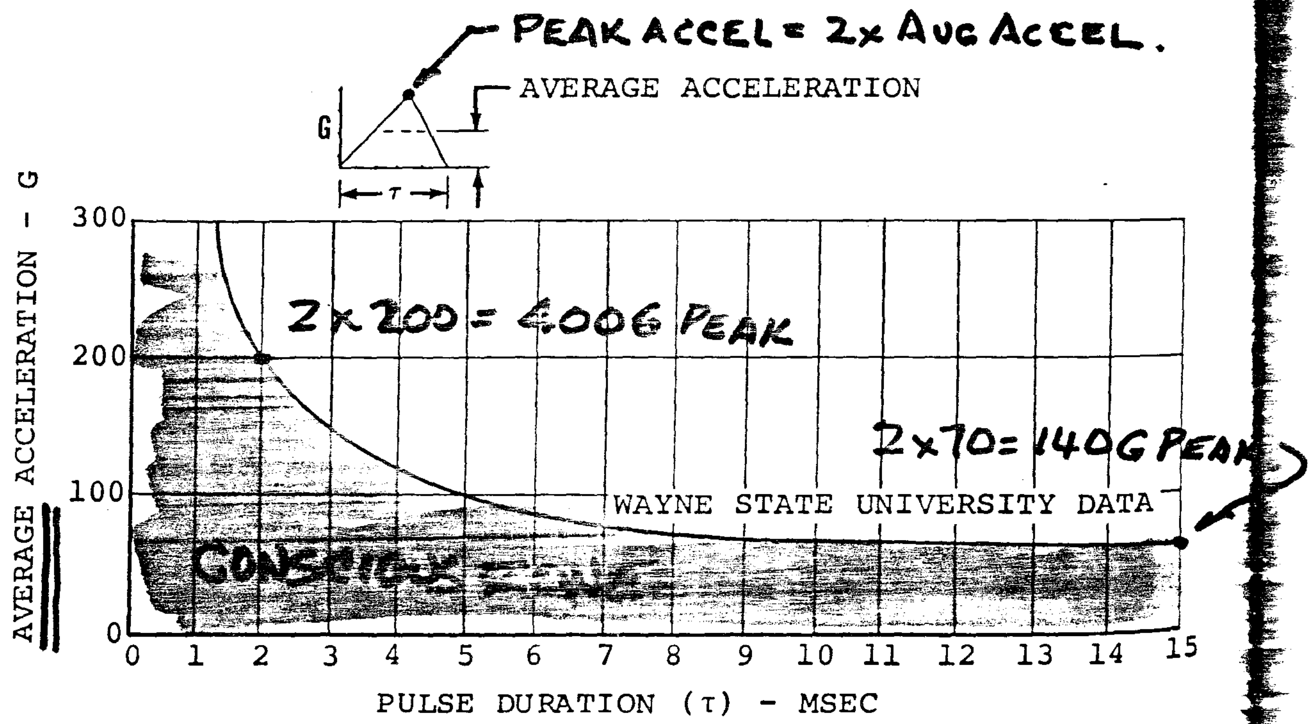


Figure 5-7. Head Tolerance to Impact as a Function of Pulse Duration as Published by Wayne State University.

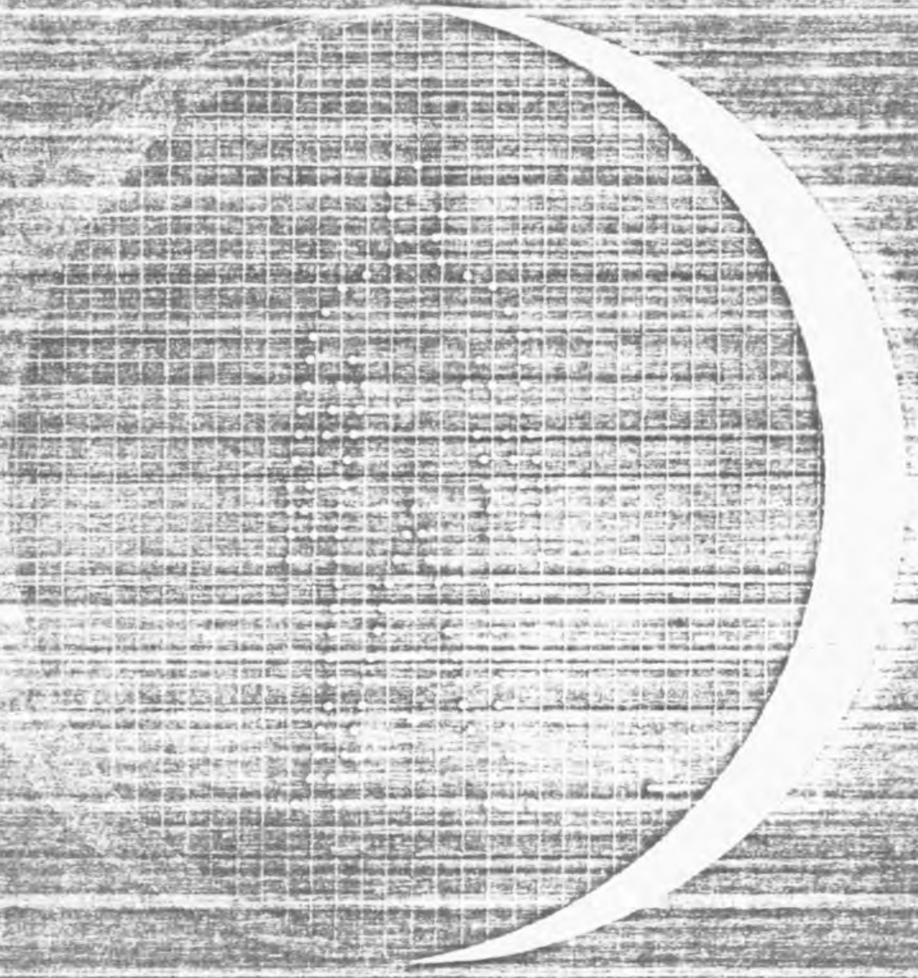
5.3.3.2 <u>Head Impact Velocities</u>: Figure 5-9 shows typical head velocities relative to the seat as measured on anthropomorphic dummies, cadavers, and live human subjects in dynamic seat tests. Various combinations of occupant restraint were used and are so indicated on each curve.

5.3.3.3 <u>Geometry of Probable Head Impact Surfaces in U. S. Army Aircraft</u>: Aircraft in the U. S. Army inventory in 1965 have been examined to determine the kinds of contact hazards

APPENDIX IV

TURNBOW

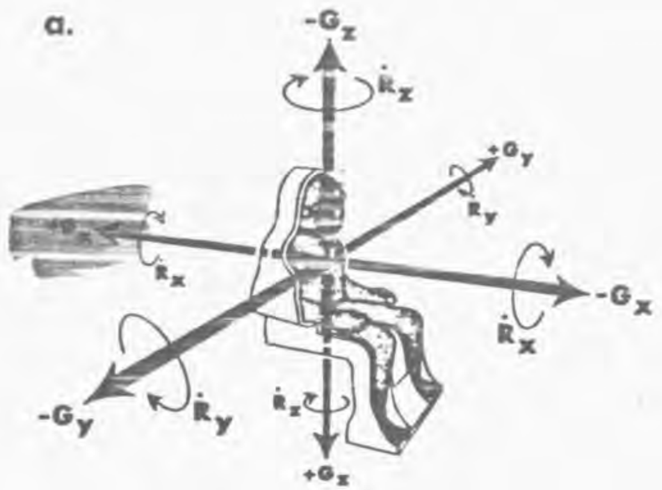
NASA SP-3006



BIOASTRONAUTICS DATA BOOK

Contributor: Randall M. Chambers, Aviation Medical Acceleration Laboratory, USN.

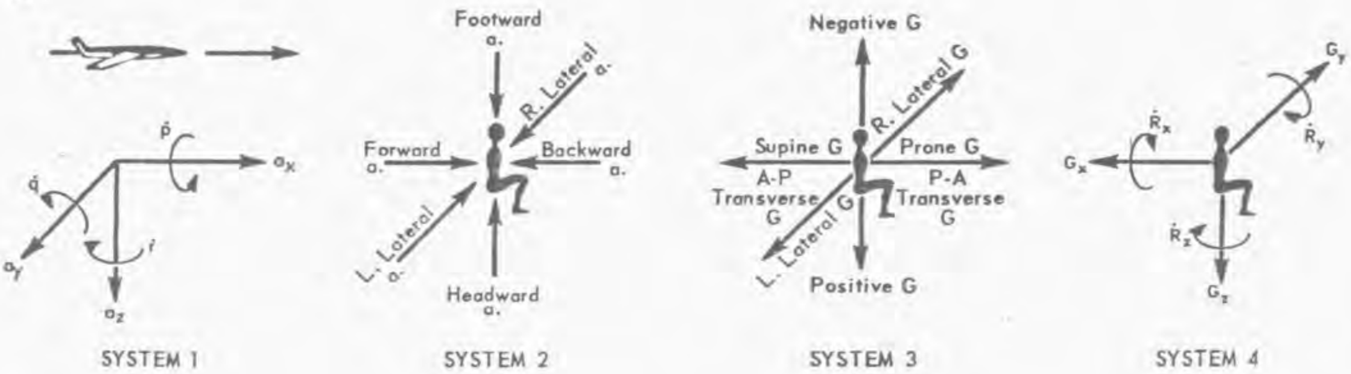
a.



[redacted] Table II below--and in particular System 4, which is based on displacement of body fluids--explains the most commonly employed terms.

Source: Adapted from Gell [18].

b.



c.

	Table I Direction of Acceleration		Table II Inertial Resultant of Body Acceleration		
Linear Motion	Aircraft Vector (System 1)	Acceleration Descriptive (System 2)	Physiological Descriptive (System 3)	Physiological Displacement (System 4)	Vernacular Descriptive (System 5)
Forward	$+a_x$	Forward accel.	Transverse A-P G* Supine G Chest to back G	$+G_x$	Eyeballs in
Backward	$-a_x$	Backward accel.	Transverse P-A G Prone G Back to chest G	$-G_x$	Eyeballs out
Upward	$-a_z$	Headward accel.	Positive G	$+G_z$	Eyeballs down
Downward	$+a_z$	Footward accel. (tailward)	Negative G	$-G_z$	Eyeballs up
To right	$+a_y$	R. lateral accel. (rightward)	Left lateral G	$+G_y$	Eyeballs left
To left	$-a_y$	L. lateral accel. (leftward)	Right lateral G -	$-G_y$	Eyeballs right
Angular Motion					
Roll right	$+\dot{p}$	cartwheel	Roll	$-\dot{R}_x$	
Roll left	$-\dot{p}$	cartwheel		$+\dot{R}_x$	
Pitch up	$+\dot{q}$	somersault	Pitch	$-\dot{R}_y$	
Pitch down	$-\dot{q}$	somersault		$+\dot{R}_y$	
Yaw right	$+\dot{r}$	pirouette	Yaw	$+\dot{R}_z$	
Yaw left	$-\dot{r}$	pirouette		$-\dot{R}_z$	

* A-P and P-A refer to Anterior-Posterior and Posterior-Anterior.

Source: Adapted from Gell [18].

The spectrum of acceleration environments is extremely large and may vary in duration, magnitude, rate of onset and decline, and direction. Some acceleration exposures may be so mild that they have relatively no physiological or psychophysiological effects, or they may become so severe that they produce major disturbances. The emphasis of this section is primarily on human performance capabilities and physiological responses as they are modified by sustained acceleration. Abrupt accelerations and decelerations lasting less than two seconds are treated in Section 5, Impact and Vibration.

The unit for the physiological acceleration is G, as distinguished from the "true" displacement acceleration, generally designated by aerodynamicists with the unit g. The physiological acceleration represents the total reactive force divided by the body mass, and hence includes both displacement and resisted gravitational acceleration effects.

The physiological acceleration axes represent directions of the reactive displacements of organs and tissues with respect to the skeleton. Please refer to the accompanying diagrams and tables. The Z axis is down the spine, with $+G_z$ (unit vector) designations for accelerations causing the heart, etc., to displace downward (caudally). The X axis is front to back, with $+G_x$ designations for accelerations causing the heart to be displaced back toward the spine (dorsally). The Y axis is right to left, with $+G_y$ designations for accelerations causing the heart to be displaced to the left.

Angular accelerations which cause the heart to rotate (roll) to the left within the skeleton are specified by the $\dot{R}_x$ unit vector, representing radians/sec^2 about the X axis. Angular velocities in the same sense are specified by the $+R_x$ unit vector, representing radians/sec about the X axis. Similarly, $+\dot{R}_y$ represents an angular acceleration producing a pitch down of the heart within the skeleton, and $+\dot{R}_z$ represents yaw right of the heart within the skeleton.

The field of acceleration research has produced a number of general principles concerning the effects of acceleration stress on physiology and performance. The following statements, many of which are illustrated in the charts of this section as shown, are hoped to be useful to designers of aerospace vehicles and equipment.

1. Physiological tolerance, or the ability to withstand acceleration physiologically, is a function of many variables--e.g., rate of onset (3-2); direction of G vector (3-3); magnitude of G (3-2); duration (3-4)--as well as the type of endpoints that are used as criteria.

2. In addition to the physiological tolerance limits which define the end points for reliable functioning of any particular physiological system during exposure to acceleration stress, there are also performance tolerance limits, which define the end points for reliable functioning of any particular performance ability.

3. Physiological and performance tolerances may be functionally related, but they need not be the same, since each is dependent upon the criteria used.

4. During exposure to acceleration stress, the type of G-protection system used has a very important influence on the pilot's ability to tolerate acceleration (chart 3-5), perform tasks, and maintain performance proficiency.

5. For an acceleration of given rate of onset and magnitude, physiological tolerance is highest for $+G_x$, next for $-G_x$, next for $+G_z$, and lowest for $-G_z$, directions of force. See 3-3.

6. Acceleration stress significantly impairs visual capabilities. As acceleration increases, visual acuity decreases (see 17-30), illumination requirements increase, and brightness contrast requirements decrease (3-10 and 3-11).

7. Major individual differences exist among pilots in their ability to perform piloting tasks during exposure to high G.

8. Certain types of acceleration exposures produce illusions, or false perceptions, of one's position and motion. These may occur in some pilots during or after the acceleration exposure.

9. Since acceleration training results in physiological adaptation and conditioning to G, as well as learning to make performance compensations, acceleration training produces major improvements in performance proficiency during exposure to high G.

10. The instrument display characteristics of a piloting task influence the measurement of performance capabilities of a pilot during exposure to high G. Among the more important display characteristics are: the position of the display instrument within the pilot's visual field, the degree of interpretation required of the pilot, the number of instruments that must be viewed by the pilot during high G, the amount of illumination, the amount of brightness contrast, the physical form in which the display information is presented, and the amount of visual instrument scanning that is required at high G.

11. The characteristics of the control device used by the pilot in performing under G have a significant effect upon proficiency. These characteristics are: the number of axes of motion; the location of the axes of motion with respect to the G and the pilot's hand; stick force gradients along each mode of control; the centering characteristics along each mode of control; dead band zone; breakout force requirements; control friction; static and dynamic balance; damping characteristics; control throw; response time of control; control harmony; cross coupling characteristics; size and shape of grip; dynamic and static balance; and control sensitivity (3-16).

12. Acceleration impairs the ability of the pilot to sense changes in control characteristics that may occur as a function of specific acceleration vectors. This may be a direct effect of the acceleration forces on the receptors, effects on the central or autonomic nervous system, or an effect on circulatory and other physiological systems which indirectly affect the ability of the pilot to sense changes in his arm, hand, and fingers.

13. Task characteristics that are relatively easy to perform in low-G environments become more difficult as G increases.

14. Intellectual skills, piloting concentration, time perception, judgment, and immediate memory are influenced by high G.

15. Response time, as well as complex psychomotor performance, is influenced by high G (3-13).

16. Anticipation of acceleration may produce emotional reactions that are greater in terms of psychophysiological impairment than the direct effects of acceleration itself.

17. If, in addition to acceleration stress, the pilot is exposed to other environmental stresses, his responses may be altered by the combined effects of these stresses. (See Section 9).

Positive (G_z) and transverse (G_x) accelerations have been emphasized in studies to date, while lateral and angular accelerations have received relatively little attention, primarily because of the lack of proper research facilities.

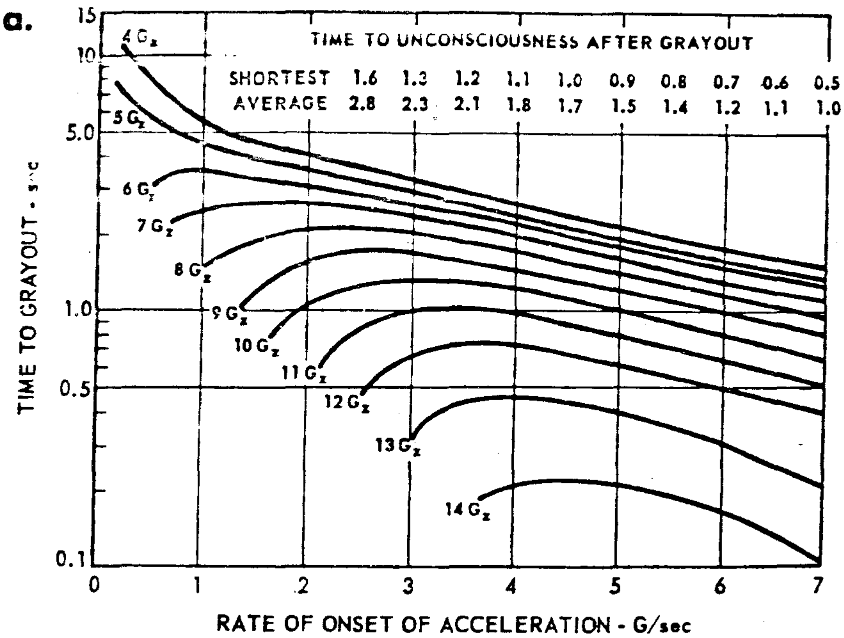
Some limitations in interpreting acceleration research data are: (a) most studies have been conducted on a small number of subjects; (b) repeated exposure to acceleration changes a subject's G tolerance, and this factor is usually not included; (c) emotional condition and motivation influence results; (d) instrumentation has not been standardized for measuring the effects of G on physiology and performance.

Recommended for general reading are the following: Otto H. Gauer and George D. Zuidema, Gravitational Stress in Aerospace Medicine [17]; Neal M. Burns, Randall M. Chambers, and Edwin Hendler, Unusual Environments and Human Behavior: Physiological and psychological problems of man in space [5]; and C. C. Clark, J. D. Hardy, and R. J. Crosbie, A Proposed Physiological Acceleration Terminology with an Historical Review [12].

This graph relates the onset rate of acceleration to time-to-end-point. It shows that for any given positive acceleration (G_z) from 4 to 14 G, the time to grayout depends on how rapidly the acceleration level was reached. Further, the table inset in the graph shows the shortest times and the average times for unconsciousness to develop following grayout, each pair of values being related to an onset rate. For example, at onset rate of 4 G/sec, the shortest time to unconsciousness was 1.1 sec, and the average 1.8 sec.

Source: Stoll [26].

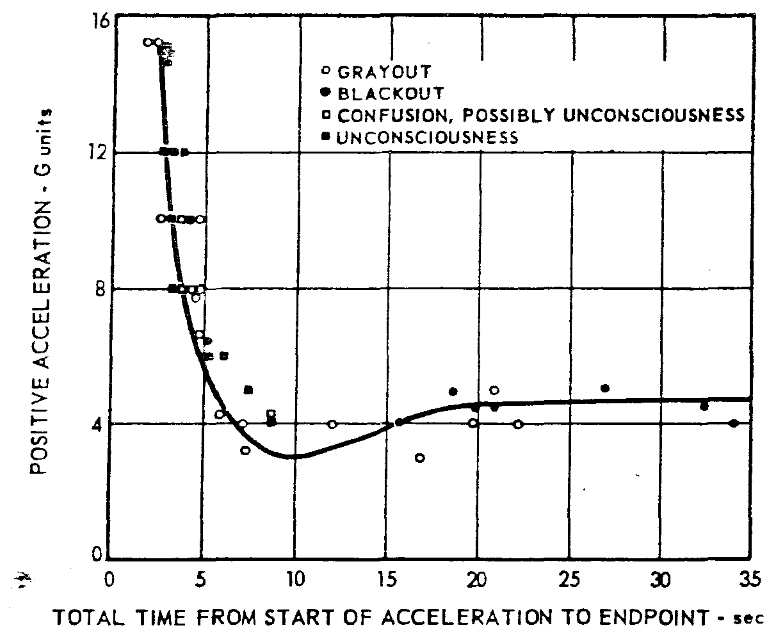
a.



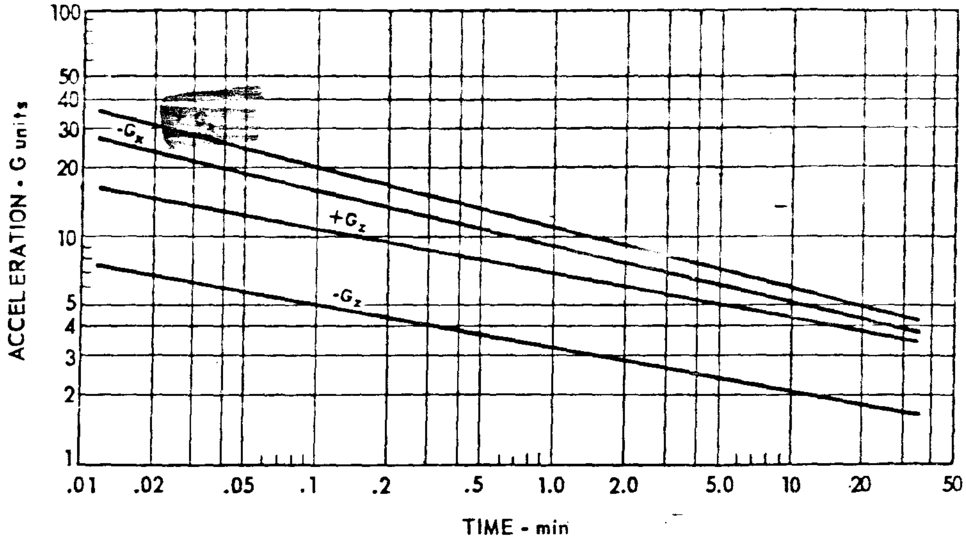
This graph shows human tolerance to positive G_z for varying rates of onset, G amplitudes, and exposure times.

Source: Adapted from Stoll [26].

b.



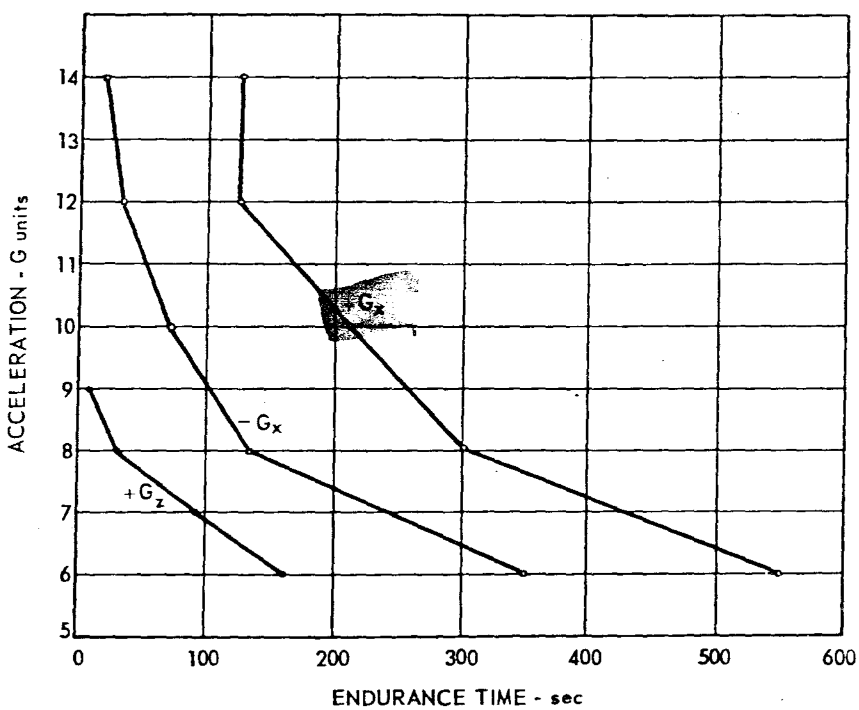
a.



Average acceleration tolerance is shown for positive acceleration (+G_z), negative acceleration (-G_z), transverse supine accleration (+G_x), and transverse prone acceleration (-G_x).

Source: Chambers [7].

b.

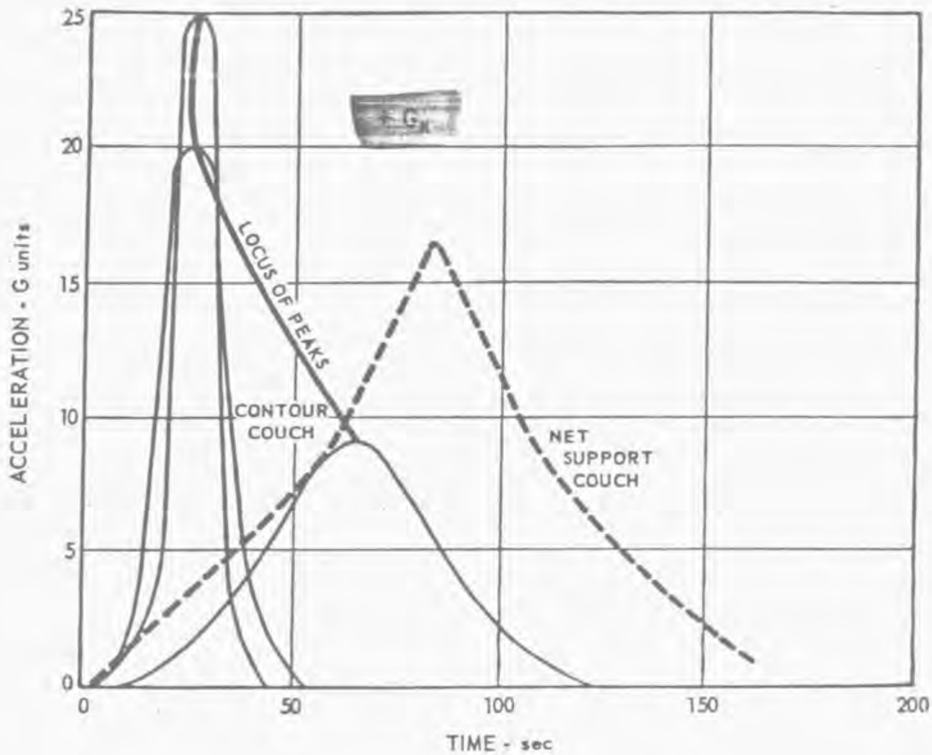


Upper limits of voluntary endurance (as contrasted with average tolerance, shown above) are plotted for a group of highly motivated test pilots, preconditioned to the effects of acceleration and suitably restrained. The pilots were able to operate satisfactorily a side-arm control device to perform a tracking task throughout the times indicated.

Source: Chambers and Hitchcock [9].

3-4. MAXIMUM TOLERABLE ACCELERATION PROFILES

a.



b.

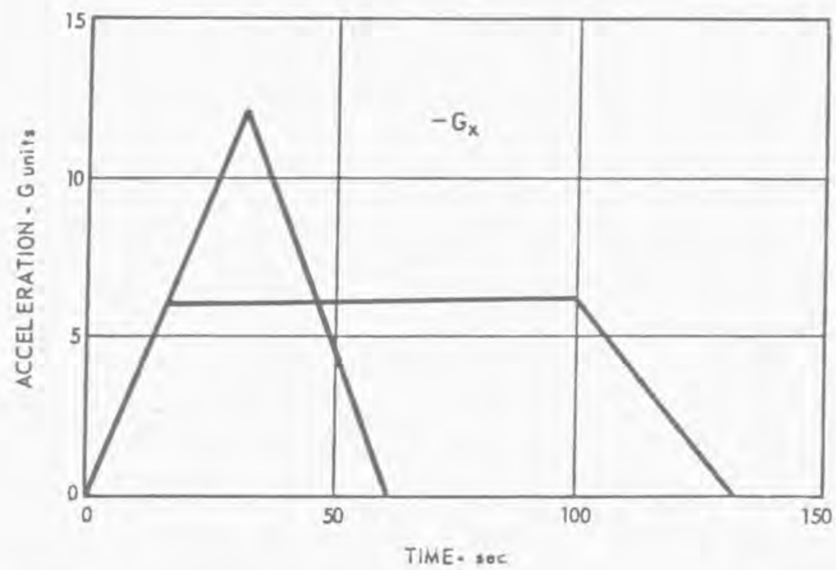
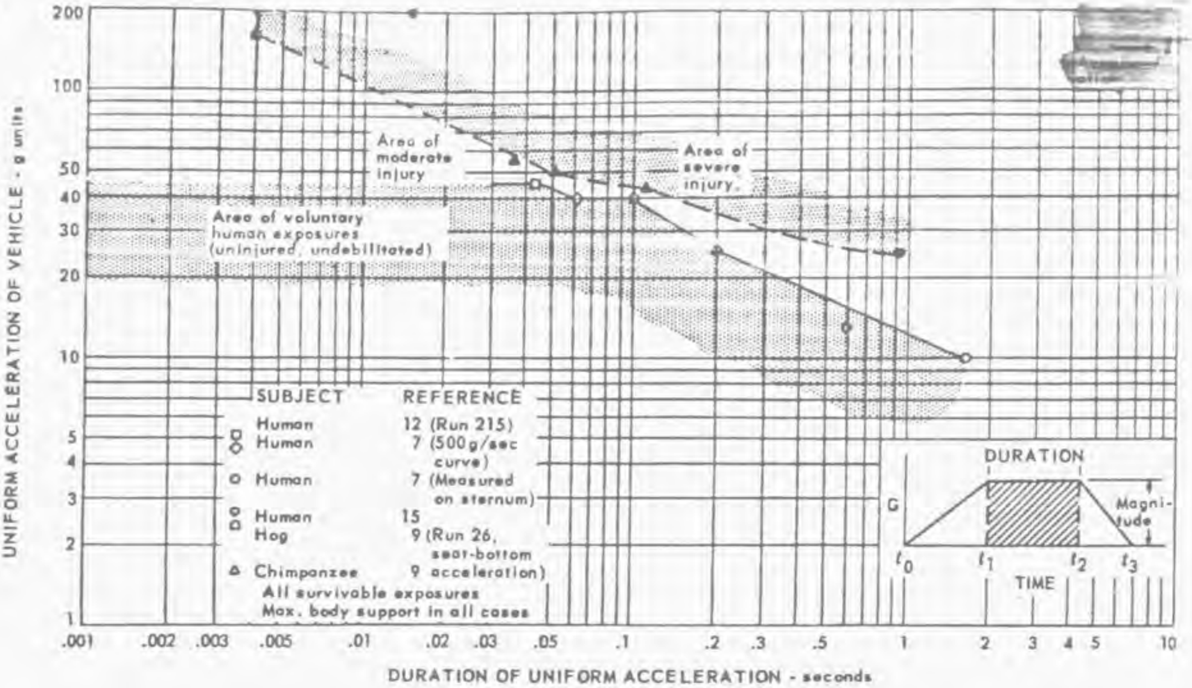


Figure a shows the greatest acceleration-time histories that have been tolerated on centrifuges when special support structures and positioning are used. Solid lines show three curves which define about the same area of $+G_x$ times time. A heavy line connects the peaks of these three curves and locates the peaks of other curves enclosing the same area. The dashed line encloses a number of possible acceleration profiles related to space flight, all of which are tolerable, since the border of the envelope has been tolerated experimentally. Figure b depicts two tolerable $-G_x$ accelerations (eyeballs out) when the subject is restrained in a special harness.

Sources: Bondurant et al. [4]; Clarke et al. [13]; Lawton et al. [24]; Collins et al. [14]; and Collins and Gray [15].

Contributor: Paul Webb, Webb Associates

a.

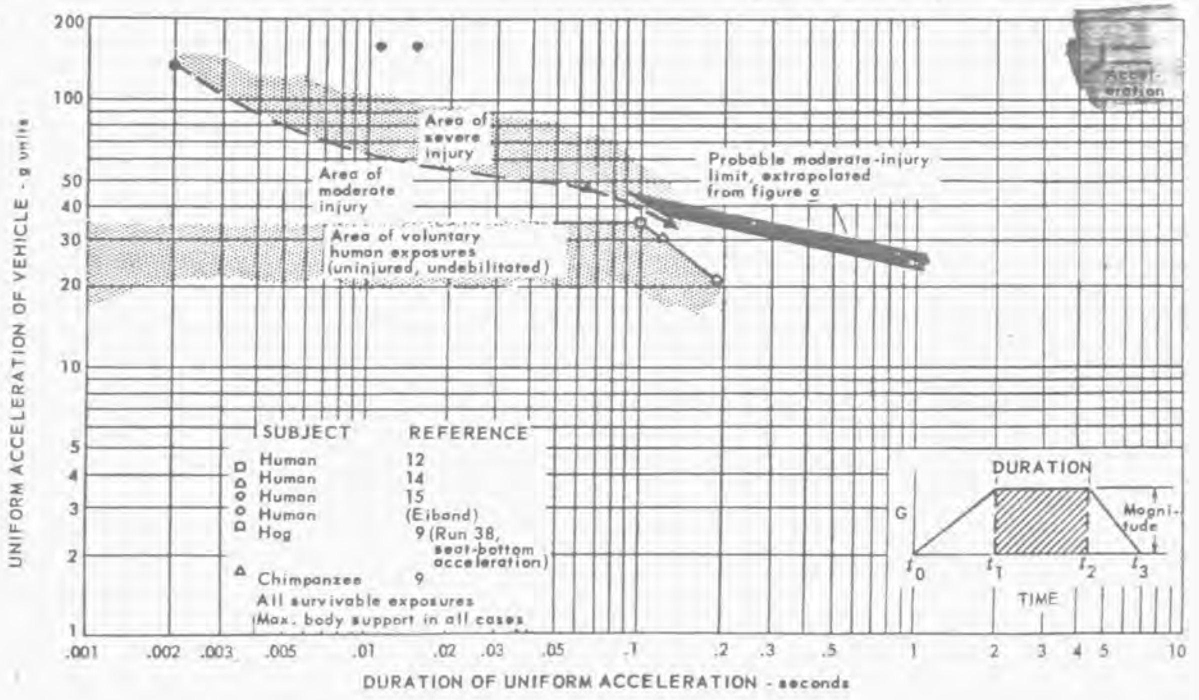


These two graphs show the durations and magnitudes of abrupt transverse decelerations which have been endured by various animals and man, showing areas of: voluntary endurance without injury; moderate injury; and severe injury. Graph a summarizes $-G_x$ data (back to chest acceleration) and b shows $+G_x$ data (chest to back acceleration). Reference numbers on the graphs are those in the original reports.

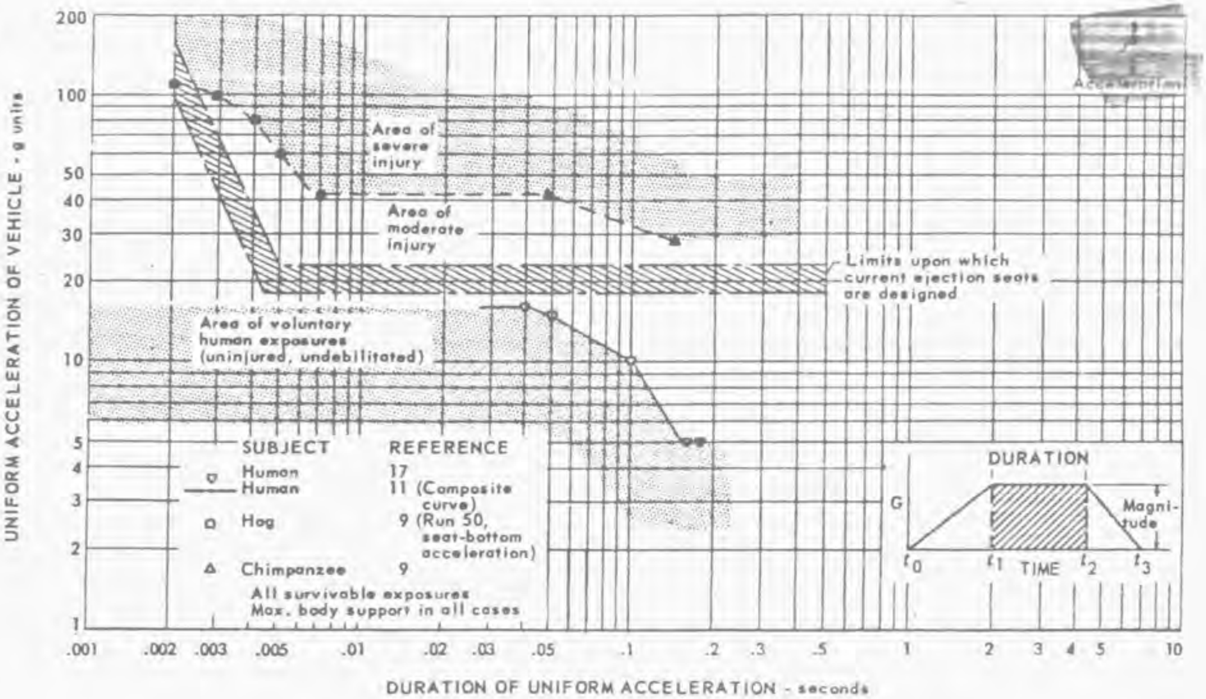
Source: Eiband [5].

REARWARD FACING

b.



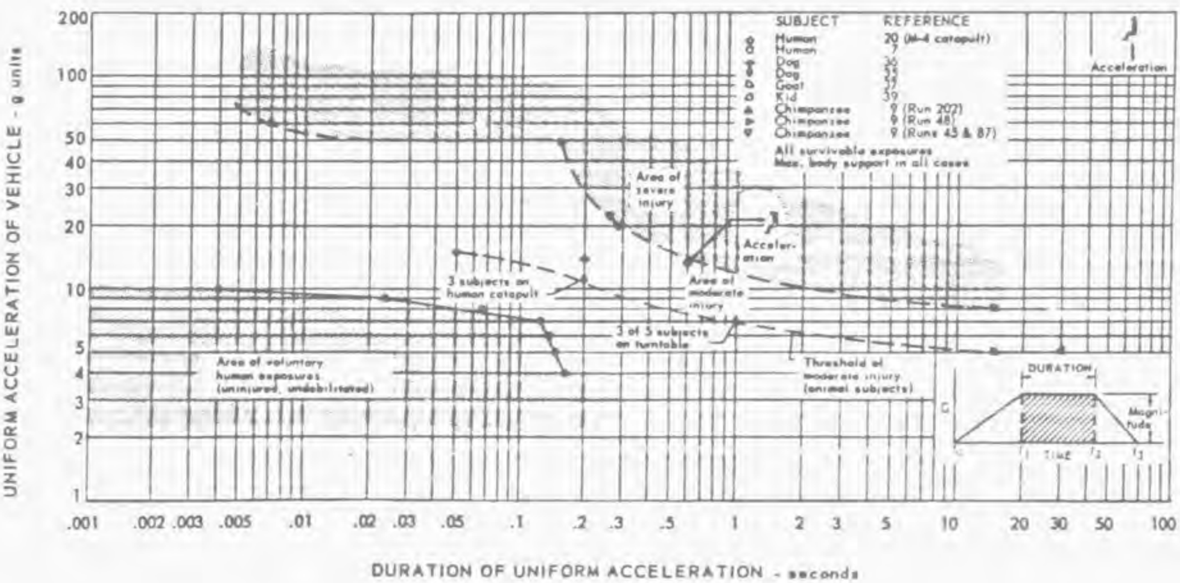
a.



These two graphs show the durations and magnitudes of abrupt deceleration in the G_Z (longitudinal) directions which have been endured by various animals and man, showing areas of voluntary endurance without injury, moderate injury, and severe injury marked by shading. Graph a shows data of $+G_Z$ acceleration (headward), and b shows data fcr $-G_Z$ acceleration (tailward). Reference numbers on the graphs are those in the original reports.

Source: Eiband [5].

b.



VITAE

ANALYSIS OF 'G' LEVELS ASSOCIATED WITH THE C-5A ACCIDENT NEAR SAIGON APRIL 4, 1975

by

James W. Turnbow, Ph.D.

Consultant - Aviation Safety

Analysis of 'G' Levels Associated With the C-5A Accident Near Saigon April 4, 1975

by

James W. Turnbow, Ph.D.
Consultant - Aviation Safety

References Used:

The following analyses and conclusions are based in part, but are not limited to, a review of the following documents:

1. USAF Collateral Report, Vols. I, II, III.

2. Photographs of the aircraft prior to and following the accident.

3. Photographs of the accident site.

4. Miscellaneous drawings of the C-5A aircraft.

5. Sworn statements of:

   Regina Aune
   Tilford Harp
   Christine Lieverman
   Keith Malone
   Marcia Tate

6. Depositions and/or trial testimony of the following:

   Regina Aune
   Tilford Harp (co-pilot)
   Christine Lieverman
   Harriett Neill
   Merritt Stark
   Marcia Tate
   Dennis Traynor (pilot)
   William Timm
   John Edwards

7. Wreckage Distribution Diagram.

8. Cutaway view of C-5A troop compartment.

9. NASA Technical Report SP-3006 'Bioastronautics Data Book,' 1964.

10. USAF Technical Report No. 5915 Part 2, 1961, 'Human Exposures to Linear Deceleration,' 1951.

11. USAAMRDL Technical Report 71-22, 'Crash Survival Design Guide,' 1971.

12. Plots of the Data Obtained from the onboard recorder (MADAR).

13. The author also draws on some 20 years of experience in aircraft accident reconstruction and full scale crash testing of aircraft. A vitae is attached for convenience of the reader.

ACCIDENT SYNOPSIS

- The crash of this aircraft consisted of two ground contacts separated by approximately 875 yards of free flight. The analysis of the data available shows the following concerning these two contacts:

Contact No. 1

This contact has been characterized by several of those aboard the aircraft as 'a near normal touch down' or 'no more than a hard landing typical of military or commercial aircraft.' The sink rate was reported to be 500 to 600 feet per minute by one of the cockpit crew (Mayor Traynor), a fact in agreement with:

a) Extrapolation of the MADAR data.

b) The aircraft attitude and speed, i.e., nose up at touchdown. (It is noted that the nose gear did not contact the ground at this point).

c) The aircraft would have been in 'ground effect' as it approached the surface with resulting tendency to reduce any existing sink rate.

d) Statements of other crew, for example: Capt. Harp said in the Schneider Trial, page 2143, line 4: 'I would say there were hardly any G forces on the first landing.'

The primary structural failure at this first contact was removal of the rear sets of landing gears, probably due to the landing on a less than normally firm runway and to the above normal touchdown speed of 270 knots, both of which could be expected to increase the drag forces on the gear.

Since the ultimate design load for each gear does not exceed 240,000 lbs, and assumption of full design load being developed on the rearmost gears, plus a limit load of 160,000 lbs on each of the forward main gears, gives a total load of 800,000 lbs. This would load the 450,000 lb aircraft to no more than 1.78g's along the longitudinal axis of the aircraft. The vertical loads would have been very consistent with those occuring for a landing at near or lower than normal sink rate. Vibratory oscillations would have been induced into the structure due to failure of the gear, however these, being of high frequency, would have been more of an 'audible' nature to passengers of the troop compartment rather than of a nature such as to produce a displacement or impact type response of those passengers.

No hazard to the occupants of either the cockpit or troop compartments can thus be expected from this contact.

Contact No. 2

This ground contact occurred after the aircraft became airborne following the initial touchdown and crossed the Saigon River. Observation of the forward main gear tire marks relative to a small dike on the far bank of the river shows (together with the absence of nose gear marks) that the aircraft again touched down in level or slightly nose up attitude. The extended nose gear and extended main gear permitted the aircraft to pass over this dike, allowing failure of all of these remaining gears with little or no contact of the bottom of the fuselage with the dike. The decelerations here would again be no more than the values occurring in the first contact. Upon passage over the dike the bottom of the aircraft began a skidding and plowing run through wet and soft rice fields to the final points of rest. Observation of the accident photos and other evidence shows the following:

a) The troop compartment and the crew compartments remained essentially intact, maintaining living space for those occupants.

b) All seats remained attached to the floor and there were no seat belt or harness failures.

c) Seats in the troop compartment are 16g seats attached to the floor with a 9g restraint. All were rearward facing.

d) Skid tracks through the wet/soft marsh-like terrain are strongly indicative of long-duration, low-level, constant deceleration for the cockpit and troop compartments.

e) Break-up of the lower fuselage occurred in many relatively small pieces consistent with many successive failures, again indicative of continued and hence low level continuous deceleration.

f) The failure of the side walls of the lower (cargo) compartment ultimately resulted in the formation of two skids or runners for the troop compartment which guided that compartment in almost a straight track, reducing lateral loads to only those of vibratory nature and allowing the floor to remain intact.

g) Adult occupants seated or kneeling on the floor between rows of seats, without any kind of restraint other than holding by hand were able to stay in place throughout the complete impact sequence without serious injury. Cuts and bruises were reported. Only those occupants in line with an isle and holding by hand appear to have been unable to retain position. These occupants would have been in a condition similar to a 'free fall' at a somewhat elevated 'g' value of about 1.5 to 2.0g as they 'fell' longitudinally along the isle to impact at or near the front bulkhead. Their injuries thus occurred in this mode.

The 'Wreckage Diagram' for C-5A SN 68-218 shows a deceleration distance for the troop compartment of about 650 yards or 1950 feet as scaled from the diagram. For an initial speed of 270 knots or 456 ft/sec the average deceleration over this distance is 1.66g.* In view of the nature of this accident it is the opinion of the author that the peak decelerations which occurred are probably not more than three (3) times this value or about 5g's. The reader should observe carefully the fact that such peaks cannot physically be applied for any appreciable period of time otherwise the aircraft would have to stop in much less than 1950 feet. [The value would be 646 feet at 5g's constant deceleration].

---

* See Appendix I.

HUMAN TOLERANCE TO DECELERATION

The voluntary tolerance of the whole human body for short duration pulses with forward facing seat and shoulder harness is at least 40g's or eight times the 5g value mentioned above. For rearward facing seats the voluntary tolerance level is well in excess of 40g. At least one 80g test has been conducted on a voluntary human subject without serious injury.

The tolerance to head impact alone, as established by a Wayne State University research group, indicates that peak accelerations of 15 milliseconds duration would have to be of the order of 140g just to produce unconsciousness. For a 2ms pulse the corresponding value would have to be about 400g.

It should be noted that in the C-5A accident in question many of the children were not even awakened by the crash. In view of: 1) The visually observed response of the children in the troop compartment to the crash (or the lack thereof) and 2) to the extremely large disparity between the probable actual decelerations (both peak and average values) and the limits of voluntary human tolerance to such loads, it appears clear that no hazard to life or health existed due the deceleration environment alone in the Saigon C-5A accident of April 1975.

For the convenience of the reader, copies of several human tolerance charts taken from reference No. 10 are included in the appendix.

CONCLUSIONS

It is the opinion of this author that it is a scientific certainty that the decelerations occurring in the April 4, 1975 Saigon C-5A accident did not provide a direct hazard to the life or health of the children or adults located in troop compartment of that aircraft. More specifically it is not possible that the magnitude of the crash decelerations were such as to result in brain damage for the seated occupants or to those adult occupants who remained in position throughout the crash.

APPENDIX I

For uniform (constant) deceleration the governing equation is:

$$G = \frac{V^2}{64.4S}$$

<u>where</u>:

V = Velocity in ft/sec
 = 270 knots = 456 ft/sec

S = Deceleration distance = 1950 feet

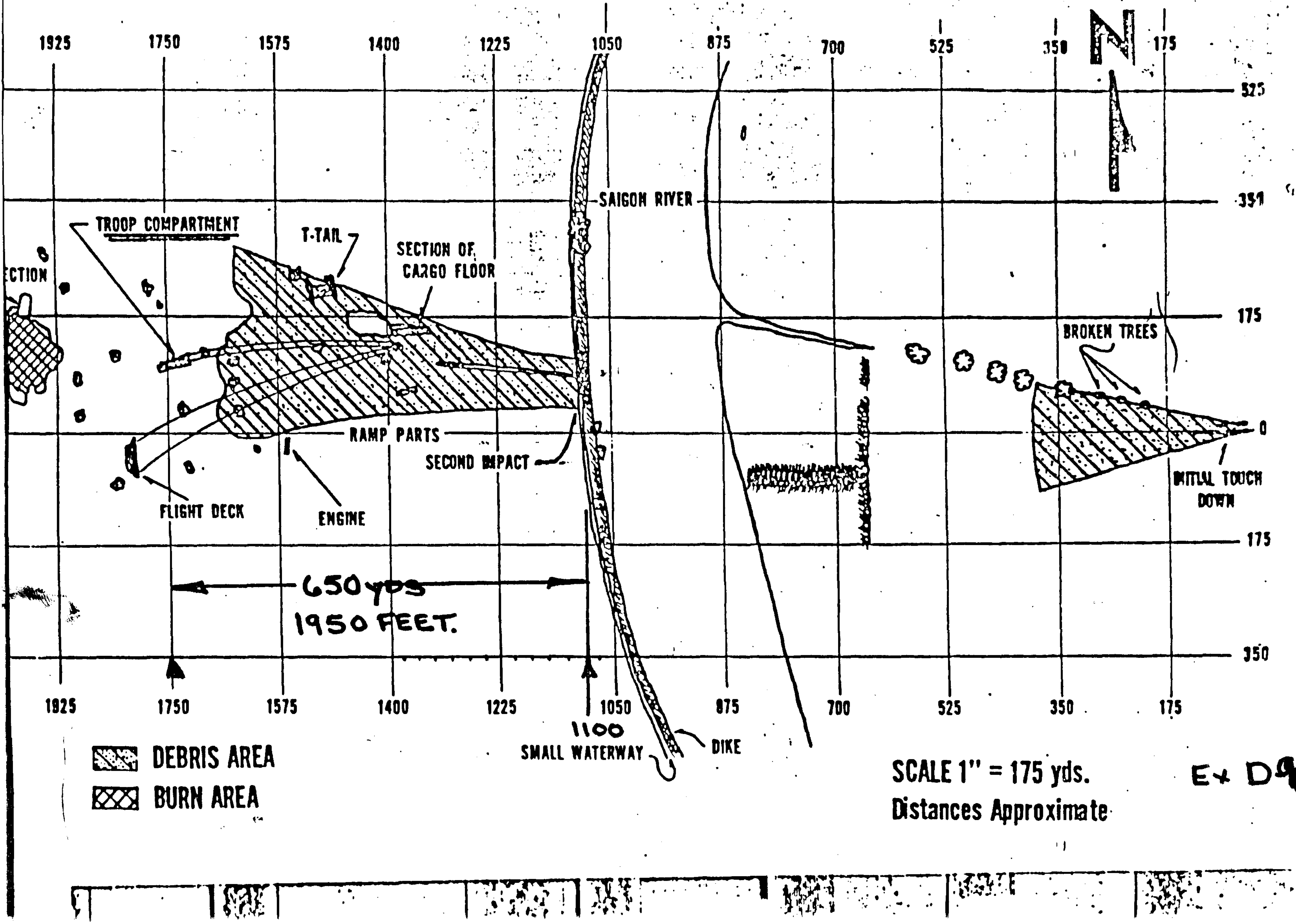
The constant 64.4 is twice the acceleration due to gravity or $2g = 2 \times 32.2 = 64.4$ ft/sec^2.

<u>Then</u>:

$$G = \frac{(456)^2}{64.4\ (1950)} = 1.66$$

APPENDIX II

C-5A SN 68-218 4 APRIL 1975



APPENDIX III

AD

USAAMRDL TECHNICAL REPORT 71-22

CRASH SURVIVAL DESIGN GUIDE

REVISED OCTOBER 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-69-C-0030
DYNAMIC SCIENCE (THE AvSER FACILITY)
A DIVISION OF MARSHALL INDUSTRIES
PHOENIX, ARIZONA

head velocity was that value of initial velocity which resulted in the impact material's being crushed to a predetermined value of strain. This strain value was dependent on the properties of the impact material chosen. The restriction on head deceleration was defined by human tolerance limitations. The head tolerance to impact is a function of pulse duration and average head decelerations as shown in Figure 5-7. In combination, these limitations define a maximum velocity curve as a function of original material thickness, above which absence of concussion (as defined by the tolerance limit of Figure 5-7) was doubtful, regardless of impact material characteristics. This curve is presented as Figure 5-8.

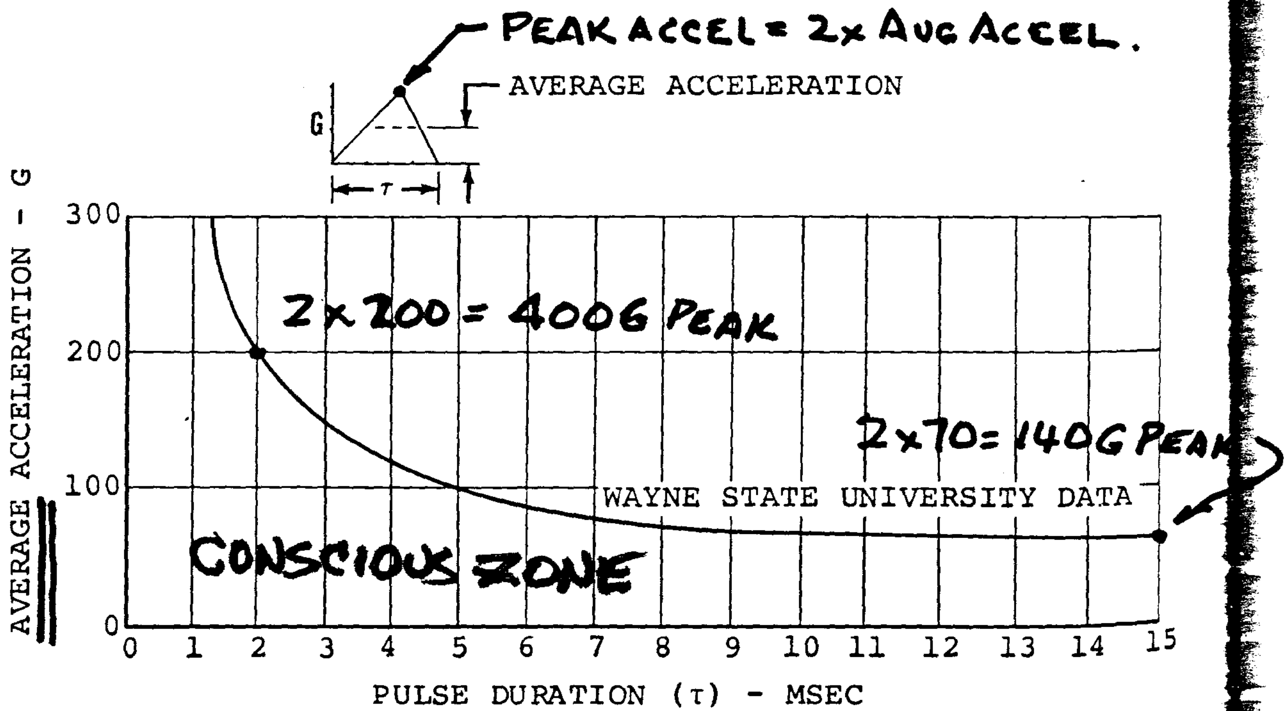


Figure 5-7. Head Tolerance to Impact as a Function of Pulse Duration as Published by Wayne State University.

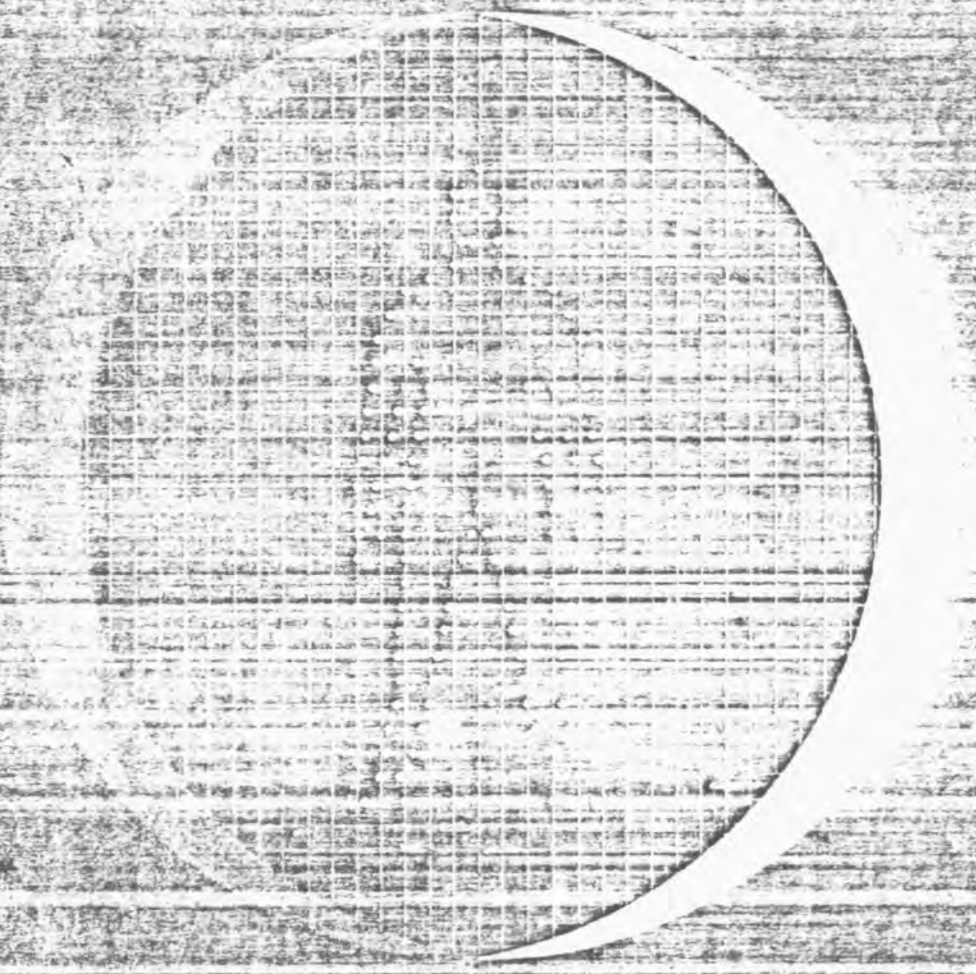
5.3.3.2 Head Impact Velocities: Figure 5-9 shows typical head velocities relative to the seat as measured on anthropomorphic dummies, cadavers, and live human subjects in dynamic seat tests. Various combinations of occupant restraint were used and are so indicated on each curve.

5.3.3.3 Geometry of Probable Head Impact Surfaces in U. S. Army Aircraft: Aircraft in the U. S. Army inventory in 1965 have been examined to determine the kinds of contact hazards

APPENDIX IV

TURNBOW

NASA SP-3006



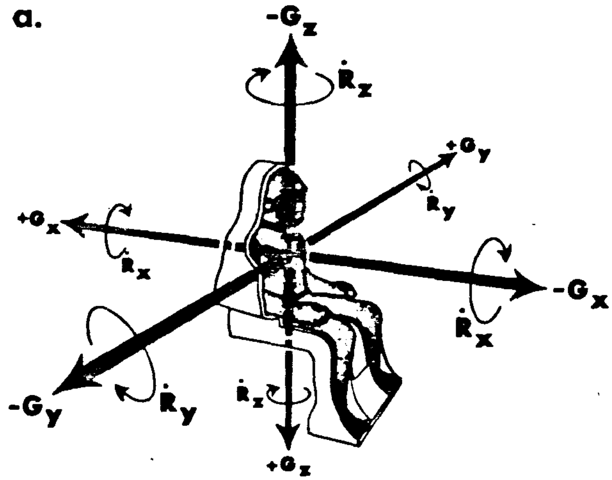
BIOASTRONAUTICS DATA BOOK

Contributor: Randall M. Chambers, Aviation Medical Acceleration Laboratory, USN.

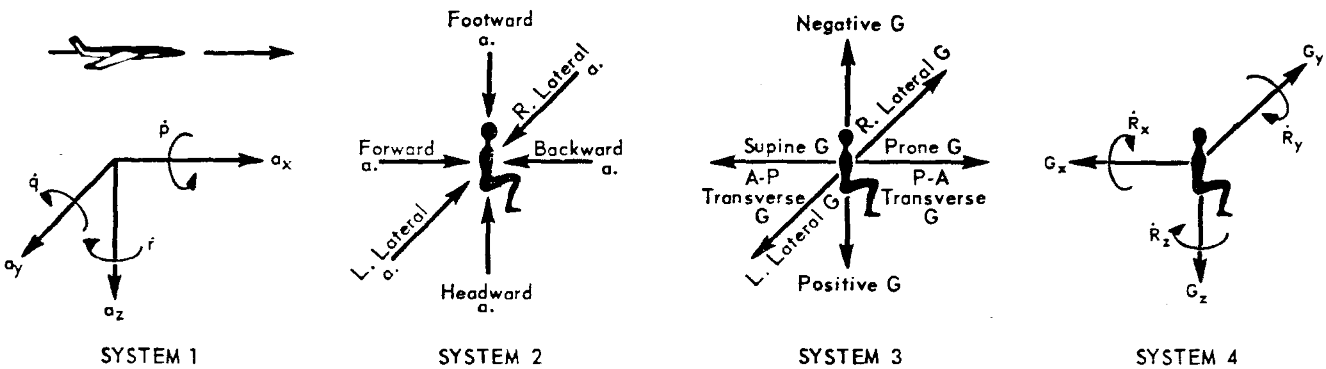
Symbols and vectors used in this book are based on the direction a body organ (e.g., the heart) would be displaced by acceleration. Table II below--and in particular System 4, which is based on displacement of body fluids--explains the most commonly employed terms.

Source: Adapted from Gell [18].

a.



b.



c.

Table I: Direction of Acceleration — Table II: Inertial Resultant of Body Acceleration

Linear Motion	Aircraft Vector (System 1)	Acceleration Descriptive (System 2)	Physiological Descriptive (System 3)	Physiological Displacement (System 4)	Vernacular Descriptive (System 5)
Forward	$+a_x$	Forward accel.	Transverse A-P G* Supine G Chest to back G	$+G_x$	Eyeballs in
Backward	$-a_x$	Backward accel.	Transverse P-A G Prone G Back to chest G	$-G_x$	Eyeballs out
Upward	$-a_z$	Headward accel.	Positive G	$+G_z$	Eyeballs down
Downward	$+a_z$	Footward accel. (tailward)	Negative G	$-G_z$	Eyeballs up
To right	$+a_y$	R. lateral accel. (rightward)	Left lateral G	$+G_y$	Eyeballs left
To left	$-a_y$	L. lateral accel. (leftward)	Right lateral G	$-G_y$	Eyeballs right
Angular Motion					
Roll right	$+\dot{p}$	cartwheel	Roll	$-\dot{R}_x$	
Roll left	$-\dot{p}$	cartwheel		$+\dot{R}_x$	
Pitch up	$+\dot{q}$	somersault	Pitch	$-\dot{R}_y$	
Pitch down	$-\dot{q}$	somersault		$+\dot{R}_y$	
Yaw right	$+\dot{r}$	pirouette	Yaw	$+\dot{R}_z$	
Yaw left	$-\dot{r}$	pirouette		$-\dot{R}_z$	

* A-P and P-A refer to Anterior-Posterior and Posterior-Anterior.

Source: Adapted from Gell [18].

ACCELERATION – INTRODUCTION

The spectrum of acceleration environments is extremely large and may vary in duration, magnitude, rate of onset and decline, and direction. Some acceleration exposures may be so mild that they have relatively no physiological or psychophysiological effects, or they may become so severe that they produce major disturbances. The emphasis of this section is primarily on human performance capabilities and physiological responses as they are modified by sustained acceleration. Abrupt accelerations and decelerations lasting less than two seconds are treated in Section 5, Impact and Vibration.

The unit for the physiological acceleration is G, as distinguished from the "true" displacement acceleration, generally designated by aerodynamicists with the unit g. The physiological acceleration represents the total reactive force divided by the body mass, and hence includes both displacement and resisted gravitational acceleration effects.

The physiological acceleration axes represent directions of the reactive displacements of organs and tissues with respect to the skeleton. Please refer to the accompanying diagrams and tables. The Z axis is down the spine, with $+G_z$ (unit vector) designations for accelerations causing the heart, etc., to displace downward (caudally). The X axis is front to back, with $+G_x$ designations for accelerations causing the heart to be displaced back toward the spine (dorsally). The Y axis is right to left, with $+G_y$ designations for accelerations causing the heart to be displaced to the left.

Angular accelerations which cause the heart to rotate (roll) to the left within the skeleton are specified by the $\dot{R}_x$ unit vector, representing radians/sec^2 about the X axis. Angular velocities in the same sense are specified by the $+R_x$ unit vector, representing radians/sec about the X axis. Similarly, $+\dot{R}_y$ represents an angular acceleration producing a pitch down of the heart within the skeleton, and $+\dot{R}_z$ represents yaw right of the heart within the skeleton.

The field of acceleration research has produced a number of general principles concerning the effects of acceleration stress on physiology and performance. The following statements, many of which are illustrated in the charts of this section as shown, are hoped to be useful to designers of aerospace vehicles and equipment.

1. Physiological tolerance, or the ability to withstand acceleration physiologically, is a function of many variables--e.g., rate of onset (3-2); direction of G vector (3-3); magnitude of G (3-2); duration (3-4)--as well as the type of endpoints that are used as criteria.

2. In addition to the physiological tolerance limits which define the end points for reliable functioning of any particular physiological system during exposure to acceleration stress, there are also performance tolerance limits, which define the end points for reliable functioning of any particular performance ability.

3. Physiological and performance tolerances may be functionally related, but they need not be the same, since each is dependent upon the criteria used.

4. During exposure to acceleration stress, the type of G-protection system used has a very important influence on the pilot's ability to tolerate acceleration (chart 3-5), perform tasks, and maintain performance proficiency.

5. For an acceleration of given rate of onset and magnitude, physiological tolerance is highest for $+G_x$, next for $-G_x$, next for $+G_z$, and lowest for $-G_z$, directions of force. See 3-3.

6. Acceleration stress significantly impairs visual capabilities. As acceleration increases, visual acuity decreases (see 17-30), illumination requirements increase, and brightness contrast requirements decrease (3-10 and 3-11).

7. Major individual differences exist among pilots in their ability to perform piloting tasks during exposure to high G.

8. Certain types of acceleration exposures produce illusions, or false perceptions, of one's position and motion. These may occur in some pilots during or after the acceleration exposure.

9. Since acceleration training results in physiological adaptation and conditioning to G, as well as learning to make performance compensations, acceleration training produces major improvements in performance proficiency during exposure to high G.

10. The instrument display characteristics of a piloting task influence the measurement of performance capabilities of a pilot during exposure to high G. Among the more important display characteristics are: the position of the display instrument within the pilot's visual field, the degree of interpretation required of the pilot, the number of instruments that must be viewed by the pilot during high G, the amount of illumination, the amount of brightness contrast, the physical form in which the display information is presented, and the amount of visual instrument scanning that is required at high G.

11. The characteristics of the control device used by the pilot in performing under G have a significant effect upon proficiency. These characteristics are: the number of axes of motion; the location of the axes of motion with respect to the G and the pilot's hand; stick force gradients along each mode of control; the centering characteristics along each mode of control; dead band zone; breakout force requirements; control friction; static and dynamic balance; damping characteristics; control throw; response time of control; control harmony; cross coupling characteristics; size and shape of grip; dynamic and static balance; and control sensitivity (3-16).

12. Acceleration impairs the ability of the pilot to sense changes in control characteristics that may occur as a function of specific acceleration vectors. This may be a direct effect of the acceleration forces on the receptors, effects on the central or autonomic nervous system, or an effect on circulatory and other physiological systems which indirectly affect the ability of the pilot to sense changes in his arm, hand, and fingers.

13. Task characteristics that are relatively easy to perform in low-G environments become more difficult as G increases.

14. Intellectual skills, piloting concentration, time perception, judgment, and immediate memory are influenced by high G.

15. Response time, as well as complex psychomotor performance, is influenced by high G (3-13).

16. Anticipation of acceleration may produce emotional reactions that are greater in terms of psychophysiological impairment than the direct effects of acceleration itself.

17. If, in addition to acceleration stress, the pilot is exposed to other environmental stresses, his responses may be altered by the combined effects of these stresses. (See Section 9).

Positive (G_z) and transverse (G_x) accelerations have been emphasized in studies to date, while lateral and angular accelerations have received relatively little attention, primarily because of the lack of proper research facilities.

Some limitations in interpreting acceleration research data are: (a) most studies have been conducted on a small number of subjects; (b) repeated exposure to acceleration changes a subject's G tolerance, and this factor is usually not included; (c) emotional condition and motivation influence results; (d) instrumentation has not been standardized for measuring the effects of G on physiology and performance.

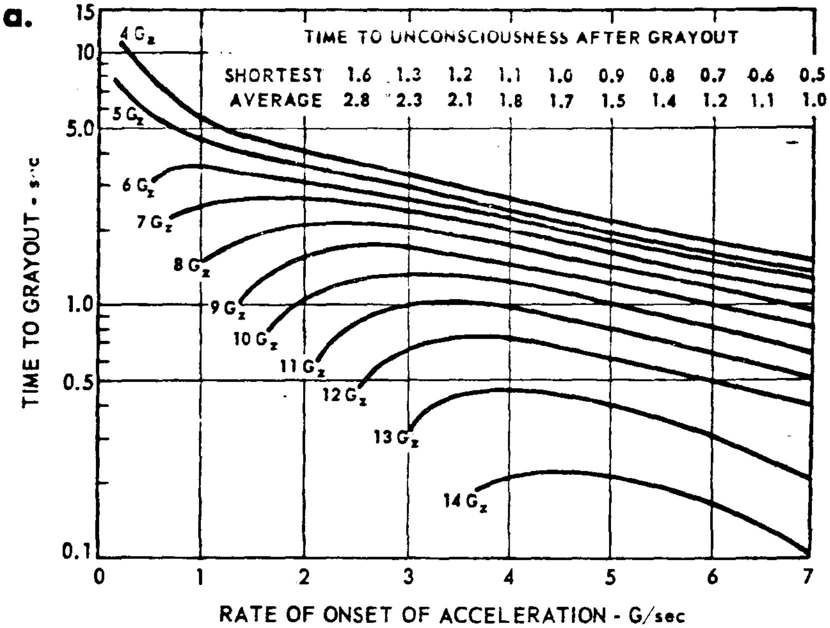
Recommended for general reading are the following: Otto H. Gauer and George D. Zuidema, Gravitational Stress in Aerospace Medicine [17]; Neal M. Burns, Randall M. Chambers, and Edwin Hendler, Unusual Environments and Human Behavior: Physiological and psychological problems of man in space [5]; and C. C. Clark, J. D. Hardy, and R. J. Crosbie, A Proposed Physiological Acceleration Terminology with an Historical Review [12].

GRAYOUT AND RATE OF ONSET OF $+G_z$

This graph relates the onset rate of acceleration to time-to-endpoint. It shows that for any given positive acceleration (G_z) from 4 to 14 G, the time to grayout depends on how rapidly the acceleration level was reached. Further, the table inset in the graph shows the shortest times and the average times for unconsciousness to develop following grayout, each pair of values being related to an onset rate. For example, at onset rate of 4 G/sec, the shortest time to unconsciousness was 1.1 sec, and the average 1.8 sec.

Source: Stoll [26].

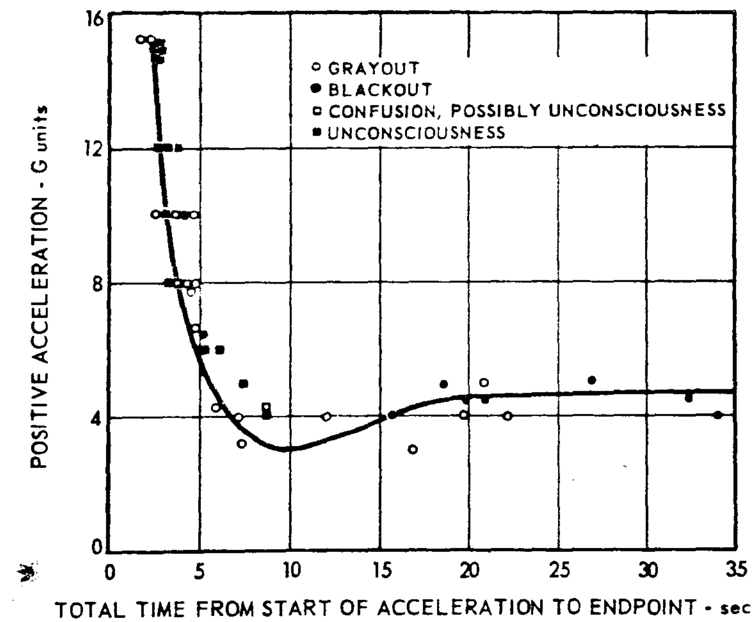
a.



This graph shows human tolerance to positive G_z for varying rates of onset, G amplitudes, and exposure times.

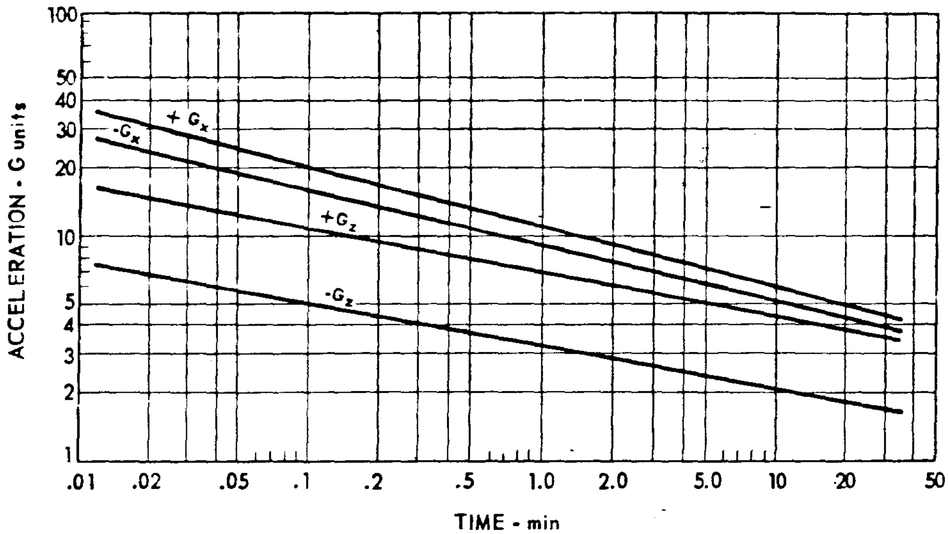
Source: Adapted from Stoll [26].

b.



3-3. G TOLERANCE IN FOUR VECTORS

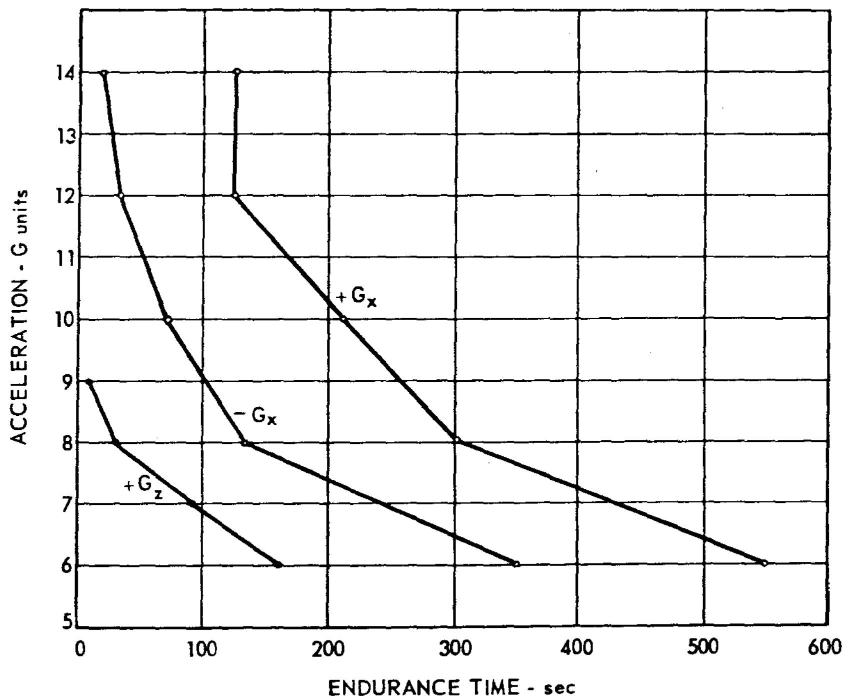
a.



Average acceleration tolerance is shown for positive acceleration ($+G_Z$), negative acceleration ($-G_Z$), transverse supine accleration ($+G_X$), and transverse prone acceleration ($-G_X$).

Source: Chambers [7].

b.

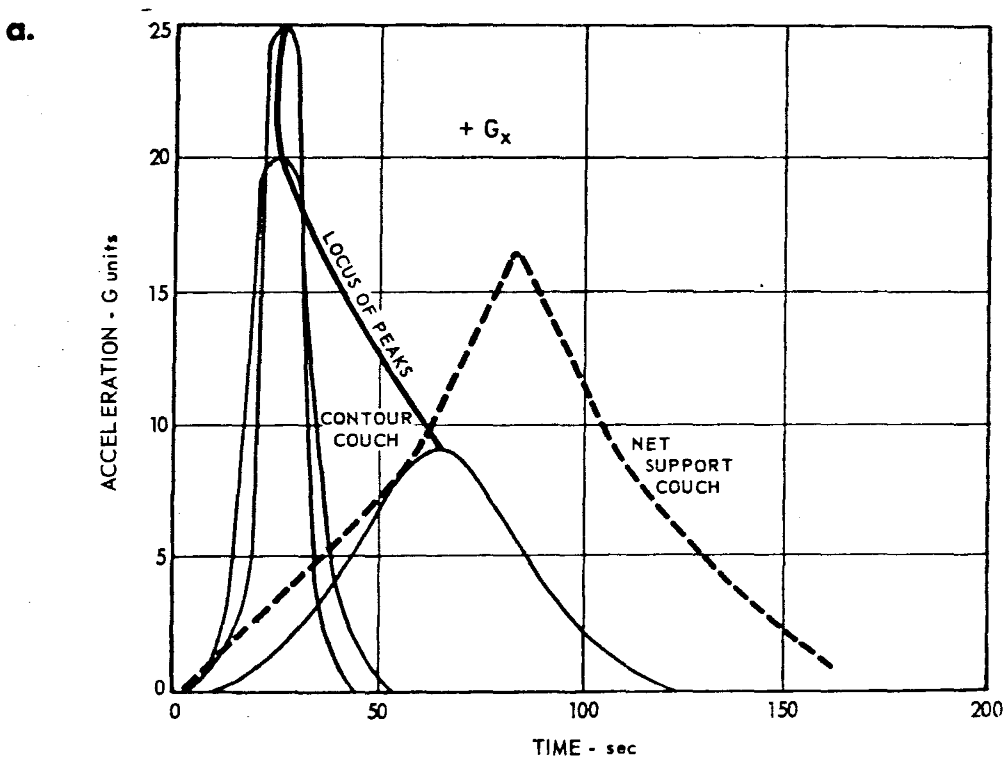


Upper limits of voluntary endurance (as contrasted with average tolerance, shown above) are plotted for a group of highly motivated test pilots, preconditioned to the effects of acceleration and suitably restrained. The pilots were able to operate satisfactorily a side-arm control device to perform a tracking task throughout the times indicated.

Source: Chambers and Hitchcock [9].

3-4. MAXIMUM TOLERABLE ACCELERATION PROFILES

a.



b.

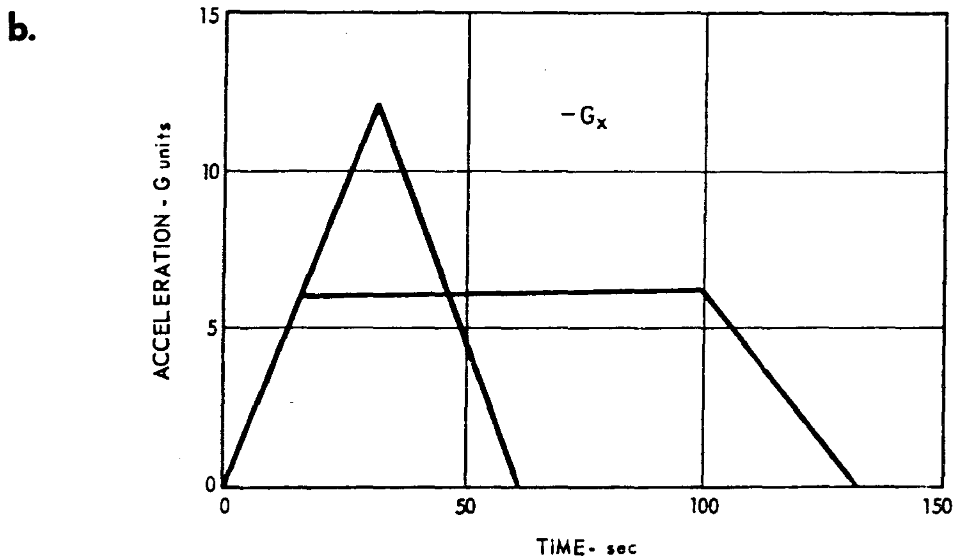
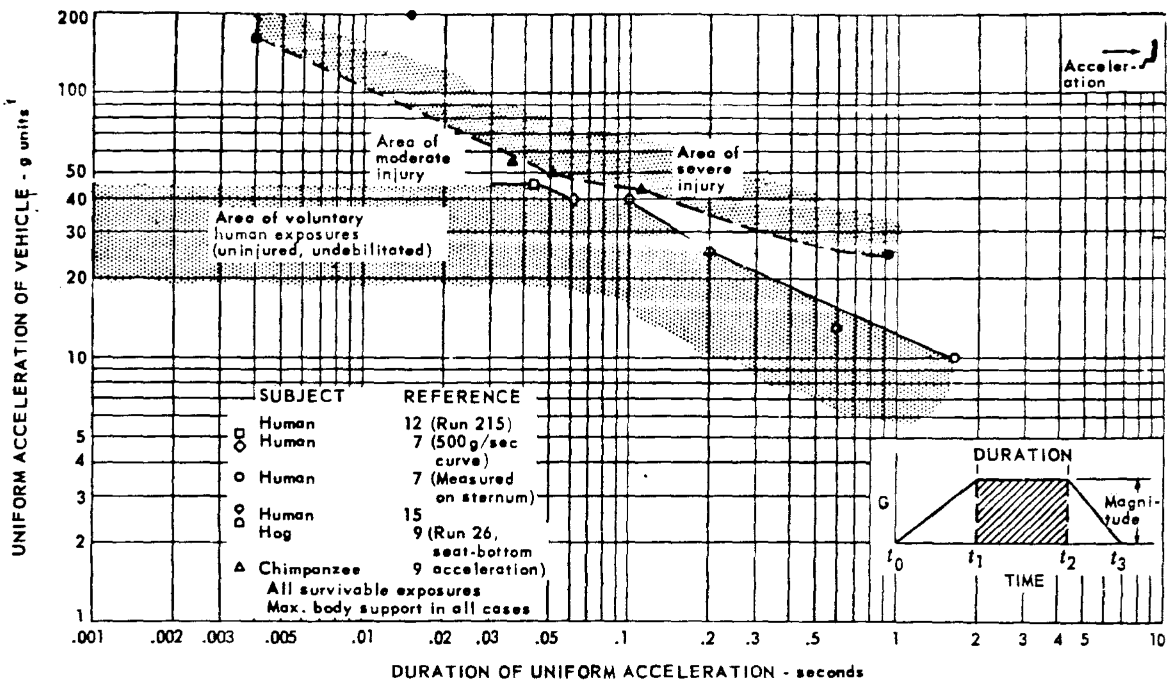


Figure a shows the greatest acceleration-time histories that have been tolerated on centrifuges when special support structures and positioning are used. Solid lines show three curves which define about the same area of $+G_x$ times time. A heavy line connects the peaks of these three curves and locates the peaks of other curves enclosing the same area. The dashed line encloses a number of possible acceleration profiles related to space flight, all of which are tolerable, since the border of the envelope has been tolerated experimentally. Figure b depicts two tolerable $-G_x$ accelerations (eyeballs out) when the subject is restrained in a special harness.

Sources: Bondurant et al. [4]; Clarke et al. [13]; Lawton et al. [24]; Collins et al. [14]; and Collins and Gray [15].

Contributor: Paul Webb, Webb Associates

a.

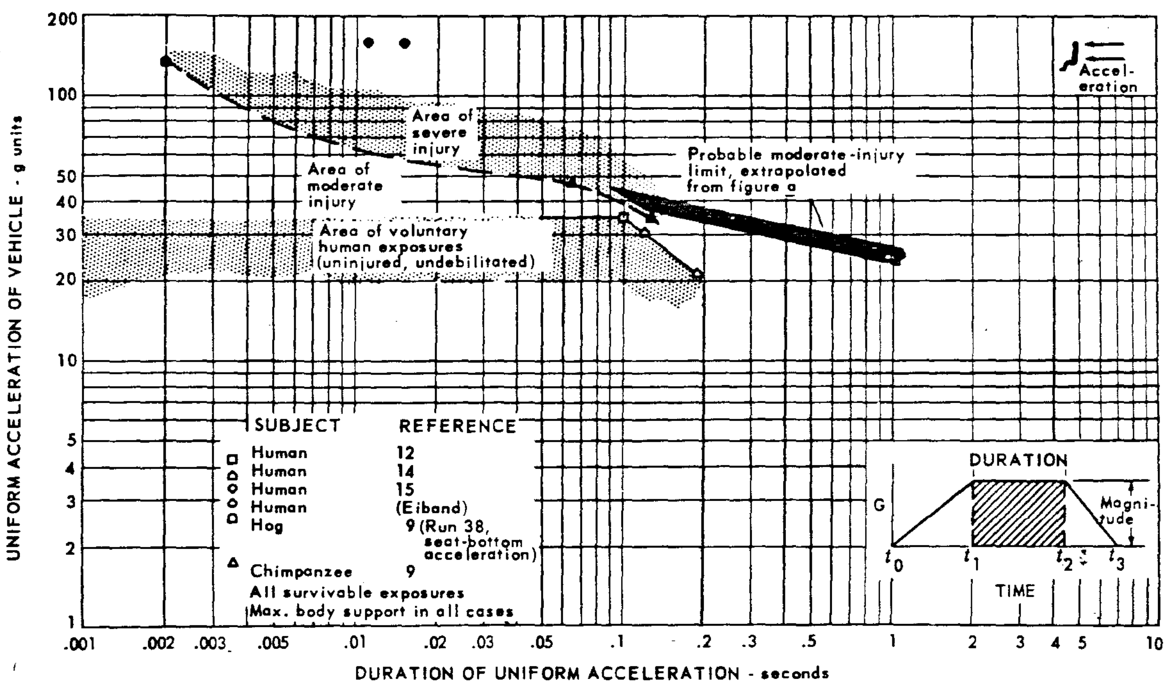


These two graphs show the durations and magnitudes of abrupt transverse decelerations which have been endured by various animals and man, showing areas of: voluntary endurance without injury; moderate injury; and severe injury. Graph a summarizes $-G_X$ data (back to chest acceleration) and b shows $+G_X$ data (chest to back acceleration). Reference numbers on the graphs are those in the original reports.

Source: Eiband [5].

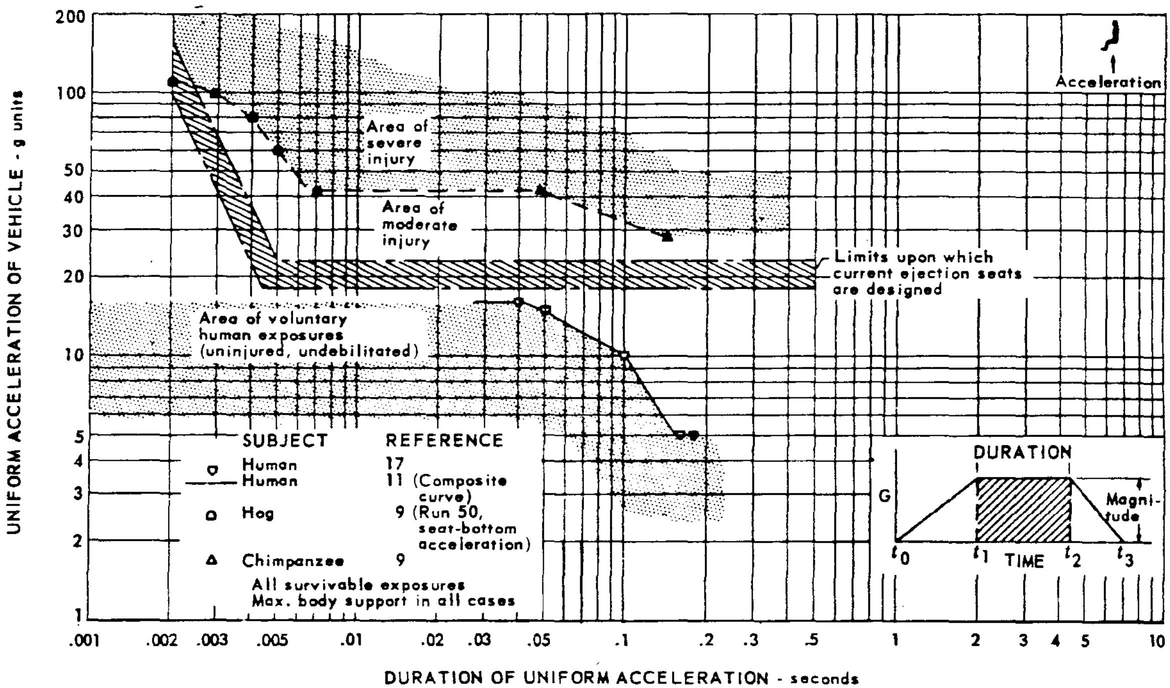
REARWARD FACING

b.



ABRUPT LONGITUDINAL DECELERATIONS

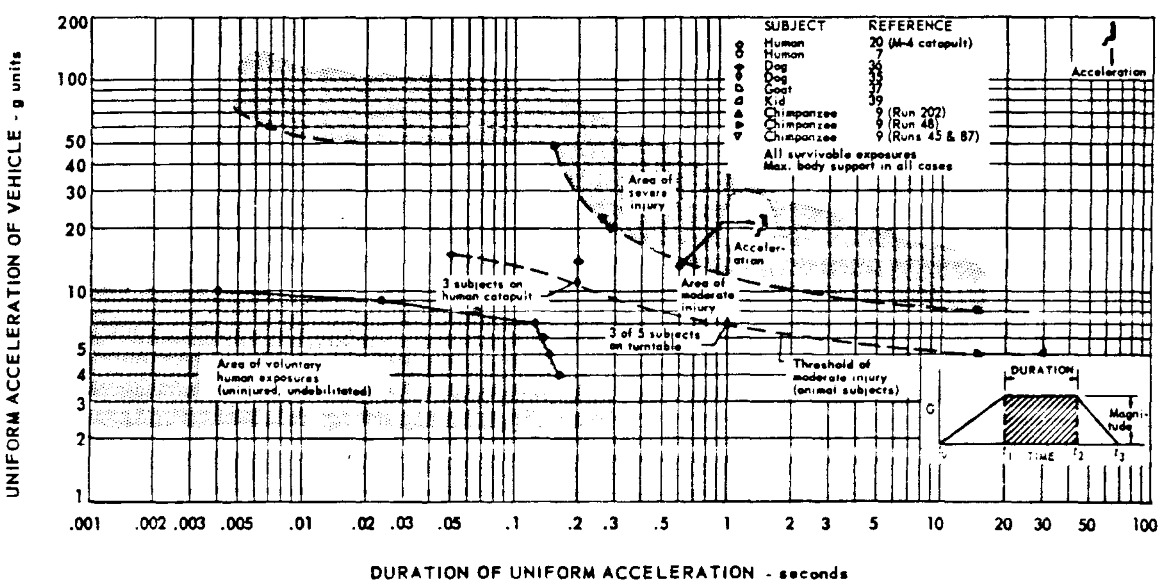
a.



These two graphs show the durations and magnitudes of abrupt deceleration in the G_z (longitudinal) directions which have been endured by various animals and man, showing areas of voluntary endurance without injury, moderate injury, and severe injury marked by shading. Graph a shows data of $+G_z$ acceleration (headward), and b shows data for $-G_z$ acceleration (tailward). Reference numbers on the graphs are those in the original reports.

Source: Eiband [5].

b.



ARIZONA STATE UNIVERSITY

James W. Turnbow
Professor of Engineering

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Ph. D.	University of Texas, 1959
M.S.E.M.	University of Texas, 1952
B.S.M.E.	Texas Technological College, 1940

Academic Experience:

1971-	Director Crash Injury Investigators School, Arizona State University
1959-	Arizona State University, Professor
1948-59	University of Texas, Assistant Professor
1948	Texas Technological College, Student Instructor
1940-41	Oklahoma A. & M. College, Instructor

Industrial Experience:

5/44-9/47	North American Aviation, Design Engineer
7/41-4/44	U. S. Army, Captain, Ordance Department

Consulting Experience:

1972-	Aviation and Automotive Accident Investigation for various legal firms
1/72	Consultant to Sikorsky Aircraft, Stratford, Connecticut
9/60-6/69	Consultant to the Flight Safety Foundation, AvSER Div., Phoenix, Arizona
9/54-9/59	Balcones Research Center, University of Texas, Research Engineering

Awards, Scholarships, and Honor Societies:

Tau Beta Pi
Alpha Chi
Convair Excellence in Teaching Award, U. of Texas
Honor ME Graduate, Texas Tech
Honor Military Graduate, Texas Tech
Sigma Xi Member

Membership in Scientific and Professional Societies:

Registered Professional Engineer, Texas and Arizona

Principal Areas of Research and Teaching Interest:

Dynamics, Vibration, Impact, Space Mechanics, Aviation and Automotive Safety

Principal Publications:

"Cushioning for Air Drop, Part I," (with other authors). Published for the Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois, July 1955, 80 pp.

"Cushioning for Air Drop, Part II, Air Drop Cost Analysis," (with C. C. Steyer). Quartermaster Food and Container Inst. for the Armed Forces, Chicago, Ill., April 1956, 37 pp. Unscheduled presentations of portions of this work were presented by Dr. Turnbow at two meetings: (a) Aerial Delivery Research Contractors Coordination Meeting at the Midwest Research Inst.,Kansas City, Mo., Jan., 1956, and (b) The Aerial Delivery Research Symposium at Fort Lee, Virginia, April 1956.

"Cushioning for Air Drop, Part III, Characteristics of Paper Honeycomb under Dynamic Loading," Quartermaster Research and Engineering Command, Natick, Massachusetts, August 1956, 9 pp.

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VITAE

JOHN EDWARDS:

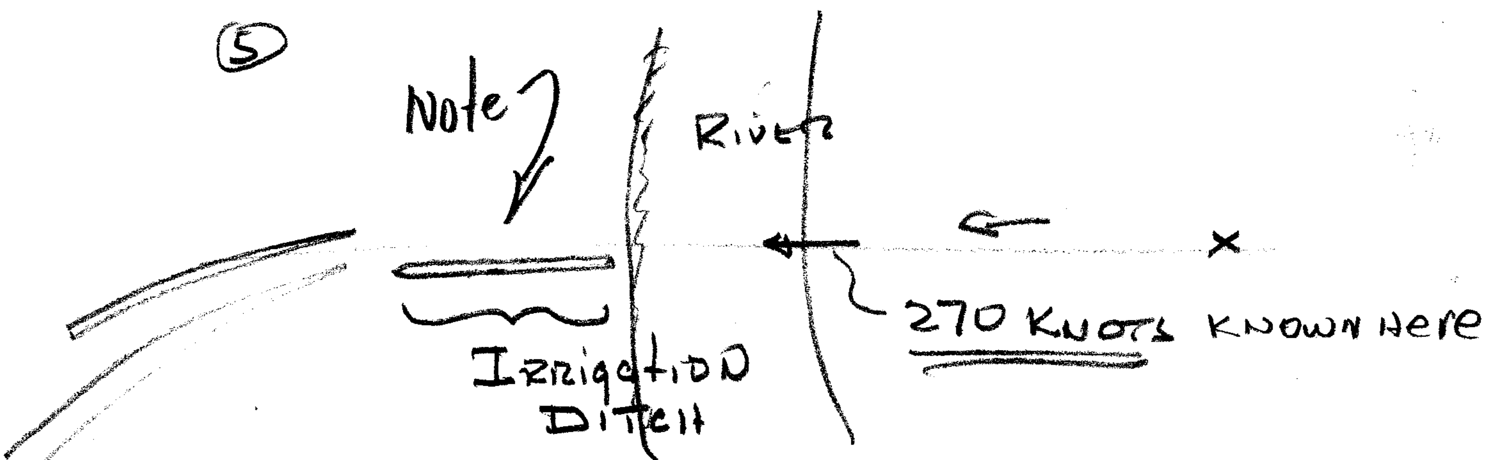
(1) 2 Fwd Main gears (wheels) put swath Between River & Dike.

(2) Nose gear DID NOT put down swath Between River and Dyke

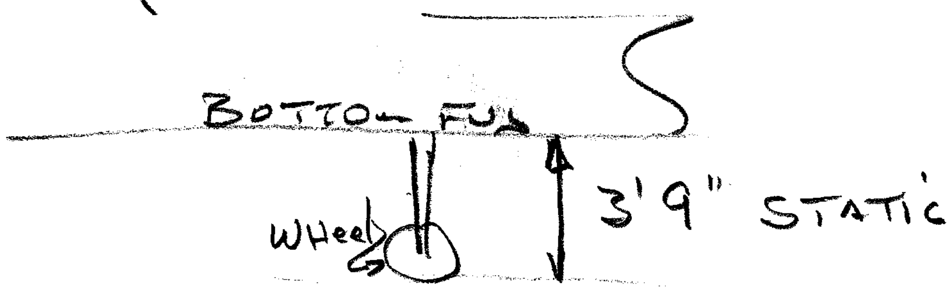
(3) Nose gear & Fwd Main gear were Removed by Dike (5' high & 5' wide)

(4) A/C then stayed on gnd & eroded soil/water

(5)



(6)



(7) Seat design 16 G — 200 # man X axis
FLOOR ATTACH 9G — X axis

(8) ONLY ONE INFANT DIED (STRANGULATION)

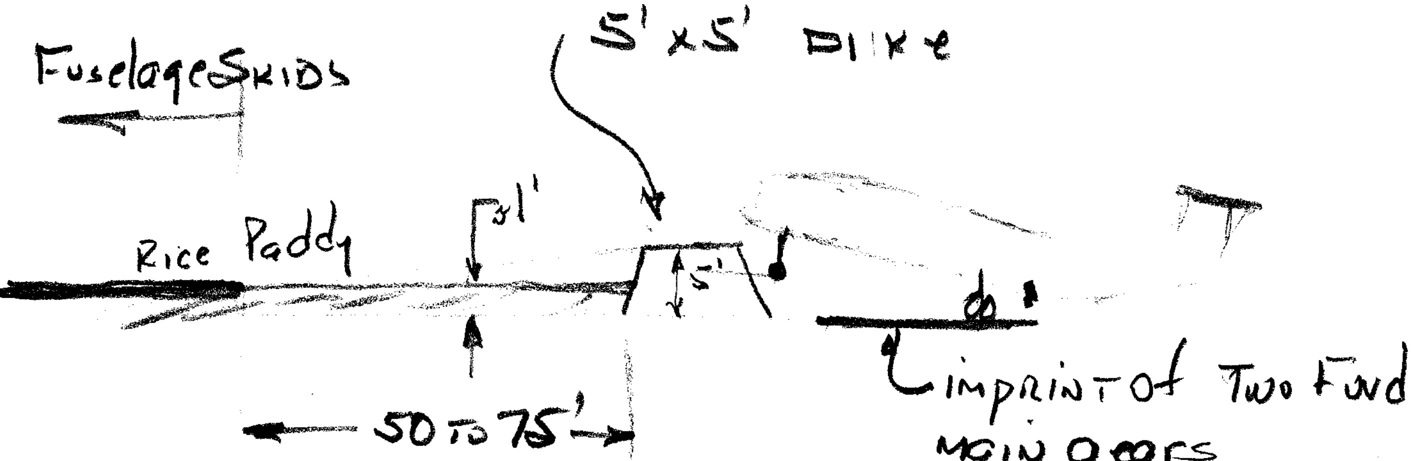
(9) ~~IN TROOP compartment~~ Two Adults died in Troop Compartment - unrestrained

(10) At least one (Possibly 2) adults were injured on being thrown forward down an isle. The one (a nurse) had a back injury.

(11) Two fwd facing loadmaster seats came loose (folded fwd?) as a result of improper installation.

(12) Condition at 1st touchdown:

(13) Condition of 2nd touch down,



JOHN EDWARDS

Day 404-424-4004 (Georgia)

Home 404-952-4865 (night)

Collateral Report — see page

70, 55,

160,000 – LL
240,000 – U.L. FOR each
of 4 years.

Attachment F to Req 0001 5.0

(APPENDIX "A" ITEM 42)

TASK NO. 5

TASK DESCRIPTION

DETERMINE EFFECTS OF DUMPING CABIN PRESSURE INSTANTANEOUSLY TO CAVITY AFT OF PRESSURE DOOR.

DISCUSSION

THIS TASK WAS ANALYZED IN TWO PARTS. THE FIRST ANALYSIS IS FOR THE PRESSURE FELT ON THE TORQUE DECK DUE TO THE INITIAL EXPANSION SHOCK WAVE (REF. ATTACHMENT 1). THE SECOND ANALYSIS IS FOR DYNAMIC PRESSURE ("Q") DUE TO THE AIR FLOW ACROSS THE SLOPING TORQUE DECK.

ANALYSIS

1. EXPANSION SHOCK WAVE

ATTACHMENT 1 STATES THE TORQUE "DECK WILL FEEL AN UPWARD PRESSURE PULSE WITH A PEAK VALUE THAT COULD APPROACH THE INITIAL CABIN PRESSURE". IF THE "MILLISECONDS" QUOTED IN ATTACHMENT 1 IS SUFFICIENT TIME FOR THE STRUCTURE TO RESPOND, THEN THE SLOPING TORQUE DECK WILL FAIL.

2. DYNAMIC PRESSURE

A PLOT OF THE DYNAMIC PRESSURE ("Q") (ATTACHMENT 1) GIVES A "Q" OF 1.57 PSIG. AS STATED IN THE ATTACHMENT THE PRESSURE ACROSS THE TORQUE DECK IS THE VALUE "Q" ABOVE COMBINED WITH THE INTERNAL PRESSURE REQUIRED TO BLOW OR VENT THE AFT CARGO DOOR OR DOORS.

-r- ANALYSIS INDICATES THE AFT DOORS WILL OPEN WHEN CAVITY PRESSURE EXCEEDS THAT SHOWN IN FIG. 2.

-r- DETAIL ANALYSIS INDICATES THE TORQUE DECK BETWEEN F.S. 2101 AND F.S. 2273 (SEE FIG. 1) WILL FAIL WITH AN UPWARD ΔP OF 1.0 PSIG NORMAL TO THE DECK. THEREFORE, THE TORQUE DECK WILL FAIL WITH AN INSTANTANEOUS DECOMPRESSURIZATION THROUGH THE AFT OPENING COMPLEX.

ASSUMPTIONS USED IN ANALYSIS

ANALYSIS BASED ON 6.5 PSIG CABIN PRESSURE.

-r- Revised to agree with Detail Analysis, 5/12/75

LOCKHEED-GEORGIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
INTERDEPARTMENTAL COMMUNICATION

ATTACHMENT 1 - TASK 5

TO W. M. Perry DEPT. 71-30 ZONE 80 DATE 18 April 1975

E-47-28-75

FROM W. E. Huie, Jr. DEPT. 72-47 ZONE 13 EXT. 4999

SUBJECT: C-5A CARGO COMPARTMENT DECOMPRESSION

A study has been conducted to determine the pressure effects on the aft fuselage structure if the aft pressure door fails open in a manner assumed to be "instantaneous and complete". This means that the entire door area is assumed to be open for decompression flow from the cabin.

8,500 5,200

Assuming initial compartment pressures of 5.0, 6.2, and 8.3 psig at an altitude of 23,500 feet, the cargo compartment will completely depressurize in 0.41 sec., 0.45 sec., and 0.53 sec., respectively. The initial expansion will produce a shock wave which will travel outward and impinge upon the downstream structure. The exact nature of this shock is very complex, but almost coincident with the pressure door failure, the torque deck will feel an upward pressure pulse with a peak value that could approach the initial cabin pressure. The duration of this pressure peak is an extremely short time (milliseconds) however. As the airflow pattern develops, the static pressure aft of the pressure door opening increases to the value required to open the cargo doors. During this period of static pressure buildup, the sloped portion of the torque deck also feels a normal component of the airflow's dynamic pressure or "q". This "q" component is estimated to be 1.25 psi, 1.5 psi, and 2.1 psi, respectively at initial cabin pressures of 5.0, 6.2 and 8.3 psig. In other words, if the cargo doors open due to pressure, the maximum pressure differential across the sloped torque deck should exceed the maximum static pressure on the cargo doors by the amount of the "q" component. For example, if the initial cabin pressure is 6.2 psig and the cargo doors open at 2.0 psig, the maximum ΔP across the sloped torque deck is 3.5 psi upward. After the cargo door failure, the torque deck ΔP drops to 1.5 psi or less, depending upon the cabin pressure at that instant. As the cabin depressurizes, the torque deck ΔP drops to zero or whatever ΔP exists between the tailcone vent and the exposed underside of the torque deck. All of this action occurs within the cabin depressurization times shown above.

If the cargo doors open due to mechanical action before any static pressure buildup on them, the ΔP across the torque deck is limited to the "q" component for the period of time it takes to depressurize the cargo compartment.

W. E. Huie, Jr. [signature]

W. E. Huie, Jr.

APPROVED: [signature]

G. G. Lee, Acting Manager
Propulsion & Acoustics Department

WEH:rn

AFT BODY TORQUE BOX

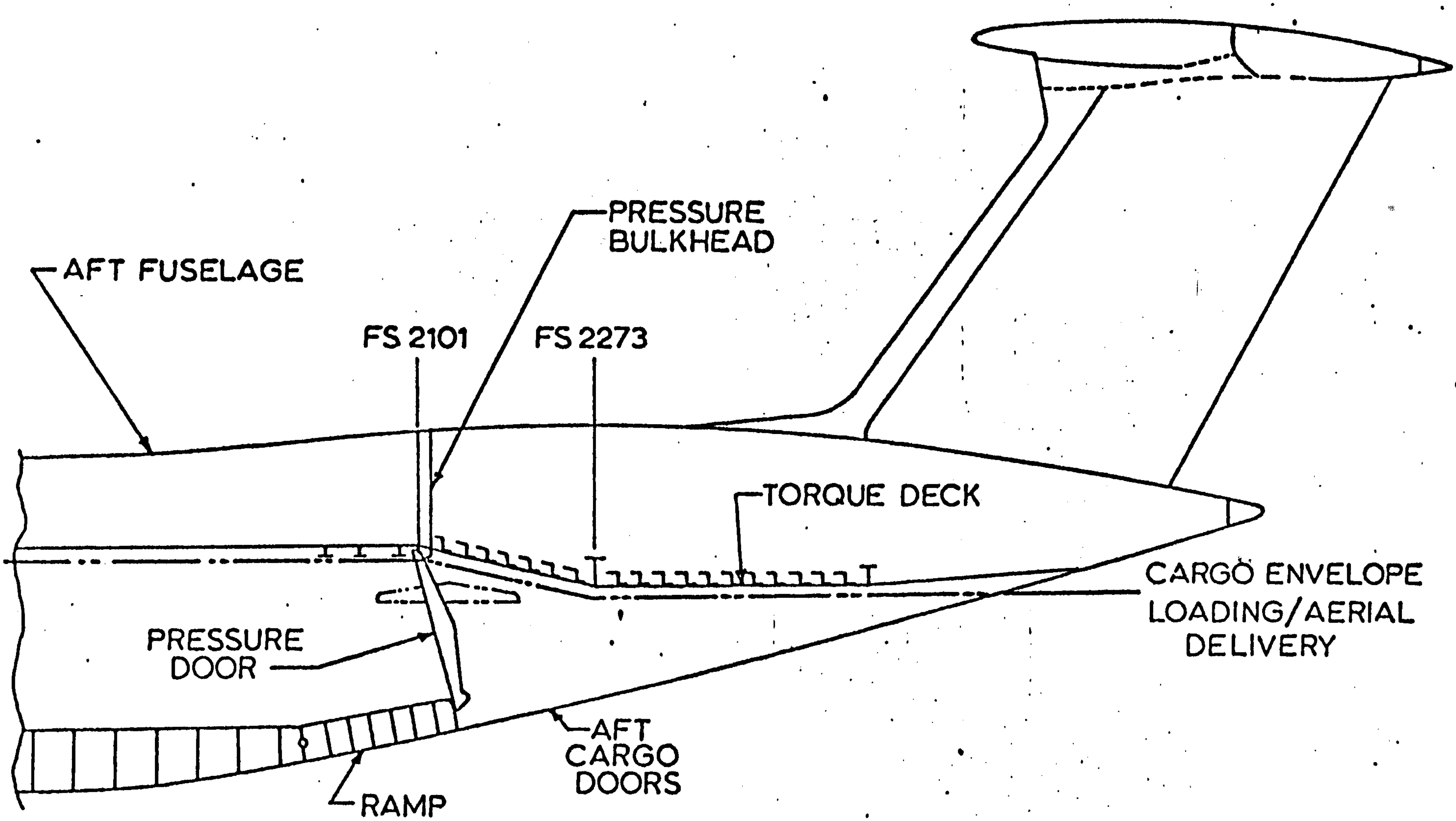


FIGURE 1 - TASK 5

	NAME	DATE	LOCKHEED-GEORGIA COMPANY A DIVISION OF LOCKHEED AIRCRAFT CORPORATION	Page	TEMP. 5.3	PERM.
Prepared	LANTZY	5/9/75				
Checked			TITLE AFT CARGO DOORS	Model C-5A		
Approved				Report No.		

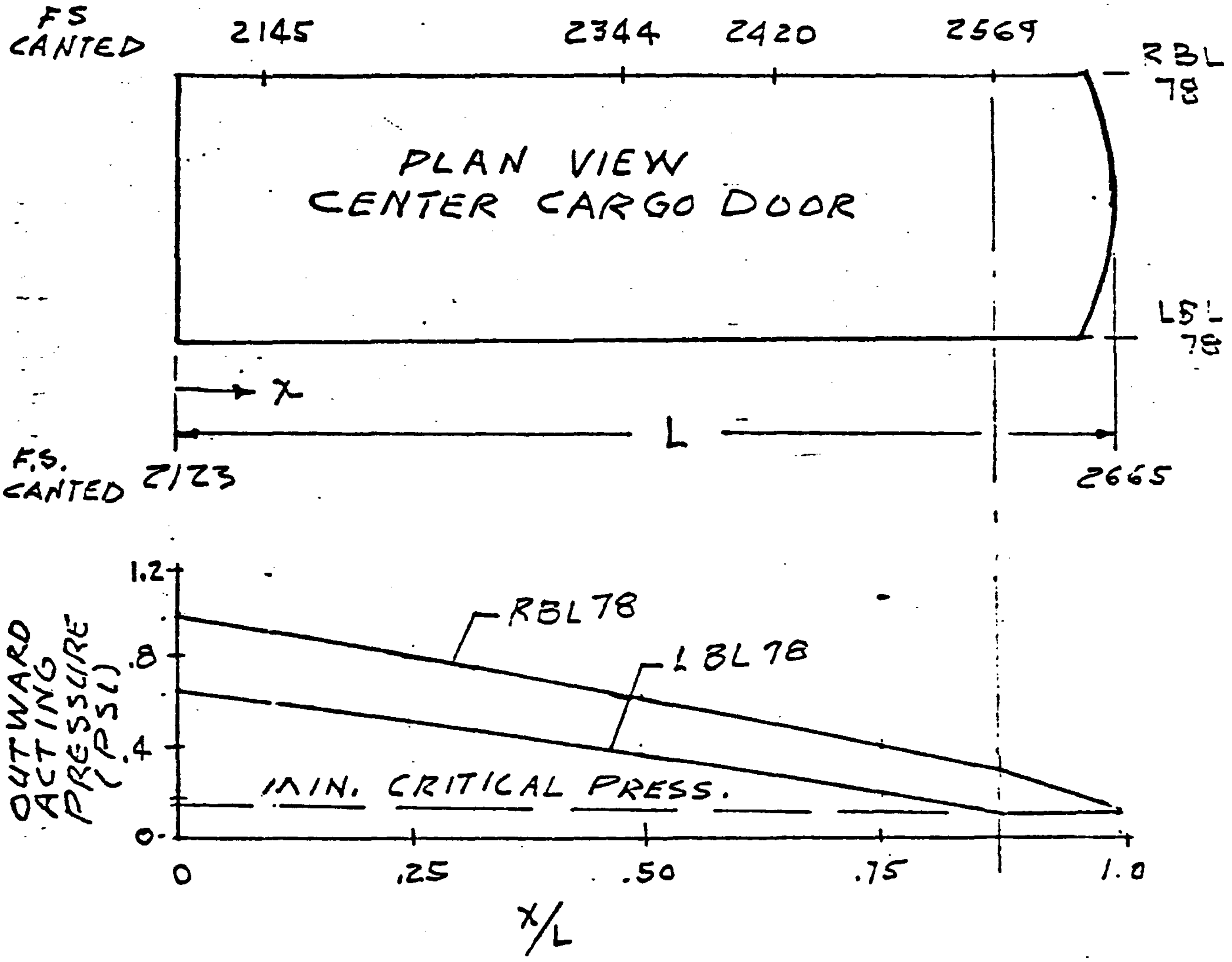
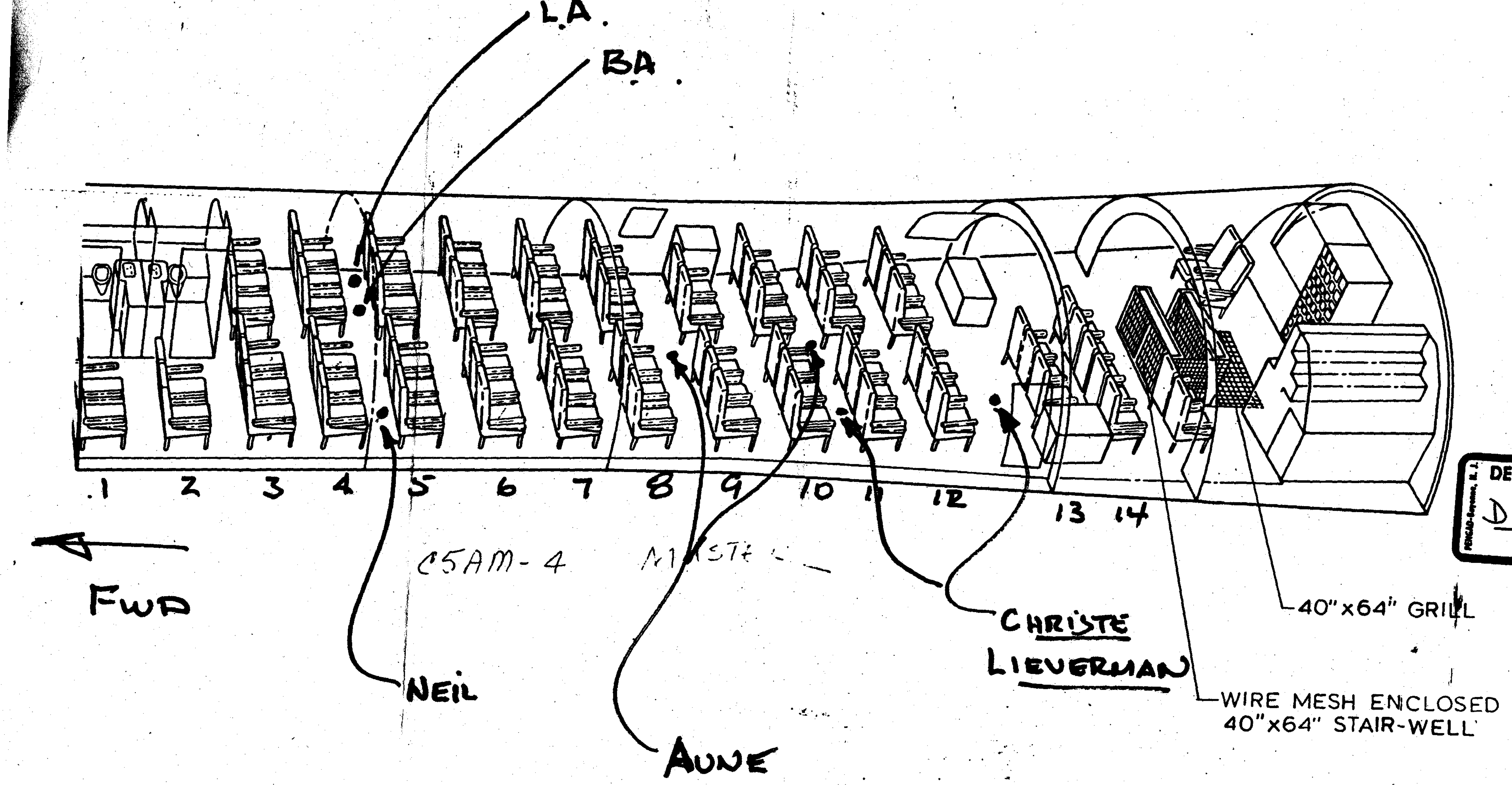


FIG. 2: CENTER CARGO DOOR BLOW-OUT PRESSURE △1

TASK 5

△1 INCLUDES AERODYNAMIC PRESSURES ON DOOR



DEFENDANT'S EXHIBIT D1210

ANALYSIS OF 'G' LEVELS ASSOCIATED WITH THE C-5A ACCIDENT NEAR SAIGON

APRIL 4, 1975

by

James W. Turnbow, Ph.D.

Consultant - Aviation Safety

Analysis of 'G' Levels Associated
With the C-5A Accident Near Saigon
April 4, 1975

by

James W. Turnbow, Ph.D.
Consultant - Aviation Safety

References Used:

The following analyses and conclusions are based in part, but are not limited to, a review of the following documents:

1. USAF Collateral Report, Vols. I, II, III.

2. Photographs of the aircraft prior to and following the accident.

3. Photographs of the accident site.

4. Miscellaneous drawings of the C-5A aircraft.

5. Sworn statements of:

   Regina Aune
   Tilford Harp
   Christine Lieverman
   Keith Malone
   Marcia Tate

6. Depositions and/or trial testimony of the following:

   Regina Aune
   Tilford Harp (co-pilot)
   Christine Lieverman
   Harriett Neill
   Merritt Stark
   Marcia Tate
   Dennis Traynor (pilot)
   William Timm
   John Edwards

7. Wreckage Distribution Diagram.

8. Cutaway view of C-5A troop compartment.

9. NASA Technical Report SP-3006 'Bioastronautics Data Book,' 1964.

10. USAF Technical Report No. 5915 Part 2, 1961, 'Human Exposures to Linear Deceleration,' 1951.

11. USAAMRDL Technical Report 71-22, 'Crash Survival Design Guide,' 1971.

12. Plots of the Data Obtained from the onboard recorder (MADAR).

13. The author also draws on some 20 years of experience in aircraft accident reconstruction and full scale crash testing of aircraft. A vitae is attached for convenience of the reader.

ACCIDENT SYNOPSIS

The crash of this aircraft consisted of two ground contacts separated by approximately <u>875</u> yards of free flight. The analysis of the data available shows the following concerning these two contacts:

Contact No. 1

This contact has been characterized by several of those aboard the aircraft as 'a near normal touch down' or 'no more than a hard landing typical of military or commercial aircraft.' The sink rate was reported to be 500 to 600 feet per minute by one of the cockpit crew (Mayor Traynor), a fact in agreement with:

a) Extrapolation of the MADAR data.

b) The aircraft attitude and speed, i.e., nose up at touchdown. (It is noted that the nose gear did not contact the ground at this point).

c) The aircraft would have been in 'ground effect' as it approached the surface with resulting tendency to reduce any existing sink rate.

d) Statements of other crew, for example: Capt. Harp said in the Schneider Trial, page 2143, line 4: 'I would say there were hardly any G forces on the first landing.'

The primary structural failure at this first contact was removal of the rear sets of landing gears, probably due to the landing on a less than normally firm runway and to the above normal touchdown speed of 270 knots, both of which could be expected to increase the drag forces on the gear.

Since the ultimate design load for each gear does not exceed 240,000 lbs, and assumption of full design load being developed on the rearmost gears, <u>plus</u> a limit load of 160,000 lbs on each of the forward main gears, gives a total load of 800,000 lbs. This would load the 450,000 lb aircraft to no more than 1.78g's along the longitudinal axis of the aircraft. The vertical loads would have been very consistent with those occuring for a landing at near or lower than normal sink rate. Vibratory oscillations would have been induced into the structure due to failure of the gear, however these, being of high frequency, would have been more of an 'audible' nature to passengers of the troop compartment rather than of a nature such as to produce a displacement or impact type response of those passengers.

No hazard to the occupants of either the cockpit or troop compartments can thus be expected from this contact.

Contact No. 2

This ground contact occurred after the aircraft became airborne following the initial touchdown and crossed the Saigon River. Observation of the forward main gear tire marks relative to a small dike on the far bank of the river shows (together with the absence of nose gear marks) that the aircraft again touched down in level or slightly nose up attitude. The extended nose gear and extended main gear permitted the aircraft to pass over this dike, allowing failure of all of these remaining gears with little or no contact of the bottom of the fuselage with the dike. The decelerations here would again be no more than the values occurring in the first contact. Upon passage over the dike the bottom of the aircraft began a skidding and plowing run through wet and soft rice fields to the final points of rest. Observation of the accident photos and other evidence shows the following:

a) The troop compartment and the crew compartments remained essentially intact, maintaining living space for those occupants.

b) All seats remained attached to the floor and there were no seat belt or harness failures.

c) Seats in the troop compartment are 16g seats attached to the floor with a 9g restraint. All were rearward facing.

d) Skid tracks through the wet/soft marsh-like terrain are strongly indicative of long-duration, low-level, constant deceleration for the cockpit and troop compartments.

e) Break-up of the lower fuselage occurred in many relatively small pieces consistent with many successive failures, again indicative of continued and hence low level continuous deceleration.

f) The failure of the side walls of the lower (cargo) compartment ultimately resulted in the formation of two skids or runners for the troop compartment which guided that compartment in almost a straight track, reducing lateral loads to only those of vibratory nature and allowing the floor to remain intact.

g) Adult occupants seated or kneeling on the floor between rows of seats, without any kind of restraint other than holding by hand were able to stay in place throughout the complete impact sequence without serious injury. Cuts and bruises were reported. Only those occupants in line with an isle and holding by hand appear to have been unable to retain position. These occupants would have been in a condition similar to a 'free fall' at a somewhat elevated 'g' value of about 1.5 to 2.0g as they 'fell' longitudinally along the isle to impact at or near the front bulkhead. Their injuries thus occurred in this mode.

The 'Wreckage Diagram' for C-5A SN 68-218 shows a deceleration distance for the troop compartment of about 650 yards or 1950 feet as scaled from the diagram. For an initial speed of 270 knots or 456 ft/sec the average deceleration over this distance is 1.66g.* In view of the nature of this accident it is the opinion of the author that the <u>peak</u> decelerations which occurred are probably <u>not more than</u> three (3) times this value or about 5g's. The reader should observe carefully the fact that such peaks cannot physically be applied for any appreciable period of time otherwise the aircraft would have to stop in much less than 1950 feet. [The value would be 646 feet at 5g's constant deceleration].

---

* See Appendix I.

HUMAN TOLERANCE TO DECELERATION

The voluntary tolerance of the whole human body for short duration pulses with forward facing seat and shoulder harness is at least 40g's or eight times the 5g value mentioned above. For rearward facing seats the voluntary tolerance level is well in excess of 40g. At least one 80g test has been conducted on a voluntary human subject without serious injury.

The tolerance to head impact alone, as established by a Wayne State University research group, indicates that peak accelerations of 15 milliseconds duration would have to be of the order of 140g just to produce unconsciousness. For a 2ms pulse the corresponding value would have to be about 400g.

It should be noted that in the C-5A accident in question many of the children were not even awakened by the crash. In view of: 1) The visually observed response of the children in the troop compartment to the crash (or the lack thereof) and 2) to the extremely large disparity between the probable actual decelerations (both peak and average values) and the limits of voluntary human tolerance to such loads, it appears clear that no hazard to life or health existed due the deceleration environment alone in the Saigon C-5A accident of April 1975.

For the convenience of the reader, copies of several human tolerance charts taken from reference No. 10 are included in the appendix.

CONCLUSIONS

It is the opinion of this author that it is a scientific certainty that the decelerations occurring in the April 4, 1975 Saigon C-5A accident did not provide a direct hazard to the life or health of the children or adults located in troop compartment of that aircraft. More specifically it is not possible that the magnitude of the crash decelerations were such as to result in brain damage for the seated occupants or to those adult occupants who remained in position throughout the crash.

APPENDIX I

For uniform (constant) deceleration the governing equation is:

$$G = \frac{V^2}{64.4S}$$

where:

V = Velocity in ft/sec
= 270 knots = 456 ft/sec

S = Deceleration distance = 1950 feet

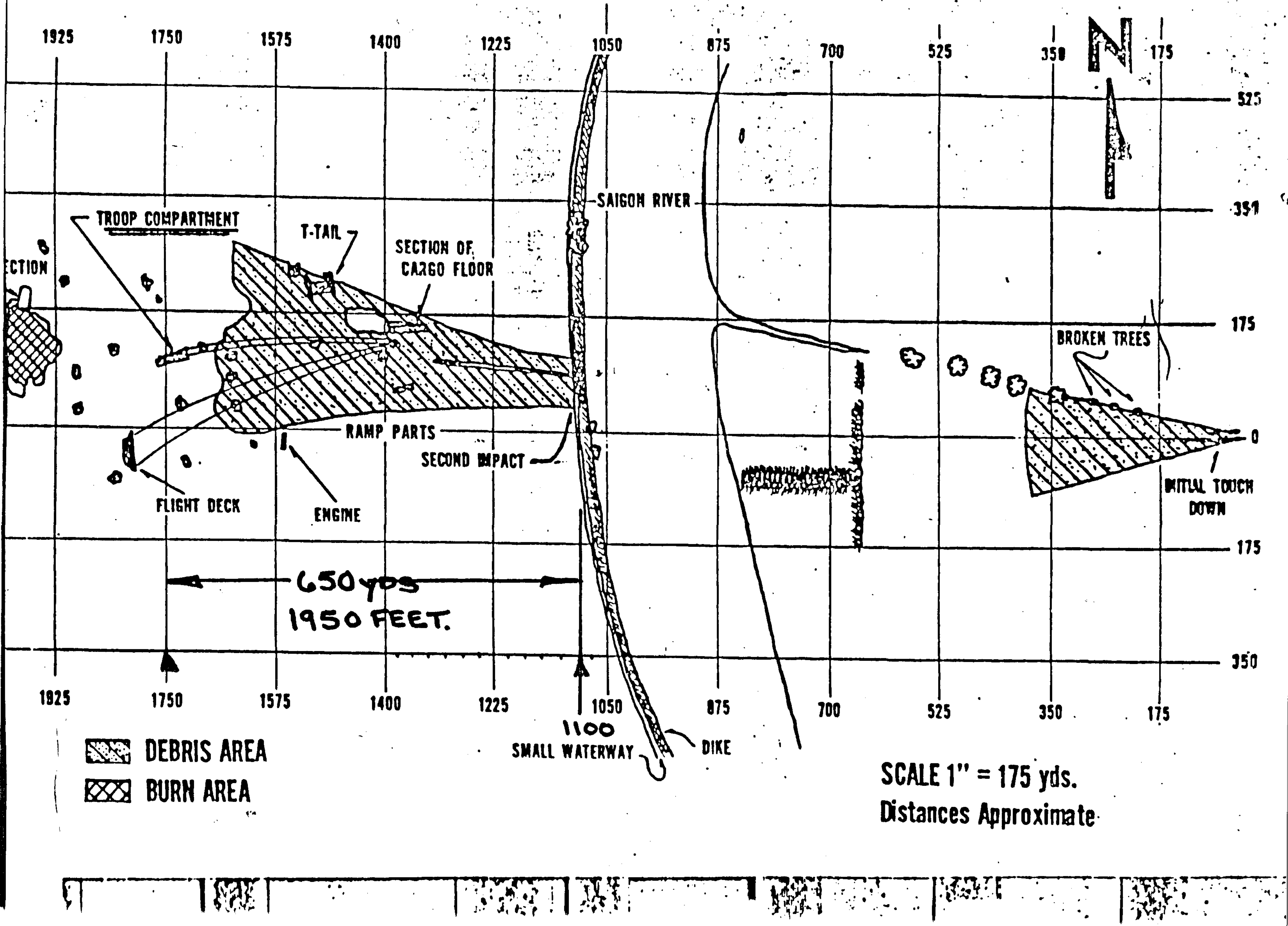
The constant 64.4 is twice the acceleration due to gravity or $2g = 2 \times 32.2 = 64.4$ ft/sec^2.

Then:

$$G = \frac{(456)^2}{64.4\ (1950)} = 1.66$$

APPENDIX II

C-5A SN 68-218 4 APRIL 1975



APPENDIX III

AD

USAAMRDL TECHNICAL REPORT 71-22

CRASH SURVIVAL DESIGN GUIDE

REVISED OCTOBER 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-69-C-0030
DYNAMIC SCIENCE (THE AvSER FACILITY)
A DIVISION OF MARSHALL INDUSTRIES
PHOENIX, ARIZONA

U.S. ARMY MATERIEL COMMAND

Approved for public release; distribution unlimited.

head velocity was that value of initial velocity which resulted in the impact material's being crushed to a predetermined value of strain. This strain value was dependent on the properties of the impact material chosen. The restriction on head deceleration was defined by human tolerance limitations. The head tolerance to impact is a function of pulse duration and average head decelerations as shown in Figure 5-7. In combination, these limitations define a maximum velocity curve as a function of original material thickness, above which absence of concussion (as defined by the tolerance limit of Figure 5-7) was doubtful, regardless of impact material characteristics. This curve is presented as Figure 5-8.

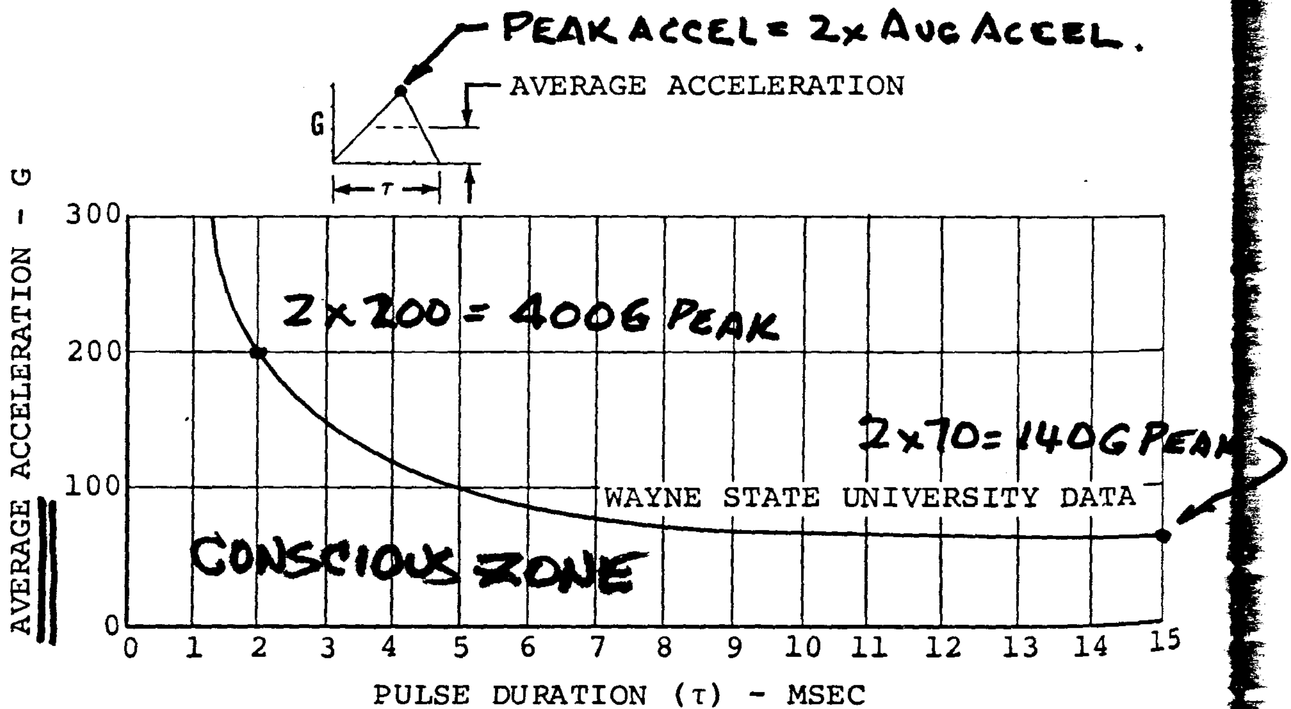


Figure 5-7. Head Tolerance to Impact as a Function of Pulse Duration as Published by Wayne State University.

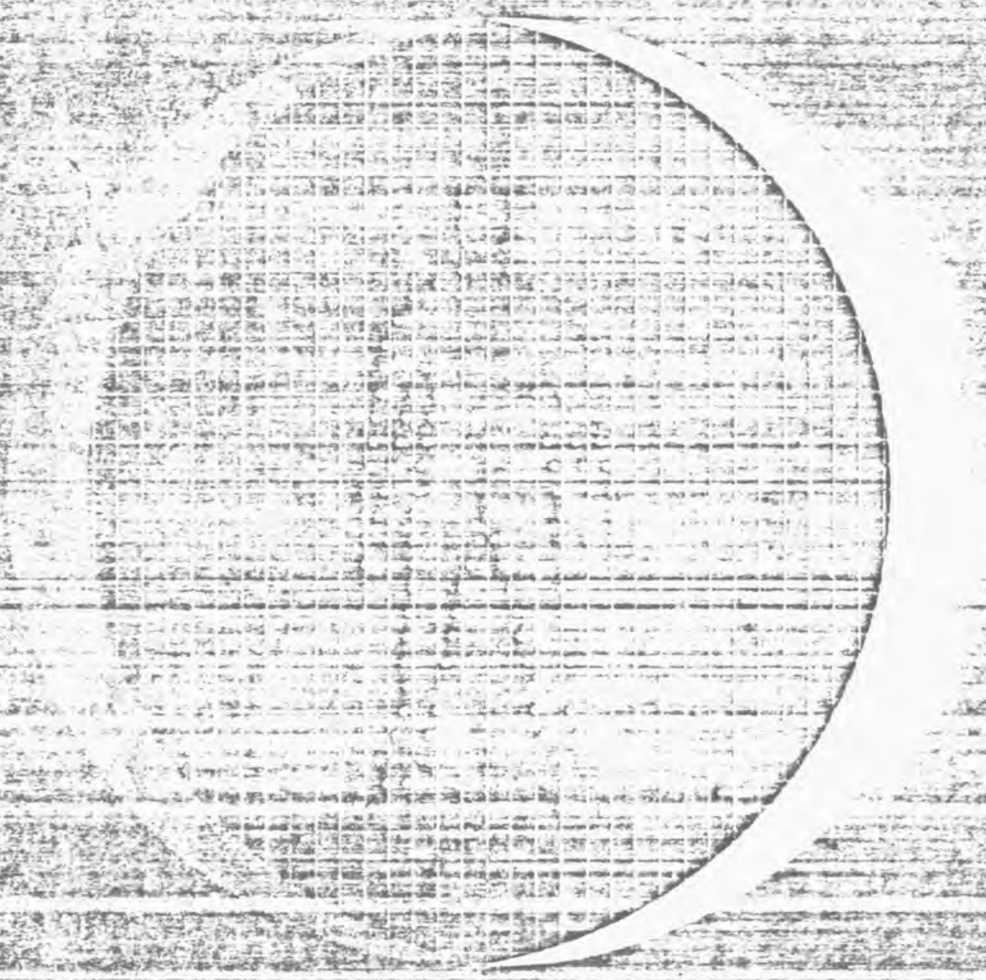
5.3.3.2 <u>Head Impact Velocities</u>: Figure 5-9 shows typical head velocities relative to the seat as measured on anthropomorphic dummies, cadavers, and live human subjects in dynamic seat tests. Various combinations of occupant restraint were used and are so indicated on each curve.

5.3.3.3 <u>Geometry of Probable Head Impact Surfaces in U. S. Army Aircraft</u>: Aircraft in the U. S. Army inventory in 1965 have been examined to determine the kinds of contact hazards

APPENDIX IV

TURNBOW

NASA SP-3006



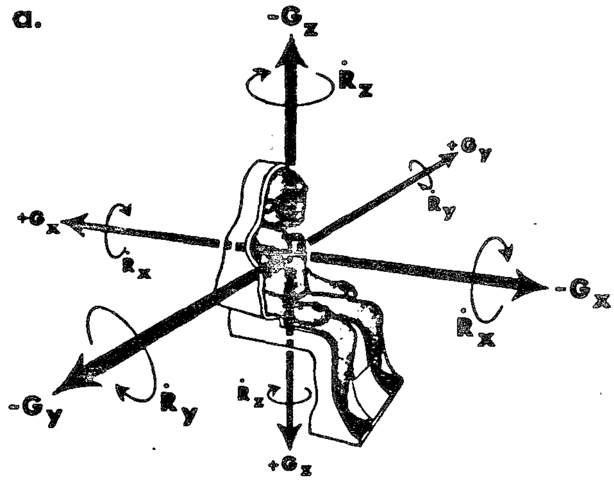
BIOASTRONAUTICS DATA BOOK

Contributor: Randall M. Chambers, Aviation Medical Acceleration Laboratory, USN.

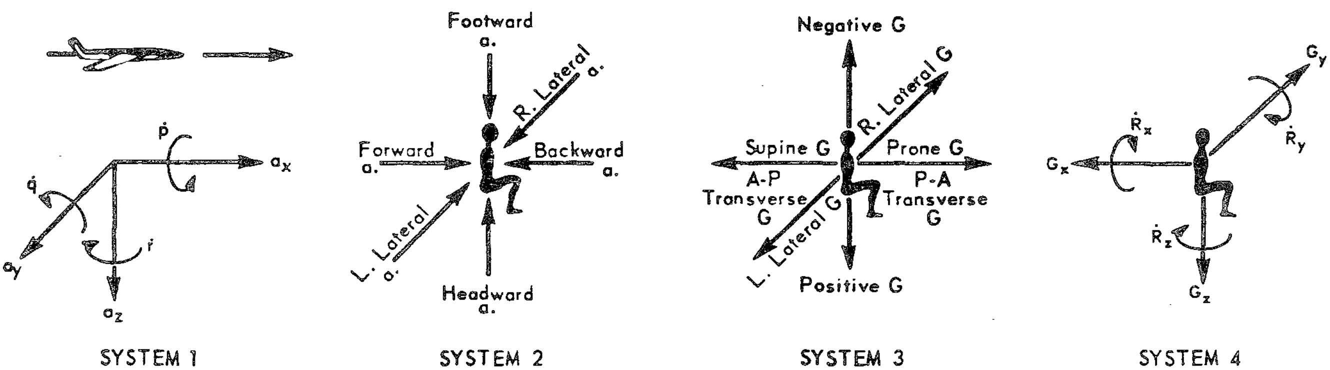
Symbols and vectors used in this book are based on the direction a body organ (e. g., the heart) would be displaced by acceleration. Table II below--and in particular System 4, which is based on displacement of body fluids--explains the most commonly employed terms.

Source: Adapted from Gell [18].

a.



b.



c.

	Table I Direction of Acceleration		Table II Inertial Resultant of Body Acceleration		
Linear Motion	Aircraft Vector (System 1)	Acceleration Descriptive (System 2)	Physiological Descriptive (System 3)	Physiological Displacement (System 4)	Vernacular Descriptive (System 5)
Forward	$+a_x$	Forward accel.	Transverse A-P G* Supine G Chest to back G	$+G_x$	Eyeballs in
Backward	$-a_x$	Backward accel.	Transverse P-A G Prone G Back to chest G	$-G_x$	Eyeballs out
Upward	$-a_z$	Headward accel.	Positive G	$+G_z$	Eyeballs down
Downward	$+a_z$	Footward accel. (tailward)	Negative G	$-G_z$	Eyeballs up
To right	$+a_y$	R. lateral accel. (rightward)	Left lateral G	$+G_y$	Eyeballs left
To left	$-a_y$	L. lateral accel. (leftward)	Right lateral G	$-G_y$	Eyeballs right
Angular Motion					
Roll right	$+\dot{p}$	cartwheel	Roll	$-\dot{R}_x$	
Roll left	$-\dot{p}$	cartwheel		$+\dot{R}_x$	
Pitch up	$+\dot{q}$	somersault	Pitch	$-\dot{R}_y$	
Pitch down	$-\dot{q}$	somersault		$+\dot{R}_y$	
Yaw right	$+\dot{r}$	pirouette	Yaw	$+\dot{R}_z$	
Yaw left	$-\dot{r}$	pirouette		$-\dot{R}_z$	

* A-P and P-A refer to Anterior-Posterior and Posterior-Anterior.

Source: Adapted from Gell [18].

ACCELERATION - INTRODUCTION

The spectrum of acceleration environments is extremely large and may vary in duration, magnitude, rate of onset and decline, and direction. Some acceleration exposures may be so mild that they have relatively no physiological or psychophysiological effects, or they may become so severe that they produce major disturbances. The emphasis of this section is primarily on human performance capabilities and physiological responses as they are modified by sustained acceleration. Abrupt accelerations and decelerations lasting less than two seconds are treated in Section 5, Impact and Vibration.

The unit for the physiological acceleration is G, as distinguished from the "true" displacement acceleration, generally designated by aerodynamicists with the unit g. The physiological acceleration represents the total reactive force divided by the body mass, and hence includes both displacement and resisted gravitational acceleration effects.

The physiological acceleration axes represent directions of the reactive displacements of organs and tissues with respect to the skeleton. Please refer to the accompanying diagrams and tables. The Z axis is down the spine, with $+G_z$ (unit vector) designations for accelerations causing the heart, etc., to displace downward (caudally). The X axis is front to back, with $+G_x$ designations for accelerations causing the heart to be displaced back toward the spine (dorsally). The Y axis is right to left, with $+G_y$ designations for accelerations causing the heart to be displaced to the left.

Angular accelerations which cause the heart to rotate (roll) to the left within the skeleton are specified by the $\dot{R}_x$ unit vector, representing radians/sec^2 about the X axis. Angular velocities in the same sense are specified by the $+R_x$ unit vector, representing radians/sec about the X axis. Similarly, $+\dot{R}_y$ represents an angular acceleration producing a pitch down of the heart within the skeleton, and $+\dot{R}_z$ represents yaw right of the heart within the skeleton.

The field of acceleration research has produced a number of general principles concerning the effects of acceleration stress on physiology and performance. The following statements, many of which are illustrated in the charts of this section as shown, are hoped to be useful to designers of aerospace vehicles and equipment.

1. Physiological tolerance, or the ability to withstand acceleration physiologically, is a function of many variables--e.g., rate of onset (3-2); direction of G vector (3-3); magnitude of G (3-2); duration (3-4)--as well as the type of endpoints that are used as criteria.

2. In addition to the physiological tolerance limits which define the end points for reliable functioning of any particular physiological system during exposure to acceleration stress, there are also performance tolerance limits, which define the end points for reliable functioning of any particular performance ability.

3. Physiological and performance tolerances may be functionally related, but they need not be the same, since each is dependent upon the criteria used.

4. During exposure to acceleration stress, the type of G-protection system used has a very important influence on the pilot's ability to tolerate acceleration (chart 3-5), perform tasks, and maintain performance proficiency.

5. For an acceleration of given rate of onset and magnitude, physiological tolerance is highest for $+G_x$, next for $-G_x$, next for $+G_z$, and lowest for $-G_z$, directions of force. See 3-3.

6. Acceleration stress significantly impairs visual capabilities. As acceleration increases, visual acuity decreases (see 17-30), illumination requirements increase, and brightness contrast requirements decrease (3-10 and 3-11).

7. Major individual differences exist among pilots in their ability to perform piloting tasks during exposure to high G.

8. Certain types of acceleration exposures produce illusions, or false perceptions, of one's position and motion. These may occur in some pilots during or after the acceleration exposure.

9. Since acceleration training results in physiological adaptation and conditioning to G, as well as learning to make performance compensations, acceleration training produces major improvements in performance proficiency during exposure to high G.

10. The instrument display characteristics of a piloting task influence the measurement of performance capabilities of a pilot during exposure to high G. Among the more important display characteristics are: the position of the display instrument within the pilot's visual field, the degree of interpretation required of the pilot, the number of instruments that must be viewed by the pilot during high G, the amount of illumination, the amount of brightness contrast, the physical form in which the display information is presented, and the amount of visual instrument scanning that is required at high G.

11. The characteristics of the control device used by the pilot in performing under G have a significant effect upon proficiency. These characteristics are: the number of axes of motion; the location of the axes of motion with respect to the G and the pilot's hand; stick force gradients along each mode of control; the centering characteristics along each mode of control; dead band zone; breakout force requirements; control friction; static and dynamic balance; damping characteristics; control throw; response time of control; control harmony; cross coupling characteristics; size and shape of grip; dynamic and static balance; and control sensitivity (3-16).

12. Acceleration impairs the ability of the pilot to sense changes in control characteristics that may occur as a function of specific acceleration vectors. This may be a direct effect of the acceleration forces on the receptors, effects on the central or autonomic nervous system, or an effect on circulatory and other physiological systems which indirectly affect the ability of the pilot to sense changes in his arm, hand, and fingers.

13. Task characteristics that are relatively easy to perform in low-G environments become more difficult as G increases.

14. Intellectual skills, piloting concentration, time perception, judgment, and immediate memory are influenced by high G.

15. Response time, as well as complex psychomotor performance, is influenced by high G (3-13).

16. Anticipation of acceleration may produce emotional reactions that are greater in terms of psychophysiological impairment than the direct effects of acceleration itself.

17. If, in addition to acceleration stress, the pilot is exposed to other environmental stresses, his responses may be altered by the combined effects of these stresses. (See Section 9).

Positive (G_z) and transverse (G_x) accelerations have been emphasized in studies to date, while lateral and angular accelerations have received relatively little attention, primarily because of the lack of proper research facilities.

Some limitations in interpreting acceleration research data are: (a) most studies have been conducted on a small number of subjects; (b) repeated exposure to acceleration changes a subject's G tolerance, and this factor is usually not included; (c) emotional condition and motivation influence results; (d) instrumentation has not been standardized for measuring the effects of G on physiology and performance.

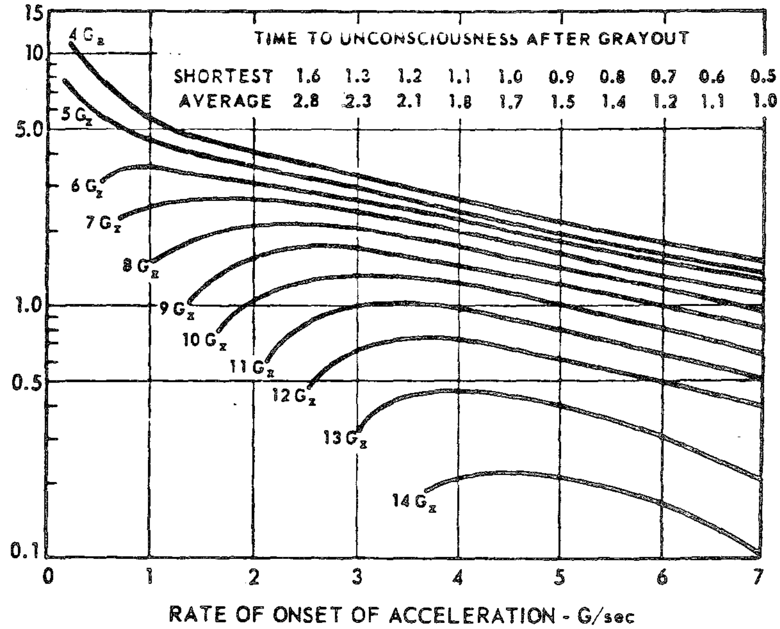
Recommended for general reading are the following: Otto H. Gauer and George D. Zuidema, Gravitational Stress in Aerospace Medicine [17]; Neal M. Burns, Randall M. Chambers, and Edwin Hendler, Unusual Environments and Human Behavior: Physiological and psychological problems of man in space [5]; and C. C. Clark, J. D. Hardy, and R. J. Crosbie, A Proposed Physiological Acceleration Terminology with an Historical Review [12].

3-2. GRAYOUT AND RATE OF ONSET OF $+G_z$

a.

This graph relates the onset rate of acceleration to time-to-endpoint. It shows that for any given positive acceleration (G_z) from 4 to 14 G, the time to grayout depends on how rapidly the acceleration level was reached. Further, the table inset in the graph shows the shortest times and the average times for unconsciousness to develop following grayout, each pair of values being related to an onset rate. For example, at onset rate of 4 G/sec, the shortest time to unconsciousness was 1.1 sec, and the average 1.8 sec.

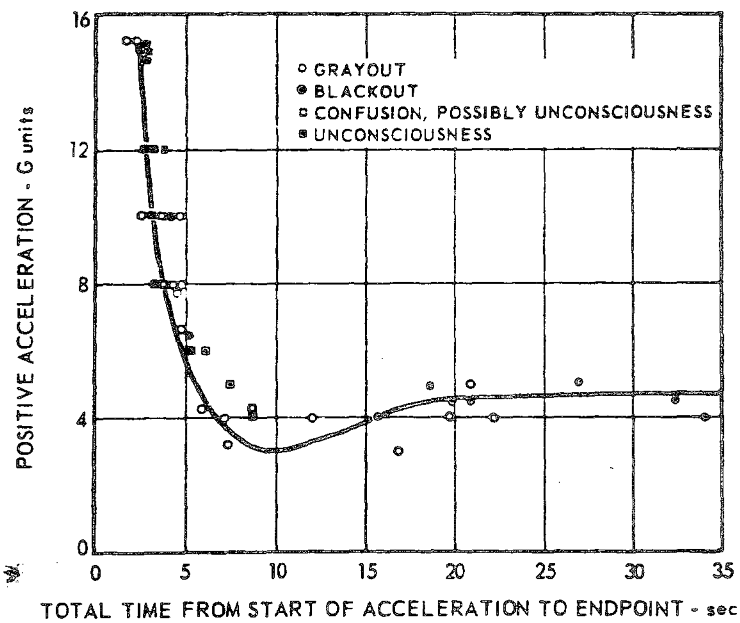
Source: Stoll [26].



b.

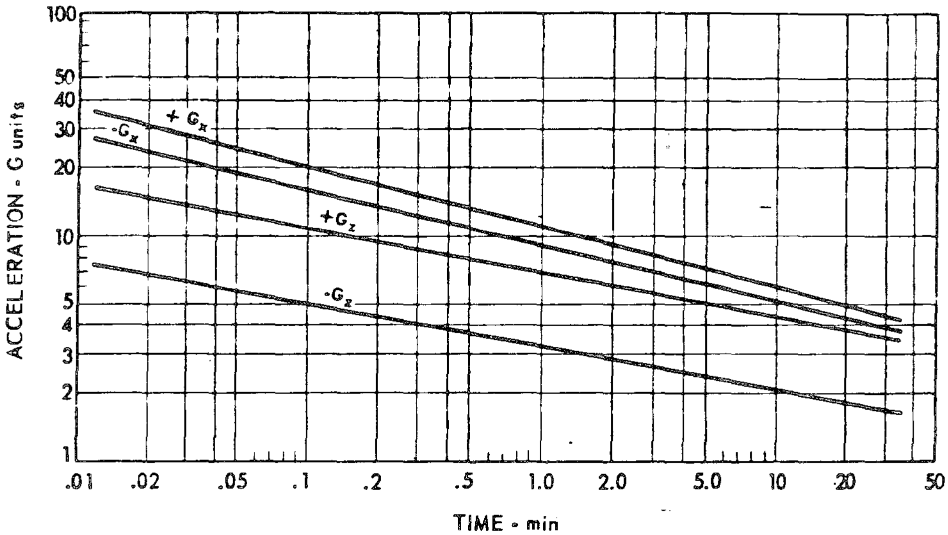
This graph shows human tolerance to positive G_z for varying rates of onset, G amplitudes, and exposure times.

Source: Adapted from Stoll [26].



G TOLERANCE IN FOUR VECTORS

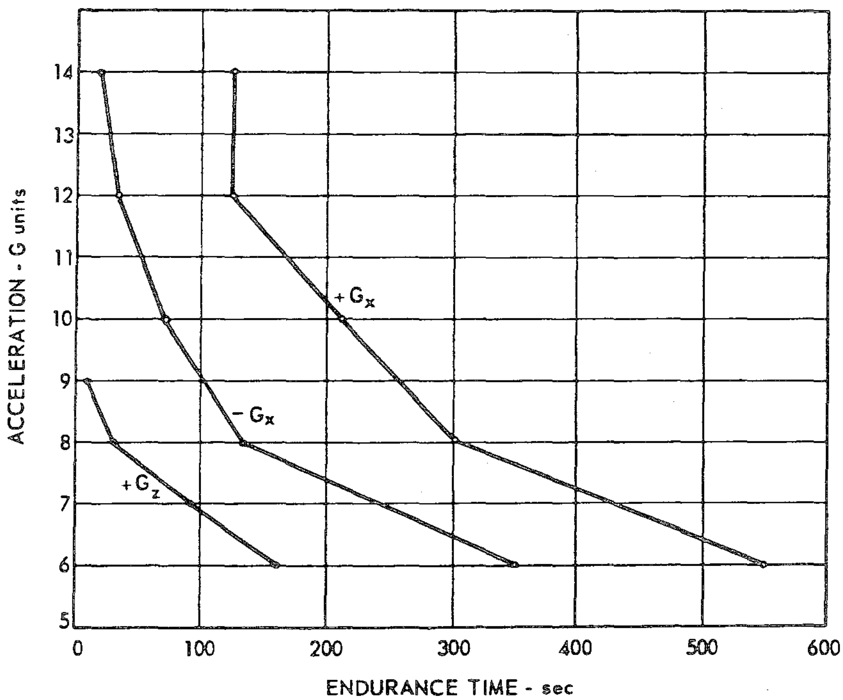
a.



Average acceleration tolerance is shown for positive acceleration ($+G_z$), negative acceleration ($-G_z$), transverse supine accleration ($+G_x$), and transverse prone acceleration ($-G_x$).

Source: Chambers [7].

b.

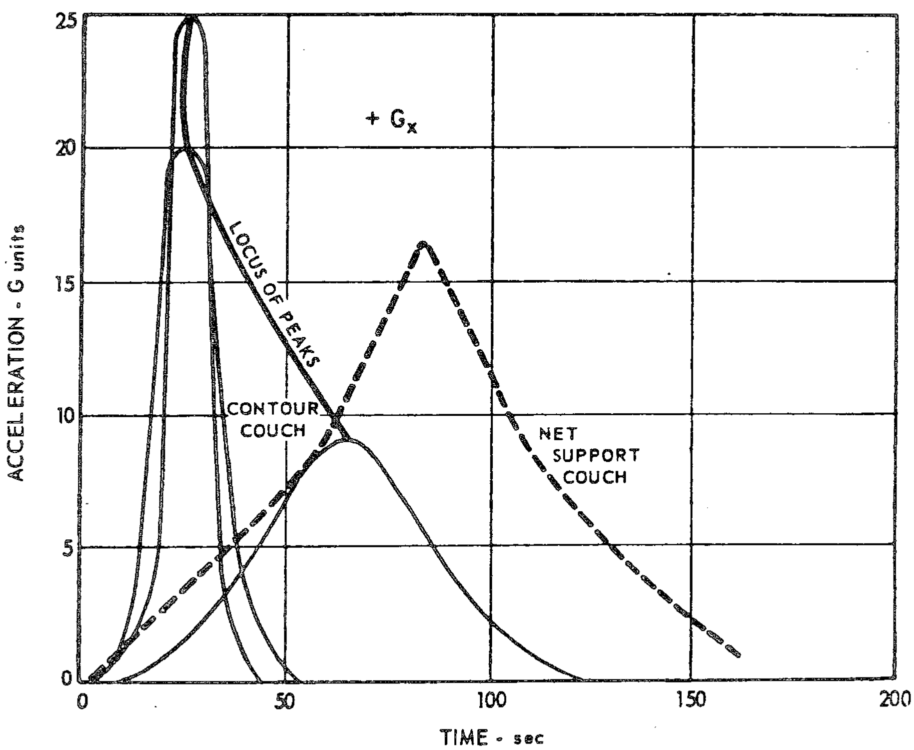


Upper limits of voluntary endurance (as contrasted with average tolerance, shown above) are plotted for a group of highly motivated test pilots, preconditioned to the effects of acceleration and suitably restrained. The pilots were able to operate satisfactorily a side-arm control device to perform a tracking task throughout the times indicated.

Source: Chambers and Hitchcock [9].

3-4. MAXIMUM TOLERABLE ACCELERATION PROFILES

a.



b.

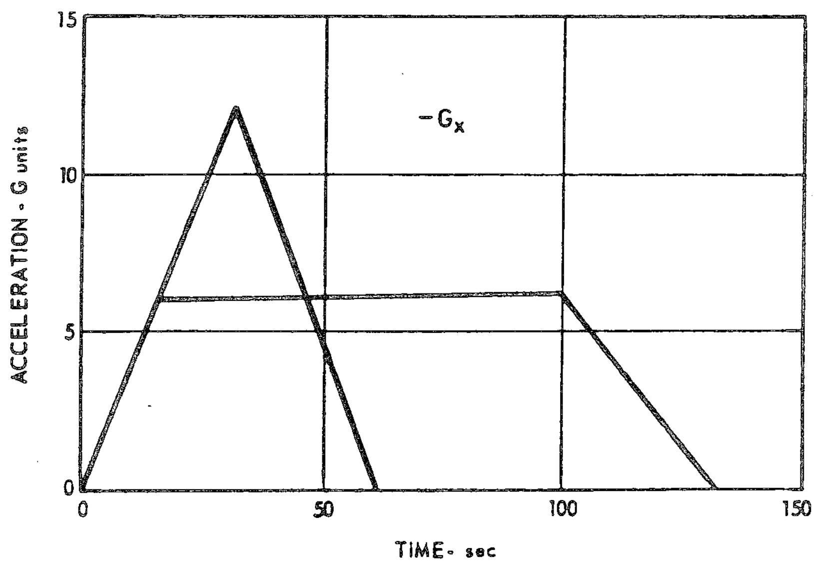
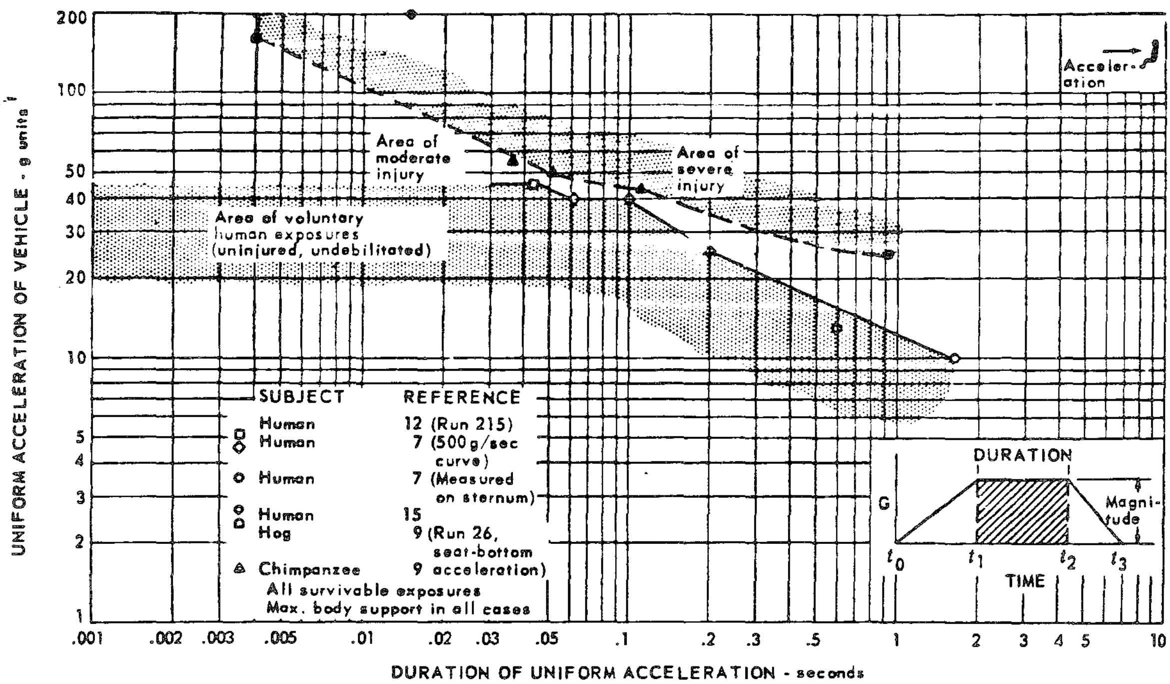


Figure a shows the greatest acceleration-time histories that have been tolerated on centrifuges when special support structures and positioning are used. Solid lines show three curves which define about the same area of $+G_x$ times time. A heavy line connects the peaks of these three curves and locates the peaks of other curves enclosing the same area. The dashed line encloses a number of possible acceleration profiles related to space flight, all of which are tolerable, since the border of the envelope has been tolerated experimentally. Figure b depicts two tolerable $-G_x$ accelerations (eyeballs out) when the subject is restrained in a special harness.

Sources: Bondurant et al. [4]; Clarke et al. [13]; Lawton et al. [24]; Collins et al. [14]; and Collins and Gray [15].

Contributor: Paul Webb, Webb Associates

a.

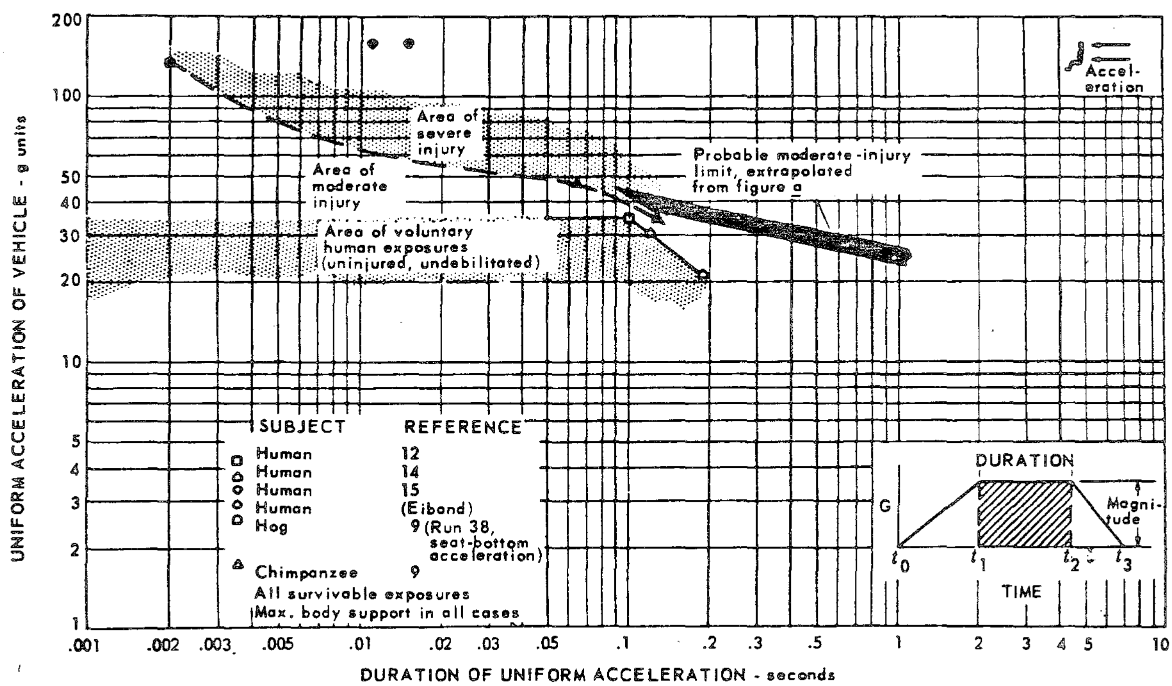


These two graphs show the durations and magnitudes of abrupt transverse decelerations which have been endured by various animals and man, showing areas of: voluntary endurance without injury; moderate injury; and severe injury. Graph a summarizes $-G_x$ data (back to chest acceleration) and b shows $+G_x$ data (chest to back acceleration). Reference numbers on the graphs are those in the original reports.

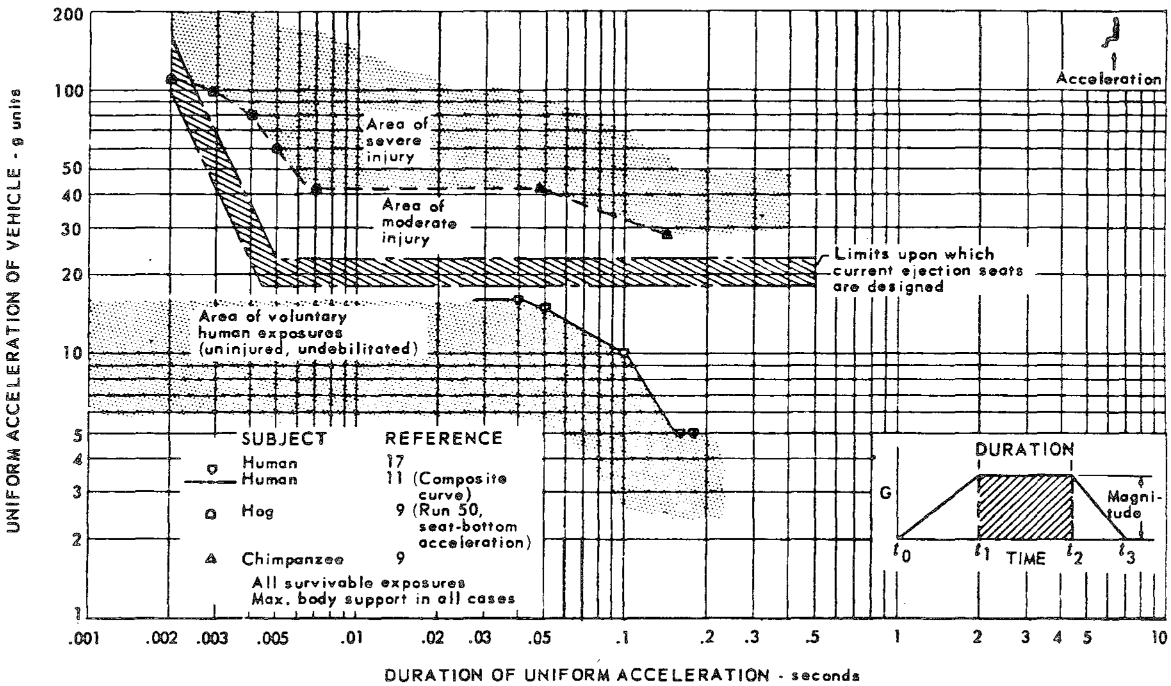
Source: Eiband [5].

REARWARD FACING

b.



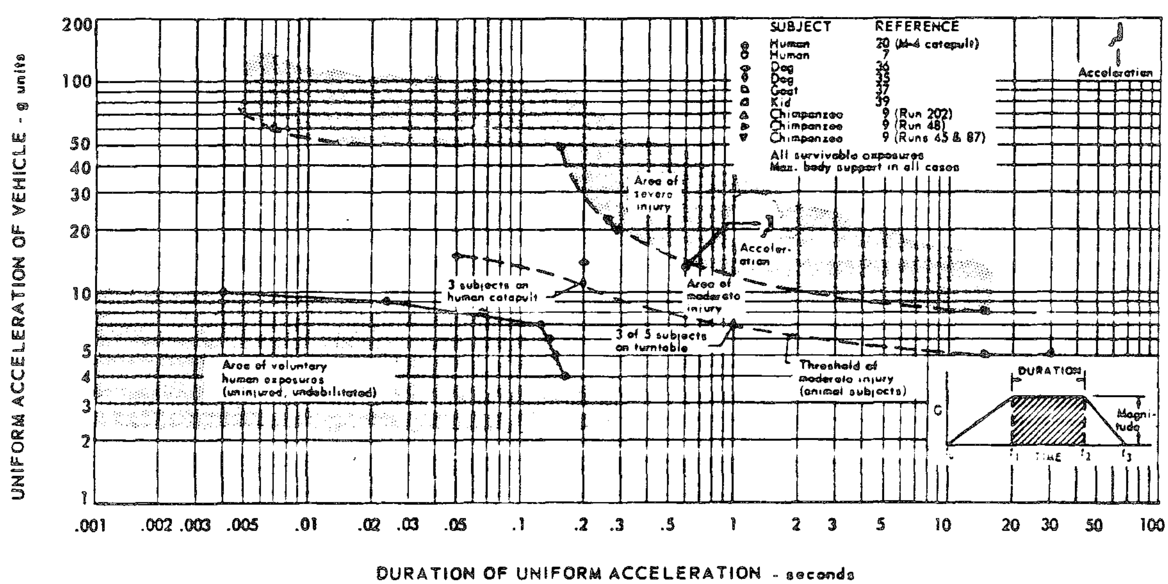
a.



These two graphs show the durations and magnitudes of abrupt deceleration in the G_z (longitudinal) directions which have been endured by various animals and man, showing areas of voluntary endurance without injury, moderate injury, and severe injury marked by shading. Graph a shows data of $+G_z$ acceleration (headward), and b shows data fcr $-G_z$ acceleration (tailward). Reference numbers on the graphs are those in the original reports.

Source: Eiband [5].

b.



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B.S.M.E.	Texas Technological College, 1940

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1959-	Arizona State University, Professor
1948-59	University of Texas, Assistant Professor
1948	Texas Technological College, Student Instructor
1940-41	Oklahoma A. & M. College, Instructor

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9/60-6/69	Consultant to the Flight Safety Foundation, AvSER Div., Phoenix, Arizona
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"Cushioning for Air Drop, Part I," (with other authors). Published for the Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois, July 1955, 80 pp.

"Cushioning for Air Drop, Part II, Air Drop Cost Analysis," (with C. C. Steyer). Quartermaster Food and Container Inst. for the Armed Forces, Chicago, Ill., April 1956, 37 pp. Unscheduled presentations of portions of this work were presented by Dr. Turnbow at two meetings: (a) Aerial Delivery Research Contractors Coordination Meeting at the Midwest Research Inst.,Kansas City, Mo., Jan., 1956, and (b) The Aerial Delivery Research Symposium at Fort Lee, Virginia, April 1956.

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