INJURY TO EYE AND FACIAL SKIN (RABBIT) ON IMPACT WITH INFLATING AIR BAG

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The air bag system operates on the premise that contact between the bag and the body will not occur until after the bag has fully inflated, but there is some apprehension about the possibility of injury occurring if for some reason the surface of a bag still inflating were to strike the face or eye. In several previous air bag inflation tests on U.S. Air Force volunteers[1] and baboons,[2),3] the respective systems operated normally and no injury was reported, but in other tests on human volunteers,[4),5] pigs,[6] and primates,[7] damage to eardrums, skin abrasion, contusion, laceration, and even death were reported. Our objective was to derive thresholds of injury occurrence in the event that an eye or the facial skin of the subject (a rabbit) came into contact with a bag while still inflating. Such threshold values would be useful to air bag designers as supplemental design data pertaining to safety limits.

1. Experimental Method

1-1. Test Plan

A multitude of factors might be conceived which could lead to secondary injuty attributable to bag inflation at the time of an automobile collision. Among them are a) vehicle factors such as impact velocity and vehicle weight, b) human factors such as passenger position and restraint, and c) air bag factors such as the characteristics of the system used. For our experiment we had to sharply restrict the factors under considiration. For vehicle factors we employed an immobilized test apparatus, for human factors we investigated only rabbit's eye and facial skin, and for air bag factors only one system, a "single tank multivalve air bag system (test stand)," was studied. In evaluating injury, three mechanical factors were taken into account: 1) bag inflation velocity, 2) bag maximum internal pressure, 3) impulse at bag impact. The corresponding degree of injury to rabbit's eye and facial skin was measured using the injury scale (IS) introduced in Table 1.

1-2. Experimental Air Bag Inflation System

A system combining 3 magnetic valves and a copper block and silicon pad for the striker. The embryos of fertilized hen's eggs take 21 days to hatch at temperatures ranging from 37.9 to 38.6°C with humidity of 56 to 60%. A total of 164 embryos in the process of incubating from zero to 16 days were used in the test. The reason is that a gap develops between the embryos and eggshell as the number of incubating days increases and the gap impedes the transmission of impact. The embryos in the eggshell floats in the white, therefore, its position is not static. Through a model test using a floating G-sensor (explanation is omitted here), we confirmed that changes in acceleration were unrelated to the position of the embryo. We also examined the thickness of the plaster (0-20 mm) used to fasten the eggs to the deck and found that it did not affect impact transmission.

Results and Comments

Table 1 shows still-birth and abnormality rates resulting from the impact of square waves and also of symmetrical triangular waves. Fig. 1 shows the test conditions and wave patterns of test code Nos. 7 and 8. In the case of triangular waves, embryo mortality test conditions were gradually increased in the order of test code Nos. 1, 2, 3, 6 and 7, reaching the test conditions of LD 50 at 7.

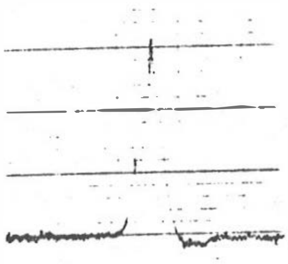
Although test code No. 8 was the only case using square wave impact, it can be compared with code No. ı because the height of dropping and the stopping distance were identical in both cases. (See Figure 1) In the case of code No. 8, mortality was 3.6%. Therefore, it can be said that the impact of square waves is safer to bodies than the impact of symmetrical triangular waves (significant with $p = 0.05$). Although the table does not show it, it is considered that there is a positive correlation between an increase in the number of incubating days (that is, an increase in the weight of the embryo) and embryo mortality under the same impact conditions.

TABLE 1 STILL-BIRTH RATES INCUBATING HEN'S EGG, PRODUCED BY IMPACT

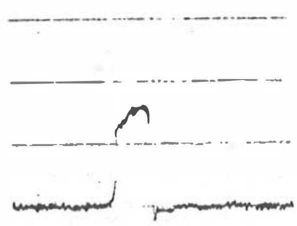
TEST CODE NO.	WAVE PATTERN	ACCELERATION PEAK G	DROP HEIGHT (m)	TOTAL EGGS	DEATHS	MORTALITY (%)	ABNORMALITY
8	SQUARE	370	4.0	28	1	3.6	0
7	SYMMETRICAL TRIANGULAR	720	4.0	18	9	50.0	0
6		550	3.0	18	3	16.7	0
3		220	1.3	30	0	0	2*1
2		190	1.0	33	0	0	0
1		160	0.5	37	0	0	0

Note: *1 Among the 2 abnormal chicks, one had undergone the impact test on the ninth day of incubation. Both legs remaind rigid until death four days after hatching. The other chick had a twisted neck posture.

FIG. 1 COMPARISON OF IMPACT ACCELERATION WAVE PATTERN FOR TEST CODE 7 VS. 8



test code 7
drop height 4m
acceleration 720G
stopping distance 11mm



test code 8
drop height 4m
acceleration 360G
stopping distance 11mm

It seems that the difference in function between bodies subjected to square wave impulse and symmetrical triangular wave impulse stems from the following assumption. It is believed that the first half of a symmetrical triangular wave until reaching the peak is a phenomenon of absorbing energy because of its characteristics, while its latter half is mainly a phenomenon of releasing energy (rebound). In the case of square waves, however, the total area shown by their wave pattern is only a phenomenon of absorption without a rebound. Because the latter half of symmetrical triangular waves is mainly a rebound, they give an added impact of rebound and, therefore, increase injury.

2. Effect of Impact Acceleration Wave Patterns on Rats Floating in Water

To represent vertebrate animals, rats were used in the test. In order to give an even impact load to the whole body, the rats were dropped while immersed in a water medium from a certain height (21 m) using the slider guide to provide impact. To eliminate analytical complexity, wave patterns were limited to square and terminal peak sawtooth waves (reboundless). Four stopping distances (A: 20 mm, B: 25 mm, C: 30 mm, D: 40 mm) were distinguished according to different length of impact absorption. An attempt was made to use the same stopping distance for both wave patterns. A total of 202 rats ranging in weight from 140 to 350 g were used in the test.

Experimental Method

The rats were left swimming without being anesthetized in an aluminum container filled with water. Its cover automatically closed as it reached the top of the dropping tower, and the rats were dropped in a submerged condition (duration: 2.0 sec). The carriage stopped when the stopping device attached to the bottom of the carriage contacted a lead block installed on the ground. The impact acceleration wave pattern at the time of stopping was controlled by the shape of the stopping device used. To

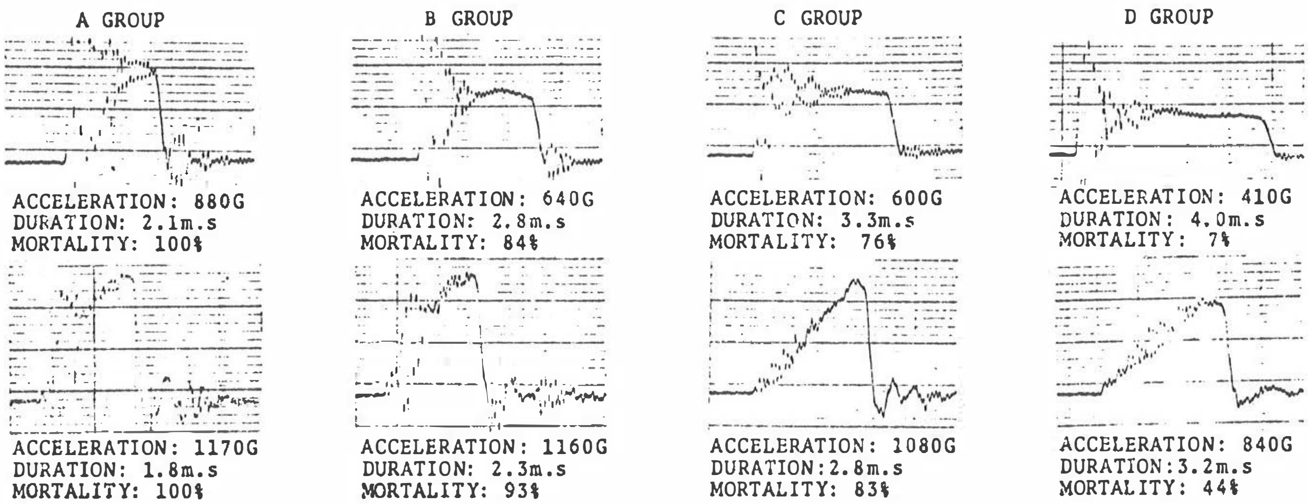
Results and Comments

Table 2 shows mortality by stopping distance and wave impact. Mortality was 100% in the case of group A under both wave impact conditions. In the case of groups B and C, the square wave impact showed a slightly lower mortality rate than that for the sawtooth wave impact. In the case of group D, the square wave impact had a definitely lower mortality rate than the terminal peak sawtooth wave impact (that is, the square wave was clearly safer).

The difference in biological effects of both wave impacts appears conspicuously at the impact level of group D. We determined an impact injury scale for the rats and made an anatomical observation of macroscopic pathological changes in them. (The impact injury scale is omitted here.) On observation, lung injuries were found in all the dead rats. The following is a comparison of the square wave impacts of groups A and D shown in Fig. 3 with respect to physical load conditions and body reaction.

When peak G was increased by about 2.2 times (880/405) and duration time was reduced by about half (2.1/4.0) while keeping impact speed constant, mortality increased by about 14 times (100/7). Fig. 4 shows that mortality increases as body weight increases. Dynamic water pressures at different depths were measured by taking into consideration the effect of the pressure of water inside the container on the rats at the time of impact. It showed that the dynamic water pressure at a depth of 2.5 cm (the height of rats) was 2.0 kg/cm^2. It is presumed that when duration time in the water is 3 ms, the limit of death (in the case of dogs) is about 10.5 kg/cm^2 (Desaga, NASA SP-3006, p. 92). It can be concluded, therefore, that dynamic water pressure alone is not a cause of death and that acceleration has an additional effect.

FIG. 3 COMPARISON OF IMPACT RESULTS AND MORTALITY IN RATS



eliminate any serious effect of the water pressure on the rats, decks were provided in the water for the rats according to their size to keep the depth of water constant. Acceleration was measured on the surface of the carriage, while water pressure was measured in the water (See Fig. 2). The rats subjected to the impact load test were observed for behavior and dissected for macroscopic pathological observation.

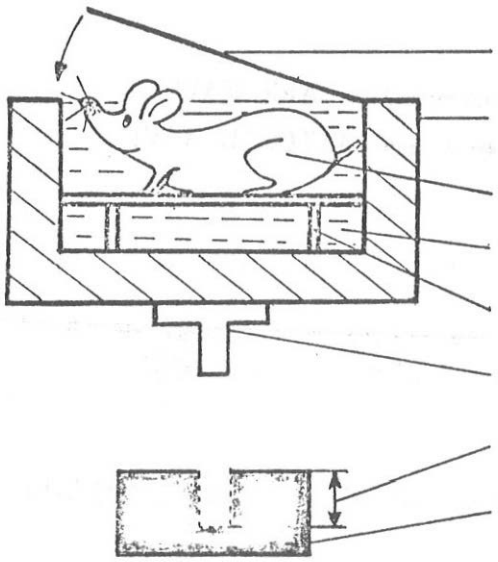


FIG. 2 CONTAINER AND STOPPING SYSTEM

Table 2 Comparison of Drop Impact Under Square and Terminal Peak Sawtooth Wave Pattern, Rat Weight 130-350 Grams

Group of Impact	Type of Acceleration Wave Pattern	Duration (ms)	Acceleration G	Total Rats (a)	Die (b)	Survival (c)	Mortality (b)/(a) 100
A=20mm	squarewave	2.1	880	15	15	0	100
	sawtoothwave	1.8	1170	10	10	0	100
B=25mm	square wave	2.8	640	25	21	4	84
	sawtooth wave	2.3	1160	27	25	2	93
C=30mm	square wave	3.3	600	25	19	6	76
	sawtooth wave	2.8	1080	18	15	3	83
D=40mm	square wave	4.0	410	30	2	28	7
	sawtooth wave	3.2	840	34	15	19	44

Notes:
1 Drop Height 21m, Constant.
2 Survival: Survived Longer Than 24hrs.

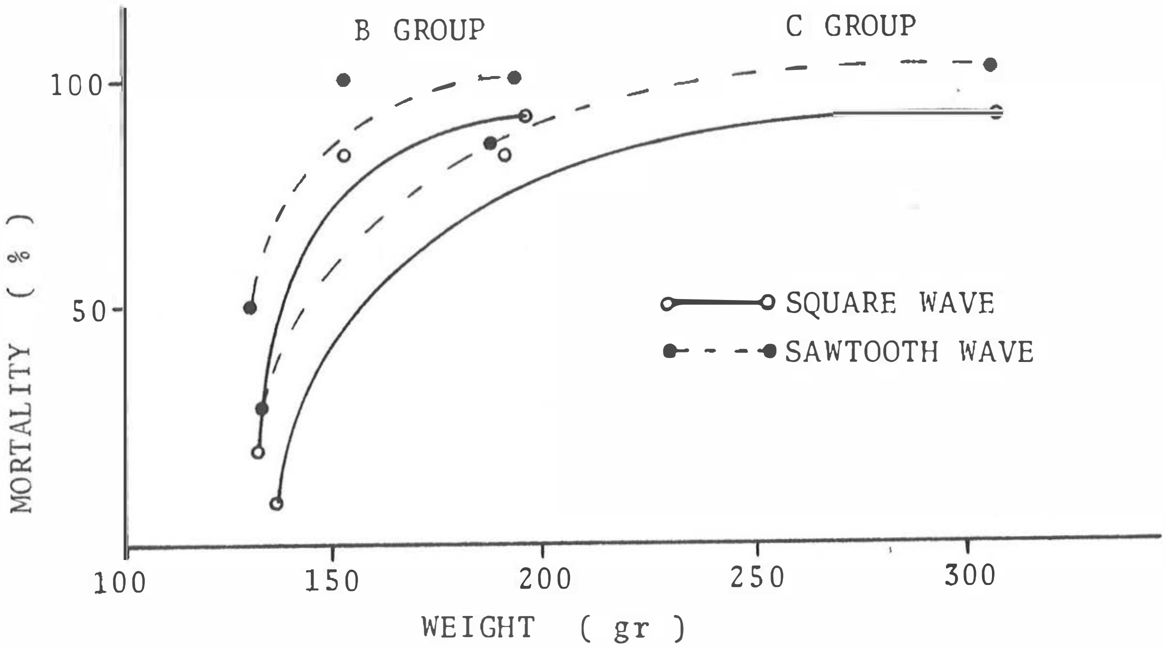


FIG. 4 COMPARISON OF MORTALITY VS. WEIGHT OF RAT, SQUARE AND TERMMINAL PEAK SAWTOOTH WAVE

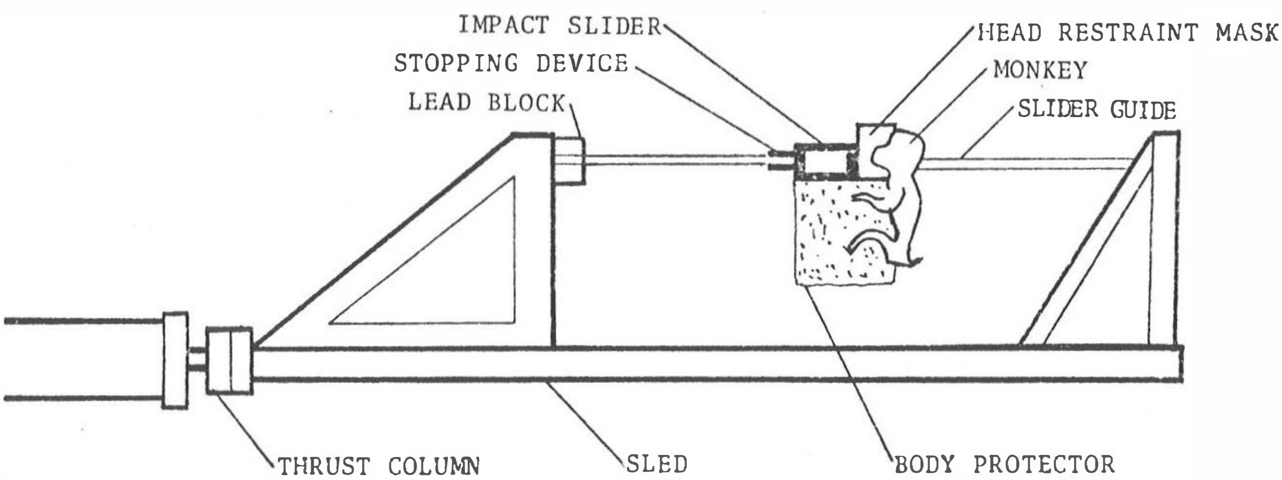


FIG. 5 A DEVICE FOR INVESTIGATION OF HEAD INJURY DUE TO LINEAR ACCELERATION

3. Horizontal Impact on Head of Primates

The impact device shown in Fig. 5 was produced to accelerate horizontal impact on the head of Japanese monkeys (Macaca fuscata) and to monimize effects on other parts of the body. The device was installed on a 12-inch HYGE shock tester. It was designed to impel a sled at the speed of 100 km/hr, with the impact slider sliding along the slider guide to hit the lead block. The head of the monkey was secured using a plaster mask and, therefore, the impact of the impact slider was directly transmitted to the monkey's head. The device was so arranged that the acceleration wave patterns generated on the slider could be changed into square or terminal peak sawtooth wave pattern by adjusting the shape of the stopping device. However, the wave patterns measured by the accelerometer attached to the monkey's occiput did not completely agree with those on the slider. Twelve monkeys ranging in weight from five to 12 kg were used in the test. As the result of testing conducted under identical conditions, including speed, a group of six monkeys ranging in weight from 5 to 8.5 kg survived, whereas another group of 6 with a weight of 8.5 to 12 kg all died (within 15 min). Therefore, it can be said that the impact mortality threshold level of monkeys is greatly affected by body weight. As regards the effect of wave patterns, the square wave impact showed a mortality rate of 44% (four of nine monkeys died), while that of the sawtooth wave impact was 66% (two of three died).

Occipital effective acceleration (Ge) was obtained from the occiput of the monkey. Shown in Fig. 6 is force curves. There are G(e) times the weight of the monkey used (kg) and plotted against the product of the WSTC (Wayne State Tolerance Curve) times the weight of a U.S. male adult of 75 kg. The WSTC is the human concussion threshold level, while the result of the test using the monkeys this time is the impact mortality threshold level of monkeys. It is interesting that the two threshold levels resemble each other.

Comments on biochemical, pathological, and physiological analyses are omitted here. We intend to study more test cases for further investigation.

4. Conclusion

We studied effects on bodies of both square and sawtooth impact wave patterns to derive mortality limits using fertilized hen's eggs as a monocellular body, rats as a vertebrate, and Japanese monkeys as a primate. As the result, the following conclusions were drawn:

a) As for acceleration patterns under the same impact conditions (speed and absorption distance being constant), the square wave pattern is safer than the terminal peak sawtooth and symmetrical triangular wave patterns.

b) As for injury to bodies inflicted at the same impact speed, acceleration acts as a greater factor than duration time.

c) As for injury inflicted on bodies under the same impact conditions,

Table 3 General Summary Test Conditions and Main Results

Expt. No.	Impact Velocity(m/s)	Max. Acceleration & Pressure (duration ms): Impact Slider,g	Monkey Head Occipital,g	Monkey Head Frontal Pressure(Kg/cm²)	Specimen Dates: Body Weight,Kg	Sex	Life
03	27.0	1556 (4.4)	2395 (3.0)	3.02	6.5	M	S
04	26.0	1478 (4.1)	2448 (3.1)	2.94	8.2	F	S
05	27.2	1530 (4.2)	1770 (3.1)	--	9.0	F	D
06	26.9	1373 (3.5)	2199 (3.5)	3.86	7.3	M	S
07	27.2	1369 (3.8)	1407 (3.5)	2.29	9.5	F	D
08	27.2	1497 (4.5)	1487 (3.4)	2.57	6.0	M	S
09	27.2	1449 (3.8)	1260 (3.4)	1.74	10.5	M	D
10	27.2	1305 (3.7)	908 (3.3)	--	5.0	M	S
11	26.9	1229 (3.8)	1393 (4.1)	--	8.0	F	D
12	27.2	1581 (4.0)	1738 (3.7)	--	10.5	M	D
13	27.3	1540 (4.3)	1363 (3.6)	--	5.0	M	S
14	27.1	1483 (4.0)	1478 (3.3)	--	11.0	M	D

Notes:
1 Expt. No. 03-11 Square of Acceleration Pulse Pattern.
2 Expt. No. 12-14 Triangular of acceleration Pulse Pattern.
3 M=Male, F=Female, S=Survival, D=Death

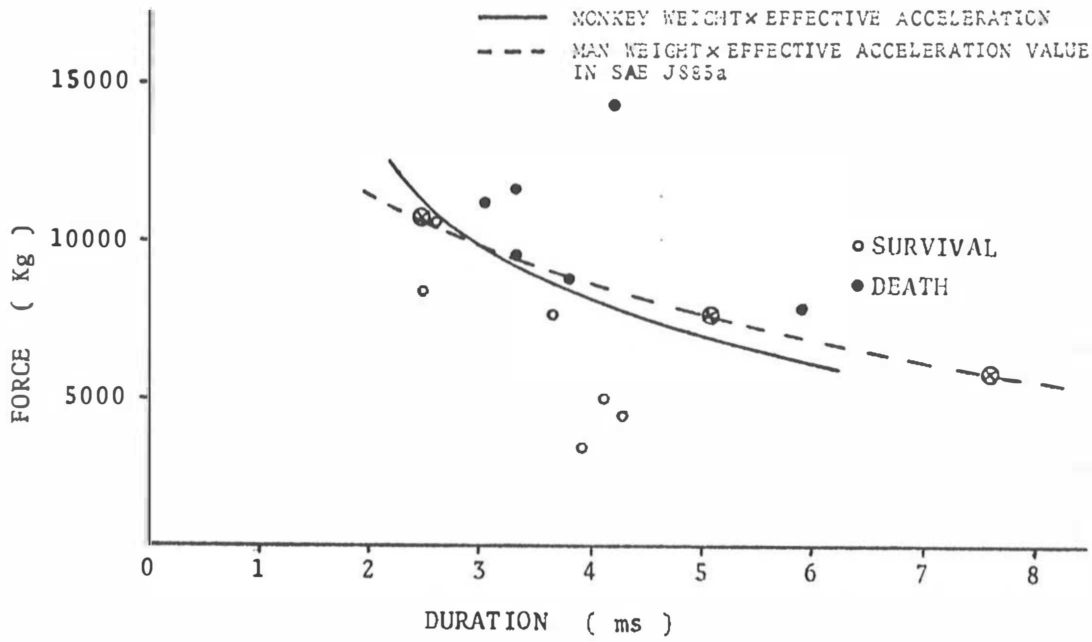


FIG. 6 TOLERANCE CURVE FOR JAPANESE MONKEY IN TERMS OF IMPACT FORCE AND DURATION

the degree of injury increases as the body weight of the test subject increases.