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THE TOLERANCE OF BIRDS TO AIRBLAST

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The response of birds to airblast was studied. The direct blast (overpressure) effects in quail, chickens, two-week-old chickens, and geese were determined by placing them at the end of a closed shock tube. Pigeons in-flight were subjected to blast from 64-lb charges. The criteria for direct-blast effects, based on the peak pressures, were no injuries, 5 psi; injuries, 10 psi; and 50-percent mortality, 20 psi. Blast-displacement effects were evaluated by translating quail, chickens, and pigeons from the end of a shock tube. The criteria for blast displacements,

20. ABSTRACT (Continued)

based on dynamic-pressure impulse, were no injuries, 5 psi · msec and injuries, 10 psi · msec. Curves relating these criteria as a function of charge weight and ground range were presented.

PREFACE

This report presents the results of a study on the response of birds to airblast. From the results, criteria for direct-blast effects and blast-displacement effects were formulated.

Curves relating these criteria in relation to range and explosive charge weight were presented.

This information may be used by government and industrial agencies required to prepare Environmental Impact Statements in connection with the detonation of high explosives.

This research was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences, National Research Council.

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INTRODUCTION

In the preparation of environmental impact statements related to the detonation of explosives, there are requirements for data on the tolerances of various species of animals to airblast. Although a number of studies have investigated the effects of airblast in mammals, very little is known about the blast tolerance levels of nonmammalian species. Since birds are usually abundant in most terrains, they were one of the first groups chosen for study.

It has been established in mammals that damage from direct-blast effects (overpressure) tends to occur in parts of the body where there are differences in density of adjacent tissues, especially in gas-containing structures such as the lungs.[1,2] Birds have pneumatized bones and a series of thin-walled air sacs connected to the lungs.[3] Thus, since the respiratory systems of birds are quite different from those of mammals, one might expect them to be less resistent to airblast than mammals.

To assess the tolerance of birds to direct-blast effects, adult quail, chickens, and geese were chosen to represent small, medium, and large size birds. These animals were exposed to reflected shock waves on the endplate of a shock tube. Two-week-old chickens were similarly tested in order to determine the effects of age on tolerance of birds to airblast. Some of the birds tested at high-injury levels were retained for 14 days to see if they would recover on their own.

To evaluate the airblast tolerance of birds in-flight, pigeons were released at a height of 10 ft and exposed to the detonation of 64-lb charges of TNT.

Another damage mechanism established with mammals is from blast displacement. This may be more far-reaching than direct-blast effects, especially in connection with larger charges. Blast-displacement hazards to birds were evaluated by translating quail, pigeons, and chickens from the open end of a shock tube and allowing them to either tumble over the ground or to impact against a barrier.

From the results of this study, blast levels that could be expected to produce no injuries, produce moderate injuries, and produce lethal injuries that would apply to all birds were selected and presented in terms of range-yield curves.

METHODS

Birds

A total of 157 quail (Coturnix coturnix), 67 pigeons (domestic), 135 chickens (hybrid pullets, Shaver Starcross 288, Shaver Poultry Breeding Farms Ltd., Galt, Canada), 18 geese (domestic), and 25 two-week-old chickens (mixed breed) were utilized. The mean body weights (with ranges) for these birds were 115 (80-151) g for quail, 356 (227-500) g for pigeons, 1.05 (0.46-1.55) kg for chickens, 4.24 (3.20-7.30) kg for geese, and 100 (65-158) g for two-week-old chickens.

Exposure Conditions

In the direct-blast injury studies, adult chickens and quail and two-week-old chickens were exposed to reflected shock waves on the endplate of a 24-inch-diameter air-driven shock tube. The length of this tube was 147 ft, 10 ft of which was the compression chamber. The birds were mounted on shelves with their left side pressed snugly against the endplate by means of a nylon net. The chickens were tested one at a time and the quail and two-week-old chickens four at a time.

Geese were exposed singly on a shelf mounted on the endplate of a 42-inch-diameter shock tube. The length of the compression chamber of this shock tube was 15 ft and the expansion chamber was 125 ft long. The birds were held in position against the endplate by means of nylon cords. Further details of these shock tubes have been presented in a previous report.[4]

In the translation studies, the birds were released by means of a solenoid-operated release mechanism just outside the open end of a 24-inch-diameter shock tube. The length of the expansion chamber of this tube was 154 ft and the compression chamber was 10 ft long. The release mechanism is illustrated in Figure 1. It consisted of a 3- x 3- x 6-inch box which was divided in the middle with each half mounted on a spring-loaded rod. When two solenoid triggers were simultaneously activated, the halves of the

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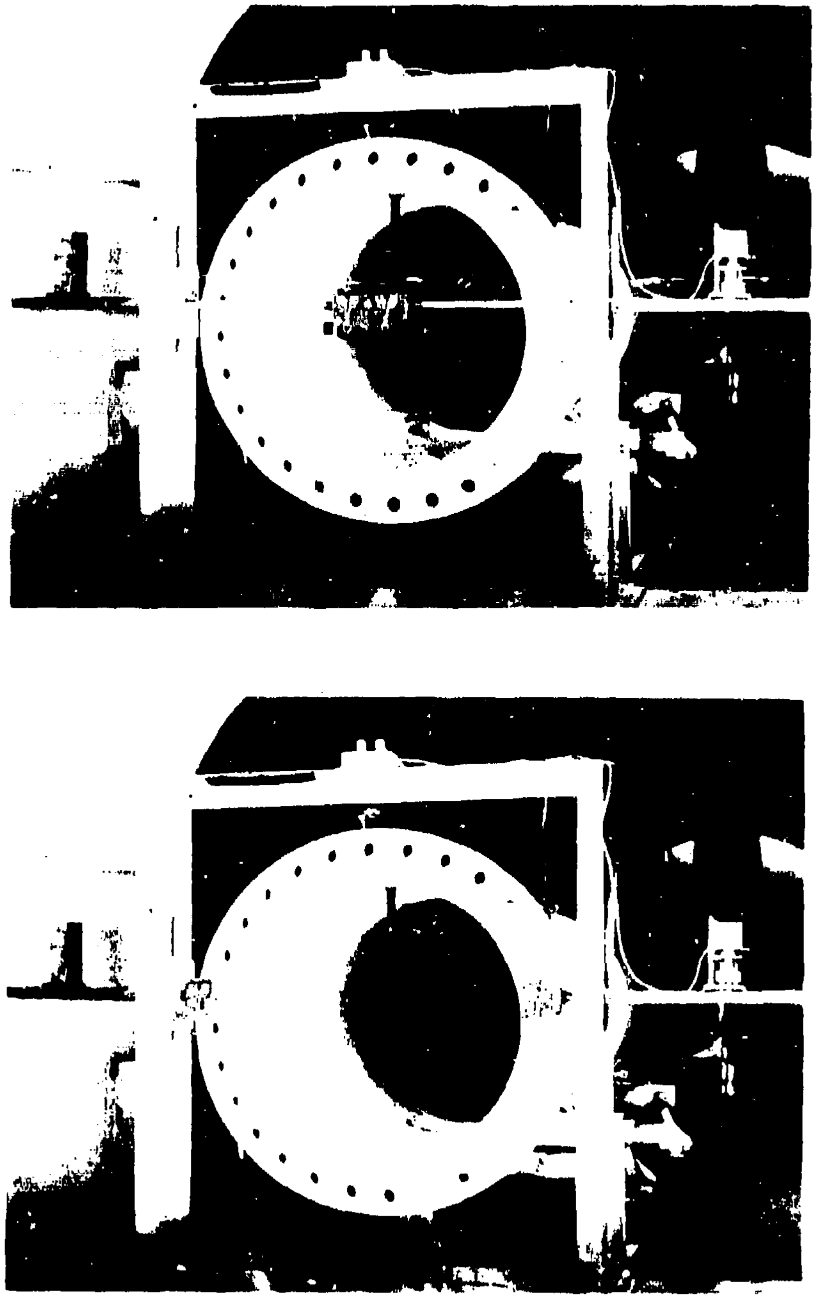

Figure 1. Bird Release Mechanism in the Closed (Upper) and in the Open (Lower) Position.

box would move apart clearing the edges of the shock tube and releasing the quail. Release of the quail was timed such that each bird was near the center of the shock tube (approximately 34 inches above the ground) when struck by the shock wave. Chickens and pigeons were suspended beneath the release box by means of a nylon net vest which allowed the wings, head, and legs to be free. When the release mechanism was triggered, the box flew apart releasing the net that supported the bird. The birds were allowed to decelerate during translation by tumbling along the ground.

In some experiments, pigeons were released from cages mounted 10 ft above the test pad and exposed while in-flight (approximately 6 to 8 ft above the pad) to the detonation of a 64-lb spherical charge of TNT at a 3 ft height of burst. Six pigeons were tested on each shot. An 80-ft length of 15-lb monofilament fish line was tied to the left leg of each bird so that the birds could be retrieved following the test.

Motion-Picture Records

In the translation studies and in the exposure of pigeons to high explosives, the release and translation of the birds was monitored by cinematography at film speeds ranging from 450 to 500 frames/sec. The displacement-time histories were measured from the film records.

Pressure-Time Measurements

Details of the pressure-time instrumentation have been presented in a previous report.[4] In the 24-inch-diameter shock tube two pressure transducers were flush-mounted side-on in the walls of the tube 3 and 12 inches upstream from the endplate. In the 42-inch-diameter shock tube two pressure transducers were flush-mounted side-on in the wall of the tube 12 inches upstream from the endplate. The reflected shock waves were generally flat-topped for about 10 msec in the 42-inch-diameter shock tube and for about 6 msec in the 24-inch-diameter shock tube. The duration of the positive phase of the initial reflected shock wave was approximately 160 msec for the 42-inch-diameter shock tube and about 80 msec for the 24-inch-diameter shock tube. The ambient pressure was 12 psi.

In the translation studies, face-on pressure-time records were obtained from a gauge mounted in a probe positioned 3 inches from the wall of the shock tube 6 inches upstream from the open end of the tube. In a few tests without birds, side-on and face-on pressure measurements were also made just outside the open end of the tube at the position where the birds were released during the exposures. For an incident pressure of 5 psi, the duration of the side-on pressure was 5 msec and the duration of the face-on pressure was about 50 msec.

Dynamic-Pressure Impulse

The dynamic-pressure impulse (DPI) for each high-explosive test was obtained from the measured side-on pressures by scaling from data presented in previous reports.[5-8] In the shock-tube tests, DPI's were calculated from the velocities of the birds measured from the film records using the following approximate relation:[8]

$$V = 4.633\ I\alpha \qquad (1)$$

where V = velocity of bird, ft/sec

I = dynamic-pressure impulse, psi·msec

α = acceleration coefficient of bird, ft^2/lb

The acceleration coefficient, α, was obtained by drop tests for each species in accordance with procedures presented in a previous report.[9]

Four drop tests each were conducted with a pigeon, chicken, and quail weighing 435 gr, 1.6 kg, and 150 gr, respectively. These tests were conducted with the wings folded against the body of the bird as in the case of the birds displaced from the shock tubes. The acceleration coefficients obtained from these tests were 0.17, 0.17, and 0.29 ft^2/lb for pigeon, chicken, and quail, respectively. An individual α was then calculated for each bird in the study by the following relation:[9]

$$\alpha_B = \alpha_A \left(\frac{M_A}{M_B}\right) \qquad (2)$$

where α_B = the acceleration coefficient for a bird of mass, M_B, and α_A is the acceleration coefficient obtained by drop tests for a bird of mass, M_A. The calculated DPI's obtained from these values agreed closely with the DPI's measured from pressure-time records from the shock tube.

Acceleration coefficients were also obtained from drop tests of pigeons and quail with their wings spread and the values obtained were 0.31 ft^2/lb for pigeons and 0.37 ft^2/lb for quail.

Postmortem Examinations

Postmortem examinations were conducted on all fatalities soon after death. The survivors were sacrificed by exsanguination. Some of the survivors of pressures in the lethal range were sacrificed and examined 24 hours after the blast and others at 14 days.

Birds exposed to sublethal pressures were sacrificed and examined 1 to 2 hours postblast. The first step in the autopsy procedure was to assess the air sacs for damage while the respiratory system was intact and ventilated by an endotracheal tube connected to a Harvard piston-type respirator. Gross injuries to the internal organs were then assessed and the lungs were removed and weighed. The coronary arteries of all animals were carefully examined with a dissecting microscope to detect the presence of air emboli.

RESULTS

Direct-Blast Mortality

Figure 2 presents the LD_{50} values and mortality curves obtained by probit analysis of the 24-hour mortality

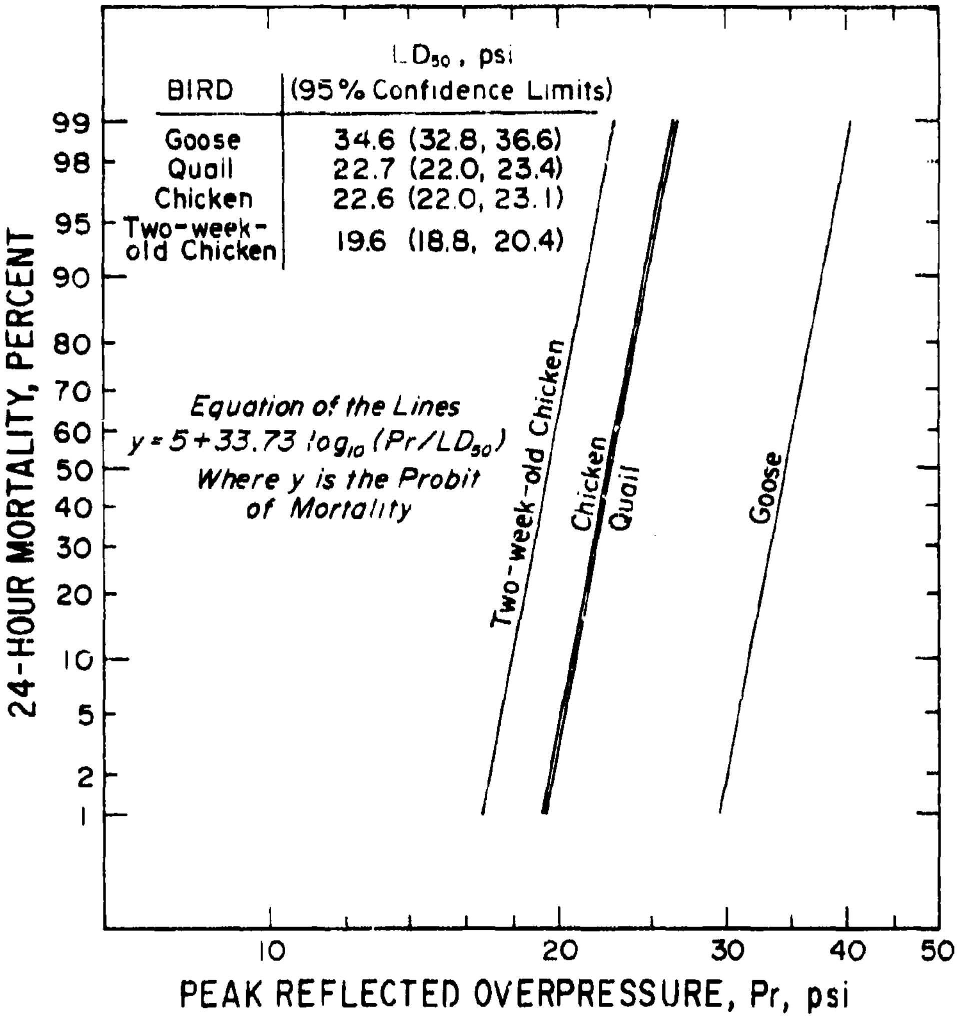

Figure 2. Probit Mortality Curves for Birds Exposed to Airblast in a Shock Tube.

data. The LD_{50} pressures (with 95-percent confidence limits) were 34.6 (32.8-36.6) psi for geese, 22.7 (22.0-23.4) psi for quail, 22.6 (22.0-23.1) psi for chickens, and 19.6 (18.8-20.4) psi for two-week-old chickens. Figure 2 also presents the equation of the mortality lines.

Direct-Blast Injuries

The major airblast injuries in the chickens, quail, and geese killed by the blast are listed in Tables 1 through 3. Most of the fatalities exhibited extensive lung hemorrhage and many of them had bilateral rupture of the kidneys, maceration or rupture of the diaphragmatic surface of the liver, rupture of the posterior portion of the tympanum, and occasional hemorrhage of the epicardium. In addition to the injuries shown in the tables, some of the birds had ruptured egg yolk with free egg yolk scattered throughout the peritoneal cavity. A few of the birds had hemorrhage in the intercostal or substernal region. There were occasional contused areas on the walls of the gastrointestinal tract or of the oviduct. No fractures were observed, the air sacs were all intact and, although air emboli were not detected in the chickens or the quail,

TABLE 1. DIRECT-BLAST INJURIES IN CHICKENS

Reflected Pressure, psi	Number of Birds	Effects
		Deaths
24.0 (21.6-27.0)	25	Twenty-three with extensive lung hemorrhages. Twenty-one with ruptured kidneys. Thirteen with ruptured livers. Fourteen with bilateral, seven with unilateral, four with no eardrum ruptures.
		Survivors-Sacrificed at 24 Hr
20.6 (20.0-22.8)	5	Five with extensive lung hemorrhages. Five with ruptured kidneys. Two with ruptured livers. Two with bilateral, one with unilateral, two with no eardrum ruptures.
		Survivors-Sacrificed at 14 Days
22.4 (19.2-25.4)	19	Eight with hemosiderin deposits on lungs. Three with remnants of kidney hemorrhages. Two with remnants of liver hemorrhages. Eight with scarred eardrums.

TABLE 1. DIRECT-BLAST INJURIES IN CHICKENS (Continued)

Reflected Pressure, psi	Number of Birds	Effects
		Survivors-Sacrificed at 1-2 Hr
15.8 (14.3-16.4)	10	Ten with extensive lung hemorrhages. Two with ruptured kidneys. Four with unilateral and six with no eardrum ruptures.
10.1 (9.6-10.5)	10	Ten with slight lung hemorrhages. Ten with kidneys intact. Ten with no eardrum ruptures.
5.5 (5.4-5.8)	5	No injuries.
		Deaths (Two-Week-Old Chickens)
20.5 (19.6-21.8)	12	Twelve with extensive lung hemorrhages. Three with ruptured livers. One with bilateral, five with unilateral, and six with no eardrum ruptures.
		Survivors (Two-Week-Old Chickens) — Sacrificed at 24 Hr
18.7 (17.4-20.0)	12	Three with extensive lung hemorrhages. Nine with slight lung hemorrhages. Three with bilateral, two with unilateral, and seven with no eardrum rupture.

TABLE 2. DIRECT-BLAST INJURIES IN QUAIL

Reflected Pressure, psi	Number of Birds	Effects
		Deaths
23.4 (20.0-24.6)	23	Twenty-three with extensive lung hemorrhage. Four with ruptured kidneys. Twenty with ruptured livers. Seventeen with bilateral, five with unilateral, and one with no eardrum rupture.
		Survivors-Sacrificed at 24 Hr
20.6 (20.0-21.1)	5	Five with extensive lung hemorrhage. One with ruptured kidneys. Three with ruptured livers. Two with bilateral, two with unilateral, and one with no eardrum rupture.
		Survivors-Sacrificed at 14 Days
22.1 (20.0-24.0)	15	Ten with hemosiderin deposits on lungs. Three with remnants of liver hemorrhage. Six with scarred eardrums.

TABLE 2. DIRECT-BLAST INJURIES IN QUAIL (Continued)

Reflected Pressure, psi	Number of Birds	Effects
		Survivors-Sacrificed at 1-2 Hr
9.9 (9.8-10.0)	8	Six with extensive, two with slight lung hemorrhage. Five with unilateral and three with no eardrum rupture.
5.1 (5.1-5.1)	8	No injuries.
2.4 (2.4-2.4)	8	No injuries.

TABLE 3. DIRECT-BLAST INJURIES IN GEESE

Reflected Pressure, psi	Number of Birds	Effects
		Deaths
36.2 (33.8-38.3)	6	Six with extensive lung hemorrhage. Six with ruptured kidneys. Six with ruptured livers. One with bilateral, two with unilateral, and three with no eardrum ruptures.
		Survivors-Sacrificed at 24 Hr
33.5 (30.8-35.1)	6	Six with extensive lung hemorrhage. Five with ruptured kidneys. Six with ruptured livers.
26.9 (24.1-30.0)	3	Three with slight lung hemorrhage. Three with ruptured livers.
		Survivors-Sacrificed at 2 Hr
9.5	1	One with slight lung hemorrhage.
5.0	1	No injuries.

one goose exhibited coronary air embolism. One chicken had a small fluid embolus, believed to consist of fat, in the coronary artery.

The major pathological findings in the surviving chickens, quail, and geese that survived blasts in the lethal range are listed in Tables 1-3. In the birds that were sacrificed 14 days after injury, most of the lung hemorrhage had been resolved except for occasional spots of residual brown rusty discoloration (hemosiderin). Likewise, most of the hemorrhage around the kidneys, although extensive in the fatalities and in those sacrificed at 24 hours, had been cleared or absorbed by 14 days. The eardrum ruptures had apparently healed by 14 days as was indicated by the presence of a yellowish colored tissue in the posterior portion of the tympanum where ruptures were seen most often in the fatalities. One of the chickens that was sacrificed at 14 days exhibited a deformed egg yolk which may have been ruptured at the time of injury but there was no residual free yolk within the peritoneal cavity. None of the other survivors exhibited evidence of egg yolk rupture.

An overpressure of 5 psi did not produce any direct-blast injuries in chickens, quail, or geese whereas 10 psi resulted in lung hemorrhage in all three species (Tables 1-3). In chickens that received 10.1 psi (9.6-10.5 psi), there was gross dilatation of the pulmonary vascular bed with a moderate amount of perivascular hemorrhage scattered throughout the lungs. Two of these animals had slight hemorrhage of the left kidney. The tympanic membranes of all of these animals remained intact.

The ten chickens exposed to 15.8 (14.3-16.4) psi sustained more pulmonary hemorrhage than did the animals in the 10-psi group (Table 1). Twenty percent of the chickens in the 15-psi group exhibited injuries to one or both kidneys. Forty percent of them sustained ruptures of their left tympanic membranes (the side that was adjacent to the end plate of the shock tube where the shock wave reflected). In all of these animals, the right eardrum remained intact. In addition to the injuries listed in Table 1, a few of the animals in this group exhibited slight subcapsular spots of hemorrhage on the liver and an occasional hematoma on the wall of the oviduct.

The gross pathological effects observed in the eight quail subjected to 9-10 psi are listed in Table 2. In general, the severity of injuries sustained by these quail was similar to that found in the chickens that received 10 psi. There was a marked dilatation of the pulmonary vascular bed and the majority of them had fairly extensive perivascular pulmonary hemorrhage. The left tympanic membrane was ruptured in 62.5 percent of these quail. The right tympanic membrane remained intact in all of them. At 5.1 psi and at 2.4 psi, there were no injuries in 16 quail.

In addition to the chickens and quail, one goose was exposed to a reflected pressure of 5 psi and one at a pressure of 9.5 psi (Table 3). At 5 psi, no injuries were produced and at 9.5 psi the only injury was slight lung hemorrage.

Injuries Produced by Tumbling Displacements

Table 4 lists the injuries produced by displacement with decelerative tumbling over the ground in quail, pigeons, and chickens. This table gives the mean incident pressure, the total pressure, the dynamic-pressure impulse estimated from the peak velocity of the bird, the distance

TABLE 4. INJURIES IN BIRDS PRODUCED BY TUMBLING DISPLACEMENT

Incident Pressure, psi	Total Pressure, psi	Dynamic Pressure Impulse, psi·msec	Distance of Travel, ft	Peak Velocity, ft/sec	Number of Birds	Effects
Quail:						
5.0 (1.8-5.3)	6.3 (5.7-6.7)	32.0 (23-42)	38.2 (33-52)	47.2 (33-69)	10	Two deaths. Ten would not fly post shot. Seven with fractures. Seven with ruptured livers. Seven with slight lung hemorrhage.
2.5 (2.2-2.7)	3.1 (2.8-3.5)	11.8 (10-13)	10.6 (8-13)	16.5 (14-19)	10	Ten flew post shot. One with slight lung hemorrhage. One with ruptured liver. Six with contused skeletal muscles. Two with no injuries.
Pigeons:						
5.4 (5.2-5.8)	6.4 (6.4-6.9)	37.6 (35-44)	27.7 (24-36)	31.6 (29-37)	10	Ten flew post shot. One with extensive lung hemorrhage. One with slight lung hemorrhage. Six with contused skeletal muscles. Three with no injuries.
Chickens:						
5.0	5.9 (5.5-6.0)	36.0 (35-37)	20.0 (16-26)	29.0 (28-30)	4	Two with slight lung hemorrhage. Two with kidney hematomas. Two with contused wing muscles.

traveled by the bird before coming to rest, the peak velocity of the bird, and the number of birds in each group. The motion-picture records revealed that each bird's velocity remained approximately constant over the 6-ft interval extending from 2 to 8 ft downstream from the initial position.

Table 4 indicates that in quail a mean incident pressure of 5.0 psi with an associated DPI of 32.0 psi·msec produced severe injuries and a mortality of 20 percent, whereas an incident pressure of 2.5 psi with a DPI of 11.8 psi·msec produced only slight injuries. In pigeons, an incident pressure of 5.4 psi with a DPI of 37.6 psi·msec produced only slight injuries and all of the birds walked and flew following the tests. In four chickens exposed to this same pressure level, 50 percent of the birds had hematomas on the kidneys and slight lung hemorrhage.

Injuries in Quail Translated Against a Barrier

Table 5 lists the injuries produced in quail by translation with impact against a barrier after 4 ft of travel. At a mean incident pressure of 2.6 psi with a DPI of 12.6 psi·msec and an impact velocity of 17.6 ft/sec,

TABLE 5. INJURIES IN QUAIL TRANSLATED AGAINST A BARRIER AFTER FOUR FEET OF TRAVEL

Incident Pressure, psi	Total Pressure, psi	Dynamic Pressure Impulse, psi·msec	Impact Velocity, ft/sec	Number of Birds	Effects
2.6 (2.5-2.8)	3.0 (2.8-3.0)	12.6 (11-15)	17.6 (16-21)	10	Five would not fly post shot. Five with slight lung hemorrhage. Four with fractured ribs. One with fractured ilium and sternum. Five with contused skeletal muscles.
1.4 (1.3-1.6)	1.6 (1.6-1.6)	5.0 (4.0-6.0)	7.0 (0.0-8.0)	10	Ten flew post shot. Five with contused skeletal muscles. Five with no injuries.

serious injuries were produced in these birds. At an incident pressure of 1.4 psi with a DPI of 5.0 psi·msec and an impact velocity of 7.0 ft/sec, only minor injuries were produced in 50 percent of the birds and all of them walked and flew following the exposures.

Effects of Airblasts from 64-Lb Charges on Pigeons In-Flight

Table 6 lists the range, incident pressure, duration of the incident pressure, dynamic-pressure impulse as estimated from the incident pressure, number of birds, and the effects in pigeons exposed to the detonation of 64-lb charges of TNT. No injuries were produced in these birds at distances ranging from 44 to 126 ft with incident pressures of 1.4 to 11.9 psi and DPI's ranging from 0.2 to 6.2 psi·msec. At ranges of 30 to 40 ft with incident pressures of 13.6 to 23.1 psi and DPI's of 7.3 to 13.5 psi·msec, serious injuries were produced including rupture of the liver, skeletal fractures (primarily wing bones) and lung hemorrhage.

TABLE 6. EFFECTS OF AIRBLASTS FROM 64-LB CHARGES ON PIGEONS IN FLIGHT

Range, ft	Pressure, psi	Duration, msec	Dynamic Pressure Impulse, psi·msec	Number of Birds	Effects
30	23.1	5.0	13.5	6	Four with ruptured livers. Six with slight lung hemorrhage. Two with fractured wing bones.
34	19.5	6.3	11.2	6	Three with ruptured livers. One with extensive, five with slight lung hemorrhage. One with fractured rib. One with fractured sternum.
36	15.2	7.0	8.4	6	Three with ruptured livers. Three with fractured wing bones. One with slight lung hemorrhage. Two with subcapsular liver hemorrhage. One with no injuries.
40	13.6	8.0	7.3	5	One with ruptured liver. One with slight lung hemorrhage. Four with no injuries.
44	11.9	8.4	6.2	6	No injuries.
58	7.4	10.0	3.2	6	No injuries.
66	4.9*	11.0*	1.8*	6	No injuries.
79	3.4*	13.0*	1.0*	6	No injuries.
126	1.4*	20.0*	0.2*	6	No injuries.

* Estimated from range.

DISCUSSION

Airblast Criteria for Birds

The results of these studies indicated that exposure of chickens, quail, or geese to reflected shock overpressures of approximately 5 psi produced no direct-blast injuries whereas 10 psi produced injuries ranging from slight to extensive and an overpressure of 23 psi produced 50-percent lethality in chickens and quail. These values are based upon studies conducted at an ambient pressure of 12 psi. Previous studies have indicated that the ambient pressure has an effect upon an animal's tolerance to the direct effects of airblast. The following relation was found to obtain:[10]

$$P = P_{12} \frac{P_o}{12} \qquad (3)$$

where P and P_{12} are overpressures which produce a given biological effect (such as 50-percent lethality) at ambient pressures of P_o and 12 psi, respectively.

When this relation was applied to the above values in order to scale them at sea level (ambient pressure = 14.7 psi), the values obtained were 6, 12, and 28 psi, respectively.

It should be emphasized that these values apply to animals oriented side-on to blasts against a reflecting surface (the worst condition of exposure for direct-blast effects). In the case of mammals, the results of previous studies have indicated that when exposed side-on to a shock wave in the open, the effective overpressure to which the animal responds is approximately the sum of the incident shock pressure and the dynamic pressure. For animals in the open in a head-on or tail-on orientation, the incident shock pressure constitutes the animal's dose.[11] For total pressures (incident plus dynamic pressure) of 6, 12, and 28 psi, the associated incident pressures are approximately 5, 10, and 20 psi, respectively. Hence, for birds exposed in the open at sea level, incident pressures of 5 psi could be expected to produce no direct-blast injuries, 10 psi would produce slight to extensive injuries, and 20 psi would produce approximately 50-percent mortality.

The solid lines in Figure 3 indicate the ranges at which these pressure levels would occur for surface bursts of charge weights ranging between 10 lb and 500 tons of

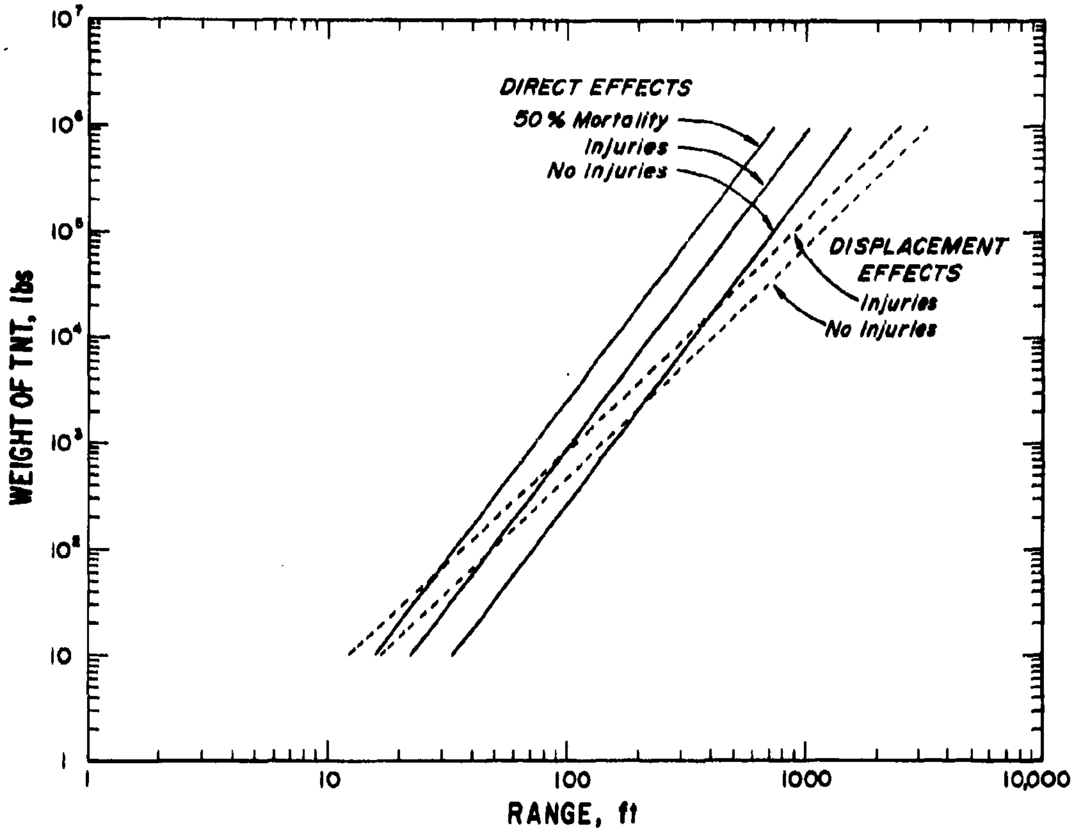

Figure 3. Biological Criteria for Birds Exposed to Airblast from a Surface Burst at Sea Level.

TNT. The dashed lines in Figure 3 indicate the ranges at which dynamic-pressure impulses of 5 and 10 psi·msec would occur. The results of this study have indicated that a DPI of 5 psi·msec produced no serious injuries as a result of shock tube displacement with impact against a barrier (the most hazardous case) or exposure to high explosives while in-flight. Serious injuries were produced at a DPI of 10 psi·msec both on the high-explosives test pad and as a result of displacement from the shock tube when it involved impact with a barrier. When the displacement from the shock tube involved decelerative tumbling without impact with a barrier, no serious injuries were produced by a DPI of 10 psi·msec.

Figure 3 indicates that for charges weighing up to 800 lb, direct-blast injuries would extend to greater ranges than the displacement effects. For charges weighing over 800 lb, the displacement effects are more far-reaching than the direct-blast effects.

The direct-airblast criteria presented in Figure 3 are based upon data from three species of birds ranging in body weight from 0.1 to 4.2 kg. This would indicate that these airblast criteria can probably be applied to birds in general although the fact that geese were somewhat more resistent to direct-blast effects than chickens or quail would indicate that the criteria may be overly conservative for large species of birds. As two-week-old chickens were only slightly less resistent to direct-blast effects than adult chickens, the curves in Figure 3 could probably also be applied to young birds.

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