761148
400

DECLASSIFIED

REPORT NO. 0-1980

DATE January 8, 1943

FR-1980

SUBJECT

Location of Armor for Pilot Protection

by

G. R. Irwin

DECLASSIFIED by NRL Contract
Declassification Team
Date: 12 Jul 2016
Reviewer's name: H. Do, P. Hanna

Declassification authority: NAVY DECLASS MANUAL
[redacted], 11 Dec 2012, [redacted] 02 SERIES

DECLASSIFIED: By authority of
5060A Dated Jan 1958
Entered by: E. Bliss Code 2027

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.

DECLASSIFIED

SERIAL No. 16

[redacted]

January 8, 1943 NRL Report No. 0-1980



[redacted]

NAVY DEPARTMENT

Report On

LOCATION OF ARMOR FOR PILOT PROTECTION

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

| | |
|---|---|
| Number of pages: | Text - 5 Plates - 2 |
| Authorization: | BuOrd ltr. S13-1(4/173)(QB), 13 Dec. 1934. |
| Date of Investigation: | Nov. 11, 1942 - December 1942. |
| Prepared by: | G. R. Irwin |
| Reviewed by: | Ross Gunn |
| Approved by: | A. H. VanKeuren, R. Admiral USN, Director |
| Distribution: | BuOrd - 10<br>BuShips - 2 |

df

## TABLE OF CONTENTS



## Appendix



[redacted]

## Abstract

This report discusses the development of armored seat type of aircraft armor for protection of pilots summarizing the advantages and disadvantages. On the basis of necessary weight of plating and coverage of the pilot for attacks at angles from the rear the armored seat has important advantages. Experimental information from gun fire tests using rabbits held against armor plate indicates the pilot may lean against his armor in the case of cal. 50 impacts without injury from shock. It is suggested armored seat type of pilot protection should be reconsidered and that in any event the plating used to protect pilots can be advantageously located closer to his normal flight position than the aircraft armor specifications now permit.

[redacted]

AUTHORIZATION

1. This problem was authorized by Bureau of Ordnance letter S13-1 (4/173)(QB), 13 December 1934. Other references of interest are as follows:

(a) "Helmets and Body Armor in Modern Warfare" Bashford Dean, 1920. Yale University Press.

(b) S13-1(4) (K13,Ma12),28 April 1938, BuOrd to BuAero.

(c) Letter S13-1(H14,Ma13,Q11), 5 Feb. 1940, BuOrd to BuAero.

(d) NRL Report No. O-1600, 21 March 1940, "7th Partial Report on Light Armor" G.R. Irwin and R.A. Webster.

(e) BuAero Specification SR-35B, 22 April 1942, "Aircraft Armor Installations".

(f) Watertown Arsenal Report No. 710/454 "Mechanism of Armor Penetration" C. Zerner and J.E. Holloman, 3 September 1942.

DISCUSSION

2. This report gives a discussion of pilot seat type armor protection and transmission of shock through armor to personnel. In addition a report prepared by the Naval Medical Center describing experiments with rabbits at the Naval Research Laboratory is forewarded as an appendix to this report.

3. With aircraft armor the main problem has generally been how to employ most usefully an extremely limited weight allowance of armor. An early trial of aircraft armor in World War I by Germany is reported in reference (a) whereby nearly 900 lbs of armor were employed in a twin engined bomber 24 feet long with a 43 foot wing span. In view of the probable weight limitations of this airplane its 106 square feet of armor illustrated rather an extreme conception of aircraft armor. All other known trials of aircraft armor have been based on obtaining a partial protection with a total added weight of armor that does not greatly reduce flying speed, maneuverability, or fire power.

4. It is natural in designing aircraft armor to give a high priority to protection of the pilot. In order to accomplish this, with least weight various proposals have been considered. It seems evident that the coverage of the pilot per unit weight of armor will increase regularly as the distance of the pilot from the armor decreases. As a means of obtaining a minimum value for this distance without proceeding to the extreme of body armor, the advantage of making the pilot's seat of armor is apparent.

[redacted]

5. According to reference (a) the first aircraft armor approved for purchase by the armed forces of this country in World War I was an armored pilot seat of the bucket type, Plate 1. This seat was made of 0.3" 5% nickel type hard homogenous armor to specifications of the Army Aircraft Armament section. The seat appears to have been made of four formed sections bolted together, weighed less than 100 pounds, and did not protect the pilot's head. Unfortunately no units were completed in time to be of service before the end of the War in 1918.

6. It is believed aircraft armor used in planes for the recent Chinese and Spanish Wars were mainly of the flat plat bulkhead type. An ONI report dated 11 March 1938 described the bulkhead type armor on the British Hawker "Hind" and stated no other British planes were believed to carry armor.

7. In April 1938 the Bureau of Ordnance suggested in reference (b) that a special armored seat of 3/8" to 1/2" plating be made the subject of a design study. A number of armored seats modeled about as shown on Plate 2 were purchased and tested at Dahlgren. Reference (c), February 1940, describes the results of a considerable portion of this armored seat development program. It appeared most promising to make the seat of face hardened rolled armor rather than cast it. A 140 lb. seat was able to provide considerable protection from AA fragments and Cal. 50 bullets as well as complete Cal. 30 bullet protection for attack from the rear.

8. In March 1940 this Laboratory issued a report, reference (d), describing the possibilities of aluminum alloys for armor. As an illustration an armored pilot seat constructed entirely of high strength aluminum alloy was proposed. In addition to the difference in armor material, this seat possessed the novelty of having its back shadowed by oblique shields for tumbling projectiles prior to impact on the main unit of armor plate. The scheme seemed likely to provide slightly better Cal. 30 and worse Cal. 50 protection than the simpler 140 pound seat developed by the Bureau of Ordnance. The estimated weight of this seat was 108 lbs. Both designs could have been improved.

9. Although the first aircraft armor drawings developed in the Bureau of Aeronautics were based on the armored seat idea, the armored seat came to be considered impractical and the armor protection provided for Navy pilots consists principally of flat shields located at various distances from the pilot. Reference (e) states "In providing protection for the pilot from the rear, the pilot shall be considered in the normal flight position. ........ Armor shields shall be used in preference to armor seats for personnel protection. The armor shall not be placed closer than three inches to personnel, where practicable, nor shall it be mounted in such a manner that direct impact shock will be transmitted to personnel". The normal flight position reference above coupled with the specifications definition of cone of protection determines the required extent and weight of armor. For example the

[redacted]

cone of protection for class VF planes for pilot head and shoulders from the rear has an included angle of 30 degrees.

8. The protection provided is critically dependent upon the separation of the armor from the pilot even though his normal flight position is completely in the shadow of the armor when viewed from within all points of the cone of protection. The reasons for this are twofold. (1) the attack from the rear upon the plane very often exceeds a 15 degree angle with the axis of the airplane in which event the partial coverage of the pilot by his armor is much better the smaller his separation from the protective plates. (2) In combat the pilot is quite likely to be fired upon while in a position forward from normal flight position as when using his gun sights. In this event unless the armor is close to his back when in normal flight position he is dangerously exposed to bullets even from within the cone of protection.

9. It has been felt by Dr. Ross Gunn and others at the Naval Research Laboratory that insufficient consideration has been given to the advantages of aircraft armor of pilot seat type. The statement quoted above from reference (e) relative to impact shock to personnel indicates that the disfavor with which the armored seat is viewed is based to a considerable degree upon the supposed injury to personnel by high speed shock transmitted through armor. It was believed here this shock injury feature might be considerably overestimated. In order to obtain direct experimental information of a decisive character, arrangements were made with the Naval Medical Center group directed by Capt. Greaves for performance of tests using live subjects held directly against the rear face of an armor plate at the time of bullet impact.

10. The tests performed are described in the appendix, "Naval Medical Center Report". The subjects were rabbits. The sensitivity of rabbits to shock is considerably greater than that of humans. Cal. 50 Ball ammunition, striking velocity 2640 ft/sec, and a 1/2" X 30" X 36" Jessop armor plate of the new aircraft homogenous type were used. The impacts were sufficiently heavy to bulge the back of the plate 1/8". The back of each rabbit was held firmly against the portion of the plate bulged by the impacts. Five rabbits were tested. As stated in Appendix A "none of the animals exhibited any gross injuries, there were no fractures, and the behavior following exposure to bullet impact appeared normal". A 16 mm. film prepared by the personnel of the Medical Center, shows in detail the mounting of the rabbits for test. This film is available at the Naval Research Laboratory.

11. Further details relative to the mechanics of the experiment are as follows. The ammunition was of the M1 757 grain Cal. 50 ball type and gave about 2640 f/sec average velocity at 100 yards range. Velocities were measured with a modified Aberdeen type chronograph using 16 ft base length between two screens. The plate was mounted for normal impact with short dimension horizontal and the impacts were upon the central portion. The plate was clamped to two 2" X 4" wooden timbers placed behind the long edges. The unsupported span was 24". The timbers were secured against a heavy steel framework. This arrangement allowed plate displacements as large as

would be present in the back of a pilot seat with side plates as shown on plate 2.

12. Calculations based upon formulae given in reference (d) indicate the surface in contact with the rabbit moved back about 0.1 inches in addition to the bulging and that the maximum velocity attained was about 150 ft/sec. In a lighter weight plate subjected to the same impact the maximum displacement and velocity may be expected to increase about inversely as the square of the plate thickness. However, for Cal. 50 impact the protection quickly becomes unsatisfactory for other reasons than shock as the plate thickness is reduced below 1/2". For armor piercing type projectiles and face hardened plate it is believed the plate displacement and velocity would be generally less than that pertaining to the experiment described above. A moderate increase in the maximum velocity might be obtained by using fully yawed Cal.50 bullets at 3000 ft/sec velocity.

13. Whether or not the possible effect of 20 mm quick fuzed type bullets should be considered here is debatable. The projectiles must pass into the fuselage and may explode before reaching the pilot seat. In addition 20 mm Ball or AP ammunition may be fired against aircraft armor manufactured in future months. In this case lack of protection by the 1/2" armor from penetration will be more important than from shock transmission to personnel. In any event there appears to be a considerable margin of safety from injuries caused by shock in the above Cal. 50 rabbit experiments so that without test one cannot assume dangerous injury will be suffered by personnel in contact with armor even when the armor is struck by 20 mm H. E. projectiles.

14. Aside from the impact shock to the pilot which now appears to be a minor consideration, there may be objections to pilot seat type protection because (1) the seat is less easily attached to the structure of the plane than the flat shields; (2) the pilot's movements, in particular "bailing out" in emergencies, may be impeded; (3) projectiles which hang in the armor and heavy bulges may cause cuts and bruises. (4) The back of the customary pilot seat can stop some punchings and low velocity projectile fragments if separated from the armor. Of these armored seat disadvantages (1) and (2) are matters of design which were well along toward satisfactory solution prior to the trend away from the armored seat type of aircraft plating. It should be possible to pad the armored seat so that (3) above is satisfactorily eliminated. With respect to (4), the contention that the aluminum alloy back of the usual pilot seat plus the armor shield at a distance of 10 to 15 inches is preferable to the back of the armored pilot seat is a statement implying preference for a particular scheme of divided armor. The gain over a single thickness of armor in the seat on an equal weight basis is, if anything, small.

15. The advantages of the armored pilot seat for protection of pilots have been stated above and are considered sufficient to justify a thorough reconsideration of the protection provided for pilots particularly of fighter planes. They may be summarized with some additions as follows:

(1) The coverage of the pilot by his armor is much more complete for attacks at angles outside the cone of protection and for pilot positions forward of normal flight position.

(2) A greater distance is allowed for tumbling of projectiles either from passage through the fuselage covering or from passage through a tipping screen before impact on the armor.

(3) The sides and bottom of the armored seat furnish convenient locations for utilizing the exceptional high obliquity resistance of aluminum alloy in protecting the pilot.

16. It should be noted that the information supplied by this report relative to shock transmission to personnel through armor plate is not limited in application to the plating of armored pilot seats. Furthermore, flat armor shields supported independently of the customary pilot seat but positioned very close to the pilot may furnish an attractive and practical compromise with the arguments presented above.

## SUMMARY

17. On the basis of a considerable development history and advantages with respect to weight and coverage the armored seat type of protection for pilots deserves further consideration. The flat armor shield type of protection as described in existing Navy specifications encourages location of the plating at unnecessarily large separations from the pilot. Information presented by this report with respect to shock transmission through armor shows the pilot may safely lean against his armor particularly if padding sufficient to minimize cuts from hung projectiles is provided. The advantages discussed in this report for having the armor close to the pilot are believed important. In the event the pilot seat may be impractical for other reasons than shock transmission, considerable gains in protection can be still had by requiring very small separations between the pilot and his flat armor shields.

[redacted]

# A STUDY OF POSSIBLE CONCUSSION INJURY FROM BULLET IMPACT ON PROTECTIVE AIRPLANE ARMOR
## (Project X-90, General 10)

Experiments designed to ascertain the amount and type of injury to small animals which might result from bullet impact, transmitted through airplane armor plate, were carried out at the Naval Research Laboratory on November 11, 1942.

Firing was done with a .50 caliber machine gun barrel in a fixed mount, the 0.5 inch armor plate being placed 100 yards from the muzzle of the gun.

Service (M-1) ammunition components were used, assembled by hand, each charge being weighed on a balance. The ballistic specifications for the ammunition used follow:

| | | | | |
|---|---|---|---|---|
| Bullet | - | | Ball, (M-1) 757.75 grains | |
| Powder | - | | Du Pont No. 1770, 210 grains | |
| Velocity | - | | Shot #1 - | 2400 f/p.s. |
| | | | #2 | - - - - |
| | | | #3 | 2630 |
| | | | #4 | 2600 |
| | | ( | #5 | 2640 |
| | Burst | ( | #6 | 2620 |
| | | ( | #7 | 2660 |
| | | | Average | 2591 |

Kinetic Energy - 11,300 ft. -lbs.

Rabbits were secured in a prone position to three, resilant sheets of perforated steel, and were suspended vertically, in such a manner that the entire dorsal surface of the body was in firm contact with the far surface of the armor plate.

Each animal was subjected to a single impact, with the exception of Rabbit No. 5 which received the impact from 3 shots, to simulate a "burst".

The bullets struck the plate opposite the animals' bodies in the following positions:

| | Shot No. | Portion of body immediately opposite point of impact |
|---|---|---|
| | 1 | Midline, sacrum |
| | 2 | Midline, neck |
| | 3 | Midline, between the scapulae |
| | 4 | Two cm. to the rt. of spine; at level of lower border of the ribs |
| | ( 5 | Center of impact about 1 cm. to the rt. of spine; at level of lower border of the ribs. |
| Burst | ( 6 | |
| | ( 7 | |

[redacted]

Enclosure "A" indicates the points of impact graphically.

RESULTS:

Bullet impact caused the armor to bulge approximately 1/8" on the side in contact with the animals.

None of the animals exhibited any gross injuries. There were no fractures, and behavior following exposure to bullet impact appeared normal.

All animals were returned to the National Naval Medical Center for further observation and roentgenological examination.

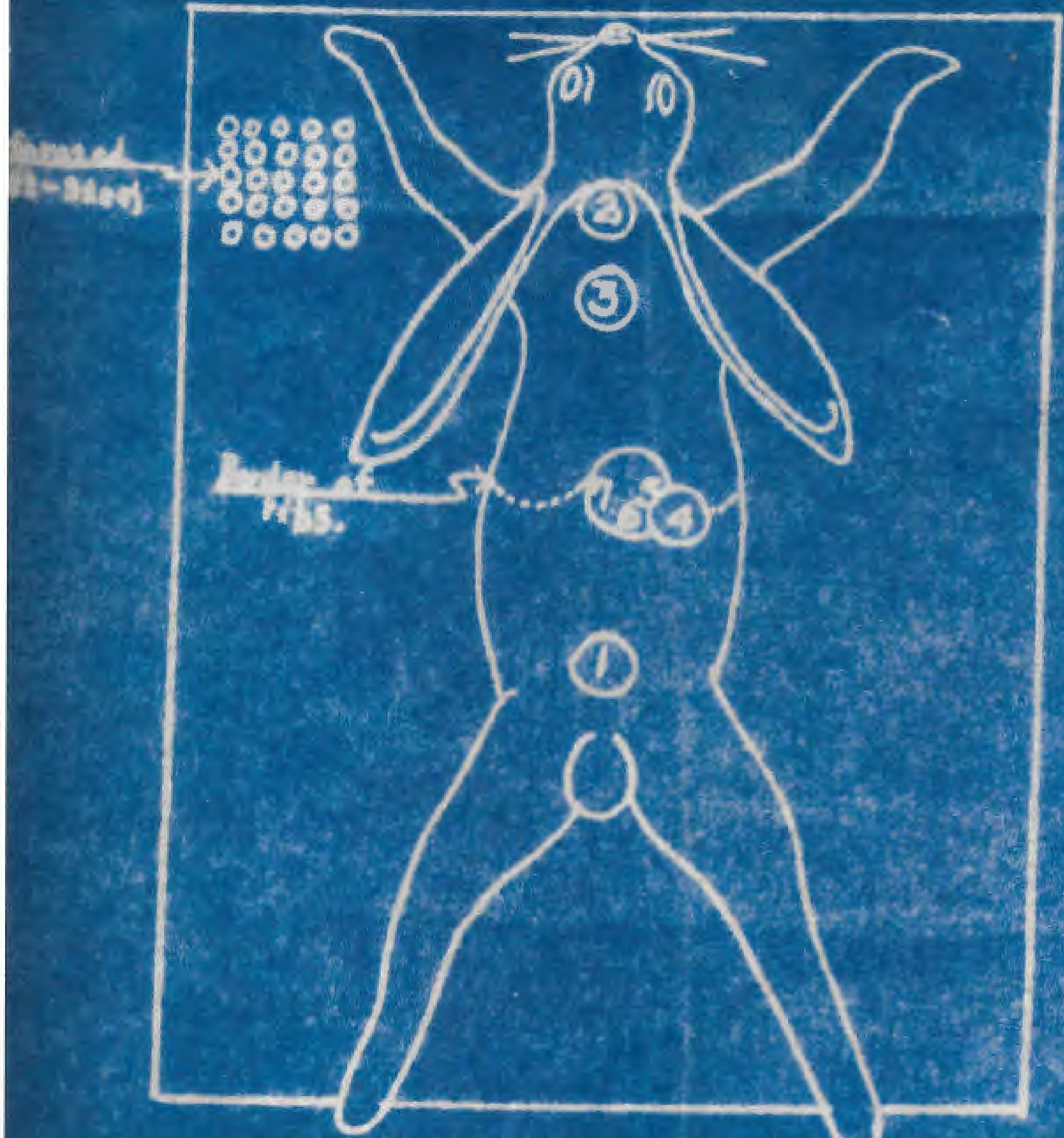
The tests indicate that airplane pilots may not be injured by bullet impact transmitted through steel armor, even though they may be in immediate contact with the protective plates.

F. C. GREAVES,
Captain, (MC), U. S. Navy.

[redacted]

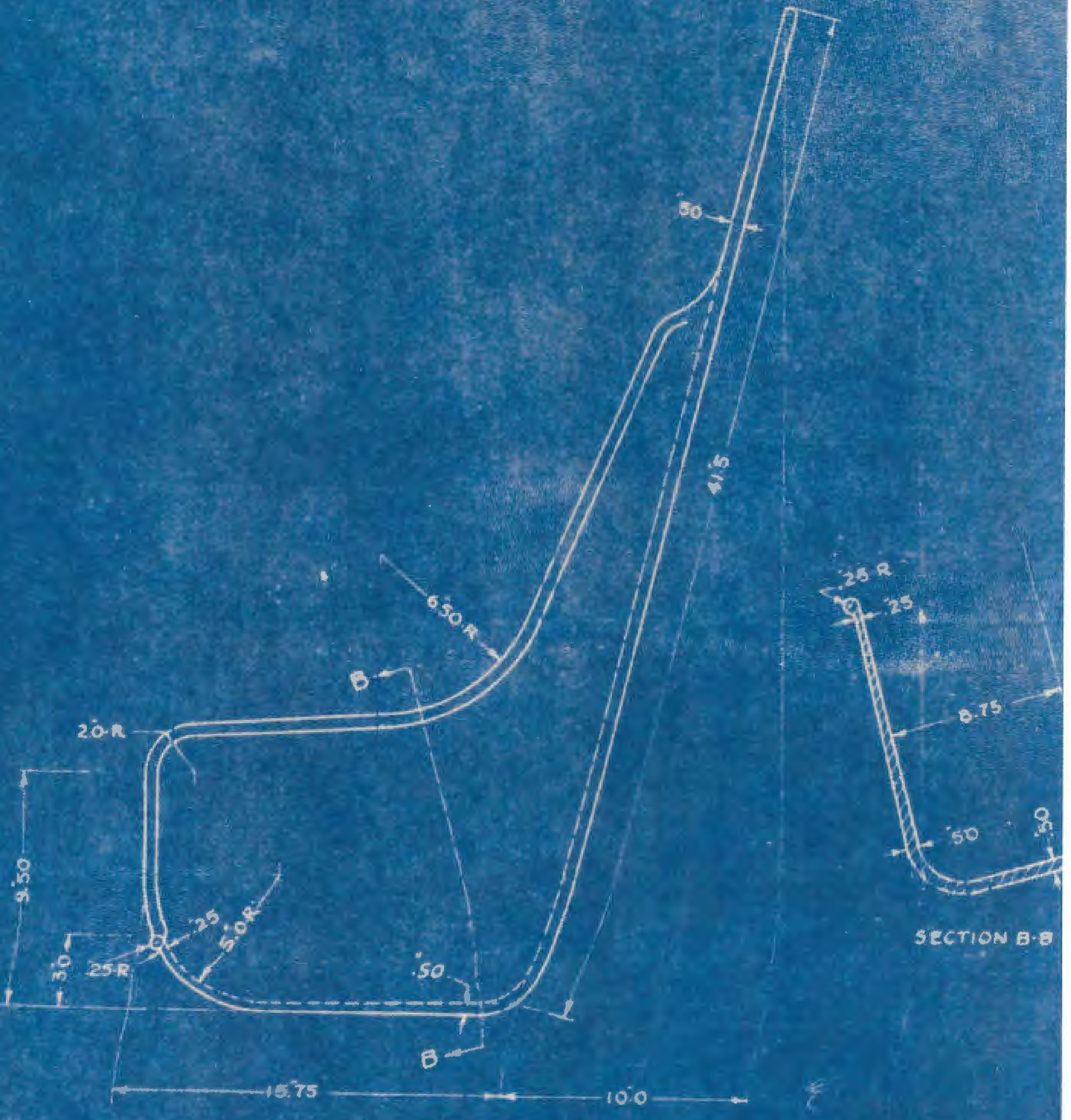
Enclosure A.

Diagram showing points of transmitted impact on animals.



Aviator's armored chair. Experimental model, American, 1918

PLATE I



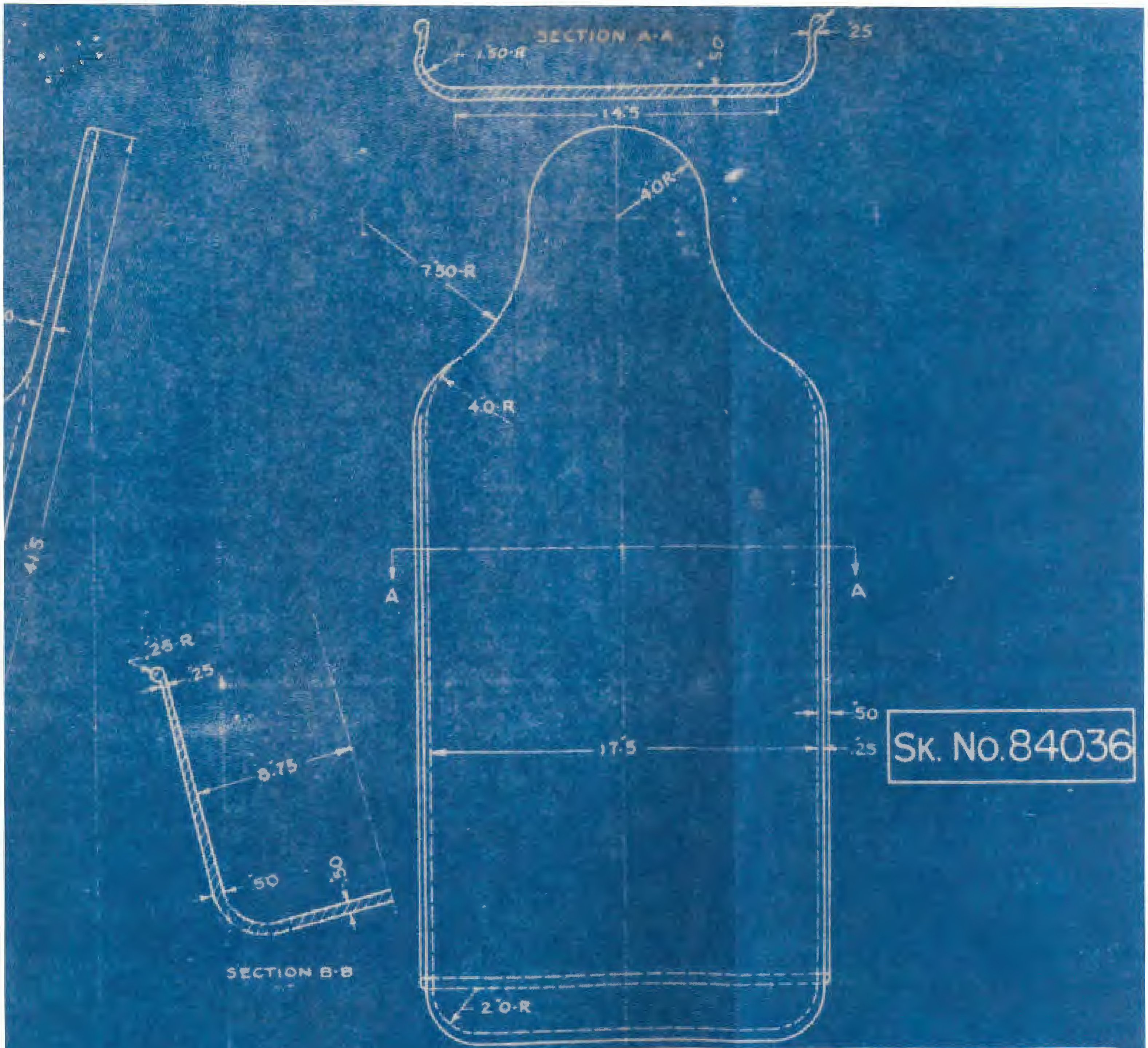

NOTE.

WEIGHT NOT TO EXCEED 150 LBS.

SPECIAL CAST STEEL HAVING BULLET PROOF PROPER

DIMENSIONS MAY BE VARIED SLIGHTLY TO SUIT FOUNDRY

PRACTICE, SUBJECT TO APPROVAL OF BUREAU OF ORDNAN




HT NOT TO EXCEED 150 LBS.
L CAST STEEL HAVING BULLET PROOF PROPERTIES
IONS MAY BE VARIED SLIGHTLY TO SUIT FOUNDRY
CE, SUBJECT TO APPROVAL OF BUREAU OF ORDNANCE.

| REVISIONS | | |
| --- | --- | --- |
| LET | NUMBER | DATE |
| | | |
| | | |
| | | |
| | | |

| EXAMINED | DATE |
| --- | --- |
| F.I.3 | 6/9/39 |
| L. G. | 6/9/39 |
| G. A. O. | 6/9/39 |
| W.E.P. | 6/8/39 |
| CHECKED | |
| W.E.P. | 6/8/39 |
| DRAWN BY | TRACED BY: S. BURG |

ARMORED PILOT'S SEAT
FOR AIRPLANES

TYPE A

SCALE $\frac{1}{4}$

NAVY DEPARTMENT
BUREAU OF ORDNANCE
WASHINGTON, D. C.
June, 12, 1939

CHIEF OF BUREAU

| BUREAU'S FILE | CLASSIFICATION |
| --- | --- |
| | AVIATION |
| JOB ORDER 1260 | ORDNANCE |

PLATE 2

CONFIDENTIAL