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REPORT NO. 710/8

LIGHT ARMOR PLATE

BY

S. TOUR

TECH. STAFF

ORD. OFFICE

APPROX. DATE 1919

WATERTOWN ARSENAL
WATERTOWN, MASS.

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UNCLASSIFIED

REPORT NO. 710/8

LIGHT ARMOR PLATE

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Highest Energy

Not Penetrated

COMPOSITION

Mfg. by	C	Mn	Si	Ni	Cr	Mo	Va	W	Ur.	Co.	Zr.	1/4	3/8	1/2	
Disston	.48	.65	.16									1075.	1773.	2434.	
"	.48	1.10	2.00	3.00								1030.	1869.	2677.	
"	.40	.30	.11	3.40	1.30							1146.	1828.	2709.	
Standard Chemical Co.	.45	.60	.60	3.00					.40			941.			
Halcomb	.14	.36	.19	4.15	1.43							1280.	1700.		Cased
Crucible	.50	.71	.20		.90	.28						1557.	1820.	2535.	
"	.22	.55	.13		.83	.35								2723.	Cased
"	.50	.75	1.25	3.25	.90	1.25	.30	1.25				1863.	2315.		
"	.55	.65	2.00	3.25	.65	.55	.25	.60							
Schneider	.24	.25	.15	5.00		5.00									
Ford Motor Co.	.42	1.08	1.56	3.01						.37	.34				
"	.39	.69	.72	2.21						1.10	.25				
"	.45	1.00	1.63	.35											
"	.44	.90	1.46	3.06		.27				.59	.37				
"	.57	1.14	1.06	3.06			.21								
"	.36	.65			1.14	.22	.20								
"	.50	.75			1.08	1.45	.18								
"	.17	.37		7.80		.54									

LIGHT ARMOR PLATE

by S. Tour - Technical Staff,

Office of Chief of Ordnance, U. S. Army.

* * * * *

BEFORE THE WORLD WAR.

Previous to the recent war the only light armor plate used was in the form of shields for artillery vehicles. These shields were 0.15 inches, 0.20 inches and 0.25 inches in thickness, and prior to the acceptance of each shield, it was tested in accordance with the following specifications: (a plus or minus tolerance of 0.03 inches was allowed thicknesses of plates)

> "Armor Plate 0.15 inches thick shall be tested by firing with a United States Magazine Rifle, Model 1903, Caliber .30, and a cupro-nickel jacketed 150-grain bullet with a muzzle velocity of 2,140 feet per second, for direct impact at a range of 50 yards, and the quality of the steel must be such that the plates shall not be penetrated, cracked, broken, or materially deformed, except, however, that very fine hair cracks formed in the back side of the bulge made by any impact may be permitted."

> "Armor plate 0.2 inches thick shall be tested by firing with the United States rifle,caliber .30, a cupro-nickel-jacketed, 150-grain bullet with a muzzle

velocity of 2,700 feet per second for direct impact at a range of 75 yards."

"Armor plate 0.25 inches thick will be tested in the same manner as for 0.2 inches thick, except that the range will be 20 yards. All other requirements for 0.2 inches and 0.25 inches thick plate will be the same as for 0.15 inches plate."

"When fired at, armor plate must be supported in a similar manner to that occupied when assembled to its vehicle. The point of impact of the bullet must, except as below, be on the side which will be toward the front of the vehicle when on the firing line. In no case, however, must the bulge on the plate interfere with the proper functioning of the parts or with the correct attachment and fitting of hinges, brackets, etc. If in exceptional cases the available space for the point of impact is too limited, the plate may be fired at from the rear side."

It will be noted that no armor piercing ammunition was used in the above tests. In the fall of 1917 a short resume of conditions indicated that there were some thirteen different kinds of steel which, under the proper conditions of manufacture, would resist the standard test for plates 0.15 inches thick, using the usual tolerances of plus or minus of .03. The loss on the ballistic range, however, ran very high, at times being as much as 60%. This loss was discouraging to the manufacturers as it was not possible to immediately detect all of the reasons for the high percentage of failures so as to better control the production and thus the uniformity of the product. It was found that in hardly any case had the manufacturer been able to produce any quantity of material which would successfully pass the ballistic test without exceeding the mean thickness of 0.15 inches and approaching the maximum thickness 0.180 inches. The average thickness was estimated to have been between 0.175 inches and 0.178 inches.

The steels which were manufactured into light armor plate for the U. S. Government prior to the war were made by both crucible and electric furnace processes and could be divided roughly into two classes, nickel steels and chrome nickel steels. In Table I will be found a list of the compositions of steels which had been used and which were advocated, and in many cases still are advocated, as the best compositions known. The practise was to heat treat the plates by quenching in a suitable medium from a temperature between 1450 and 1500 degrees Fahrenheit, until not quite cold and then temper at a temperature sufficient to give the desired brinell hardness.

DURING THE WORLD WAR.

War conditions necessitated the immediate development of both thicker and thinner light armor plate than those mentioned above. The thinner plate was required for helmets (which will not be discussed in this paper) and the thicker was required for the protection of tanks.

In the Fall of 1917 the first serious effort was made to procure thin armor plate for the six-ton American Renault Tank. Some twenty steel concerns were approached with regard to their facilities and their willingness to attempt to manufacture this plate. It was considered necessary to place contracts with steel manufacturers for the completed article, as a great deal of the drilling and machining would have to be done prior to the heat treating process which prepares the plate for the ballistic test. Very few of the American steel makers had had experience in the manufacture of thin armor plate of a thickness 0.25 inches and practically none of them had had any experience in the manufacture of plate in thicknesses above 0.25 inches. Approximately 70% of the thin armor plate on the Renault Tank was 0.60 inches in thickness, while the balance was divided between 0.312 inches and 0.25 inches. No specifications for ballistic testing of plate of these thicknesses existed. The Engineering Division with the assistance of some of the other divisions created ballistic test specifications founded as well as possible upon standards taken from the British and French. The specifications as created by the Ordnance Department required the testing of every plate, although it was understood that the French on certain types of plate were content with the testing of one out of every twenty-five. As a result of the queries sent out to the various steel manufacturers only one manufacturer appeared to be interested in attempting the work as there was so little data available in this country.

The following are the specifications which were issued by the Ordnance Department at this time for the ballistic testing of plates 0.25 inches, 0.312 inches and 0.6 inches in thickness.

"For 0.25 inches thickness of plate the same ballistic test shall be used as that specified in Ordnance pamphlet #434, for shields 0.25 inches in thickness for Artillery Vehicles." (this is the same ballistic test which was described at the first of this paper for this thickness).

"For 0.312 inches thickness of plate five shots of service ammunition (2700 f.s. 150 grains) shall be fired from a machine gun at one point on the plate at a range of ten yards. The above test to apply to all plates of 0.312 inches thickness containing a flat surface of not less than 64 square inches, clear of holes, on plates not having an un-interrupted area as great as 64 square inches, one shot shall be fired from a service rifle at the same range, using the same ammunition."

"Each plate of the first three hundred sets of plates 0.6 inches in thickness shall be subjected to five shots fired with service ammunition (2700 f.s.-150 grains) bullets reversed, at a range of ten yards and striking within a circle of five inches in diameter. If the plates so tested appear satisfactory to a properly instructed government agent, consideration shall be given to the dropping of this test for the remaining plates of 0.6 inches thickness. All plates 0.6 inches in thickness shall be subjected to five shots, fired at a range of fifty yards, all striking within a ten inch circle, using armor piercing bullets (2800 f.s.). The above test shall apply to all plates 0.6 inches thick containing a flat surface of not less than approximately 144 square inches, clear of holes. On plates not having an uninterrupted area as great as 144 square inches, one shot shall be fired, with bullets reversed, at ten yards and one shot using armor piercing bullets at fifty yards."

"The quality of steel must be such that the plates shall not be penetrated, cracked, broken, or materially deformed, except that very fine hair cracks formed in the back side of the bulge, made by the impact may be permitted. A deep hole made by an armor piercing bullet is not considered as a deformation of the plate."

These specifications as originally adopted, were later changed for the 0.6 inches thick plate, to the following: "All plates 0.6 inches thick shall be tested by having three shots fired at a range of fifty yards, widely separated, using armor piercing bullets (2800 f.s.). "All plates 0.6 inches thick not having an un-interrupted area as great as 144 square inches, shall be tested by having one shot fired at them, using armor piercing bullets at fifty yards."

Although there was some difficulty at first in arousing the interest of the manufacturers in this problem there was eventually produced under the above specifications thousands of tons of light armor plate. That it was possible to obtain these plates from a number of different concerns was in a large part due to the fact that representatives of the Ordnance Department and the manufacturers were able to cooperate. A meeting of the manufacturers of light armor plate was held in Washington in January 1918 and there were present many manufacturers of steel and officers of the Ordnance Department. The various concerns had been requested to lay on the table for the use of all competitors all data which had been accumulated by them and which had enabled them to produce a satisfactory product. Although this was a decided departure from the ordinary procedure in peace times, it was in line with the procedure taken by the Ordnance Department in the manufacture of other material than light armor plate and the best possible method for the procuring of maximum good for the country. The manufacturers seemed to feel that notwithstanding the fact that it had cost them considerable money and years of experience to develop their practices the Government was asking only for that to which it was entitled. They were willing to give to their competitors the benefit of coming into their plants and seeing with their own eyes just what was being done. This cooperation was a very great assistance to a number of the companies, inasmuch as one company happened to have had considerable difficulty in flattening and straightening, but were having a very prohounced success in producing plates of high physical quality, whereas, some other concerns had practically no difficulty in the flattening and straightening operations, but did not have the success along the other lines.

Some of the analyses which were used in the production of these plates are shown in Table I. The practice in a majority of the plants was to anneal the plate after rolling, in order to allow of machinability. In the cases where plate was purchased from one manufacturer to be furnished to another manufacturer before heat treatment, it was specified that the plates be annealed in such a manner as to have a brinell hardness not to exceed 300. As a general rule it was found that for the compositions used a properly annealed plate worked very satisfactorily on punching and machining. Due to warping, shrinkage, etc. it was, of course, necessary to drill in the heat treated plate the very important holes which had little dimensional tolerance, but a majority of the punching and machine work was done on the annealed plate. Some of the difficulties which were encountered in attempting to assemble light armor plate are described by Col. H. B. Jordan of Rock Island Arsenal in an article on the manufacture of Mark VIII tanks in the July-August 1920 issue of Army Ordnance. The heat treating of the plates varied to a considerable extent in so far as methods were concerned, but all consisted of a quench from above the critical temperature of the steel followed by a temper. In some cases the plates were held in a so-called "flattener" for oil quenching, in order to decrease warpage. In some cases the tempering was done between heated dies, which at the same time perfected a flattening of the plate. In a number of cases no device was used during quenching or drawing to decrease warpage, but the plates were flattened on the anvil by "saw-smithing." The latter method of flattening plates is, of course, open to the objection that it is an expensive operation as well as to the objection that it detracts from the strengbh of the plate by introducing local strains at various points.

It will be noticed from the above that the requirements for light armor plate were changed from those of protection from a .30 caliber service bullet before the World War to protection from a .30 caliber armor piercing bullet during the World War. It will later be seen that the requirements have become still higher, inasmuch as they demand protection from a heavier and more powerful .30 caliber armor piercing bullet and from a .50 caliber armor piercing bullet similar to the German 13 m/m anti-tank armor piercing bullet. It is practically impossible to make a definite comparison between a service bullet which has a cupro-nickel jacketed lead bullet and an armor piercing bullet which consists of a cupro-nickel jacket containing a lead envelope in which is a hardened steel core of projectile shape. In Table VII will be found the characteristics of these different types of bullets. The results obtained in competitive tests of these bullets will be discussed in a further portion of this paper.

DEVELOPMENT WORK DURING THE WORLD WAR.

Light armor plate is still very much in the development stage. Development work was initiated just as soon as it was found necessary to armor artillery materiel with plate more resistent than that which had previously been used. Certain data submitted to the Ordnance Department seemed to indicate that some definite results would be obtained if arrangements were made whereby some one or more concerns with competent personnel could go very extensively into the problem of developing light armor plate. Such arrangements were made in the Fall of 1917. The metallurgists at one of these concerns considered that in the light of previous experiments in studying the properties of zirconium and molybdenum steels, the best type of plate could be made from these steels. In

Table IV is a list of compositions of steels which were experimented with in this manner. After an enormous amount of experimental work had been done on these steels critical studies of the ballistic results obtained indicated that there probably existed in the experiments, certain uncontrolled irregularities, as a result of which many of the results seemed to be irrational and contradictory.

In considering the different groups of alloy steels shown in Table IV, the ability of the various metals to resist penetration was considered of chief importance. The best results were obtained from nickel-cobalt-zirconium alloy steels, which although of widely divergent chemical analysis, gave excellent ballistic tests. The nickel-silicon-zirconium alloys gave the next best results, although in these there was a great lack of uniformity and the wide variation in the analysis of the different heats of this group rendered it unwise to make a definite decision regarding the qualities of the material without further investigation. The tests on alloy steel containing chromium nickel and molybdenum in various combinations seemed to show no marked advantages of this class over the nickel-silicon-zirconium class. The results of all of the analyses, however, taken as a whole, showed such lack of uniformity that it seemed impossible to arrive at a definite conclusion as to which of the various alloys presented the most desirable features.

In determining the ballistic values of thin armor plates, it is, of course, necessary that the character of the steel slug as regards weight, quality and position in the bullet should be well established and all of the other ballistic conditions accurately determined. An investigation of the ammunition used in testing the plates referred to in the paragraph above and shown on Table IV, showed that it was very non-uniform. The weight of the bullet core varied from 59.30 grains to 64.7 grains and the chemical analysis of a number of the cores showed that some contained 1% carbon and 1.3% chromium, whereas others contained approximately 1% carbon and only 0.10% chromium. One of the observers of the tests was also led to the opinion that certain of the steel cores were not concentric in their matrix of lead and this would, of course, tend to decrease the value of the results.

Although there was found this great irregularity in ammunition, it did not seem to fully account for the erratic ballistic results and therefore the method of manufacture and heat treatment of the plates was carefully gone into. It was found that plates only twelve inches square and 0.380 inches thick varied greatly in brinell hardness. One plate varied from 364 to 502, another from 387 to 463, etc. In some cases it was found the actual brinell hardness of a plate was not that which the records showed for that plate, for example, one plate which was supposed to be of brinell hardness 477, was found to have a hardness varying from 524 to 565. It is not to be taken for granted that all of the many plates showed such tremendous irregularity as the ones noted above, but the fact that a percentage of the plates were irregular cast a doubt upon all of the plates.

Realizing that further development work upon light armor plate should be conducted in such manner as to make more definite conclusions possible, a further program was drawn up for the work. Some time had then elapsed since experiments had been started on the development of thin armor plate and practically all that had been learned was that there were numerous compositions which if properly prepared and treated would give thin armor plate of very good or superior ballistic properties. It was decided that effort should first be concentrated on experiments to produce an armor plate of 0.25 inches thickness. A list of compositions as shown in Table V, was drawn up and a program was prepared covering the manufacture of steels of these compositions into plates of 0.25 inches in thickness. This program covered both the obtaining of physical characteristics of these steels and the testing of the plates ballistically in order that the steels might be evaluated properly and comparisons made between them. Shortly after the placing of the order for these steels, the Armistice was signed.

DEVELOPMENT WORK SINCE THE SIGNING OF THE ARMISTICE.

It was decided that further development work upon light armor plate would be pushed, but that time would be taken to carefully study all of the data so far obtained and to draw up a program for the future which was as scientific and comprehensive as possible. At about this period the Small Arms Division became very active in work towards the development of better and more powerful .30 caliber armor piercing ammunition. It had already been found that the service armor piercing ammunition gave very irregular results and also inferior to some of the types of armor piercing ammunition developed abroad. Since no detailed specifications had at any time been prepared covering ammunition for the testing of light armor plate, other than stating that it should be service ammunition, it was at once evident that if the service ammunition were changed the results obtained upon plates before and after this change would not be directly comparable.

It immediately became apparent that to scientifically conduct experimental work on light armor plate it would be necessary to adopt a standard ammunition to be used in ballistic testing irrespective of whether or not this ammunition was the best which could be developed. It was believed that within certain limits the light armor plate which proved best with whatever special armor testing ammunition was decided upon would also prove best with the service ammunition used during the war or with such improved ammunition as was in process of development.

It might, of course, be possible to conduct a sufficient number of tests with two different types of ammunition to develop a conversion factor by which the value of a given piece of armor plate could be changed from being in terms of one bullet to being in terms of another bullet. The questions of ballistics and ballistic performance of armor piercing ammunition and of light armor plate are in such an undeveloped state that it is practically impossible at the present time to give an absolute conversion factor such as indicated above although some approximation might be obtained. In Table VII are given some figures which to some extent can be used for a comparison of a few of the different types of ammunition.

Not only was it considered necessary to standardize the ammunition used but it was also thought necessary to standardize the methods of testing to as great a degree as possible. In a later portion of this paper will be given the standard method of testing light armor plate as adopted at this time and as revised but very slightly to date.

It was decided that the plates made up of the compositions shown on Table V should be tested in accordance with this standard method of testing and it was directed that the work of preparation of these plates should proceed as rapidly as possible. It was expected that the results which would be obtained upon these plates would be of great interest and value. After the plates were rolled, annealed and ready for heat treatment it was found that a mistake had been made at the establishment at which the annealing of the plates had been conducted and that the plates had been annealed in an oxidizing atmosphere for a period of forty-eight hours at approximately 1000°C. As a result of this annealing the plates were very heavily scaled and were decarburized to such an extent as to make them of no value for the development of light armor plate. This set of plates was therefore scrapped and it was necessary to initiate a new program.

At about this time it became evident that the question of the development of light armor plate was of importance not only to the Ordnance Department but also to the Navy Department and to the Air Service. Arrangements were then made under which the three could cooperate in the work. It is very gratifying to be able to state that this cooperation has continued up to the present time and it is hoped that it will continue in future work and result for the good of all services concerned.

The Navy Department took up the question of determining the value of zirconium steel for light armor plate. The work was very carefully outlined in an attempt to avoid all of the difficulties which had been encountered in work previous to that date. Under very careful supervision, steels were prepared and light armor plate manufactured. The plates were very carefully heat treated and physical tests were made to determine as close as possible the properties of the finished plates. Ballistic testing was carefully conducted in accordance with the method agreed upon and referred to previously in this paper. Considerable difficulty was encountered in manufacturing the steels, the results obtained were not very near to those desired in so far as zirconium contents were concerned. It was also found that the plates as rolled were not of uniform thickness, and that each plate in itself was non-uniform in hardness. Ballistic tests of these plates, although disappointing as a whole, seemed to indicate that the best that could be expected of a plate 0.25 inches in thickness was resistance to penetration by the 150-grain .30 caliber armor testing ammunition at a striking velocity of 1600 f.s.

The Navy Department have not limited themselves, however, to a study of only the zirconium steels, but are carrying out an extensive program upon numerous steels of compositions represented by various reputable steel concerns as being worthy of consideration. The Navy Department have not been limiting themselves entirely to plates 0.25 inches thick although this thickness is primarily the one in which they are interested, and for which they are in the market. In order to carry on the development of light armor plate they have obtained hundreds of plates of various compositions, thicknesses and hardnesses.

It soon began to be realized that too little was known about the relations between hardness, thickness, composition and ballistic properties of light armor plate. Some believed that there was a certain optimum hardness for a given composition of plate, whether that plate was 0.25 inches or 0.50 inches in thickness. Others believed that for each thickness of plate there was a certain optimum hardness. Assuming that plates of various compositions were properly heat treated to bring out the best qualities of the steel, it was believed by some that the properties of the steel as reported by tensile test results could be used as indicative of ballistic values. It was decided thatwork along this line should be conducted. Five compositions as shown in Table VI were selected to be used in a study of the relations of hardness, velocity and thickness. From each of the five compositions, the following material was obtained:

15 feet one-inch rounds.
16 plates, 12" x 12" x .25" thick.
2 plates, 12" x 12" x .312" thick.
16 plates, 12" x 12" x .375" thick.
2 plates, 12" x 12" x .437" thick.
16 plates, 12" x 12" x .5" thick.

The first step in the work was to study the five compositions as represented by the fifteen feet of one-inch rounds and to determine the proper quenching temperature to be used for each. Using this quenching temperature the tensile strength, elastic limit, elongation, reduction of area and brinell hardness curves for tempering temperatures up to 1000° F. were determined. A few pieces of scrap plate from each of the compositions were then experimentally heat treated in order to determine the applicability of the data obtained upon the one inch rounds to the heat treating of flat plate. The next step was to take eight plates of 0.25 inches in thickness, eight plates of 0.375 inches thickness and eight plates of 0.5 inches thickness of each composition and after quenching temper them at temperatures of 500, 600, 700, 800, 900, 1000, 1100 and 1200° F. This has given plates of each thickness of each composition of varying hardnesses. Ballistic tests are now being conducted upon these plates to determine the striking velocity necessary to penetrate each. For each thickness hardness-velocity curves will be plotted in order to show the ballistic properties of plates of different hardnesses, but of the same thicknesses and compositions. From these curves it is hoped it will be possible to determine the hardness giving the best ballistic properties for each thickness and for each composition. The remaining plates of the list of varying thicknesses shown above will then be treated to give these apparent best hardnesses. They will then be tested ballistically and thickness-velocity curves plotted in an endeavor to show the effect of thickness on ballistic properties. It is hoped that the results of the above experiments will indicate to some extent what the effects are of various treatments and various thicknesses upon the ballistic properties of plate of these five respective compositions.

METHOD OF TESTING EXPERIMENTAL LIGHT ARMOR PLATE.

The following method of testing experimental light armor plate is the one which has been referred to previously in this paper and the one which has been adopted by the Ordnance Department in cooperation with the Navy Department and the Air Service in order that results may be as near comparable as possible.

"The object of the ballistic testing of experimental light armor plate shall be to determine the actual striking velocity necessary to penetrate the plate with the standardized ammunition and under the standardized conditions noted below. The size of plates to be used in this work shall be 12" x 12". The thickness of the plates shall be uniform and within the ordinary limits prescribed for light armor plate, namely plus .03" minus .02". The plates shall be supported on a standard butt. The bolts at the four corners of the plates shall be so tightened that the plate is rigidly held against the heavy timber frame-work. All impacts for the determination of properties of the plate shall be normal and the minimum distances between impacts shall be one inch. All ammunition used in the test shall be fired from a rifle in a fixed rest and with operators protected against accident."

"A standard ammunition having a standard bullet in which is a standard steel dart or bullet core of a standard size, composition, hardness and position shall be used. This armor piercing bullet shall be the caliber .30 150-grain armor testing bullet, with 73 grain core. A properly heat treated steel shall be used for the bullet core. Steps shall be taken to control the velocity of this ammunition to such an extent as to be able to determine the actual limit of the plate. This control shall be obtained as follows:

(a) By using ammunition loaded to varying velocities in increments of 100 feet per second, from 1,200 to 3,000 feet per second.

(b) By moving the plate or the rifle so as to obtain varying distances between the muzzle of the rifle and the plate.

(c) By using distance velocity curves of the ammunition to correct for the varying distances."

"A chronograph shall be used to measure the velocities of each shot fired. Photographs shall be taken of the front and back of each plate after test. The following information shall be painted upon the plate before photographing: (1) Number of plate, (2) The face of plate, either front or back, (3) By each impact, its sequence number, that is, first, second, third shot, etc. The test of each plate shall be reported on a standard form and attached to this form shall be such photographs as are taken before or after the test."

DEVELOPMENT WORK ON PLATES THICKER THAN 0.6 INCHES.

The development work so far described has been on thin armor plate for resisting .30 caliber armor piercing ammunition. This requires a plate up to 0.6 inches in thickness. In the Summer of 1919 information was received from the Tank, Tractor and Trailer Division that it was desired to armor tanks for protection against the German 13 m/m anti-tank armor piercing ammunition and that it was desired to develop a U. S. .50 caliber armor piercing ammunition equal or superior to this 13 m/m ammunition. It was desired to know what thickness and kind of armor plate it would be necessary to use to resist this bullet. Some tests were immediately conducted to determine the penetration of this ammunition at various ranges. The thickest plate which had been used up to this time was 0.6 inches. Penetration tests were conducted using one or more of these plates, both with an air gap between them and clamped together. It was found by comparing the identations in these tests, that, contrary to accepted theories, the armor piercing bullet core penetrated farther when two plates of armor were separated by an inch of air space, than when the two plates were so clamped together as to virtually form one plate 1.2 inches in thickness. It was found that two plates 0.6 inches in thickness would be necessary to afford ample protection against this 13 m/m armor piercing ammunition at all ranges, but that two such plates would not be able to withstand two hits in the same place. It was also found that a single plate of 0.6 inches thickness was perforated at ranges up to 900 yards. These tests were all conducted with impacts normal to the plate. Further tests were conducted to determine the maximum penetration at a distance of twenty-five yards by this ammunition in armor plate at angles of 10, 15, 20, 30 and 45 degrees from normal. Again there were not available plates greater than 0.6 inches in thickness and the tests were conducted upon composite plates made up by clamping thin plates together. The following results were obtained in this work:

Angle	Penetration in Inches
10°	1.133
15°	0.994
20°	0.7507
30°	0.255
45°	0.133

The penetration figures shown above represent the depth of indent made, and not the thickness of plate required to withstand the ammunition. A plate 0.133 inches thick will not withstand the ammunition at an angle of 45°, although a plate 1.2 inches thick at an angle of 45° will only be indented a depth 0.133 inches. The minimum thicknesses which were found to be necessary to stop the bullet were:

Angle	Thickness to stop bullet in inches.
20°	0.912
30°	0.85
45°	0.6

For normal impact the following results were obtained with this bullet at ranges as indicated:

Distance in yards.	Depth of penetration in inches.	Minimum thickness in inches to stop bullet.
25 yards	1.062 inches	1.124 inches
100 "	.934 "	1.062 "
200 "	.674 "	.912 "

All of the above results were obtained by firing the 13 m/m armor piercing ammunition at composite plates. That is to say, a heavy plate was made up by clamping together a number of thinner plates. In this work it was found that the total penetration obtained was different when the combination plate was made up by using a .6 inch thick plate backed by a plate .312 inches thick, or by a .312 inches thick plate backed by a .6 inches thick plate. It was also found that the penetration obtained varied with the method of supporting the plate when fired at. Tests have not as yet been conducted to determine the penetration which would be obtained against solid plates, due to the fact that such solid plates have not been available.

In order to at the same time carry on development work of plates greater than 0.5 inches in thickness for protection against the German 13 m/m ammunition or the soon to be developed U. S. .50 caliber armor piercing ammunition, it was decided to enlist the aid of several experienced steel manufacturers. To do this a proposal was sent out and after some time arrangements were made with three different establishments. In this work it is the object to develop the following:

(1) A plate 0.5 inches or less in thickness, whose ballistic properties will be such that it will be able to resist penetration of the .30 caliber armor testing bullet weighing approximately 150 grains with 2800 f.s. striking velocity, (2) a plate 0.75 inches or less in thickness, whose ballistic properties will be such that it will be able to resist penetration of the .50 caliber armor piercing bullet, weighing approximately 800 grains and with 2500 f.s. striking velocity, (3) plates of 0.1875 inches, .25 inches and 0.375 inches thickness which will have maximum ballistic properties in resisting penetration of the .30 caliber armor testing bullet, with striking velocities less than 2800 f.s. (4) plates of thicknesses 0.625 inches and 1.00 inch which will have maximum ballistic properties in resisting penetration of the .50 caliber armor piercing bullet, with striking velocity less or more than 2500 f.s.

In general, the means and methods of executing the work are being left to the contractors. Plates 0.5 inches or less in thickness submitted for test are required to be 12 inches square. Plates 0.625 inches or more in thickness submitted for test are required to be 18 inches square. All plates are required to be free from seams, flaws and other surface defects and must be rolled and not forged, to size. The contractors are permitted to use any composition or treatments or combinations of same which in their opinion are most suitable for the work. It is specified, however, that at least three compositions shall be used for each thickness of plate and for each composition there shall be submitted for test not less than six or more than ten plates of each thickness. No physical tests are being required other than the ballistic tests although the department has reserved the right to make such tests at its own expense as it sees fit. Plates of each of the thickness mentioned above are being accepted and payment for same authorized when the contractor has shown that the plates so submitted for acceptance have the best ballistic properties of any which he has been able to produce.

CASE HARDENED LIGHT ARMOR PLATE.

Some tests have also been conducted and some are being planned for the future of case hardened light armor plate. There are in general two courses which can be followed in the developing of light armor plate. One is the developing of a plate of uniform composition and heat treatment throughout, while the other is the developing of a plate which is case hardened on the side facing the fire but which has a tough back. It is evident that the bullet core of the armor piercing ammunition must be harder than the plate in order to be able to penetrate the plate if the body of the latter is of sufficient strength to withstand the impact without bulging. If the plate has sufficient strength not to bulge under the impact, and the bullet core is softer than the plate, there is little chance for penetration. Any composition of steel that is used for light armor plate must be such that it can be readily forged and rolled into the desired thickness, and also that it can be annealed so that it can be machined and drilled. These conditions limit the ultimate hardness and toughness that can be allowed in the finished plate. It is also necessary to limit both the composition of the steel and the heat treatment of same by paying due consideration to the difficulties of hardening without cracking or excessive warping. The bullet cores after being finished ready for heat treatment can be subjected to a very severe quenching and consequently it should be possible to make them very much harder than any plate hardened all the way through. This means that no matter what kind of steel and heat treatment we use for light armor plate, a bullet can be made of equally good material and heat treated so that it possesses greater hardness than the plate and consequently it should be able to penetrate the plate. If a plate, however, could be case hardened on the side facing the firing and still retain a back sufficiently strong and tough to withstand the impact, it could present to the bullet a hardness equal to or greater than that of the bullet core and the bullet core should be broken up without penetration. In heat treating such a plate it might even be possible to go to the extreme that the case hardened surface could be full of cracks and checks and still give excellent protection against armor piercing ammunition, if the back of the plate had sufficient strength to resist the tendency to bulge under the impact. If the above line of reasoning is true, or even approximately true, a case hardened plate should give a maximum protection as long as the impact of the bullet is insufficient to break the back of the plate and the hardness of the plate is sufficient to break the bullet. If, however, the bullet is fired with a velocity such that its striking energy is too great to be withstood by the tough back of a case hardened plate, then it can be expected that the resistance to penetration offered by such a case hardened plate will be less than that offered by a homogeneous plate of equal thickness.

Some case hardened plates are being obtained in sizes from .25 inches thick to .75 inches thick in order to study the value of such a process and the above line of reasoning. There are of course a great many objections from a manufacturing standpoint to a case-hardened light armor plate but it is believed that these can and must be overcome if the protection offered by such a plate is considerably greater than that offered by a homogeneous plate.

.30 CAL. ARMOR TESTING AMMUNITION.

Although considerable firing has been conducted in accordance with standard method outlined above, the method has not proven entirely satisfactory because of the fact that the ammunition used has not been very uniform. The first difficulty encountered in ammunition was with the bullet cores. Some bullet cores seemed to shatter immediately upon hitting the plate, others "mushroomed" and still others made clean indents without any deformation to themselves. A very careful investigation of the bullet cores showed that there was a decided lack of uniformity of the material from which they were being made and in the heat treatment to which they were being subjected. A better quality of steel has been specified for the bullet core and a very careful inspection is being instituted to see that the material is uniform and it is hoped that in the future there will be no difficulty from non-uniformity of cores.

Considerable difficulty has also been encountered, due to the non-uniformity of velocity of this special ammunition. It has been found that the actual velocity, as recorded by a chronograph varies in many cases as much as 100 feet per second, plus or minus, from the velocities shown on the cartons as the ones to which the ammunition was loaded. To some extent this non-uniformity can be explained by the fact that the cartridges are being made up with reduced charges to give low velocities and the density of loading has thus been very materially changed.

It is necessary to carefully shake the powder down towards the head of each cartridge before same is inserted in the rifle. It has been found that a variation of plus or minus 50 feet per second can be readily obtained by warming or cooling the cartridge before inserting same in the rifle and due to this fact the velocities obtained vary with the climatic conditions of the day.

Recently it has been found that the bullets seemed to be going through the chronograph screens in a tipped position indicative either of tumbling or excessive yaw. A further study of this phenomenon by the taking of photographs of the bullets in flight has indicated that the bullets have a very excessive yaw which no doubt is accentuated by the chronograph screens. Tests have not as yet been conducted to determine the distance the bullet must travel before it "settles down." If the armor plate is so close to the rifle that the bullet has not had time to "settle down" before making impact, it is evident that the penetration obtained will not be comparable to that which would have been obtained had the bullet been traveling with the same velocity but without "yaw."

It is hoped that these difficulties with ammunition will be overcome in the very near future.

CONCLUSION.

The work of development of light armor plate has been subjected to a great many set-backs. Numerous difficulties have been overcome only at the expense of a great amount of labor and time. Many difficulties are still to be met no doubt and it is hoped that they will be overcome with some measure of success.

The work to date has been conducted at numerous plants throughout the country and directed as well as conducted by an ever changing personnel. In order to centralize the work of ballistic testing experimental light armor plate for the Ordnance Department as much as possible, it has been proposed to install a "Light Armor Plate Testing Range" at Aberdeen Proving Ground. With this range in operation under competent direction, it is intended to send to Aberdeen Proving Ground for ballistic testing all of the experimental plates which are being obtained on the various programs previously described in this paper. Plans at present also include the obtaining of more plates, but these programs have not as yet been worked out in sufficient detail to allow of discussing them at this time.

It is hoped that a further paper can be presented after the additional data is obtained from each of the various programs referred to in this paper.

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FINIS

TABLE I

COMPOSITIONS OF LIGHT ARMOR PLATE USED BEFORE WORLD WAR

C	Mn	P	S	Si	Ni	Cr	V	Mo	Co
0.35-0.45	0.30-0.45	0.025 Max.	0.025 Max.	0.10-0.25	6.00-7.25				
0.35		0.025 Max.	0.025 Max.	0.2 Max.	7.0 - 8.0		0.20-0.30		
0.37-0.47	0.90-1.05	0.02 Max.	0.0 2 Max.	0.15-0.25	1.75-2.25		0.18-0.25		
0.30-0.40	1.25-1.50	0.02 Max.	0.02 Max.	0.60-0.70	1.40-1.50		0.40-0.50		
0.30-0.40	0.37-0.42	0.015-0.02	0.015-0.02	0.25-0.275	3.75-4.00	3.50-3.75	Trace		0.45-0.50
0.34-0.44	0.25-0.35				3.40-3.60	1.05-1.20		0.25-0.40	
0.45	0.60			2.00	3.00				

TABLE II

COMPOSITIONS OF LIGHT ARMOR PLATE MANUFACTURED (NOT EXPERIMENTAL) DURING WORLD WAR

C	Mn	P	S	Si	Ni	Cr	V	Mo	Co	Remarks
0.35-0.40	0.50-0.80	0.05 Max	0.05 Max.	0.15-0.35	2.85-3.15					Thickness .15". .20" & .25".
0.48	0.80	0.027 Max.	0.038 Max.	0.90	3.25	0.07				
0.31	0.30	0.025 Max.	0.013 Max.	0.12	5.30					Thickness .312".
0.35-0.40	0.30-0.40	0.02 Max.	0.02 Max.	0.10-0.25	6.00-7.25					.312". & .60".
0.35-0.40	0.40-0.50	0.035 Max.	0.04 Max.	0.15-0.20	1.00-1.50	0.50-0.60				Thickness .60"
0.38-0.45	0.40-0.60	0.04 Max.	0.04 Max.	0.15-0.25	1.00-1.50	0.50-0.70				" .60", & .25".
0.50				0.24	3.00	1.25				
0.35-0.45	0.45-0.80	0.04 Max.	0.04 Max.	0.35 Max.	3.25-3.75	1.25-1.50				Recommended in Ord. Specs.
0.32	0.20	0.010	0.014	0.20	4.70	0.56				Thickness .6"
0.32-0.42	0.30-0.40				3.20-3.40	1.10-1.20	0.20	0.25		" .15", .20" & .25".
0.34-0.44	0.25-0.35				3.40-3.60	1.25-1.50	0.20	0.40		Thickness .15". .20" & .25".
0.28-0.38	0.50-0.80	0.04 Max.	0.04 Max.	0.35 Max.	4.50-5.25			0.75-1.00		Recommended in Ord. Specs.
0.24-0.35	0.20-0.40	0.04 Max.	0.04 Max.	0.10-0.20	4.50-5.10			0.50-0.75		Thickness .6", .312" & .25".
0.50	0.70			2.00	2.75-3.00					Thickness .25" .312", .5" & .6"
0.40-0.50	0.70-0.90	0.03 Max.	0.03 Max.	1.00-1.30	3.00-3.25					
0.30-0.40	0.40-0.70	0.04 Max.	0.04 Max.	1.50-2.00	3.00-4.00					Recommended in Ord. Specs.
0.30-0.40	1.25-1.50	0.02 Max.	0.02 Max.	0.60-0.70	1.40-1.50		0.40-0.50			
0.37-0.47	0.90-1.05	0.02 Max.	0.02 Max	0.15-0.25	1.75-2.25		0.15-0.25			Thickness .15" & .25".

TABLE II (CONTINUED)

COMPOSITIONS OF LIGHT ARMOR PLATE MANUFACTURED (NOT EXPERIMENTAL) DURING WORLD WAR

C	Mn	P	S	Si	Ni	Cr	V	Mo	Co	Remarks
0.40-0.50	0.40-1.00	0.02 Max.	0.02 Max.	0.20-0.25		0.60-1.00	0.06-0.15			Thickness .25", .312" &60". Recommended in Ord. Specs.
0.35-0.45	0.50-0.80	0.04 Max.	0.04 Max.	0.35 Max.		1.00-1.25	0.20-0.30	0.75-1.00		
0.30-0.40	0.35-0.45	0.02 Max.	0.02 Max.	0.20-0.30	3.75-4.00	3.50-3.75			0.45-0.50	

TABLE III

COMPOSITIONS OF LIGHT ARMOR PLATE USED BY FOREIGN COUNTRIES

C	Mn	P	S	Si	Ni	Cr	V	Mo	Cu	Remarks
0.25-0.35	0.40-0.50	0.02 Max.	0.02 Max.	0.10	3.50-4.00	1.25-1.50				British
0.46	0.89	0.029	0.02		3.12					"
0.25-0.35	0.20-0.40	0.04 Max.	0.04 Max.	0.10-0.20	4.50-5.25			0.50-0.75		French
0.15-0.20	0.25	0.04 Max.	0.04 Max.	0.06	2.50	0.50		0.50		"
0.30	0.25	0.04 Max.	0.04 Max.	0.06	2.25-2.50	0.50				"
0.34-0.39	0.25	0.04 Max.	0.04 Max.	0.06	3.70-4.20	1.50-1.75				"
0.15-0.25					3.50-4.50	1.00-2.00				" (Ni+Cr= not less than 5%).
0.41	0.385				2.91.	3.02				French, 15 m/m (0.59").
0.35	0.64				4.04	0.36				French, 17 m/m (0.67").
0.14-0.20	0.50-0.60	0.03 Max	0.03 Max.	0.25-0.30	6.00-6.50	0.60-0.70				French
0.15-0.20	0.35-0.60			0.25-0.30	6.00-6.50	0.20-0.70				"
0.37	0.59	0.023	0.007	1.60	1.73	0.29				German, 4 m/m (0.15").
0.30	0.66	0.08	0.03	1.60	1.85	0.34				German, 4 m/m (0.15").
0.36	0.39	0.04 Max.	0.05 Max.	0.12	3.45	0.32			0.13	German, 30 m/m (1.12").
0.36	0.40	0.02 Max.	0.04 Max.	0.11	4.10	1.50			0.15	German, 16 m/m (0.63").
0.32	0.32			0.15	4.00	1.43				German, 16 m/m (0.63").
0.65	0.65	0.02 Max.	0.02 Max.		2.00	0.75	0.25			German

TABLE IV

COMPOSITIONS OF LIGHT ARMOR PLATE EXPERIMENTED WITH DURING WORLD WAR

C	Mn	P	S	Si	Ni	Cr	V	Mo	Co	Zr	Cu	Al
0.50-0.60	0.65-0.85			0.35	3.50-4.00							
0.40-0.50	0.85	0.02	0.02	2.00	3.00							
0.27	0.33	0.011	0.029	0.21	2.93	1.11						
0.45	0.41	0.01	0.022		3.10	1.11						
0.30	0.42	0.022	0.022	0.10	3.50	1.34					0.03	
0.31	0.44	0.010	0.024	0.10	3.61	1.30					0.03	
0.32	0.40	0.02	0.022	0.10	3.66	1.29					0.03	
0.29	0.44	0.013	0.023	0.10	3.86	1.30					0.04	
0.47	0.54	0.016	0.026	0.32	0.31	1.33	0.24	0.99				
0.48	0.55			0.35	3.50-4.00			0.25-1.00				
0.50-0.60	0.65-0.85			0.35	3.51			0.75-1.00				
0.53	0.49			0.22	3.81			0.92				
0.50-0.60	0.65-0.85			0.35		1.00-1.25	0.15-0.25	0.75-1.00				
0.49	0.75	0.04		0.35			0.15	0.75-1.00				
0.48	0.80	0.036	0.027	0.90	3.25	0.07						
0.46	0.79	0.020	0.015	1.43	3.25							
0.449	1.01	0.022	0.025	1.63	3.49							
0.409	0.80	0.014	0.011	1.65	2.93					0.36		
0.34	0.82	0.020	0.016	1.32	2.60					0.29		
0.39	0.77	0.020	0.021	1.82	3.33					0.24		
0.37	1.14	0.036	0.015	2.16	3.64					0.63		0.12
0.48	0.88	0.012	0.029	1.16	3.45					0.28		0.35
0.39	0.78	0.017	0.138	1.59	3.17					0.33		
0.38	0.89	0.027	0.016	1.39	3.25					0.43		0.12
0.409	1.01	0.034	0.019	1.56	3.40					0.56		0.39

TABLE IV (CONTINUED)

COMPOSITIONS OF LIGHT ARMOR PLATE EXPERIMENTED WITH DURING WORLD WAR

C	Mn	P	S	Si	Ni	Cr	V	Mo	Co	Zr	Cu	Al
0.54	0.72	0.021	0.035	0.95	3.19					0.30		0.07
0.36	0.82	0.035	0.015	1.01	3.14					0.25		0.05
0.46	0.81	0.010	0.010	0.572	2.88					0.45		0.12
0.48	0.96	0.022	0.015	0.93	3.01					0.16		
0.45	0.71	0.029	0.03	1.26	2.16					0.54		
0.43	0.72	0.018	0.018	1.71	3.13					0.13		
0.398	0.84	0.018	0.031	1.22	3.34	0.88				0.28		
0.39	0.99	0.02	0.017	1.66	3.54	0.54				0.25		
0.43	0.95	0.017	0.028	1.50	3.21	0.60				0.25		0.10
0.459	0.93	0.022	0.011	1.05	2.74	0.117				0.23		
0.167	0.36	0.016	0.020	0.47	7.86			0.54		0.29		
0.428	1.08	0.023	0.028	1.56	3.01				0.37	0.34		
0.39	0.69	0.047	0046	0.72	2.21				1.10	0.25		0.04
0.44	0.90	0.018	0.010	1.46	3.06			0.27	0.59	0.37		
0.459	0.93	0.022	0.011	1.05	2.74	0.117				0.23		
0.568	1.14	0.034	0.017	1.08	3.05		0.21					
0.36	0.65	0.018	0.028	0.14		1.14	0.20	0.22				
0.507	0.75	0.055	0.054	0.16		1.08	0.16	1.45				
0.34	0.87	0.016	0.025	0.22		1.30	0.28	0.84				
0.16	0.38	0.018	0.032	0.19	7.77			0.54				
0.42	1.09	0.010	0.020	1.28	3.45			0.70	0.38			

TABLE V

COMPOSITIONS OF LIGHT ARMOR PLATE MANUFACTURED FOR EXPERIMENTAL WORK
BUT RUINED IN ANNEALING BEFORE HEAT TREATING AND BALLISTIC TESTING

C	Mn	P	S	Si	Ni	Cr	V	Mo	Zr
0.40	0.65	0.04 Max.	0.04 Max.	0.20 Max.	4.50	1.00			
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	0.75		0.25	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	0.50		0.50	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	0.25		0.75	
0.40	0.65	0.04 "	0.04	0.20 "	4.50			1.00	
0.30	0.65	0.04 "	0.04 "	0.20 "	4.50	0.50		0.50	
0.50	0.65	0.04 "	0.04 "	0.20 "	4.50	0.50		0.50	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	1.[illegible]		0.25	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	1.[illegible]		0.50	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	1.00		0.75	
0.40	0.65	0.04 "	0.04 "	0.20 "	4.50	1.00		1.00	
0.40	1.00	0.04 "	0.04 "	1.25	3.25				
0.40	1.00	0.04 "	0.04 "	1.00	3.25				0.25
0.40	1.00	0.04 "	0.04 "	0.75	3.25				0.50
0.40	1.00	0.04 "	0.04 "	0.50	3.25				0.75
0.40	1.00	0.04 "	0.04 "	0.25	3.25				1.00
0.40	1.00	0.04 "	0.04 "		3.25				1.25
0.30	1.00	0.04 "	0.04 "	0.75	3.25				0.50
0.50	1.00	0.04 "	0.04 "	0.75	3.25				0.50
0.40	1.00	0.04 "	0.04 "	1.25	3.25				0.25
0.40	1.00	0.04 "	0.04 "	1.25	3.25				0.50
0.40	1.00	0.04 "	0.04 "	1.25	3.25				0.75
0.40	1.00	0.04 "	0.04 "	1.25	3.25				1.00
0.40	0.65	0.04 "	0.04 "	0.20		1.25	0.25		
0.40	0.65	0.04 "	0.04 "	0.20		1.00	0.25	0.25	

TABLE V (CONTINUED)

COMPOSITIONS OF LIGHT ARMOR PLATE MANUFACTURED FOR EXPERIMENTAL WORK
BUT RUINED IN ANNEALING BEFORE HEAT TREATING AND BALLISTIC TESTING

C	Mn	P	S	Si	Ni	Cr	V	Mo	Zr
0.40	0.65	0.04 Max.	0.04 Max.	0.20		0.75	0.25	0.50	
0.40	0.65	0.04 "	0.04 "	0.20		0.50	0.25	0.75	
0.40	0.65	0.04 "	0.04 "	0.20		0.25	0.25	1.00	
0.40	0.65	0.04 "	0.04 "	0.20			0.25	1.25	
0.30	0.65	0.04 "	0.04 "	0.20		0.75	0.25	0.50	
0.50	0.65	0.04 "	0.04 "	0.20		0.75	0.25	0.50	
0.40	0.65	0.04 "	0.04 "	0.20	3.25	1.25			
0.30	0.50	0.04 "	0.04 "	1.25	7.50				
0.30	0.50	0.04 "	0.04 "	1.25	7.50				0.25
0.30	0.50	0.04 "	0.04 "	1.25	7.50				0.50
0.30	0.50	0.04 "	0.04 "	1.25	7.50				0.75
0.30	0.50	0.04 "	0.04 "	1.25	7.50				1.00
0.30	0.80	0.04 "	0.04 "	1.25	8.00		0.25		
0.30	0.80	0.04 "	0.04 "	1.25	8.00		0.50		
0.30	0.80	0.04 "	0.04 "	1.25	8.00		0.75		
0.30	0.80	0.04 "	0.04 "	1.25	8.00		1.00		
0.40	1.00	0.04 "	0.04 "	1.25	6.00				
0.40	1.25	0.04 "	0.04 "	1.25	5.00				
0.40	1.50	0.04 "	0.04 "	1.25	4.00				
0.40	2.00	0.04 "	0.04 "	1.25	3.00				
0.414	0.52	0.015	0.013	0.195	5.76			1.22	
0.988						1.05	1.03		
0.380	0.70	0.010	0.032		3.20		0.45		
0.338	0.53	0.010	0.020	0.16	5.65				
0.422						1.22	0.88		
0.380	1.30	0.015	0.033	0.175	3.98				
0.314						1.80	0.56		
0.364						4.30	0.50		
0.422						4.35	0.82		

TABLE VI

COMPOSITIONS OF LIGHT ARMOR PLATE BEING USED TO STUDY
HARDNESS - VELOCITY - THICKNESS RELATIONS

C	Mn	P	S	Si	Ni	Cr	V	Mo
0.50-0.60	0.50-0.80	0.03 Max.	0.03 Max.	0.15-0.25				
0.30-0.40	0.20-0.30	0.02 Max.	0.02 Max.	0.15-0.20	4.5			0.50-0.70
0.35-0.45	0.90-1.10	0.02 Max.	0.02 Max.	0.15-0.20	2.5 - 3.0		0.20-0.30	
0.35-0.40	0.30-0.35	0.02 Max.	0.02 Max.	0.10-0.15	3.25-3.5	1.00-1.25		
0.45-0.50	0.90-1.10	0.03 Max.	0.03 Max.	1.75-2.00	3.00-3.50			

TABLE VII

SOME CHARACTERISTIC OF BULLETS USED FOR TESTING LIGHT ARMOR PLATE

Kind of Ammunition	Weight of Bullet Grains	Weight of Steel Core Grains	Muzzle Velocity	Remarks
.30 Cal. Service, (full velocity).	150	- -	2800	Cupro Nickel Jacket, lead filled.
.30 Cal. Service, (reduced velocity).	150	- -	2140	Cupro Nickel Jacket, lead filled.
.30 Cal. Service Armor Piercing (1918).	150	63	2700	See Note I - Cupro Nickel Jacket with Steel Core in Matrix of Lead.
.30 Cal. Heavy Armor Piercing.	190	95	2600	Cupro Nickel Jacket with Steel Core in Matrix of Lead
.30 Cal. Armor Testing.	150	73	1000 to 3000	See Note I - Cupro Nickel Jacket with Steel Core in Matrix of Lead. Velocities in increments of 100 f.s. from 1000 to 3000 f.s.

NOTE I - Relative values of .30 Caliber Armor Testing Ammunition and the .30 Caliber Service Armor Piercing 1918 Ammunition are indicated as follows:

(a) The striking velocity of the Armor Testing Ammunition to completely penetrate a plate .475" thick was found to be 2644 f.s. whereas the plate was not seriously damaged by the 1918 Armor Piercing Ammunition at striking velocities over 2800 f.s.

(b) The striking velocity of the Armor Testing Ammunition to completely penetrate a plate .450" thick was found to be 2467 f.s. whereas the plate was not seriously damaged by the 1918 Armor Piercing Ammunition at striking velocity of 2800 f.s.

TABLE VII (CONTINUED)

SOME CHARACTERISTICS OF BULLETS USED FOR TESTING LIGHT ARMOR PLATE.

Kind of Ammunition	Weight of Bullet Grains	Weight of Steel Core Grains	Muzzle Velocity	Remarks	
13 m/m German Armor Piercing (Approximately .50 Cal.).	805	485	2500	Copper Clad Steel Jacket with Steel Core in Matrix of Lead. Boat-tailed Bullet with Boat-tailed Core.	(c) The striking velocity of Armor Testing Ammunition to completely penetrate a plate .400" thick was found to be 2387 f.s. whereas the plate was not completely penetrated by the 1918 Armor Piercing Ammunition at striking velocity of 2800 f.s. (d) The striking velocity of the Armor Testing Ammunition to completely penetrate a plate .375" thick was found to be 2175 f.s. whereas a striking velocity of 2556 f.s. was necessary for complete penetration by the 1918 Armor Piercing Ammunition.