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RELATIVE TECHNOLOGICAL ACHIEVEMENTS IN WEAPON CHARACTERISTICS IN USSR AND USA

DR. W. B. SHOCKLEY

30 JANUARY 1946

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30 January 1946

MEMORANDUM FOR: Dr. Edward L. Bowles.

From: Dr. W. B. Shockley.

Subject: Relative Technological Achievements in Weapon Characteristics in USSR and USA.

ABSTRACT

For the purpose of this study, information has been gathered and systematized so as to show the relative technological advancements made in various weapons by the U.S. and the U.S.S.R. prior to and during the War. The data and the analysis are given in the following sections. The conclusions reached from the study in regard to the time lag in reaching equal achievements and the rate of development are as follows:

Subject	Rate of Development	Time Lag
Aircraft	approximately equal	USSR ranging from 1 to 3 years behind
Ordnance	approximately equal	USSR ranging from 2 years behind to 2 years ahead
Tanks	approximately equal	US ranging from 1 to 3 years behind
Rockets	data inadequate	plus or minus about 2 years
Electronics	?	USSR at least 2 years behind
Oil Refining	USSR $\frac{1}{2}$ as fast	USSR at least 5 years behind
Gas Warfare	data inadequate	data inadequate

On the basis of aircraft production information, it is estimated that for 1944 U.S.S.R. total war production was 40% of U.S. total war production.

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I. INTRODUCTION.

There are several reasons for selecting the development of weapons during war time as an index of the technological potential of a nation. During war time, questions of priority and emphasis are much simpler than in peace time and a nation must inevitably advance the quality and number of its weapons to the best of its ability. In general, the objectives towards which development is aimed are so obvious as to be the same for all nations and frequently expressible simply in quantitative form; the horsepower of aircraft engines, the speed of fighter aircraft and the penetration of anti-tank guns are good examples. Weapons, furthermore, tend to be the product of an individual nation more than do peace time technologies; this is due to the reduced contact between nations, the need for self reliance and the general atmosphere of secrecy about such developments - all of which increase the isolation between weapon developments in different nations. These considerations illustrate the particular importance of including weapon development in the assessment of the relative technological potential in the U.S. and U.S.S.R. The developments in the two nations have been compared graphically and the time lag between them analysed.

In order to understand the method of estimating the time lag between the two nations, consider Figure 4 which portrays Fighter Speeds.* Since the U.S.S.R. put little emphasis on high altitude performance, only the 15,000 foot altitude curves are to be considered. We see that each nation introduced a series of new types having ever increasing performance. Between the dates of the introduction of new types, there was some improvement of old types so as a consequence an exact representation of the increasing performance would be a stairway with the steps sloping up slightly and abrupt jumps at the dates of the new types. For purposes of presentation and analysis, the exact step-wise rise is inconvenient and instead we use a "trend line", made in some cases by connecting the performance points by a continuous line and in other cases by "averaging" the points with a smooth curve. (More exact procedures are possible; however, the results will be essentially the same as those obtained by the method just described. See Appendix D.)

Once the trend lines have been drawn to represent the performance as rising continuously, it is possible to analyse the time lag. Thus we see that the U.S.S.R. achieved 300 miles per hour early in 1938. The U.S.

* On all charts the vertical date lines indicate 1 January of the designated year.

trend line reaches this speed in the middle of 1937. Hence we say the U.S.S.R. lag was 0.5 years at 1938. Similarly we say that at the beginning of 1944 the U.S.S.R. lag was 1.1 years.

It is better to deal with time lags rather than time leads for the reason that hindsight is more accurate than foresight. Thus we can say quite definitely that at the beginning of 1944 the U.S.S.R. lag was 1.1 years but we cannot predict as reliably the U.S. lead in 1944 because we do not know when the U.S.S.R. will achieve the U.S. trend value of 430 miles per hour. For this reason, time lags are used to express all time intervals between the dates when the nations reach equal achievements in any weapon characteristics.

A considerable number of charts have been worked up for various weapon developments. For each of these, where the data permits, time lags have been found. The results have then been plotted so as to show how the time lag has varied for each characteristic from year to year. These time lag curves are assembled on two graphs -- Figure 1 for aircraft development; and Figure 2 for tank, anti-tank artillery, anti-aircraft artillery and other developments.

The conclusions stated in the Abstract are based principally upon the time lag graphs. However, some items have been included for which the data did not warrant drawing graphs; these are discussed in later sections and appendices.

The time lags quoted here are probably a reasonable guide for estimating the future relative position of the two nations in technologies similar to those represented in this study. However, several qualifying comments should be borne in mind.

During the war, Russia was under attack and a certain portion of her research and development establishment was destroyed. This undoubtedly had the effect of increasing her time lag as of 1944 and 1945. For this reason the figures quoted probably overestimate her lag for the future when her facilities are rebuilt.

On the other hand it may be pointed out that in some cases our development appears farther behind than it actually was or needed to be because our emphasis was placed on factors other than those plotted. This may well be true; for example, no information on miles per breakdown on tanks has been included because adequate data was not available. However, such qualifications, especially those involving

questions of decisions on policy may tend to obscure the main issue. An inspection of the curves shows that the values of most of the characteristics considered did in fact increase steadily under the development programs of both nations. With this fact as a basis, comparisons of the dates when equal developments were achieved by the two nations can be made and the time lag found. In this study the existence of the time lags is the main point; it should not be lost sight of in detailed - although probably profitable and informative - inspection of the reasons for and meanings of the differences of development involved.

The type of conclusion reached from the data is in a sense more negative than positive. There is so much scatter, even in a single item such as aircraft development, that it is unwarranted to predict any specific time lag for any particular development. However, there is a general consistency in the data in the sense that U.S.S.R. time lags of as much as 3 years are practically absent. For this reason the negative assertion can be made that in technologies closely related to those involved in building planes, tanks, guns, etc., as covered in this report, the U.S.S.R. will not lag by more than 3 years.

At this point I should like to acknowledge the wholehearted and ingenious cooperation of my collaborators in G-2, A-2 and Statistical Control, without whose aid this study could not have been prepared.

II. AIRCRAFT DEVELOPMENT

The information on U.S.S.R. engines has been largely obtained from captured German documents. There are a sufficiently large number of points so that it is reasonable to average them with a smooth curve. The trend curve for U.S. types is based on data which is at present being checked, for this reason no exact dates or powers are shown; however, when definite values are established, the trend curve will certainly not be materially altered. For both cases, the dates involved correspond not to design or acceptance tests but to the dates at which quantity production commenced for military use at the indicated rated take-off power.

No particular comments are required for Fighter Speed except to remark that dates correspond to initiation of quantity production of the indicated type.

The Fighter Ranges are maximum distances which can be flown by military type aircraft with no bomb load but with external tanks when authorized at optimum cruising speed and altitude with no allowance for fuel reserve at the end of the range.

In working up information on Bomber Speed, any aircraft (including heavy, medium, light and fighter bombers) carrying a bomb load of at least 2,000 pounds has been included.

Since Bomber Range and Bomb Load are closely related, the following convention has been adopted. Bomb Load is the maximum authorized for each particular type of aircraft; aircraft considered have been restricted to heavy and medium types capable of carrying a minimum specified load of at least 4,400 pounds. Maximum range is at optimum cruising speed with the heaviest corresponding load, no allowance for fuel reserve on landing being made.

III. LAG IN AIRCRAFT DEVELOPMENT

The range from 1500 to 2200 horsepower was covered by the U.S.S.R. in 2 years compared to 4.5 years for the U.S. This is reflected in the Lag graph which shows a continuously decreasing time lag for the U.S.S.R. This increased rate of development in the U.S.S.R. is due in part to increased urgency during the War years. The engines developed were modifications of German, French and U.S. designs; however, the higher horsepower developments were not copies of similar developments in the U.S. but instead represented original engineering along independent lines by the U.S.S.R.

Fighter Speed has been discussed in the Introduction. It is pertinent to point out that although we have kept ahead in this field, we did not materially widen the gap between 1937 and 1944. This means that the U.S.S.R. development went at the same rate as ours with the whole program between six months and a year behind.

In considering the time lag for Fighter Range, it should be borne in mind that the U.S.S.R. concept of a fighter involves close support of ground force operations and that additional armament is preferred to more range. Consequently, little if any effort has gone to increasing the range.

No particular comments are called for in the case of Bomber Speeds, Range or Bomb Load.

The material on Aircraft Development was furnished and checked by the Defensive Branch of the Technical Advisors Section of A-2.

IV. GROUND WEAPONS

The method of plotting and analyzing the data is essentially similar to that for aircraft developments and will not be discussed again here. The dates of introduction are defined as follows:

Tank Development: date at which quantity production for military use commenced in both countries.

Anti-Aircraft and Anti-Tank Artillery Development: date of acceptance of type involved.

The following comments prepared by the Military Research Section, Military Branch of M.I.S. give general background about the nature of this data:

General

It is imperative to realize that the information furnished for the graphs on Russian equipment is extremely inadequate. Our most valuable sources of technical information on Russian equipment are:

(a) Russian handbooks sent from Military Attaches in Moscow, Finland and Stockholm, etc.

(b) Observer reports from overseas theaters and Military Attaches.

(c) Documents by the German Army on Russian weapons captured or used by the Germans.

Of these sources,

(a) has been very inadequately exploited owing to the paucity of Russian technical translators.

(b) Observer reports from overseas theaters are based on examination of specimens of equipment captured by the Germans on the Eastern front, and possibly modified by them to suit their own (German) needs. These reports, while therefore of a limited value, have been fully exploited. Observers in Russia are highly limited in the variety of equipments which they may see, and are rarely allowed a close inspection.

(c) The Germans took an intense interest in Russian equipment, and made a continuous study of it, adapting many weapons to their own needs. Examples of this are shown in the fact that the Germans took the Russian 85 mm AA gun and rebored it to fire their own 88 mm ammunition. When American troops over-ran Hillersleben Proving Ground in May 1945, a specimen of the 100 mm antitank gun Model 44 (1944) and ammunition were recovered. The Germans therefore had built up considerable studies of Russian capabilities. Exploitation of such German studies has reached a very early stage, and the number of documents awaiting processing in America, Great Britain and Germany is measured in tons rather than individual documents.

It is only by bearing these facts in mind the general picture of Russian development as compared to American development can be seen in its true perspective.

Antiaircraft Artillery

The Russian antiaircraft organization is divided into two groups, the tactical group and the strategical group. The tactical group was used in forward areas, whereas the strategical group was deployed in the defense of the big cities, such as Leningrad, Moscow, and other places of strategic importance. Of the two groups the strategic group had the highest priority on new weapons, and only when their demands had been satisfied were those of the tactical group met. Information on Russian AA weapons is therefore limited to the older types as very few, if any at all, belonging to the strategic group were captured by the Germans.

The graphs do not indicate any production beyond the 85 mm stage with a ceiling of 34,500 feet. It is inconceivable that research did not continue during the war years, and, indeed, German documents tentatively list a 122 mm and a 152 mm AA gun. These weapons would have correspondingly higher ceilings.

Antitank Artillery

The graphs show that the Russians were ahead of the Americans in both aspects of caliber and armor penetration. The 37 mm gun was some 8 years ahead of the American 37 mm gun, which was based largely

on the German 37 mm Pak designed by Rheinmetall.

The advance by the Russian antitank artillery to higher calibers and performance figures, is understood if the picture of the armor race between Russia and Germany is borne in mind. Each country was producing tanks of greater armor thickness, or using spaced armor necessitating more powerful antitank guns.

With the advent of the hollow charge principle, assisted by rocket-fired projectiles, weapons in the form of the bazooka appeared. These weapons tended to retard pure antitank guns as such in the American development.

Both hollow charge projectiles, and guns designed on the tapered bore principle were produced by the Americans and Russians. Of the former, little is known of Russian development, while of the latter, development took place almost simultaneously in the two countries and appears to have originated in the German designs.

It is interesting to note that both countries had to make use of old field guns when small caliber antitank guns became outclassed by armor. The Russians used their Model 36 (1936) 76.2 mm Field Gun, while the Americans used a 75 mm Field Gun of Schneider 1897 design.

Tanks

The graphs show that the U.S.S.R. is 1½ to 2 years ahead of the U.S. in this field. Although in the years prior to World War II, the Russians had not progressed beyond other large nations in the production of tanks, defense of their homeland against the German army in 1941 called for drastic steps. It was not until 1943 that the U.S. army came face to face with German tanks, and although the experience gained by the British in desert tank warfare had been available to the U.S. army, this cannot be compared with the terrific tank battles fought on Germany's eastern front, where the Russians encountered the German 'Panther' and 'Tiger' models, the latter with more than 100 mm armor protection and mounting the famous 88 mm gun.

Although during the period U.S. tanks were rapidly developed, production never made up for the original boost given to Soviet tank

production. By the end of hostilities Russian tanks were more heavily armored, had more powerful armament, and, as a direct result, lower speed than U.S. tanks. (Because speed has decreased rather than increased, no use of it has been made for time lags.)

On the armament graph, American development stops at a 90 mm gun. The Americans did mount a 105 mm Howitzer on tanks, but as this weapon has an inferior performance to the 90 mm guns, it has not been included.

V. ROCKETS*

Information on Rockets, while not permitting a comparison in the form of graphs, is in sufficient detail to allow some comparison to be made in more general terms. A table showing general characterisitics is shown at the end of this section. Before drawing any conclusions from this table, the contents of the table will be first clearly evaluated.

U.S.S.R. Tables

a. Sources of the material are first considered. The tables are based upon data concerning 5 different projectiles; these are the 82-mm, 132-mm, Elongated 132-mm and two 400-mm rockets, the TS-16 and TS-20, representing five of the total number of seven projectiles about which any data at all is available. These tables therefore represent almost the whole known picture of Russian rocket development up to 1943. Information concerning the 82-mm has been obtained from translations of Russian documents and may be regarded as completely reliable. An Italian report, an Intelligence Summary dated 1943, supplied data regarding the 82-mm, 132-mm and Elongated 132-mm rockets; the layout of this information and the fact that data applying to the 82-mm agreed with those already received indicate that the existence of these two projectiles may also be accepted as certain. Slight doubt exists concerning the two 400-mm projectiles, the TS-16 and TS-20. They were first reported in 1943 in an M.A. report (evaluation A-1) giving brief details; mention has been made of them also in German documents. No drawings have ever been received and a recent though most vague report from Moscow indicates that the largest caliber of rocket is only 300-mm; this recent report is uncertain and the others were fairly reliable, so it is assumed that the projectiles do exist. These tables, therefore, can be said to present a fair, if limited, picture of Russian development.

b. Dates given in the table represent dates that information was first obtained. They therefore do not give a more accurate picture than that the Russians were using that type of rocket at that time. Whether the rocket was in the experimental stage (denoted in the U.S. by the letter "T") or whether they were in general manufacture at that time is not definitely known from the dates available. At best these

* Prepared by Military Research Section, Military Branch of M.I.S.

dates give an optimum, in that the rockets may have been in use for some time in which case the date of general production for military use will be earlier than that shown.

U.S. Tables

a. Dates given in the table attempt to present the time when the rockets were first used. These dates, though reliable in themselves, are not comparable to the Russian dates. In some cases the rockets were designed and test-fired, and manufactured in limited quantity for operational use. In the course of the following year, either production for military use began, or small quantities were produced for "limited procurement", or the projectile design was dropped in favor of later and more efficient designs. It is therefore extremely difficult, accurately, to present dates, in a form from which any comparison could be made.

Conclusions

Bearing in mind these comments, the following general conclusions can be reached.

a. Russia was striving towards longer range and had achieved a range of 7,100 meters with a projectile of 42 kg. The American optimum range was 4,800 meters with a projectile of 19.3 kg. The Russians therefore lead in this field, though the time factor is not accurately known.

b. On the Air to Ground side, the Russians are ahead in range, though at the expense of weight of the projectile. On fire delivery (weight of projectile multiplied by range) the Americans are ahead, as shown by the final column of the table.

In both these conclusions, no reference is made to "Accuracy"; this being one of the major criteria of rocket performance. While accuracy and dispersion figures are available for American rockets, no such figures are available for Russian rockets, and no comparison can be made.

Russian -- Ground to Ground

Name	Date	Weight* Kg.	Range Meters	No. fired per salvo	Fire delivery per salvo
82-mm	1942	6.85	5500	42	
400-mm TS-16	1942	81	2500	4	
400-mm TS-20	1942	77	3000	4	
Elongated 132-mm	1942	42	7100	16	
Russian -- Air to Ground					
82-mm	1942	6.85	6200	8	4.25×10^4
132-mm	1943	23.1	7100	8	16.4×10^4
American -- Ground to Ground					
2.36 in.	1942	1.6	550	1	(Bazooka)
4.5 in. M8	1942	18.2	4250	8, 16, & 60	
4.5 in. M16	1944 (end)	19.3	4800		
7.2 in. T24	1943 (A)	23.5	3000		

Note (a) - 1943 is date when a "limited procurement" was made, this rocket was standardized in 1945.

American -- Air to Ground					
4.5 in. M8	1942	18.2	4250		7.7×10^4
5 ins. HVAR	1944	61	3700		22.6×10^4

* This is the weight of the unfired round. The weight of propellant is of the order of 15% in most cases.

VI. ELECTRONICS

Data was sufficient for comparison only on two items of information. A pentode manufactured in 1937 or 1938 was about 4.5 years behind U.S. art. Furthermore, this development was based largely on imported skill and equipment.

The U.S.S.R. had frequency modulation equipment in military use in 1943, about two years after we did.

These two items are plotted as points on Figure 2.

VII. OIL REFINING

The evidence for oil refining is not such as to justify drawing graphs. The information obtainable (Appendix C) indicates (1) that the U.S.S.R. did not place high priority on self reliance in this field; (2) putting a refinery up and into operation in the U.S.S.R. takes between 2 and 3 times as long as in the U.S.; and (3) the U.S.S.R. would probably require 5 to 10 years to catch up to our present skill if they gave this project higher priority.

VIII. CHEMICAL WARFARE

Insufficient information is currently available to make any statement regarding relative technological position on this subject.

IX. RELATIVE PRODUCTIVE CAPACITY

In order to complete the picture of U.S.S.R. and U.S. technological war potential, it is desirable to have a comparison between the productive capacities of the two nations. Such a comparison is difficult because of the diversity of materials to be considered and the lack of adequate information on these. However, a reasonably good estimate can be made on the basis of production in a single field -- aircraft production is actually used -- provided an estimate can be given of the entire production compared to the single field.

The estimate made here is admittedly rough and approximate. However, since the comparison is made along strictly parallel lines for the two nations, the resulting ratio may well be more accurate than the indices used for each nation. However, the main purpose of this section has been not so much to derive an accurate ratio but rather to show that U.S.S.R. production efficiency cannot be negligible compared to ours but must be of the order of one-fourth to one-half as great.

The U.S. War Expenditures in 1944 were 76 billion dollars, of which 23 billion were directly and indirectly for the Air Forces. In other words, the Air Forces represented about 30% of the total expenditures. The total war production must, therefore, have been approximately 100%/30% - 3.3 times as large as aircraft production. Since the U.S. production of AAF aircraft amounted to 52,000 aircraft weighing 1.1 x 109 pounds in 1944, this implies that the total war production was equivalent to 3.6 x 109 pounds of aircraft.

U.S.S.R. military aircraft production in 1944 is estimated as 57,000 aircraft weighing 3.8 x 108 pounds. However, before comparing this with U.S. production, the ratio of total U.S.S.R. war production to aircraft production must be known.

The U.S.S.R. emphasis on aircraft can be estimated from the size of the armed forces. These are as follows:

	Million	%		Million	%
U.S. AAF	2.4	21	U.S.S.R. Air	1.4	15
U.S. AGF and ASF	5.3	47	U.S.S.R. Ground	7.5	82
U.S. Navy	3.6	32	U.S.S.R. Navy	0.3	3
TOTAL	11.3	100	TOTAL	9.2	100

It is incorrect to compare industrial efforts to personnel in the Armed Forces directly. This is seen from the fact that the AAF, with 21% of the personnel, accounted for 30% of the War Expenditures; whereas the remaining 79% of the personnel accounted for 70% of the expenditures. Thus each AAF member is more expensive than the remaining types in the ratio of 30/70 times 79/21= 1.6 Hence the U.S.S.R effort should not be taken as 15 for Air versus 85 for other but 15 times 1.6 = 24 for Air versus 85 for other, thus giving 22% for Air. On this basis we estimate that the total U.S.S.R. war production in 1944 was equivalent to 100/22 = 4.5 times the aircraft production; that is, equivalent to 1.7 x 109 pounds of aircraft.

Comparing the U.S. figure of 3.6 x 109 with the U.S.S.R. figure of 1.7 x 109 indicates that in 1944 their productive capacity was 47% of ours.

One further correction should be introduced. In addition to production for the Armed Forces, the U.S. produced between 10 and 20 per cent additional equipment for Lend-Lease. This means our production should be represented by 4.2 x 109 pounds of aircraft. Lend-Lease is not included in the U.S.S.R. production estimate so that their figure is unaltered. On this basis U.S.S.R. production in 1944 is estimated as equivalent to 40% of the U.S. production.

Several qualifying comments should be made. Because of our extensive use of air transport, which involves a large ratio of equipment to personnel, it may well be that while our airmen are equivalent to 1.6 of the remaining types (so far as industrial production is concerned), the U.S.S.R. airman is equivalent to less, perhaps only to 1.3. If this is true then actually U.S.S.R. production will be relatively higher than the 40% estimated above.

U.S.S.R. construction involves more wood and fabric than ours. This may introduce some modification in estimating the equivalent value per pound.

LAG BETWEEN DATES OF EQUAL ACHIEVEMENT

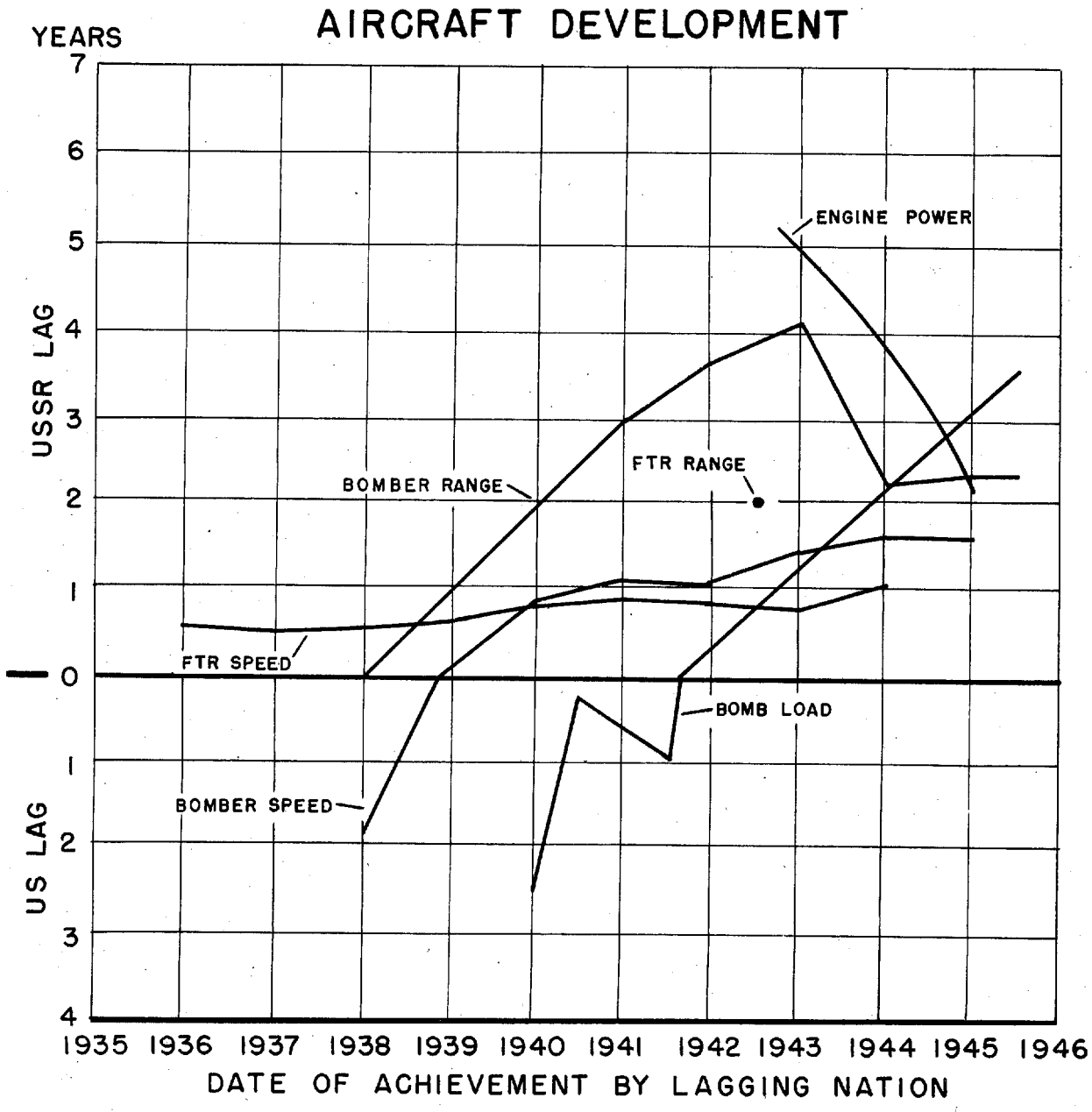
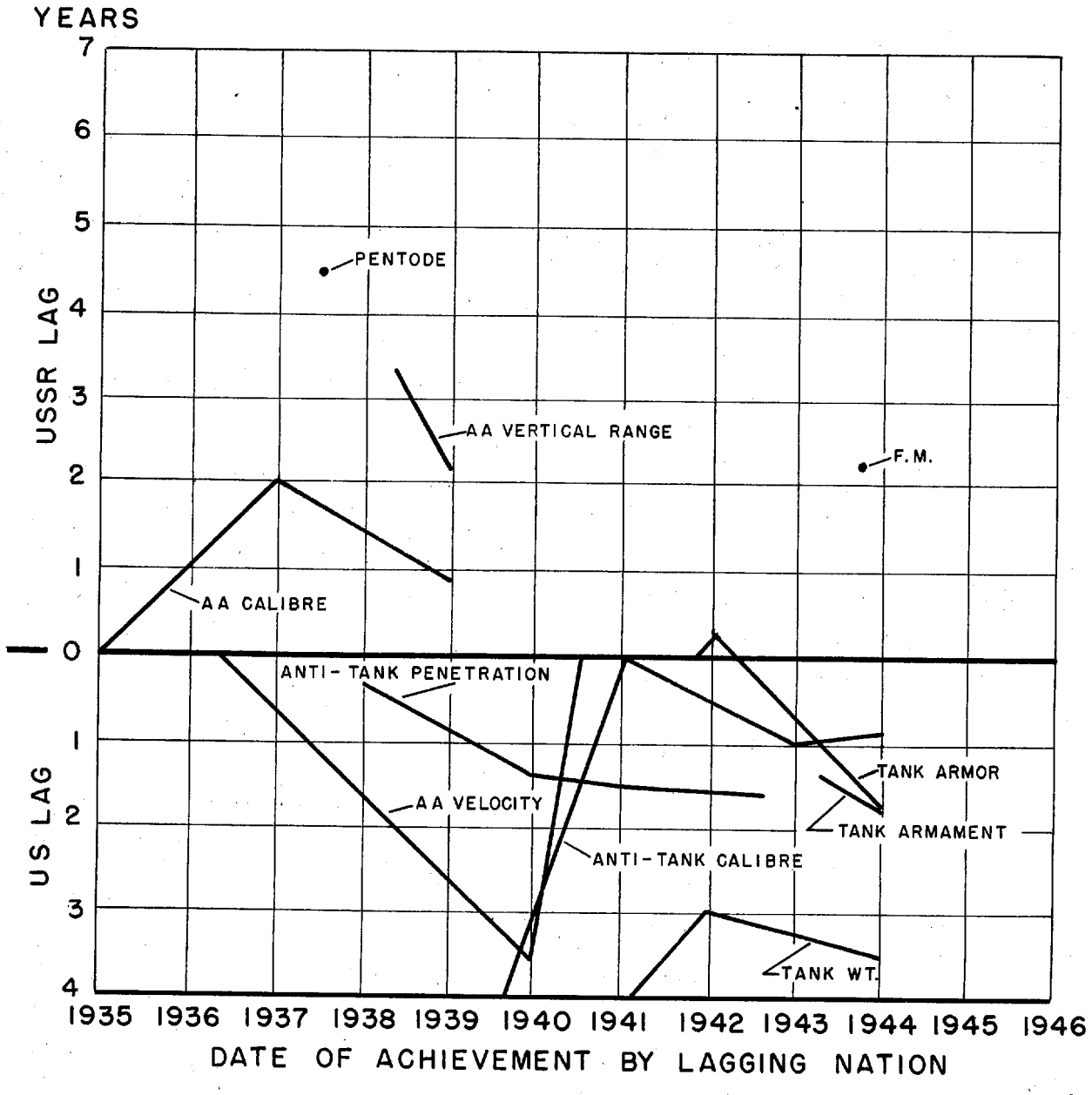


Figure 1

LAG BETWEEN DATES OF EQUAL ACHIEVEMENT

ORDNANCE, TANK, AND ELECTRONICS



AIRCRAFT DEVELOPMENT

RATED TAKE OFF ENGINE POWER

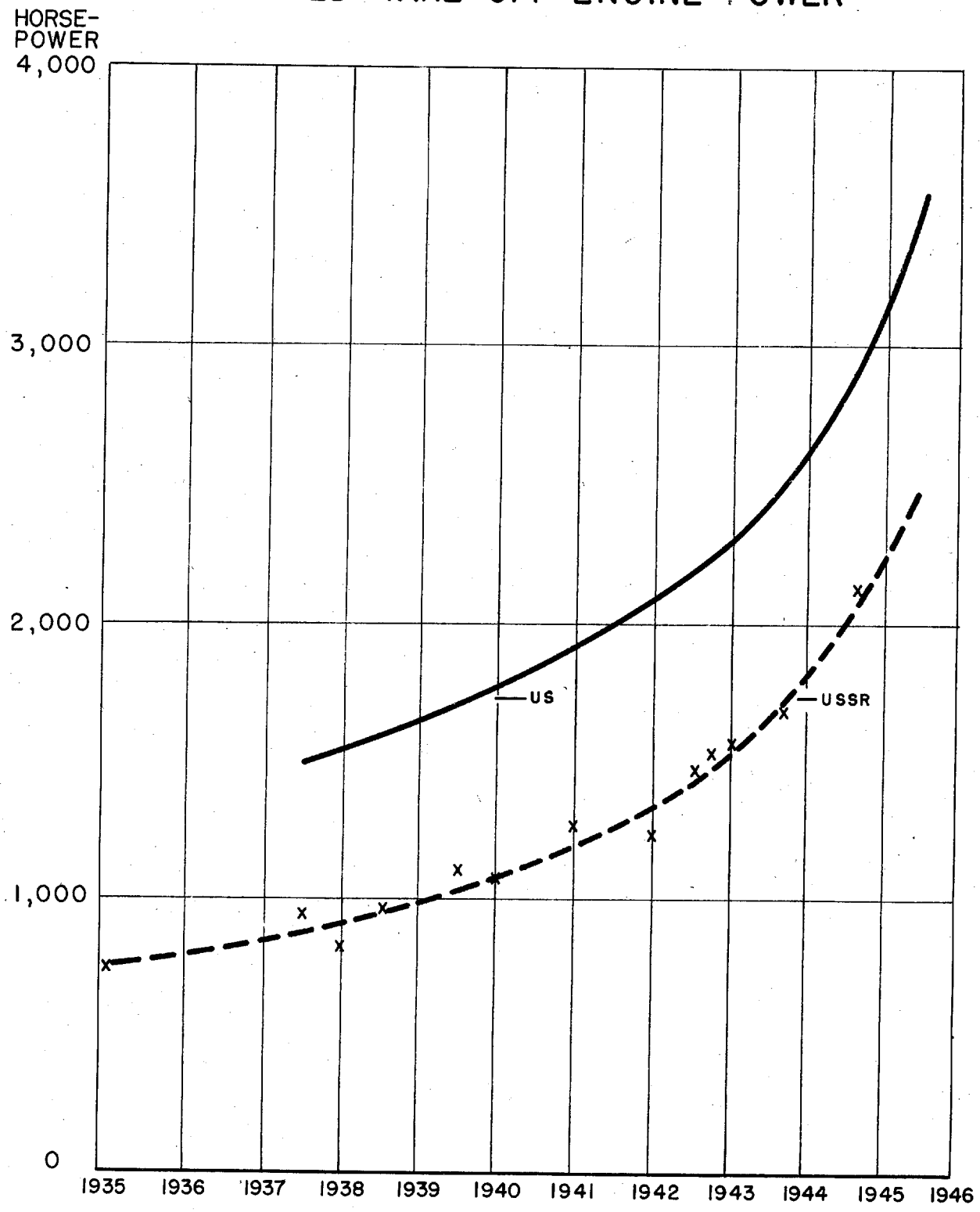


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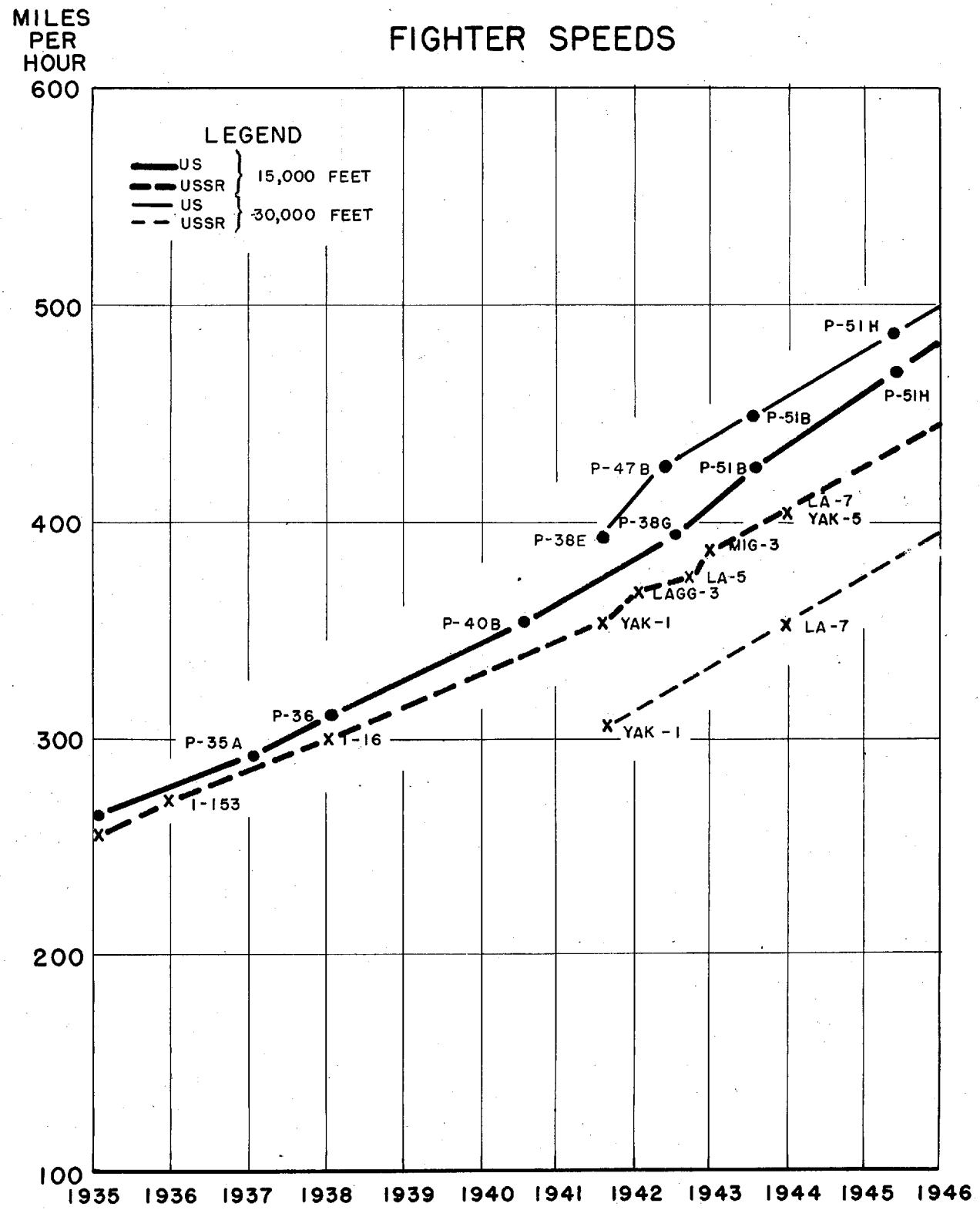
Figure 3

AIRCRAFT DEVELOPMENT



28 JAN 1946 SECRET Figure 4

AIRCRAFT DEVELOPMENT

FIGHTER RANGE

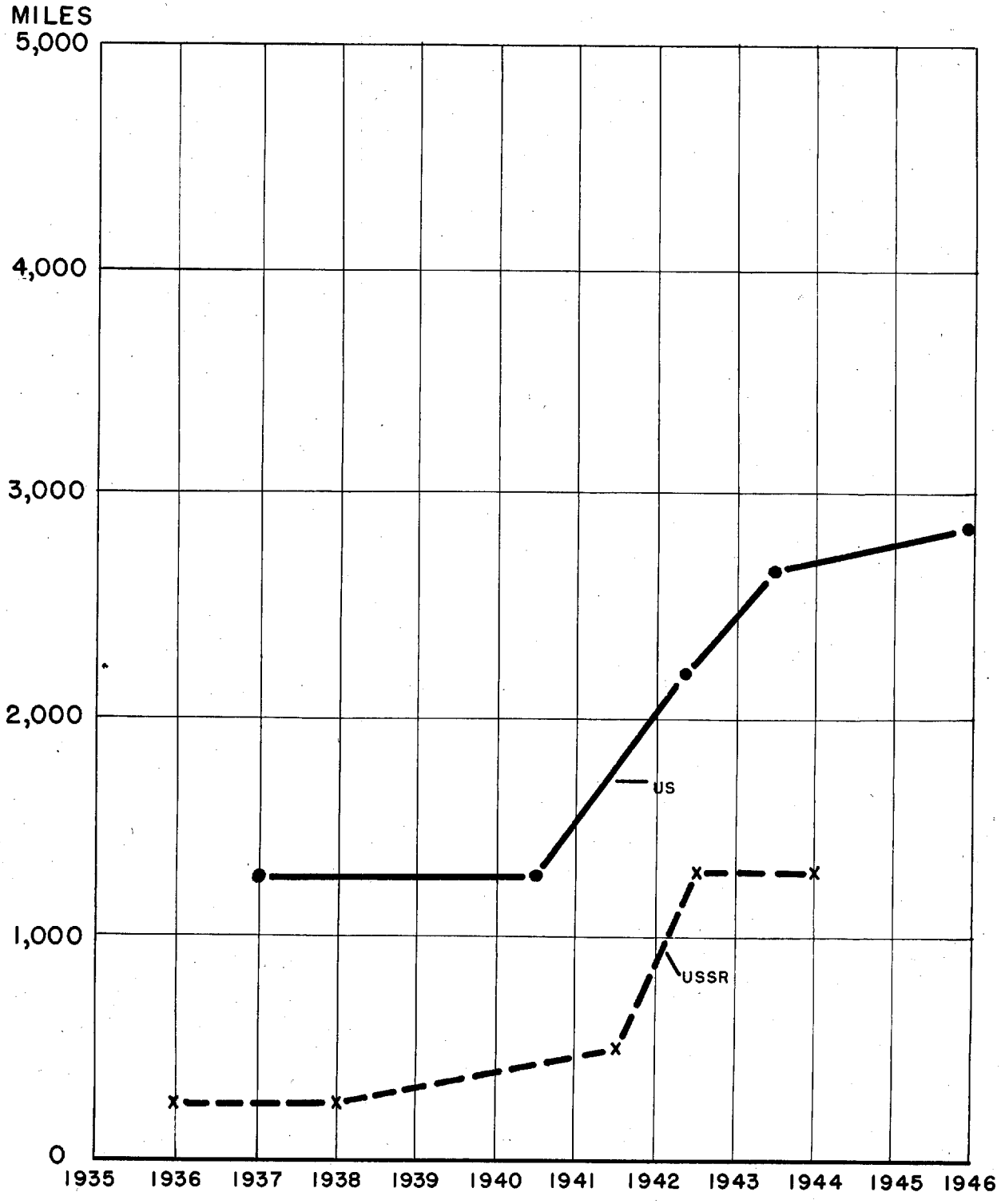


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Figure 5

AIRCRAFT DEVELOPMENT

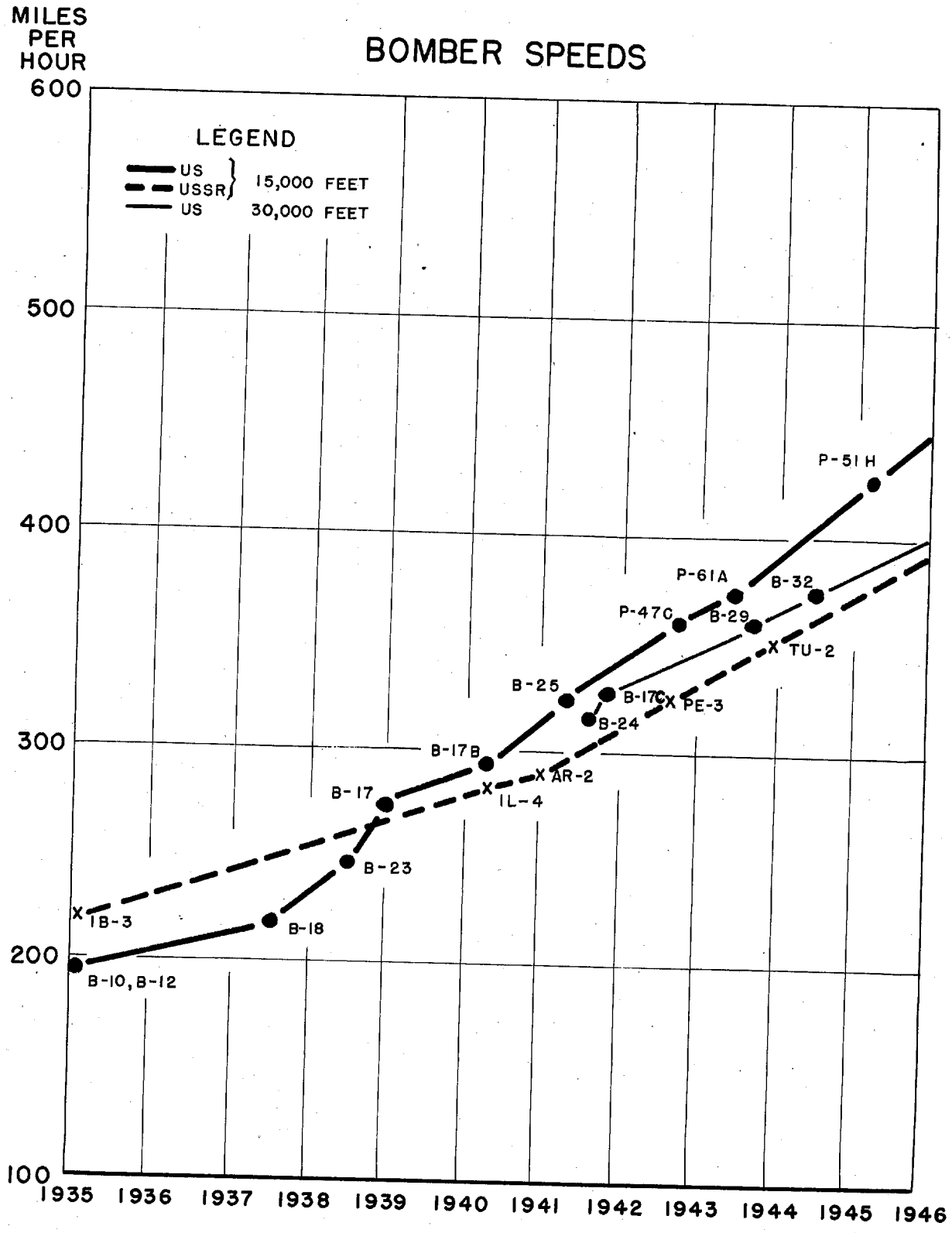

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Figure 6

AIRCRAFT DEVELOPMENT

BOMBER RANGE

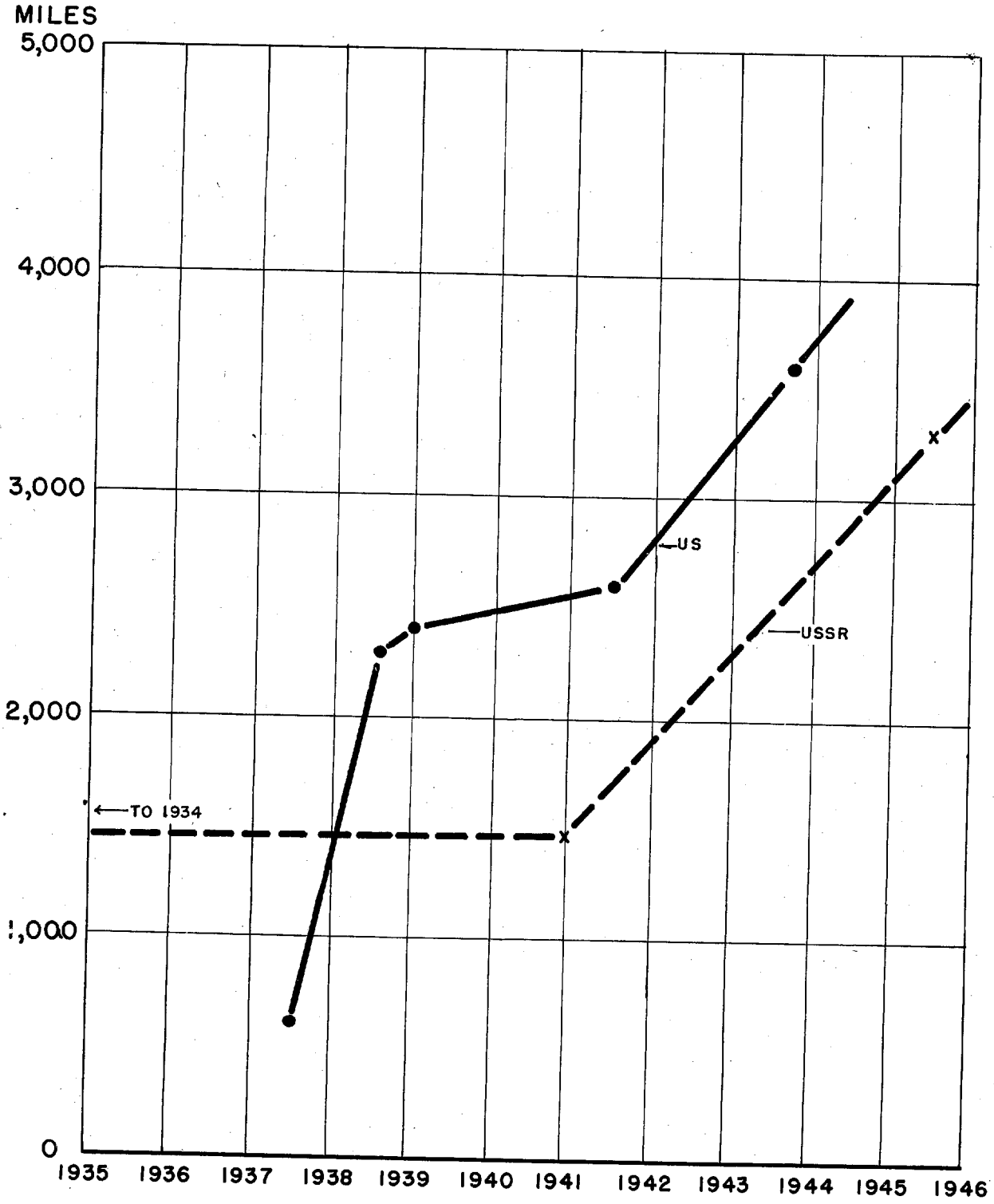

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Figure 7

AIRCRAFT DEVELOPMENT

MAXIMUM BOMB LOAD

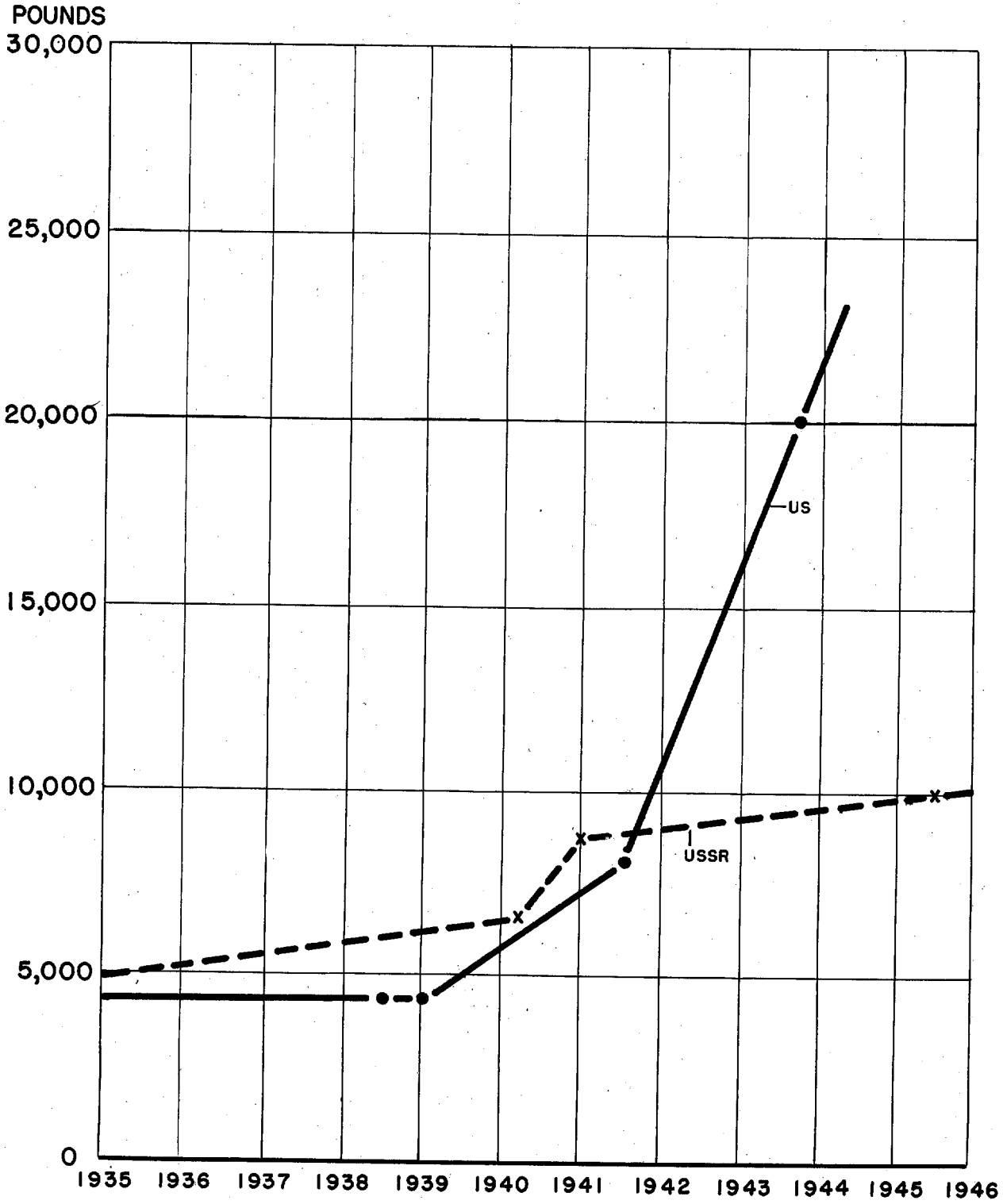

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Figure 8

TANK DEVELOPMENT

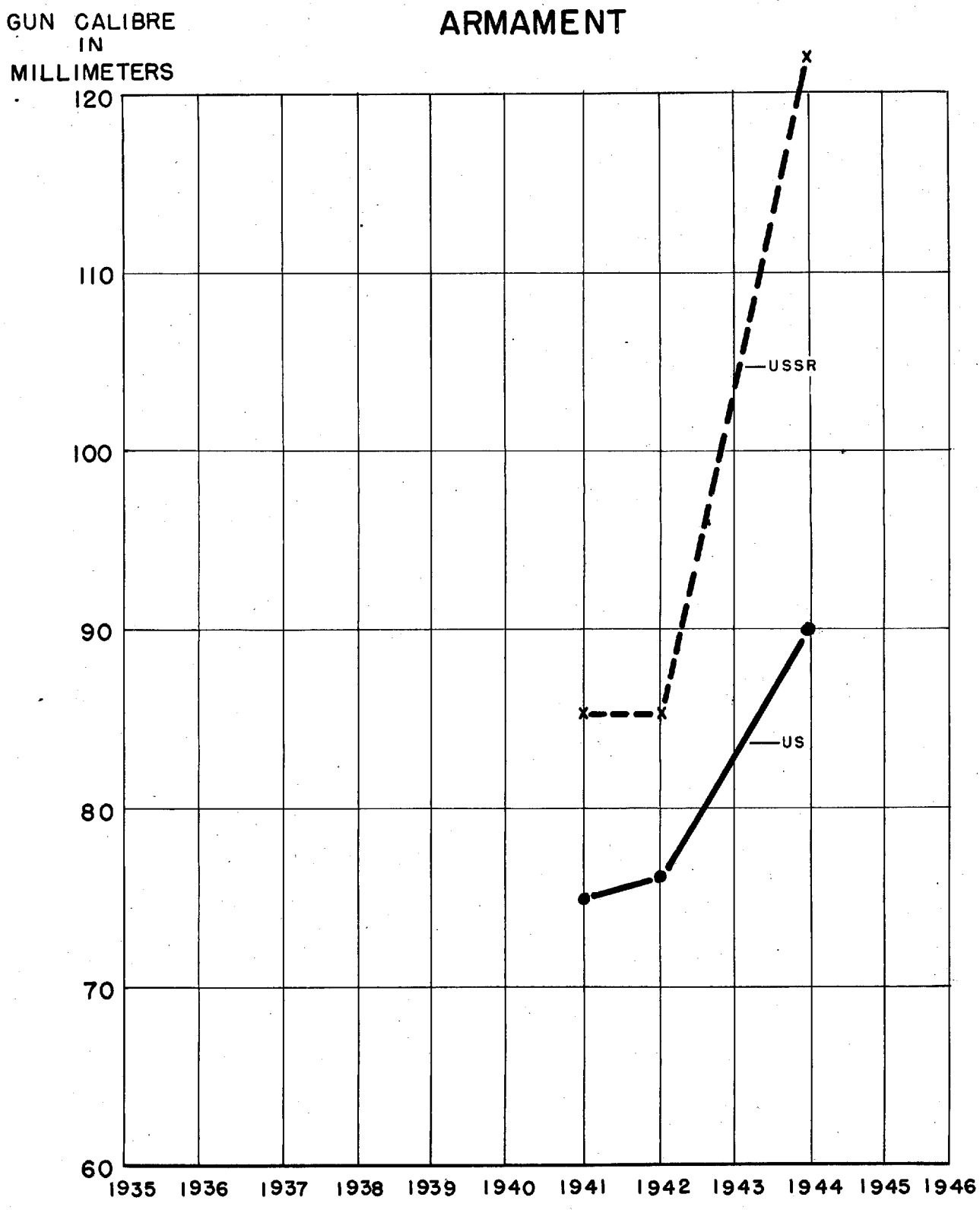

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Figure 9

TANK DEVELOPMENT

ARMOR THICKNESS

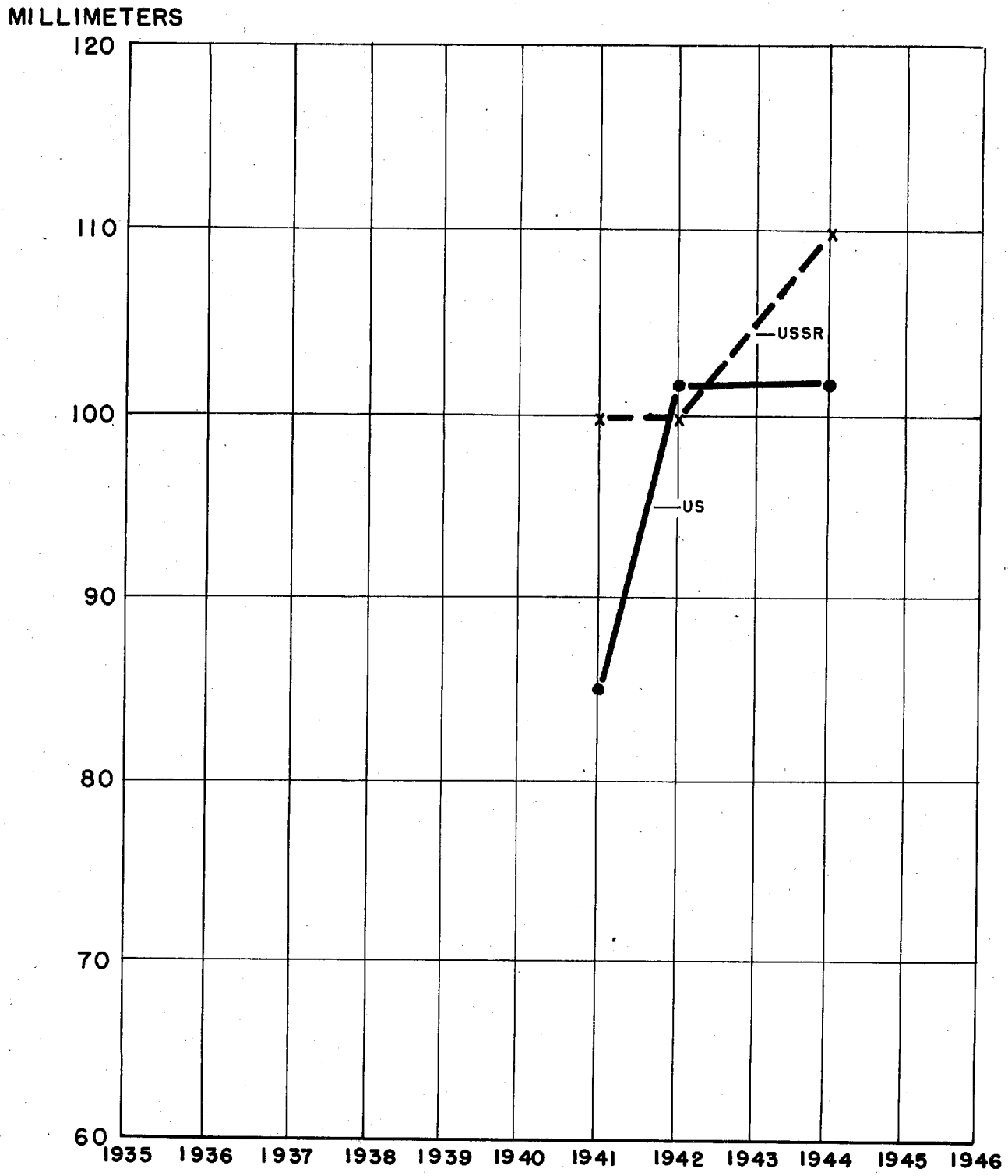

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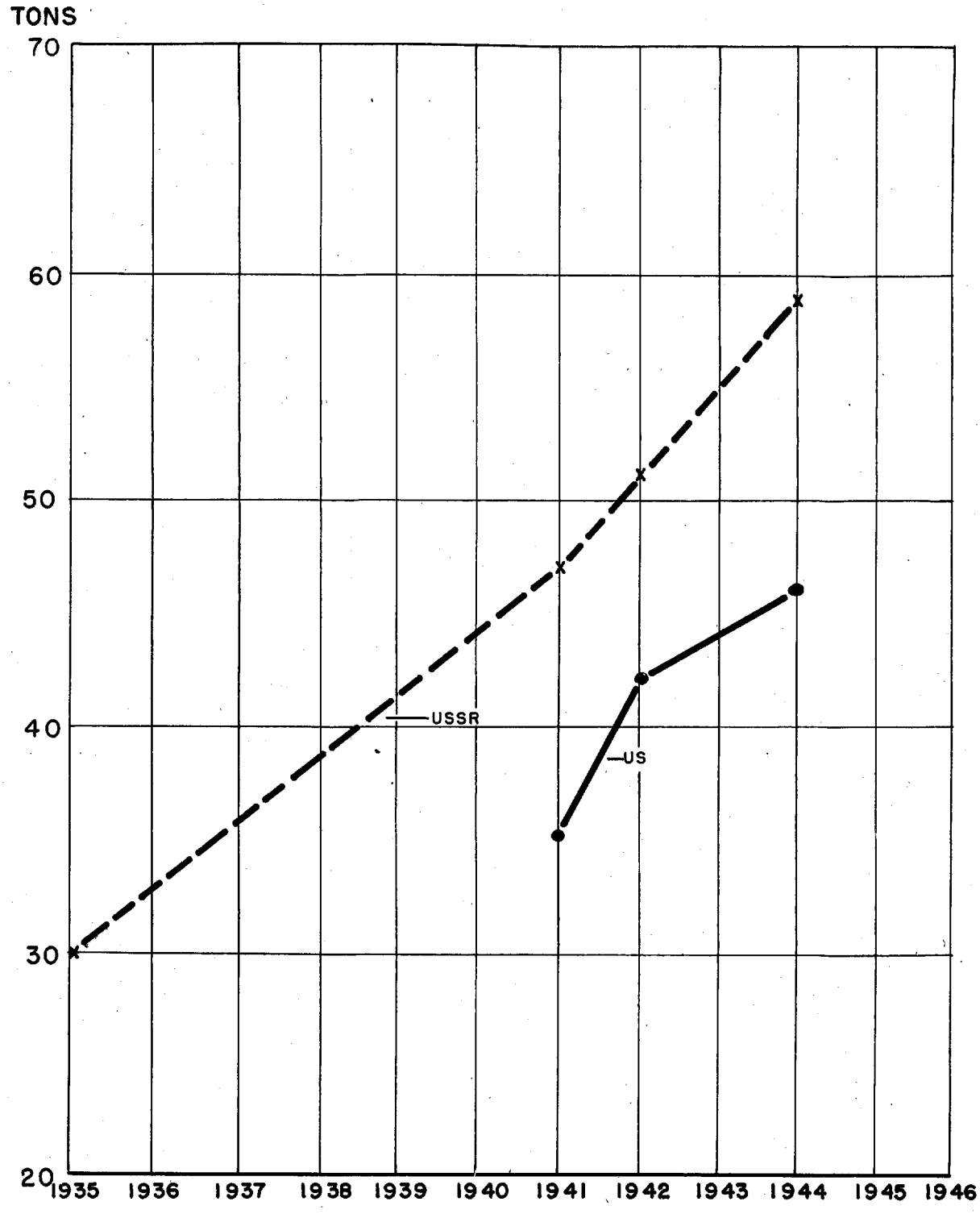
Figure 10

TANK DEVELOPMENT

WEIGHT



28 JAN 1946

SECRET

Figure 11

TANK DEVELOPMENT

CRUISING SPEED

28 JAN. 1946

SECRET

Figure 12

ANTI-AIRCRAFT ARTILLERY DEVELOPMENT

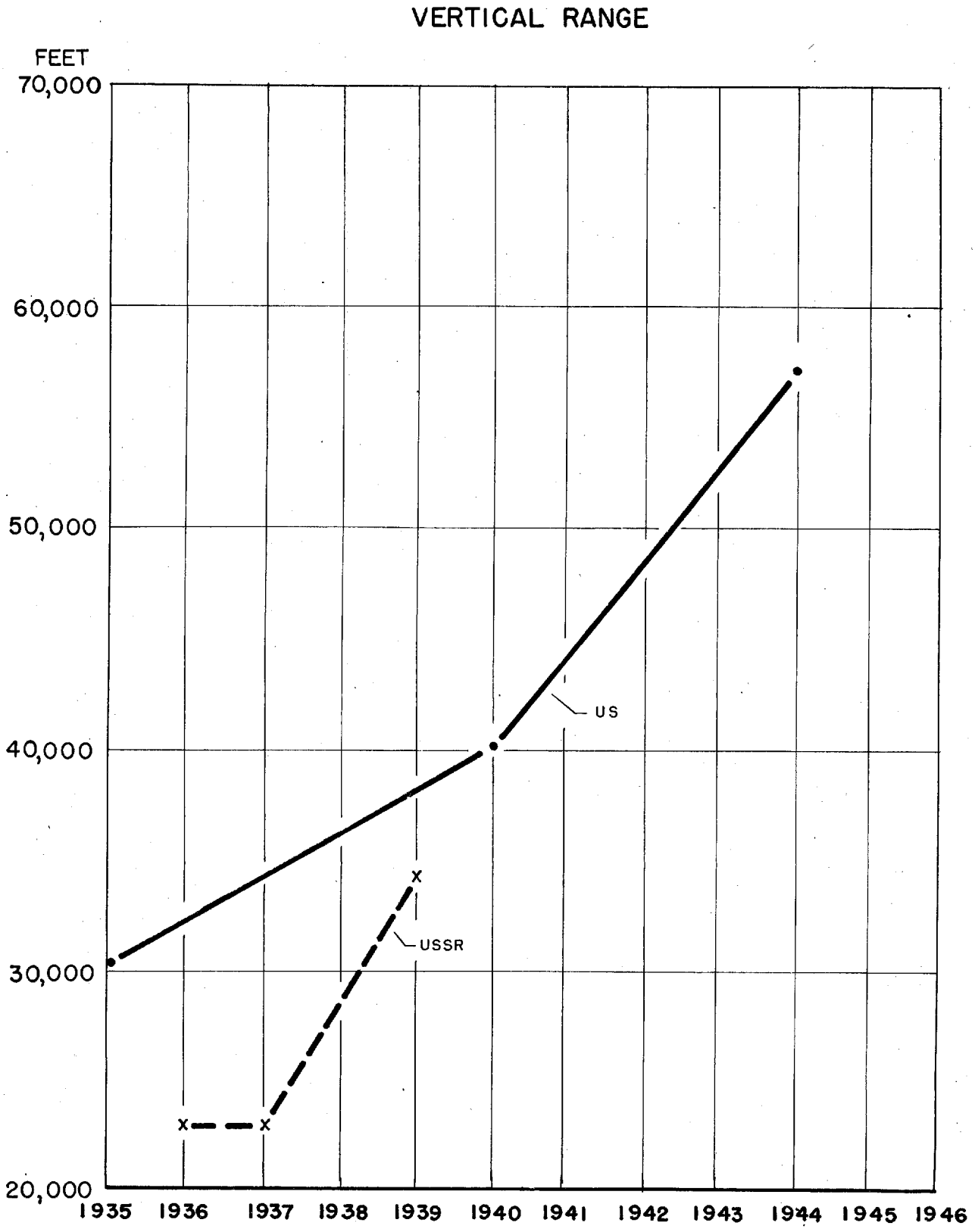
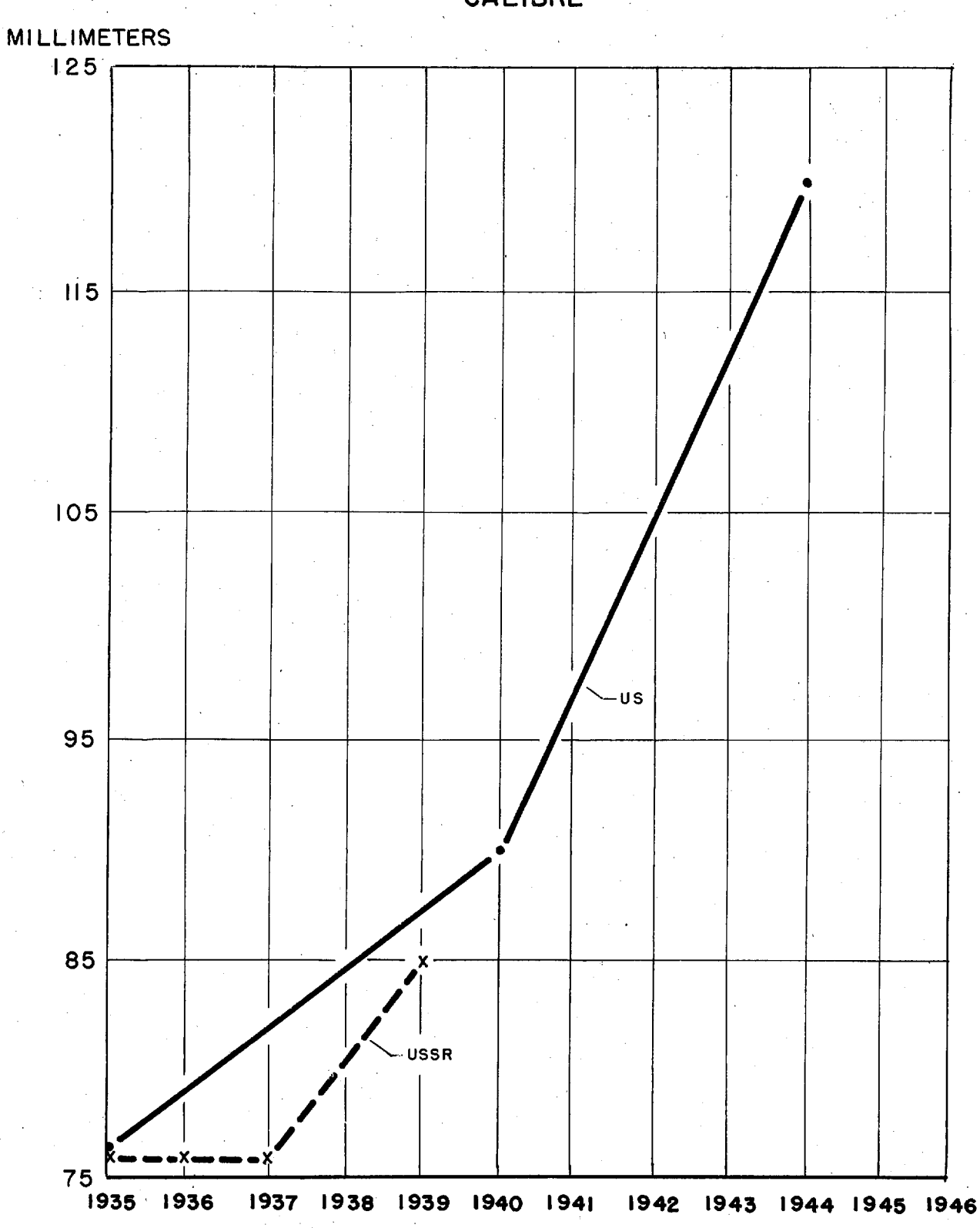
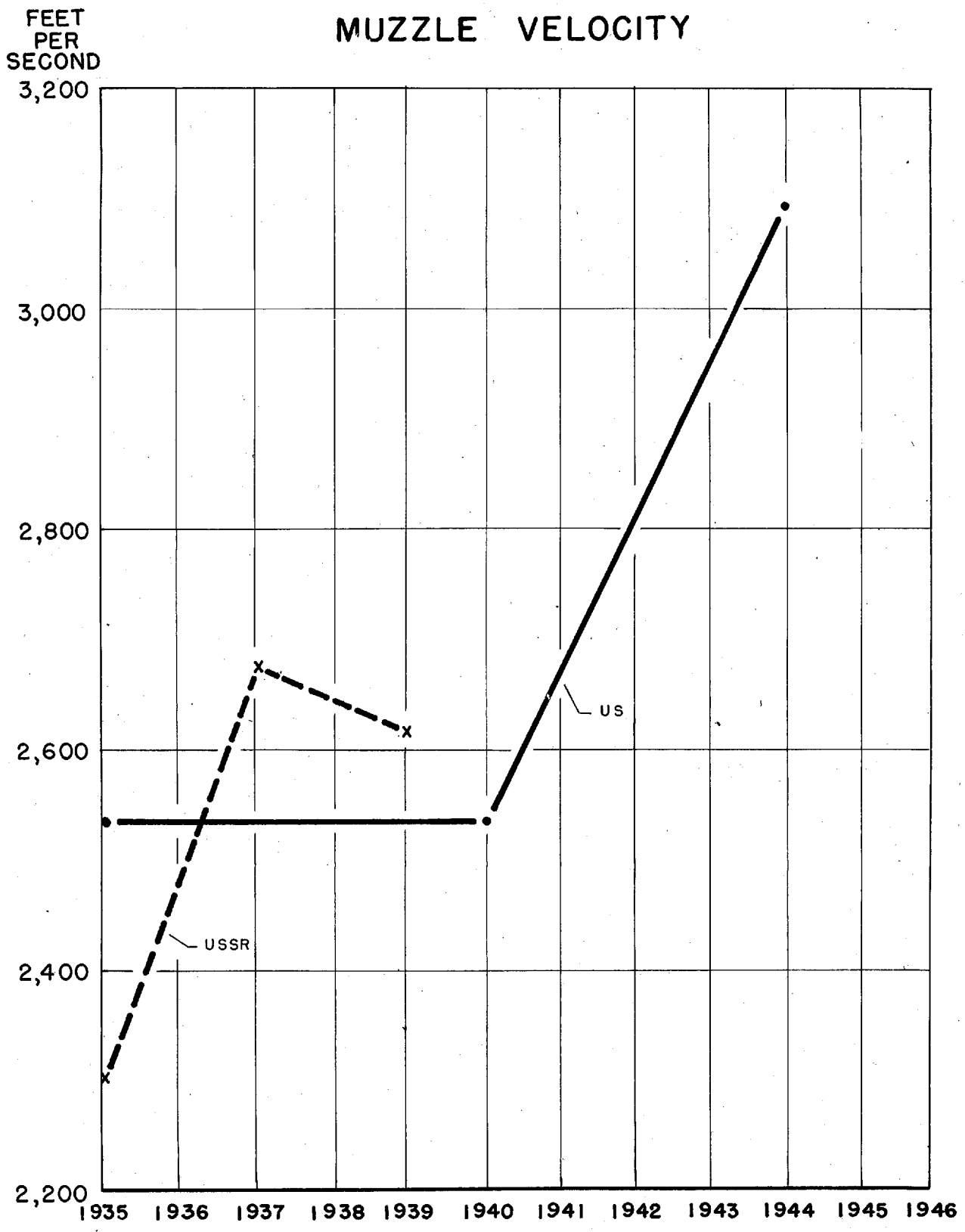


Figure 13

ANTI-AIRCRAFT ARTILLERY DEVELOPMENT

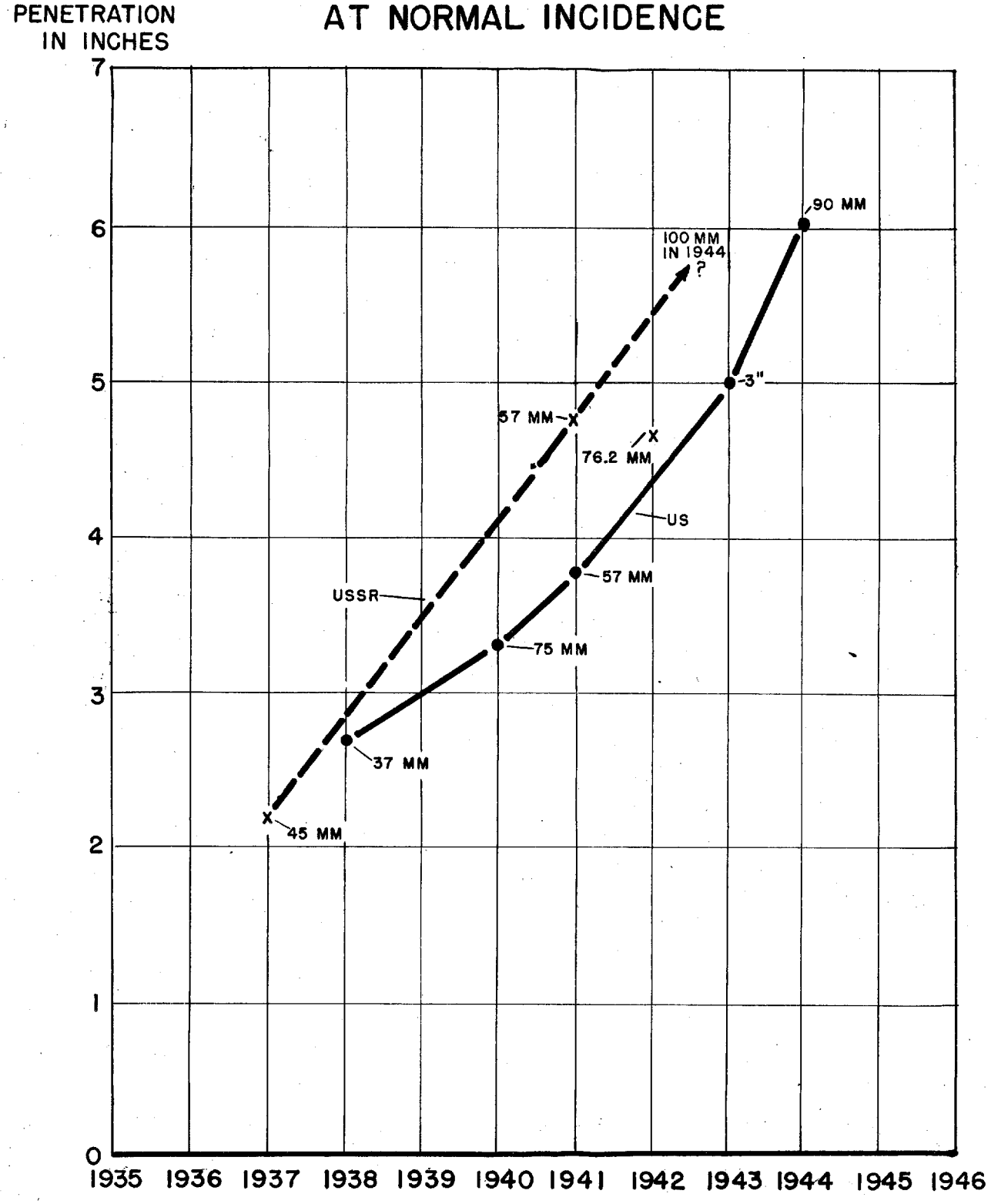


ANTI-AIRCRAFT ARTILLERY DEVELOPMENT



ANTI-TANK ARTILLERY DEVELOPMENT

PENETRATION OF ARMOR AT 500 YDS AT NORMAL INCIDENCE



ANTI-TANK ARTILLERY DEVELOPMENT

CALIBRE

(Muzzle Velocity In Feet Per Second)

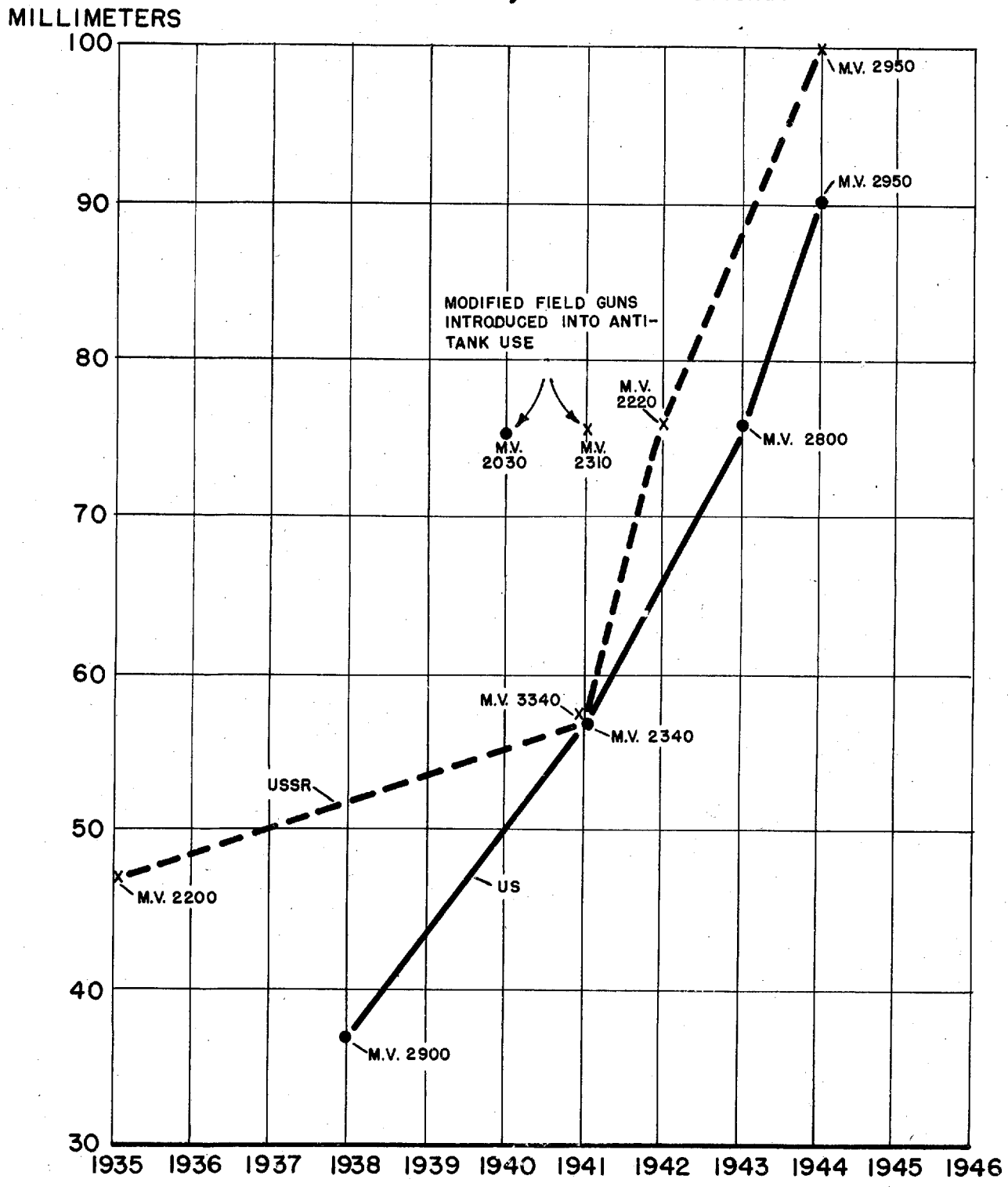


Figure 17

APPENDIX A

ELECTRONICS

The statements made on electronics are based on the following two communications:

5 January 1946

"SUBJECT: Development of Electronics in Russia.

TO: Office of the Secretary of War
Room 4E935, Pentagon Building
Washington 25, D. C.
ATTN: Dr. W. B. Shockley

1. In response to your request for information on the technological advance of electronics in Russia, the following information based on correspondence and telephone conversations between Captain H. E. Morgan of this Branch and Mr. Karl Dreyer of the Radio Corporation of America, Lancaster, Pa., is submitted. For purposes of information Mr. Dreyer recently spent some time in Russia on matters of vacuum tube negotiations between RCA and the Soviet Union.

2. The operating characteristics of two Soviet vacuum tubes (2K2M and C0257) were submitted by Mr. Dreyer. Both of these tubes are of the variable-mu Pentode receiving type having a 5-pin octal base and a glass-metalized bulb and are completely of Soviet design, probably based on similar American and German types. The nearest American prototype for these tubes is the series of tubes such as the 6C6, 6D6, 77, 78, 57 and 58 as were developed and in production by the Radio Corporation of America in 1933. The best estimates by Mr. Dreyer on the date of the first production for these Soviet tubes is 1937 or 1938.

3. The facts noted in paragraph 2 indicate that production of Soviet designed tubes took place from four to five years after the similar American types.

4. Although information on other types of Russian tubes is not readily available, it is believed by the representatives of RCA and the Scientific Branch that the technological development of electronics equipment in Russia has been about four to five years behind that of the United States.

(signed) ROBERT L. SNIDER (GSC)

ROBERT L. SNIDER
Colonel, GSC
Chief, Scientific Branch, MIS"

An informal communication on 11 January 1946 for Dr. W. B. Shockley states that:

"Lt. Hall reports that in the field of frequency modulation, we had SCR-509 and 510 in August 1941. From the examination of the material, Lt. Hall says they had (it) in September 1943, and consequently in that field of development were a little over two years lag.

Lt. Hall and Major Kingman went over the material carefully and say that for frequency modulation and pentode tube they did not find any really good items for comparison."

APPENDIX B

COMPARISON BETWEEN STATUS OF PETROLEUM REFINING ART IN THE U.S. AND U.S.S.R.

1. In order to estimate the technological position of the U.S.S.R. in chemical engineering an appraisal of oil refining has been made. The information presented herewith is based on a discussion between Mr. Herman B. Dunn of the M. W. Kellogg Company and Dr. W. B. Shockley. During 1944 and 1945, Mr. Dunn was associated with the Petroleum Administration for War as Chief of the Russian Section in the Office of the Director of Foreign Refining. In this office he made a study of refining capacity in the U.S.S.R. making use of files in FEA, OSS and PAW. Furthermore, during 1930 and 1931 he worked in the U.S.S.R. in connection with installing U. S. refining equipment. He has read and concurs with this summary.

2. Information about U.S.S.R. activity in this field is insufficient to permit a good appraisal of their potential ability to develop refining methods and equipment. It is believed this is partially due to the fact that they have been able to rely upon imports of equipment and techniques prior to the war and in addition upon imports of products during the war. It is probable that they have not tried to be foremost in this field but have, instead, been content to count on using foreign art. For these reasons, the actual U.S.S.R. development may lead to an underestimate of what their potential development could be with first priority in this field.

3. In 1931 and 1932, Mr. Dunn's experience lead him to the conclusion that to assemble and install a refining plant from completed component parts in the U.S.S.R. took between two and three times as long as in the U.S. A Houdry Process plant shipped to the U.S.S.R. in August 1943 was not in satisfactory operation in January 1946, since, under comparable conditions, it would require not more than one year in the U.S., the U.S.S.R. rate is more than twice as slow.

4. Mr. Dunn estimates on the basis of his general experience and information that without outside aid, the U.S.S.R. would require at least five years to advance their art to our present stage if they gave this project higher priority. It might well take twice as long.

5. Mr. Dunn stated that based upon his experiences, the U.S.S.R. engineers show a definite reluctance to take chances in oil refining engineering development. This is confirmed from his own personal experience in Russia in getting the Russian engineers to assume the

responsibility for oil refining operations after the new refining units had been placed in operation and had met guarantees. Also another example in this regard is evidenced by the fact that in 1942 a Russian delegation to this country selected the Houdry process to be furnished them under Lend-Lease in spite of the fact that all the latest developments in other catalytic cracking processes were made available to them. At that time the Houdry process was the only catalytic cracking process which had several years of proven refinery operations behind it although there had been developed but not completely perfected, other catalytic cracking processes which gave evidence of soon outstripping the Houdry process in economy and production; and which processes had been almost universally accepted in 1942 for all future catalytic cracking units that were subsequently installed in the U.S. The delegation was unwilling to gamble on what, from an engineering point of view, was a relatively sure thing.

As further evidence on this point, there were trained in this country 55 Russian engineers over a period of 6 months to two years in order to acquaint them with the oil refining equipment being furnished to Russia under Lend-Lease. At the end of the training program the Russian Government requested the assistance of American operators to place the Lend-Lease oil refining equipment in operation. The lack of completing the construction of the equipment before the end of the war with Japan prevented the sending of the American operators who had been signed and under contract to go to Russia for that purpose.

W. B. Shockley

14 January 1946

APPENDIX C

CHEMICAL WARFARE

The statements about chemical warfare are based on the following document:

Comparison of U.S. and Russian Reasearch and Development on New War Gases

9 January 1946

1. As requested of Captain W. E. Schmertz, Scientific Branch, MIS, the following report is submitted:

a. Information on Russian research and development on new war gases has been obtained almost completely from German or Japanese intelligence sources and is sparse and incomplete. No information is available on how many man-hours of work were devoted to this subject, what funds were allocated to the project, nor what results were obtained by this research.

b. It is therefore concluded that there is insufficient information to draw a comparison such as is desired by Dr. Shockley in the compilation of this present report.

2. These results were concurred with by the Chief of Russian O/B Section, Military Branch, Lt. Col. Shimkin, and by the Acting Chief of the Intelligence Branch, Office of the Chief, Chemical Warfare Service.

APPENDIX D

ON THE THEORY OF TREND LINES

In the introduction it was stated that a "trend line" would be drawn through the points representing the performance of each newly introduced model. It was also stated that this method is only approximately correct. We shall see why it may lead to a serious error and what can be done to correct it. Suppose nations A and B achieve fighter aircraft performance as follows:

	Jan. 1940	Jan. 1941	Jan. 1942	Jan. 1943	Jan. 1944
A	400		420		440
B	400	410	420	430	440

The "trend" lines for these two cases will be the same, but B's will have two more points on it. Furthermore, it is clear that half the time B has 10 miles more speed than A. Hence, although B is obviously ahead, the trend lines do not show the difference.

What we should do is take into account the duration over which the speed was held. Proceeding in this way, we say that A had 400 at Jan. 1941 and 420 at Jan. 1943; i.e. A held 400 from Jan. 1940 to Jan. 1942, so that the average date was Jan. 1941. Using these average dates we have:

A 400 Jan. 1941; 420 Jan. 1943.
B 400 July 1940; 410 July 1941; 420 July 1942; 430 July 1943.

Trend lines drawn through these points will show that B is six months ahead of A. This is consistent with the fact that B's speed is five miles faster than A's on the average (i.e. 10 miles faster half the time) which corresponds to a time difference of six months with a rate of progress of 10 miles per hour increase per year.

An alternative procedure is to say that the speed at the date of introduction of a new model is taken as the average between those of the new and old models. This leads to the same trend line as taking the average date.

Mathematically, both of these procedures produce a trend line having the same area under it as the step function. Such a line has a further advantageous feature (which will not be proved here) in that it predicts correctly the average date at which an achievement will be attained - dates earlier and later than the predicted date being equally likely. On the other hand, a line drawn through the performance points tends to be too early by half the average interval between models.

The refinements considered in this Appendix have not been introduced in the body of the argument for several reasons: (1) They would not alter the conclusions materially; (2) They would complicate the argument; (3) Improvements of models between introductions of new types would have to be considered and sufficient data would not be available. The reason why no important change would come about is as follows: the correct trend line is delayed by half the interval between models from the approximate one. For the U.S. and U.S.S.R., the interval between models is much the same on each chart (although it differs markedly from one chart to another); consequently, both trend lines would shift by the same amount, leaving the relative position essentially unaltered.

APPENDIX E

BASIC DATA FOR RELATIVE PRODUCTIVE CAPACITY

The U.S. expenditure figures are taken from Memoranda prepared in the Research and Analysis Branch of Statistical Control on 4 December 1945 and 28 January 1946. The Armed Forces Personnel figures are from the latter memorandum. The production of U.S. aircraft is based on a report from the same source dated 29 January 1946.

The U.S.S.R. personnel figures and aircraft production was obtained through the Science Branch of M.I.S. The production in 1944 was given in terms of types as shown below and other data was furnished for one month (January 1945) which permitted estimates of the average empty weight per aircraft to be made:

	Number of Aircraft	Weight Per Aircraft	Total Weight (millions of lbs.)
Fighters	22,000	4,600	100
Bombers	6,400	12,000	77
Ground Attack	15,500	9,500	147
Trainers	8,860	4,800	42
Transports	4,980	2,500	12
	57,740		378

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