8. Penetration.

Striking velocity, M69: 225 ft/sec (approx.), cluster released at 25,000 ft., opening at 5000 ft. will penetrate light to medium roof construction: 1 inch wood sheathing covered with 2 layers asphalt felt; terra cotta tile, slate, 2 to 5 inch cinder concrete, 3 inch light concrete (not reinforced).

9. Performance, Probability, M-18 cluster containing AN-M69 bombs.

Malfunctions	Percentage	
Clusters not opening	5	
Air Bursts	3	*Probability of
Tails torn off	2	bomb functioning
Flatlanders	3	as expected: .84
Fuze Failures	2	(.95) (.97) (.98)
Nonejection, nonignition, mechanical failures.	2	(.97) (.98) (.98) = .84

*This factor, a characteristic of the bomb; does not consider the type of target.

10. Remarks and Recommendations as to Uses of the M-18 Cluster.

a. In production but not yet in service are two modifications of the M69: (1) The M69X, similar to the M69, but containing slightly less fuel, and an explosive charge of tetryl. (2) The M69WP, similar to the X bomb, but containing a charge of white phosphorous in place of the tetryl. Both of these modifications, designed to hinder and drive away fire fighting personnel, will be included in varying quantities with M69's in the aimable cluster.

b. Because of its low striking velocity the M69 has heretofore been regarded as suitable only for attacks on residential areas. Intelligence gained from adequate aerial cover indicates that most industrial roofs in Japan are of light construction, and recent incendiary attacks have demonstrated the ability of the M69 to penetrate and set fire to typical Japanese plants. This characteristic of the M69 makes it a good choice for use in mixed IB-HE raids where the primary target is industrial and the secondary target, for bombing through clouds, is an urban area. The M69 bomb is by far the best weapon now available for urban areas.

c. In level bombing the recommended minimum altitude of operation with the M-18 is 3000 ft. (opening at 1000 ft.). Inability to set the T39 or T55 fuze at less than 5 secs. limits the utility of the cluster at lower altitudes and for dive bombing, as the action of the cluster striking as a unit is not efficient.

d. To be effective a small incendiary must land in a favorable location. The tail ejection feature of the M69 greatly enhances the probability that the fuel will finally come to rest adjacent to easily ignitable material.

e. The M-18 is being replaced by the recently CWS developed E46, 500-lb. aimable cluster containing 38 M69's. Significant differences between the M-18 and E46 are (1) increase in weight to 425 lbs. for the E46, (2) incorporation in the E46 of two tail fuzes and a mechanical opening feature in place of a single nose fuze and primacord burster, and (3) a better streamlining of the E46. Improvement in the overall functioning of the M69 is indicated from proof testing of this cluster. A supplementary Data Sheet No. 2 will be issued when the cluster is available for use in the field.

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REPORT
of

THE ARMY AIR FORCES BOARD

IV, A, 2

SUBJECT

A STUDY OF INCENDIARY BOMBS FOR EMPLOYMENT
BY THE UNITED STATES ARMY AIR FORCES

PROJECT No. (M-5) 261

DATE

COPY No. 511

1 October 1944

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AAFTAC-8/24/44-CW1043

FOR INFORMATION ONLY

THE ARMY AIR FORCES BOARD
Orlando, Florida

1 Oct 44

ARMY AIR FORCES BOARD PROJECT NO. (M-5) 261.

A STUDY OF INCENDIARY BOMBS FOR EMPLOYMENT BY THE UNITED STATES ARMY AIR FORCES

I. OBJECT:

The object of this project is to investigate the incendiary bombing situation with a view to the development of principles governing (1) the selection of the best incendiary bombs for a target (2) the determination of quantity requirements for a mission and (3) the employment of formation pattern bombing to achieve maximum incendiary effectiveness.

II. FACTUAL ELEMENTS OF THE PROJECT:

(a) The following staff study was prepared on the verbal request of the Commanding General, Army Air Forces, Washington, D.C., to the President of the Army Air Forces Board, Orlando, Florida.

(b) The study was prepared with the aid of

(1) reports and analyses of official army tests
(2) actual field tests
(3) other reports originating in American and British governmental agencies
(4) conferences of qualified personnel
(5) results of American and British combat operations

III. CONCLUSIONS: - It is concluded that:

(a) The decision to employ incendiary bombs should be based on careful consideration of target combustibility factors, pages 4, 14, 15, 16, 69, 74.

(b) Quantity requirements and tactics, pages 38, 59, 64, for an incendiary bombing mission should be planned with reference to

(1) the inflammability and combustibility of different parts of the target, pages 15, 16.
(2) the existence and location of barriers to the spread of fire, pages 4, 15, 16.
(3) the nature and strength of enemy fire-fighting measures, pages 4, 14, 41.

(c) Incendiary bomb selection for a target, pages 35, 36, 69, 70, 74, should be made with regard to;

(1) the inflammability and combustibility of the target (or of its various parts) - pages 15, 16.
(2) precision and density requirements based on the subdivision of the target by fire barriers and on other vulnerability considerations, pages 4, 15, 16.
(3) penetrability of the target, pages 30, 31, 35.

(d) Standardized incendiary bombs vary in their penetrating, precision, and fire-raising properties in such a way that each type of bomb is best adapted to particular types of targets, pages 22, 35, 69, 70, 74.

(e) Quick-opening clusters of small IBs are restricted as follows:

(1) because of susceptibility to wind effects they should be used from altitudes below 8,000 ft., page 22.
(2) because of hazards from cluster parts and bombs they should be used only from formations which have no lower rear elements, page 22.

(f) Aimable clusters offer a lower plane-loading efficiency than quick-opening but are not subject to the above restrictions. When dropped from altitudes above fifteen thousand (15,000) feet and set to open at five thousand (5,000) feet, aimable clusters possess precision properties comparable to those of general purpose bombs, page 30.

(g) Incendiary bombing attacks achieve their maximum destructive effect when area conflagrations are produced, page 5.

(h) Conditions favorable to area conflagrations are unusual in German targets. In highly combustible built-up Japanese areas of about 40% roof coverage or more conflagrations may be expected, page 5.

(i) In an IB-attack on a highly combustible target, the value of large HE bombs for disruption of fire defenses is offset by their adverse effects on quickly developing fires, page 9.

(j) In the case of typical built-up Japanese areas, 20-lb. fragmentation bombs furnish, at present, the best form of HE from the viewpoint of hampering fire-fighters without unfavorably affecting combustibility of the target, page 9.

(k) A loading ratio of 80% IBs and 20% fragmentation bombs released in a co-extensive pattern on Japanese built-up areas offers the most effective co-ordinated employment of the two munitions, page 9.

(l) In a target of good combustibility, fire and heat present greater possibilities than blast of producing complete and irreparable damage, page 5.

(m) Improvised incendiary munitions, such as oil drums and droppable gasoline tanks, are satisfactory for use under limited conditions, pages 30, 31, 32.

(n) Impact patterns obtained by dropping bombs from tactical formations possess properties of precision, density, and distribution not predictable on the basis of releases from single planes, pages 50, 55, 64.

(o) Tactical formation patterns constitute the most appropriate unit to employ in considering the quantity, precision, area, and density requirements of a given target, pages 50, 55, 64.

IV. RECOMMENDATIONS: - It is recommended that:

(a) The decision to make incendiary bombing attacks be based on analyses of incendiary vulnerability properties of enemy targets, pages 4, 14, 15, 16, 69, 70, 74.

(b) Selections of bombs and clusters for an attack be made in relation to target vulnerability properties, pages 4, 15, 16, 35, 69, 70, 74.

(c) Planning of quantitative requirements be based on a study of target vulnerability properties, pages 4, 14, 15, 16, 36, 50, 64, 74.

(d) In a primarily incendiary mission against an area target, HE be used only for its effect in disrupting fire defenses, pages 9, 41.

(e) For highly combustible areas of light structures (Jap targets), 20-lb. fragmentation bombs be used, in a ratio of 20% HE (frag.) and 80% IB, page 9.

(f) Field tests be conducted to determine tactical formation patterns for the M7, M12, M13, and M18 clusters and such other bombs and clusters as may later become standardized pages 50, 55, 64.

(g) Operational records be kept in all theatres, for analysis purposes, of combat operations involving employment of incendiary bombs. Copies of such records should be forwarded to the AAF Board for evaluation, in order that a comprehensive doctrine of employment may be developed, based on actual operations, page 80.

(h) The inclosed survey be reclassified CONFIDENTIAL in order to assure proper distribution to using personnel.

(i) The inclosed survey be distributed without delay to all Air Force and Bomber Commanders.

V. DISCUSSION:

(a) Since the advent of large scale aerial operations in the present war, the development of systematic incendiary bombing has rapidly taken place. A variety of experiments in combat and in field tests, and numerous valuable but uncoordinated studies, have led to conflicting theories of incendiary bomb employment which required a general survey of the situation. In several instances, theories were so conflicting as to require actual field tests to determine correct principles. The results of such tests are contained in the inclosed survey.

(b) The contents of this report are intended to assist the Air Commander in the proper selection of incendiary targets and the incendiary bombs best suited for them. The report should also assist in the planning of the best methods of target destruction, with due consideration of required incendiary bomb density on the target, the type of formation, and the number of aircraft needed to perform the mission successfully.

(c) The survey which led to the above conclusions and recommendations in contained as an inclosure. It is organized under the following chapter headings:

I. Fires and conflagrations.
II. Targets.
III. Incendiary bombs.
IV. Selection of bombs in relation to targets.
V. Incendiary bomb requirements for targets.
VI. Patterns in relation to tactical formations.
VII. Bomb densities based on patterns.
VIII. Illustrative mission and discussion of principles.

VI. INCLOSURES: "Survey of the incendiary bombing situation."

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SURVEY OF THE INCENDIARY BOMB SITUATION

PREFACE

This report deals with incendiary bombs which have been standardized and made available for operational use in various theatres. It does not attempt to cover bombs now under development or undergoing tests.

The first chapter contains a brief discussion of types of fires. Targets are then studied with regard to their vulnerability to incendiary bombing attack. Corresponding to target vulnerability conditions, there is a classification of IBs which facilitates the choice of munitions for use against a particular target. A table of targets and corresponding recommended incendiary bombs is in Chapter IV. The report then takes up the problem of estimating quantity requirements under various conditions of attack. Special attention is given to impact patterns resulting from formation bombing, and a chapter is devoted to bomb densities based on such patterns, since these are vital considerations in the problem of delivering bombs on a target with appropriate distribution and in sufficient quantity to achieve the desired effect. The report terminates with an application and general discussion based on the material just outlined.

I. FIRES AND CONFLAGRATIONS

§1. ANALYSIS OF A TARGET INTO FIRE DIVISIONS:

a. **Nature and Importance of Such Analysis.** - Combat operations have disclosed the importance of studying the way in which a target falls into fire divisions, or areas isolated by barriers to the ordinary spread of fire. Such barriers may be fire walls within a large building. In an area target, they may be air gaps (railroad tracks, wide avenues, rivers, waterways, or parks, see photographs on pages 6, 7.) Since a fire will generally damage only the division in which it originates, an attack should be planned with a view to hitting each division with enough bombs to assure an uncontrolled fire. The damage to the target is the sum total of fire damage in the fire divisions, large and small. In cases where knowledge of the target is insufficient for a definite analysis into fire units, it has been found highly desirable to employ a tentative analysis based on the best available expert opinion. (See photograph on page 8.)

b. **Influence on Scale of an Attack.** - A fire starting from a bomb dropped in a given division is called a primary fire. Secondary fires sometimes arise (1) by fire-brands being carried from one division to another, (2) by a break in the barrier between divisions, or (3) by the flash-over effect in which a blaze starts from the intense heat due to radiation from a fire in a neighboring unit area. The scale of an attack is, of course, planned to be so large as to destroy the target by primary fires alone. An understanding of the size of fire divisions may be obtained from the fact that they average approximately 1,000 to 4,000 sq. ft. (individual buildings) in German domestic targets and are of the order of 3,000,000 sq. ft. in Japanese cities (several blocks).

Individual industrial targets requiring large areas of uninterrupted floor space may present fire divisions of as much as 40,000 sq. ft.

§2. TYPES OF FIRES, CONFLAGRATIONS:

a. **Classification of Fires.** - Fires can be classified according to whether they can be extinguished by (1) inexperienced and untrained personnel with make-shift equipment, (2) organized amateur fire squads, (3) two or three professional fire companies with modern equipment, or (4) the combined efforts of the fire-fighting resources of an entire city. When a fire passes beyond all human control and involves many buildings, it is called a major conflagration.

b. **Fire Defense and Scale of Attack.** - For a particular division of a target, enough fires must be produced of the type possible in that division to overtax the enemy's maximum fire-fighting effort and thus insure destruction. This aspect of mission planning will receive further attention in Chapter V.

c. **Conditions Favoring Conflagrations.** - An area conflagration in Japan is possible only in a division containing many highly inflammable, densely-packed structures. ~~Roof~~ coverage of the area must be about 40% or more. Conditions favorable to conflagrations are rare in German targets. High concentrations of incendiary bombs have, however, produced conflagrations in German targets. (See photograph of Aachen on page 20.) Historic conflagrations were favored by unexpectedness, unpreparedness of fire defenses, weather conditions and occasionally by breaking of water mains, disruption of traffic, and general confusion resulting from earthquake. If production of an area conflagration in Japan is the object of an attack, the plan of attack should involve taking advantage of dry, windy weather and putting the bombs where the wind will tend to spread the fire. An adverse wind can keep fire out of a threatened area. Some of the effects of earthquakes can be created by the use of high explosives. The one condition that can hardly be hoped for is unpreparedness of enemy fire-fighters. Their increased wartime efficiency and alertness, and the existence of trained civilian groups, well distributed over city and other vulnerable areas, are serious obstacles to the creation of conflagrations or important fire damage. Adequate supplies of anti-personnel bombs are required, along with enough incendiaries to overwhelm all fire defenses; and such bombs need to be supplemented by more incendiaries in sufficient quantity to produce a mass of unattended fires, so concentrated as to coalesce into a genuine conflagration.

d. **Destructive Force of a Conflagration.** - Within its area, a conflagration has complete destructive power (See photographs on pp 10, 11.) Temperatures are so high as to raise objects to the flash-point several hundred yards from the actual fire, thus starting new blazes across ordinary barriers to the spread of fire. Non-combustible materials, such as machinery and fireproof buildings, can be irreparably damaged by heat, and a degree of destruction is achieved usually beyond that of the most concentrated demolition attacks.

§3. COMPARATIVE EFFECTS OF HE AND IB:

a. **Efficacy of Heat vs. Blast.** - As a destructive agent, heat is more efficacious than blast, for the damage done by the former is more complete and permanent in character. (See photographs on pages 10 - 13.) Food, clothing and rubber goods, for example, which might be partly destroyed by explosives, will suffer complete destruction from fire and smoke resulting from a successful incendiary attack. Fire damage is relatively difficult to repair. The standing walls of large gutted buildings are generally cleared away with no attempt at reconstruction.

b. **Analysis of Attacks over Germany.** - The effectiveness of incendiary bombs has been especially noted in connection with German industrial targets, where high explosives were expected to do much greater damage. The Operational Research Section of the 8th Bomber Command reported instances of raids on German industrial targets in which the incendiary load was but 5 to 10% of the total load yet caused fire damage over a more extended area then the HE bombs. In these cases, the structural damage by fire was estimated to be three times that of the assessed structural damage of HE. It cannot be accurately determined, of course, just how much the HE-added to the fire damage; still, the effectiveness of IB on these targets is not to be considered lightly, in view of the relative proportions of the total load. In consideration of damage assessment reports, the 8th Bomber Command adopted a policy of increasing the ratio of IB to HE up to 33 1/3% of the total. Accounts of recent operations indicate that this has now been increased to about 50%. The ratio of IB to HE to achieve maximum damage from either munition depends upon target qualities. Highly combustible targets require a relatively high ratio of IB. Targets of medium to low combustibility are proper HE targets. The use of IB on them is sometimes questionable. The optimum ratio for Japanese area targets would be higher than for German, because of the greater vulnerability to incendiary attacks. Beyond the point where HEs actually intensify the incendiary aspect of a raid (chiefly by interfering with fire defenses) it must be realized that each replacement of IBs by HEs decreases the probable fire damage effect by so much. Analysis based on the results of actual combat experience is the best way to approach the determination of optimum proportions.

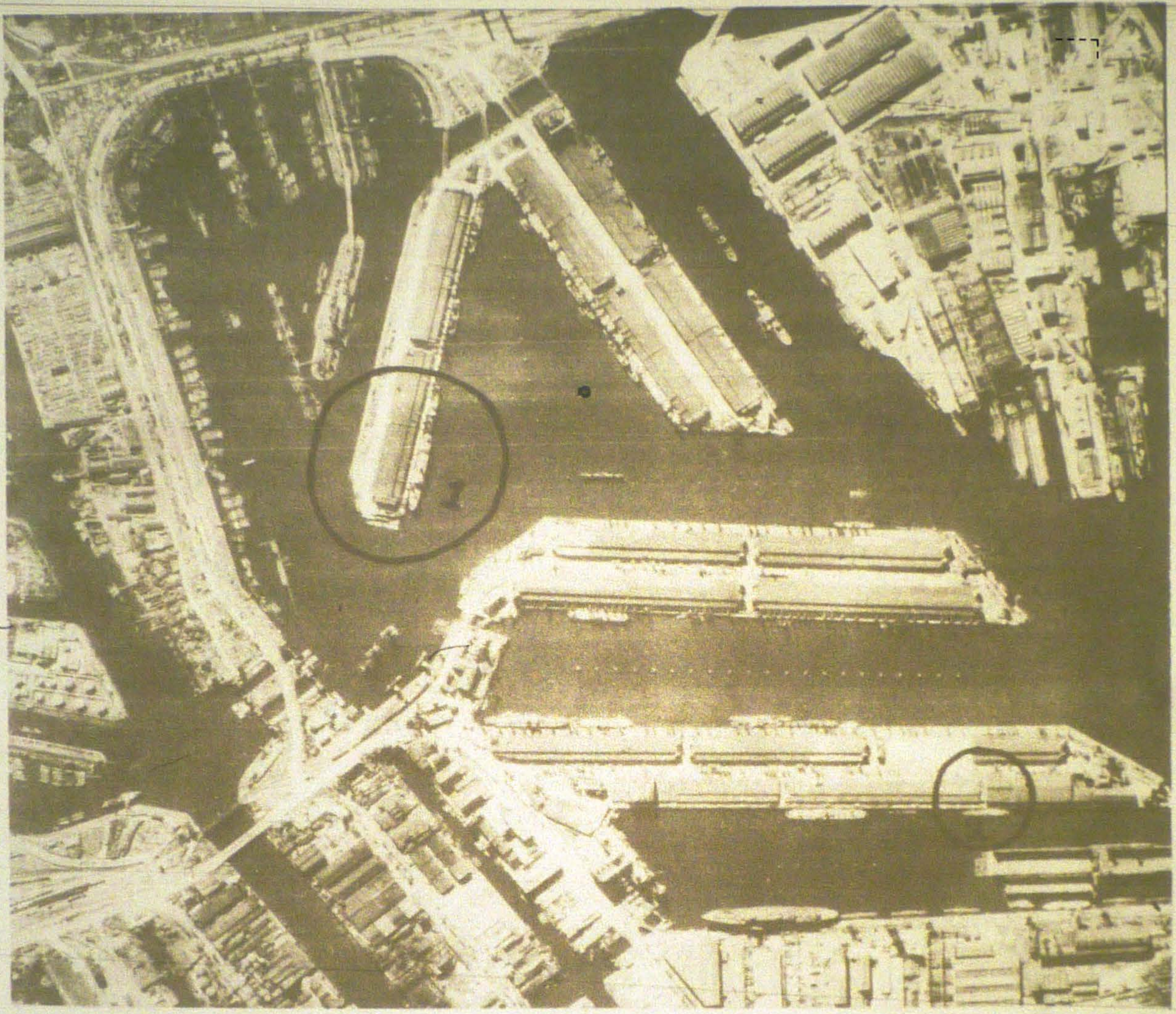


Illustration of a Fire-Division in a Warehouse.

Hamburg (Before): July 1943. The existence of a fire-resistant wall is revealed in the next following photograph.

generally good incendiary objectives: Residential areas, railway stations, combustible railway rolling stock, combustible shipping, processing plants, warehouses, other stores of supplies, arsenals, supply and fuel dumps, tented areas, contonments, bivouac areas, and transportation parks. Harbor installations and power plants, while rather poor incendiary targets in a majority of instances, may, in some cases, be vulnerable to incendiary attack, depending upon the degree of combustibility of their construction and contents. Factories and aircraft maintenance and repair shops may be good incendiary targets if their roofs are combustible, oil storage tanks, oil refineries, and oil installations are not good incendiary targets without the use of high explosives. Best results are obtained with the use of approximately 95 per cent high explosives and five per cent incendiary bombs.

b. **Grouped Targets.** - Grouped targets, such as cities and industrial groups, afford the possibility of dealing simultaneously with several objectives. Because of the spreading nature of fire, these grouped targets are peculiarly appropriate for incendiary attack. The above list is suggestive primarily of strategic bombing. However, incendiary bombing attack is often appropriate against tactical targets in an effort to damage supplies and material and thus help to isolate a battlefield.

c. **Anti-Personnel Effects.** - While incendiary bombs are not primarily anti-personnel weapons, incidental casualties are to be expected. This is especially true since about 20% of certain clustered bombs contain high explosive charges to discourage fire fighters by their anti-personnel effects.

d. **Dehousing of Workers.** - With respect to enemy industrial productivity, the dehousing of workers has an effect comparable to that of direct damage to industrial establishments. The housing area is frequently adjacent to or near the industrial target. It is well to consider this fact in planning a mission.

3. **VULNERABILITY CONSIDERATIONS:**

a. **Principal Factors.** - The following is quoted from "The Theory of Primary Fire-Raising with Small Incendiary Bombs," by Dr. R.B. Fisher and Dr. J. Bronowski, issued by the British Ministry of Home Security, Research and Experiments Department: "The mean area of fire-divisions in a target area is a prime factor in determining the vulnerability of the target, and (2) analysis of a target by an expert on the mapping of fire-walls can be used to give far more accurate estimates of vulnerability, on a quantitative basis, than are at present available." A later passage reads: "For two otherwise similar targets, in which the areas of fire-divisions are in the ratio of two to one, densities of attack in the ratio of one to two will give substantially the same distribution of hits." The principal other factors entering into a determination of vulnerability are (1) combustibility of the target, (2) its resistance to penetration, and (3) fire control measures which the enemy can apply.

b. **Combustibility and Inflammability.** - Vulnerability to incendiary bombing varies so greatly among different targets of the same type, that each separate target must be individually evaluated. If the target consists of a built-up area, then its combustibility depends on the percentage of roof coverage of the area, on the amount and distribution of fire-resistive construction, on the general structure of the buildings, and on their contents. Inflammability of a target can be measured by the quantity of incendiary material, the temperature, and the burning time required to start a fire.

c. **Precision.** - Precision requirements are related to the analysis of the target into fire-divisions, which, with the degree of combustibility, helps determine the selection of munitions, the quantity to be used, and the mode of employment. Further discussion of this topic and also of penetration properties appears in Chapter V, on bomb requirements, and such considerations for certain targets enter into the table of recommended bomb selections in Chapter IV.

d. **Defenses.** - Enemy defenses (anti-aircraft, fighter-plane, and fire-fighting), are aspects both of vulnerability and of the closely related subject of bomb requirements. Once an incendiary target is under consideration, its vulnerability properties determine the type, quantity, and technique of employment of incendiary bombs. Consequently, the discussion of certain topics is distributed among the present chapter, Chapter IV and Chapter V.

e. **Vulnerability of Parts of Area Target.** - Grouped targets transcend all others from the viewpoint of incendiary attack. Such targets are analyzable not only into fire-divisions but also into areas of different values and degrees of vulnerability. If these areas are large enough and their locations known, then the attack can be adjusted speciflallly to the most vulnerable parts of the target. Otherwise, formation patterns must be relied upon, of sufficient density to assure enough hits on the highly inflammable areas. Most built-up areas of housing, groups of docks and warehouses, and industrial plants are of the type vulnerable to such scatter bombing.

f. **Inflammability Classes Within Grouped Targets.** - Cities and large industrial groups include areas which can be classified as (1) highly combustible, (2) combustible, and (3) unprofitable (See photographs on pages 17-21.) Heights, structure and contents of buildings are determining factors. This is more useful than an analysis into zones on a functional basis, since an area of old highly inflammable buildings in one target might correspond to modern, fire-proof buildings falling into the unprofitable class in an otherwise similar target. German domestic structures are, on the average, less vulnerable to incendiary attack than Japanese. (See photographs on pages 17 - 21.)

§4. **APPLICATION TO PARTICULAR TYPES OF TARGETS:**

The following comments relate to vulnerability properties of special types of targets and are intended to illustrate the principles governing bomb selection. Such selection is based on a correspondence between target properties and the properties of available bombs.

a. **Dry Forests and Grain Fields.** Incendiary attack against forested areas devoid of combustible ground cover have proved unsuccessful in starting any large or continuing fires. However, when adequate combustible ground cover is present, and the trees constituting the forest are also combustible, large scale forest fires may be expected from incendiary attack. Penetration is not desired, since a bomb which buries itself in the ground will not be effective. Precision properties are unimportant, for small areas would not be worthy of attack. Numerous bombs with good distribution of incendiary filling are desirable to ensure merging, spreading fires. The M69s and M74s (see Chapter IV) would be appropriate.

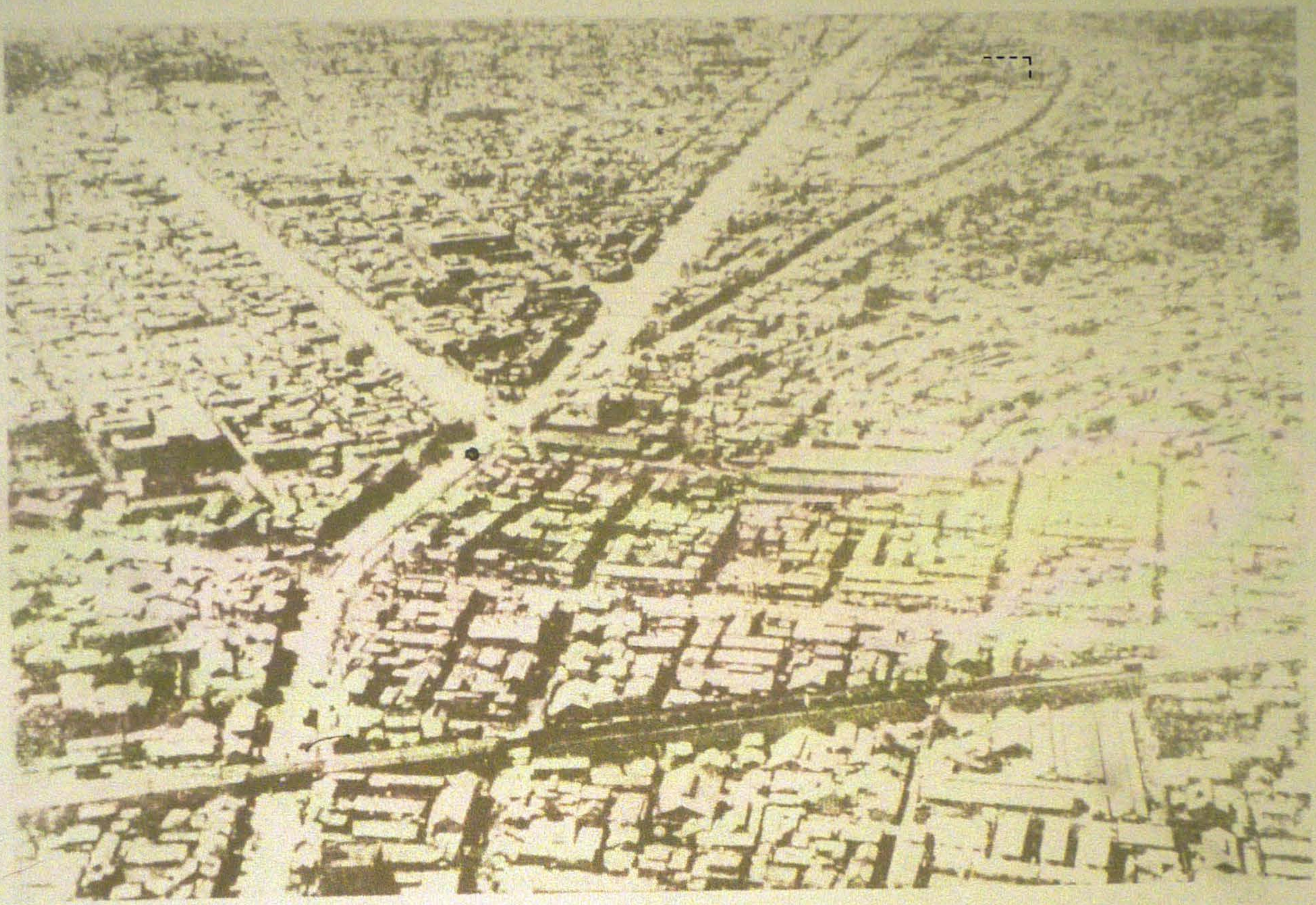
b. **Area Targets of Light to Medium Construction (At Least 30% Roof Coverage).** - If roof coverage is too low, then the buildings become separate targets. Strongly penetrating bombs are not required. Large numbers of small incendiary bombs dropped with a scatter bombing technique are desirable in order to secure merging and spreading fires. Enemy defenses call for large quantities of incendiary bombs and possibly for some use of high explosives to disrupt fire control measures. If fire-divisions are small, large plane loads of the smallest bombs are appropriate, since the present type of target is quite vulnerable, and it is desired to deliver bombs on all unit areas.

c. **Bivouac Areas, Camp Storage Areas, Supply Dumps.** - Penetration is again not needed to any considerable degree. In some cases, small bombs will have sufficient fire-raising power. In others, where inflammability is less, larger masses of incendiary material, with good distribution properties, are needed. The anti-personnel effects and supplementary damage of high explosives are of value.

d. **German City Areas.** - Here, medium, light, or heavy structures might predominate, governing the desired penetrability properties. A considerable number of patterns of appropriate density is required, depending on the size and arrangement of inflammable areas, and on the adequacy of enemy control measures.

e. **Isolated Factory Plants.** - Since combustible material will generally not be distributed over the entire floor space of factory buildings, incendiaries which scatter their fillings may be desirable. Penetrability varies from target to target, and so does the degree of combustibility. Enemy defenses demand anti-personnel bombs; and the supplementary damage to water supplies and automatic sprinklers by demolition bombs is generally important.

f. **Refineries, Fuel Stores, and Tank Farms.** - Here the use of high explosives plays the dual role of (1) breaking piping, tanks, and containers of inflammable substance, and (2) igniting their contents. Tank farms are especially vulnerable. The tanks can be ruptured by HE's, permitting their contents to spread out where IB's can ignite them. Heat radiating from

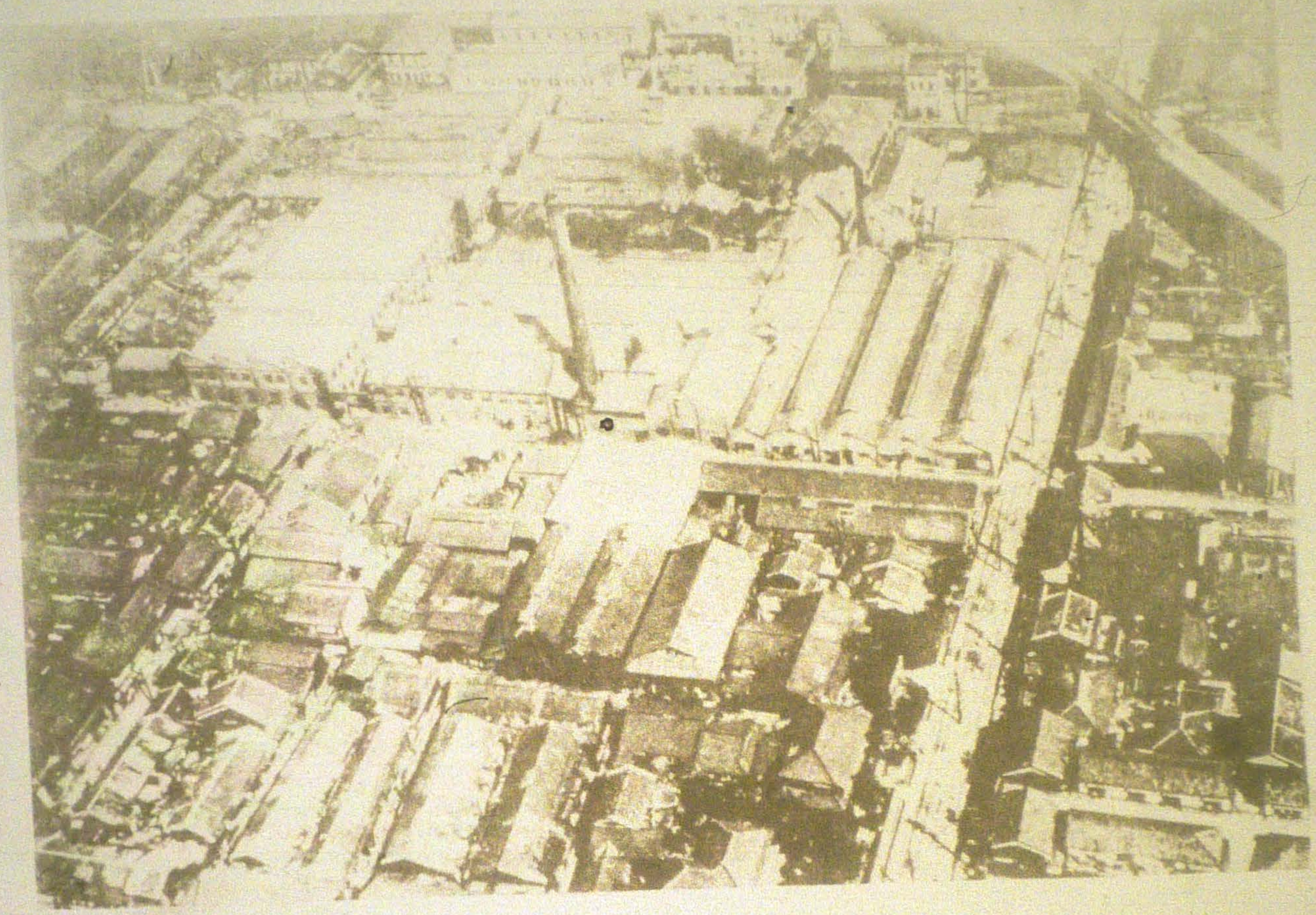


TOKYO, a highly inflammable region, showing large unit fire areas, with few fire breaks.

YOKOHAMA. Highly inflammable area, showing lack of fire breaks and large unit fire areas.

FUKUOKA. A large, highly inflammable unit fire area.

AACHEN: A German area target, showing large-scale gutting of fire-divisions with a heavy concentration of IB's.



DUNLOP RUBBER PLANT; eastern part of Kobe. The congestion of warehouses and workers' houses makes a possibility of spreading fires; such conditions are less likely in German industrial areas.

the resulting fire can burst adjacent tanks, causing fire to spread throughout the area.

The above list is not intended to be exhaustive, but rather to present samples of the reasoning underlying the tabulated recommendations in Chapter IV.

§5. SUMMARY:

Vulnerability to incendiary attack depends on combustibility of buildings and contents, areas of fire divisions, penetrability, and defensive measures. Grouped targets present special problems, combined with possibilities of great fire damage. Study of particular targets with reference to vulnerability properties reveals those qualities which are desirable in corresponding incendiary munitions.

III. INCENDIARY BOMBS

§1. STANDARD AMERICAN IB'S.

a. **Types of Bombs; Responsibility of CWS.** - In order that fire can be placed on the target to accomplish its powferful effect, careful consideration must be given to the incendiary bomb properties best suited to each type of target. The Chemical Warfare Service is responsible for the development, procurement, production, and issue of all incendiary bombs.

b. **Functional and Penetrative Classes.** - Incendiary bombs are classified as follows, with respect to distribution of incendiary filling:

1. Scatter type incendiary bombs.
2. Intensive type incendiary bombs.

From another viewpoint, they are divided into

1. Bombs that penetrate heavy structures.
2. Bombs that penetrate medium structures.
3. Bombs that penetrate light structures.

The bombs designed for the penetration of heavy structures include the larger ones which penetrate deeply and contain large quantities of incendiary material. Deep penetration is also afforded by certain small bombs of good structural strength and high terminal velocity. The next chapter discusses fully the evaluation of each bomb in relation to the target upon which it is to be used.

c. See pages 23 to 29 for tabular survey and illustrations.

§2. DESCRIPTION OF CLUSTER BEHAVIOR:

a. **Quick-Opening Clusters.**- Quick-opening clusters break open on release, generally in the slipstream of the plane. There is an immediate scattering of bombs and an even greater scattering of cluster parts. These trail so seriously as to menace succeeding planes in the formation. Hence the use of such clusters is confined to formations not involving lower rear elements. Impact patterns from individual quick-opening clusters tend to be large and hence not very dense. Formation bombing corrects this situation (See Chapter VII), since the separate cluster patterns overlap, reinforce one another, and merge into a single formation pattern. The latter constitutes the most appropriate unit in area bombing. Wind effects are relatively serious for bombs from quick-opening clusters, especially for those with low terminal velocities. The resulting lack of precision is increasingly serious at higher altitudes, and it has therefore been determined, at a joint bomb and fuze conference, that 8,000 feet should be the maximum altitude for use of quick-opening clusters. In compensation for the disadvantages of quick-opening clusters, there is the considerably greater loading efficiency. The 500-lb. quick-opening clusters contain 16% more bombs than the aimable clusters for the M50 and 58% more for the M69. Up to the recommended altitudes at least, aimability is satisfactory with the use of bombing tables devised for quick-opening clusters. Minimum altitude releases of such clusters are effective, save in the case of clusters of M69's. The latter should not be released from less than 1,000 feet above the target, because these bombs are relatively slow to stabilize and tend to strike at bad angles if released from low altitudes. This results in a high percentage of malfunctioning, since the bomb does not have an "all-ways" fuze. Bombardiers require detailed instruction in the technique of release of quick-opening clusters.

CHARACTERISTICS OF STANDARD CLUSTERED IB'S

	AN-M50A2 AN-M50xA3	AN-M69	M74
Filling and wt. in lbs.	Mg. 1.3 Th. 0.62 Tetryl 38g (in M50xA3)	IM 2.8 or NP 2.8	WP 0.3 NP 1.94 or WP 0.3 PT_1 2.2
Method of Functioning	Intensive: Filling stays near bomb	Tail ejection: Burning sock of mixture is ejected up to 75 yds.	Tail ejection
Bomb Fuze		M1	M142 (all-ways fuze)
Burning time	5 - 7 min	4 - 5 min	4 - 6 min
Bomb wts. (lbs)	3.7 (4-lb. type)	6.2 (6-lb. type)	7.5 or 8.2 (10-lb. type)
Terminal velocity	420 ft/sec	225 ft/sec	Over 400 ft/sec
Penetration at T.V.	4" reinforced concrete (heavy construction)	2" to 3" concrete (light to medium construction)	4" concrete (heavy construction)
Quick-Opening clusters of 100-lb type (symbol, wt., contents, adapter)	AN-M6: 145 lb. 34 bombs M5 adapter	AN-M12: 105 lb. 14 bombs M4 adapter	135 lb. (est.) 14 bombs
Quick-Opening clusters of 500-lb type (symbol, wt., contents. adapter)	M7: 540 lb. 128 bombs M6 adapter	AN-M13: 417 lb. 60 bombs M7 adapter	550 lb. (est.) 60 bombs
Aimable 500-lb. clusters (symbol wt, contents, adapter, fuzes, burster)	AN-M17A1: 490 lb. 110 bombs M10 adapter T55 nose fuze Primacord	M18: 350 lb. 38 bombs M9 adapter T55 nose fuze T53 tail fuze Primacord	400 lb. (est.) 38 bombs T55 nose fuze T53 tail fuze Primacord
Altitude Recommendations	Quick-Opening: from 8000' ft or less Aimable: Medium to high, with cluster burst set for 5000'	Quick-Opening: from 1000' to 8000' Aimable: Medium to high with cluster burst set for 5000'	Quick-Opening: from 8000' or less. Aimab;e: Medium to high, with cluster burst set for 5000'

CHARACTERISTICS OF LARGER STANDARD IB'S

	M47A2	M76	Belly Tank
Filling and wt. in lbs.	IM 40 lbs or NP 40 lbs	PT-1 180 lbs	Gasoline Gel
Method of Functioning	Scatters over a 50' radius	Scatters over a 150' raduis	Spreads over 60' x 120' for 75 gal. tank
Fuzes	AN-M126 AN-M126A1	AN-M103 nose AN-M101A2 tail	Igniter
Burning time	10 min (Approx)	20 min (Approx)	
Bomb wt. (lbs)	69 (100-lb. type)	473 (500-lb. type)	
Terminal velocity	825 ft/sec	1000 ft/sec	
Penetration	5" concrete from 25,000'	15" concrete from 25,000'	Instantaneous Burst
Bursters	M12 or M13	M14 Adapter-Booster M115	
Altitudes	Min safe release: 200'. Penetration Good from 15,000' and higher.	Min safe release: 300'. Penetration Good from 15,000' and higher.	Minimum Altitude
Comments	May be multiple-suspended (Special loadings): 2, 3, or more bombs at a station	May be used in low level attack when building or contents are combustible. Also effective when extreme penetration is required	For use from fighter aircraft against various targets.

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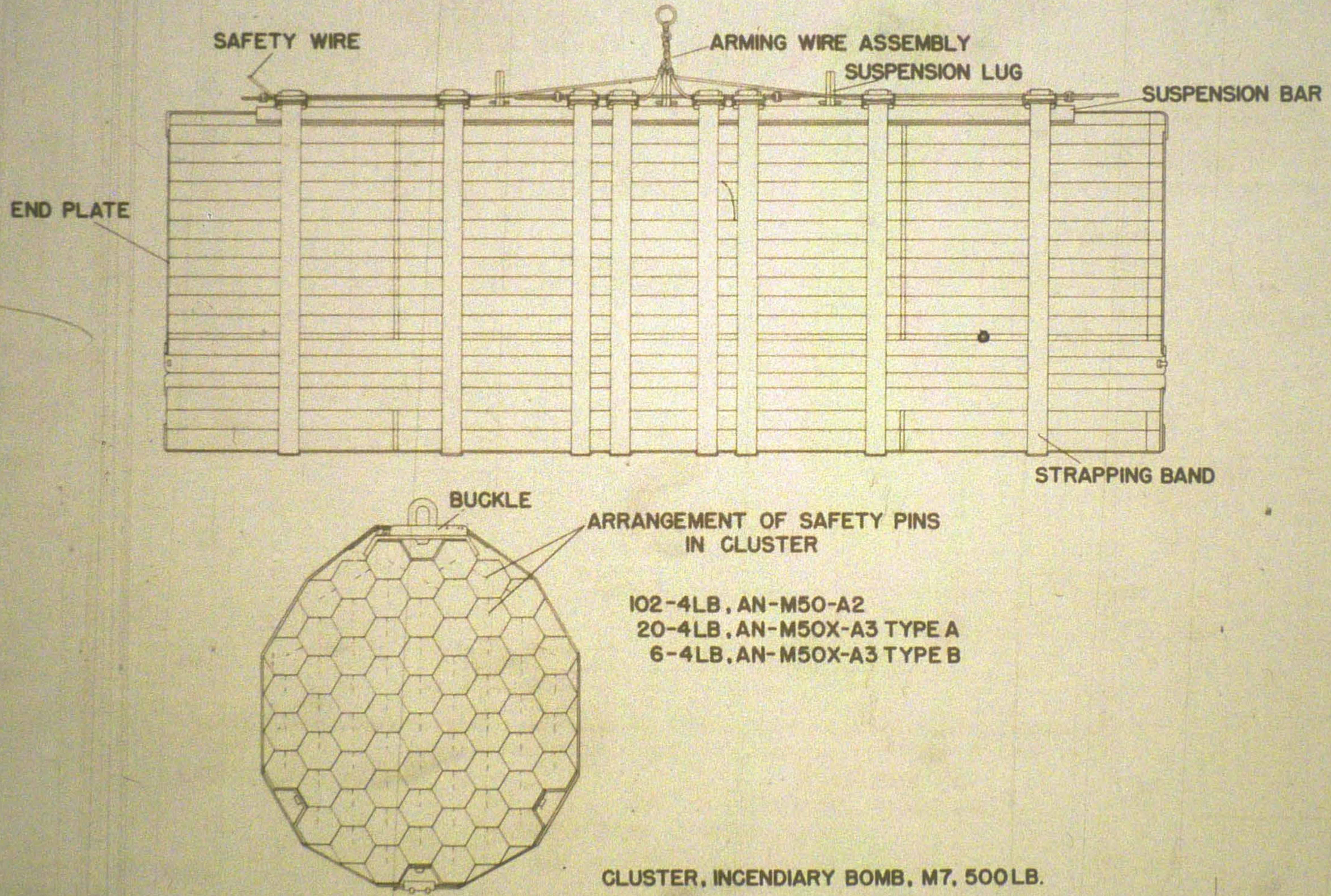

CLUSTER, INCENDIARY BOMB, M7, 500LB.

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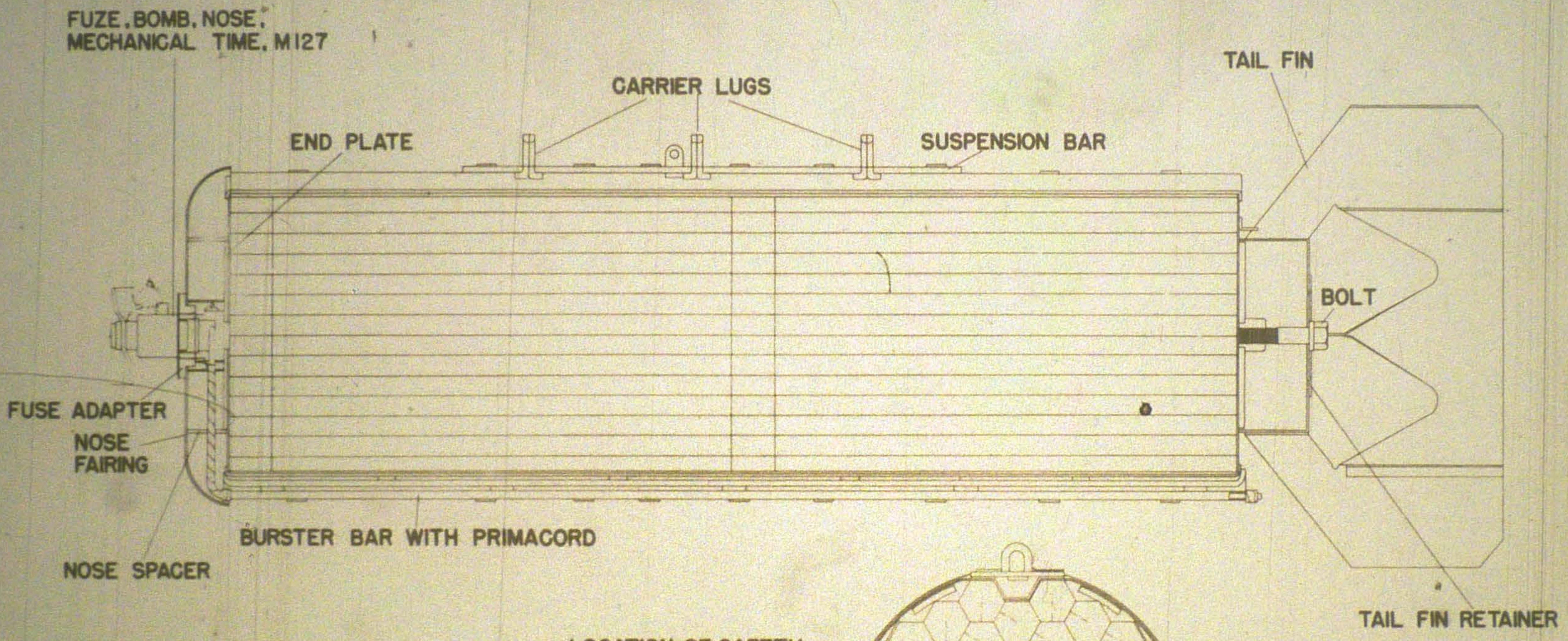

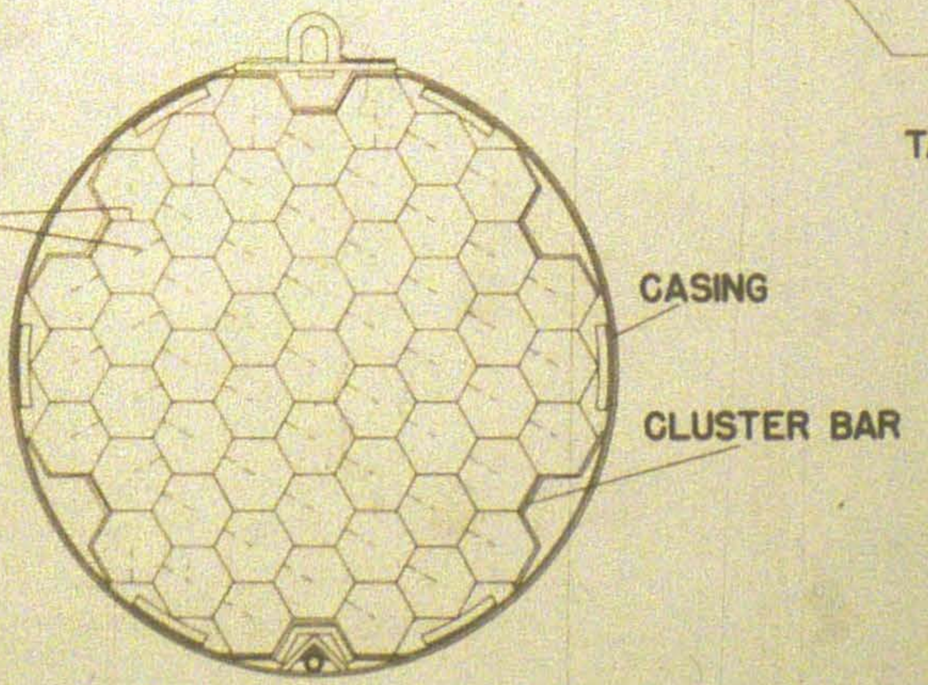

CLUSTER, AIMABLE, INCENDIARY BOMB, M17

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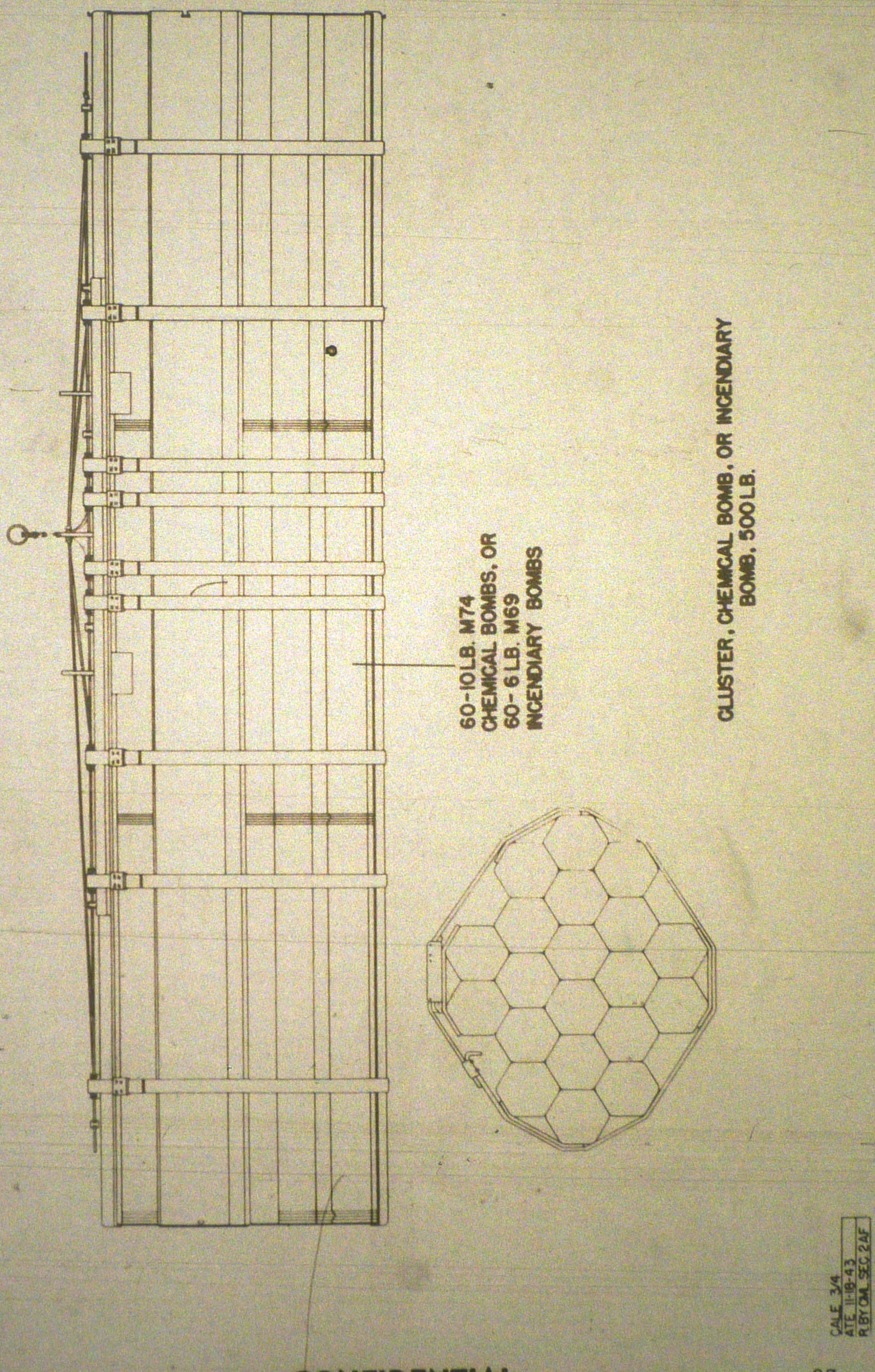
60-10LB. M74
CHEMICAL BOMBS, OR
60-6LB. M69
INCENDIARY BOMBS
CLUSTER, CHEMICAL BOMB, OR INCENDIARY
BOMB, 500LB.
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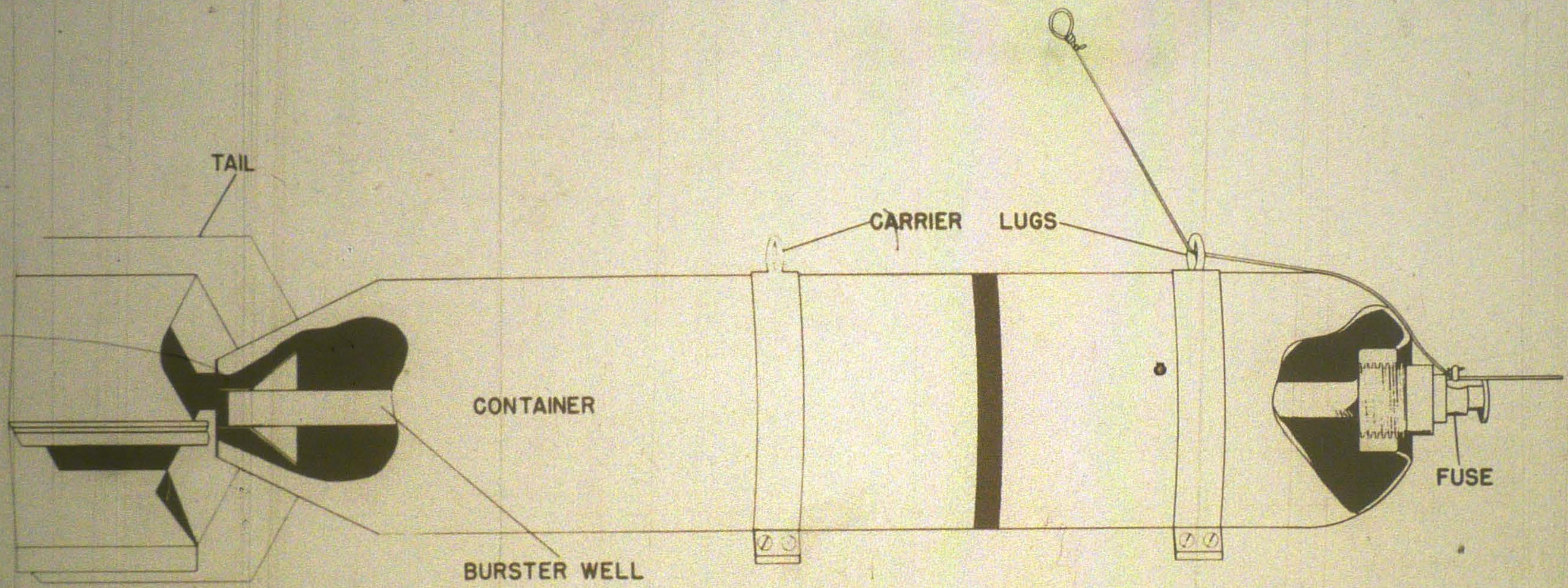

100 LB. M47 BOMB
M47A1 BOMB
M47A2 BOMB

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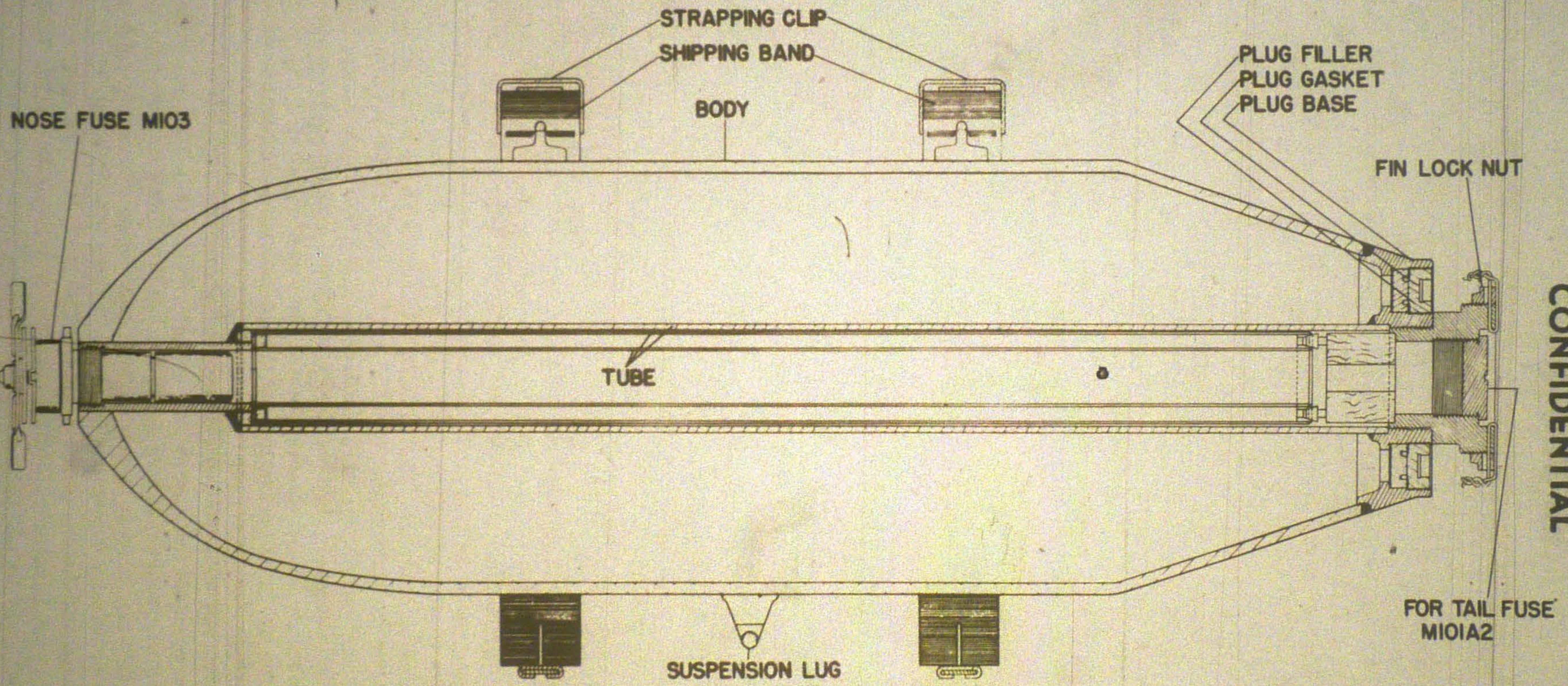

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500LB. INCENDIARY BOMB M76

29

SCALE FULL SIZE
DATE 11-17-43
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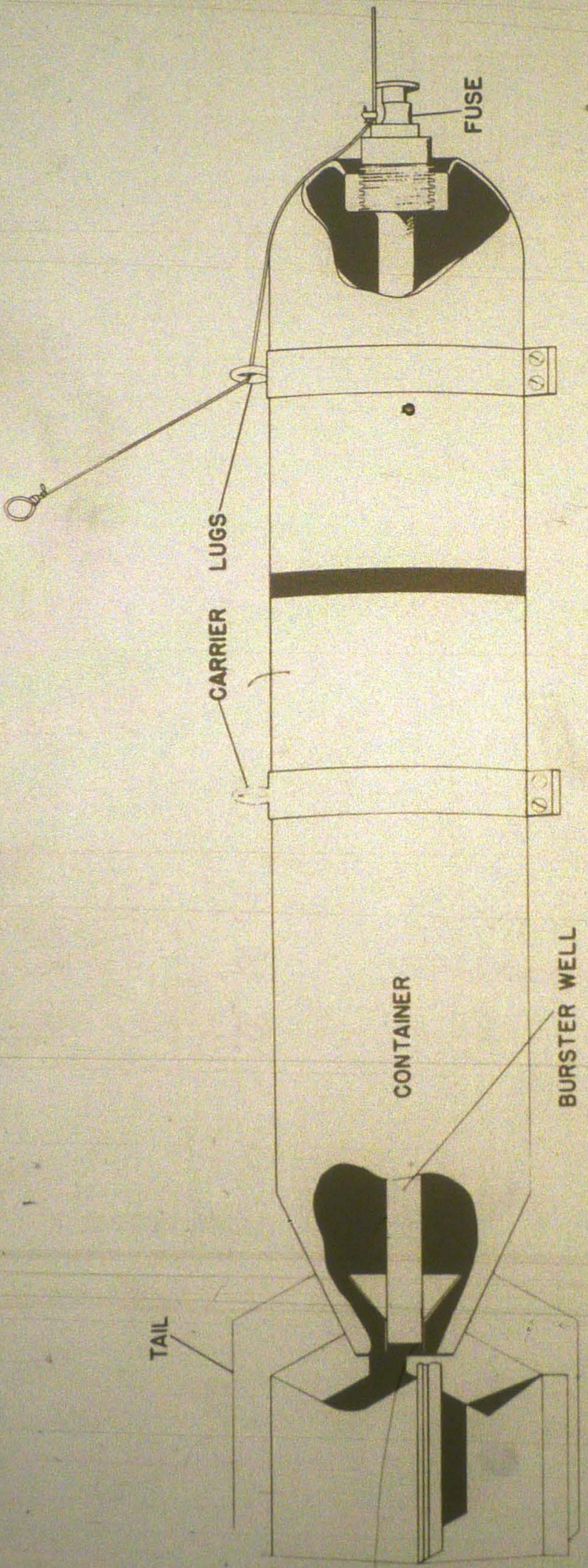

100 LB. M47 BOMB
M47A1 BOMB
M47A2 BOMB

SCALE FULL SIZE
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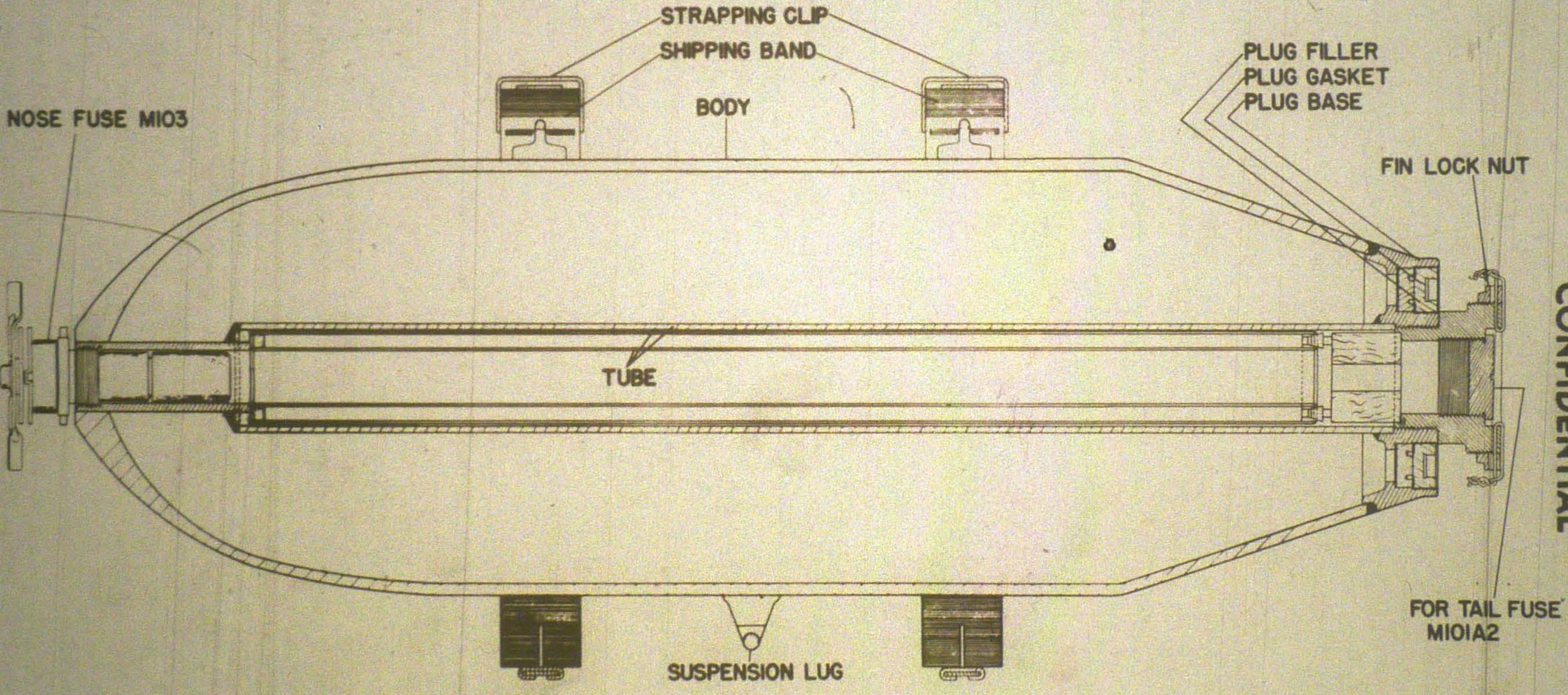

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500LB. INCENDIARY BOMB M76

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b. **Aimable Clusters.**- Aimable clusters are designed to have ballistic properties comparable to those of GP bombs. They operate by time fuzes which can be set to function at various altitudes. The scattering of bombs on cluster opening is much less than in the case of quick-opening clusters, so that individual cluster patterns are relatively compact and dense. Formation patterns are also different for aimable as compared with quick-opening clusters (See Chapter VII), and the former, of course, impose no special restrictions on the formations from which they are released. When aimable clusters open, they are generally moving at velocities higher than the terminal velocities of the individual small bombs. The latter are therefore less subject to wind effects than when they are released from quick-opening clusters. After an aimable cluster bursts, the bombs decelerate toward their terminal velocities. If they strike with excessive speeds, there may be malfunctioning due to rupturing or collapse of the bomb on impact. To allow for sufficient deceleration and for stabilization of the bombs in flight, it is recommended that clusters be set to open at 5,000 feet. With such an altitude of cluster opening, it is possible to bomb from high operational altitudes and achieve the same sort of precision as with GP bombs. On twenty-two drops of the M17 cluster at Eglin Field (AAF Board Project No. (M-5) 54) from altitudes ranging between 5,000 and 25,000 feet, the average circular error of the center of impact of the pattern was somewhat over 500 feet and ranged from 50 to 1,000 feet. The M17 cluster was found to trail the 500-lb. M43 GP bomb by approximately 30 mils for releases from 20,000 and 25,000 feet. In the case of the M18 cluster (AAF Board Project No. (M-5) 140), aimability was found satisfactory, with special bombing tables and with a presetting of trail into the bombsight.

§3. **BEHAVIOR OF DIFFERENT BOMBS ON TARGETS:**

This section is intended to describe, insofar as available information permits, the behavior of standard bombs on targets of various sorts. Specific matching of bombs with given targets is treated in Chapter IV.

a. **Striking and Terminal Speeds.**- Bombs may strike with velocities considerably different from their terminal velocities shown in the table on pages 23, 24. From low and medium altitudes, the M47 and M76 strike with considerably less than their terminal velocities, since these bombs accelerate relatively slowly. The M50 may strike with less than terminal velocity if dropped from a low altitude, with a resulting decrease in penetrating power. This is not true of the M69, because its terminal velocity (150 mi/hr) is not high as compared with the speed of a plane on a bombing run. Low altitude releases result in some increase in the percentage of malfunctioning small bombs, since the bombs have less opportunity to stabilize in flight and hence tend to strike at bad angles of impact.

b. **M50.**- This bomb should not be used on easily penetrable domestic targets which might permit the bomb to go clear through the inflammable parts and bury itself ineffectively or function in an unfavorable position. The filling of this bomb remains in the immediate vicinity of the place where it functions. For its efficiency, it depends on landing in a location where "kindling" is available. Large numbers of M50's can be loaded in a plane, resulting in a large distribution of bombs within the target area. The fire-raising effects depend, of course, on the existence of an appropriate distribution of kindling in the target.

c. **M69.**- Penetration of light and medium, but not heavy, construction is afforded by this bomb. If it lands on too strong a roof, it may bounce off or it may stick in the roof, ejecting its incendiary filling exterior to the target, where its effectiveness is much reduced. It has appropriate penetrative powers for a slate roof and ½ inch wood sheathing but not for several inches of strong reinforced concrete. Functioning of the M69 occurs about three seconds after the initial impact, allowing the bomb to go through a roof and perhaps penetrate to a lower floor, if the structure is light, before functioning, this bomb ejects its incendiary material with sufficient force to carry the bulk of it as much as 75 yards in the open. The ejective feature results in a distribution of filling on walls, furniture, and so on, where it adheres while it burns. Thus the M69 is freed from the necessity of function-

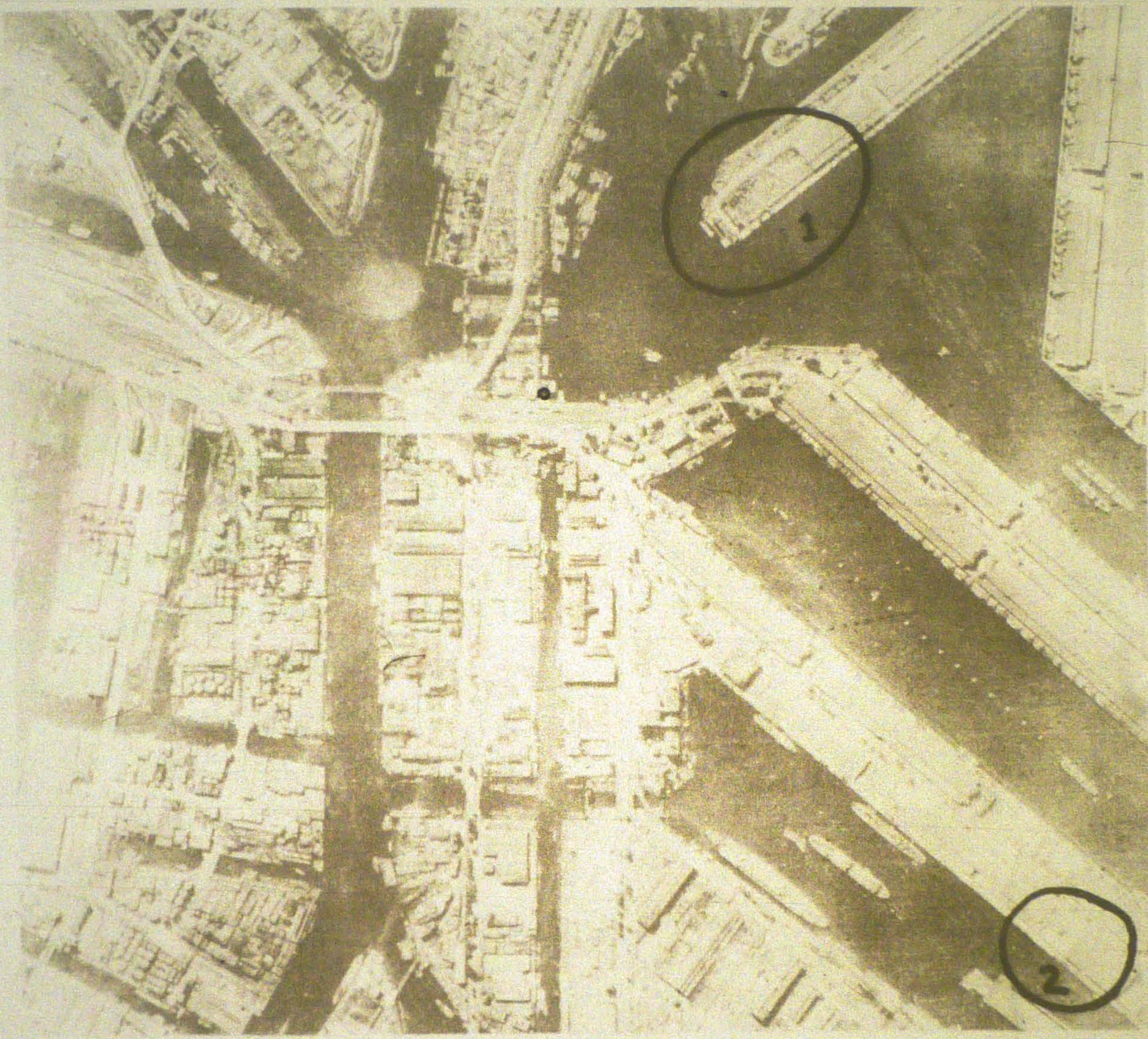
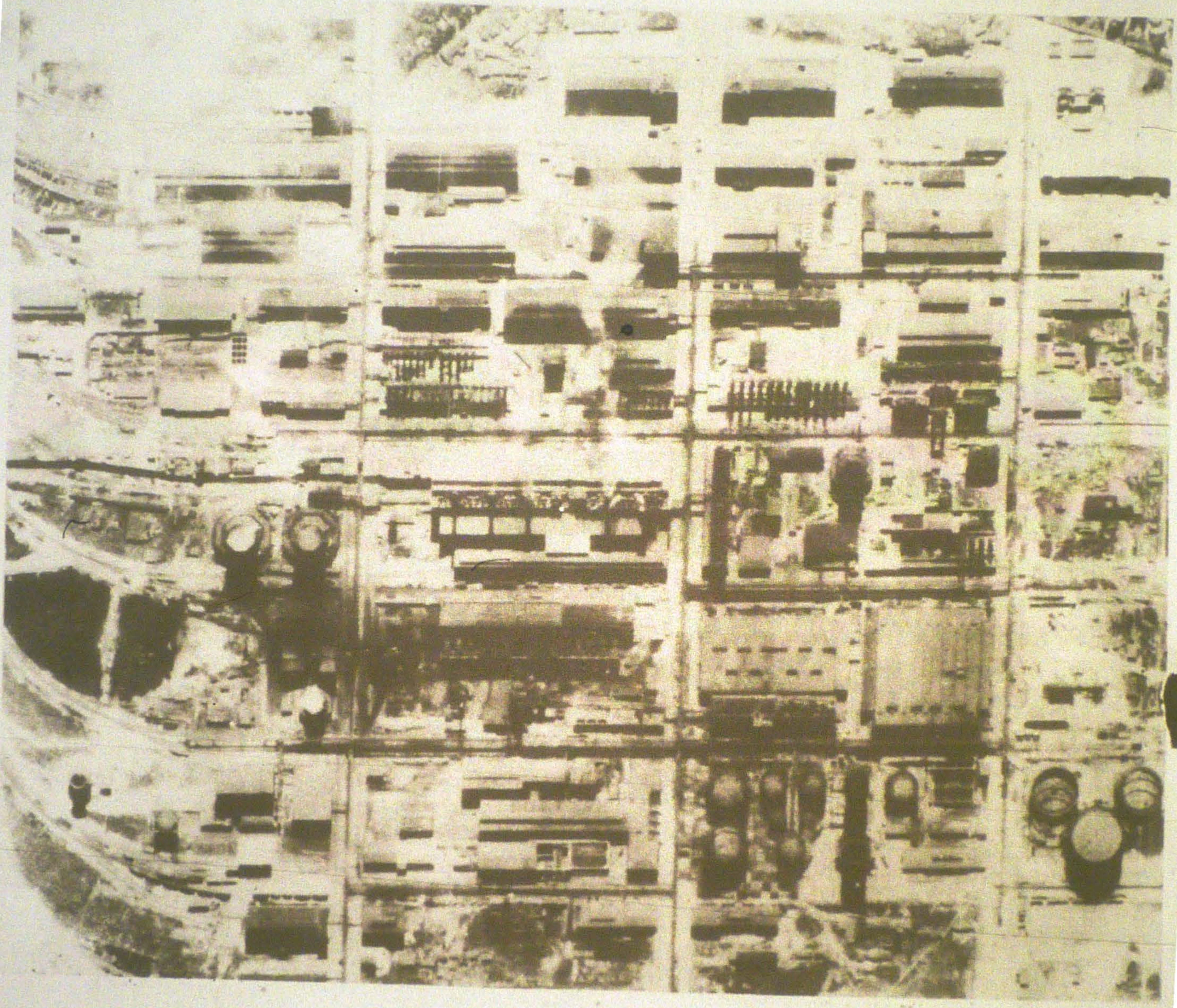


Illustration of a Fire-Division in a Warehouse.
After.

Hamburg: July 1943. The existence of a fire resistant wall is revealed. One fire-division, the end of a warehouse (1), was completely destroyed, the other end remained intact. In another part of the picture (2) is an example of HE damage.



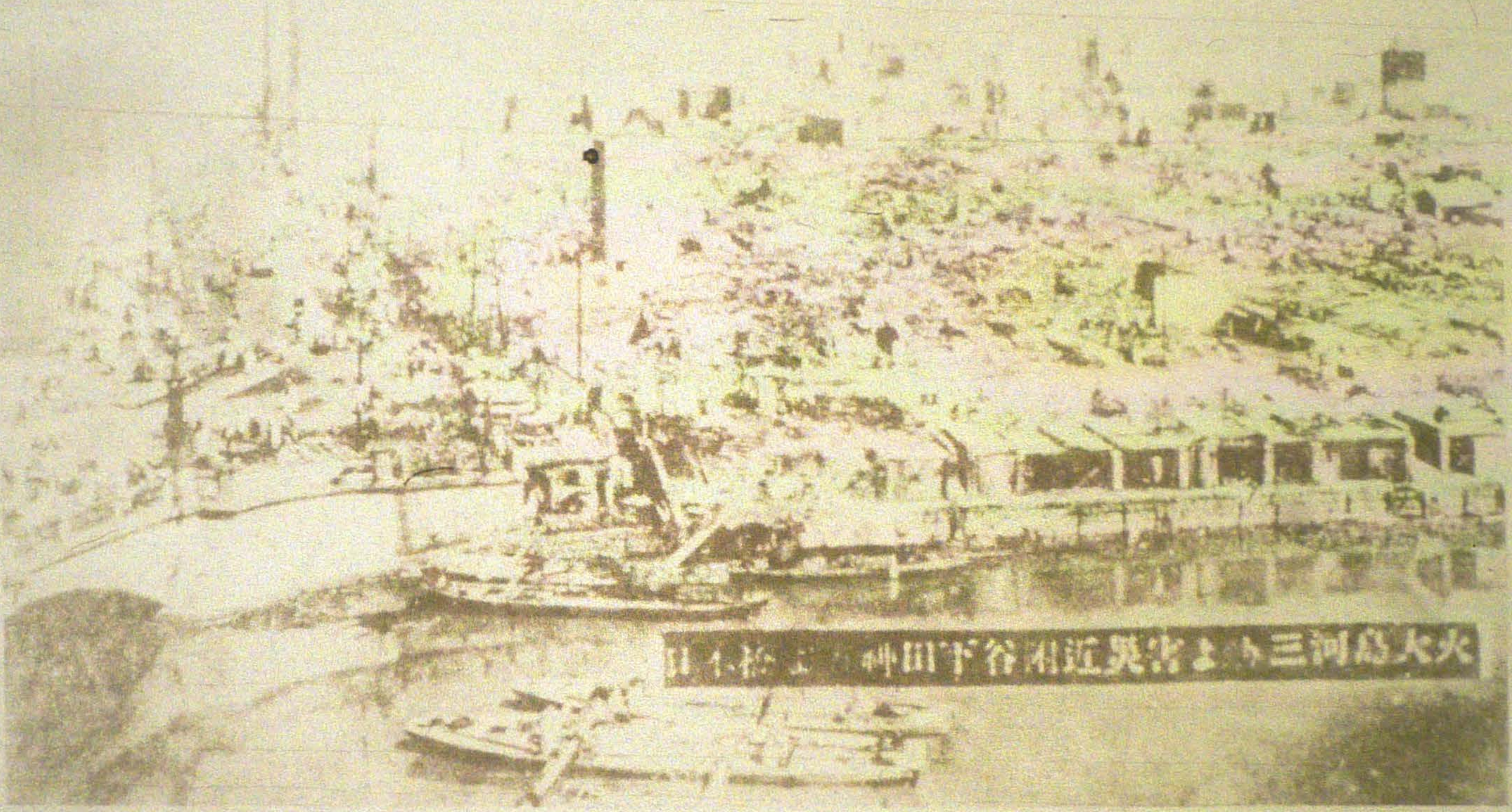
Huls, Germany: Synthetic Rubber Plant.

An industrial group target requiring expert analysis into fire-divisions.

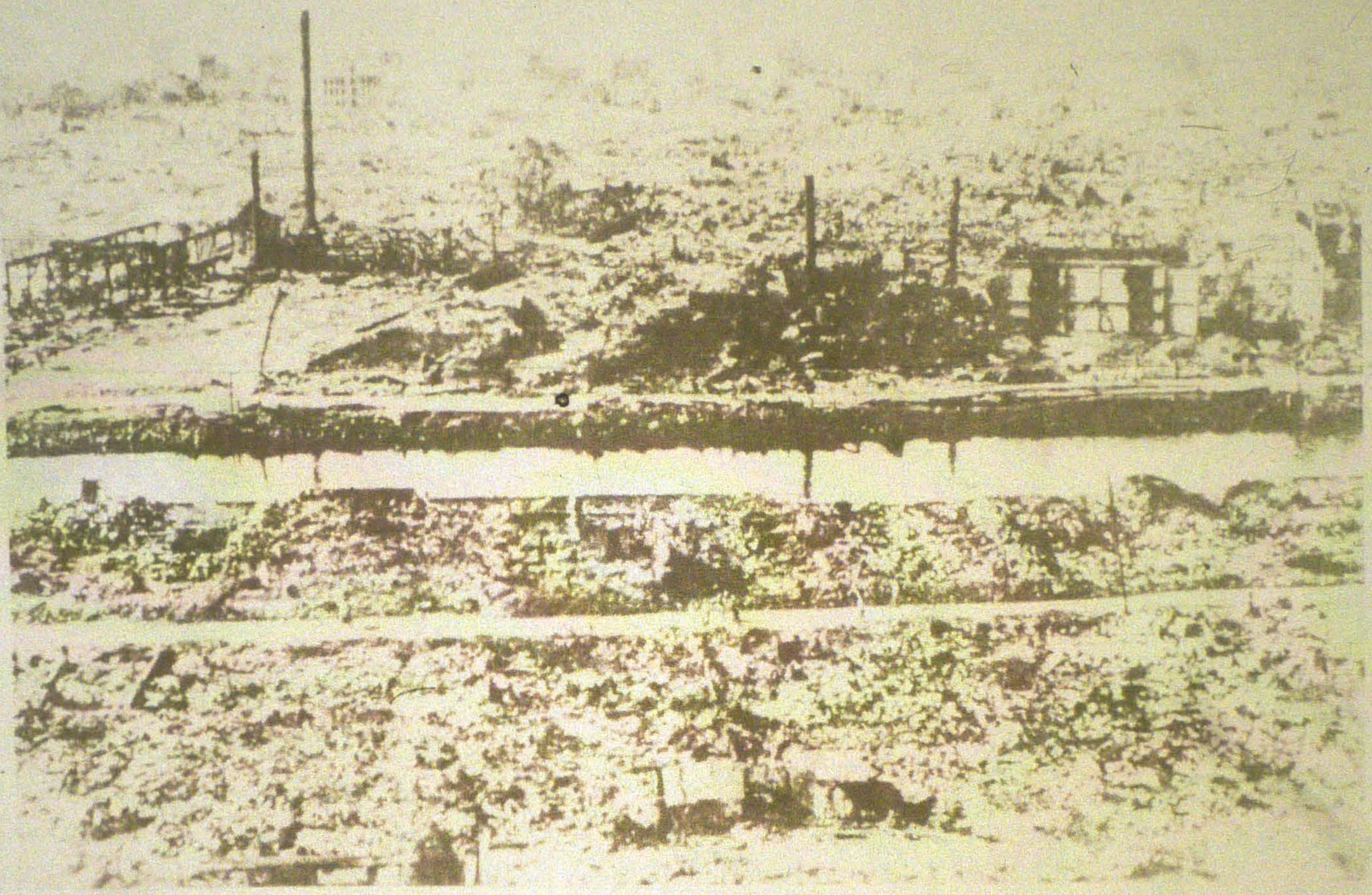
c. **Results of Tests at Eglin Field.** - Recent tests conducted at Eglin Field, to determine the effects of HE in a primarily incendiary area attack, disclosed that HE actually retarded the incendiary action. Area targets containing prototype Japanese dwellings, each constituting an area roughly 150 x 300 yards, were constructed. 100-lb. demolition bombs were dropped on them. The HE blew out walls and did some damage to the buildings in general, but did not start a fire of any proportions. Such fires as were started were easily controlled. Incendiary bombs (M69) were then dropped on the No. 2 Target. Although only 10 per cent of the IBs actually hit the target, a fire had developed which within four minutes was in a conflagration state. Due to the intensity of the fire, trained fire-fighters and professional equipment had to be withdrawn from fire-fighting, and the target was consumed. On the No. 3 Target, IB was again dropped followed by HE. The HE (100-lb.) acted to blast out fires that had started, and the fires were brought under control. On Target No. 4 the HE was dropped first, followed by the IB. In this case, the fires were much slower to develop as the broken timbers were slower to take hold. Trained fire-fighters adequately controlled the fires. On Target No. 5, IB and fragmentation bombs were employed. The IB effectively started fires similar to those in Target No. 2, and the fragmentation bombs were of insufficient blast to affect materially the initial burning phases or to damage the buildings to an extent which affected their burning characteristics. Since these tests disclosed that HE offered no fire-aiding qualities, but rather acted to retard the rapid effect of IB, it was concluded that HE is not satisfactory in any large quantities on incendiary area missions, but should be used only for the confusion, fear and delay it may create. It was further concluded that the best method to obtain this result was by the simultaneous use of the 20-lb. fragmentation bombs together with the IBs, in a coextensive pattern, the fragmentation bombs constituting 20% of the load.

d. **Mutual Effects of HE and IB.** - While the best proportion of HEs in an incendiary attack appears to be smaller than was believed in earlier stages of the war, it is certain that the use of some HEs, suitably coordinated with the IBs, tends to increase the damage for German targets. Not only the proportions but the methods of coordination are still subjects for operational analysis. Since tests disclose that HE directly mixed with IB sometimes decreases the incendiary effects of an attack, the use of HE should be closely evaluated. Further analysis should be made of the best allocation of HEs and IBs among planes, squadrons, or groups; the order of use of HEs and IBs; the relative altitudes to employ; and the question, depending on the target, whether to plan an attack as a coordination of incendiary and demolition missions or as an incendiary mission supplemented by a small proportion of high explosives. Primarily, the demolition bombs serve, along with fragmentation and anti-personnel IBs, to hinder the enemy's fire-fighting activities by disrupting traffic, creating confusion and panic, and occasionally breaking water mains. For built-up Japanese area targets, 20-lb. fragmentation bombs are best (see the preceding paragraph). A few targets, as fuel storage tanks and oil refineries, become more vulnerable to incendiary attack after being broken by HE bombs. Other targets become less vulnerable. The value of HEs in window breaking and otherwise creating drafts is questionable, since (1) large quantities of HEs, displacing a corresponding weight of IBs, are required for extensive window breakage and (2) the HEs may disrupt a target in such a way as to prevent the flash-point being reached in certain portions. A small incendiary bomb, in a room, starts to burn intensively and sets nearby material ablaze. As the heat increases and the flash-point (or kindling temperature) is reached for different objects in the room, they burst spontaneously into flames. Such temperatures are reached more easily if the room is not over-ventilated, in the initial stages, by broken windows or walls, which allow the heat created by the bomb to be carried off. There is generally sufficient oxygen to permit the development of a flash-point temperature. However, as the oxygen is consumed, the fire tends to subside. In most cases, the heat from the first three to five minutes of fire, when a room or area becomes enveloped in flames is sufficient to break windows and admit enough air to sustain the fire. Disruption of the room in advance by demolition bombs will frequently prevent attainment of the flash-point.

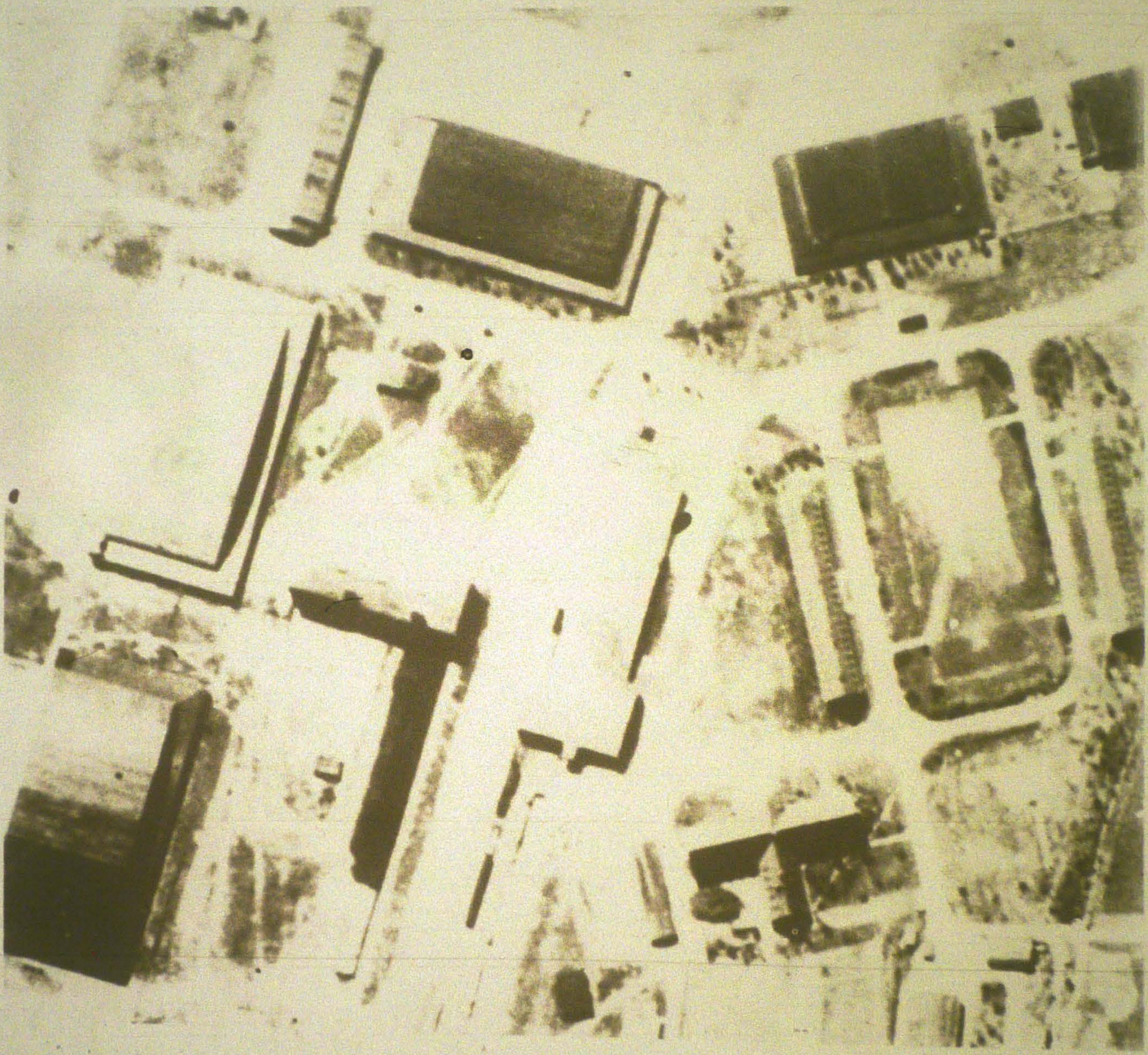
e. **Fires Started by HE.** - Some fires are, of course, started by general purpose bombs: for example (1) by the explosion flash igniting highly inflammable material, (2) by dis-



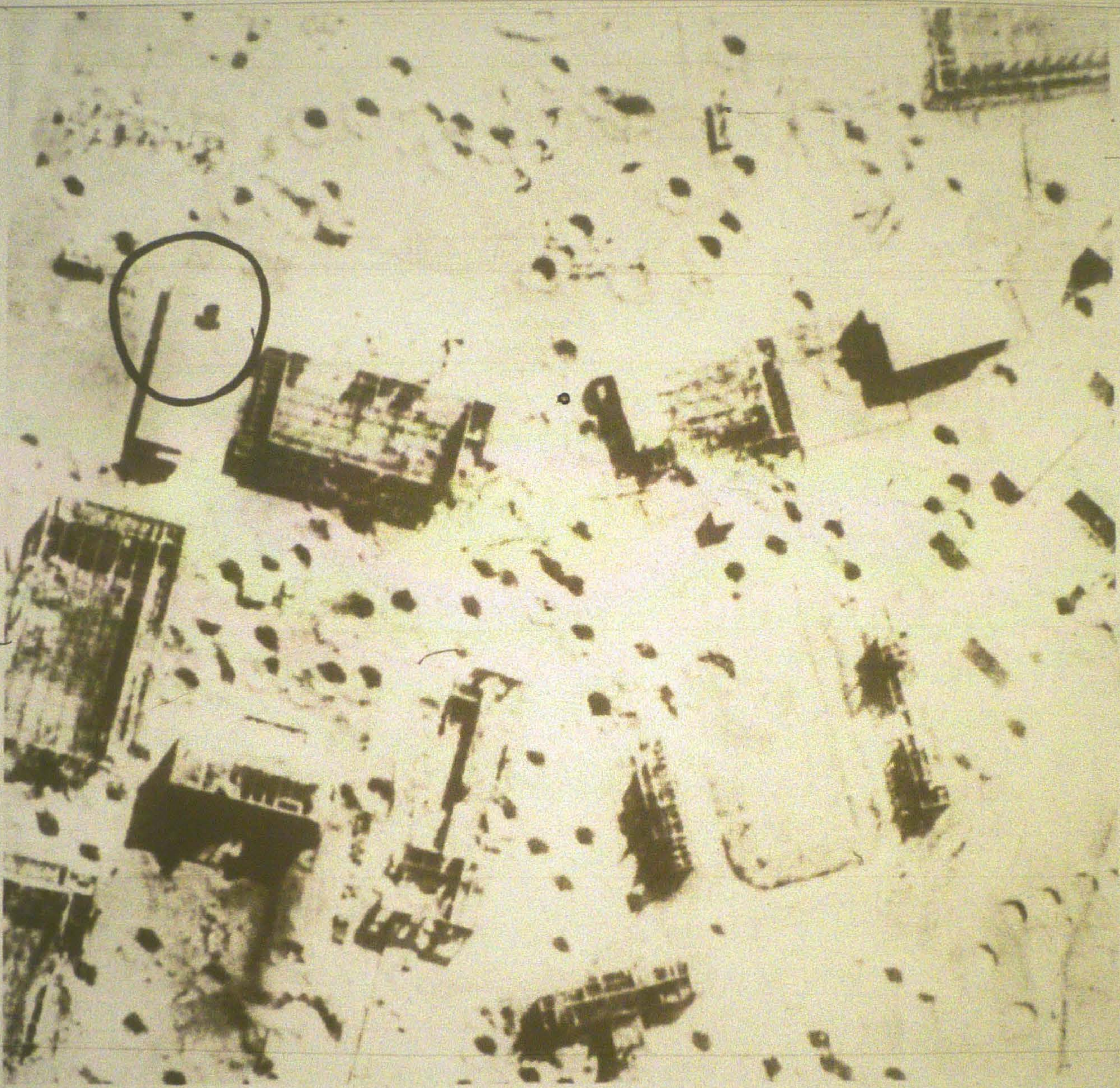
RUINS IN TOKYO after the earthquake and fire of 1923, illustrating the destructive power of a conflagration.



RUINS IN YOKOHAMA after the earthquake and fire of 1923, illustrating the destructive power of a conflagration.



An aircraft assembly plant at Marienburg, raided about 9 October 1943. See next page.



The same assembly plant after the raid. Complete fire destruction is seen in several buildings. In one building, (circled in ink) there is a hole near one end from a high explosive. Possibly the entire building would have been destroyed by fire.

ruption of electric circuits and gas mains, (3) by scattering of fires in stoves, furnaces fire-places, etc., and (4) by temperature of bomb fragments. The last-named effect is relatively infrequent, except in the most vulnerable type of targets, such as ammunition and fuel dumps. The reason is that although HE particles attain very high temperatures, they retain these temperatures only for short periods of time, and both intensity and duration of heat are factors in fire-raising. The fires created by HE are not to be ignored. They contribute so much added fire damage. However, such added damage is not to be counted on in advance in a primarily incendiary attack, since one cannot rely on the development of a definite percentage of fires from HE. The primary action of HE is blast damage and such fires as occur constitute an added net profit in the raid.

§4. SUMMARY:

Basic in the planning of an incendiary attack is a study of fire divisions in the target, so that the magnitude and method of assault can be planned relative to the desired probable damage. Conflagrations are to be hoped for only under very special target and weather conditions, but when they occur, the ultimate in incendiary damage is attained. High explosives, correctly selected and judiciously used in suitable proportions, will intensify fire damage. If excessively or unwisely used, they substantially decrease the weight of incendiaries on the target and are very likely to have detrimental effects on fire-raising and the spread of fire.

II. TARGETS

§1. INTRODUCTION:

a. **Importance of Careful Target Analysis.** - The basic objective of an incendiary attack is to cause maximum fire damage. This can be accomplished only when a thorough knowledge of the target is available and analyzed. In view of the nature of some targets, the best that can be hoped for is fire damage in the immediate vicinity of the bombs, because of fire-resistant barriers. In other cases, continuing fires in adjacent areas can be expected from a bomb because of the ability of the initial fire to transmit its blaze to adjacent structures and material. These factors very definitely affect the bomb load and technique of employment. They are prime target considerations.

b. **Bomb Density and Fire Defense.** - In consideration of each target and corresponding bomb density required for maximum effect, the factor of fire defense is highly important. As an example, if five bomb units over an area of 3,000 sq. ft. would be ample density to cause maximum damage, it is possible that the trained fire defense personnel could extinguish or control all of the fires thus created. However, if ten units are placed in the same area, it is not likely that control could be exercised over all the fires thus created. In this case, four or five fires, or perhaps more, might develop to sufficient extent that irreparable damage would be accomplished. By careful analysis of the pattern that can be expected, a density requirement can be determined which should insure maximum damage for a given target. This density will, naturally, vary with the combustibility of the structure and contents of the target. On easily inflammable targets the density can be lighter, because the task of controlling the fires is more arduous. The fire-fighters must cope not only with the bombs, but also with easily ignited material in which fire may gain rapid headway. On less inflammable targets, the initial fire-fighting efforts are less arduous and have a better chance to cope with the bombs, since the resulting fires are slower to gain headway and reach proportions beyond local control.

§2. LIST OF INCENDIARY TARGETS:

a. **Individual Type of Targets.** - A target is a good object for incendiary bombing attack if (1) it is vulnerable to fire and (2) the probable damage to the enemy, as compared with the cost of the attack, is greater than by other methods. Many types of enemy targets clearly fulfill these conditions; in the case of other types, special circumstances determine whether or not incendiary bombing is the most appropriate mode of attack. The following are

Contents

SURVEY OF THE INCENDIARY BOMB SITUATION

Page

I. FIRES AND CONFLAGRATIONS........ 4
1. Analysis of a Target into Fire Divisions........ 4
2. Types of Fires - Conflagrations........ 4
3. Comparative Effects of HE and IB........ 5
4. Summary........ 14

II. TARGETS........ 14
1. Introduction........ 14
2. List of Incendiary Targets........ 14
3. Vulnerability Considerations........ 15
4. Applications to Particular Types of Targets........ 16
5. Summary........ 22

III. INCENDIARY BOMBS........ 22
1. Standard American IB's........ 22
2. Description of Cluster Behavior........ 22
3. Behavior of Different Bombs on Targets........ 30
4. Fire-Raising Effectiveness........ 31
5. Foreign Incendiary Bombs........ 32
6. Improvised Incendiary Munitions........ 35
7. Summary........ 35

IV. SELECTION OF BOMBS IN RELATION TO TARGETS........ 35
1. Principles of Selection........ 35
2. Table of Recommended Incendiary Bombs........ 36

V. INCENDIARY BOMB REQUIREMENTS FOR TARGETS........ 36
1. Nature and Reliability of Estimates........ 36
2. Area Targets........ 40
3. Point Targets........ 42
4. Probability Analysis........ 42
5. Summary........ 42
6. Table of Plane Loads........ 42

VI. PATTERNS IN RELATION TO TACTICAL FORMATIONS........ 50
1. Introduction........ 50
2. Essential Pattern Characteristics........ 50
3. Cluster Patterns, Train Patterns, M47 Patterns........ 50
4. Comparison of Aimable and Quick-Opening Clusters........ 55
5. Formation Cluster Patterns (Results of Tests)........ 55
6. Factors Determining Patterns........ 55
7. Summary........ 64

VII. BOMB DENSITIES BASED ON PATTERNS........ 64
1. Relation to Earlier Chapters........ 64
2. Densities Experimentally Obtained (Quick-Opening Clusters)........ 65
3. Densities Experimentally Obtained (Aimable Clusters)........ 67
4. Dependence of Densities on Altitudes........ 69
5. Application to Tactical Conditions........ 69
6. Summary........ 74

Contents (Cont'd)

SURVEY OF THE INCENDIARY BOMB SITUATION

VIII. ILLUSTRATIVE MISSION AND DISCUSSION OF PRINCIPLES 74
1. Introduction 74
2. Illustrative Mission 74
3. Discussion of Principles 78

ing in the immediate neighborhood of kindling. In built-up domestic areas, the M69 offers the possibility of raising some fires by outside ejection hits from bombs which miss buildings.

d. **M74.**- The M74 has much in common with the M69, but differs from it in several important respects. The M69 achieves stability and has a low terminal velocity because of the use of cloth tail streamers. The M74 is stabilized by a metal tail fin which springs into place on release of the bomb from its cluster. It has a higher striking velocity and considerably greater weight, with a resulting increase in penetrating power. Having an "all-ways" fuze, it does not share the restriction of the M69 from low altitude release, since functioning is not dependent on the striking angle. Functioning of the M74 is more prompt after impact, so that the incendiary filling is frequently ejected in the upper part of a target, perhaps in an attic, just after the bomb goes through the roof. The white phosphorus in the M74 produces dense smoke, obscuring the seat of the fire and thus deterring fire-fighters.

e. **M47A2.**- The M47A2, on impact, sprays its filling over a radius of 50 feet or more in the open. When it hits a roof of light, medium, or heavy construction (up to 4" reinforced concrete), it crashes through and distributes burning incendiary mixture within the target. While the bomb has strong penetrating power if dropped from 15,000 feet or higher, its size, shape and manner of functioning make it impossible for the bomb to bury itself ineffectually. It is, therefore, a good all-around incendiary for most industrial targets. However while effective for most targets, the M47 is relatively inefficient for targets whose small fire divisions indicate the use of smaller bombs. The M47 carries with it a large enough quantity of incendiary material to start a very rapidly developing fire even in a target lacking a good distribution of kindling material. Since the M47 starts a fire which immediately calls for professional fire-fighting appliances, it is classified as an "appliance" bomb.

f. **M76.**- In targets requiring its use, the large quantity of pyrotechnic mix, and the extreme penetrating power (from 15,000 feet or higher) give this bomb good fire-raising potentialities. Its use should be restricted to those targets which really demand the penetrating powers of the M76. This is in accordance with the general principle of incendiary bombing that the greatest efficiency is achieved by taking advantage of the high loading possibilities of the smallest bomb adapted to the vulnerability properties of the target. Efficiency is measured by damage per plane load, rather than per bomb. In the case of the M76 bomb, despite the scattering of its filling, near misses are not effective. This is associated with a delay of .025 seconds in bursting the bomb, even when the fuzes are set instantaneous.

g. **Belly Tank.**- This weapon is used to obtain a wide-spread, quickly-consuming fire for targets in the open where penetration is not involved. When it functions, burning gasoline may spread over an elliptical area of 60 by 120 yards. It has value against pill boxes, slit trenches, and supply dumps, for example.

§4. FIRE-RAISING EFFECTIVENESS:

Effectiveness can be tested in simulated targets with suitable combustibility. The difficulty of evaluating and reproducing the combustibility of an enemy target is so great that it may frequently be impossible to determine the relative effectiveness of different types of bombs in certain targets. In addition to combustibility, this effectiveness depends, for each target, on (1) bomb concentrations or densities, as related to fire-division areas, (2) coordinated use of high explosives and (3) efficiency of fire defenses. Such considerations are treated elsewhere in this report.

Bombs are tested in connection with the time required to raise a given room to the flash-point, or kindling temperature. The small bombs depend on inflammable material in the target to achieve this result. Larger bombs have incendiary fillings capable of producing sufficient sustained heat to raise a room to its flash-point. All bombs are generally assisted by burning material in the target. Where the fire-watching standard is high, larger bombs have the advantage of quickly producing a blaze requiring a fire hose, rather than a stirrup pump. This should be weighed against the numerically large plane loads of smaller bombs, which, if enough kindling material is in the target, can overwhelm fire guards with numerous smaller fires.

35. FOREIGN INCENDIARY BOMBS:

a. Nature and Purpose of Information.- This report does not attempt to evaluate foreign IB's but lists some of them here to permit comparison with our bombs. Since no comprehensive, up-to-date survey exists on the subject of foreign bombs, the facts have been collected from a variety of reports. It is not intended that the lists should be exhaustive. but it is felt that the types of bombs most interesting for the purposes of this survey are covered.

b. Tabular Survey.-

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Country	Approximate Weight	Nature of Filling	Comments
British	4 lb.	Magnesium	Like our M50
British	12 lb.		Covers floor area about 2.7 x 7 ft., when it functions.
British	30 lb.	Methanized gasoline (10 lb.)	Depletes oxygen unless windows break. Action of the bomb can cause such breakage. Clustered 14 to an aimable 500-lb. cluster. Emits a jet of flame, like a blow-torch, about 8 ft. long.
British	50 lb.	Pyrotechnic Mixture	Contains gasoline, crude rubber, phosphorus.
British	250 lb.	Oil	
Russian		Thermite 50 Kg type	The only Russian IB currently available.
Russian		Phosphorus Sulphur (About 1 qt.)	Phosphorus incendiary spheres which ignite spontaneously when containers break on impact. (Information indirect, through enemy report.)
German	2.2 - 4.8 lb	Thermite	Eight types, with usual properties of small thermite bombs. One has a steel nose for greater penetration, (slate roof and several floors of British housing). One has a separating explosive nose, and a total weight of 4.8 lbs., with a delayed fuze up to 7 minutes.
German	26.5 lb.	Thermite	This bomb was never used against England
German	99 lb.	15 lb. Benzine 86% Rubber 10% Phosphorus 4%	
German	90 lb.	30 lb. Same proportion as above	
German	75 lb.		"multi-incendiary" bomb, consisting of a case which bursts on impact scattering smaller IB's. It contains 60 small IB's, 6 larger ones and 12-15 lb. of high explosive in the nose. (Springbrand C50)
German	240 lb.	110 lb. Crude oil Aluminum Magnesium Petrol ingition	Three or four variations of this general type, none of which have been used against England.

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Country	Approximate Weight	Nature of Filling	Comments
German	240 lb.	72 liters mix. Petroleum solvent 87.7% Polystyrene 11.7% Phosphorus 0.5%	
German	240 lb.	110 lb. Phosphorus 86.5% Benzene 13.1% Polystyrene 0.4%	
German	440 lb.	220.5 lb. crude oil Mg/Powder Ignition	Also a slightly heavier bomb (462 lb.) of the same general nature, with aluminum in the filling. (Never used against England.)
Japanese	1 kg.	Red Phosphorus	Fragmentation, with shrapnel effect.
Japanese	12 kg.	Thermite	
Japanese	32 kg.	Incendiary Pellets	Combined HE and IB of air-burst type. It showers down 198 incendiary pellets of steel filled with phosphorus.
Japanese	50 kg.	Anti-Personnel Pellets	Pellets of phosphorus and rubber are scattered 75 yds. on explosion.
Japanese	60 kg.	Oil	A thickened oil bomb of scatter type.
Japanese	50 kg.	Incendiary Pellets	440-450 rubber pellets 1" by 1", impregnated with phosphorus and carbon disulphite. They are scattered by explosion. One of them will burn for about two hours.
Japanese	60 kg.	Thermite surrounded by paraffin wax & kerosene	
Japanese	70 kg.	Black powder. Thermite in four containers	The containers are scattered when the bomb bursts.
Japanese	250 kg.	See Comments	A combined IB and HE bomb of great effectiveness. It is of air-burst type (100 to 175 feet above ground) and showers 756 incendiary cylinders over a radius of 175 yds. It contains 75 lb. of high explosive.
Japanese			Reported bomb clusters in development stage for use against aircraft in flight.

CONFIDENTIAL

§6. IMPROVISED INCENDIARY MUNITIONS:

a. **Reasons for Them.** - Under certain conditions, situations have developed in which it was expedient to use especially improvised incendiaries rather than standardized bombs. Since such situations are not prevalent enough to justify the development of special IB's, it has been considered advisable to utilize instead existing field equipment with slight modifications.

b. **Improvised Oil Drums.** - These are empty 55 gallon oil drums that can be field-filled, for example with low octane motor Quartermaster gasoline in 6.1% of Napalm. Suspension lugs and impact igniters are attached to the drum. This improvised incendiary bomb finds effective applications on docks and warehouses or large piles of inflammable material. It is also effective in dropping on water and igniting oil slicks, and it can be used to cause a fire of short burning time on water when small craft and light docks are the target. It is best released from altitudes of 1,000 to 5,000 feet. The fins of 1,000-lb. GP bombs are attached to the drum and it then possesses reasonable flight stability. Two such drums can be placed together and made into a single bomb. Such a bomb would represent a 1,000-lb. incendiary oil bomb. (Because of poor ballistic properties of oil drums, the precision required for pinpoint targets requires releases from between 150 ft. and 500 ft. The effective bursting radius is 50 feet.

c. **Droppable Gasoline Tanks.** - Past operations have disclosed that targets have often presented themselves, for which a large quickly-consuming fire is most effective. Such targets have been aircraft closely parked, inflammable stores, camps, wharves, warehouses of light construction, troop concentrations, and troops firmly "dug in" in fox holes or trenches. For such targets, the droppable gasoline tank, 75 gallon, has been used. It is the regular 75 gallon auxiliary tank filled with thickened gasoline and having two M4 igniters, one attached to each side of the tank. Upon impact, the igniters function, spreading the burning gasoline over an elliptical area of about 100 yards by 30 yards. This improvised incendiary, or "fire bomb," is especially efficient for low level attack on vulnerable targets. A great quantity of fire can be laid over a sizeable area by fighter aircraft, causing untold damage. In view of the fact that all parts of this weapon are standard, and that only the putting of the Napalm mixture in the tanks is required, this incendiary is especially useful under field conditions, if suitable targets are available.

§7. SUMMARY:

Small and large incendiary bombs of considerable variety exist, possessing specialized properties peculiarly suiting them to various corresponding types of targets and of enemy fire defenses. The small ones are clustered in quick-opening and in aimable clusters. The quick-opening are of restricted usefulness because of (1) hazard from cluster parts in some formations, and (2) wind disturbance. The aimable clusters involve smaller pay loads than quick-opening, but are adapted to all formations and have better precision properties. Incendiary bombs differ in (1) distribution of incendiary material on functioning, (2) speed of raising a room to the flash-point, (3) number of bomb units per plane load, (4) terminal velocity, and (5) penetrating power. Standard bomb sights and special bombing tables can be used for all the standard bombs and clusters, though some are more affected than others by the wind. The larger oil bombs have great fire-raising powers, but they are generally less efficient per plane load when the target can be ignited by smaller bombs. The British, possibly the Russians, the Germans, and the Japanese have incendiary bombs in considerable variety.

IV. SELECTION OF BOMBS IN RELATION TO TARGETS

§1. PRINCIPLES OF SELECTION:

a. **Corresponding Properties of Bombs and Targets.** - Incendiary bombs should be selected to do maximum damage to the target at minimum cost to the attackers. The relative efficiency of different types of bombs for a given target is to be judged by the following comparison of target and bomb properties discussed in the two foregoing chapters: (1) The inflammability and combustibility of the target correspond to the fire-rising powers of the bomb. (2) Roof strength of the target corresponds to penetrating powers of bombs. (3) Target and fire-division areas correspond to precision and pattern properties. (4) Fire defenses correspond to rapidity of fire-development, anti-personnel features and coordination with fragmentation bombs or possible other HE's. Another aspect of the problem is possible plane loadings, which help determine the selection of both bombs and planes for a mission. A table of loadings in in the next chapter.

b. **Vulnerability Variations.** - Conditions governing bomb choice vary among targets of similar type and also vary over a period of time in individual targets, because defenses can be changed, new barriers to the spread of fire introduced, roofs reinforced, and so on. In view of this variation in vulnerability properties and also because matters of availability may restrict selections, the tabular recommendations below contain alternative choices for most types of targets.

c. **Fire-Division Sizes.** - It is to be emphasized that large bombs are generally inappropriate where fire-divisions are small, since the smaller bombs have better pattern density properties. If the total target area is small, either clusters or large bombs may be used, according to vulnerability properties.

d. **Probability.** - The probability considerations involved enter into quantity requirements, which are treated in the next chapter.

e. **Low Altitude Possibilities.** - Where low altitude attacks are defensively permissible, quick-opening clusters, selected for penetration and fire-raising powers, or heavy incendiary bombs with delayed action fuzes may be used. Possibilities of low altitude attacks can arise in connection with inadequately defended built-up areas, with certain stores of materials, and occasionally with industrial establishments. The larger bombs, and quick-opening clusters of M50's (perhaps also of M74's) can be thrown from minimum altitudes into vertical walls.

32. TABLE OF RECOMMENDED INCENDIARY BOMBS:

The recommendations on pages 37, 38 and 39 are based on operational experiences, tests, and studied analysis of targets and bombs. It is to be emphasized that these recommendations relate to the average targets within the different categories and that unusual target conditions might lead to other choices. The M74, recently standardized, is expected to be available in quantity to theaters during the first quarter of 1945. Until the M74 is available, the M69 may be substituted.

V. INCENDIARY BOMB REQUIREMENTS FOR TARGETS

31. NATURE AND RELIABILITY OF ESTIMATES:

a. **Effects of Poor Estimates.** - The considerations involved in incendiary bomb requirement estimates include problems which are either intrinsically difficult to solve or which require information not easily obtainable for enemy targets. Nevertheless, it is of great importance to develop the most reliable estimates possible, for (1) inadequate use of munitions involves total or partial failure of an attack and (2) it is wasteful of munitions, men and equipment to send out unnecessarily large quantities. In the latter connection, British analyses of their own operations have led to the conclusion that densities above 200 tons per square mile on the central portions of German cities (using equal weights of HE and IB) involved serious waste of weapons. No return in damage can be expected from bombs dropped in excess of what is needed for saturation of the target. Furthermore, additional aircraft carrying excess munitions may be destroyed with no compensating damage to the enemy. A possible source of over-estimating is the adding up of separate safety factors to take care of such things as enemy defenses, duds, weather, and so on. On the other hand, too weak an attack may burn out part of a target, create new fire breaks, and decrease the vulnerability to a follow-up attack.

b. **Difficulty of Estimating.** - In view of the difficulties inherent in bomb requirement problems, it is not surprising that widely varying estimates for the same problems have come from different sources. Some of the figures given below are quoted because they seem to be the best available, even though further experience, especially under operational conditions.

CONFIDENTIAL

TARGET	INCENDIARY BOMBS RECOMMENDED	REMARKS
1. Isolated industrial plants. (Factory buildings separated by at least 100 ft. from nearest highly combustible residential areas.	(1) M47A2, 100-lb. (2) M50A2) M17A1 M50A3) Clusters (3) M74 or M69 in aimable clusters	Industrial targets in which the percentage of floor are vulnerable to fire is greater than 25% are considered to be good precision incendiary targets. M-47's have a wider range of initial incendiary action than do the M-50's, and the M-47, M-50 and M-74 all have adequate penetration characteristics for most industrial structures. The M-69 can only be used if the roof structures of an industrial plant are known to be very light. Aimable clusters are provided for M-50's, the M-74's, the M-69's. In general the M17A1 cluster of M-50's is the preferred incendiary weapon for use on industrial targets when fire division size is small and roof construction is known to be wood.
2. Dock and warehouse areas.	(1) M74 (2) M50 (3) M69 (4) Improvised incendiaries a. droppable gasoline tanks b. oil drums	Dock and warehouse areas are good incendiary targets if they are not multi-story heavily reinforced concrete buildings used as storage space for incombustible materials. Where warehouse buildings and contents are known to be moderate to highly combustible, the M-50, M-74, and possibly the M-69 may be used. Fire resistant multi-story structures with moderate to highly combustible contents will be vulnerable on the top floor to the M-47. Improvised incendiaries such as oil drums, etc., can be used in some cases where penetration is not essential, but a wide distribution of burning oil over combustible material is of first importance.
3. Refineries, fuel stores, synthetic rubber factories.	(1) M74 (2) M50	The use of high proportions of incendiary bombs against oil refinery and synthetic oil plants is not recommended, because the vital areas of such plants are invulnerable to I.B. Heavy densities of 500# or 250# H.E. bombs are required to take out the vital processes. Such processes in oil refineries include distillation cracking units, pumping stations, furnaces and power houses. In synthetic oil refineries, high pressure hydrogenation stalls, compressors, injectors and circulators, pumping stations and power houses are vital processes. The ground area covered by vital processes is of the order of 5% of the ground area covered by plant. Certain useful, but not vital areas of oil refineries and synthetic oil plants, which also cover a low percentage of ground area, are combustible. These include warehouse buildings, storage tanks, and so on. They are frequently ignited by HE at the HE density required to damage vital production processes. However, the use of 5% IB and 95% HE has proved successful in insuring ignition of these combustible parts. The IB's are here a secondary weapon.
4. Tank farms (Tactical targets)	(1) M69 (2) M74	Tactical tank farm targets in which the destruction of oil and gasoline in storage is the primary objective may be fractured by HE and ignition may be assured by a small amount of M-69 or M-74 incendiary bombs.
5. Japanese area targets of light or medium structures, (at least 30% roof coverage)	(1) M74 (2) M69	The Japanese domestic target consists of large area fire divisions bounded by air gaps (wide avenues, etc.) Bombs may be laid in such a pattern as to receive maximum wind benefit; the M-69 will satisfactorily penetrate, and the M-74 with its all-ways fuse, may be expected to cause a large number of individual fires capable of merging. When the roof coverage is low, (30% to 40%) the bomb pattern should be dense. When roof coverage is above 50% the pattern can be less dense and more extended. (See photographs of Japanese are targets, also pattern data and plots in Chapter VI.) The effort here is to cause continuing fires consuming and damaging more area that would be practicable to destroy by H.E. bombs which require more effort and munitions. In case there are several large area fire divisions in the target, an attack should be so planned as to increase the probability of ignition on either side of air gap barriers. Fire resistant buildings and contents located in areas of highly combustible residential and commercial buildings can be severely damaged by exposure to intense heat developed in an area conflagration.

CONFIDENTIAL

TARGET	INCENDIARY BOMBS RECOMMENDED	REMARKS
6. German area targets of heavy construction, (at least 30% roof coverage)	(1) M50A2 - 3 (2) M74	The M50A2-3, perhaps also the M-74, offers sufficient penetration. Most German city area targets are very well separated by parapetted fire walls into small fire divisions, and dense patterns are required to produce as many fires as possible in separate fire divisions. If roof coverage is low, increase the density; if it is high, decrease the density and lengthen the pattern. The M50XA3 bomb contains a lethal anti-personnel charge, and in most cases, if the inflammability factor is at all present, will keep personnel away sufficiently long to allow the bomb to start a good fire, probably beyond householder's control.
7. Oil Slicks	(1) M47A2 with sodium burster (M13) (2) Improvised Incendiaries. a. Oil drums b. Droppable Gasoline tanks	The M47A2 with sodium burster causes additional fires and insures that the oil slicks will ignite. In some cases, oil drums containing incendiary mixture can be dropped. These contain M4 igniters and all-ways fuzes. The contents are ignited on impact and fire spreads over the surrounding oil slick. Droppable gasoline tanks operate in the same manner.
8. Bivouac areas, camp storage areas	(1) M69 or M74 (2) M47A2	In most of these targets, penetration is of small importance, since the targets are either in the open or lightly constructed. The M69 and M74 offer the best coverage, as they will distribute burning material over considerable distances and are capable of starting numerous fires which, in turn, may destroy other stores. The M47A2 would be used only on sheds and other large storage areas where large fires at the beginning are capable of doing more damage.
9. Supply Dumps	(1) M74 (2) M69 (3) M47A2	The attack should be a mixed HE-IB load of approximately 60-40 ratio. As much damage usually can be done by HE on supply dumps as by IB but the chance remains that inflammable stores are present, in which case the IB will be effective. The M74 and M69 will cover more fire area and they may offer the best capability. The deterrent effect of the W P in the M74 is to be considered. Where stores are in large groups, the M47A2 may be best as a large fire is started immediately.

CONFIDENTIAL

CONFIDENTIAL

TARGET	INCENDIARY BOMBS RECOMMENDED	REMARKS
10. Railway stations and yards containing rolling stock.	(1) M50A2 (2) M76, 500-lb. PT	In all such targets, penetration is essential; steel boxcars, etc. require at least the M50 to penetrate. A dense pattern of M50's throughout the area will in most cases be more effective than HE. For repair shops and stations, the M76, 500-lb. PT bomb is preferable, as a large sudden fire is required.
11. Fields of dry grain & dry forests.	(1) M69 or M74 (Quick-opening cluster) (2) Droppable belly tanks	The M69 or M74 is the best choice, because the scattering effect of the oil and the large plane loads which can be carried make the resulting fires most difficult for the enemy to control. More penetrating bombs would bury themselves in the ground.
12. Hangars containing planes; repair shops near airdromes.	(1) M50 (2) M74 (3) M47A2 (4) M69 (5) M76	Being "point" targets, these require clusters or bombs of accurate aimability. The M47A2 will penetrate, is accurate, and will distribute its burning material over sufficient distance within the building to cause serious fires. In cases of larger installations requiring more penetrability, the M76, 500-lb. PT bomb in low level attack is indicated. The smaller plane loads of such bombs are offset by their immediate creation of large fires.

CONFIDENTIAL

may lead to important revisions. New tactics of incendiary bomb employment, as well as improved methods of analysis, will affect the estimated quantities.

c. Concentration of Attack in Time and Space. - Incendiary bombs in an attack must be concentrated in time as well as in space, because of the supporting effect of simultaneous fires and the difficulty to the enemy of fighting such fires.

d. Estimates Based on Experience. - The estimates most closely derived from combat experience are those resulting from analyses of American and British raids on German targets and German raids on British targets.

§2. AREA TARGETS:

a. Statement of the Problem. - The requirement in terms of fires is that there be at least one (preferably more) continuing, uncontrolled fire in each fire-division. By definition of fire-division, the spreading effect of the fire may carry it over the whole division. The question then becomes the following: How many bombs must be dropped, by tactically sound methods, to achieve a reasonable assurance of an uncontrolled, continuing fire in every division?

b. Organization of Material. - This chapter relates to desirable bomb densities; the next chapter relates to the densities which have been experimentally obtained with standard bombs and tactically sound formations.

c. Methods of Estimating. - Density figures based on fire-raising properties of bombs vary significantly from target to target. They need to be estimated in each case by qualified target analysts, who take into consideration the question of (1) incendiary efficiency of different types of bombs, (2) the results of scatter bombing theory, (3) enemy fire defenses, (4) penetration properties, and (5) a fire-division analysis of the target. Analysis of an Eighth Air Force group pattern of M47's dropped on a domestic type of target in Germany, 10 October 1943, shows that "the probability that an M-47, striking a German domestic type fire division, will cause visible fire damage is between 0.38 and 0.52, and that the best estimate, on present evidence is 0.46. Taking the weight of the M-47 as 70 lb. and the mean area of a fire division as 1/15 acre, the corresponding index of effectiveness is 1.0 acres per long ton, compared with 7.4 acres per long ton for the British 4 lb. IB and 1.7 acres per long ton for the British 30 lb. Mark III IB." Estimates of density requirements for small clustered bombs have sometimes been based on individual cluster patterns. However, recent developments in formation pattern studies avoid the use of cluster patterns. Since the tactical unit in most bombing is a formation of planes, the realistic figures to employ are those relating to formation patterns, and future estimates for targets should be made accordingly. Further tests are desirable to accumulate more data along the lines of the results to be found in the next chapter.

d. German Attacks on York and Exeter. - In the matter of incendiary effectiveness of different types of bombs, information can be obtained from operational studies. For example, consider the results of British analyses of raids by the Germans on York and Exeter, employing small magnesium bombs. At York, 11% and at Exeter, 25% of the bombs striking buildings failed to cause fires because of lack of penetration, malfunctioning, or burning out unattended. The remaining 89% at York and 75% at Exeter, of the bombs that scored hits, were potential fire-raisers. On the basis of total bombs dropped (misses as well as hits), the figures for fire-starting bombs become 36% for York and 25% for Exeter. In the former town, 31 buildings per ton of IB's released were partly or completely destroyed. The figure for Exeter was 42 buildings per ton. Effectiveness of a weapon against an area target is thus measured by the weight of bombs required to cause a stated level of damage.

e. Attacks on British and German Targets. - The following are some more figures taken from British analyses of German raids on British targets. In the case of a number of 1kg. bombs which actually penetrated British buildings, 33% started potentially dangerous fires and about 10% actually destructive fires. Analysis of fourteen raids revealed 16 appliance fires per metric ton of German 1 kg. (2.2 lb.) magnesium bombs and from 11% to 19% of the fires started actually destroyed buildings. In raids on the British in 1940-41, 9% of the small IB's caused fires (about 80 fires per ton) and 2% caused appliance fires, (about 14.5 such fires per ton).

f. Fire Defense Allowance. - A sample of the type of reasoning involved in allowing for fire defenses is the following from an estimate pertaining to German targets: If there are 1,400 fire squads per square mile, a reasonable figure, each squad can handle about three slowly destructive fires, or possibly a single rapidly destructive fire. If all the squads in a pattern area (assumed to be 100 x 400 yards) are required to extinguish the fire of a of a single M47, then five such bombs per block should assure enough hits to saturate defenses and develop a sufficient number of continuing fires. The above figure of 1,400 squads per square mile might be increased to about 2,000 in Japan. It has been estimated that 13 continuing fires per cluster area would be needed in Germany and 7 in Japan because of relative inflammability. According to recent reports, Japanese fire defenses are highly organized on a basis of ten-house units, with wardens in charge. (Note: The numerical values quoted here and elsewhere in this chapter are not to be taken as thoroughly established, accurate figures. They are quoted from estimates based on such information as was available at the time.)

g. Anti-Personnel Bombs Against Fire Defenses. - A chemical warfare publication (CW 325, 3 January 1944 - "Air Chemical Requirements") recommends that the bomb load in incendiary attacks contain from 5% to 25% of various delayed-type explosives to hamper fire-fighting crews. It is believed, on the basis of recent tests, that the best deterrent to fire-fighters now available is the 20-lb. fragmentation bomb, for targets of light structure. The use of "butterfly" bombs is also highly effective.

h. Nature of Allowance for Fire Defense. - Certain estimates in the literature have credited enemy fire-fighters with the ability to handle "as much as 80% of all dangerous fires". Such reasoning is fallacious, since the fire-fighters would at best be able to handle a certain maximum number of fires, and all fires beyond that number would remain uncontrolled. In a light attack they might extinguish 100% of the fires. In a heavy attack it might be physically impossible for them to control more than 50%, or some other figure dependent on the strength and nature of the assault.

i. Effectiveness (Figures from Tests). - Many analyses have been made of the proportion of appliance fires in different targets relative to unit munitions of various types. Tests at Dugway Proving Ground on typical Japanese targets have resulted in figures of from 55 to 140 appliance fires (depending on roof coverage) per ton of M69's in vulnerable Japanese cities; also to an estimate of 113 appliance fires per 1,000 single hits with M69 bombs released over a Japanese area of 50% roof coverage. Tests of similar nature led to estimates that from 1.4% to 1.9% of Mk. IB (or M50) bombs dropped on German targets of 50% roof coverage would start fires. Recorded British experience gave figures of 2% to 5% (depending on fire defenses) which represents reasonably good agreement with the estimates, since fire-fighting efficiency is difficult to evaluate.

j. Effectiveness (Figures from Attacks on Germany). - Operational Research Reports from photographic assessments indicate that in an attack of moderate intensity using 50% HE and 50% IB, about 10 destructive fires resulted for every 100 IB's dropped in city areas in German targets. A report of the British IB committee, dated 15 December 1942, calculated that a full plane load of 2,640 Mk. IV (M50) bombs dropped on a German area of 50% roof coverage caused from 77 to 132 appliance fires. A later report gave the number of such bombs required per appliance fire as between 20 and 40. The average value of 30 corresponds to about 3.3% of the bombs dropped. The range in values takes into account the varying efficiency of fire defenses.

k. Estimates of Desirable Fire Densities. - The figures just cited relate to what certain types of bombs can do. They are merely a sample of such figures to be found in the records of tests and combat operations. The next figures relate to what sort of fire densities and bomb densities are required to destroy Japanese and German built-up areas. Fire densities ranging all the way from 730 to 5,000 appliance fires per square mile have been suggested. The lower figure corresponds to fires about 65 yards apart (Japanese targets), the higher to fires about 25 yards apart (German targets), which appears to be an excessive concentration. (The more conservative figure of 50 yards apart, leading to about 1,200 fires per square mile, has also been suggested for German targets). For the most inflammable Japanese areas, estimates of required bomb densities have ranged from 6 to 26 tons of M69's per square mile. For somewhat less inflammable areas, the range is from 10 to 42. More recent calculations also exist, but it is not the purpose of this report to decide on precise figures for particular targets. The figures quoted are merely suggestive of the general order of magnitude of the quantities involved, the nature of the reasoning used in the estimates, and the discrepanies between estimates from different sources.

§3. POINT TARGETS:

This designation will be taken to signify targets of areas so small, say 100 x 100 yards, that a typical cluster pattern could include the entire target in its interior, rather than be included in the target area. The line of demarcation between area targets and point targets is somewhat arbitrary, but a genuine distinction in method of attack is involved. The distinction is between those targets which are best attacked by scatter bombing over an area, and those for which precision bombing is more appropriate. Actually, once the required number of hits on the target is decided for a desired probability of destruction, the quantity requirement problem can be put in the following form: Taking expected aiming errors and pattern properties into account, what plane loads, what formations, and what intervalometer settings are required to give a reasonably high assurance of the desired number of hits?

§4. PROBABILITY ANALYSES:

Probability analyses of train bombing have been carried out, tables prepared, and circular slide rules developed by the National Defense Research Committee to aid in the solution of such problems. Also, the relatively difficult problem of probabilities in scatter bombing over an area has been treated and the results put on a slide rule from which such things as the number of bombs per unit area, (for example, per fire-division) can be estimated to achieve a pre-assigned degree of assurance that all unit areas will receive at least one hit. Under scatter bombing methods, one attempts to place a pattern on a given area, individual bombs having chance dispersions. Approximate uniformity of distribution is assumed (compare results in the next chapter) so that the probability of hits on the various parts of the target depends only on their respective areas. If the degrees of vulnerability of different areas of the target are roughly known, an estimate can be formed of the probable destruction for a given intensity of attack.

§5. SUMMARY

Preliminary numerical estimates of requirements for various categories of targets are not always very reliable, but they serve two purposes: (1) They give the best available idea of the probable requirements in advance of operational procedures. (2) They serve to illustrate methods applicable to specific targets in the light of later, more detailed information. Gross over-estimates increase greatly the cost of attack without paying dividends in added damage to the enemy. Estimates of relative efficiencies of different bombs on a given target take into account fire-raising probabilities, the enemy's fire-defense ability, probabilities of hits on vulnerable areas, probabilities of penetrating, of functioning, and of transmitting continuing fires. These, along with fire-division analysis, are subjects for expert consideration relative to each incendiary target. Operational analyses of American, British, and enemy raids throw light on the estimates for similar targets with similar munitions. Pattern properties and probability considerations are essential to complete the analysis for either area targets or "point" targets.

§6. TABLE OF PLANE LOADS:

a. Explanation of Table: Case of the M47.- The required quantity and type of bombs imply certain plane requirements. The choice among available planes may be facilitated by the following table. Also, if the choice of bombs is not otherwise determined, this table helps to select the one providing for the greatest loading economy. Under special conditions, larger loads than those given here can be carried. Length of the mission and nature of defenses influence the choice between normal and maximum loads. The M47 is omitted from the table. It can be loaded with one bomb at each 100-lb. station, but more efficient special loading methods exist, employing cable-slings to fasten as many as four M47's at a single 500-lb. station. It is not possible, however, to put a group of four M47's at every 500-lb. station. The following loadings are among those which have been achieved without bad ballistic effects. (See M47 loading diagrams).

b. **Special Loadings of M47's** (See charts on Pages 44, 45.

Loadings of the B-17F with

(1) 8 500-lb. HE's plus 20 M47's (5,400-lb.)

(2) 42 M47's (Total weight, 2,940 lb.)

(3) 10 500-lb. HE's plus 10 M47's (5,700-lb.)

Loadings of the B-24 with

(1) 52 M47's (3,640 lb.)

(2) 8 500-lb. HE's plus 19 M47's (5,330-lb.)

(3) 4 1,000-lb. HE's plus 19 M47's (5,330-lb.)

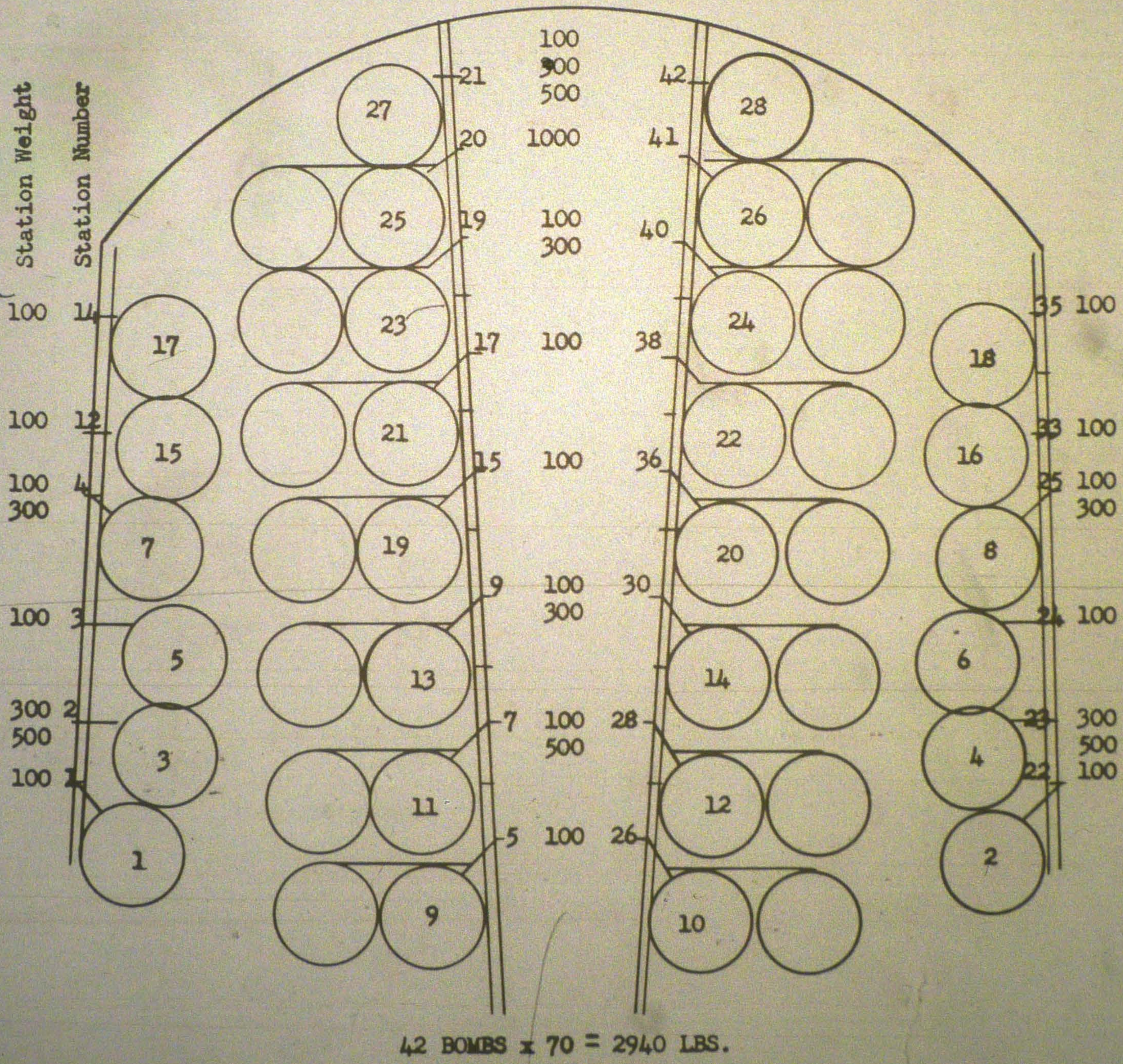
These loadings illustrate the great loss in IB-carrying capacity when HE's are combined with incendiaries. Only for special targets and conditions discussed elsewhere in this report, would the HE's have an effect to justify such sacrifice of IB's on a primarily incendiary mission.

c. **The Plane Loading Table.-** The following chart is based on numbers of 100-lb. and 500-lb. stations on the different types of planes as given in "Armament and Bomb Installations", Army Air Forces Aircraft Monthly Chart, 1 May 1944, issued at Wright Field, Dayton, Ohio. In this table, "N" stands for "normal" and "M" for "maximum". The distinction depends on whether such things as length of the mission or strength of enemy fighter defenses makes it advisable to carry a lighter load, to carry supplementary fuel, or to carry added defensive munitions.

B-17F LOADING
M-47 INCENDIARY BOMBS
SCALE

10"

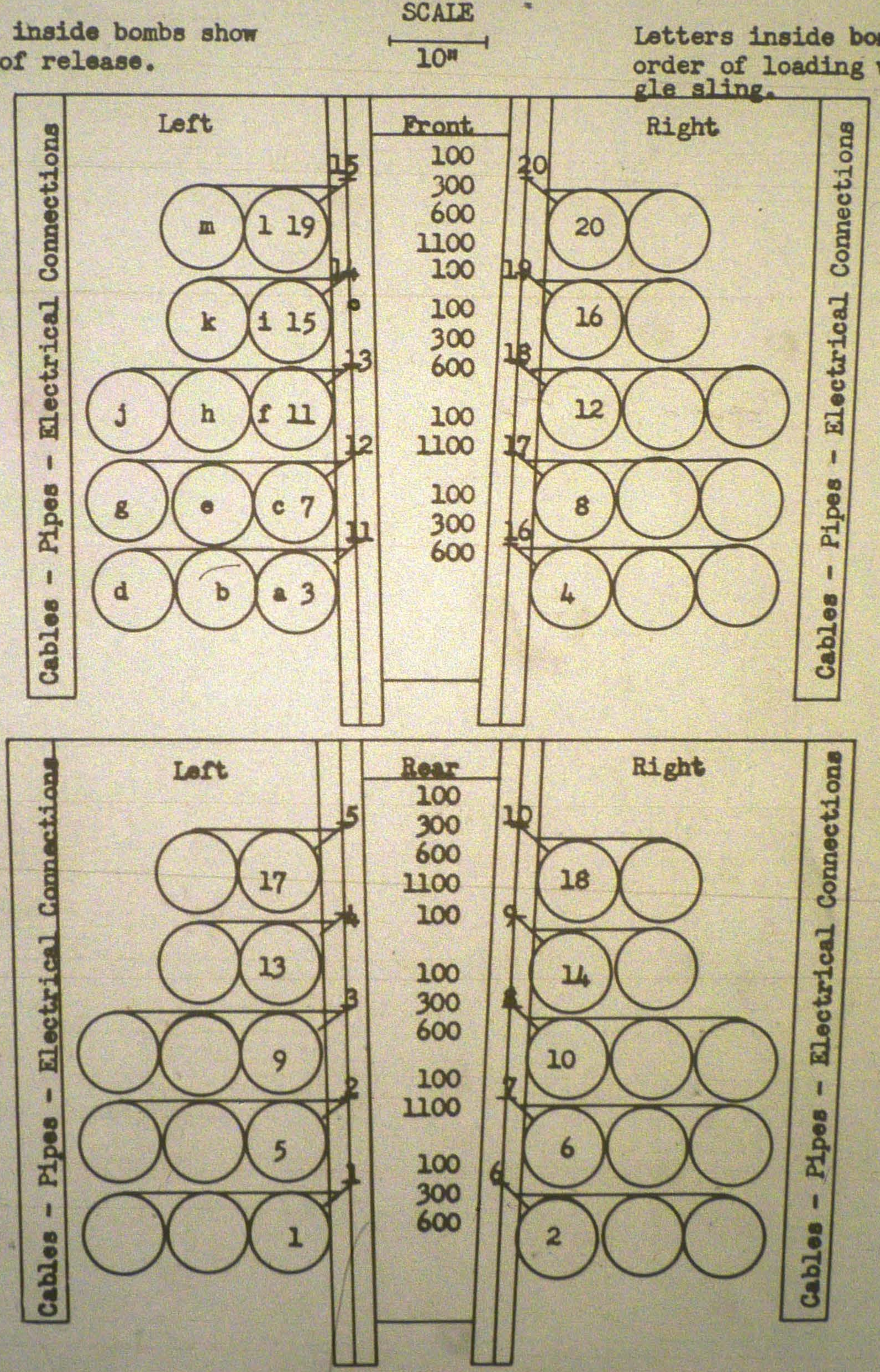
Numbers inside bombs show the order of release



B-24 LOADING
M-47 INCENDIARY BOMBS

Number inside bombs show order of release.

Letters inside bombs show order of loading with toggle sling.

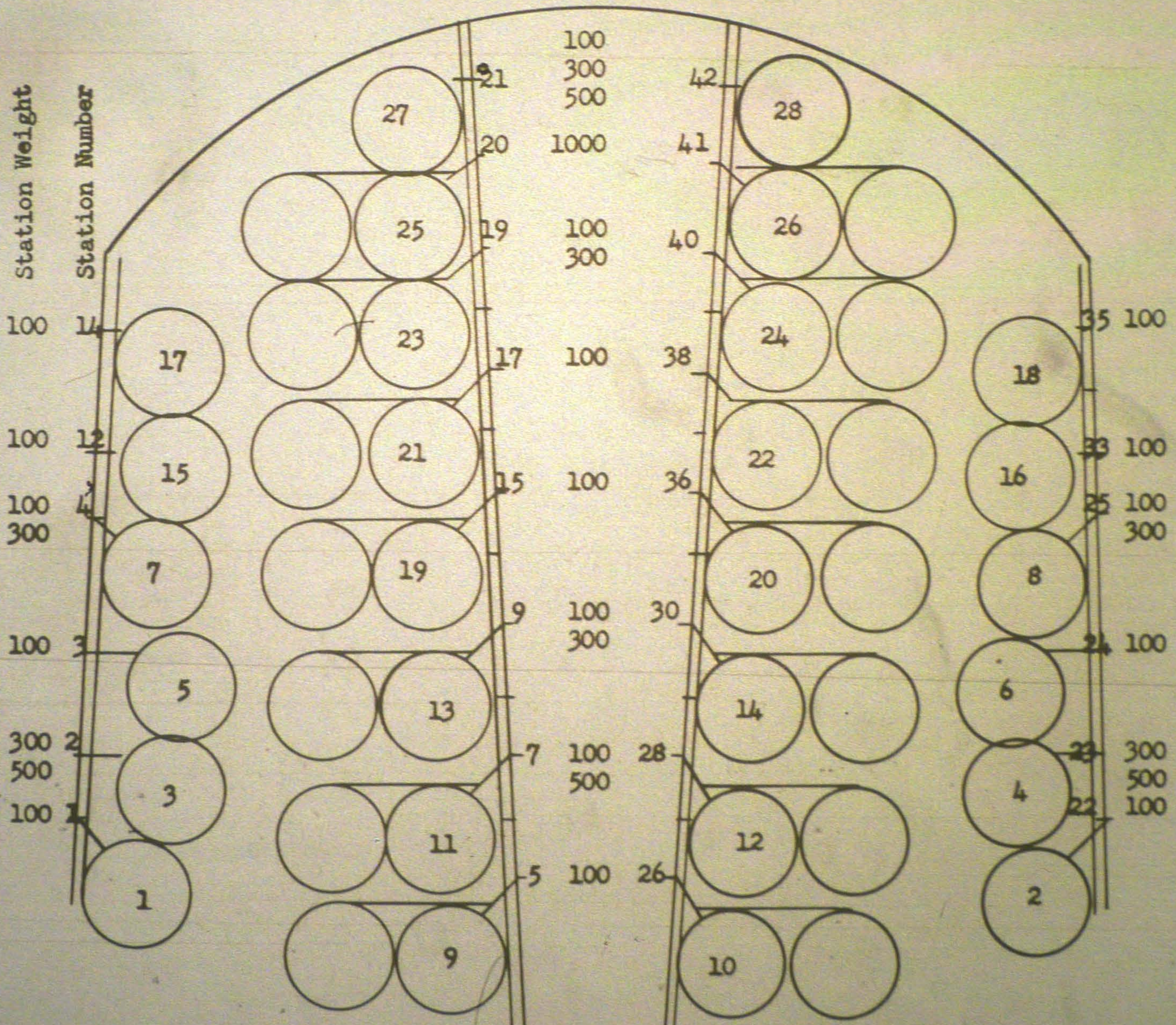


52 BOMBS x 70 = 3640 LBS.

B-17F LOADING
M-47 INCENDIARY BOMBS
SCALE

10"

Numbers inside bombs show the order of release



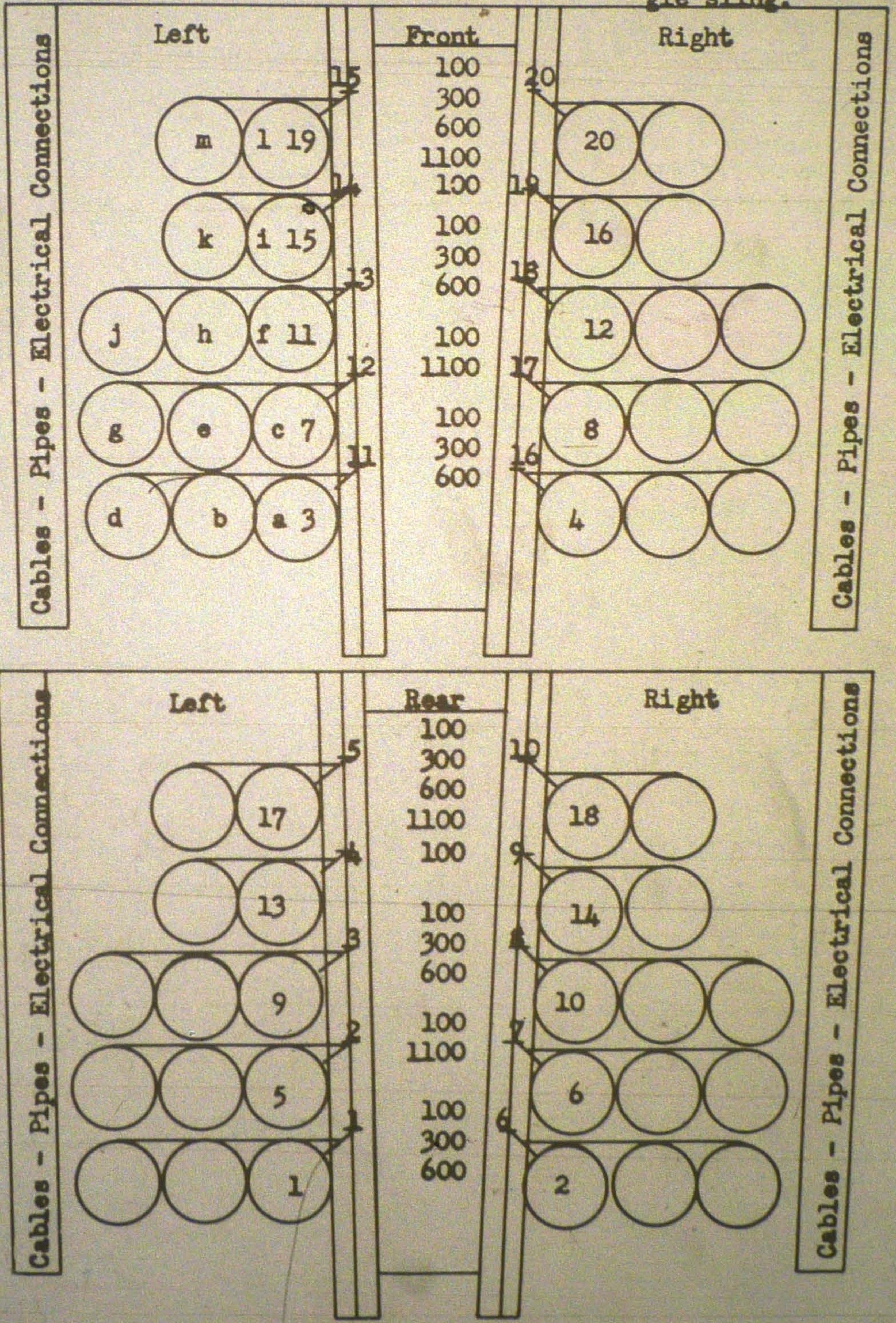
42 BOMBS x 70 = 2940 LBS.

B-24 LOADING
M-47 INCENDIARY BOMBS

SCALE
10"

Number inside bombs show order of release.

Letters inside bombs show order of loading with toggle sling.



52 BOMBS x 70 = 3640 LBS.

CONFIDENTIAL

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)	
PLANES	100 lb.		500 lb.		BOMBS IN 100 lb. CLUSTERS				BOMBS IN 500 lb. CLUSTERS							
					M 50		M 74 or M 69		Quick Opening				Aimable			
									M 50		M 74 or M 69		M 50		M74 or M 69	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
A-20A	10	20	2	2	340	680	140	280	256	256	120	120	220	220	76	76
A-20B	10	14	1	3	340	476	140	196	128	384	60	180	110	330	38	114
A-20C 1, 5, 10 A-20G1, 5, 10, 15	0	4	2	4	0	136	0	56	256	512	120	240	220	440	76	152
A-20G20																
A-20 H-J	0	8	2	8	0	272	0	112	256	1024	120	480	220	880	76	304
A-24A	2	2	1	1	68	68	28	28	128	128	60	60	110	110	38	38
A-24 B1, 5	2	2	1	3	68	68	28	28	128	384	60	180	110	330	38	114
A-25, A1, 5,10	2	2	2	2	68	68	28	28	256	256	120	120	220	220	76	76
A-~~25~~ A15, 20 25, 30	2	4	2	4	68	~~136~~	28	56	256	512	120	240	220	440	76	152
A-26 B1	0	20	0	10	0	680	0	280	0	1280	0	600	0	1100	0	380
A-28A A-29 A-29A	8	8	0	0	272	272	112	112	0	0	0	0	0	0	0	0
A-30 A-30A	0	0	4	4	0	0	0	0	512	512	240	240	440	440	152	152
A-31	0	0	2	2	0	0	0	0	256	256	120	120	220	220	76	76
A-31C	0	0	2	4	0	0	0	0	256	512	120	240	220	440	76	152
A-35, A, B,	0	2	2	4	0	68	0	28	256	512	120	240	220	440	76	152
A-36 A	0	0	2	2	0	0	0	0	256	256	120	120	220	220	76	76

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PLANES	(1) 100 lb.		(2) 500 lb.		(3) BOMBS IN 100 LB. CLUSTERS M 50		(4) BOMBS IN 100 LB. CLUSTERS M 74 or M 69		(5) BOMBS IN 500 LB. CLUSTERS Quick-Opening M 50		(6) BOMBS IN 500 LB. CLUSTERS Quick-Opening M 74 or M 69		(7) BOMBS IN 500 LB. CLUSTERS Aimable M 50		(8) BOMBS IN 500 LB. CLUSTERS Aimable M 74 or M 69	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
B-23; B-25; B-25A, B, C, D	12	12	4	6	408	408	168	168	512	768	240	360	440	660	152	228
B-25, C1-25, D1-30; G1, 5, 10 H1-10, J1-30	12	20	4	6	408	680	168	280	512	768	240	360	440	660	152	228
B-26, B-26A, A1	20	30	4	8	680	1020	280	420	512	1024	240	480	440	880	152	304
B-26B, B2-20 B-26B25, 55	20	20	4	6	680	680	280	280	512	768	240	360	440	660	152	228
B-34	0	6	0	6	0	204	0	84	0	768	0	360	0	660	0	228
B-37	0	7	0	0	0	238	0	98	0	0	0	0	0	0	0	0
B-17B, C, D, E	20	20	4	8	680	680	280	280	512	1024	240	480	440	880	152	304
P-17FG (all models)	20	24	4	12	680	816	280	336	512	1536	240	720	440	1320	152	456
B-24 (all models)	20	20	4	12	680	680	280	280	512	1536	240	720	440	1320	152	456
P-29-1, 5 YB-29	0	80	4	40	0	2720	0	1120	512	5120	240	2400	440	4400	152	1520
B-19-10, 15, 25 B-32	0	0	4	40	0	0	0	0	512	5120	240	2400	440	4400	152	1520
YB-35, B35	0	0	20	80	0	0	0	0	2560	10240	1200	4800	220	8800	760	3040
AT-6B, C, D	0	4	0	0	0	136	0	56	0	0	0	0	0	0	0	0
AT 11,	0	10	0	0	0	340	0	140	0	0	0	0	0	0	0	0

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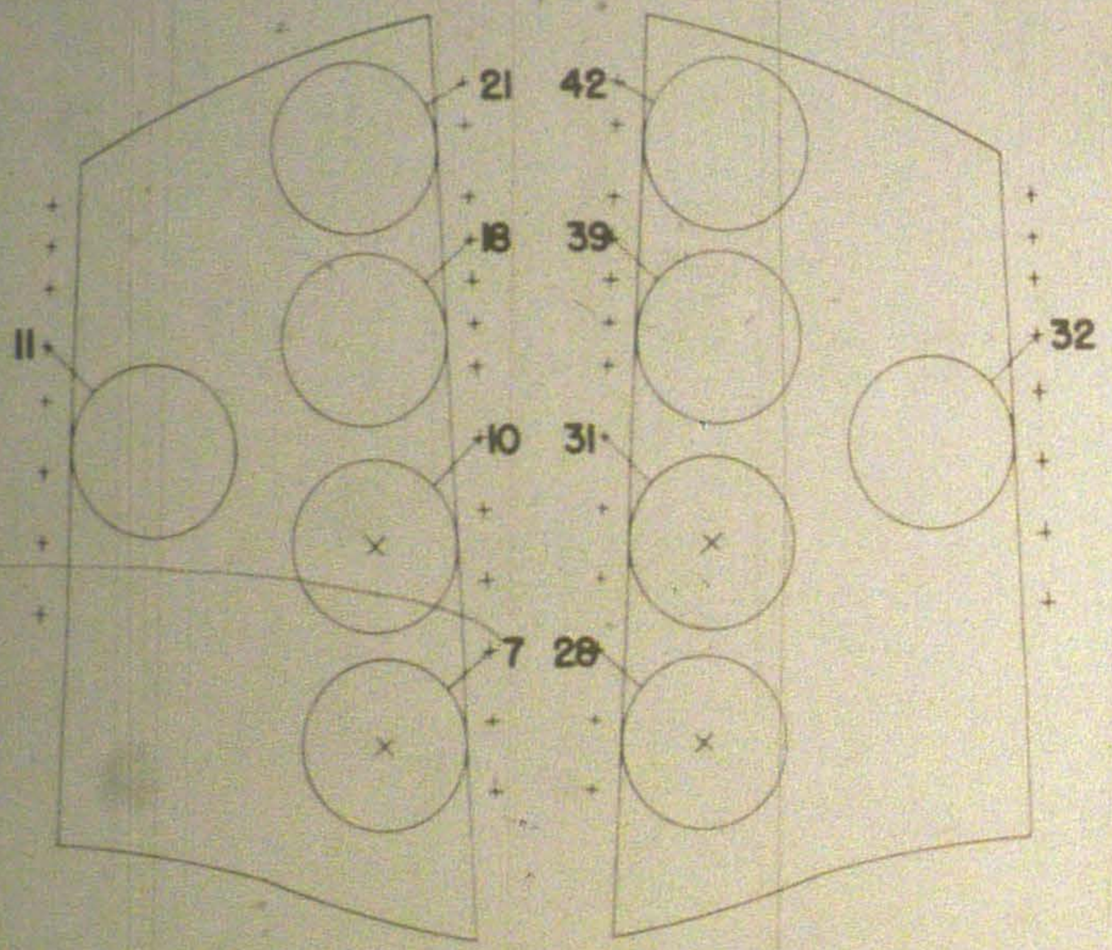
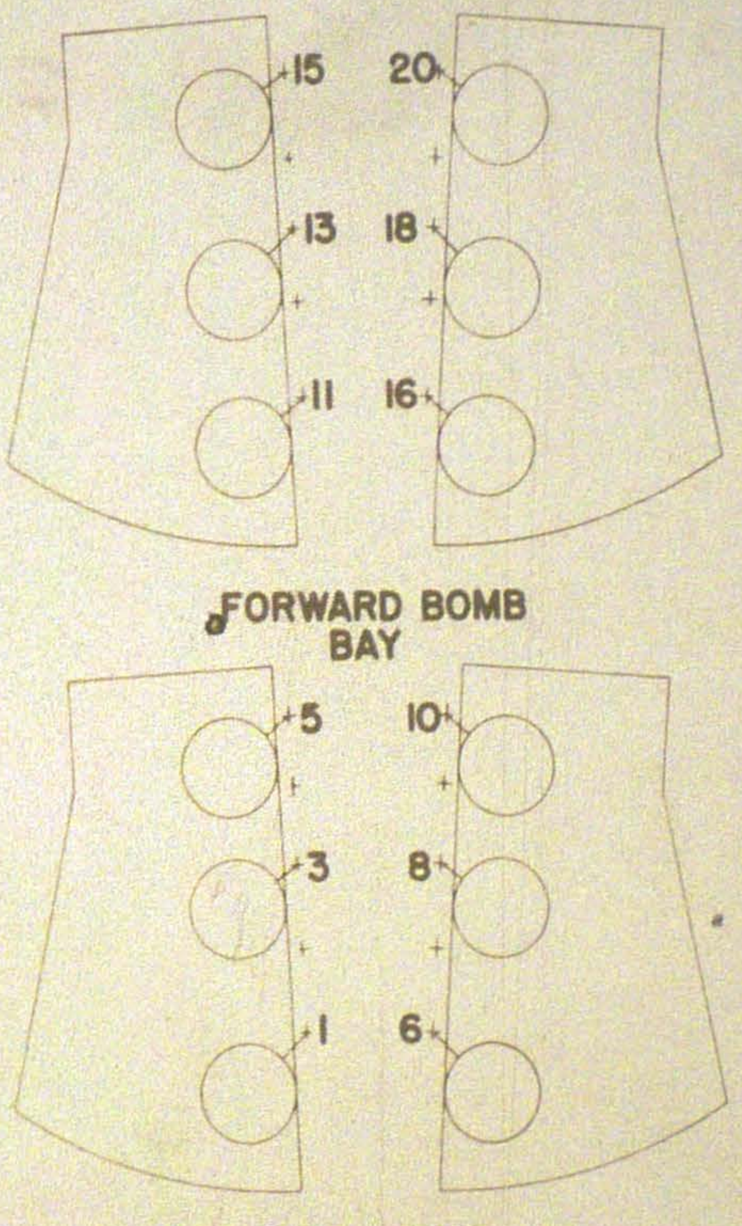
PLANES	(1) 100 lb.		(2) 500 lb.		(3) BOMBS IN 100 lb. CLUSTERS: M 50		(4) BOMBS IN 100 lb. CLUSTERS: M 74 or M 69		(5) BOMBS IN 500 lb. CLUSTERS: Quick-Opening: M 50		(6) BOMBS IN 500 lb. CLUSTERS: Quick-Opening: M 74 or M 69		(7) BOMBS IN 500 lb. CLUSTERS: Aimable: M 50		(8) BOMBS IN 500 lb. CLUSTERS: Aimable: M 74 or M 69	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
P-38 (all models)	0	2	0	2	0	68	0	28	0	256	0	120	0	220	0	76
P-39 (all models)	0	1	0	1	0	34	0	14	0	128	0	60	0	110	0	38
P-40D, P-40E1	0	1	0	1	0	34	0	14	0	128	0	60	0	110	0	38
P-40E, F1-F20 G, K1-15, L1-20, M1-10, N1	0	3	0	1	0	102	0	42	0	128	0	60	0	110	0	38
P-40-N5-30	0	3	0	3	0	102	0	42	0	384	0	180	0	330	0	114
P-51 (all models)	0	2	0	2	0	68	0	28	0	256	0	120	0	220	0	76
P-63 (all models)	0	1	0	1	0	34	0	14	0	128	0	60	0	110	0	38
P-70B2	0	4	0	4	0	136	0	56	0	512	0	240	0	440	0	152
P-75A1	0	2	0	2	0	68	0	28	0	256	0	120	0	220	0	76



L.H. BOMB BAY
NORMAL LOAD-4

R.H. BOMB BAY
MAXIMUM LOAD-10

B-17F AIRPLANE



AFT BOMB BAY

NORMAL LOAD-4

MAXIMUM LOAD-12

B-24 C, D, E AIRPLANE

MAXIMUM LOAD SHOWN
BOMBS MARKED "X" INDICATE NORMAL LOAD
500 LB. AIMABLE CLUSTER
M17

VI. PATTERNS IN RELATION TO TACTICAL FORMATIONS

§1. INTRODUCTION:

a. Importance of Patterns. - The impact patterns that can be expected from various tactical formations are of direct importance as a mission planning factor for incendiary targets. With a sufficient knowledge of the type of pattern that can be expected from the formation flown, the area of coverage and bomb density can be rather accurately evaluated before the mission. This, then, will exercise a deciding influence on the number of aircraft necessary to cover the target. Analysis of the target, as discussed in Chapters II, IV and V, will indicate the bomb density required for successful incendiary action.

b. Source of Available Data for Formations. - Patterns have not been experimentally studied for all types of formations and bombs. However, patterns for a nine-plane combat box (stagger) formation using 4-lb. incendiaries in both quick-opening and aimable clusters have been developed in a series of tests at Avon Park Bombing Range, Avon Park, Florida, under Army Air Forces Board Project No. (M-5) 198, title, "Development of Incendiary Bomb Patterns, 4-lb., in Combat Formations".

c. Need for Testing. - These tests disclosed the impracticability of using single cluster patterns released from individual aircraft, since the pattern developed by the tactical formation was not in accord with the placing of several single cluster patterns together over an area to represent additional aircraft. Tactical formation patterns were developed for releases of single clusters per plane, releases of trains of clusters, and salvo releases. For planning purposes, it is desirable to base the area and density of the target requirement on the tested pattern of the tactical formation.

§2. ESSENTIAL PATTERN CHARACTERISTICS:

An incendiary impact pattern may be evaluated in terms of:

a. Effective Pattern Area. - The effective area represents the core, or area of greatest density, the total area being the entire pattern. Inclosing rectangles are used. Those bombs outside of the effective area become of considerable importance when several tactical formations are bombing simultaneously. In such a case the bombs to the left of the effective area from one formation and the bombs to the right of the effective area from the next adjoining formation may merge together, forming a combined pattern of almost uniform density.

b. Uniformity of Distribution. - Variations in density within the effective pattern area, which occur to a limited extent, can be compensated by using bombs in such numbers that even the less dense portions of the area will give an adequate number of hits per fire-division.

c. Precision Characteristics. - The center of the effective pattern rectangle can be used in figuring errors relative to the aiming point. Other definitions of pattern center are permissible and may present certain advantages. If the method of "dropping on the leader" is followed, then the aiming error of the leader's bombs can be compared with those of the entire pattern. Some progress was made along this line at the Avon Park experiments, but difficulties in identifying the leader's bombs make further investigations desirable. On a point target, aiming errors figured relative to the pattern center are less important than the question whether the effective pattern area blankets a region including the target.

d. Densities of Bombs in the Effective Pattern Area. - The topic of densities is so important that Chapter VII is devoted to the subject. The importance is due to the basic nature of the questions of the bomb densities required for a given target and of the type of pattern bombing methods whereby these densities can be obtained.

§3. CLUSTER PATTERNS, TRAIN PATTERNS, M47 PATTERNS:

a. Cluster Pattern Properties. - Patterns from individual clusters of M50 bombs have areas averaging about 100 yards across track by 400 yards along track. They have been found, in Edgewood Arsenal tests, to have generally a dense core containing about half the bombs, a larger effective area, containing about 70% of the bombs, and an irregular fringe containing about 30% of the bombs. All cluster patterns are aimable with satisfactory precision, save where excessive wind effects are present in sufficient strength to spoil the aimability of quick-opening clusters.

b. **Sample Pattern.** - A sample pattern, obtained during the tests of M18 clusters cited in Chapter 5 (AAF Board Project No. (M-5) 140) is reproduced on the following page.

c. **Precision Properties of Clusters.** - Different definitions have been used or suggested for cluster pattern centers. These include the mean point of impact, the center of a "50% rectangle" (containing the "central 50%" of the bombs), the center of a "70% rectangle", the point determined by the coordinates of the "middle bomb" in range and the "middle bomb" in deflection, and the center of a circle of preassigned radius, roughly so placed as to include as many bombs as possible. Despite the desirability of generally accepted, standardized definitions, it will be necessary in this review to quote results in terms of the various definitions used in other reports. In reports from Edgewood Arsenal, Maryland, 25 drops of the M17 cluster resulted in centers of impact of 16 clusters being within 100 yards of the target and only three at distances exceeding 200 yards. Clusters were released from an average altitude of 10,000 feet and opened, on the average, at 2,000 feet. (Later tests have revealed 5,000 feet as the optimum cluster-burst altitude.) Satisfactory precision results have also been obtained with quick-opening clusters of M50's and M69's from low to medium altitudes and without interfering winds.

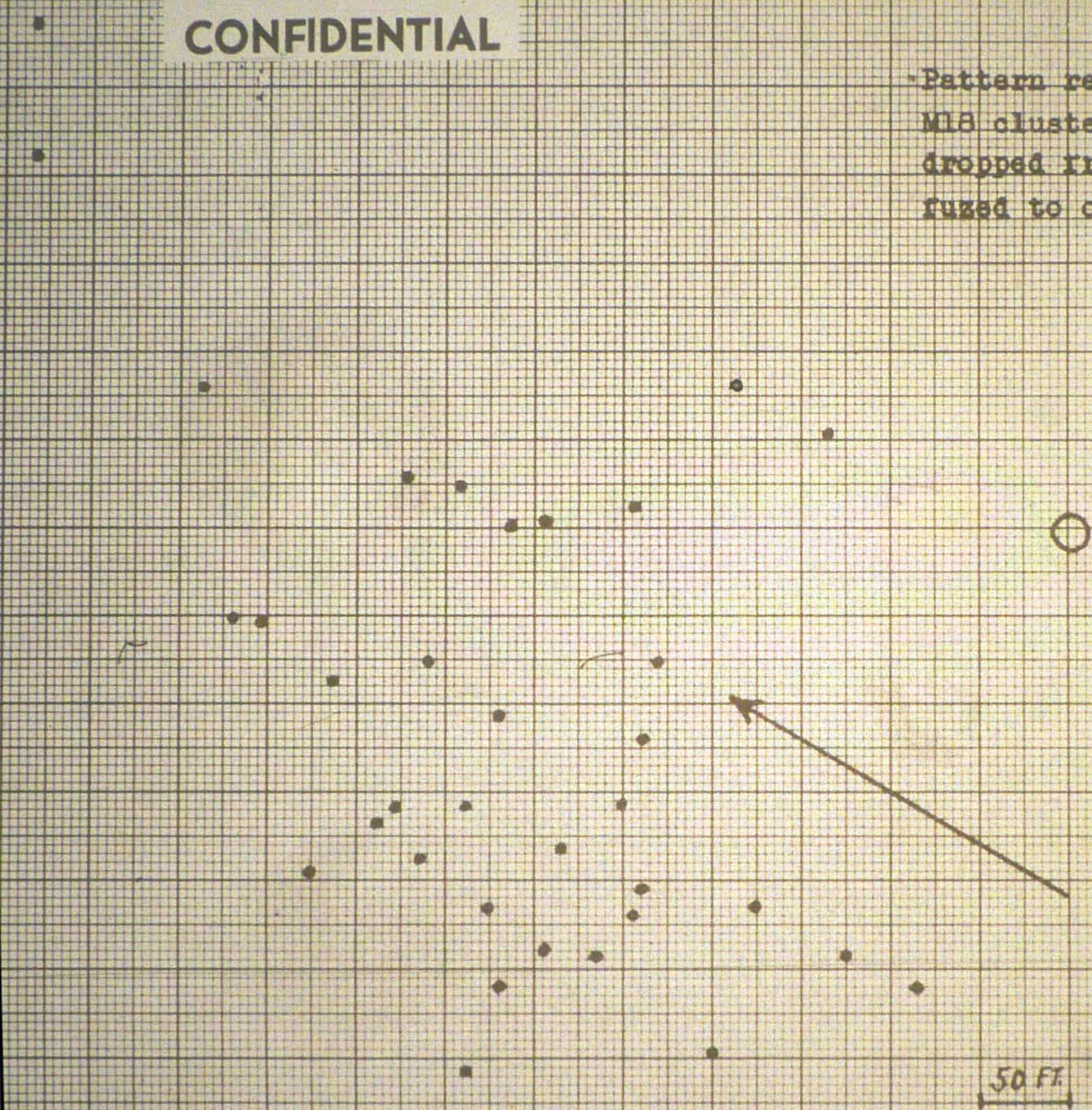
d. **Train Patterns.** - Train patterns of clusters average about 100 yards in width. In length, they can be varied from five or six hundred yards to several miles under practice conditions without spreading the bombs too thinly for highly combustible targets. However, in combat, bombing runs long enough to produce trains more than a mile or a mile and a half in length give the enemy time to achieve accuracy with his anti-aircraft fire. In train patterns, there is an effective core, with a small fringe along the sides and a few stray bombs at either end. In order to place the center of the train approximately on a given aiming point, the bombardier has the problem of allowing for half the train length in his aiming. Sometimes, depending on target conditions, an aiming point may be established for the initial cluster of the train.

e. **M47 Formation Patterns.** - Groups of planes dropping M47's obtained the following results, based on seven plots:

	Average Values
Altitude	24,000 ft.
No. planes per group	20
No. bombs per plane	37
No. bombs per group pattern	740
No. identified at burst	167
Width of pattern	590 yds.
Length of pattern	1,130 yds.
Area of pattern	670,000 sq. yds. (somewhat over 1/5 sq. mi.)
Distance between bombs, (assuming uniform distribution)	34 yds.

This illustrates that such patterns can be dropped so densely that the scattering of filling from the bombs bridges the gap between them. Note also that the distance between bombs corresponds favorably with some of the estimated required distances between appliance fires as listed in the preceding chapter.

Pattern resulting from a single M18 cluster of M69 IB's (38 bombs) dropped from 20,000 feet and fuzed to open at 5,000 feet.



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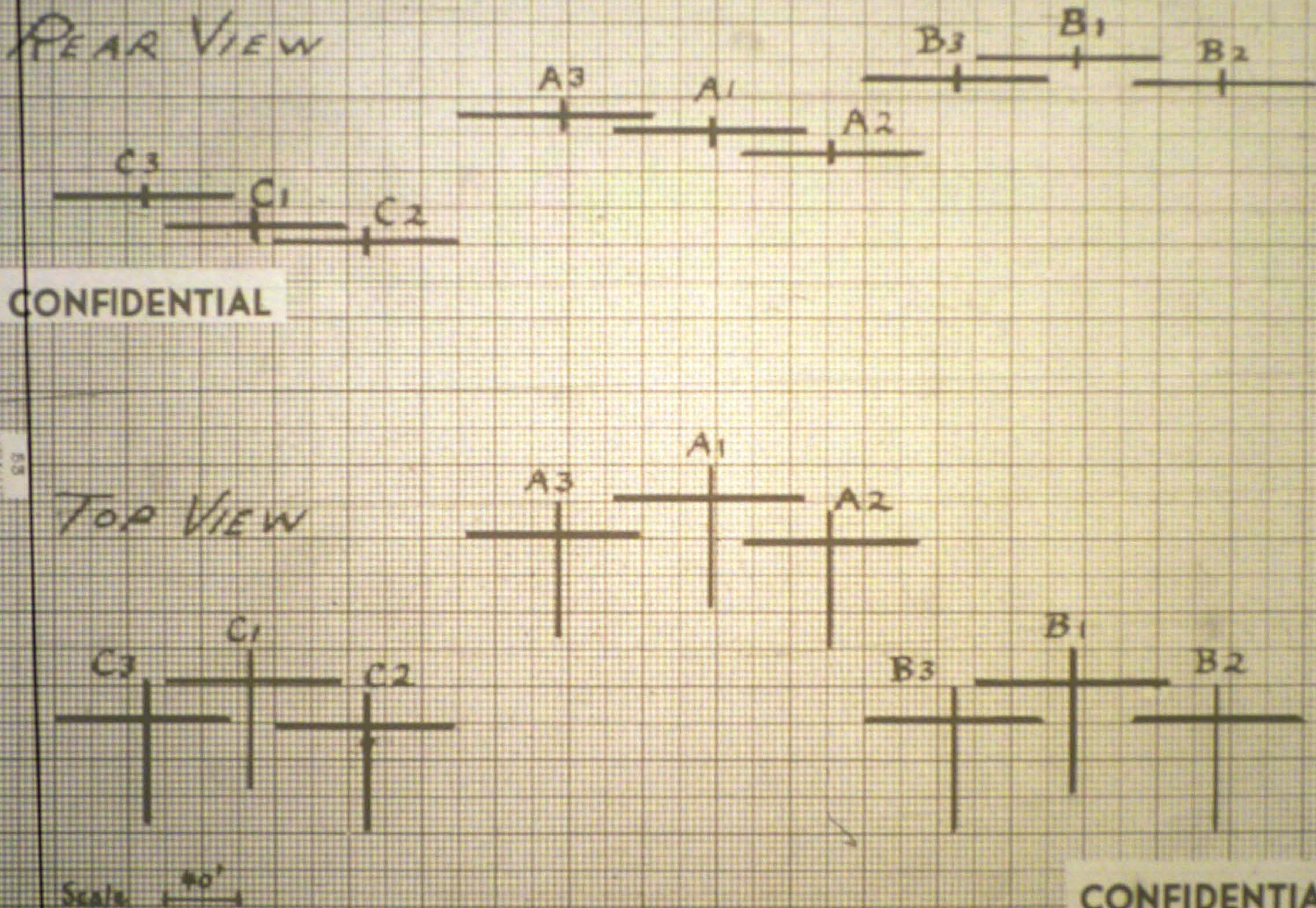

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Combat box formation plot

QUICK-OPENING M8 CLUSTERS OF M54 BOMBS

NO. OF CLUSTERS DROPPED	NO. OF BOMBS DROPPED	ALTITUDE (FEET)	GROUND SPEED (MI/HR)	TOTAL PATTERN RECTANGLE W (YDS)	TOTAL PATTERN RECTANGLE L (YDS)	EFFECTIVE PATTERN RECTANGLE W (YDS)	EFFECTIVE PATTERN RECTANGLE L (YDS)	AIMING ERRORS (YDS) RANGE	AIMING ERRORS (YDS) DEFLECTION	AIMING ERRORS (YDS) CIRCULAR	COVERING OF AIMING CIRCLE	REMARKS
8	272	1,050	180	430	480	400	200	-15	-100	100	Effective	One plane failed to release
10	340	3,200	180	500	360	110 200	200 200	+60	-90	108	"	One plane released 2 clusters. Effective area in 2 parts due to gap in formation.
9	306	7,400	196	570	1,140	340	340	+120	+120	170	"	
9	306	10,600	202	390	830	310	620	+70	+90	114	"	
17	578	1,100	202	560	540	180 200	230 290	-150	-50	158	Covered (at corner of effective area)	One plane released just one cluster. Effective area in 2 parts due to gap in formation. Minimum intervalometer spacing (10 ft.)
19	646	3,040	200	510	580	400	410	+5	0	5	Effective	One plane released 3 clusters. Minimum spacing.
8	272	4,510	198	500	780	400	500	-50	+100	112	"	One plane failed to release
18	612	5,200	155	530	1,030	300	500	-150	+50	158	"	Minimum spacing
17	578	7,300	160	410	1,000	300	420	-40	+50	64	"	One plane released just one cluster. Minimum spacing.
18	612	10,500	225	450	1,190	400	690	-45	0	45	"	Minimum spacing.
171	5,814.	7,400	150	620 (estimated)	Over one mile	350 (200)	1,600 (1,600)	+100	-125	160	"	9 clusters not released. A very dense core in effective area. Intervalometer set for 200 feet.
90	3,060	8,400	190	440	1,210	380	650	+25	+110	113	"	Minimum spacing
178	6,052	6,300	190	460	1,150	400	800	+100	+100	141	"	2 clusters not released. Min. spacing
Average Aiming Errors								72	76	111		

Taking positive and negative signs into account gives an average range error of about 2.3 yards and an average deflection error of about 19.6 yards. These are small enough so that no systematic error is indicated. Pattern plots for the 5th, 8th, 10th and 11th entries in this table are on the next pages.

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§4. COMPARISON OF AIMABLE AND QUICK-OPENING CLUSTERS.

For general purposes, aimable clusters, rather than quick-opening, are being supplied to the theatres. The quick-opening clusters, for reasons brought out in the following discussion of field tests, are useful only by restricted formations in area bombing where either (1) accuracy can be obtained by low-level flying or (2) accuracy is not an important factor in the attack. The usefulness of quick-opening clusters, which present larger plane-loading possibilities, is recognized under these special conditions and such clusters are being supplied in limited quantities.

§5. FORMATION CLUSTER PATTERNS (RESULTS OF TESTS):

a. **The Test Procedure.**- The following, briefly, was the procedure at the Avon Park tests, referred to at the beginning of Chapter VI. A target area was laid out consisting of a square, one mile on a side, gridded at 100 yards intervals. An aiming circle was used 20 yards in radius and having a bullseye in the center. The combat box formation, illustrated on Page 53, was used in all save one run over the target, when a javelin down formation was used for comparison. The formations were flown with 9 instead of 18 planes, the lower elements of each group of six being omitted because of (1) availability considerations, (2) hazard from bombs and cluster parts in the quick-opening clusters, and (3) the ability to determine the pattern area of the 18-plane formation by use of 9 planes since the lower elements do not affect pattern size but require only a doubling of the density computation. Percentage recovery of bombs ranged from about 50% to over 90%. To assure that the bombs not recovered (due to the nature of the terrain) were distributed approximately like those actually plotted, spotters were located along the sides of the target area, at safe distances, and were able to specify, with good results, the location of the total pattern. This total area was then uniformly covered by locaters, plotters, and a clean-up crew. A tabulator survey of the results is on pages 54 and 60, except in so are as density questions, to be discussed in Chapter VII, are involved.

b. **Table for Quick-Opening Cluster.**- The patterns for quick-opening clusters were developed through the use of M8 clusters of M54 bombs. Since functioning characteristics are not relevant to pattern developments, the M54, being non-standard and available, was the best munition to employ in determining formation pattern properties. The M54 has the same weight and about the same terminal velocity as the M50. Furthermore, both bombs are clustered in the same way, 34 bombs to a 100-lb. cluster. The conclusions based on the tests can therefore be reliably applied to the standard M6 clusters of M50 bombs. All the following material should be read with this in mind.

In the tables, aiming errors are measured from the aiming point to the center of the effective pattern. Range errors are taken as positive if the pattern center falls beyond the aiming point and negative if it falls short. Deflection errors are taken as positive to the right and negative to the left.

§6. FACTORS DETERMINING PATTERNS:

a. **List of Factors.**- Pending further experimental work, the extent to which the above results can be carried over to other situations merits attention. Pattern characteristics depend chiefly on (1) the type of formation flown, (2) the spacing of the planes in the formation, (3) the types of bombs and clusters, (4) the total load, (5) altitudes of release, (6) ground speed, (7) wind, (8) intervalometer spacing, (9) method of coordinating the releases. The dependence on intervalometer spacing affords the most significant way of manipulating pattern densities and lengths as discussed in the next chapter.

b. **Effects of Formations.**- The most generally suitable formations for incendiary bombing are those in which the parallel tracks of the separate planes are uniformly spaced, so that there will not be a double covering of certain parts of the pattern and a single covering of other parts. If planes are regularly spaced and not spread too far apart laterally, then the pattern will have good uniformity. In the Avon Park tests, a lateral distance of 200 ft. (fuselage to fuselage) in a drop from 3,000 ft. was noticeable as causing a thin strip in

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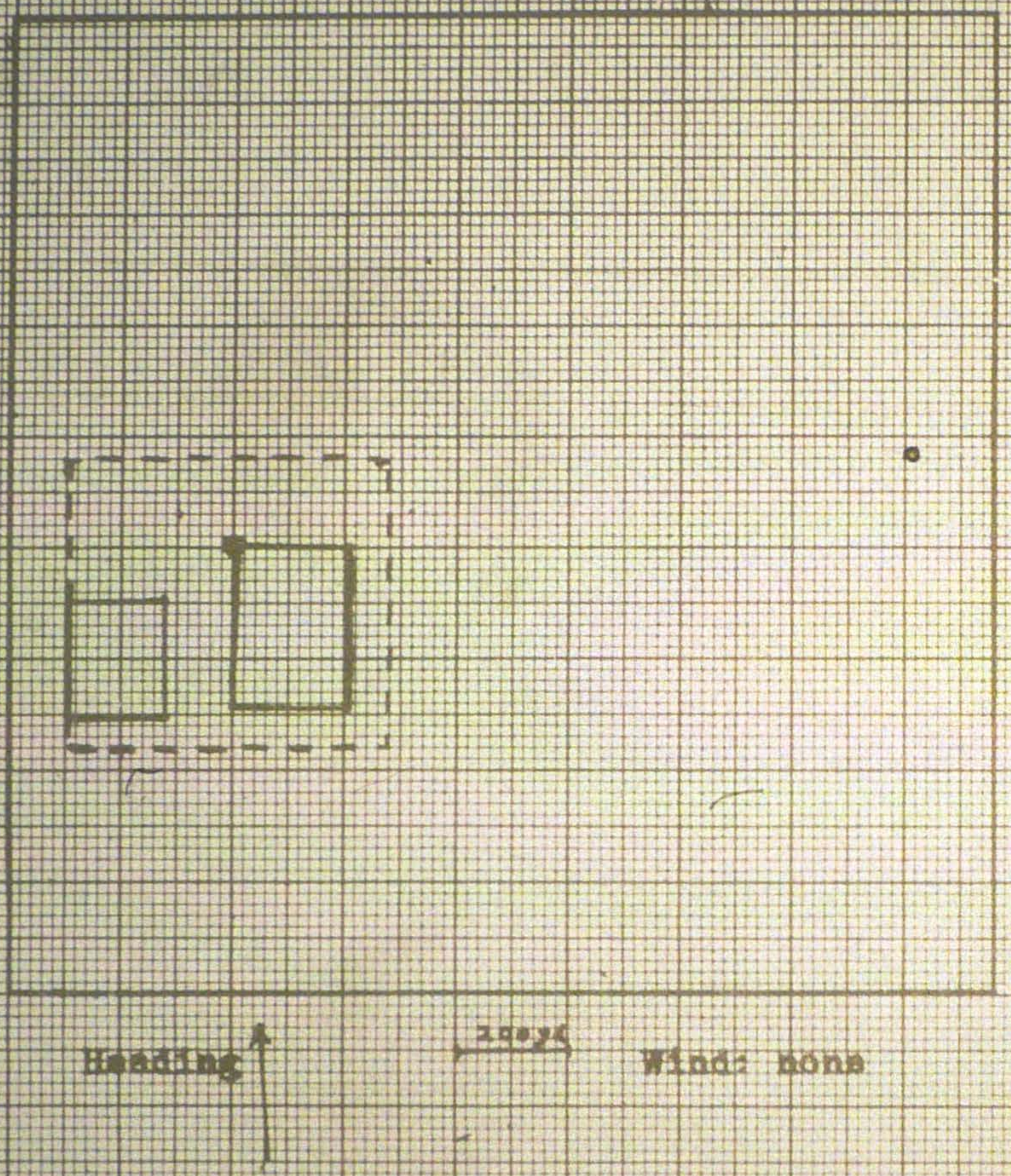
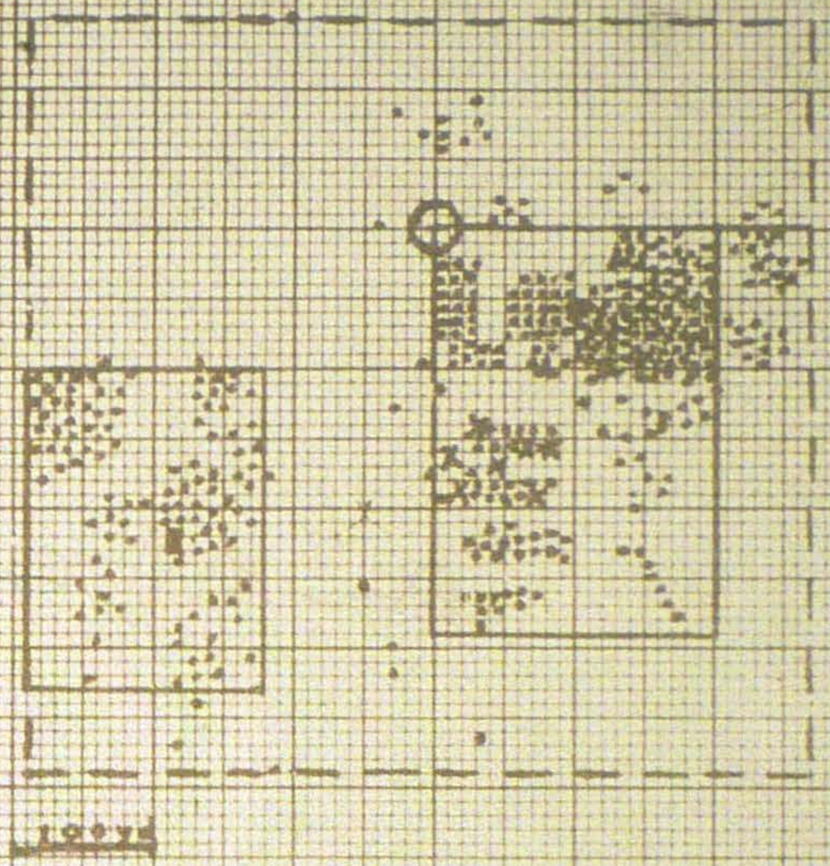
Quick-opening M8 clusters: Pattern 5





O: aiming circle

X: identified leader's bombs

■: unopened cluster

17 clusters (578 M54 bombs) were dropped

Altitude: 1100 ft

Ground speed: 202 m.p.h.

Remark: Effective pattern is in two parts, due to gap between left element and the rest of the formation. A3 released 1 second late. B2 dropped just 1 bomb. C3 released 1 second late

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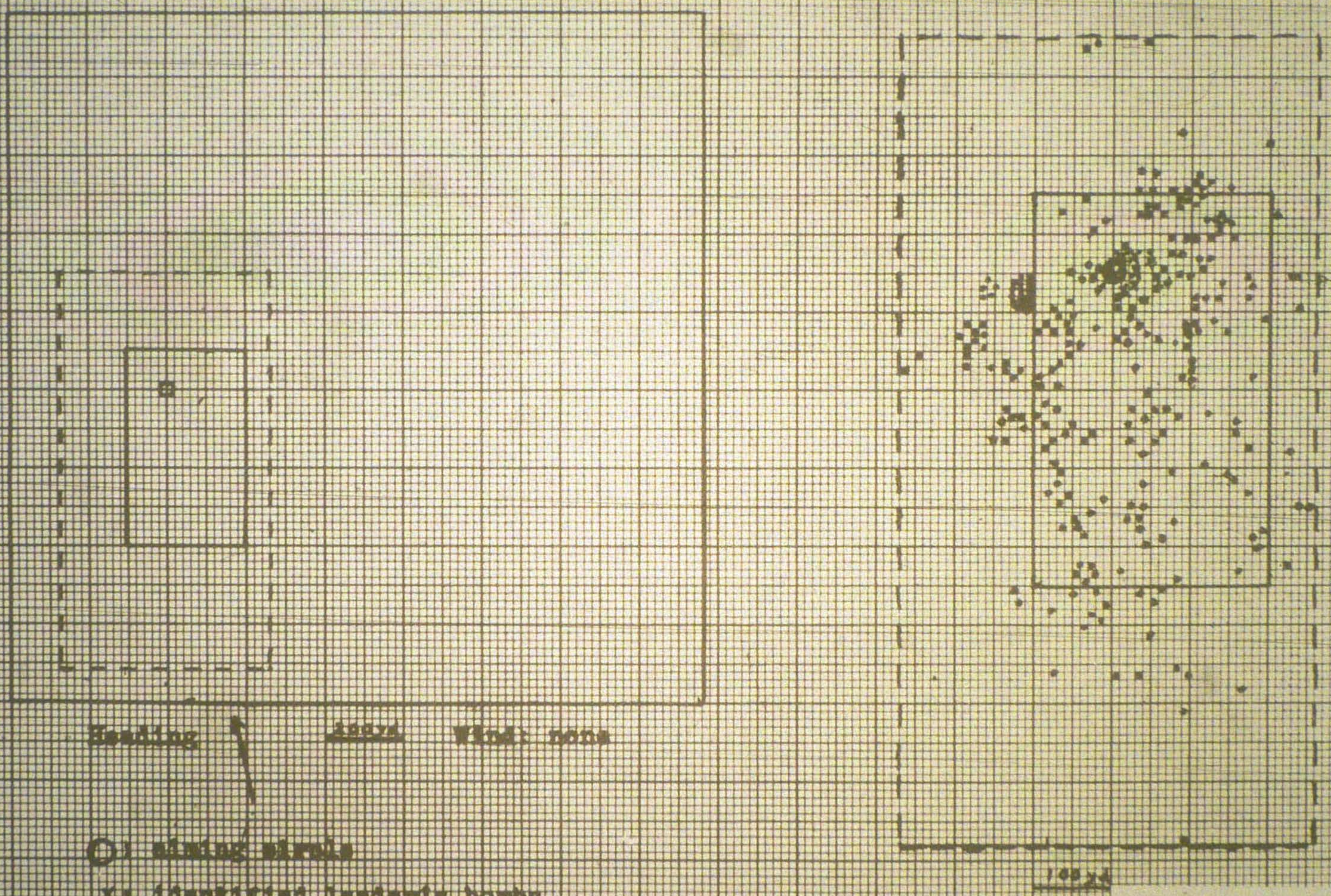
Quick-opening M8 clusters: Pattern 8



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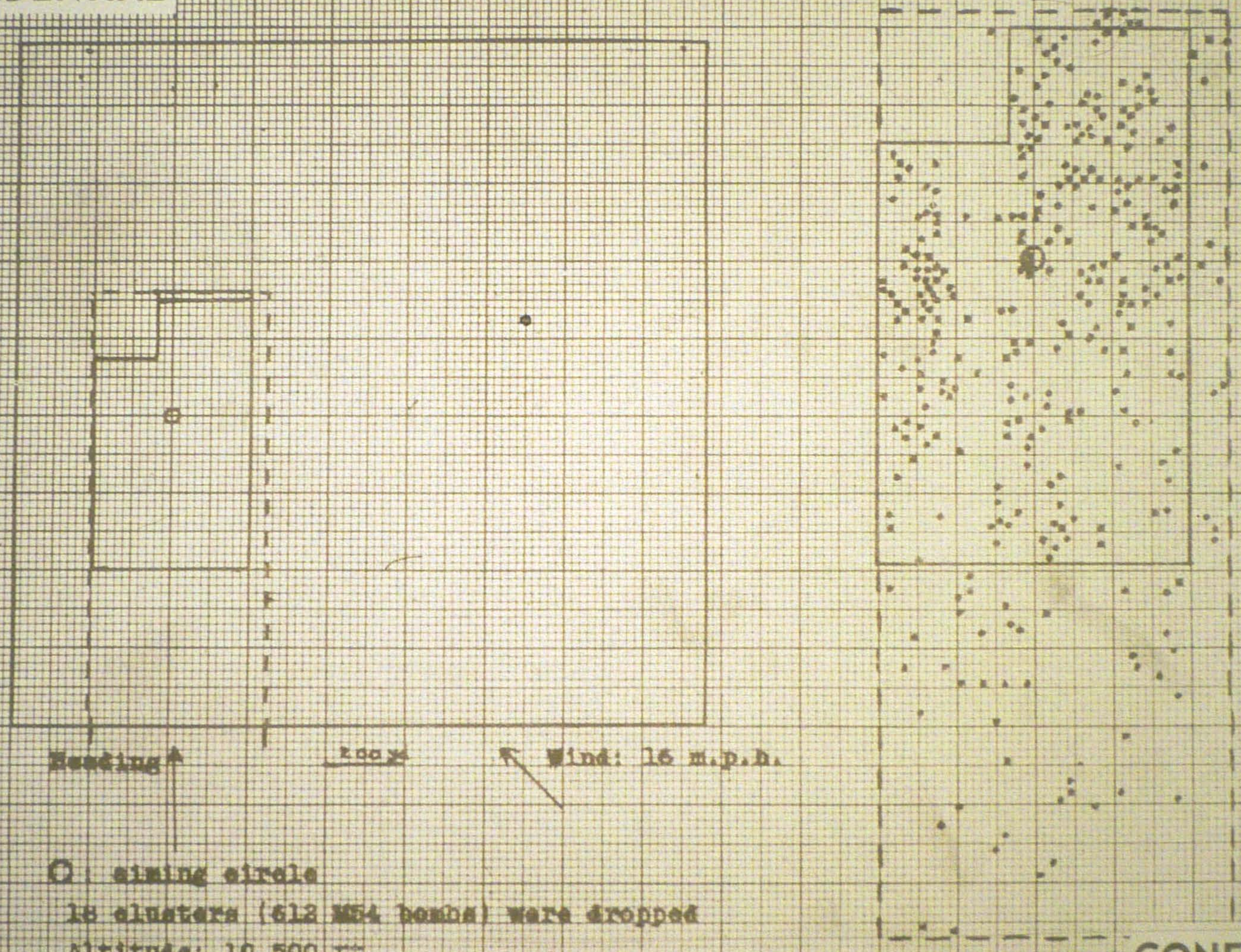
57

Quick-opening M8 clusters: Pattern 10



O : aiming circle

18 clusters (612 M54 bombs) were dropped

Altitude: 10,500 ft.

Ground speed: 225 m.p.h.

Remark: About 15 bombs lost in swampy land south of target.

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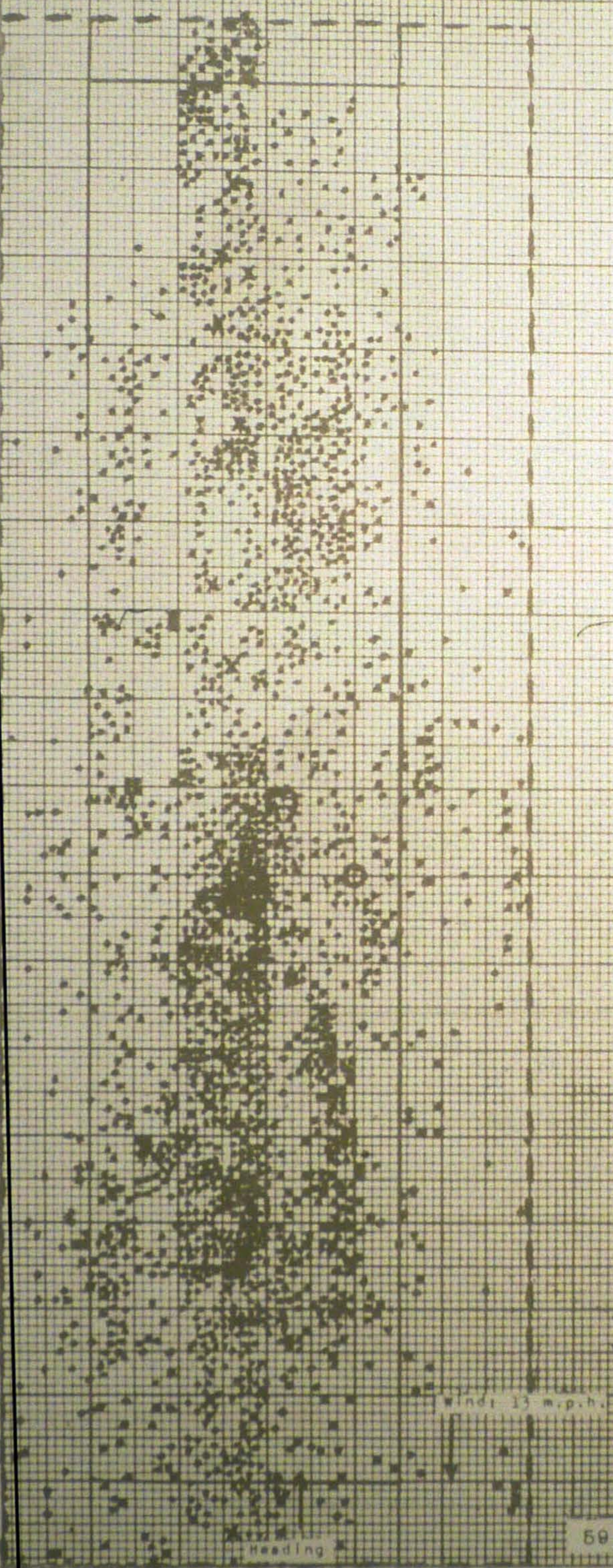
Quick-opening clusters: Pattern 11



O : aiming circle

X : identified leader's bombs

■ : unopened clusters

171 clusters (5814 M50 bombs) were dropped, 20 from each plane, with a 200-ft. intervalometer setting.

(9 clusters were not released over the target.)

Altitude: 7400 ft.

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Ground speed: 150 m.p.h.

Remark: This plot, 500 yds. wide by 1 mile long, represents the bombs on the target area. There was a scattering of bombs north, west, and south of the target.
[illegible] released only 17 clusters.
[illegible] released only 19 clusters.
B1 dropped one of the clusters which failed to open.
C3 salvoed 3 clusters about 2 seconds late (off target area).

AIMABLE M17 CLUSTERS OF M50 BOMBS

NO. OF CLUSTERS DROPPED	NO. OF BOMBS DROPPED	ALTITUDE (FEET)	APPROXIMATE ALTITUDE OF CLUSTER BURST	GROUND SPEED (MI/HR)	TOTAL PATTERN RECTANGLE W (YDS)	L	EFFECTIVE PATTERN RECTANGLE W (YDS)	L	AIMING ERRORS (YDS) RANGE	DEFLECTION	CIRCULAR	COVERING OF AIMING CIRCLE	REMARKS
9	990	16,000	5,000	224	430	600	350	300	-50	-25	56	Effective	
18	1980	16,000	5,000	222	580	650	450	400	-200	-175	266	Effective (on edge)	Minimum intervalometer spacing (10 ft.)
53	5830	16,000	5,000	227	550	600	400	400	0	-100	100	Effective	One cluster not released. Minimum spacing.
9	990	15,900	5,000	224	570	390	500	300	+50	-150	158	Effective	
9	990	26,400	5,000	235	600	580	600	400	+100	+200	224	Effective	
7	770	15,800	5,000	220	560	510	325	300	-50	-160	168	Effective (on edge)	2 clusters not released.
9	990	21,000	10,000	228	680	580	500	450	-75	-50	90	Effective	
9	990	21,000	5,000	232	600	700	500	450	-125	+100	160	Effective	
Average aiming errors									81	120	153		

Taking positive and negative signs into account gives an average range error of about -44 and an average deflection error of -45. These are small enough so that no systematic error is indicated. The consistent covering of the aiming circle with the effective pattern, for both aimable and quick-opening drops, is a highly satisfactory precision property. The patterns from aimable clusters are significantly shorter and more compact than those from the quick-opening. Their greater width is probably associated with the higher altitudes at which the formations flew. Pattern plots for the 1st, 3rd, and 7th entries in this table are on the next pages.

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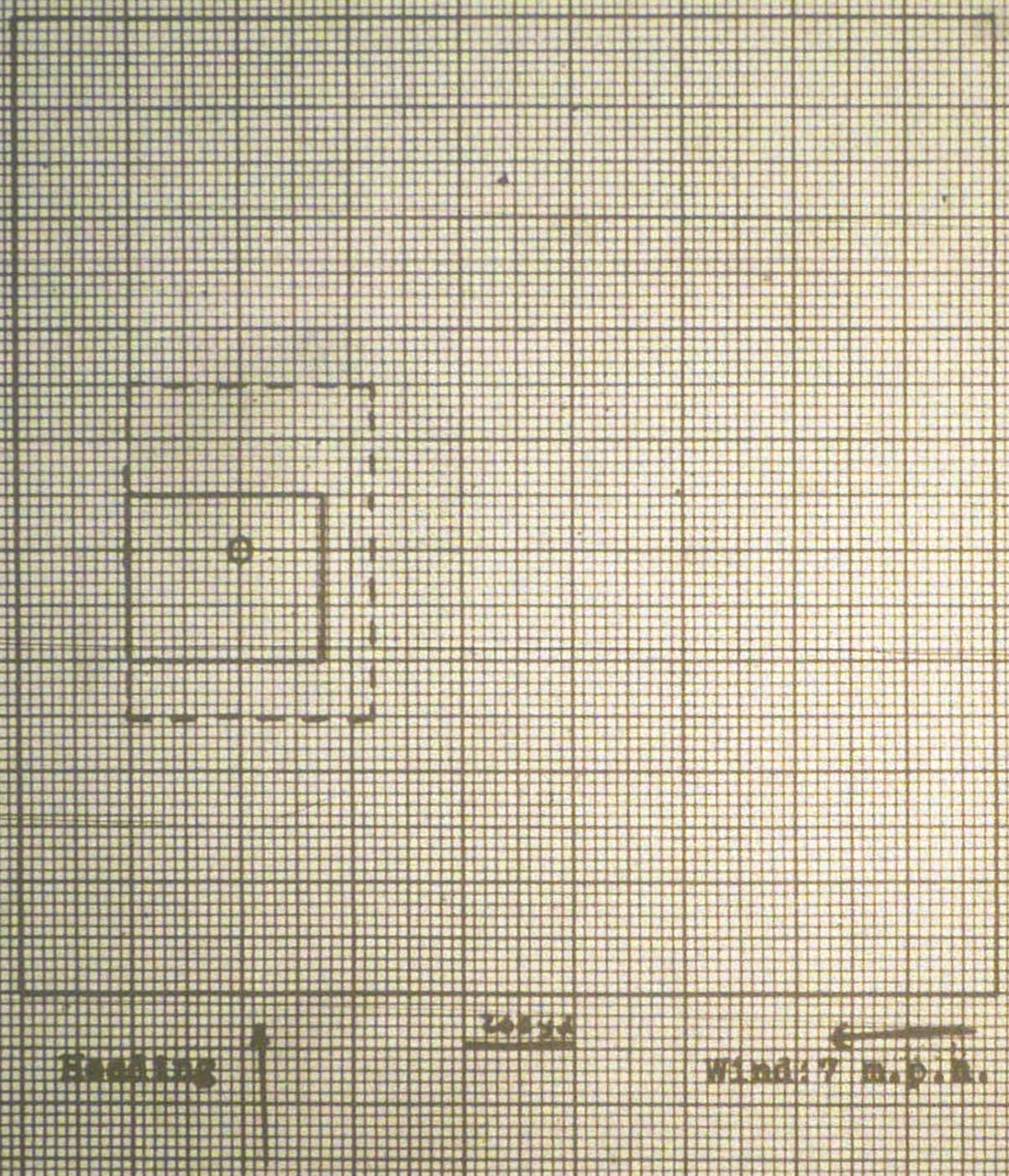
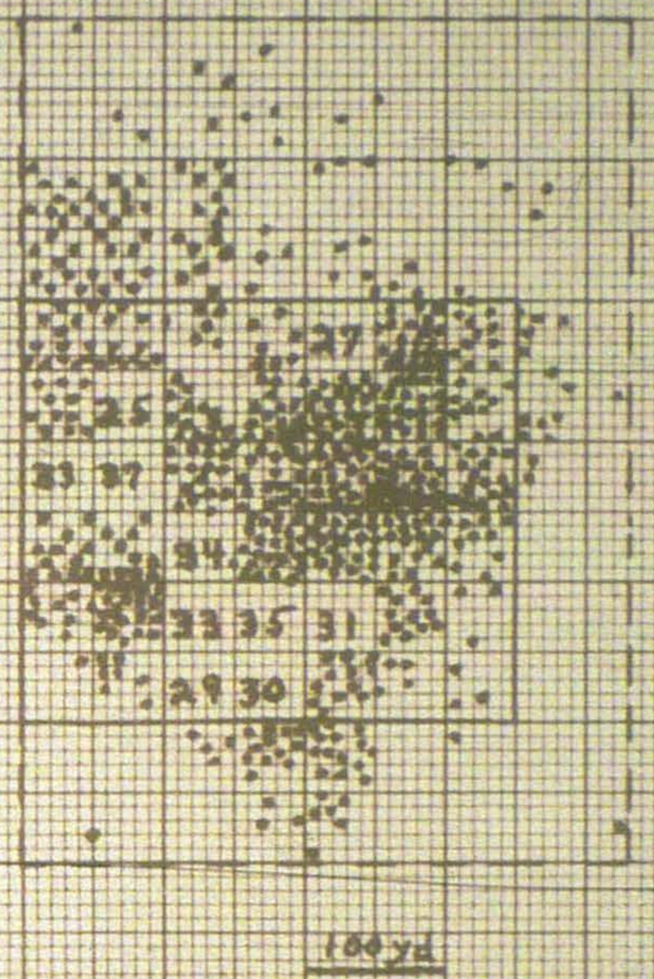
Aimable M17 clusters: Pattern 1





O : aiming circle

Figures represent impacts too dense for plotting in 50-yd. squares.

9 clusters (990 M50 bombs) were dropped.

Altitude: 15,000 ft. Clusters set to open at 5,000 ft.

Ground speed: 224 m.p.h.

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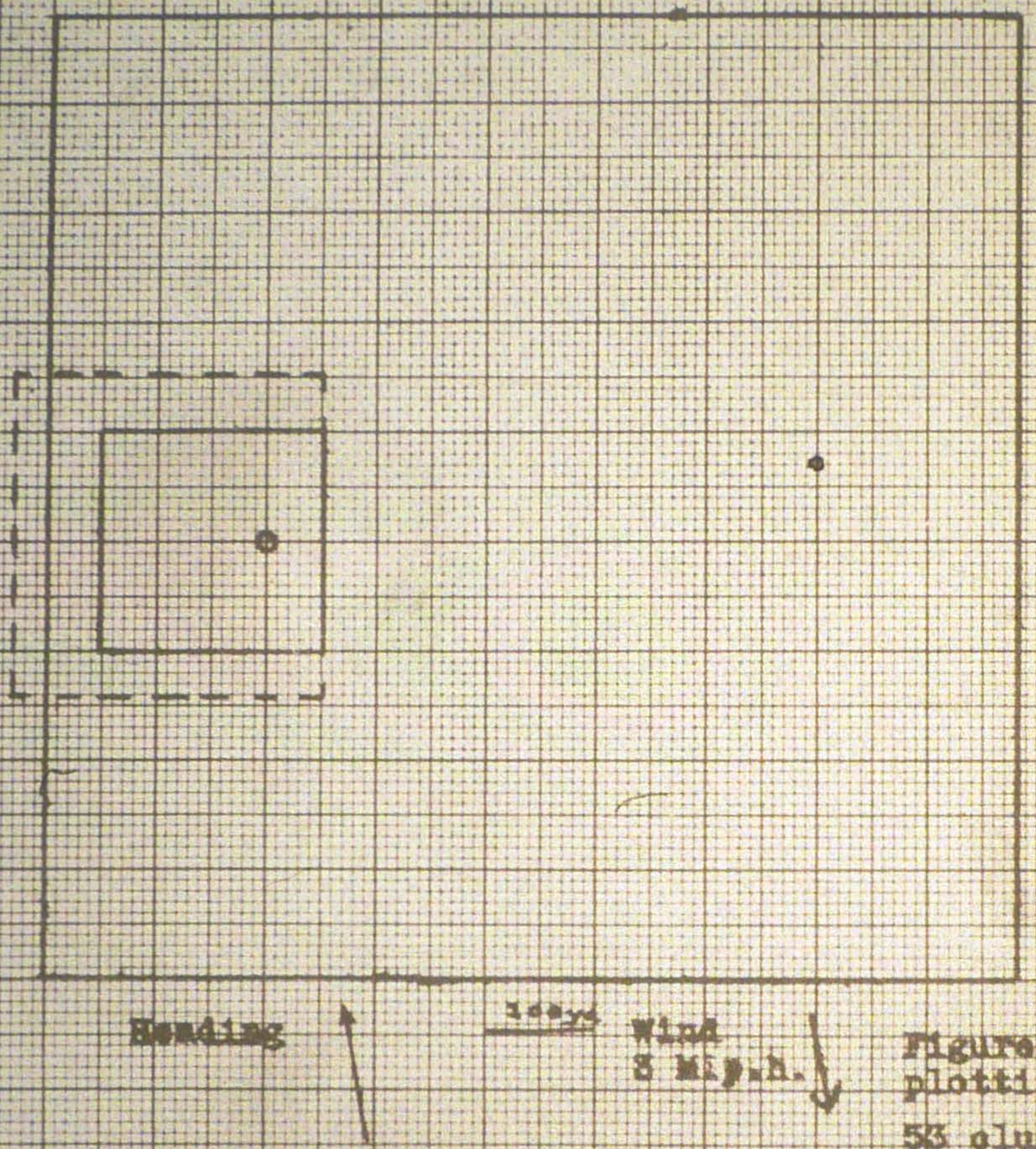
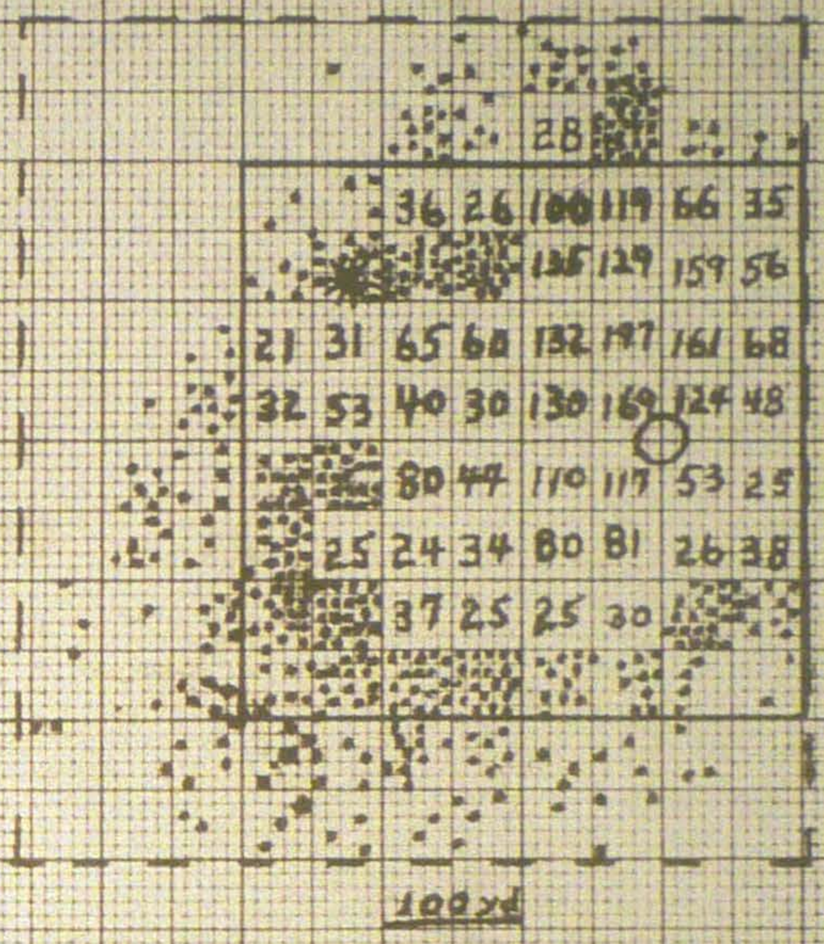
Aimable M17 cluster: Pattern 3





O: aiming circle

✱: impact burst of entire cluster (crater 4 ft. across, 3 ft. deep)

Figures represent impacts too dense for plotting in 50-yd. squares.

53 clusters (5830 M50 bombs) were dropped, there being 6 to a plane with one cluster not released. Minimum intervalometer setting (12 ft.)

Altitude: 16,000 ft. Clusters set to open at 5,000 ft.

Ground speed: 227 m.p.h.
Remark: 185 bombs landed in aiming circle.

Remarks: Air bursts about simultaneous. B3 dropped just 5 clusters, instead of 6. C1 released cluster safe, accounting for impact burst.

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PLANES	(1) 100 lb.		(2) 500 lb.		(3) BOMBS IN 100 LB. CLUSTERS M 50		(4) BOMBS IN 100 LB. CLUSTERS M 74 or M 69		(5) BOMBS IN 500 LB. CLUSTERS Quick-Opening M 50		(6) BOMBS IN 500 LB. CLUSTERS Quick-Opening M 74 or M 69		(7) BOMBS IN 500 LB. CLUSTERS Aimable M 50		(8) BOMBS IN 500 LB. CLUSTERS Aimable M 74 or M 69	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
B-23; B-25; B-25A, B, C, D	12	12	4	6	408	408	168	168	512	768	240	360	440	660	152	228
B-25, C1-25, D1-30; G1, 5, 10 H1-10, J1-30	12	20	4	6	408	680	168	280	512	768	240	360	440	660	152	228
B-26, B-26A, A1	20	30	4	8	680	1020	280	420	512	1024	240	480	440	880	152	304
B-26B, B2-20 B-26B25, 55	20	20	4	6	680	680	280	280	512	768	240	360	440	660	152	228
B-34	0	6	0	6	0	204	0	84	0	768	0	360	0	660	0	228
B-37	0	7	0	0	0	238	0	98	0	0	0	0	0	0	0	0
B-17B, C, D, E	20	20	4	8	680	680	280	280	512	1024	240	480	440	880	152	304
B-17FG (all models)	20	24	4	12	680	816	280	336	512	1536	240	720	440	1320	152	456
B-24 (all models)	20	20	4	12	680	680	280	280	512	1536	240	720	440	1320	152	456
B 29-1, 5 YB-29	0	80	4	40	0	2720	0	1120	512	5120	240	2400	440	4400	152	1520
B-19-10, 15, 25 B-32	0	0	4	40	0	0	0	0	512	5120	240	2400	440	4400	152	1520
YB 35, B35	0	0	20	80	0	0	0	0	2560	10240	1200	4800	220	8800	760	3040
AT-6B, C, D	0	4	0	0	0	136	0	56	0	0	0	0	0	0	0	0
AT 11,	0	10	0	0	0	340	0	140	0	0	0	0	0	0	0	0

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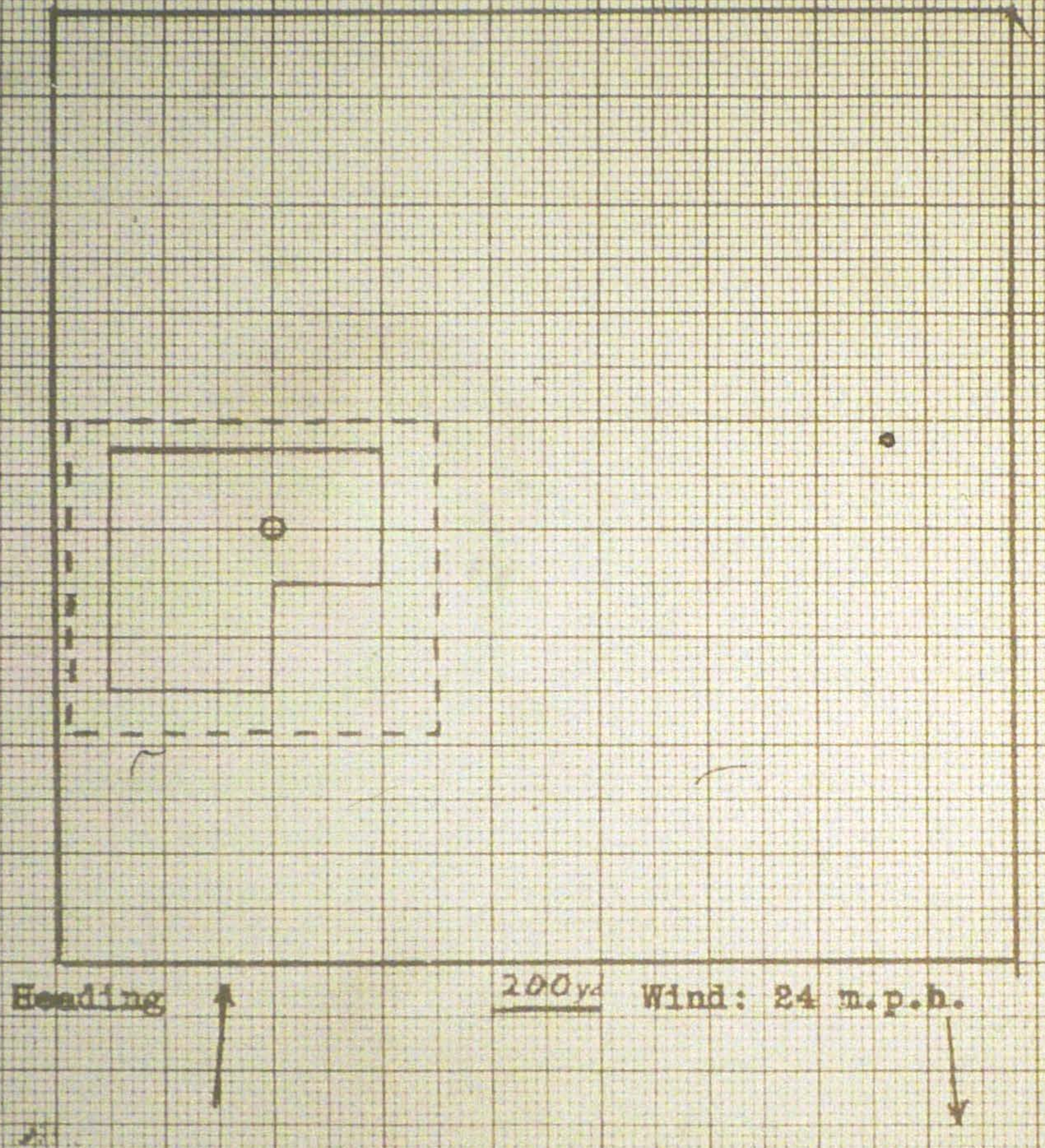
Aimable M17 clusters: Pattern 7



O : aiming circle

Figures represent impacts too dense for plotting in 50-yd. squares.

9 clusters (990 M50 bombs) were dropped

Altitude: 21,000 ft. Clusters set to open at 10,000 ft.

Ground speed: 228 m.p.h.

Remark: B1 dropped 1.5 seconds late.

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the formation pattern. On the other hand, lateral spacings of about 100 ft. made for good uniformity from low altitudes. From altitudes of 15,000 and higher, spacings of 200 ft. and even 300 ft. had no apparent effect on uniformity when aimable clusters were dropped.

c. **Effects of Bomb and Cluster Types.**- Types of bombs and clusters are expected to have more effect on density than on other pattern characteristics. The carrying out of further tests is desirable, however, to obtain reliable information on the subject.

d. **Effects of Spacing (Other Considerations).**- Intervalometer spacing, combined with total load, determines pattern length, as revealed by the contrast in the above table between the results with a minimum (10 ft.) setting and the results with a 200 ft. setting. In the tests just quoted, releases were all "on the leader." Such releases, as nearly simultaneous as can be arranged, make for less scattering in length than separate aiming procedures. The effect of other procedures on the pattern, however, is not easy to predict, beyond the likelihood of irregularities in the pattern due to divergencies in timing of releases. In view of the remarkably good precesion properties secured in the above drops on the leader, it is difficult to see how improvements in accuracy would result from other techniques. It might, however, well be true that a squadron of 9 or 18 planes is the largest formation which should drop on a single bombardier, and that certain combat conditions might call for having leaders of three or six-plane elements do the aiming, each one with a suitable chosen aiming point. It is not to be supposed that the precision properties and densities achieved under the practice conditions at Avon Park can be consistently attained in combat.

e. **Miscellaneous Aspects of Test Patterns.**- Accidental errors in coordinating releases, (delays due to (1) obscuring of vision of bombardiers relative to lead bombardier, (2) failure of bombardiers to release promptly (3) failures of mechanical equipment) have obvious effects on patterns, as revealed in some of the results at Avon Park. Late releases stretch out the length of the total pattern and detract from either the size or the concentration of the effective pattern. These effects were sufficient, in the tests, to obscure the influence of speed, wind, and, except for the aimable clusters, of altitude.

§7. SUMMARY:

Cluster patterns and stick (or train) patterns are of minor importance in comparison with formation patterns, which are the basic unit for the study of almost all daylight incendiary bombing. It is not possible to deduce formation pattern characteristics from those of individual clusters or even from stick patterns. Total pattern areas for 9-plane (or 18-plane) formations, with suitable lateral spacing, average about 500 yards in width, (with lengths depending on plane loads and intervalometer settings), when quick-opening M8 clusters of M54 bombs were used, from altitudes of 1,000 to 10,000 feet. The widths average about 570 yards for aimable M17 clusters of M50 bombs from altitudes of 16,000 to 26,000 feet. Effective patterns on the Avon Park tests had average widths of about 360 yards for quick-opening and 450 yards for aimable. Higher altitudes, resulting in looser formations, probably influenced pattern width more than the types of bombs and clusters. More compact patterns, as far as length goes, were obtained from aimable than from quick-opening clusters, despite the altitudes. Excellent precision results were obtainable in formation pattern bombing as seen in the above tables. Extensions of the findings to other conditions require suitable adjustments for (1) lateral spacing of planes (2) loading of planes (3) altitudes, (the differences being significant and increasing for altitudes above 15,000 feet as compared with the lower altitudes), (4) ground speed and (5) intervalometer setting. Wind effects on quick-opening clusters are difficult to predict. Evasive and deceptive maneuvers just before the bombing run will probably have effects on both the accuracy and the compactness of patterns. In this connection, variations in combat formations will cause some change in pattern areas.

VII. BOMB DENSITIES BASED ON PATTERNS

§1. RELATION TO EARLIER CHAPTERS:

The practical application of the results of the foregoing chapters requires a knowledge of the densities which can be achieved in formation bombing and of the means of achieving them. This topic is intimately related to the subject matter of Chapter VI, and the principal results are drawn from the Avon Park Tests there cited.

§2. DENSITIES EXPERIMENTALLY OBTAINED (QUICK-OPENING CLUSTERS):

a. **The One-Cluster Releases.**- For the purpose of presenting the density results, the following organization of data is appropriate. The eight-cluster and ten-cluster patterns are explained by accidental failures to release and by accidental extra releases. These same patterns are included in the table on page 54. In this and in later tables, "total" (or "effective") density means density in the total (or effective) area.

Single-Cluster Releases of M8 Clusters from Nine-Plane Formations.									
NO. CLUSTERS	NO. BOMBS	ALTITUDE	TOTAL PATTERN AREA (Sq. Yd)	TOTAL DENSITY (BOMBS PER 10,000 sq. yd.)	DENSITY ADJUSTED FOR COMPLETE DROP (306 BOMBS).	APPROX. % BOMBS IN EFFECTIVE PATTERN	EFFECTIVE AREA	EFFECTIVE DENSITY	ADJUSTED EFFECTIVE DENSITY (306 BOMBS)
8	272	1050	206,000	13.4	14.9	86	80,000	29.2	32.9
10	340	3200	180,000	18.9	17.	93	62,000	51.0	45.9
9	306	7400	650,000	4.7	4.7	65	116,000	17.2	17.2
9	306	10600	324,000	9.44	9.44	96	192,000	15.3	15.3
8	272	4510	390,000	6.97	7.85	74	200,000	10.1	11.3
AVERAGES			350,000	10.7	10.8	83	130,000	24.6	24.5

With uniform distribution, this means that bomb hits averaged about 20 yards apart effective pattern area. This is an overall average for the effective area. In some 100 x 100 yd. squares, the average would be about 10 yards apart. It should further be noted that these figures are for releases of only one cluster per plane, instead of a full load of twenty. Such single cluster releases were intended to give a basis for estimating the results for releases in train of larger numbers of bombs.

b. **The Two-Cluster Releases.**- A set of five releases of two clusters per plane was carried out, from approximately the same altitudes as the single-cluster releases, with a view to seeing how the density of the pattern would be reinforced by the double load. The two clusters were released in as quick succession as practicable, yet some lengthening of the pattern resulted, along with an increase in bomb density (see table on page 54). The results follow.

Double-Cluster Releases of M8 Clusters from Nine-Plane Formations.									
NO. CLUSTERS.	NO. BOMBS	ALTITUDE. (FT.)	TOTAL PATTERN (SQ. YD.)	TOTAL DENSITY BOMBS PER 10,000 SQ. YD.	ADJUSTED DENSITY (612 BOMBS)	APPROX.% IN EFFECTIVE AREA	EFFECTIVE AREA	EFFECTIVE DENSITY	ADJUSTED DENSITY (612 BOMBS)
17	578	1100	302,000	19.1	20.3	86	99,400	50.0	53.0
19	646	3040	296,000	21.8	20.7	87.5	144,000*	39.2	37.7
18	612	5200	546,000	11.2	11.2	64	150,000	26.1	26.1
17	578	7300	410,000	14.1	14.9	67	126,000	30.7	32.5
18	612	10500	586,000	11.4	11.4	79.5	250,500*	19.4	19.4
AVERAGE			418,000	15.5	15.7	77	154,000	33.1	33.7

*Effective pattern taken as only part of a rectangle. Hence area is not the product of the dimensions given in the table on page 54.

The total density is here increased as compared with the single cluster releases by about 45% and the effective density by about 37.5%. The results are explainable by the fact that the patterns from releases of the second clusters are carried further along (giving greater length) and also overlap with those from releases of the first clusters (giving greater greater density). Bombs average about 17.4 yards apart in the effective area.

c. **The Ten and Twenty-Cluster Salvo Releases (Quick-Opening).-** Ten-cluster and twenty-cluster releases, M8, from a nine-plane formation, with minimum intervalometer setting (compare table on page 54).

NO. CLUS-TERS.	NO. BOMBS	ALTI-TUDE (FT.)	TOTAL PATTERN (SQ. YD.)	TOTAL DENSITY (BOMBS PER 10,000 SQ. YD.)	APPROX. % IN EFFEC-TIVE AREA	EFFECTIVE AREA	EFFECTIVE DENSITY
90	3060	8400	532,000	57.5	79.5	247,000	98.4
178	6052	6300	529,000	114 (116)	86	320,000	163 Maximum Density (165)

The densities in parentheses are adjusted to the full load of 180 clusters, to take account of the two clusters not released.

Here the pattern densities, as well as the areas, increase significantly. The ten-cluster release has about four times the effective density of the single-cluster release and about three times that of the double-cluster release. This ten-cluster release is a half-load for B_{17} bombers. The twenty-cluster release resulted in an effective density about:

(1) 7 times that of the single-cluster release
(2) 5 times that of the double-cluster release
(3) 1.7 times that of the ten-cluster release

In the ten-cluster release, the bomb hits average a little over ten yards apart in the effective area. In the twenty-cluster release, they average about 8 yards apart. Such distances can be used in forming an estimate of the average number of fires per unit area, based on the target's vulnerability properties in relation to the type of bomb employed. This release was made by the method which gives maximum density for a nine-plane B-17 formation carrying M8 clusters.

d. **Dependence of Area and Density on Load.-** The following table reveals how pattern areas are affected by the number of clusters per plane in salvo releases. The behavior of the effective pattern area is more significant than that of the total area, since the latter is more subject to the influence of stray bombs and irregularities in the coordination of releases. (See graphs on pp. 68, 71.)

NO. OF CLUSTERS PER PLANE	TOTAL PATTERN AREA (SQ. YDS.)	EFFECTIVE PATTERN AREA (SQ. YDS.)	EFFECTIVE DENSITY (BOMBS PER 10,000 SQ. YDS.)
1	350,000	130,000	24.5
2	418,000	154,000	33.7
10	532,000	247,000	98.4
20	529,000	320,000	165.0

e. **The 20-cluster Train Release.-** As a guide to extending results from salvo releases to train releases, one drop was made of the following sort:

TWENTY-CLUSTER TRAIN RELEASE OF M-8 CLUSTERS FROM A NINE-PLANE FORMATION, WITH A 200 FOOT INTERVALOMETER SETTING								
NO. CLUSTERS	NO. BOMBS	ALT. (FT.)	TOTAL PATTERN ON TARGET AREA (SQ. YDS.)	APPROX. NO. BOMBS ON TARGET AREA	APPROX. TOTAL DENSITY ON TARGET	APPROX. % IN EFFECTIVE AREA	EFFECTIVE AREA	EFFECTIVE DENSITY
171*	5814	7400	995,000	5,000	50.3	86	560,000	89.6

*Accidental failures to release account for the fact that only 171 clusters were dropped instead of 180.

This represents bombs, on the average, about 10.5 yards apart over the effective area, consisting of a strip about 1600 yards long and 350 yards wide. The central 200 yards of the strip, however, was more densely hit than the rest. (See plot for "Quick-opening Cluster, Pattern 11"). The period of straight level flight required to approach the release line and drop the train amounted to from forty to sixty seconds. This would be a fairly long, but not impractical, bombing run over a well-defended target.

DENSITIES EXPERIMENTALLY OBTAINED (AIMABLE CLUSTERS):

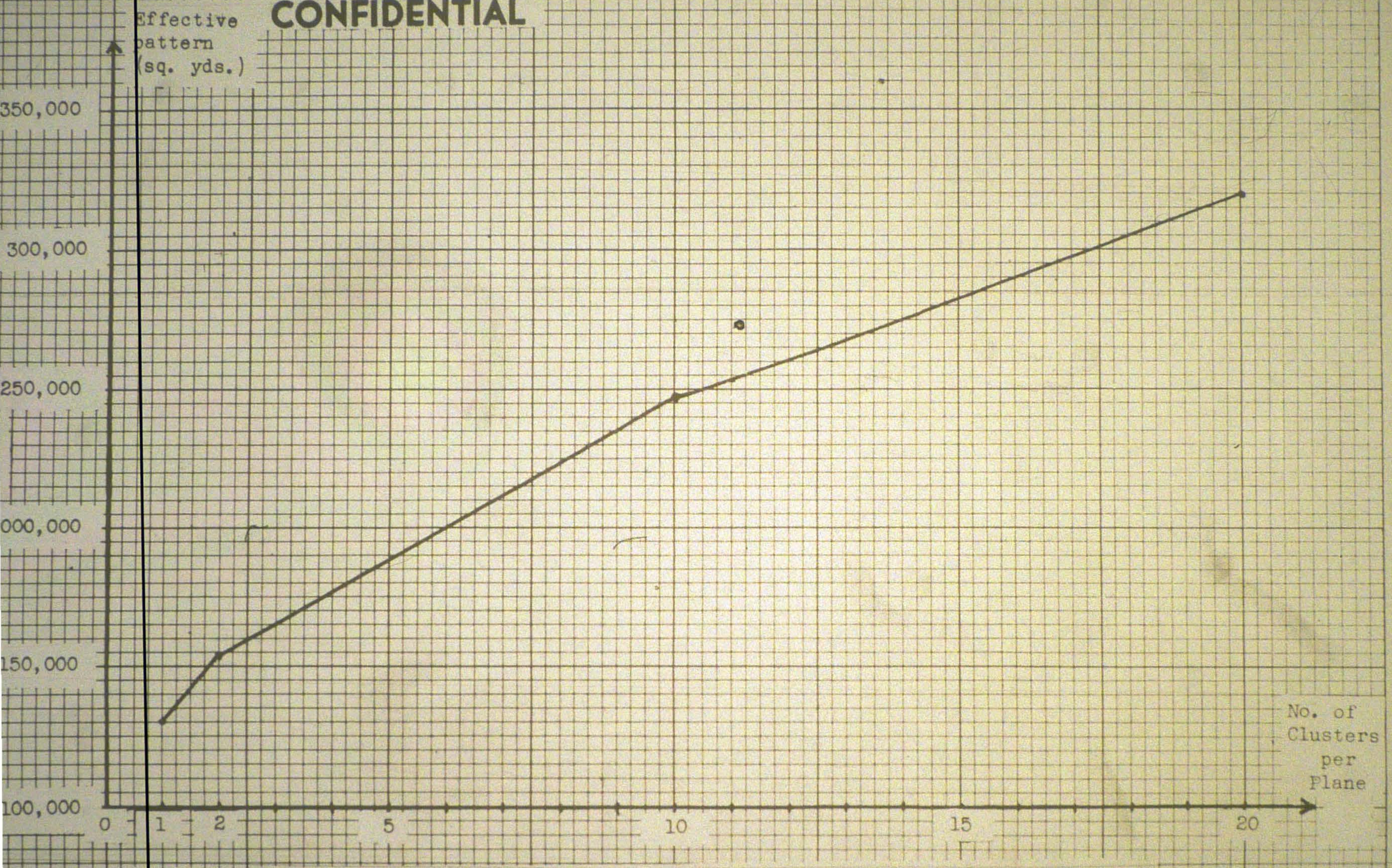
The behavior of patterns was found to be different for the aimable as compared with the quick-opening clusters. The aimable clusters produce shorter, more compact patterns, since the bombs do not disperse so widely on cluster opening. In the case of the quick-opening cluster, this scattering of bombs is probably due to the effects of the slipstream of the plane. The more concentrated patterns lead to possibilities of very great densities, especially when whole squadron loads are released with minimum intervalometer setting. The illustrative problem in the final chapter of this report makes use of such extreme densities. These same releases are involved in the table on page 60.

a. Single-Cluster Releases of M17 Clusters From Nine-Plane Formations.--								
NO. CLUSTERS DROPPED	BOMBS DROPPED	ALTITUDE OF:		TOTAL PATTERN (SQ. YD.)	TOTAL DENSITY (BOMBS PER 10,000 SQ. YD.)	APPROX. % IN EFFECTIVE AREA	EFFECTIVE AREA (SQ. YD.)	EFFECTIVE DENSITY
		CLUSTER RELEASE	CLUSTER BURST					
9	990	16,000	5,000	258,000	38.4	83	105,000	81.7
9	990	15,900	5,000	222,000	44.6	95	120,000*	78.4
9	990	26,400	5,000	348,000	28.5	88.5	240,000	36.5
7**	770	15,800	5,000	286,000	26.9	82	97,500	64.8
9	990	21,000	10,000	394,000	25.1	90	165,000***	53.9
9	990	21,000	5,000	420,000	23.6	90	225,000	39.6
AVERAGE				321,000	31.2	88	159,000	59.2

* Effective pattern was a rectangle 500 x 300 with a corner 150 x 200 subtracted.
** There were accidental failures to release on the part of two planes in the formation.
*** Effective pattern was a rectangle 500 x 450 with a corner 200 x 200 subtracted.

This implies bombs about 13 yards apart on the average in the effective pattern area.

b. **Multiple Releases of M17 Clusters from Nine-Plane Formations.** - These same releases appear in the table on page 60.



C Variation of effective pattern area with the number of clusters released per plane. (Quick-opening clusters, minimum intervalometer setting)

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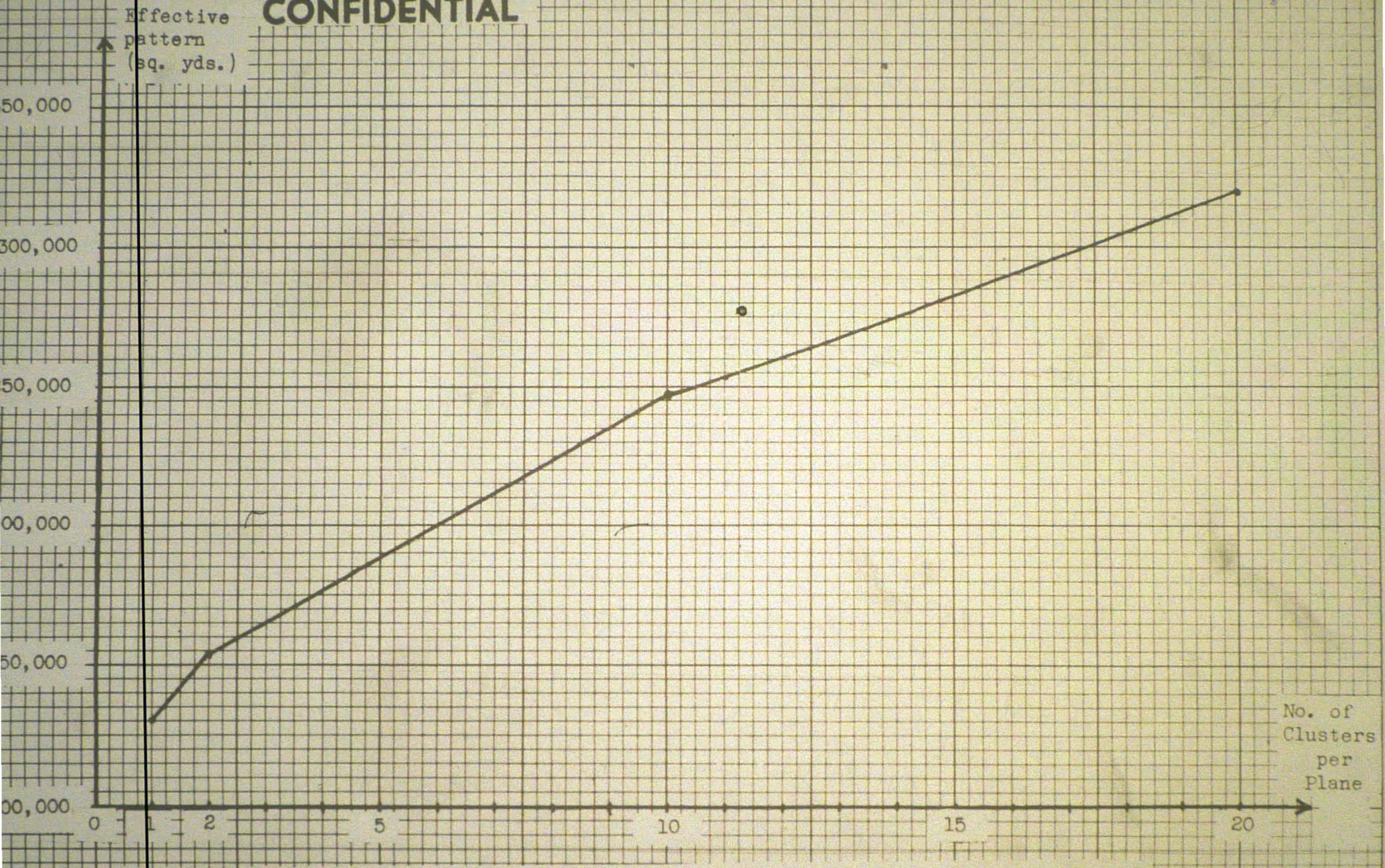

C Variation of effective pattern area with the number of clusters released per plane. (Quick-opening clusters, minimum intervalometer setting)

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NO. CLUSTERS DROPPED	NO. BOMBS DROPPED	ALTITUDE OF		TOTAL PATTERN (SQ. YD.)	TOTAL DENSITY (BOMBS PER 10,000 SQ. YD.)	APPROX. % IN EFFECTIVE AREA	EFFECTIVE AREA	EFFECTIVE DENSITY	AVERAGE DISTANCE APART OF BOMBS IN EFFECTIVE AREA
		CLUSTER RELEASE	CLUSTER BURST						
18	1980	16,000	5,000	377,000	52.8	95	180,000	104	10 yds.
53	5830	16,000	5,000	380,000	177	90	160,000	328	5.5 yds.

The double release has about 1.75 times the effective density of the single release and the six-cluster per plane release about 5.5 times the effective density of the single-cluster release. An extrapolation gives an effective density of over 600 bombs per 100 x 100 yard square for the twelve cluster salvo, which means an average distance apart of a little over four yards. It is to be emphasized that this expected density of 600 bombs per 10,000 square yards if far higher than can be obtained with quick-opening clusters using similar releases. This gives maximum density for the formation. The following principle is suggested. (see graph, p. 71) subject to verification or modification on the basis of further tests and analyses: **When aimable clusters are salvoed, the density, for a given type of cluster, is approximately proportional to the number of bombs dropped. The pattern area remains roughly the same.** In this statement, "salvoing" is taken to mean a release with minimum intervalometer setting, about 10 feet, this being mechanically simple and making for a more compact pattern than a genuine attempt to salvo by manual release.

§4. **DEPENDENCE OF DENSITIES ON ALTITUDES:**

a. **Nature of Dependence.** - The above results on aimable clusters show a pronounced effect of altitudes on patterns. This appears to be true for releases from about 15,000 feet and depends not so much on dispersion as on the increasing difficulty of flying tight formations as the altitude increases above this level. The graphs on pages 72, 73, show the behavior on the basis of these tests. They should be accepted only with due consideration, of the limited number of observations on which they are based.

§5. **APPLICATION TO TACTICAL CONDITIONS:**

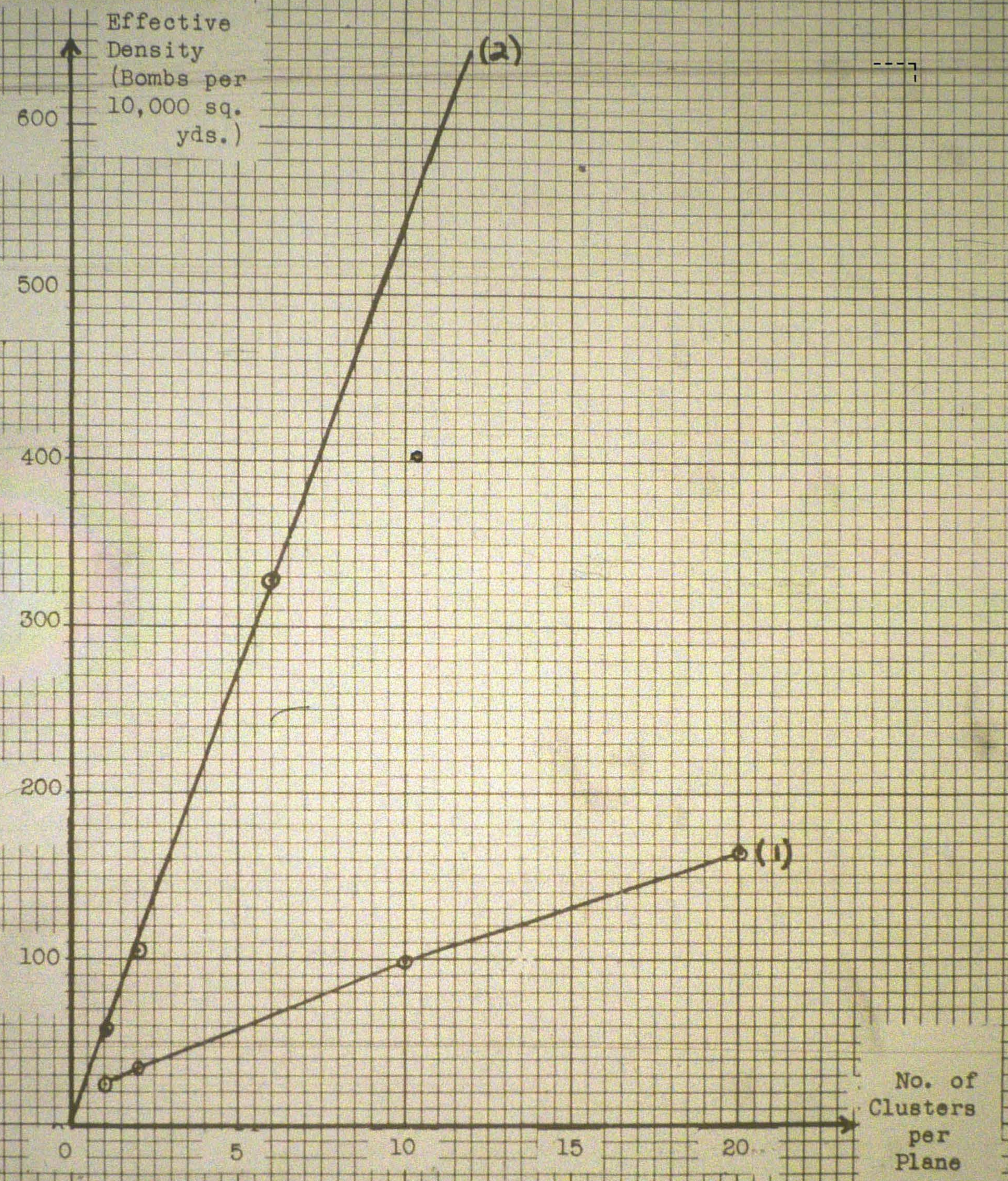
a. **Mission Planning.** - In a practical problem of attack on a target, the mission-planning officer uses the best available estimates of the following vulnerability properties, which determine the required density: (1) the target area and its analysis into fire-divisions: (2) The percentage of the target area which is combustible: (3) the percentage of duds to be expected: (4) the percentages of bombs which either (a) fail to transmit fire, (b) produce non-continuing fires, or (c) produce fires which can be controlled by defenses. On the basis of the knowledge, he is able to estimate how many hits per fire-division are required to insure destruction of the fire vulnerable portion of the target. The number of hits per fire-division gives a density requirement. However, the number of bombs delivered on the target should be more than enough to produce this density, since random variations might result in fairly thin parts of the pattern landing on some of the fire-divisions. This use of a higher density than seems necessary has the effect of introducing a safety factor to compensate for thin parts of the target. Probability tables for scatter bombing, or a scatter-bombing calculator, give an idea of how big a factor to use for a required assurance of destruction. The results of the present chapter enable one to determine, for the most appropriate incendiary bomb and planes, how best to achieve the necessary pattern area and density.

b. **Example 1.** - In the next chapter, an illustrative problem will be carried through to demonstrate the use of the entire body of results contained in this paper. For present purposes, ar assumed tactical situation will be more briefly discussed, with emphasis on the bomb density phases of the problem. An industrial group of buildings forms an area target covering a rectangle 800 x 1,200 yards. About 30% of the target area is covered with buildings of fire resistant roof construction containing combustible materials distributed over about two thirds of the area within the buildings. Taking into account separate buildings and fire-stops within them, it is found that the 288,000 square yards of combustible buildings present an estimated forty fire-divisions, having a mean area of 7,200 square yards; (for example 60 x 120 yards). Fire defenses are assumed organized, with squads assigned to each fire-division, so that an average of six slowly destructive fires, or two rapidly destructive per division can be handled.

c. **Solution.** - In order to emphasize the density requirement aspect of the problem, let it be supposed, without detailed argument, that penetration, inflammability, and availability considerations reduce the choice to aimabl M17A1 clusters or else M47 bombs carried in formations of B-17F planes. In order to assure destruction, let it be required that an expected four fires per division be started over and above what the defenses can handle. In terms of slowly destructive fires,(M17A1 clusters), this implies 10 containing fires in each division, six being subject to enemy control. The bombs in these clusters being of the intensive type, and inflammable materials covering only two-thirds of the fire-divisions area, about fifteen bombs would have to function within each division to start the required number of fires. Let it be supposed that experiments with simulated targets have revealed that 25 hits per section afford a reasonable allowance for duds, failures to penetrate roof, and failures to transmit fires. This density corresponds to 35 bombs per 100 x 100 yard square, but a considerably higher density is needed to give reasonable assurance against the escape of some fire divisions due to thin parts of the pattern landing on them. The target area can be covered, with a reasonable allowance for aiming error, by two effective patterns about 500 x 1,400 yards. Such patterns are obtainable from 20,000 feet, with the use of twelve M17 clusters in each of nine B17-F bombers. An intervalometer setting of 380 feet assures the correct effective pattern length. The effective pattern area is 700,000 square yards. If nine-plane formations are used, then each formations drops 11,880 bombs, and an estimated 10,000 (a little less than 90%) will be in each effective pattern. This gives an effective density of about 143 bombs per 100 x 100 yard square, approximately four times the required density. It gives, on the average, 100 hits per fire-division area and thus affords reasonable assurance that no fire-division will escape with fewer than 25 hits. Hence, the employment of eighteen B-17F bombers loaded with twelve M17A1 clusters each offers a high probability that the entire target will be destroyed. Consider next the use of M47 bombs. The special loading of forty-two to a B-17 bomber (See Chapter V) will be assumed. Again, two nine-plane formations will be required, and a spacing of bombs and planes such as to assure a pattern about 1,400 yards long by about 500 yards wide for each formation. This gives patterns totalling 200 yards wider and longer than the target, so as to allow for aiming errors. Assuming the total of 378 bombs from each formation to fall on the expected 700,000 square yards, there results a density of 5.4 bombs in each square 100 X 100 yards or 4 bombs for each area the size of a 60 X 120 yard fire-division. The M47 is of the scatter type and, in the present problem, falls so densely that the scattering of burning oil can almost bridge the gap between impacts. Assuming 100 percent functioning and a regular distribution of bombs, the fire defenses would be saturated, as in the previous solution, and the target destroyed. However, with an average density of only 4 bombs per fire-division, the chances of some divisions escaping entirely, or receiving just one or two hits controllable by fire-fighters is good as compared to the corresponding possibilities using M17 clusters.

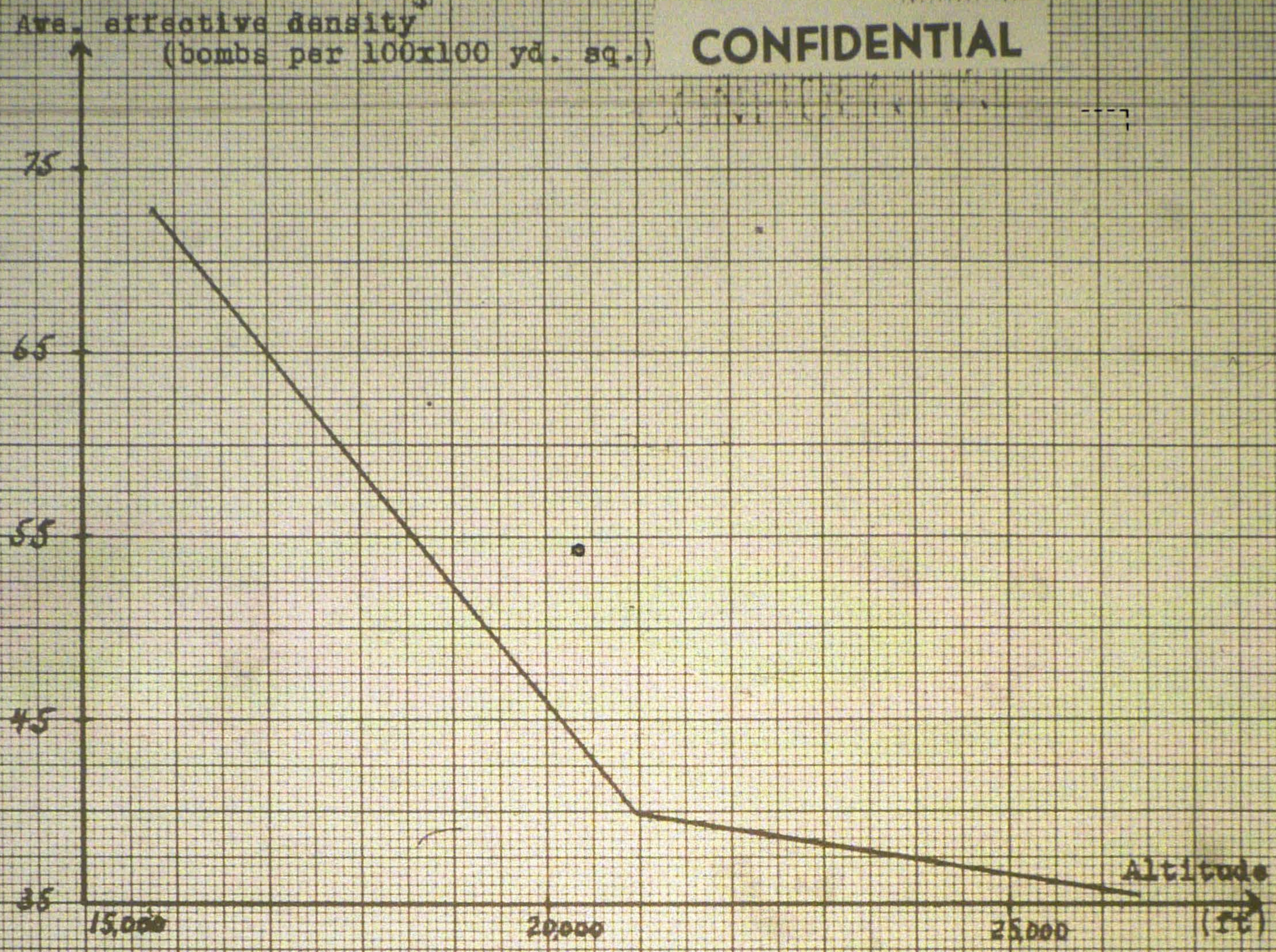
d. **Conclusion.** - In the present case, either the M17A1 clusters or the M47 bombs, used in eighteen B-17 planes flying nine-plane combat box formations would give a good probability of target destruction. The probability of complete target destruction is higher for the M17A1's which therefore are selected.

NOTE: In the preceding example, if the fire-divisions were sufficiently larger, the M47's would be the chosen bomb, since they would start many quickly-destructive fires per division on the average. If the fire-divisions were made smaller than in the preceding ex-

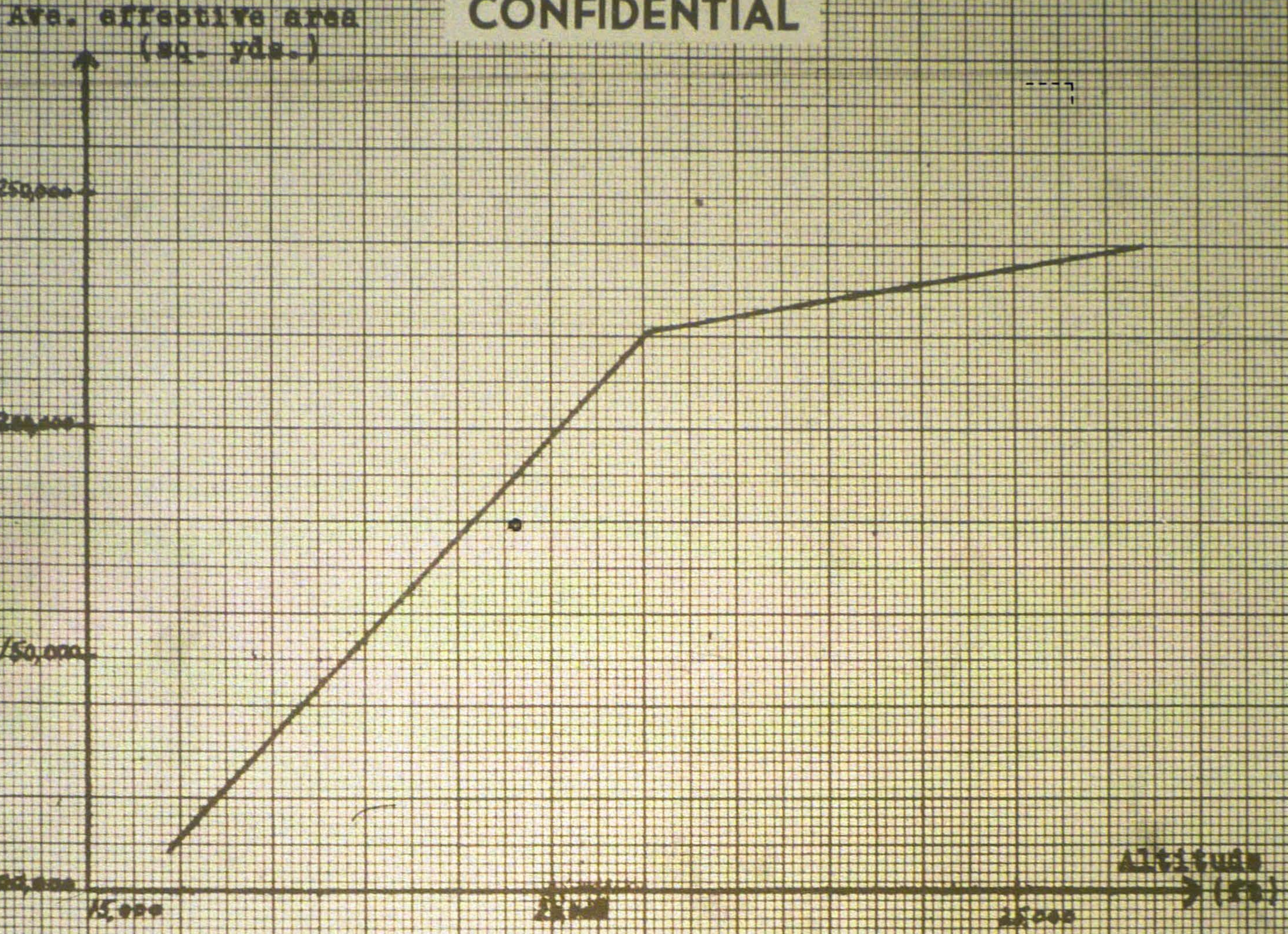


Variation of effective density with number of clusters released per plane, using minimum intervalometer setting.

(1) Quick-opening clusters.
(2) Aimable clusters (three plotted points, together with the best-fitting straight line)



Variation of average effective density with altitude for formation patterns resulting from aimable M17 clusters dropped by 9 planes in combat box formation. Based on experimental drops, one cluster per plane, with clusters set to open at 5,000 ft.



Variation of average effective area with altitude for formation patterns resulting from aimable M17 clusters dropped by 9 planes in combat box formation. Based on experimental drops, one cluster per plane, with clusters set to open at 5,000 ft.

ample, their probability of escape with the M47 would increase, and the relative advantages of the M17 clusters would be more pronounced.

e. Example 2. - A built-up area of highly inflammable light structures with 60% roof coverage is to be attacked. Conditions are favorable to a conflagration. A detailed analysis of this sort of target reveals that the M74 is the most favorable choice, (with the M69 as second best), in view of (1) its tail-ejection* scattering properties, (giving it the advantage over other small bombs), and (2) its greater plane-load efficiency for this type of target, as compared with the larger bombs, especially if tactical considerations make quick-opening clusters practicable. The expected concentration of uncontrolled, continuing fires is larger for the M74 or M69 than for other types of bombs in the present case.

§6. SUMMARY:

Experimental results disclose the sort of pattern densities obtainable with formations which are tactically sound and adapted to incendiary bombing attack. A study of various nine-plane formation releases [1 cluster, 2 cluster salvo, 10 cluster salvo (quick-opening), 20 cluster salvo (quick-opening), 6 cluster salvo (aimable) and 20 cluster train (quick-opening)] gives a basis for approximate computation of pattern characteristics for different plane loadings, altitudes, and intervalometer settings. Further tests are desirable to strengthen the statistical basis for these studies and extend them to other types of bombs and clusters. The results of the present chapter complete the practical basis for incendiary mission planning. It is safe to conclude that on vulnerable area targets of 300 x 300 yards or larger, formation patterns can be dropped with such density as to saturate all fire defenses and give a high degree of assurance that the target will be destroyed. If the target is too large to be covered by a single pattern, several formations, each with its assigned area and aiming point, can distribute patterns so dense as to saturate all defenses and assure target destruction. If a domestic area target is such that a conflagration is possible, then (with the aid of good wind conditions) a sufficient number of fires started in one part of the area can be expected to sweep through the entire target, by virtue of the spreading effects of fire.

VIII. ILLUSTRATIVE MISSION AND DISCUSSION OF PRINCIPLES

§1. INTRODUCTION:

The successful employment of incendiary bombs requires careful consideration of all the factors affecting their use. The final tactical recommendation that directs their employment should be based on the considerations discussed in the present report. If it is decided that a particular target is combustible and that more destruction can be created by fire than by high explosives, then the raid becomes an incendiary mission, and the prime weapon is the incendiary bomb. Target destruction must be assured by considering the target properties which determine (1) the best bomb to be used, (2) the quantity required on the target, and (3) the method of placing the bombs on the target. Only when all these factors have been properly evaluated can a fair estimate of expected target damage by incendiaries be made. If the target is one of low combustibility due to structure, contents, etc., and if incendiaries with high explosives can be profitably employed, then high explosives constitute the primary weapon and incendiaries should be used only as a supplement to cause such additional damage as possible. In such cases, their effect should not be evaluated from the viewpoint of target destruction by incendiaries but rather from the viewpoint of damage supplementary to that caused by high explosives.

§2. ILLUSTRATIVE MISSION:

Before the findings and recommendations arising from this report are formulated, an illustrative solution of an assumed practical incendiary mission-planning problem is given. This will serve to summarize and coordinate the various parts of the paper, showing how each topic treated enters into the most practical of applications.

a. Statement and Analysis of Problem. - Assume the target is a group of buildings, of the sort mapped in the diagram on page 76. A rectangle drawn just big enough to enclose the target measures 800 yards by 1,200 yards. The target is first analyzed into fire-divisions, (See Chapters I and II). A map based on aerial photographs and other information may fail to reveal all the fire-divisions, but experts familiar with the type of construction insert probable fire-divisions if their presence seems likely. These are suggested in the diagram by dotted lines, representing assumed fire-stops. It is decided that the fire divisions marked with diagonal lines in the diagrams are primary targets, because of their size, their combustibility, and the fact that they include parts of the industrial area necessary to continued production. The mean fire-division area is found to be about 1,070 square yards (or 9,630 square feet). The considerable number of small divisions indicates the use of clustered small bombs rather than larger bombs. Fire guards are well-organized, but since the target area can be covered by a single, well-placed formation pattern, it is decided not to sacrifice any of the plane capacity to high explosives, but rather to depend on a heavy concentration of IB's, some being of the anti-personnel type, to overwhelm the defenses. The M50XA3 contain sufficient charge to be lethal in a confined space. The penetration requirement is strong, ruling out M69's. Results of tests on analogous structures with the same sort of contents have shown that about one intensive-type small bomb out of six functioning within the target can be expected to start a continuing fire. This measures the degree of vulnerability (Chapter II). Fire-fighters are assumed able to control a maximum of five such fires per fire-division (Chapter II). The bomb best satisfying the requirements for this particular target is the M50 bomb. This is determined with the aid of the above target analysis compared with the analysis in Chapter III of bomb properties. Anti-Aircraft defenses force the attackers to work at altitudes of 25,000 feet, so that aimable clusters, being subject to less wind effect, and being adapted to the tactical formations flown by the aircraft, are preferred to the quick-opening types (Chapter III). The decision having been made to use aimable clusters of M50's from 25,000 feet, the next question is that of quantity requirement. Thirty penetrating bombs per division should, according to the above, start five dangerous fires, enough fully to occupy the fire defenses. An added eighteen per division should start three more such fires, enough to insure destruction even if the fire-squad, by unusual efforts, extinguishes one or two fires above their expected maximum. This gives a desired total of 48 penetrating, functioning bombs per division. Occasional non-penetrating and malfunctioning bombs have been found, by tests, to average 11% of the load. Hence 54 hits per fire-division are required. That means a density of 54 hits in every 1,070 square yards or 502 hits in every 100 x 100 yard square (10,000 square yard area). On the basis of the work of Chapter VI, it is estimated that effective patterns about 600 yards wide may be expected from a combat box formation dropping from 25,000 feet. This would allow 200 yards leeway for possible deflection errors in trying to lay a pattern the length of the target. This leeway of 100 yards either side, however, allows for a deflection error of only 100 yards. Accordingly, it is decided to have two squadron formations fly across the target, with the indicated headings and aiming points. The allowable deflection error then becomes 150 yards. The pattern length should be adjusted to about 700 yards, by suitable spacing, so as to allow 150 yards for possible range error in aiming the effective pattern center. Since the desired pattern length is only 100 yards longer than the minimum pattern length, the distances from the first pattern center to the last, in train, should be 100 yards. There being 12 clusters in a train, using B-17F's, the correct setting is a little over 9 yards. An 18-plane combat box formation putting 90% of its load of 23,760 M50 bombs into an effective area of 600 x 700 (420,000 sq. yds.) achieves a density of about 510 bombs per 100 yard square. This is just a trifle over the required density of 502, and therefore does not allow a good safety factor for irregularities in density. However, a safety factor was used in giving each fire-squad three more fires than it can handle, so the density should be sufficient for a reasonable assurance of target destruction. It is decided to send two 18-plane combat box formations of B-17's against the target, fully loaded with M17A1 clusters, using an intervalometer setting of 27 feet. The diagram on page 77 shows, superimposed on the target, one of the single-cluster, 9-plane formation patterns from the

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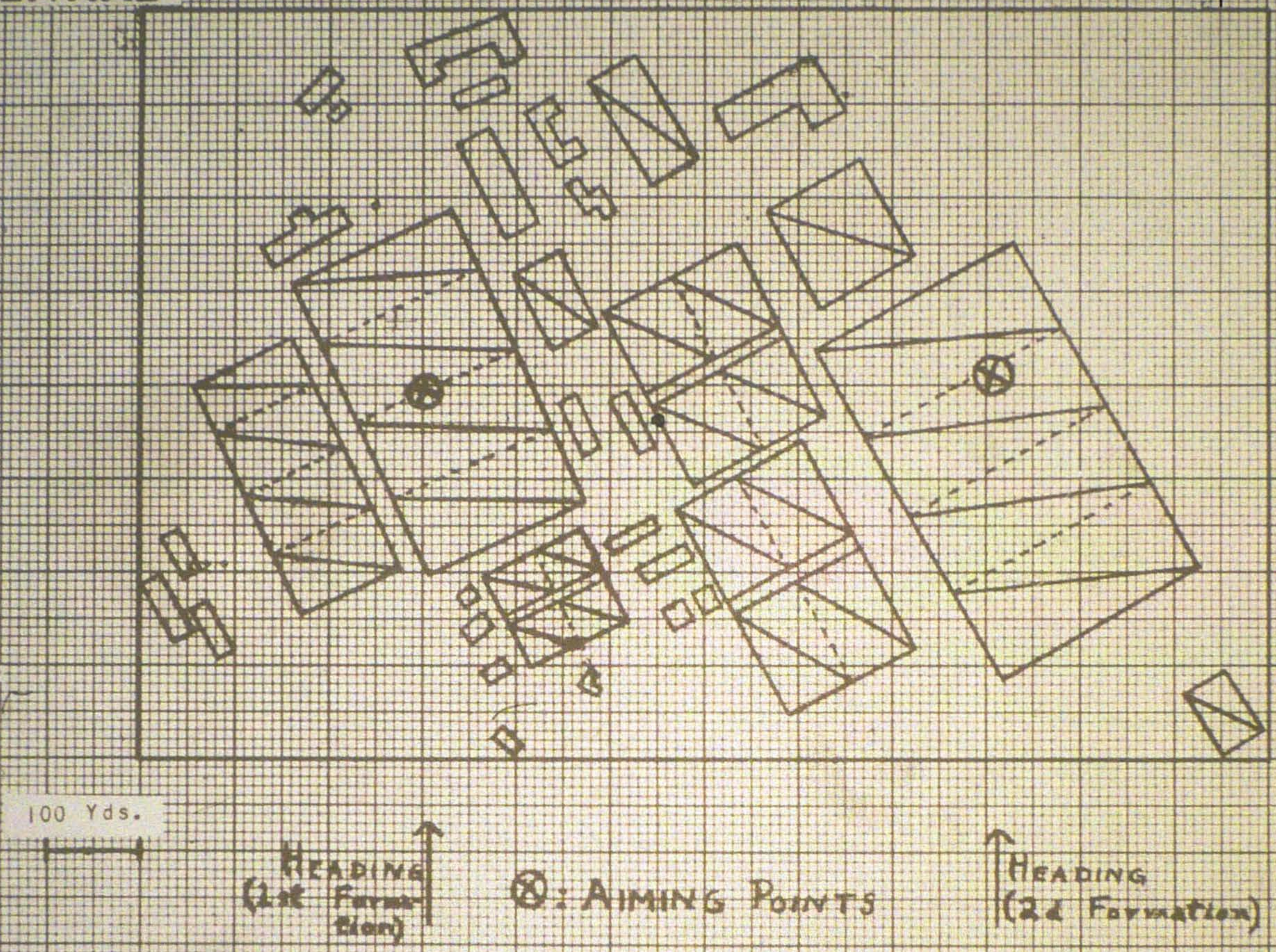

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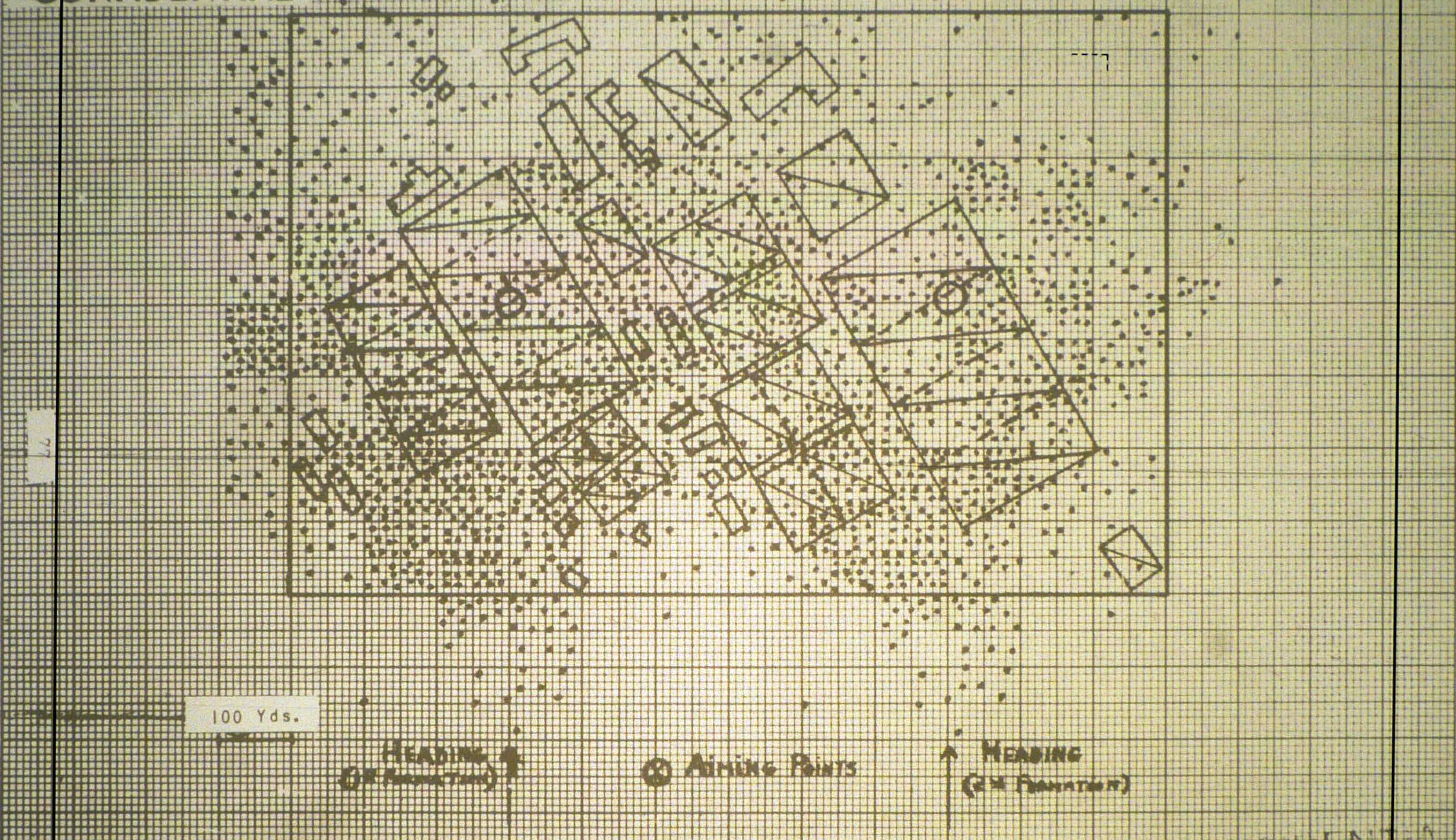

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Avon Park tests. In the present case, this is 1/24th of the total bomb load. This pattern can be thought of as reproduced 24 times in a train with effective length of 700 yards, to get an idea of density. M17 clusters were used.

b. **Influence of Fire Divisions.**- Note that the heavy density requirement in the above example is associated with fairly small fire-division areas as compared with built-up areas of inflammable housing with 50% roof coverage. Heavy bomb density requirements are to be expected in industrial targets.

§3. DISCUSSION OF PRINCIPLES:

a. **Targets.**- From the foregoing report, it is evident that different theatres of operations present differences in vulnerability between incendiary targets of the same general nature as, for example, built up areas of housing. German targets are as a general rule more heavily constructed, offer medium combustibility and, due to the relatively numerous fire-divisions contained within a target area, together with abundant fire control squads, present little chance of general conflagrations. The tactical decision to attack the average target in the European Theatre with incendiary bombs should be based on the thought of fire damage that can be created within the area actually hit by bombs. The hope of causing fires to engulf surrounding areas is remote, and it is not recommended that incendiary missions be planned with this in mind. However, it is not implied that attempts at large-scale area damage by fire should be abandoned. If a large-scale effort is planned, then the area in which incendiary bombs are to be dropped becomes the target area, and all factors of planning used to carry out a successful smaller target mission must be utilized. Random incendiary bombing of light density will seldom, if ever, produce results in German area targets; first, because adequate fire control measures are available to counteract the bombs, or their resultant fires, due to their lack of concentration and second, because of fire-divisions which preclude the hope that over-looked or unattended fires may develop into large area conflagrations. In the Far Eastern Theatre (Japan), the target generally presented offers all the capabilities of conflagration. Target considerations for Japan should include the objective of destroying large fire-divisions with the aid of spreading fires. The bomb pattern need not cover an entire fire-division, (area bounded by wide streets or waterways) but may be so placed as to start major fires located with consideration of the probable effects of surface winds on their continued development and spread. Throughout all theatres of operations and combat zones will appear targets different from the types most frequently considered in this report. Such targets may be native villages, isolated docks and warehouses, materiel and buildings adjoining runways at advanced air bases, etc. Each of these types of targets must necessarily be considered with respect to the following questions:
(1) Is it combustible? (2) Is it easy or difficult to penetrate? (3) Will the effective pattern area of a single tactical formation sufficiently cover it? When these questions are properly evaluated, the selection of an appropriate bomb, with the aid of tables of bomb properties, will give the best available assurance of success in destroying the target.

b. **Bombs and Clusters.**- Incendiaries are not an all-out, all-purpose weapon. There is a time, place, and condition for the use of each type of bomb and cluster. The quick-opening cluster, as a general rule, will not be suitable because of (1) limitation due to the danger of cluster parts striking succeeding aircraft in tight tactical formations and (2) the reduced aimability in increased altitudes due to adverse effects of winds upon the falling bombs. As a general rule, the aimable cluster is best for most operational activities, because of (1) its suitability for use from high altitudes, (2) the pattern densities obtained and (3) the fact that it is released in the same manner as any GP bomb, so that no restriction is imposed on the tactical formation to be used. However, since quick-opening clusters always contain more bombs, pound for pound, than aimable clusters (58% more in the case of M74's and M69's) the quick-opening cluster should not be completely rejected. For low altitude release, the quick-opening cluster presents a very satisfactory method of "throwing" the bombs into the target. Such methods result in saturating the target and increase the probability of hits. Tests indicate that on certain built-up areas, a striking angle of 70° reduces the "dead space" between structures by roughly 38%. With a 30 degree angle, a bomb just missing the roof of a typical one-story building will strike the side or top of the next, even if the adjoining building is 21 feet distant. Therefore, low-level raids produce the optimum of hits and necessarily must be made with quick-opening clusters. Certain tactical formations can be flown from medium to high altitudes in which quick-opening clusters can be used. Such a formation is the squadron front (V of V's stacked down), in which there are no lower following elements of the formation to be endangered by cluster parts. This formation has been used in Italy with marked success with quick-opening clusters. The aimability of quick-opening clusters from 8000 feet or less is quite satisfactory. However, it must be noted that the effective area of the quick-opening cluster in formation patterns contains about 65% to 75% of the bombs, while the effective area of the aimable cluster contains from 85% to 90% of the total bombs. Therefore, from a tactical standpoint, it appears that

(1) Quick-opening clusters should be used on releases from deck-level to medium altitude (8000 ft.)

(2) Aimable clusters should be used from medium to high altitudes with fuzes set to burst the clusters at about 5,000 ft.

c. **Bomb Selection.**- Once the decision to use incendiaries has been made, the next most important step is the selection of the incendiary bomb most likely to produce the best results. The tactical recommendations for the bomb to be used should be weighed carefully considering the following factors:

(1) Type of target.

(2) Penetrability.

(3) Fire-division areas.

(4) Capability of fire development.

By careful consideration of each bomb's capability, it is noted that restrictions must be placed on its usage. As an example, the M50 4-lb. magnesium bomb will penetrate too readily for a typical Japanese house. It is very likely to pierce the structure and come to rest under the house where its fire-raising capabilities are at a minimum. On the other hand, the M69, with only one-half the striking velocity of the M50, will come to rest somewhere inside the structure and where its maximum fire raising effect can be produced. If an industrial target is of such type that developing fires of major proportions must be created in the minimum time so as to be beyond the control of amateur fire defenses, the M47A2 bomb should be selected. For each bomb there is a definite requirement and capability and when these are properly matched to the target, the maximum can be expected in fire damage. The table in Chapter IV sets forth the recommended bombs for most types of targets. When considering a target not covered by those recommendations, the closest approximation to the target at hand with the table can be used. After operational use of all the incendiary bombs by combat organizations, damage assessment records of the organizations will substantiate and influence all IB selections. For the present, the aforementioned table will serve as a tactical guide.

d. **High Explosives and Incendiaries.**- The decision to use high explosives in excess of 100-lb. bombs in connection with an area incendiary mission must be made with the knowledge that the HE will not aid the incendiary action. In some cases, the use of HE for specific targets in connection with an incendiary mission may be indicated. However, the use of HE bombs in excess of 100 pounds for supplementary action of increasing fire or disrupting fire defenses, within the incendiary target area, should be discouraged. Tests on typical Japanese built-up area targets have proven that no aid is given to the fire development. On the contrary, such bombs diminish the development of fire. However, the use of 20-lb. fragmentation bombs in clusters may prove to be highly effective in disrupting fire defenses, and these bombs are of insufficient violence to affect developing fires. Therefore, it is considered that 20-lb. fragmentation bombs with the IB's are (among present standardized bombs) the ideal HE-IB combination for Japanese built-up areas in overall proportions of approximately 20% HE fragmentation and 80% IB. In cases where 20-lb. fragmentations cannot be obtained, the 100-lb. HE can be used, but is recommended only as an alternative. These bombs can be so laid as to intermingle with the IB pattern.

e. **Formations and Altitudes.** - The formations to be used and the altitudes flown are usually tactically dictated in the combat area, due to defensive considerations. The necessity for closely considering the formation is clearly indicated in the tactical patterns discussed in the preceding chapters. Therefore, when defensively permissible, the tactical formation should be selected for an incendiary mission on the basis of target coverage. A direct relationship exists between altitude and formations; since, as the altitude increases, the difficulties of maintaining a tight formation increase. Formations at altitudes of 25,000 feet are usually looser than at 10,000 feet. Therefore, breaks in pattern may develop and an increase in pattern size usually occurs with a corresponding decrease in bomb density. When placing incendiaries on any target area, the tactical element, whether it is 3, 9, or 18 airplanes must be considered as the pattern unit. The expected pattern from this unit must be evaluated against the target area in order to determine coverage and density. With a knowledge of the type of target in relation to its inflammability and penetration, the area of coverage can be arranged by flight plots of the tactical formation to be flown; and, with knowledge of bombs required per given area to saturate the fire defense, the altitude and intervalometer settings can be decided. Thus, the tactical recommendation as to altitude and formation for optimum results can be determined, as indicated in the preceding illustrative example.

f. **Records.** - In view of the fact that incendiary bombing to date by our Air Forces, has been confined chiefly to use of the 100-lb., M47A2, complete and thorough incendiary damage assessment records for all types of bombs are not available. It is urgently recommended that tests of the sort described in Chapters VI and VII be conducted, using tactical combat formations, for all types of incendiary bombs and clusters. It is further recommended that accurate damage assessment records be kept in all theatres for the various incendiary bombing operations. Copies of such records should be forwarded to the AAF Board for evaluation, in order that a comprehensive doctrine of employment may be developed based on actual operations.

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