U. S. AIR FORCE

PROJECT RAND

RESEARCH MEMORANDUM

U. S. ACTIVE AIR DEFENSE, 1956-1960:
ATTRITION AND TARGET DAMAGE ESTIMATES

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RM-1166

ASTIA Document Number ATI 210800

5 January 1954

Assigned to ____________________

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PREFACE

This is one of a series of RAND Research Memoranda which discuss aspects of the active air defense of the continental United States. The series is a part of RAND's study of high-attrition air defense, reported in RAND Report R-250, Active Air Defense of the United States, 1954-1960, December 1, 1953 (Secret Restricted Data). The study evaluates various choices in development, procurement, and deployment for several budget levels, including budgets considerably higher than current ones. The time period studied includes operations between 1956 and 1960; the general framework of the study is similar to that described in RAND Report R-227, Air Defense Study, October 15, 1951 (Secret), except that a wider range of questions is considered. In many ways this series serves to extend, modernize, and modify R-227 and its supporting Research Memoranda. A list of the publications in this series are given on the next page.

Since this research memorandum describes the analyses pertaining to the discussion and conclusions in R-250, it is based on information available at the time of preparation of that report (fall, 1953). Unfortunately the pressure of other tasks has delayed publication of RM-1166 for a little more than one year. For this reason, some of the radar and weapons programming data and some of the nomenclature are out of date as of the time of publication (March, 1955). In writing this memorandum no attempt was made to take into account other air defense studies such as ADR54-60, or the AFDAP DPO, or the deliberations of Project Lamplight. The Air Defense budget level to which most attention is given in this study is intermediate between the present ADC budget and the level proposed in ADR54-60. For the budget level considered, the air defense effectiveness estimates presented are felt to be realistic. It is hoped, furthermore, that the methodology and detailed treatment of weapon characteristics will be useful to those engaged in future air defense studies.

LIST OF PUBLICATIONS PERTAINING TO THE

RAND HIGH-ATTRITION AIR DEFENSE STUDY

No.	Title	Author	Date	Class.
R-250	Active Air Defense of the United States, 1954-1960	Barlow	12/1/53	Secret RD*
RM-1031	Distant Early Warning in the Defense of the United States	Barlow	11/24/52	Secret
RM-1075	Possible Offensive Capability Against the U.S.: 1953-1960	Johnston Barlow Dadant	5/1/53	Secret*
RM-1076	Notes on Targets in Planning the Air Defense of the U.S.	Capron	5/1/53	Secret*
RM-1077	Contiguous Radar Coverage in the U.S. Air Defense System: 1953-1960	Barlow	5/1/53	Secret
RM-1078	Identification Procedures for Air Defense	Barlow Attaway	5/1/53	Secret
RM-1079	Data Handling Systems for Air Defense	Dadant Reich	5/1/53	Secret
RM-1080	Electronic Countermeasures Against U.S. Air Defense: 1953-1960	Barlow	5/1/53	Secret
RM-1081	Examination of a Subsonic Area Defense Missile with Low Altitude Capability	Barlow White Mallett	5/1/53	Secret
RM-1082	The Use of Atomic Explosives in Air Defense	Barlow Holbrook	5/1/53	Secret* **
RM-1100	The Use of Atomic Explosives in Air Defense--Including Supplementary Data	Barlow Holbrook	12/22/53	Secret RD*
RM-1166	U.S. Active Air Defense, 1956-1960: Attrition and Target Damage Estimates	Attaway Brom Dadant Dudley Keith	1/5/54	Secret*
RM-1170	Air Defense Study: Cost Methodology (Radar Network, Aircraft, and Missile Systems)	Cost Analysis Section	9/2/54	Secret RD*

* Limited Distribution
** With AEC Restricted Data Supplement

ACKNOWLEDGMENTS

The analysis described in this research memorandum is the work of a number of technical personnel at RAND, aided in many essential respects by outside organizations. Much valuable and pertinent information furnished by outside agencies was obtained informally, and it has not been possible to indicate these sources by footnote references to published reports.

The work described here was part of a broader program directed by E. J. Barlow assisted by J. F. Digby. The authors wish to thank them for their invaluable guidance and assistance throughout the study.

In addition, the authors wish to acknowledge participation of the following people within RAND:

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D. E. Emerson
R. H. Johnson
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SUMMARY

This research memorandum outlines the methods of campaign analysis which were used in the high-attrition air defense study reported in RAND Report R-250.(1) The assumptions concerning the deployment and employment of U.S. defense forces were based in part on Air Force programs and in part on logical extensions of these programs to reflect increased air defense budgets. Assumptions were made concerning the vehicles which the USSR could use in an attack on the U.S. during each two-year interval. Russian force programming and tactics were optimized for each time period subject to a fixed budget constraint, to reflect changes in U.S. defenses and in the state of the art for bombs and delivery vehicles.

The method of strike analysis which evolved during the study was based on a detailed map exercise for each strike. The bomber forces were engaged by the active defenses in detail, and numerous tactical decisions were made during the course of each strike. Probability calculations were used to compute the outcome of each engagement. As the work continued, a two-stage map exercise developed. For each strike a preliminary estimate of attrition for various attack patterns was worked out by the offense. This estimate included a choice of targets and routes as well as the assignment of the numbers of bombers, bombs, and in some cases decoys to each target. The operations of the defense were then considered in detail to obtain a final estimate of bomber attrition and bomb damage for the particular strike pattern chosen. If these final results were significantly different from the preliminary offensive estimates, some aiming points and routes were changed to achieve maximum effectiveness by the offense. Target systems considered were SAC bases, urban centers, oil and steel production, and

Washington, D. C. The scoring of success was in terms of the amount of "war industry value added" which could be destroyed in an attack, and in terms of the number of SAC bases destroyed. Sixteen strikes were carried out, covering a period from 1956 through 1960 and assuming Russian use of TU-4, IL-28, Type 31, and B-47-type bombers, and Snark-type missiles.

It appeared that with bomber forces which the Soviet Union might conceivably prepare at any time during the period studied it would require a considerable additional defense effort (over the basic effort assumed herein) to keep the damage in a bombing attack below 15 percent of U.S. war industry value added. A damage of 30 percent to 60 percent might be achieved by the offense in 1956 if defense system performance were seriously degraded.

To keep pace with the Soviet forces assumed in this study, an expenditure of 40 to 80 billion dollars on active air defense during the 1954-60 period is required to confine the damage to the U.S. to the 15 percent level cited above. This requirement would be from 60 to 100 billion dollars if the Soviet forces were increased by 50 percent over those assumed here.

Ways in which defense effectiveness might be improved include:

- o Purchase of additional weapons
- o Improved low-altitude effectiveness of area- and local-defense weapons
- o Increased training of defense personnel to handle large raids
- o Improved IFF equipment and procedures
- o Increased numbers of controllers and control channels for interceptors
- o Availability of atomic warheads for defense

- Deployment of interceptors to locations where important targets exist and adequate control can be maintained
- Development of an optimum interceptor commitment policy

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LIST OF SYMBOLS

$A(t)$	Area "swept out" or searched by interceptor's radar in time t.
A_b	Vulnerable area of bomber.
A_f	Vulnerable area of interceptor.
A_o	Area of bomber formation.
B_{OT_j}	Expected number of bombs arriving at the j^{th} target.
B_{ZI}	Total number of bombs entering the ZI.
C_{D_j}	Percentage destroyed of the oil or steel production capacity of the whole country.
C_{ij}	Probability that four interceptors, having been scrambled as an element, attack a bomber so that bomber fire is split j ways, but only i interceptors fire effectively.
C_j	Percentage of the oil or steel production capacity of the country contributed by the j^{th} plant.
CR	Combat radius for combat time t_c.
CR_o	Combat radius for zero combat time.
D	Probability that a given firing attempt by either interceptor or defense missile would not abort due to human error.
D_1	Probability that a given interceptor pass would not abort due to human error in such a way that armament was not fired.
D_2	Probability that a given interceptor pass would not abort due to human error in such a way that armament was fired.
D_A	Number of decoys entering the area defenses in a particular track.
D_L	Total number of decoys in a given track that should survive the area defenses.
D_ℓ	Optimum number of decoys which should accompany the β_ℓ bomb carriers into the local defense area so that R_ℓ bomb carriers would survive.
K_{86}	Expected number of bombers shot down by an F-86D on close control.

LIST OF SYMBOLS (Cont'd.)

K_{89}	Expected number of bombers shot down by an F-89D on close control.
$K_{99A(B,C)}$	Expected number of bombers and/or decoys killed by the firing of one F-99A(B,C).
K_{102}	Expected number of vehicles killed by an F-102 (armed completely or primarily with atomic warhead rockets) on close control.
K_{102R}	Expected number of bombers killed by an F-102R (armed completely with small rockets) on close control.
K_A	Area kill potential for the track.
K_L	Expected number of vehicles destroyed by the local defenses.
$K_{N(CW,W)}$	Expected number of vehicles killed by one battery of Nike (Talos CW, Talos W) missiles.
K_ϕ	Effectiveness of a given type of interceptor.
K'_ϕ	Probability that one pass of an interceptor destroys a missile.
$M_{99A(B,C)}$	Number of F-99A(B,C) missiles fired which could reach the bomber stream during a given air battle.
N_S	Number of salvos per battery of local-defense weapons which could be fired at a single vehicle headed directly over the battery (for one guidance unit per battery).
N'_S	Number of salvos per battery of local-defense weapons which could be fired at a single vehicle headed directly over the battery (for two guidance units per battery).
N_b	Number of rounds of bomber ammunition fired per interceptor attacking simultaneously with one or more other interceptors.
N_f	Number of rounds of interceptor ammunition fired in one salvo.
P_{BS}	Probability that a given bomber survives an air battle.
P_{D_j}	Probability that at least one bomb was delivered to a given aiming point.
P_{dc}	Probability of detection and conversion on close control.
$\overline{P_{dc}}$	Probability of detection and conversion on broadcast control.

LIST OF SYMBOLS (Cont'd.)

$\overline{P_{dc}}'$ Probability of detection and conversion on uniform broadcast control.

P_{kb} Probability that a given missile or salvo of rockets fired at a vehicle kills that vehicle.

P_{kb_j} Probability that an interceptor kills a bomber in a firing pass in which the bomber's fire is split j ways.

$P_{k\phi}$ Probability of kill of an interceptor by a bomber.

R_M Maximum firing range for local defense missile.

R_b Probability that a given bomber survives when the formation is attacked by one element of F-89D's which have been sent out on broadcast control ($\phi_b = 2$).

R_i Probability that a given bomber survives when the formation is attacked by one element of F-89D's on broadcast control on its i^{th} pass ($\phi_i = 2$), the interceptors having been originally close controlled.

R'_i Probability that a given bomber survives when the formation is attacked by any number of F-89D's on uniform broadcast control.

R_{i_S} R_i when computed for β equal to lesser of the number of bombers in the battle and 6, using the uniform broadcast control values of $\overline{P_{dc}}'$ instead of $\overline{P_{dc}}$.

R_ℓ Number of bomb carriers desired by offense to survive a given local defense area.

R_m Minimum firing range for local-defense missile.

S Lesser of 1 and $\frac{6}{\beta}$.

S_l Number of local-defense missiles per salvo.

V Closing speed of interceptor.

V_F Interceptor speed.

V_ℓ Number of vehicles entering a given local-defense region.

VAD_{ij_n} Marginal value-added destroyed by the n^{th} bomb assigned to the i^{th} aiming point in the j^{th} target.

LIST OF SYMBOLS (Cont'd.)

X_{1-1}	Probability that an element of two F-89D's has split but each interceptor independently attacks the same bomber on the second pass.
$\overline{X_{1-1}}$	Same definition as X_{1-1} except that it applies to an element of two F-89D's which is on broadcast control all the way.
X_{ij}	Same as w_{ij} but applies only to the second pass of an element of two F-89D's which were on close control on their first pass.
$\overline{X_{ij}}$	Same definition as X_{ij} except that it applies to an element of two F-89D's which is on broadcast control all the way.
Y_{1-1}	Probability that an element of two F-89D's has split but each interceptor independently attacks the same bomber on the third pass.
Y_{ij}	Same as w_{ij} but applies only to the third pass of an element of two F-89D's which were on close control on their first pass.
Z_{ZI}	Total number of aiming points for the particular strike.
Z_j	Number of aiming points in the j^{th} target.
a	Time interval between local-defense missile salvos.
a_1	Ratio of the cost of a bomb carrier to cost of a decoy (plus its portion of a decoy carrier).
b	Reciprocal of effective missile speed in seconds/nautical mile.
$b_{N(CW,W)}$	Number of batteries of Nike (Talos CW, Talos W) in a given local-defense region.
c	Missile launcher tie-up time.
d	Maximum distance in nautical miles which could be flown by an IL-28 at low altitude.
g	Siting factor for local-defense missiles.
k	Nautical miles of combat radius lost by an interceptor per minute of combat time (at the specified conditions).
k_1	Relative armament effectiveness number.
m_K	Area defense kill potential.

LIST OF SYMBOLS (Cont'd.)

m_{kb}	Expected number of offense vehicles destroyed by Bomarc missiles.
n_{ϕ}	Total number of interceptor passes in a given air battle.
p	Distance in nautical miles from the uncoupling point of the IL-28 to the target.
p_j	Probability that a given bomber arrived at the particular target for which it was briefed.
r	Distance of interceptor from point of impact at time of firing rockets.
r_1	Detection radius.
r_2	"Limit of interceptor distribution" as found in solutions for P_{dc}.
r_F	Distance between interceptor and bomber at time of impact.
r_{ℓ}	Ratio of bomb carriers sent to decoys sent.
r_{δ}	Minimum range of fire of interceptor.
s	Overtake speed.
t	Time of search by interceptor's radar.
t_c	Combat time in minutes.
u_{ab}	Interceptor operational non-abort factor between scramble and point of firing at invader.
u_b	Interceptor operational non-abort factor after completion of one pass and before firing stage of next pass.
v_{i_j}	Value-added which would be destroyed by one bomb dropped on the i^{th} aiming point in the j^{th} target.
w_{ij}	Probability that two interceptors, having been scrambled as an element, attack a bomber so that bomber fire is split j ways, but only i interceptors fire effectively.
$\overline{w_{ij}}$	Same definition as w_{ij} except that it applies to an element of two F-89D's which is on broadcast control all the way.
Δ	Greater of $\alpha\beta$ and γ.
α	Probability that a given bomber of a group of bombers would be tracked by the radar system.

LIST OF SYMBOLS (Cont'd.)

β	Number of bombers in a formation at a given point along the bomber route.
β_A	Number of bomb carriers for a particular track entering the area defenses.
β_L	Total number of bomb carriers for each track that should survive the defenses.
β_K	The number of bombers expected to be killed by a given number of a particular type of interceptor.
β_{OT}	Number of bombers expected to arrive on target.
β_{OT_j}	Expected number of bombers arriving at the j^{th} target.
β_{ZI}	Total number of bombers entering the ZI.
β_{ZI_j}	Number of bombers which entered the ZI briefed for the j^{th} target.
β_{ℓ}	Number of bombers entering a given local-defense region.
γ	Number of close-controlled passes by interceptor elements in a given air battle.
δ	Number of decoys entering a given air battle.
θ	Greater of 1 and $\frac{\gamma}{\alpha\beta}$.
ν_b	Maximum rate of fire of bomber.
σ	Standard deviation of a normal distribution.
σ_b	Equivalent dispersion of bomber armament.
σ_f	Equivalent dispersion of interceptor armament.
ϕ	Number of a given type of interceptor.
ϕ_b	Number of F-89D's in a given battle which were on broadcast control all the time.
ϕ_2	Number of F-89D's on their second pass in a battle, and hence on broadcast control, which had originally been on close control on their first pass.

LIST OF SYMBOLS (Cont'd.)

ϕ_3	Number of F-89D's on their third pass in a battle, and hence on broadcast control, which had originally been on close control on their first pass.
ϕ_{86}	Number of F-86D's on close control in a battle.
ϕ_{89}	Number of F-89D's on close control in a battle.

LIST OF ABBREVIATIONS

ADC	Air Defense Command
ADDC	Air Defense Direction Center
AEW and C	Airborne early warning and control
AI	Airborne intercept
AMTI	Airborne moving target indicator
CEP	Circular error probable
db	Decibels
DC	Direction center
DEW	Distant early warning
DGZ	Desired ground zero
ECM	Electronic countermeasure
FFAR	Folding Fin Aerial Rocket
FY	Fiscal year
KT	Kiloton
MT	Megaton
MTI	Moving target indicator
UHF	Ultra high frequency
VAD	Value added destroyed
VHF	Very high frequency
ZI	Zone of the interior

INTRODUCTION

In RAND's High Attrition Air Defense Study, which is reported in R-250,(1) an attempt was made to estimate the probable effectiveness of air defense of the continental United States in the event of a large-scale Soviet attack in the years 1956 to 1960. One of the main purposes of the study was to determine the relation of defense effectiveness to defense cost and to the weight of the Soviet attack. Thus an important part of the analysis was preparing estimates, for a number of different types of strikes, of the attrition which the defenses might inflict on an incoming bomber force and the resultant target damage achieved by the attackers. It is the purpose of this memorandum to present the assumptions and techniques used in making these estimates, and the results produced.

Contrary to the case of studies comparing various weapon systems against a common enemy none of the many factors involved in the estimates of this study cancel out, because the intent is to find an absolute result--or a true expected result--for each situation. This means that a great deal of care must be taken to reflect the pertinent factors in the most realistic manner. It was felt that these factors could be reflected most easily--and most realistically, under the limitations of the study--by the use of the "map exercise" technique.* As employed, this technique performed three functions:

1. It embedded the attrition estimates in the correct constraints as regards the geograpnical distributions of Soviet bases,

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*Insight gained via the map exercises might permit a less cumbersome technique for similar studies in the future.

continental U.S. targets,* and defense system components.

2. It provided a decision process whereby "Soviet planners" could select a set of aiming points.*

3. It provided the inputs for the estimation of overall attrition and bomb damage.

The sequence of steps within the analysis was as follows. First the Soviets were given a stockpile of bombs and bombers which could be committed to an attack against the U.S. Zone of the Interior (ZI). The former were specified in number and yield, and the latter as a number of TU-4's which could be exchanged for other types on an equivalent-cost basis. The defense was also given a budget level, specified in numbers of each component of the defense system. Then, on the assumption that the Soviets had a rather good idea of the ZI defenses, the bomb and bomber stockpiles were assigned to that set of aiming points which would maximize the damage to the target system. This was accomplished via the map exercises, in which were also performed the commitment of the defense weapons and measurements of where the battle would be joined by each weapon. The exercises thus reflected the value of each aiming point, the defense weapons defending each aiming point, the geographical relationships involved, etc. The outputs of the map exercises were the inputs to the actual attrition calculations and bomb damage assessments.

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*Throughout this memorandum <u>target</u> means a metropolitan area, SAC base, or any group of one or more aiming points protected by one local defense installation or in a city apart from other cities. <u>Aiming point</u> means the specific point on the ground over which the offense wants a bomb to explode; it is used as synonymous with <u>DGZ</u> (desired ground zero).

This report follows the same order as the analysis. Chapter I presents the assumptions on offense forces, defense forces, and targets. Chapter II extends the first by describing the effectiveness assumed for each component of the defense system. Chapter III describes the map exercises as actually performed. Chapter IV indicates the methods by which the exercise outputs were processed to obtain the overall attrition and bomb damage assessments. In Chapter V the results are presented in terms of the total damage achieved for each of the hypothetical attacks. These are given in tabular form in Table XVI. Some operational conclusions drawn from these analyses are also presented in this chapter, as is a discussion of the influence of some of the more important assumptions involved in the study. A more complete discussion of the implications of the larger study of which this was a part can be found in R-250.[1]

CHAPTER I

ASSUMPTIONS AS TO FORCES AND TARGETS

Calculations of the effectiveness of a defense system depend upon a great many input parameters involving the attacking force, the target system to be attacked, the defense system itself, and the inter-relations among these three. This chapter discusses the assumptions used for the three basic factors and the geographic relation between the target system and the defense system.

ENEMY FORCES

Vehicles

The enemy vehicles which are thought possible for the period of this study are described in Table I. This is a slightly modified version of the table appearing in RM-1075.[2] It was assumed that all of the manned bombers would be equipped with radar-directed tail turrets with twin 23-mm gun mounts. No very-high-performance aircraft or missiles were assumed to become operational before 1960. None of the submarine-launched threats listed in the table were actually considered in the study because of lack of information on the status of anti-submarine warfare. A simple extension of the type of calculations made here could be used to cover the submarine-launched cases if the size of the threat could be estimated reliably.

In order to achieve as much surprise as possible, saturate the defenses, and avoid possible retaliation between attacks, only single, maximum-strength strikes were considered in these analyses. Table II shows "basic" forces which were considered to arrive over the ZI for each year for which strikes were analyzed. As can be seen from the table, a fundamental strike

Table I

RUSSIAN STRATEGIC OFFENSE POSSIBILITIES

Weapon Delivery System	Range(1) (n.mi.) Un-refueled	Once Refueled	Speed (kn) Cruise	Target	Altitude (ft) Cruise	Target
1. TU-4	4250	5500	215	350	10,000	30,000
2. IL-28 (Wing-coupled to TU-4)	5000 (1165 for IL-28 only)		390	420	35,000	40,000
3. Submarine-launched V-1-type missile	250		450	450	Low	
4. Submarine-launched turbojet missile	500		460	520	40,000	
5. Submarine-launched jet airplane	1000		420	470	30,000 to 40,000	40,000
6. Type 31 (turboprop)	6600	8500	350	400	30,000 to 35,000	40,000 to 45,000
7. Subsonic jet bomber	3400	4150	425	475	30,000 to 40,000	45,000
8. Submarine-launched V-2-type missile	300		3000		45° angle	
9. Subsonic jet bomber (advanced)	5600	7000	425	475	40,000	43,000
10. Surface-to-surface missile (low-speed, similar to Snark)	5000		520 to 800	520 to 800	50,000	

(1) The ranges quoted are the maximum still-air distances that the airplane can fly, making the usual allowances for reserves.

(2) The term "low altitude," as used in this study, is intended to mean:

	Over water	Over land
Daylight, good visibility	50 feet	200 feet
Night or poor visibility	200 feet	500 feet

	Range loss per mile at target vel. and alt. (n mi)	Low Altitude[2] Speed (kn) Cruise	Target[3]	Range loss per mile at low alt. (n mi)	Estimated Radar Echoing Area[4] (m^2)	Date 100 Aircraft Operational	Assumed Maximum Quantity Over U.S.[5]
	1.0	200	275	0	45	now	500
	1.4	275	450	1.2	15	1955	400
					0.5	1955	50 subs with 2 each
		limited capability[6]			0.5	1955	Same as No. 3
	1.4	300	450	1.2	1.0	1955	As No. 3 but one per sub
	1.0	350	400	1.0	40	1956	200
	1.4	300	450	1.2	27	1956	400
					0.1	1956	Same as No. 5
	1.4	300	450	1.2	27	1958	450
			no capability		5	1958	1200

(3) These are maximum speeds at low altitude. All aircraft were considered to be capable of sustaining these speeds for approximately one hour prior to target on one-way missions. For the IL-28 this time was cut to 40 minutes because of range limitations.

(4) Microwave echoing areas obtained > 50% of the time, but neglecting the side-on echoing areas, are estimated here.

(5) This is a plausible assumption about the number of carriers which might reach the U.S. in a saturation strike against ZI targets, if the present and near-future effort of the Soviet LRAF is maintained. This study also examines the effect of increasing the basic Russian stockpile of bombers and bombs.

(6) Guidance is the limiting factor for this threat at low altitude. A fair capability should exist against coastal targets, but CEP would probably be prohibitive for any but the largest inland cities requiring more than 150 miles of flight.

Table II

ATTACKING FORCE ARRIVING OVER ZI DEFENSES

Year	Equivalent TU-4 Stockpile	Vehicle Type	Typical Number Arriving over ZI
1956	470	TU-4	195
		IL-28	150
1958	556	IL-28	110
		Type 31	238
1960	654	Snark-type missile	390
		Decoys	2040
		Advanced B-47-type bomber	213
		Decoys	1650

expenditure, in terms of equivalent TU-4 bombers, was set down for each year. This expenditure was then converted into numbers of the preferred weapons for each year by using cost ratios between the various vehicles. Operational abort factors were applied to the resulting weapon combinations to determine the number which might arrive over the ZI. At the same time, in the 1958 and 1960 strikes, the proportion of the force comprised by each vehicle was adjusted in order to maximize the expected damage to the U.S. Thus the final column in Table II presents numbers of vehicles which were considered to arrive over the ZI in a typical case where standard offense and defense budgets were assumed. (The exact numbers and proportions changed with any changes in target selection, budget level of either offense or defense, and attack strategy, as will be discussed in later sections.)

All of the manned bombers were given a capability for carrying out either high-altitude or low-altitude penetration of the ZI. For high-altitude attacks, the reasonable operational altitude limits of the aircraft were used. For low-altitude penetrations, figures were used which, it was felt, represented minimum feasible operational altitudes. These were:

	Over Water	Over Land
Daylight, good visibility	50 ft	200 ft
Night or poor visibility	200 ft	500 ft

An elementary examination showed the low-altitude attacks to be the most effective by a large factor in 1956 and 1958, and still the most desirable in 1960 by a smaller factor. Consequently all manned bomber attacks which were studied in detail were assumed to be at low altitude.

The long-range surface-to-surface missiles were not given a capability at low altitude, however, because of the large circular error probable (CEP) which would be caused by expected errors in the guidance system in such an attack. Hence the Snark-type missiles were envisioned as attacking at 50,000 feet altitude.

Not listed in Table I but included in Table II are the decoy vehicles for which the Soviets were given a capability in 1960. These would be small, cheap, turbojet- or ramjet-powered missiles. They would be equipped with broad-band radar repeaters which would make them appear, to all search and tracking radars of the defense system (both ground-based and airborne), identical to the bombers which they accompanied. They would have very simple guidance systems which might have an accuracy of 3% of range from their launch point. Such decoys would necessarily travel at the same speed and altitude as the bombers they were intended to simulate, and could be either a short-range type for use only against local defenses or a long-range type for primary use against area defenses. From four to ten of these decoys might be carried by a bomber, depending upon the range of the decoys and the type of bomber, and possibly six to sixteen in a cargo aircraft.

It was felt that the longer range decoys would have more utility, since all of them would dilute the area defenses and about one-half of those surviving the area defenses would be accurate enough to dilute the fire from the local defenses as well. It was also found to be cheaper per decoy used to carry them to the edge of the defended region in large cargo aircraft which did not themselves penetrate the defenses. Cargo aircraft similar to C-132's were postulated for this task, and 10 decoys of 1000 to 1200 miles' range were assumed to be carried in each. The total number of decoys which could be available for one strike was set at about 3100.

Bombs and Bombing Tactics

The Soviets were assumed to have atomic bombs of a nominal 100-kiloton (KT) yield available in considerable numbers by 1956. Since a large portion of their stockpile of bombs would probably be required for attacks on other areas and for a strategic reserve, only 375 such bombs were assumed to be assigned to a 1956 strike against the ZI.

For later years, both the stockpile numbers and the bomb yield assumptions were increased. In 1958 enough 100-KT bombs were envisioned to allow one in each vehicle launched against the ZI. It was felt that the Soviets could have a large number of fusion bombs available by 1958. Therefore, an alternative strike was studied for this year in which each carrier had a 5 megaton (MT) fusion weapon.

For the 1960 strikes the fusion weapon was considered as the prime threat, with again enough 5-MT bombs to have one in each carrier.

Three primary methods of bomb drop were considered for the low-altitude attack, where the escape problem prohibits conventional tactics. The first was toss-bombing at the end of a short, rapid climb just prior to target. Although marginally satisfactory for small yields, this operation would not allow the crew to escape a large bomb burst. The second method was a drogue parachute drop after a climb to a suitable altitude (3000 to 5000 feet for a 100-KT bomb). This has the disadvantage of placing the carrier in a position which is very vulnerable to defense action, particularly by local defenses where they exist, both during and after the climb. The third and preferred method, particularly for larger yield bombs, was use of a rocket-boosted bomb which might be launched 5 to 10 miles from the aiming point. The bombing accuracy achieved in this case would probably be acceptable, and the aircraft would be permitted to remain at a very low altitude, thus presenting the most difficulty to the defense.

Intelligence, Routes, and Coordination

A high degree of intelligence of the United States Zone of the Interior defense system was assumed for the Russians in this study. They were given credit for knowledge of the number and location of radars, fighter aircraft, and defense missiles. In addition they were assumed to know the performance parameters of all of the components, and to be able to predict the expected outcome of air battles within limits.

The most likely locations of launching bases assumed for the strike analyses are shown in Fig. 1, along with likely flying routes and distances to U.S. targets. It can be seen from this figure that one-way missions were in general a necessity, with refueling required for some missions. The Type 31 could perform a two-way strike against some targets without refueling, and against many targets with refueling. However, the target strategies which maximized the damage to the U.S. for a given offense budget always precluded all but a few two-way missions for the Type 31. Another notable fact from Fig. 1 is that a large portion of our targets can be attacked not only from the north, but from the southeast or southwest by Type 31's or refueled TU-4's.

As indicated in Fig. 1, the various bomber streams or groups of an all-out attack would probably come via different routes. This brings up the question of how well synchronized the various penetrations of first detection lines might be. Flights of this length could probably not be kept rigorously to a time schedule, but because of the unpredictability of the relative departures from programmed times and the possibilities of offsetting these by operational procedures (loitering if ahead of schedule, for example), the streams of bombers were treated as if they were perfectly coordinated, or

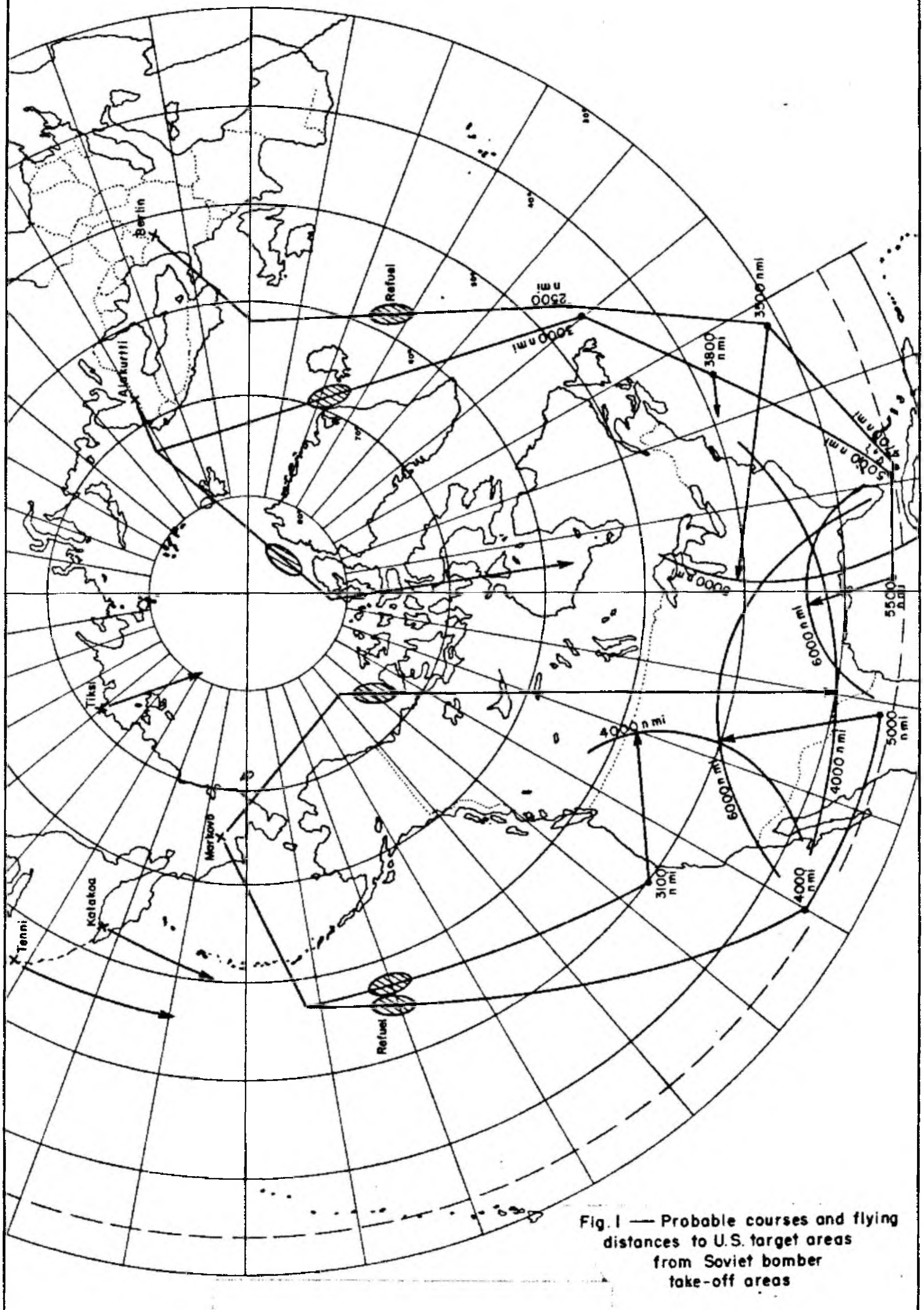

Fig. I — Probable courses and flying distances to U.S. target areas from Soviet bomber take-off areas perfectly timed for their respective penetrations of the defended areas. The effect of this assumption on the results of the analysis is discussed in Chapter V. To be fully effective, a bomb delivered against a SAC base should arrive before the aircraft based there can be flown away. Since the relative scheduling of bomber detections can cause some bases to receive premature warning, and hence allow aircraft to become airborne before being bombed, well-coordinated attacks upon SAC bases are essential. This effect of relative timing of bomb delivery upon SAC damage has not been considered in this study.

Cell Tactics

In this study the Soviets were given credit for having developed a station-keeping technique whereby one bomber could fly in a certain position relative to another by observing a return signal from it on the bombing radar or some specially built radar equipment. This radar was hypothesized as having about an 80-mile range on a beacon in the other bomber at high altitude, being limited at low altitude by the radar line of sight. Each bomber was presumed to be able to stay in its relative position with a CEP of one-half to one mile, and it was considered that upwards of 100 bombers could navigate on one lead aircraft by this method.

With this accuracy in keeping station, bombers could not fly closer than about a mile apart without danger of collisions. The resulting loose formation would have a certain tactical advantage for the offense, since interceptors could not be vectored in a group against a group of invaders. In general, therefore, the bombers attacking an area were pictured as flying in a loosely knit group or stream, the boundaries of which were defined by the maximum range of radar station-keeping ability cited above.* This stream followed down one main track into the target area, with portions of it breaking off at various points to head for individual targets.

One strike as visualized here would then consist of several of these streams of attacking aircraft coming into the various areas of the U.S. These streams would be timed to enter the defended areas according to a schedule designed for maximum tactical advantage. One or two aircraft in each stream would do the primary navigation, all others keeping station on them.

Small groups would break away from the main streams at well-defined navigational check points and head for other check points enroute to specific targets. Each such group would have a lead aircraft, the others again keeping station on the leader until reaching the last check point prior to target, from which each bomber would make an independent bombing run.

Countermeasures and Evasions of Defense

Many types of electronic countermeasures and tactical evasions of defense were considered available to the attacking force. Most of these are more fully discussed in R-250,[1] RM-1080,[3] and RM-1090.[4] They include such things as decoys, chaff in all of its applications, spot and barrage jamming of radars, jamming of communication channels, blinkers, low-altitude flights, devious routings into the U.S., evasive maneuvers,

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*The Soviets were not permitted to extend the station-keeping grid by the use of aircraft equipped with repeater beacons. Also, the defense was not given any capability for utilizing in its operations the radiation from the station-keeping system.

etc. Employment of some of these measures precludes the use--or advantageous use--of others; for example, low-altitude flights impede evasive maneuvers and mass applications of chaff. In all cases the efficacy of a countermeasure or evasion tactic must be weighed against the cost, in terms of effort and loss of performance, of using the measure, and also against other possible measures with which it may be incompatible. Also to be considered are the probability of defense employment of counter-countermeasures and the resulting "degradation confidence"* of the countermeasure.

No countermeasure was assumed to be available in 1956 which would require high-altitude attack for its optimum use and which would be as advantageous to the offense as low-altitude attack. Therefore, low-altitude attack was assumed to be chosen by the offense. In 1958 it was assumed that a capability of mass sowing of chaff by unmanned vehicles (a high-altitude measure) was available to the Soviets. However, when the pertinent factors were considered, it appeared that again the best choice for the Soviets was to execute a low-altitude attack. Among these factors were the amount of radar cover and number of control channels available at low altitude, the portion of the bomber strength which would have to be converted to chaff dispensers and cargo aircraft, and the fact that airborne moving target indicators (AMTI) would not be available for any interceptors other than the F-102. It was assumed that in 1960 advanced ground radars of the Muldar and AN/FPS-7 types would have moving target indicators (MTI) able at least to ameliorate the effects of area chaff, and that the Russians could have a large number of

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*The "degradation confidence" of a countermeasure is the probability that an expected defense degradation will result if the countermeasure is executed as intended. The concept is discussed fully in RM-1090.[4]

decoys. These considerations led to the use of both high- and low-altitude attacks utilizing decoy countermeasures.

No other specific countermeasures or defense evasions were inserted into the attacks (with the possible exception of the route selections), partially because of the difficulty in predicting confidence levels and resulting degradations to the effectivenesses of the defense system components. However, some strikes were analyzed wherein the probability of the personnel involved in the defense action doing their jobs correctly was cut in half. Part of this degradation was considered to be the result of adding some low-cost, low-confidence countermeasures to the attack.

TARGETS

In a large-scale effort to knock out the ZI, the Soviets might have any of several objectives in mind. Broadly these objectives fall into three categories: to destroy our military potential, in particular our immediate retaliatory capability; to destroy our economic system; and to disrupt our organizing and governing procedures. With these objectives in mind, a logical target system can be derived. The target system used for this study consisted of four basic parts, as outlined below.* All of the targets are shown in Fig. 2, which gives a good indication of their concentrations.

Strategic Air Command

An attempt to destroy our retaliatory capability would involve an attack against the Strategic Air Command bases in this country. This effort would attempt to destroy the SAC facilities and as many of the

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*See reference (5) for further details.

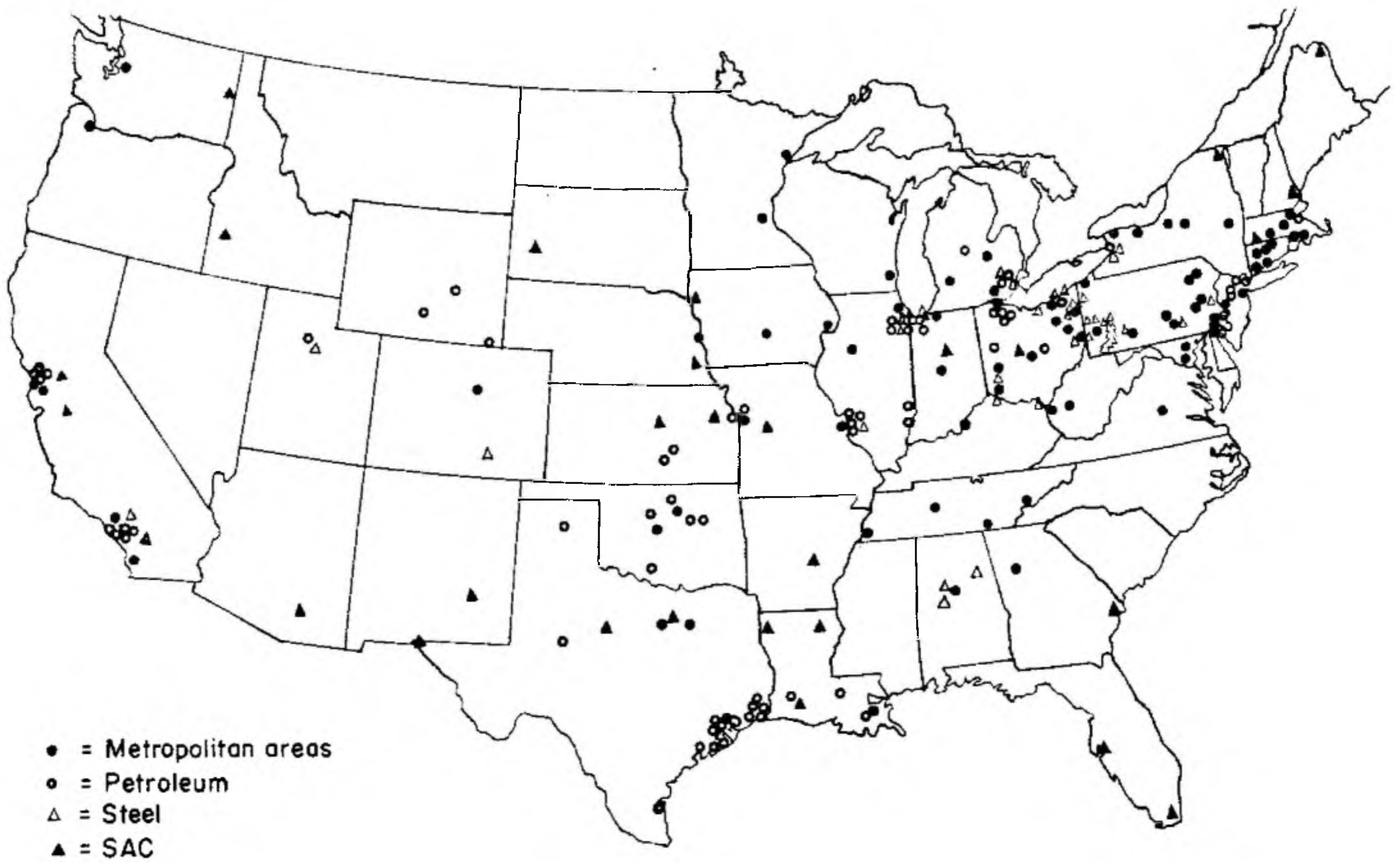

Fig. 2 — Target system

aircraft as could be caught on the bases. The SAC bases considered in this study are listed in Table III.

Urban Industrial Concentrations

Our large cities might be prime targets for a Russian attack for several reasons, among which are the destruction of population, disruption of communications and transportation, and destruction of industrial potential. Since certain types of industries contribute directly to our military potential, a bomb dropped on these facilities would serve the double purpose of destroying the economic system and the military capabilities. In this study all metropolitan areas were therefore rated on the basis of the "value added by manufacturing in war and war-connected industries" in those areas.* Damage to other industries and to communications, transportation and population were considered as either incidental or proportional to the war industry value destroyed.

Table IV lists the 159** metropolitan areas used as targets in this study, along with the total value added by manufacturing in war and war-connected industry in each area. Accurate figures for this value added were available only for the 53 largest*** metropolitan areas, so an approximation was used for the other 106, based on the total value added by all manufacturing in these areas. Although this approximation may be quite inaccurate for an

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*"Value added" is a term used by the Bureau of the Census. It is used here to mean the dollar worth added by war-related manufacturing facilities in the area to all materials brought into or originating within the considered area.

**Actually the 165 metropolitan areas listed in reference (6) were examined, but 6 of these were not included as targets because of their small values.

***Largest in total manufacturing output but not necessarily in war and war-connected manufacturing output.

Table III

STRATEGIC AIR COMMAND BASES

Abilene, Tex.	Lincoln, Nebr.
Altus, Okla.*	Little Rock, Ark.
Barksdale, La.	Lockbourne, O.
Bergstrom, Tex.*	MacDill, Fla.
Biggs, Tex.	March, Calif.
Blytheville, Ark.*	Mountain Home, Ida.
Bunker Hill, Ind.	Offutt, Nebr.
Carswell, Tex.	Pinecastle, Fla.*
Castle, Calif.	Plattsburg, N.Y.
Davis Monthan, Ariz.	Portsmouth, N.H.
Dow, Me.*	Ramey, P.R.
Ellsworth, S.D.	Sedalia, Mo.
Fairchild, Wash.	Selman, La.*
Forbes, Kan.	Sioux City, Ia.*
Great Falls, Mont.*	Smoky Hill, Kan.
Homestead, Fla.	Travis, Calif.
Hunter, Ga.	Turner, Ga.*
Lake Charles, La.	Walker, N.M.
Limestone, Me.	Westover, Mass.

*During the course of RAND's study, Blytheville was added to SAC's programmed list of bases and later deleted. Altus and Pinecastle were also added and Selman and Sioux City deleted. Bergstrom, Dow, Great Falls, and Turner are strategic fighter bases, and were included in some phases of the study.

Table IV

VALUE ADDED BY MANUFACTURING IN WAR INDUSTRIES

IN 159 METROPOLITAN AREAS*

		Value in $ millions
1.	Chicago, Ill.	3,245
2.	New York, N.Y.-N.E. New Jersey, N.J.	3,032
3.	Detroit, Mich.	2,457
4.	Pittsburgh, Pa.	1,357
5.	Philadelphia, Pa.	1,340
6.	Los Angeles, Calif.	1,170
7.	Cleveland, Ohio	1,169
8.	Buffalo, N.Y.	677
9.	St. Louis, Mo.	667
10.	Milwaukee, Wis.	596
11.	Boston, Mass.	570
12.	Baltimore, Md.	529
13.	Youngstown, Ohio	519
14.	San Francisco-Oakland, Calif.	461
15.	Dayton, Ohio	373
16.	Akron, Ohio	350
17.	Rochester, N.Y.	341
18.	Cincinnati, Ohio	336
19.	Indianapolis, Ind.	317
20.	Flint, Mich.	311
21.	Toledo, Ohio	311
22.	Minneapolis-St. Paul, Minn.	279
23.	Bridgeport, Conn.	270
24.	Houston, Tex.	255
25.	Canton, Ohio	239
26.	Providence, R.I.	218
27.	Syracuse, N.Y.	217
28.	Hartford, Conn.	197
29.	South Bend, Ind.	197
30.	New Britain-Bristol, Conn.	194
31.	Kansas City, Mo.	193
32.	Wheeling, W.Va.-Steubenville, Ohio	189
33.	Allentown-Bethlehem-Easton, Pa.	186
34.	Birmingham, Ala.	186
35.	Erie, Pa.	175
36.	Columbus, Ohio	168
37.	Springfield-Holyoke, Mass.	166
38.	Grand Rapids, Mich.	164
39.	Louisville, Ky.	161
40.	Waterbury, Conn.	157
41.	Albany-Schenectady-Troy, N.Y.	152
42.	Worcester, Mass.	150

Table IV (Cont'd.)

		Value in $ millions
43.	Peoria, Ill.	140
44.	Trenton, N.J.	133
45.	Seattle, Wash.	132
46.	Utica-Rome, N.Y.	121
47.	New Haven, Conn.	115
48.	Reading, Pa.	101
49.	Portland, Ore.	90
50.	York, Pa.	83
51.	Atlanta, Ga.	64
52.	New Orleans, La.	50
53.	Fall River-New Bedford, Mass.	50
Total in 53 areas		25,320
54.	Dallas, Tex.	120
55.	Fort Wayne, Ind.	112
56.	Richmond, Va.	108
57.	Wilmington, Del.	104
58.	Memphis, Tenn.	100
59.	Denver, Colo.	99
60.	Rockford, Ill.	94
61.	Charleston, W.Va.	90
62.	Beaumont-Port Arthur, Tex.	89
63.	Lancaster, Pa.	89
64.	Winston Salem, N.C.	89
65.	Davenport, Ia.	85
66.	Omaha, Neb.	84
67.	Lawrence, Mass.	81
68.	Binghamton, N.Y.	80
69.	Stamford-Norwalk, Conn.	80
70.	Lansing, Mich.	78
71.	Chattanooga, Tenn.	75
72.	Kalamazoo, Mich.	75
73.	Fort Worth, Tex.	74
74.	Evansville, Ind.	72
75.	Harrisburg, Pa.	72
76.	Hamilton-Middleton, Ohio	69
77.	Nashville, Tenn.	68
78.	Baton Rouge, La.	66
79.	Lorain-Elyria, Ohio	66
80.	Greensboro-High Point, N.C.	64
81.	Greenville, S.C.	64
82.	Racine, Wis.	62
83.	Wilkes Barre-Hazelton, Pa.	62
84.	Huntington, W.Va.	60
85.	Knoxville, Tenn.	60

Table IV (Cont'd.)

		Value in $ millions
86.	Washington, D.C.	60
87.	San Jose,Calif.	59
88.	Saginaw,Mich.	58
89.	Springfield,Ohio	56
90.	Tacoma,Wash.	54
91.	Muncie,Ind.	52
92.	San Diego,Calif.	51
93.	Johnstown,Pa.	50
94.	Kenosha,Wis.	50
95.	Tulsa,Okla.	49
96.	Lowell,Mass.	48
97.	Mobile,Ala.	46
98.	Columbus,Ga.	45
99.	Des Moines,Ia.	44
100.	Durham,N.C.	44
101.	Jackson,Mich.	44
102.	Norfolk-Portsmouth,Va.	44
103.	Pittsfield,Mass.	42
104.	Wichita,Kan.	42
105.	Cedar Rapids,Ia.	41
106.	Decatur,Ill.	41
107.	Scranton,Pa.	41
108.	Brockton,Mass.	40
109.	Charlotte,N.C.	40
110.	San Bernardino,Calif.	38
111.	Savannah,Ga.	38
112.	Galveston,Tex.	36
113.	Lima,Ohio	36
114.	Manchester,N.H.	36
115.	Oklahoma City,Okla.	36
116.	Spokane,Wash.	36
117.	Gadsden,Ala.	35
118.	San Antonio,Tex.	35
119.	Jacksonville,Fla.	34
120.	Tampa-St.Petersburg,Fla.	34
121.	Stockton,Calif.	32
122.	Waterloo,Ia.	32
123.	Terre Haute,Ind.	31
124.	Asheville,N.C.	29
125.	Augusta,Ga.	29
126.	Fresno,Calif.	29
127.	Salt Lake City,Utah	29
128.	Duluth,Minn.	28
129.	Green Bay, Wis.	28
130.	Springfield,Ill.	28
131.	Portland,Me.	26
132.	Sacramento,Calif.	26
133.	St. Joseph,Mo.	26

Table IV (Cont'd.)

		Value in $ millions
134.	Bay City, Mich.	25
135.	Madison, Wis.	25
136.	Roanoke, Va.	25
137.	Hampton-Newport News-Warwick, Va.	22
138.	Miami, Fla.	22
139.	Sioux City, Ia.	22
140.	Corpus Christie, Tex.	21
141.	Phoenix, Ariz.	21
142.	Charleston, S.C.	20
143.	Little Rock-North Little Rock, Ark.	19
144.	Macon, Ga.	19
145.	Pueblo, Colo.	19
146.	El Paso, Tex.	18
147.	Lincoln, Neb.	18
148.	Altoona, Pa.	16
149.	Dubuque, Ia.	16
150.	Waco, Tex.	16
151.	Jackson, Miss.	15
152.	Shreveport, La.	15
153.	Topeka, Kan.	15
154.	Columbia, S.C.	14
155.	Montgomery, Ala.	12
156.	Atlantic City, N.J.	11
157.	Sioux Falls, S.D.	11
158.	Wichita Falls, Tex.	11
159.	Springfield, Mo.	10
Total in 159 areas		30,325
Total in U.S.		35,590

*Values for nos. 54 through 159 and total for 159 areas may be inaccurate because of approximations used (see text).

See references (1) or (3) for more complete information on 53 largest metropolitan areas.

individual metropolis it is satisfactory on the average, and, since these are the smaller targets, it is estimated to have produced no significant error in the strike results.

Many of the metropolitan areas in Table IV are so large geographically that they could not be completely destroyed by one bomb. For these situations the manufacturing facilities were located on maps, upon which were then overlaid circles of destruction corresponding to the lethal radii of the bombs. These circles were moved to positions which gave the maximum value added destroyed (VAD) by the first bomb, the second bomb, etc. The VAD's thus achieved were then compiled into lists of bomb damage per DGZ for the different bomb sizes considered. These lists were used in assigning bombers for each strike.

Selected Industries

Another enemy strategy might be to attack a selected list of plants in a relatively small number of important industries so as to deprive the United States of essential military materiel. Such a bombing criterion would attempt to destroy a high percentage of the capacity of each industry attacked in order to create critical bottlenecks in military production. Only two such industries were considered here, petroleum and steel. Each is of major importance and has the added interest of forming a target system geographically different from the metropolitan areas. Lists of the facilities of these two industries can be found in references (1) or (5).

Washington, D. C.

The nation's capital appears only on one list so far mentioned, and then in an inconspicuous position far down on the list. Undoubtedly, the

Soviets would attach more importance to Washington as a target than is thus indicated. Therefore the city was put into a separate category as a target of great political value and given a position of importance on all strikes.

THE DEFENSE SYSTEM

The defense system was visualized as being composed of two essential parts: the sensing system and the weapons system. The former was responsible for detecting, tracking, and identifying airborne objects, evaluating patterns of attack, assigning weapons on a broad basis, and supplying adequate acquisition or control data to the weapons system. The latter was in turn responsible for attacking hostile targets.

The defense system used in this study started with the currently programmed system in the early years and additions were made to it for the later time periods. The amounts added were determined by a compromise between the present budget and what was believed to be necessary for a minimum acceptable defense level. For the later years the defense budget was allocated to components of the defense system according to two rules:

1. Development and production requirements should not be increased greatly over the programmed levels.
2. The "best" (most efficient from the defense viewpoint) and most necessary (in order to remove deficiencies in the system) components should be purchased first.

The proposed defense system which was ultimately used is outlined in Table V. In this table are shown the quantities of the components which were assumed to be operational by the end of each fiscal year. Since the attacks which were studied were considered to occur near the end of each calendar year in question, use of the corresponding fiscal year (FY) defense system quantities allowed approximately six months' additional time for the equipment to become operational. (For example, 1958 strikes used the defense system listed under FY 58, which were considered to be operational by 30 June 1958. But a 1958 attack was thought of as occurring in December, 1958, so the defenses as used were actually about six months behind the schedule listed in Table V.)

Fuller details on the proposed defense system, including cost and manning estimates, can be found in R-250.[1]

The Sensing System

The sensing system was composed of four essential elements: a system for the contiguous overland surveillance of aircraft; a system for the contiguous overocean surveillance of aircraft; warning lines to apprise the defenses of incoming air traffic; and the system to correlate, evaluate, and take action upon all of the data thus acquired. Although surveillance may actually be performed by such other agencies as ground and sea observers and aural and electronic passive detection devices, primary responsibility for this function was given to the radars in the defense net, and this was the only system which was considered to produce usable data.

The overland coverage came from the large "primary" radars (including permanent and mobile stations) plus a number of small sets which are required to fill the low-altitude gaps caused by curvature of the earth and shielding by terrain. Performance estimates for the various types of radars in the system were taken from RM-1077.[7] The presently operational and planned sites were assumed for all radars listed in the Air Defense Command (ADC) program. To the coverage thus achieved was added that made available by the assumed increases in numbers of radars, the network being augmented

Table V

EQUIPMENT QUANTITIES FOR ASSUMED AIR DEFENSE SYSTEM[1]

Item	FY 54[2]	FY 55	FY 56	FY 57	FY 58	FY 59	FY 60	FY 61
RADAR NET								
1. Permanent-plan ZI radar stations[3] and ADCC								
AN/FPS-3	50	50	50	50	50	50	50	20
AN/CPS-6B	25	25	25	25	25	15	0	0
ADCC	11	14	18	18	18	18	18	18
2. Canadian permanent-plan radar stations and ADCC								
U.S. manned								
AN/CPS-6	3	3	3	3	3	3	3	3
AN/FPS-3	13	14	14	14	14	14	14	14
Canadian manned	14	16	16	16	16	16	16	16
Canadian ADCC	1	1	1	1	1	1	1	1
3. First-phase mobile radar stations								
AN/MPS-11	0	8	8	8	8	8	8	4
AN/FPS-8	0	7	7	7	7	7	7	0
AN/MPS-7	3	17	17	17	17	17	17	17
AN/TPS-1D	0	12	12	12	12	8	2	0
4. Second-phase mobile radar stations								
AN/MPS-11	0	6	10	10	10	10	10	0
AN/MPS-7	0	5	9	9	9	9	9	0
AN/TPS-1D	0	8	16	16	16	16	0	0
5. Low-altitude radar stations								
AN/CPN-18	0	100[4]	175[4]	175	175	175	175	175
LACR	0	0	50[4]	150	275	375	475	575
6. Lincoln Laboratory Muldar stations	0	0	0	0	0	30	70	130
7. AEW aircraft (C-121C and C-121D)	11	35	60	85	110	135	160	185
8. Lincoln Transition Data Systems—air divisions	0	0	0	0	2	4	7	12

INTERCEPTORS								
9. Present-generation interceptor squadrons								
F-86D	39	43	39[4]	37	28	10	0	0
F-89D	3	7	22[4]	22	13	10	0	0
F-94C	9	7	0[4]	0	0	0	0	0
10. Next-generation interceptor squadron (F-102)								
Equivalent squadrons not carrying A-bombs	0	0	0[4]	2	5	15	21	10
Equivalent squadrons carrying A-bombs	0	0	0	0	15	25	40	51
11. Canadian interceptor squadrons	8	8	9	10	11	11	11	11
MISSILES AND GUNS								
12. Nike missile battalions	10	28	45	50	37	20	5	0
13. Talos-type missile battalions								
C-W Talos	0	0	0	0	5	18	30	25
Talos W (for defense other than SAC)	0	0	0	2	11	14	15	22
Talos W (for SAC bases)	0	0	0	0	0	0	2	13
14. Skysweeper battalions	8	8	8	8	8	6	4	0
15. Area-missile squadrons (55 missiles —24 in revetments)								
F-99A	0	0	0	0	5	10	10	10
F-99B	0	0	0	0	0	5	20	40
F-99C	0	0	0	0	0	0	5	25
A-BOMBS								
16. Stockpile A-bombs for interceptors								
Early	0	10[4]	30[4]	30	30	30	30	30
Later	0	0	0	20	20	20	20	20
17. Stockpile A-bombs for Talos W[5]	0	0	0	120	660	840	1020	2100
18. Special A-rockets for interceptors[5]	0	0	0	0	550	1000	1600	2040
19. Later stockpile A-bombs for F-99B[5]	0	0	0	0	0	120	480	960

[1] From Table 9 of reference (1), with some modifications to reflect numbers actually used in strikes.

[2] Dates indicate fiscal year end; e.g., FY 54 is June 30, 1954.

[3] The underlined word indicates the unit of the numerical quantities listed.

[4] Figures not in currently programmed and planned air defense.

[5] The numbers show the actual quantities considered available for combatting a single mass attack.

first where the greatest increase in defense effectiveness would result. For example, low-altitude coverage was first used to aid in the identification of aircraft along the more important entry routes. Next, low-altitude coverage was made solid in the northeast section in order to give some real protection to that important target area against low-altitude attacks. Then warning and solid cover were provided for other target areas in the order of their importance.

For contiguous over-the-ocean surveillance, surface picket ships and airborne early warning and control (AEW and C) stations were assumed to be in operation. Since the radar performance for the picket ships is quite limited, as shown in RM-1077,[7] these stations were used primarily to facilitate data processing. The performance of the AEW and C radars is inadequate against high-altitude, small-echoing-area targets in its present state. The performance was presumed to have been improved for 1958 by such feasible expedients as an increase in transmitter power to 5 megawatts, antenna redesign for reshaping the beam pattern, concentration on better maintenance, and possibly scanning with the antenna alternately pointed high and low. A backup ratio of 5 to 1 was used for the AEW and C aircraft, and the stations available were placed where it was felt that they would most increase the defense potential.

The only early warning line assumed for this study was a "McGill" line, roughly along the 54th parallel, with a seaward extension from Cape Race, Newfoundland, to Bermuda. This line was considered to give only warning, rough count, and rough direction in the portion over Canada, while the Navy AEW planes in the overwater portion were considered capable of giving warning and track information through their coverage. The Distant Early Warning (DEW) line, which is discussed at some length in R-250,[1] was considered for this study. It was rejected at the budget levels employed, however, because of its high cost, the need to use the money to correct more pressing deficiencies in the defense system, the problems brought up by "spoofing" of the line, questions concerning its defense, and the political questions involved in its establishment and operation.

Figures 3, 4, and 5 show the surveillance situations assumed for 1956, 1958, and 1960.

The data-handling and weapons-control facilities[8] of the present network were assumed to be materially improved by 1956 by the training which will be provided through the Systems Training Program jointly sponsored by ADC and RAND. There were also presumed to be modifications of equipment and procedures which would increase the capabilities of the system by that time. Eighteen Air Divisions were used, as programmed by ADC and shown in Fig. 3. All manning requirements were considered to be satisfied for this period, the number of directors at each air defense direction center (ADDC) being made equal to the number of ground-to-air channels programmed for that station.* Table VI lists these numbers of directors. Each AEW and C station was regarded as having four directors.

Identification of aircraft approaching the target areas of the ZI was considered to be done principally by the corridor identification system, which is discussed in RM-1078.[9] The statistical raid recognition technique was also assumed to be in use in the ZI and in Canada.

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*It should be noted that this is substantially more directors than are currently programmed by ADC. It should further be noted, as discussed in Chapter V, that the still-too-small number of directors and channels used here was one of the limiting factors in the defense potential.

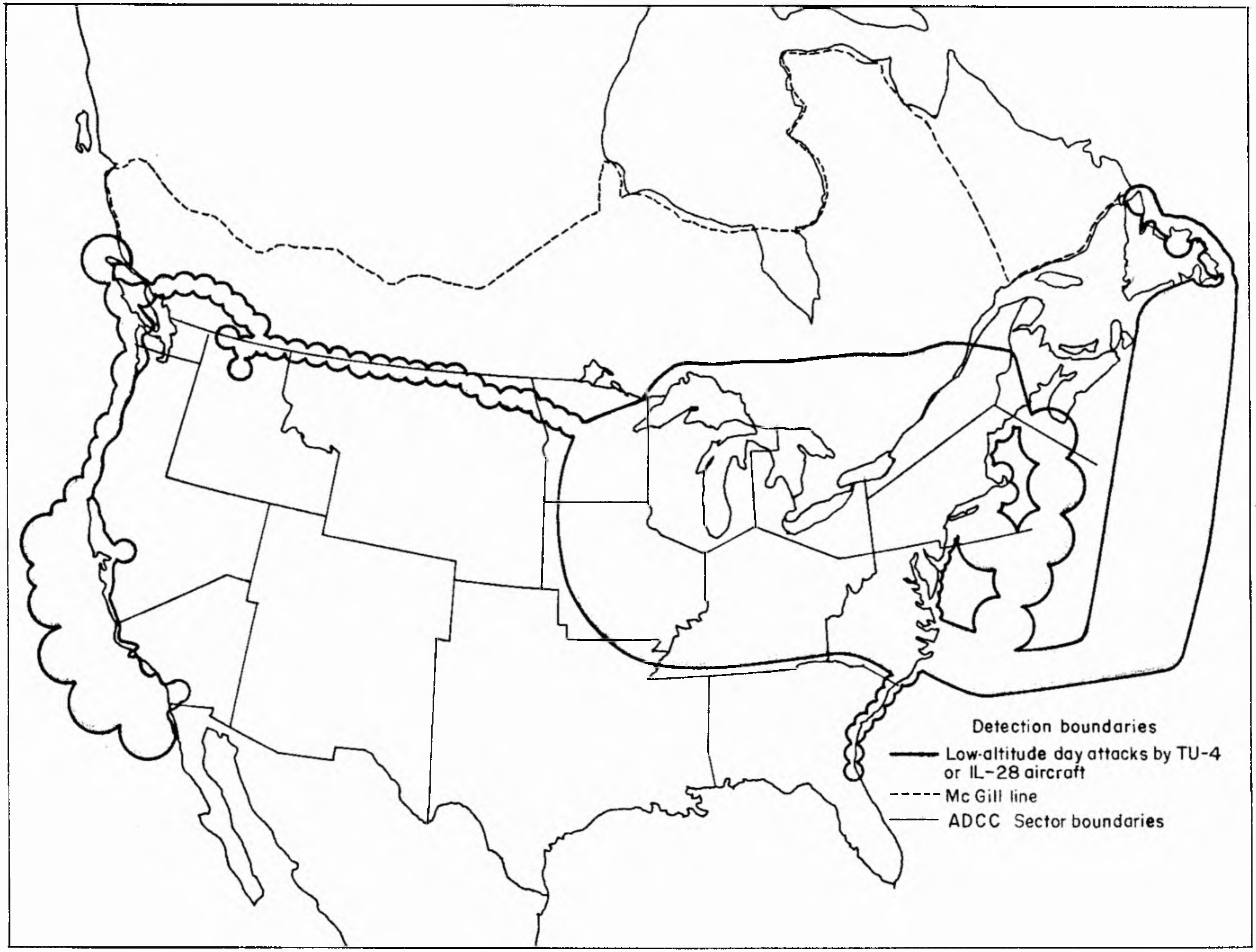


Fig.3 — Radar coverage of proposed air defense system 1956

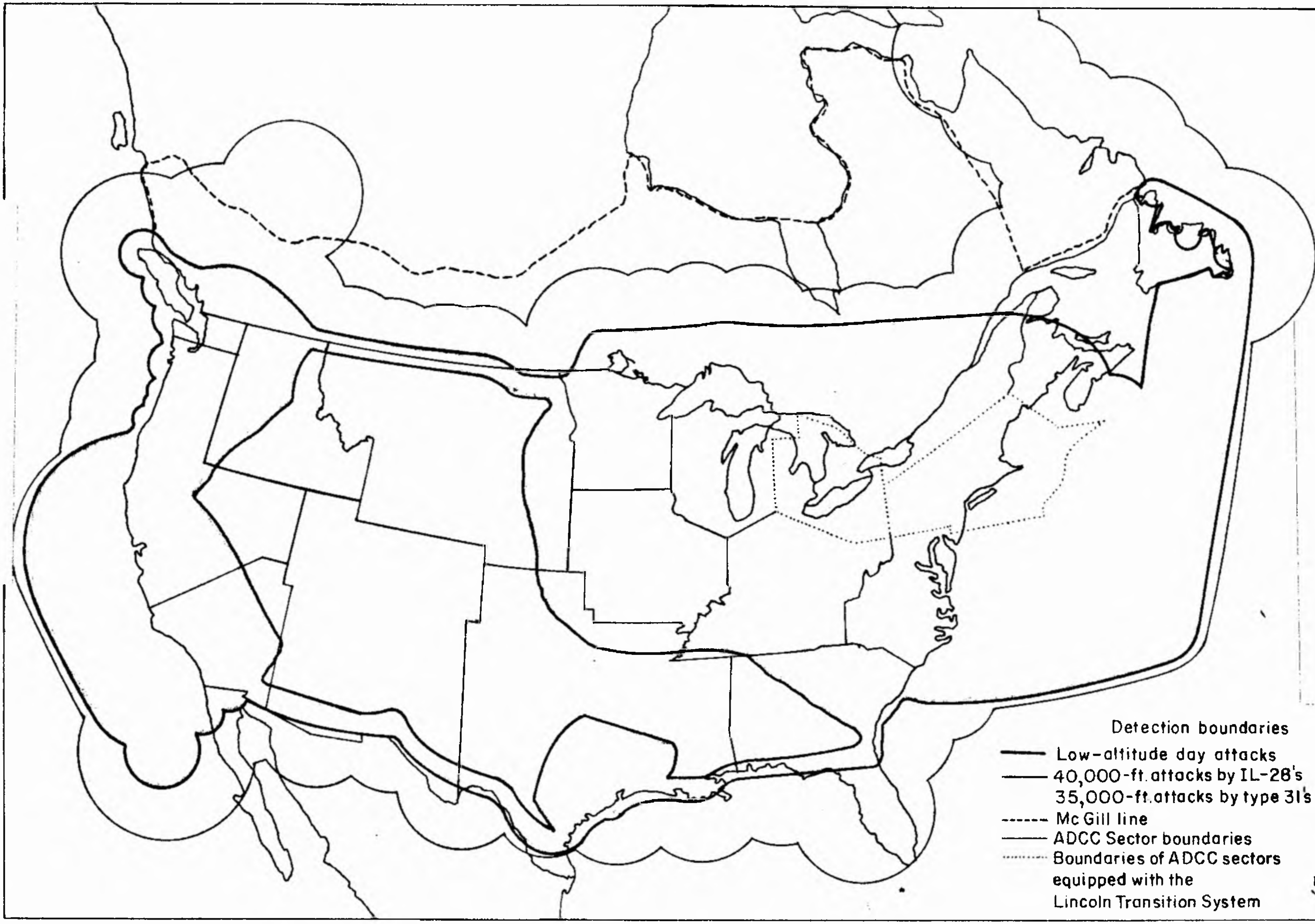


Fig.4 — Radar coverage of proposed air defense system 1958

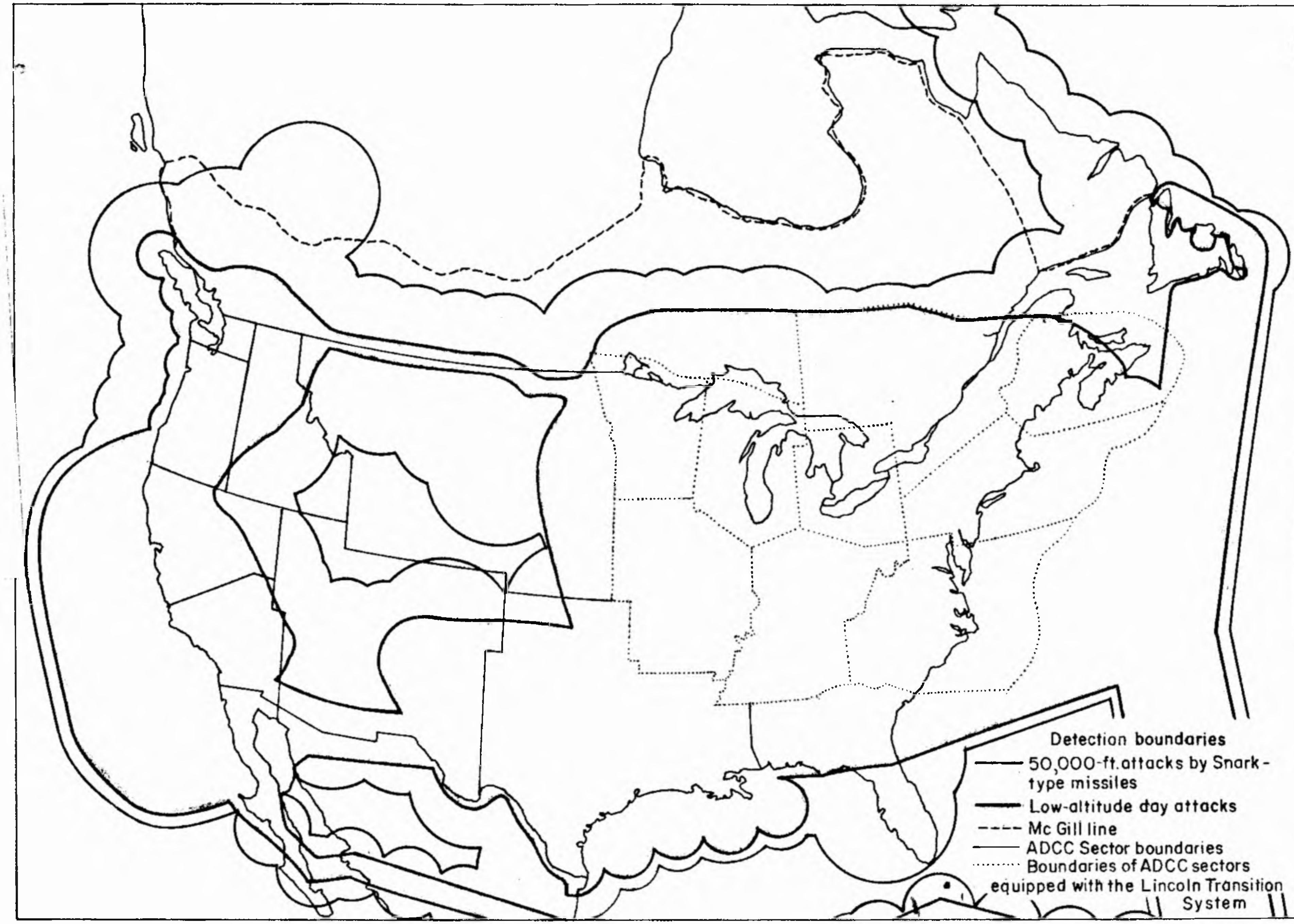


Fig. 5—Radar coverage of proposed air defense system—1960

Table VI

ASSUMED NUMBER OF CONTROLLERS AT EACH ADDC

Site Number*	Number of Controllers 1956	Number of Controllers 1958	Site Number	Number of Controllers 1956	Number of Controllers 1958
1	12	10	54	12	10
2	8	8	55	8	8
6	8	8	56	8	8
7	4	8	57	8	8
8	8	8	58	12	10
9	12	10	59	12	10
10	12	10	60	8	8
11	4	8	61	8	8
12	4	8	62	8	8
13	12	10	63	8	8
14	12	10	64	12	10
15	12	10	65	8	8
16	4	8	66	8	8
17	4	8	67	8	8
18	4	8	68	4	8
19	4	8	69	8	8
20	12	10	70	8	8
21	12	10	71	8	8
24	4	8	72	8	8
25	4	8	73	8	8
26	4	8	74	4	8
27	4	8	75	4	8
28	4	8	76	8	8
29	4	8	77	12	10
30	12	10	78	12	10
31	12	10	79	12	10
32	4	8	80	12	10
33	4	8	81	12	10
34	12	10	82	4	8
35	12	10	85	4	8
37	4	8	88	2	8
38	12	10	89	2	8
39	8	8	90	3	8
40	8	8	91	2	8
42	12	10	92	3	8
43	4	8	94	4	8
44	8	8	95	3	8
45	8	8	96	3	8
46	12	10	97	3	8
47	12	10	98	2	8
49	8	8	99	2	8
50	8	8	100	3	8
51	4	8	103	3	8
52	12	10	107	2	8
53	12	10	108	3	8

*These are the site numbers as given in the [redacted] Command Program of March, 1953.

Table VI (Cont'd.)

ASSUMED NUMBER OF CONTROLLERS AT EACH ADDC

Site Number	Number of Controllers 1956	1958
112	3	8
113	2	8
115	3	8
116	3	8
117	3	8
118	2	8
119	2	8
120	2	8
121	2	8
122	2	8
124	3	8
125	3	8
126	3	8
127	2	8
128	2	8
129	3	8
130	3	8
138	3	8
139	3	8
143	3	8
145	3	8
146	4	8
147	3	8
148	3	8
149	2	8
150	2	8
151	5	8
152	2	8
153	2	8
154	3	8
155	5	8
156	2	8
157	2	8
159	4	8
160	2	8
161	2	8
162	2	8
163	2	8
164	2	8
165	3	8
166	3	8

Canadian Sites

Site Number	Number of Controllers 1956	1958
1	4	8
2	4	8
3	4	8
4	4	8
5	4	8
7	4	8
8	4	8
9	4	8
10	4	8
11	4	8
14	4	8
15	4	8
16	4	8
17	4	8
18	4	8
19	4	8
20	4	8
21	4	8
33	4	8
34	4	8
35	4	8
36	4	8

In the 1958 analysis the data-handling system was further improved by the addition of intercept computers (AN/GPA-23) throughout, and by the change to UHF ground-to-air communications. A slightly higher number of these UHF channels were made available than was the case with VHF in 1956. This is reflected in the number of directors per station which were assumed as listed in Table VI. Installation of the Lincoln Transition System in two Air Divisions also improved the over-all performance. The two divisions chosen are those encompassing the most valuable target areas (see Fig. 4). Other features of data handling were unchanged from 1956.

The seven Lincoln sectors used in 1960 covered almost the entire Eastern Air Defense Force, as shown in Fig. 5, and played a major role in the protection of the targets in that area. Automatic transmission of commands to the interceptors and Bomarcs, as well as automatic assignment of bombers, was assumed. The non-Lincoln sectors were treated the same as in the 1958 analysis.

Defense Weapons Systems

Three principal types of weapons made up the defense weapons systems used in this study. These were interceptors, local-defense missiles, and area-defense missiles. (Local-defense guns were also considered, but were given credit for only negligible effectiveness.) The configurations and deployments of these weapons are discussed here; estimates of their capabilities are stated in the next chapter. Table VII lists the interceptor deployment assumed for 1956, 1958, and 1960, and Table VIII lists the local-defense missile deployment assumed. These are shown geographically for each of the years in Figs. 6, 7, and 8, respectively.

Table VII

ASSUMED INTERCEPTOR DEPLOYMENT FOR 1956, 1958, 1960

Name of Base	1956 Type of Inter-ceptor	1956 No. of Squad-rons	1958 Type of Inter-ceptor*	1958 No. of Squad-rons	1960 Type of Inter-ceptor*	1960 No. Squa rons
Presque Isle AFB, Me.	F-86D	1	F-86D	1	F-102	1
Otis AFB, Mass.	F-86D	2	F-86D	2	F-102R	1
Hanscom AFB, Mass.	F-86D	2	F-102	2	F-102	2
Westover AFB, Mass.	F-86D	1	F-89D	1	F-102	1
Suffolk Co. Apt, N.Y.	F-86D	2	F-86D	2	F-102	2
Mitchell AFB, N.Y.	F-89D	2	F-102	2	F-102	2
Griffis AFB, N.Y.	F-89D	1	F-89D	1	F-102	1
McGuire AFB, N.J.	F-86D	1	F-86D	1	F-102	1
New Castle AFB, Del.	F-89D	1	F-89D	1	--	0
Olmsted AFB, Pa.	F-86D	1	F-86D	1	F-102R	1
Dover AFB, Del.	F-86D	1	F-102	1	F-102	1
MCAS Quantico, Va.	F-89D	1	F-102	1	F-102	1
Pope AFB, N.C.	F-86D	1	F-86D	1	F-102	1
MacDill AFB, Fla.	F-86D	1	F-86D	1	—	0
McGhee-Tyson AFB, Tenn.	F-86D	1	F-102	1	F-102	1
Greater Pittsburgh Apt, Pa.	F-89D	2	F-89D	2	F-102R	2
Youngstown Apt., Ohio	F-89D	2	F-102	2	F-102	2
Wright-Patterson AFB, Ohio	F-86D	1	F-86D	1	F-102	2
Niagara Falls AFB, N.Y.	F-86D	2	F-102	2	F-102	2
Selfridge AFB, Mich.	F-86D	2	F-86D	2	F-102	2
Oscoda AFB, Mich.	F-89D	2	F-102	2	F-102	2
Baer AFB, Ind.	F-89D	2	F-89D	2	F-102	2
Kinross AFB, Mich.	F-86D	2	F-86D	2	F-102	2

Table VII (Continued)

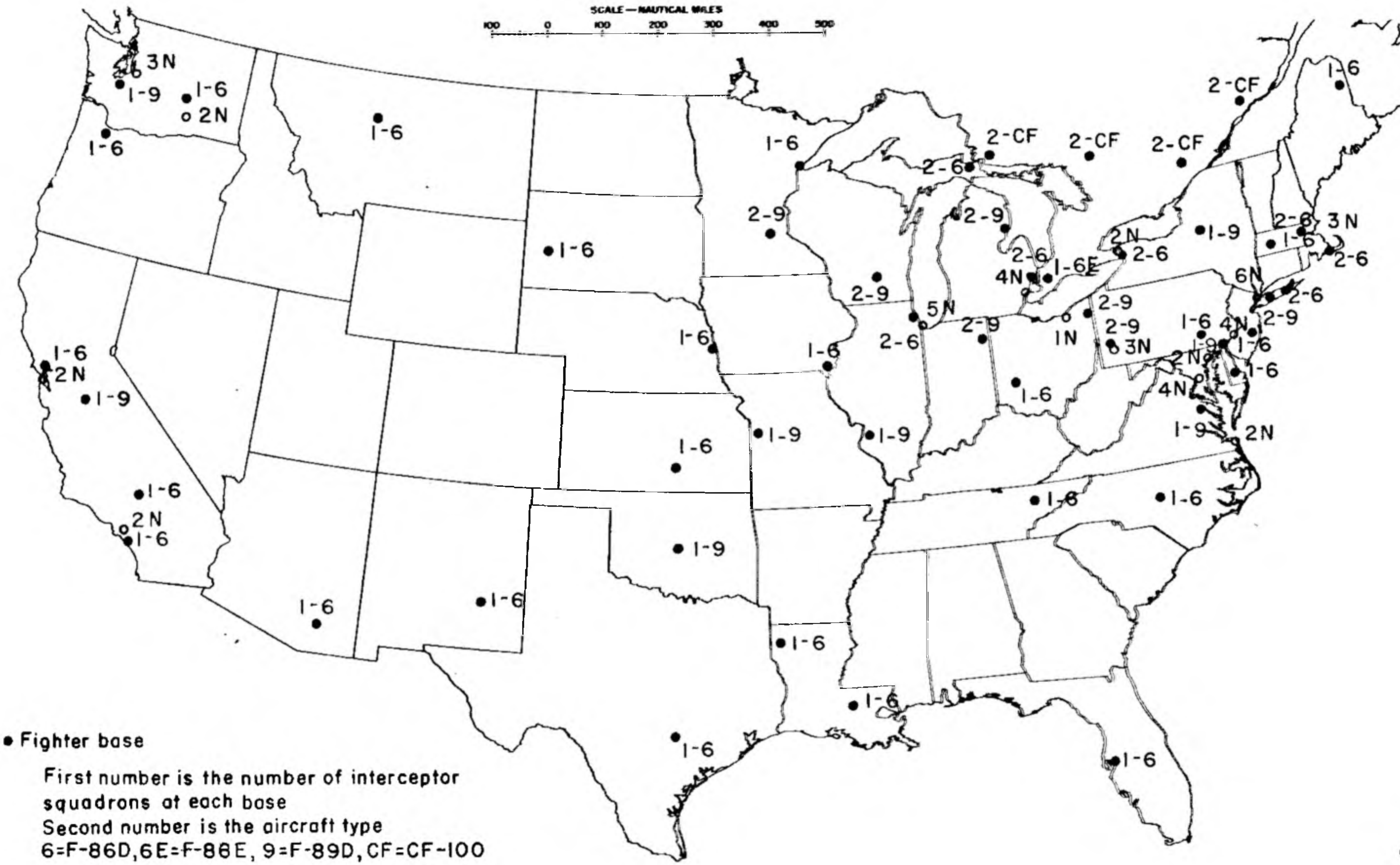
Name of Base	1956 Type	1956 No.	1958 Type	1958 No.	1960 Type	1960 No.
O'Hare-Chicago Intl Apt, Ill.	F-86D	2	F-86D	2	F-102	2
Truax AFB, Wisc.	F-89D	2	F-102	2	F-102	2
Burlington Mun. Apt, Iowa	F-86D	1	F-86D	1	F-102	2
Scott AFB, Ill.	F-89D	1	F-102	1	F-102	1
Houma AFB, La.	F-86D	1	F-86D	1	F-102	1
Barksdale AFB, La.	F-86D	1	F-86D	1	F-102R	1
Grandview AFB, Mo.	F-89D	1	F-89D	1	F-102	1
Minn-St. Paul Intl Apt, Minn.	F-89D	2	F-89D	2	F-102	2
Duluth Mun. Apt., Minn.	F-86D	1	F-86D	1	F-102	1
Ellsworth AFB, S.D.	F-86D	1	F-102	1	F-102R	1
Offutt AFB, Neb.	F-86D	1	F-86D	1	F-102	1
Wichita Apt, Kas.	F-86D	1	F-86D	1	F-102R	1
Tinker AFB, Okla.	F-89D	1	F-89D	1	F-102	1
Bergstrom AFB, Tex.	F-86D	1	F-102	1	F-102	1
Walker AFB, N. Mex.	F-86D	1	F-86D	1	F-102	1
Davis-Monthan AFB, Ariz.	F-86D	1	F-86D	1	F-102R	1
Great Falls AFB, Mont.	F-86D	1	F-86D	1	F-102	1
Larson AFB, Wash.	F-86D	1	F-89D	1	F-102R	1
McChord AFB, Wash.	F-89D	1	F-102	1	F-102	1
Portland Intl. Apt, Ore.	F-86D	1	F-86D	1	--	0
Hamilton AFB, Calif.	F-86D	1	F-86D	1	F-102	1
Castle AFB, Calif.	F-89D	1	F-89D	1	F-102R	1
George AFB, Calif.	F-86D	1	F-102	1	F-102	1
Long Beach, Calif.	F-86D	1	F-86D	1	F-102	1
Robins AFB, Ga.	-	0	-	0	F-102	1
Kellogg, Mich.	-	0	-	0	F-102	1

* Interceptor squadrons designated F-102 were partially equipped with atomic warheads. The F-102R squadrons were totally equipped with 2 in. FFAR's.

Table VIII

ASSUMED LOCAL DEFENSE DEPLOYMENT FOR 1956, 1958, 1960
(NUMBER OF BATTALIONS AT EACH SITE)

Site	1956 Nike	1958 Nike	1958 Talos CW	1958 Talos W	1960 Nike	1960 Talos CW	1960 Talos W
Boston,Mass.	3	3				3	
New York City,N.Y.	6	6		1		4	1
Philadelphia,Pa.	4	4				2	2
Washington,D.C.	4	3		1		2	1
Baltimore,Md.	2	2				2	
Norfolk,Va.	2	1		2		1	
Niagara Falls,N.Y.	2	2				2	
Pittsburgh,Pa.	3	3				3	
Cleveland,Ohio	1	2				2	
Detroit,Mich.	4	2		2		2	3
Sault Locks,Mich.				2			
Chicago,Ill.-Gary,Ind.	5	5		1		3	2
Milwaukee,Wis.							1
St.Louis,Mo.		2				1	
Houston,Tex.			2				1
Los Angeles,Calif.	2			2			2
San Francisco,Calif.	2		2			1	1
Hanford,Wash.	2	2				2	
Seattle,Wash.	3		1				1
SAC Bases					5	1	1



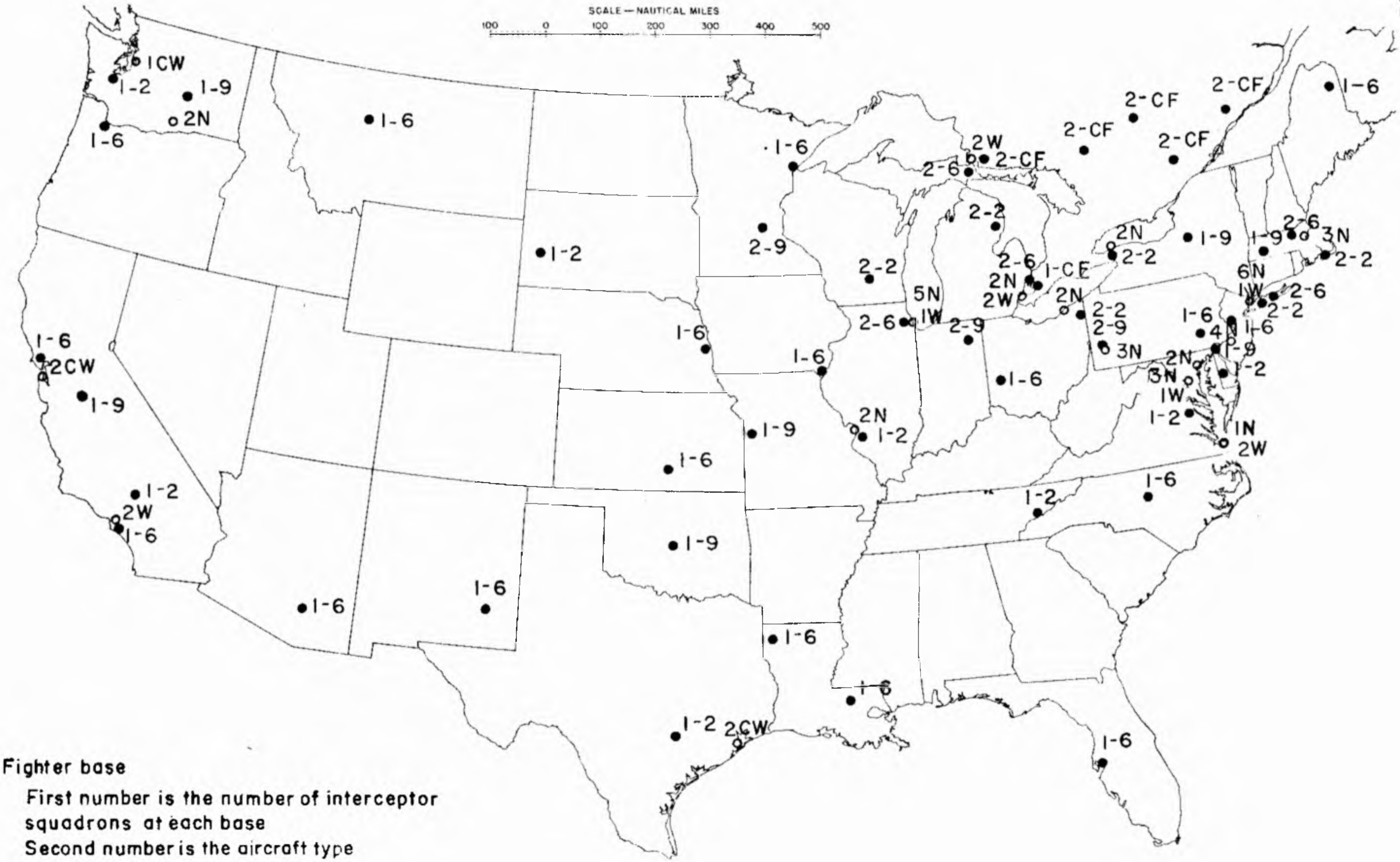
• Fighter base

First number is the number of interceptor squadrons at each base
Second number is the aircraft type
6=F-86D, 6E=F-86E, 9=F-89D, CF=CF-100

o Local defense weapon location

First symbol is the number of battalions
Second symbol is the weapon type
N = Nike

Fig. 6
1956 Deployment of weapons



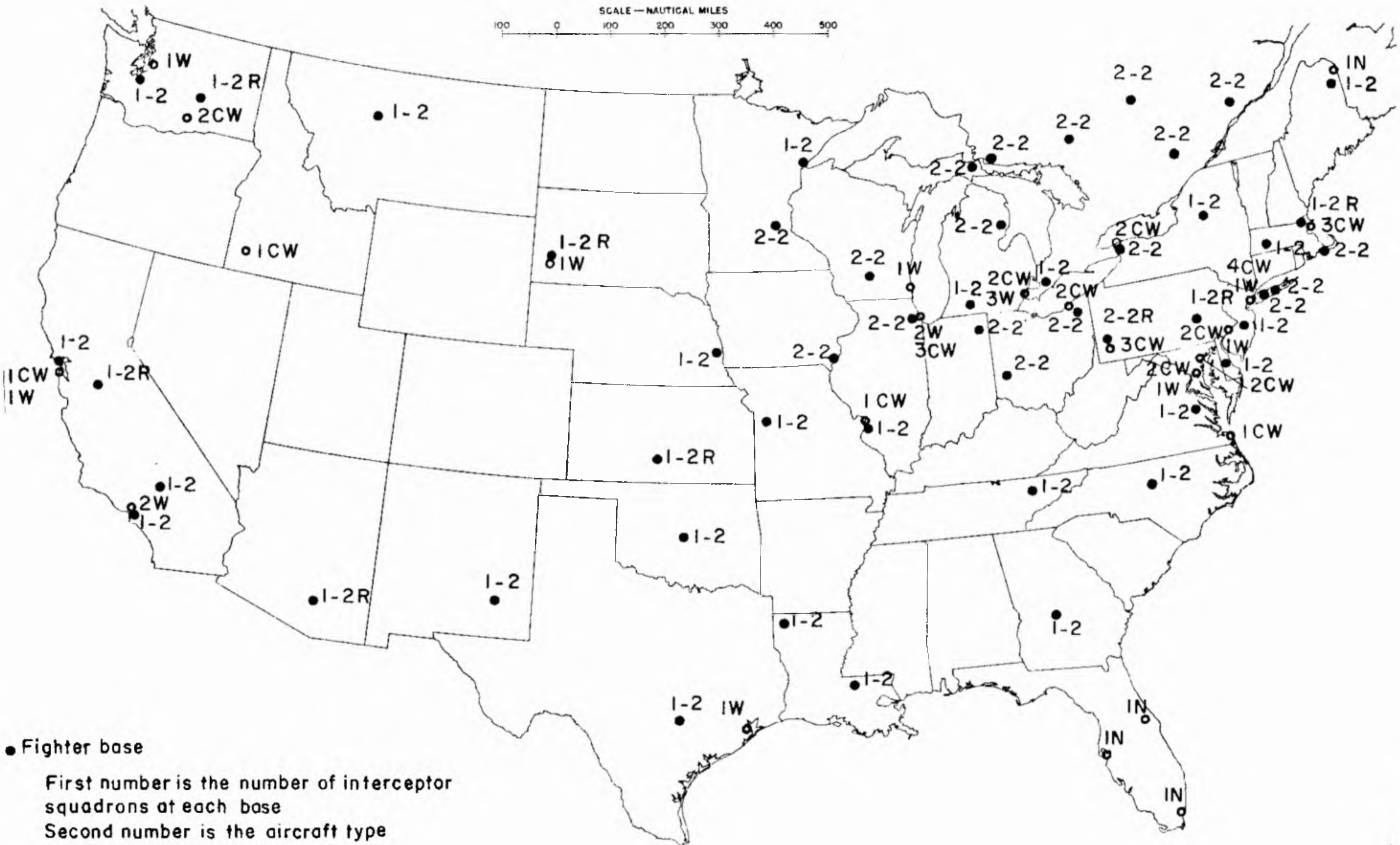
• Fighter base

First number is the number of interceptor squadrons at each base
Second number is the aircraft type
6=F-86D, 9=F-89D, 2=F-102, CF=CF-100

o Local defense weapon location

First symbol is the number of battalions
Second symbol is the weapon type
N=Nike, CW=Talos CW, W=Talos W

Fig. 7
1958 Deployment of weapons



• Fighter base

First number is the number of interceptor squadrons at each base
Second number is the aircraft type
2=F-102, 2R=F-102 R

o Local defense weapon location

First symbol is the number of battalions
Second symbol is the weapon type
N=Nike, CW=Talos CW, W=Talos W

Fig. 8
1960 Deployment of weapons

1956: In the 1956 analysis the system did not include any area defense missiles. The area weapons consisted of F-86D's armed with 24 2.75-inch Folding Fin Aerial Rockets (FFAR) each, and F-89D's armed with 108 2.75-inch FFAR each.* These interceptors were assumed to have the programmed configurations and power plants, and to be equipped with the programmed radars and fire-control systems.

The local-defense missiles used in the 1956 analysis were Nike missiles, of the early or Nike-I type. This missile uses command guidance and has two tracking radars, one acquisition radar, and one large computer per battery. It has a maximum effective range of 25 nautical miles and an altitude ceiling of 60,000 feet, and carries a 300-pound fragmenting warhead. Only one missile per battery can be in the air at any one time. A low-altitude limitation of 15 mils above the horizon was assumed for the tracking radars. In order to obtain some capability at low altitudes, it was assumed that the radars could guide missiles launched either from immediately adjacent areas or areas offset 4 to 6 miles, in which case the missile guidance dead zone would not cancel the zone of best radar performance.

These various weapons were not deployed in the same manner as that scheduled by ADC. A new deployment was worked out on the basis of attempting to balance the weapon strength in each area against considerations of the target values in the area and the warning and battle times available for the weapons. For example, more weapons were located in areas containing more target value, roughly in proportion to the value of the targets.

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*The Canadian CF-100 was considered to be exactly equivalent in over-all performance to the F-89D, so was treated as if it were the latter.

Since interceptors were assumed to have a fairly slow rate of becoming available after warning (see Chapter II), they were deployed more heavily in areas where warning time would be short. Local-defense missiles were placed at targets having high value and little warning time and at singularly high-valued targets in other areas. An attempt was also made to leave no area of the country completely unprotected against a high-altitude attack. Some areas had to be left completely unprotected against low-altitude attacks because of the lack of adequate low-altitude radar coverage.

1958: For the 1958 analysis, the weapons system included F-86D's, F-89D's, F-102's, F-99A's, Nike missiles, Talos CW battalions, and Talos W battalions. The armament for the F-86D's was 48 2-inch FFAR* each; the F-89D's were assumed to carry 216 2-inch FFAR each. Large rockets with atomic warheads(10)(11) were assumed available in limited quantities for use with the F-102's. These rockets were distributed evenly among the F-102 squadrons, and the first fifteen aircraft scrambled from each squadron were considered to be armed with two atomic warhead rockets apiece. Each additional interceptor which became available in these squadrons was assumed to be armed with substitutable racks containing 216 2-inch FFAR. The F-102 interceptors were also assumed to have airborne intercept (AI) radars equipped with an early form of AMTI, in addition to the rest of their programmed fire-control system.

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*The size of this rocket was not actually specified. Rather it was assumed to be a rocket of roughly the same effectiveness as the 2.75-inch FFAR and of such a size that twice the number of them could be carried.

The F-99A was taken to be the first edition of the Bomarc missile; it would have a maximum range of 125 miles, a maximum altitude of 60,000 feet, and would carry a 300-pound fragmenting warhead. This missile would be guided by the regular Lincoln radar surveillance and control network in its mid-course phase, and would have an active radar seeker for homing on its target. The radar seeker was not assumed to have AMTI.

The Nike missiles and their ground networks were assumed to be the same as in 1956. For the Talos battalions which were added to the system, it was postulated that both missiles and ground guidance units would be in short supply. It was therefore assumed that in order to defend a number of targets only "single simplex" batteries, which could subsequently be modified, would have been formed. These were assumed to consist of only one guidance unit per battery and to fire only one missile per salvo.

Both Talos CW and Talos W missiles were assumed to have a range capability of 50 nautical miles and an altitude ceiling of 50,000 feet. For the CW version a programmed beam-rider type of mid-course guidance, a semi-active homing system with a CW radar illuminator, and a 440-pound expanding-rod warhead were assumed. A programmed beam-rider type of mid-course guidance and a command fuse with no additional terminal guidance were envisioned for the Talos W, which was assigned a 5-KT atomic warhead.

The same deployment of interceptors was assumed for the 1958 strikes as for the 1956 strikes except for the conversion of some squadrons to F-102's, as listed in Table VII. The actual deployment is depicted geographically in Fig. 7, along with the deployment of the local-defense weapons and the Bomarcs. The locations of the local defenses are listed in Table VIII.

1960: The analysis for 1960 assumed that all interceptor squadrons were converted to F-102's, which were now considered to be equipped with a much improved AMTI. The aircraft of ten of these squadrons were armed with 216 2-inch rockets each, of the type assumed for 1958, while the other 51 squadrons were assigned enough atomic warhead rockets to put two in each of the first fifteen aircraft scrambled. These 15 planes also carried 108 2-inch rockets apiece, and any additional interceptors scrambled from these 51 squadrons were armed with 216 2-inch rockets each.

Three different types of Bomarc missiles were assumed to be in operation in 1960: the F-99A, the F-99B, and the F-99C. The F-99A was considered to be the first model of Bomarc, which is currently under development. The F-99B was considered to be a longer range (250 miles) missile having the same guidance system as the F-99A and an atomic warhead. The F-99C was also considered to be a long-range missile, but with a pulse-doppler seeker to give it low-altitude capability and an HE warhead. The Talos W and Talos CW missiles were considered to be of the same type as in 1958, but the batteries were assumed to be of the "dual simplex" type, having two guidance units per battery. In the case of Talos CW, two missiles were assumed to be fired in each salvo.

Deployment of the interceptor forces for this year is listed in Table VII also, there being only slight change from the previous deployments. Table VIII gives the locations of the local-defense missiles, and Fig. 8 shows the geographic deployment of all of the defense weapons used.

The Double Defense System

Some of the 1958 attacks were analyzed in an attempt to find out what gain in actual protection could be obtained by increasing the defense budget. It was felt that the most immediate gain and the greatest increase of protection per dollar spent could be realized by a general increase in the numbers of defense weapons and the facilities for their control. An examination was therefore made of the effect of an increased budget in 1958 by doubling the number of interceptors of each type, the number of local-defense missiles, the number of area-defense missiles, and the number of control channels available for use with these weapons.* Particular modes of spending more money for air defense are of interest; for example, a large increase of just the number of directors available at the GCI stations. However, only the double defense system described here was studied.

There were two notable exceptions to this doubling, however. One of these was in the atomic warhead rockets for interceptor armament, and the other was in the interceptor control capacity in the AEW and C aircraft. It was felt that the number of atomic warheads for air defense was already quite high under the basic proposal, and the feasibility of obtaining twice that number was seriously questioned. It was therefore decided that each of the additional F-102's should be armed only with 216 2-inch rockets. In the case of the AEW and C program, the opinion was that these aircraft were carrying about all of the load in personnel and equipment that they could. The only way to increase the control capacity was to put new equipment into the aircraft or to put more airplanes on station. The first of these would require a new development, which would be very desirable but would in all

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*It should be noted that this does not correspond to a double defense budget, but something substantially less than that.

probability not be ready by 1958. The second method was rejected because of the expense involved, the overloading of production capabilities required, and the operational questions about using many such stations in a small area. Consequently the over-ocean control capacity was left the same as for the basic case.

The radar coverage at both high and low altitudes was unchanged from the original cases done for 1958, as was the data handling function. A new deployment did have to be worked out for the weapons against the background of unchanged target systems and radar coverage. This was done in the same manner as previously, and resulted in the deployments of interceptors given in Table IX and local defenses listed in Table X. Both of these are shown geographically in Fig. 9.

STATE OF WARNING

For all of the strikes analyzed, a general state of world tension was assumed to exist so that the defense system was more or less on guard and fully manned against a possible attack. Intelligence warning was presumed to exist of a Soviet build-up, but no specific intelligence indication of the strike was supposed. Thus no condition of previous alert existed at the time of the initial detection of any attack, but rather a condition of readiness was postulated which it was felt could be continuously maintained by the defensive forces.

Knowledge of the specific targets of a strike was not assumed, nor even of the general classes or types of targets being attacked. It was assumed, however, that the defenses had some vague idea of the possible maximum weight of an all-out effort against the U.S. ZI, and of the possible types of bomb carriers to expect and their approximate performances.

Table IX

DOUBLE DEFENSE INTERCEPTOR DEPLOYMENT FOR 1958

Name of Base	Type of Interceptor*	Number of Squadrons
Presque Isle AFB, Me.	F-86D	1
Otis AFB, Mass.	F-86D	1
Hanscom AFB, Mass.	F-102	2
Westover AFB, Mass	F-89D	1
Suffolk Co. Apt., N.Y.	F-86D	2
Mitchell AFB, N.Y.	F-102	2
Griffiss AFB, N.Y.	F-89D	1
McGuire AFB, N.J.	F-86D	1
New Castle AFB, Del.	F-89D	2
Olmsted AFB, Pa.	F-86D	1
Dover AFB, Del.	F-102 F-102R	1 1
MCAS Quantico, Va.	F-102 F-102R	1 1
Pope AFB, N.C.	F-86D	2
MacDill AFB, Fla.	F-86D	2
McGhee-Tyson AFB, Tenn.	F-102 F-102R	1 1
Greater Pittsburgh Apt, Pa.	F-89D	2
Youngstown Apt., Ohio	F-102	2
Wright-Patterson AFB, Ohio	F-86D	1
Niagara Falls AFB, N.Y.	F-102	2
Selfridge AFB, Mich.	F-86D	2
Oscoda AFB, Mich.	F-102	2
Baer AFB, Ind.	F-89D	2

Table IX (Continue

Name of Base	Type Inter r*	Number of Squadrons
Kinross AFB, Mich.	F-86D	2
O'Hare-Chicago Intl. , I.	F-86D	2
Truax AFB, Wis.	F-102	2
Burlington Mun. Apt., Iowa	F-86D	1
Scott AFB, Ill.	F-102 F-102R	1 1
Houman AFB, La.	F-86D	2
Barksdale AFB, La.	F-86D	2
Grandview AFB, Mo.	F-89D	2
Minn.-St. Paul Intl. Apt., Minn.	F-89D	2
Duluth Mun. Apt., Minn.	F-86D	1
Ellsworth AFB, S. D.	F-102	1
Offutt AFB, Neb.	F-86D	1
Wichita Apt., Kas.	F-86D	1
Tinker AFB, Okla.	F-89D	2
Bergstrom AFB, Tex.	F-102 F-102R	1 1
Walker AFB, N. Mex.	F-86D	2
Davis-Monthan AFB, Ariz.	F-86D	2
Great Falls AFB, Mont.	F-86D	2
Larson AFB, Wash.	F-89D	2
McChord AFB, Wash.	F-102 F-102R	1 1
Portland Intl. Apt., Ore.	F-86D	2
Hamilton AFB, Calif.	F-86D	2
Castle AFB, Calif.	F-89D	2
George AFB, Calif	F-102 F-102R	1 1

Table IX (Continued)

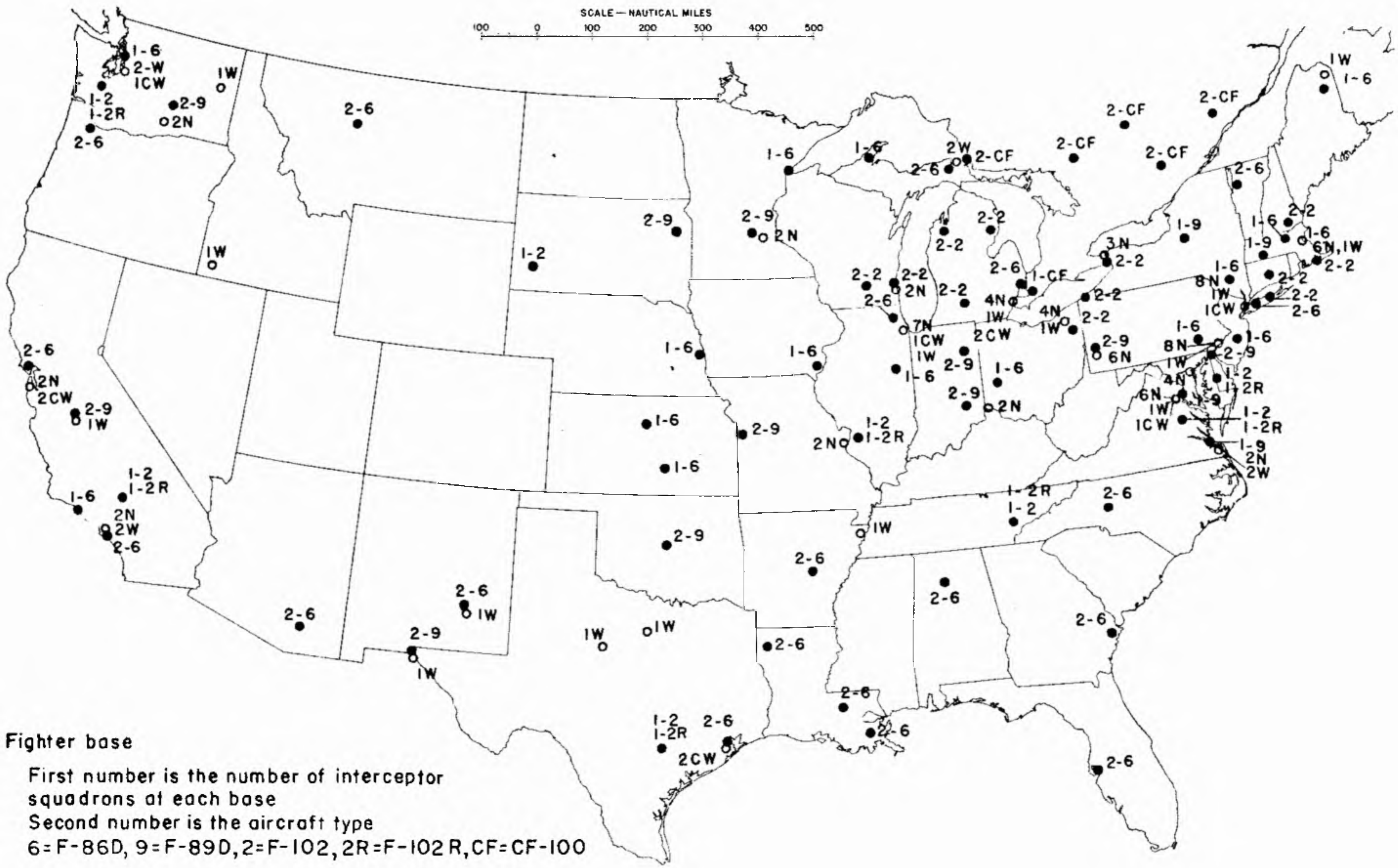
Name of Base	Type of Interceptor*	Number of Squadrons
Long Beach, Calif.	F-86D	2
Burlington Apt., Vt.	F-86D	2
Grenier AFB, N.H.	F-102R	2
Brainard, Conn.	F-102R	2
Stewart AFB, N.Y.	F-86D	1
Bolling AFB, Wash. D.C.	F-89D	1
Longley AFB, Va.	F-89D	1
Port Erie, Pa.	F-102R	2
Traverse City, Mich.	F-102R	2
General Mitchell, Wis.	F-102R	2
Kellogg, Mich.	F-102R	2
Chanute AFB, Ill.	F-86D	1
Freeman, Ind.	F-89D	2
Chatham AFB, Ga.	F-86D	2
Birmingham, Ala.	F-86D	2
Adams, Ark.	F-86D	2
Ellington AFB, Tex.	F-86D	2
Moissant Intl. Apt, La.	F-86D	2
Victoria AFB, Kas.	F-86D	1
Watertown, N.C.	F-89D	2
Biggs AFB, Tex.	F-89D	2
Oxnard, Calif.	F-86D	1
Paine AFB, Wash.	F-86D	1
Houghton Co. Apt., Wisc.	F-86D	1

* Interceptor squadrons designated F-102 were partially equipped with atomic warheads. The F-102R squadrons were totally equipped with 2-in. FFAR's.

Table X

DOUBLE LOCAL DEFENSE DEPLOYMENT ASSUMED FOR 1958
(NUMBER OF BATTALIONS AT EACH SITE)

	Nike	Talos CW	Talos W
Boston,Mass.	6		1
New York,N.Y.	8	1	1
Philadelphia,Pa.	8	1	
Washington,D.C.	6	1	1
Baltimore,Md.	4		
Norfolk,Va.	2		2
Niagara Falls,N.Y.	3		
Pittsburgh,Pa.	6		
Cleveland,Ohio	4		1
Cincinnati,Ohio	2		
Detroit,Mich.	4	1	2
Sault Locks,Mich.			2
Chicago,Ill.-Gary,Ind.	7	1	1
Milwaukee,Wis.	2		
Minneapolis-St.Paul,Minn.	2		
St.Louis,Mo.	2		
Houston,Tex.		2	
Los Angeles,Calif.	2		2
San Francisco,Calif.	2	2	
Hanford,Wash.	2		
Seattle,Wash.	2	1	
SAC Bases			9



• Fighter base

First number is the number of interceptor squadrons at each base
Second number is the aircraft type
6 = F-86D, 9 = F-89D, 2 = F-102, 2R = F-102 R, CF = CF-100

o Local defense weapon location

First symbol is the number of battalions
Second symbol is the weapon type
N = Nike, CW = Talos CW, W = Talos W

Fig. 9— 1958
Double defense deployment of weapons

CHAPTER II

EFFECTIVENESS OF DEFENSE SYSTEM COMPONENTS

This chapter presents the estimates of effectiveness which were used in this study for each of the components of the defense systems. Most of these estimates were derived from theoretical reasoning based on experimental data which varied from meager to extensive. There may be, therefore, a wide diversity in the solidity of the foundations upon which these figures are built. In all cases the latest available data were used, and an attempt was made, wherever possible, to check the resulting effectiveness estimates against evidence obtained in field use.

Since this memorandum deals with the three time periods of 1956, 1958, and 1960, each of the sections of this chapter is divided into parts discussing the estimates used for each of these periods. Although this manner of presentation may require some thumbing of pages in order to piece together all of the numbers for one year, it has been used to avoid needless repetition of the many assumptions which remain unchanged from one period to the next. Tables XI through XV summarize for easy reference the more important numbers used in the analyses.

THE SENSING SYSTEM

Detection of Aircraft--(1956, 1958, 1960)

The succinct way to describe the coverage of a radar network versus a particular aircraft is to present contours of equal cumulative probability of detection. The cumulative probability of detection for a single radar versus a single aircraft is a function of radar type, bomber type, bomber altitude, bomber speed, and bomber track relative to the radar, as well as other factors. The radar network problem is even more complex, because of the existence of multiple targets and the overlap in radar coverage. The latter two problems have not been considered in this study. All detection lines refer to the cover of a single radar versus a single aircraft. Consequently, all such lines represent detection ranges less than those which would have been achieved by a network against multiple targets.

Previous work at RAND has shown that at high altitude the range of 0.5 cumulative probability of detection occurs at roughly the same range as the 0.1 blip/scan ratio. The latter is a relatively simple point to estimate, and has been used throughout this analysis as the point of 0.5 cumulative probability of detection at high altitude. The high-altitude detection contours of Figs. 3, 4, and 5 are thus loci of 0.1 blip/scan points on single bombers of the considered types for single radars of the defense system.*

At extremely low altitude the relationship stated above does not exist between the 0.1 blip/scan ratio and 0.5 cumulative probability of detection. The low-altitude detection contours of Figs. 3, 4, and 5 are radar line-of-sight ranges from single radars to single bombers flying at altitudes of 200 feet over the land or 50 feet over water. The average height above terrain of the ground-based antennas was taken as 100 feet for these computations, except for the sets looking over the

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*These points were taken from RM-1077,[7] where 0.1 and 0.5 blip/scan vertical beam patterns are presented for many radars of interest in present and future air defense environments.

ocean, where actual heights were used wherever available. The AEW aircraft were regarded as flying at 3000 feet. In all of the ground radar cases the 0.5 blip/scan ratio was found to be exceeded at the horizon when the bomber was at low altitude. For the AEW planes the line-of-sight range at low altitude corresponded to a blip/scan ratio of 0.1 to 0.5, depending upon the bomber type. Because of the high blip/scan ratio obtaining at the horizon, the range of 0.5 cumulative probability of detection should correspond closely to that of the line-of-sight. Low-altitude detection ranges could be extended considerably beyond the line of sight by the phenomenon of ducting, particularly over water.

Each bomber stream was considered to be detected when its leading edge crossed the appropriate detection contour as defined above. The McGill line, as stated in Chapter I, was assumed to detect aircraft at all altitudes and give a rough count and rough velocity vector.

<u>Identification of Raids--(1956, 1958, 1960)</u>

The Soviets were presumed to send single bombers to a target only if there was practically no chance of attrition on that bomber, either because of lack of adequate radar cover or lack of defensive weapons. For these single-plane attacks, therefore, identification was important only from the viewpoint of alerting the defense network. All penetrations by these single aircraft, however, were treated as being simultaneous with the first detection of a mass raid against some other portion of the nation. For these reasons the identification of single attackers lost its importance, and its probability was not evaluated for the analysis.

All targets where defensive action was possible were assumed to be attacked by a number of bombers sufficient to saturate the defenses and insure that some bombers survived to bomb-release line. This supposition led to large numbers of bombers in most streams. A raid on a section of the target system consisted of one to four streams following roughly parallel tracks into that section. The probability of proper identification by contiguous cover radars of all such raids was taken as unity, with a two-minute period following detection allowed for the identification procedure. Identification at the McGill line was pictured as occurring by statistical raid recognition only. Because of the large numbers of bombers involved across the nation, the probability of correct assessment here was also assumed to be unity. The same delay of two minutes between detection and identification was applied.

Time from Detection to System Alert--(1956, 1958)

Upon the completion of identification, the information was imagined to be relayed by "hot line" voice and teletype links throughout the system. A delay of three minutes was postulated for notice of an alert to be circulated within an Air Division and the remainder of the defense system, making a total of five minutes from detection to the alert condition.

Another delay was regarded as existing in the system for data which had to be passed between Canadian and U.S. forces. Here the existence of "hot lines" at the lower echelons was not assumed, meaning that information had to be passed up and down the chains of command before the alert became effective. Fifteen minutes were presumed to be taken by this conveyance of the alert status.

Time from Detection to System Alert--(1960)

By this time period, the tie-in of the Canadian and U.S. defenses was considered to be complete, and the last delay mentioned above was dropped.

The time between detection and the alert of the complete U.S.-Canadian system was then taken as five minutes.

Tracking Capability--(1956, 1958, 1960)

Non-Lincoln: An aircraft was said to be tracked by a given ADDC (or group of ADDC's) if a director could be assigned to vector an interceptor to that aircraft. The tracking capability was defined as the fraction of all enemy aircraft within the total surveillance area of the concerned direction centers (DC's) which could be tracked during a ten-minute period. This fraction, called α, was assumed to be a function of the number of enemy aircraft within the area and independent of the size of the area or number of DC's within the area. The function was approximated by a step function which is shown in Fig. 10. The tracked or untracked condition of a specific bomber was assumed to be independent between ten minute periods.

Lincoln: An aircraft was said to be tracked in a sector equipped with the Lincoln Transition System if the computer could assign and vector a fighter to that aircraft. The tracking capability was defined as above except that "the sector" replaces "the total surveillance area of the DC." The fraction took on only two values in this case: 0.95 for the first ten-minute period within the Lincoln sector and 0.98 thereafter.

Control Capability--(1956)

Three modes of controlling or directing interceptors were presumed available to the defense network: close control, broadcast control, and a variation of the latter referred to herein as uniform broadcast control. An ADDC could presumably use all three simultaneously--although a given

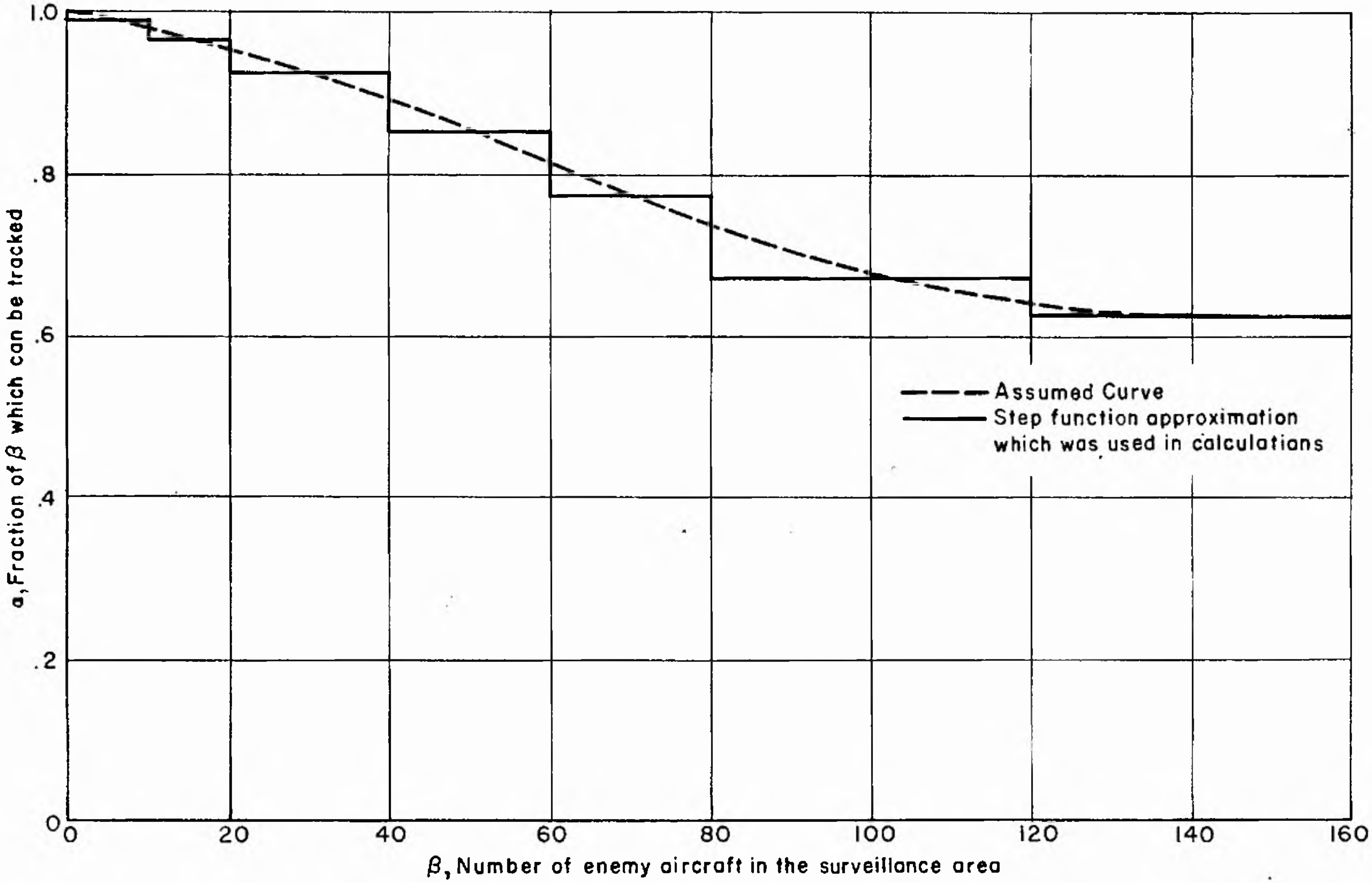

Fig. 10 — Fraction of aircraft tracked in a battle (without the Lincoln Transition System)

director could use only one in any ten-minute period--or the best mixture of the three. The vectoring accuracy was defined as the standard deviation of the displacement of an interceptor normal to the attempted relative axis of approach to the bomber after the interceptor has been released by the GCI director and has begun its AI radar search (see "Probability of Detection and Conversion ...," page 76). The standard deviation was presumed to be constant throughout the AI radar search phase following release by the GCI director. The sensing system was assumed capable of discerning all bomber track changes. However, three minutes were allowed to pass before the course change could influence the vectors given an interceptor group.

Close control is defined as that mode of operation wherein a director has jurisdiction over a particular interceptor element and tries to vector it to a point where it can make visual or radar contact with a particular bomber and will be in a favorable position for making a firing pass. Each director was considered capable of close-controlling two closures of interceptor elements on bombers in each ten-minute period. Each interceptor element involved could consist of from one to four F-86D's or one or two F-89D's. Since only low-altitude bombers were used, each closure was made from off the tail of the bomber, with a 50-knot closing speed. The vectoring accuracy was taken as 6000 feet. The senior director was assumed capable of spreading the close-control capacity uniformly* over

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*When the number of interceptor elements being close-controlled was less than the number of bombers being tracked, they were assigned one element per bomber until the elements were all assigned. When the number of such elements exceeded the number of bombers being tracked, each bomber was assumed to have assigned to it a number of elements equal to the total number of such elements divided by the total number of tracked bombers.

the bombers being tracked in each "battle" or ten-minute interval. For these minimum altitude attacks, very little overlap of radar cover would exist between ADDC's. When more than one ADDC could vector interceptors to a single bomber stream during one battle, each was pictured as vectoring to a different portion of that stream, and the uniform assignment of interceptors to bombers was still assumed.

Broadcast control is defined as that mode of control wherein a director broadcasts for use by a number of interceptor elements the coordinates and velocity vector of points of a bomber stream, whereupon each element navigates itself into the stream and searches through it attempting to make visual or radar contact with any single bomber upon which it can make a firing pass. Each director was considered capable of broadcasting the bomber data of one stream continuously, but was thereby excluded from performing any other control duties. Only one director was presumed necessary to perform the broadcast control function at any one time for any one bomber stream. All bomber streams were assumed to be large enough so that the interceptor navigation accuracy was sufficient to allow all elements on broadcast control to get into the bomber stream.

Uniform broadcast control is defined as that mode of operation wherein a director broadcasts the coordinates and velocity vector of a single bomber, and any number of interceptor elements can try to navigate themselves into a favorable position for making visual or radar contact with the bomber and completing a firing pass on it. Each director was allowed the capability to broadcast continuously the data for six individual bombers, but could not perform any other control duties. The senior director was supposed capable of spreading the uniform-broadcast-control capacity uniformly across the bombers being tracked (i.e., one unit of such control per bomber until either control capacity or number of tracked bombers was exhausted), but the interceptor elements on uniform broadcast control were spread randomly over the bombers whose positions were being thus broadcast (i.e., each such bomber was given equal probability of being chosen to be attacked by each such interceptor). The accuracy with which interceptors employing uniform broadcast control positioned themselves with regard to a bomber was defined as for close control. Because of the absence of landmarks and navigational aids at low altitude over the ocean, the accuracy there was assumed to be less than that over land. The accuracy over the ocean was assumed to be five nautical miles and the accuracy over land three nautical miles, as will be discussed in the section on interceptors. Uniform broadcast control was employed versus a given stream only when the bombers numbered less than 10 for a stream approaching from the ocean, and less than 15 for an overland approach.

Control Capability—(1958)

Non-Lincoln: In those sectors not equipped with the Lincoln Transition System the control capabilities for all three modes were assumed to be the same in 1958 as in 1956 except for the number of close-controlled closures each director could handle. The addition of the intercept computer AN/GPA-23 was considered to so facilitate the close-control function that each director could maintain the same vectoring accuracy* while completing the vectoring of three closures every ten minutes.

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*It should be noted that the vectoring accuracy for an interceptor making a 180° approach to a bomber at low altitude was thought to be limited more by the quality of the radar data than by the computer aids available to the director.

Lincoln: In sectors equipped with the Lincoln Transition System, the control capacity would be a function of the number of radar returns which the computer would have to correlate per unit time. An average figure of 200 interceptor closures per sector per battle was used for the vectoring capacity, or alternately 100 interceptor closures and 100 Bomarc missile closures per sector per battle. The system was also considered capable of performing the broadcast control function for each stream of bombers over the sector, but this function was never called upon. The vectoring accuracy was still assumed to be 6000 feet.

AEW and C: It was assumed that AEW and C aircraft flying immediately off the coast of a sector in which the Lincoln system was in operation would be tied into that system with automatic data-transmission links. The boundary of this sector was therefore extended out to 150 miles offshore, and the fact that the overwater portion came from AEW and C stations was neglected. All other AEW and C aircraft were given the same capabilities as they had been given for 1956.

Control Capability--(1960)

Lincoln-equipped sectors, non-Lincoln-equipped sectors, and AEW and C aircraft were all treated the same in the 1960 analysis as for the 1958 except that the vectoring accuracy in the sectors with the Transition System equipment was taken to be 3000 feet.

Weapon Commitment Policy--(1956, 1958, 1960)

Two tenets defined the basic commitment philosophy employed. First, the weapon assignments should be divided, on the basis of kill potential, as uniformly as possible among all bombers. Second, all weapons should be dispatched to a raid as soon as they were available and the bombers were close enough. These two policies had to be pursued within the following set of restrictions, designed to reflect as much realism as possible. (All commitment decisions were based on the premises that the defense was not aware of bomber course changes until they occurred, and that the defense had no knowledge of the specific aiming points to be attacked.)

1. No weapons were dispatched until the bombers were within contiguous radar cover.
2. When a raid was approaching, interceptors from a particular base were not dispatched until it appeared that they would have enough fuel upon reaching the bombers to make a number of passes equal to or greater than the number for which they were armed. In order to make this estimate the defenses presumed that the bombers would not change course after interceptors were scrambled. (The number of passes for which the interceptors were armed is specified in the section on interceptors.)
3. Interceptors were not allowed to combat bombers in an area where local-defense missiles were effective.* This sometimes meant loss of passes because interceptors reached a bomber stream too shortly before it penetrated a local-defense area.
4. When an early and a delayed scramble of an interceptor would have resulted in the same number of passes, the early scramble was preferred.

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*Note in a later section that in the 1956 analysis the Nike missiles were considered ineffective at the altitudes of the attacks.

5. In the 1956 and 1958 analyses the scramble time of all interceptors committed against bombers in a sector other than that in which they were based was delayed five minutes after the interceptors became available. This delay was for the processing of orders and inter-sector communications. In the 1960 analysis the system integration was assumed sufficient to warrant deletion of this delay.
6. In the 1956 and 1958 analyses only half of the available interceptors based within 200 miles of the edge of contiguous low-altitude cover and in an unattacked sector could be scrambled against bombers in an adjacent sector. In a sector under attack, the interceptors could be used as demanded to fulfill the basic commitment policy (i.e., uniform distribution across the bomber force). This restriction was designed to reflect the natural reluctance of a sector commander to release all his interceptors to other sectors. In the 1960 analysis this restriction was not imposed.
7. When control capacity was exceeded in the 1958 and 1960 analyses, F-102's were delayed until they could be close-controlled.
8. In the 1958 analysis a director was not utilized for broadcast control of F-89D's in the air battle against a given stream until fifteen F-89D's were available, provided that the director could have been utilized by the F-102 force. However, once broadcast control had been initiated against a given stream, it was employed in all subsequent battles against that stream. This restriction sometimes led to the delayed scrambling of F-89D's.

9. F-86D's were never scrambled for broadcast control. This led to many F-86D's being delayed until control channels became available.

Many of these restrictions are discussed more fully in the chapter on strike techniques.

It was assumed that both United States and Canadian commanders pursued the above commitment policies independently. It was also assumed that either nation's interceptors could fly over the other's territory and would be controlled by the other's ground network when so doing.

INTERCEPTORS

Availability--(1956, 1958, 1960)

Interceptors of both the United States and Canada were presumed to be brought to a runway alert status, following the receipt of the red alert information, as quickly as training and maintenance requirements would allow. Curves were drawn showing the average percentage of the various types of squadrons available for scramble as a function of time from the initial alert. The curves were based on present ADC doctrine and on a state of squadron readiness assumed to be achievable on a continuous operating basis for the years of this study. A slightly different curve was used for F-102's than for the other interceptors, because of the higher degree of complexity and the resulting difficulty of maintaining this aircraft. These curves were both approximated by step functions, which allowed the interceptors to be treated as becoming available in small groups at finite time intervals.

The postulated availability curves are shown in Fig. 11. Table XI indicates the availability functions actually used in the analyses.

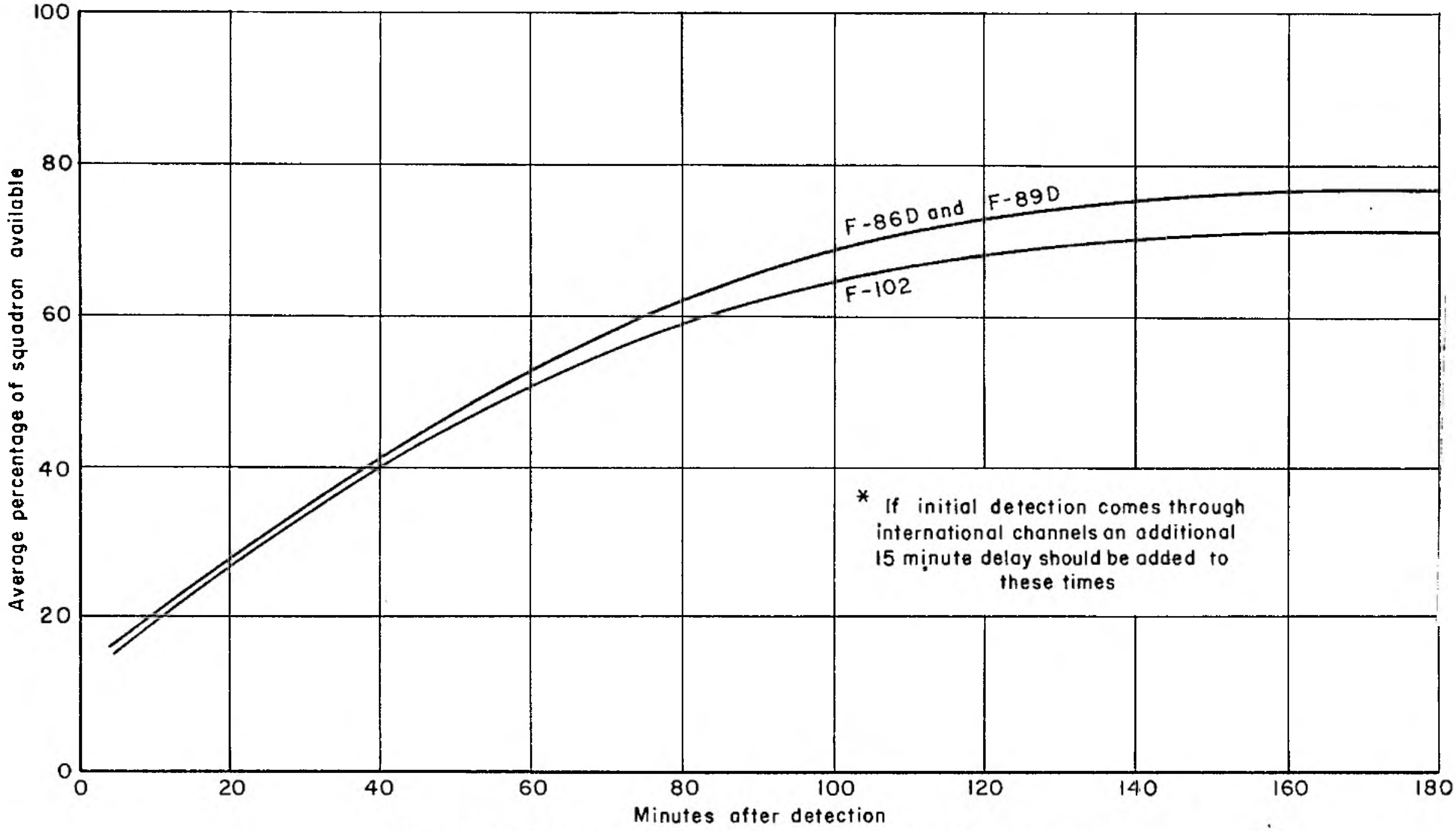

Fig.11 — Fraction of interceptors available for scramble as a function of time after detection*

Table XI

INTERCEPTOR AVAILABILITY ASSUMPTIONS

Time After Initial Detection[1]	Additional Interceptors Becoming Available for Scramble	
	F-86's and F-89's	F-102's
5 min.	4	4
25 min.	4	4
50 min.	4	4
1 hr., 30 min.	4	3
2 hrs.	2	2
3 hrs.	1	1

[1]If initial detection comes through international channels an additional 15 minutes should be added to these times.

Interceptor Climb and Combat Radius Performance--(1956, 1958)

Against the low-altitude attacks of 1956 and 1958, the interceptors were assumed to have two available procedures for flying to the battle area and doing combat with the bombers. These were:

1. Take off and climb at military power

   Cruise out at optimum altitude and optimum power setting for attaining maximum radius

   Combat at military power*

   Cruise home at optimum altitude and optimum power**

2. Take off and climb at military power

   Cruise out at 5000 feet altitude and military power

   Combat at military power*

   Cruise home at optimum altitude and optimum power**

Mode (1) was normally used on all missions. It had the advantages of allowing the maximum radius of action and the maximum combat time for a given radius of action. Mode (2) was used only when time was of the essence in intercepting bombers before bomb release line, and when the range penalty incurred did not prevent interception.

Table XII lists the actual performance figures used for each interceptor for each of these modes of operation. These figures are from data of early 1953, and are representative for the loads which were assumed to be carried by these interceptors. From the data in this table, the time

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*As will be seen below, this may be a conservative assumption for calculating maximum radius, but it was felt that it would be well to be conservative on this point rather than to overextend the range.

**In all cases the interceptor was required to return to its home base.

<u>Table XII</u>

ASSUMED INTERCEPTOR PERFORMANCES

Interceptor	F-86D		F-89D		F-102 and F-102R			
Combat Altitude	low		low		low		50,000 feet	
Climb Power	Mil.	Mil.	Mil.	Mil.	Mil.	Mil.	Mil.	AB
Cruise Out Altitude (ft.)	Opt.	5000	Opt.	5000	Opt.	5000	Opt.	45,000
Cruise Out Power	Opt.	Mil.	Opt.	Mil.	Opt.	Mil.	Opt.	AB
Cruise Out Speed (kn.)	476	570	423	530	518	635	518	1035
Combat Power	Mil.	Mil.	Mil.	Mil.	Mil.	Mil.	Part AB	Part AB
Combat Speed (kn.)	574	574	530	530	635	635	690	690
Time, T.O. and Accel. to Climb (min.)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Time, Climb to Cruise Alt. (min.)	18.6	1.0	26.0	1.3	8.0	0.6	8.0	2.2
Distance, Climb to Cruise Alt. (n mi)	122	5	150	10	70	5	70	18
Time, Accelerate to Cruise Speed (min.)	-	-	-	-	-	-	-	4.2
Distance, Accel. to Cruise Speed (n mi)	-	-	-	-	-	-	-	54
Time, Climb to Combat Alt. (min.)	-	-	-	-	-	-	0.4	0.4
Time, Accel. to Combat Speed (min.)	-	-	-	-	-	-	2.5	-
CR_0 (n mi)	421	198	482	297	646	245	628	221
k (n mi/min.)	19.4	7.6	14.4	7.3	25.9	8.6	19.0	5.6

required to reach any given radius on each mode can be ascertained. The maximum combat radius for each condition can be found from the formula:

$$CR = CR_o - kt_c$$

where

CR = combat radius for combat time t_c,

CR_o = combat radius for zero combat time,

k = nautical miles of combat radius lost per minute of combat time at the specified conditions,

t_c = combat time in minutes.

The combat radii for zero combat time presented and hence all combat radii derived from Table XII include the following range-free allowances:

1. Two minutes' operation at normal rated power at sea level for starting engines and taxi
2. One minute at maximum power for take-off and acceleration to climbing speed
3. Acceleration and climb from cruise speed and altitude to combat speed and altitude with maximum power
4. Reserve of 15 minutes at cruise altitude at the speed for maximum endurance plus 5 percent of initial fuel

The maximum combat times allowed for each interceptor in each year studied are outlined in the following sections. In practice, the actual amount of combat time available to the interceptor upon reaching the bomber stream was found for each interceptor scrambled and reduced to: (a) the maximum combat time allowed if the time available was greater than that time; (b) the next least multiple of five minutes of combat time if less than the maximum allowed; or (c) the multiple of five minutes nearest to the time measured from the moment the interceptor reached the bomber stream until the stream reached the edge of the local defense radius of action, if that time were less than (a) or (b). Thus, for the F-86D, which was always allowed only 5 minutes of combat time, operating on mode (1):

CR_o = 421 nautical miles,

k = 19.4 nautical miles/minute,

t_c = 5 minutes,

and

$CR = 421 - 19.4 \times 5 = 421 - 97 = 324$ nautical miles.

Interceptor Climb and Combat Radius Performance--(1960)

Since both high-altitude and low-altitude attacks were analyzed in the 1960 portion of this study, some additional data were required. The low-altitude modes of operation were the same as those for 1958. Against the high-altitude Snark-type missile attack, two procedures were also assumed to be available to the interceptor, namely:

1a. Take off and climb at military power

Cruise out at optimum altitude and optimum power setting for attaining maximum radius

Combat with part afterburner power (Mach 1.2)*

Cruise home at optimum altitude and power**

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*The part afterburner power setting was presumed to be required in order to give the interceptor a speed margin over the Snark-type missile. This would probably not be necessary with collision course attacks, but would be in overtaking on a pursuit course.

**In all cases the interceptor was required to return to its home base.

2a. Take off and climb with afterburner

Cruise out at 45,000 feet and with afterburner (Mach 1.8)

Combat with part afterburner (Mach 1.2)*

Cruise home at optimum altitude and power**

The maximum combat radius was determined in the same manner as outlined above for 1956 and 1958, and all other remarks of that portion apply to this time period. The performance figures used are again given in Table XII.

Employment Tactics--(1956)

F-86D: The attacks considered for 1956 were at low altitude in daylight. For this condition it was assumed that F-86D interceptors could be scrambled in elements of either two or four aircraft each, at the will of the senior director. Because of the problems involved in one man's trying to fly the interceptor and scan for bombers at the same time, and because of very poor radar performance at low altitude, it was assumed that all F-86D's would have to be close controlled in order to have any probability of finding a bomber. Only one pass was allowed for each of these aircraft, since control channels were in short supply, and this pass was taken to consume five minutes.

If an element split up in flight, only one part of the split was pictured as completing the intercept, the other part being lost to the controller and returning to base. When more than one interceptor arrived at the interception point, all such arrivers were regarded as attacking the

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*The part afterburner power setting was presumed to be required in order to give the interceptor a speed margin over the Snark-type missile. This would probably not be necessary with collision course attacks, but would be in overtaking on a pursuit course.

**In all cases the interceptor was required to return to its home base.

bomber simultaneously, any bomber return fire being split equally among them.

The interceptors in an element were assumed to fly together by either visual contact with one another or by having the AI radar of one locked onto another. All passes (or closures on bombers) were postulated as being made by pursuit courses from near the tail with visual firing. It was further supposed that the interceptors were slowed to a closing speed of 50 knots. This tail approach with low closing speed was used in order to get some benefit out of the marginal performance at low altitude by increasing the probability of detecting a bomber and allowing adequate time for firing after a detection at very short range.

F-89D: These interceptors were assumed always to be employed in elements of two aircraft each. Since the F-89D carries a radar observer, it was pictured as having more versatility than the F-86D and therefore capable of being used on any of the three modes of control. When scrambled for close control, however, only the first pass was considered to be close-controlled, the others being made on broadcast control or uniform broadcast control. A total of three passes was allowed on this method of operation, five minutes being used for the close-controlled pass and ten minutes for each of the two on broadcast control. When an element was placed on broadcast or uniform broadcast control from the start, it was given only two passes of ten minutes each.

If the aircraft in an element of F-89D's were to become separated while under close control, it was imagined that only one of them could continue that pass successfully. The other went directly into its last two, or broadcast-controlled passes, which it made independently. The one which completed the close-controlled pass also made the second and third passes individually. If planes of an element on broadcast or uniform broadcast control were to become separated, each was allowed to make both passes independently. When the element arrived at the interception point intact, the two interceptors were regarded as attacking the bomber simultaneously, any bomber return fire being split equally between them.

Because of the very short range of detection of the bomber by the interceptor, all passes were presumed to be made by pursuit course from the region of the tail with a closing speed of 50 knots and visual firing.

Employment Tactics--(1958)

F-86D: The F-86D's were employed in the 1958 analysis just as they were in the 1956 analysis, with two small exceptions which were brought on by the consideration of night rather than day attacks: the interceptors were used in elements of two only and fired by radar sighting from an overtaking collision course.

F-89D: The F-89D's were treated the same as in the 1956 analysis except for the employment of overtaking collision tactics.

F-102:* Because of the high effectiveness of these interceptors, they were postulated always to be employed individually. Furthermore, the combination of the lethality and cost of the atomic armament seemed to require that these aircraft always be close controlled by the ground network in order both to avoid destroying other interceptors which might be attacking the

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*In this paper, the designations F-102 and F-102R, when used with reference to single interceptors, mean the F-102 interceptor armed respectively with atomic warhead rockets and with "regular" small rockets. When used with reference to squadrons, they mean respectively those armed primarily with atomic warhead rockets and those armed entirely with small rockets.

same bombers and to insure that maximum use be made of this armament. Each of these interceptors was given two passes, both on close control, five minutes being allowed for each pass.

Although the range of detection at low altitude was appreciably increased for this airplane by the hypothetical addition of the early form of AMTI, it was still insufficient to allow beam attacks. All attacks were therefore presumed to be made from the region of the tail of the bomber with a 50-knot overtaking speed and collision course.

F-102R:* This interceptor also had a very high effectiveness relative to the F-86D and the F-89D. It was therefore used in single-plane elements and normally kept on close control, although it was allowed to be broadcast controlled when control channels were lacking. Two passes of five minutes each were also taken for this aircraft, and the method of attack was the same as for the F-102.

Employment Tactics--(1960)

F-102: The prevalence of the Lincoln Transition System in the areas of greatest bomber and interceptor traffic in the 1960 analysis was assumed to permit use of close control for all interceptors in this period. All F-102's were assumed to be used singly and each was given as many passes of five minutes' duration as it could make, up to a maximum of four, with the stipulation that it must retain fuel enough to return to home base

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*In this paper, the designations F-102 and F-102R, when used with reference to single interceptors, mean the F-102 interceptor armed respectively with atomic warhead rockets and with "regular" small rockets. When used with reference to squadrons, they mean respectively those armed primarily with atomic warhead rockets and those armed entirely with small rockets.

with normal reserves.

The AMTI on this interceptor was imagined as adequate to permit fairly long detection ranges (8 to 10 miles) even at low altitudes. This was sufficient to allow collision course tactics from anywhere back of about 70° off the nose of the vehicles being attacked (the high-altitude Snark-type missile, low-altitude B-47-type bomber and decoys at both altitudes). Since AMTI has no effect from directly abeam, where the radial velocity of the bomber is the same as that of the ground, the attacks at low altitudes were envisioned as being made from slightly behind the abeam position. The longer detection range did not require the slow closing speeds used in the previous analyses.

F-102R: This interceptor armed with small rockets was also used singly and on close control. Each F-102R was presumed to make as many passes of five minutes' duration as it could up to a maximum of three, and still return to its home base with normal fuel reserves.

The assumptions as to the AMTI and collision course attacks back of the beam were the same as for the F-102 armed with the atomic rocket. All attacks were presumed to be made with an interceptor-bomber course difference of 60 degrees.

Aircraft Aborts--(1956, 1958, 1960)

On the basis primarily of present operational and test data, it was supposed that fourteen percent of the interceptors which were ordered to "scramble" would not reach the point of firing at an invader because of some operational failure or malfunction. It was further hypothesized that one percent of multiple-pass interceptors which completed a pass would abort before reaching the firing stage of the next pass. Thus two non-abort factors were used, $u_{ab} = 0.86$ and $u_b = 0.99$. Any aircraft aborting its mission was considered inoperative for the remainder of the strike being analyzed.

Pilot Aborts--(1956, 1958, 1960)

In addition to the operational aborts mentioned above, it was assumed that a portion of the humans involved in the intercepts would make errors of one type or another which would result in missed conversions (or aborted passes). Some operational data from World War II indicated that about one-third of the firing passes made by fighter planes were completely in error. It was theorized that improved fire-control systems and better training procedures should bring this figure down somewhat, so a non-abort factor of $D = 0.8$ was used.

This degradation factor was further split into two parts to allow for the fact that in some of these cases the error would be great enough that no ammunition would be used. The number of aborted passes in which ammunition was used and those in which it was not were taken to be roughly equal percentages of the total number of passes. Hence two "pilot" non-abort factors were used, $D_1 = \sqrt{0.8}$ and $D_2 = \sqrt{0.8}$. It was further assumed that if either of these aborts applied, the pilot must break off his current pass attempt. The fuel and time for the pass were considered to be used, however, and if the abort was such that interceptor armament was fired (D_2 abort), the bomber also fired at that interceptor. If an interceptor's armament was not fired (D_1 abort), on the other hand, it was presumed that that interceptor was not subjected to the bomber's fire.

The different aircraft of a given formation were subjected independently to these two types of pilot aborts. The ones affected were assumed to go immediately to a broadcast control status for F-89D's, to base for F-86D's, and into the next close-controlled pass for F-102's and F-102R's (provided that none of these aircraft were killed by the bomber). All aborting aircraft were assumed separated from all other interceptors in the original element.

Probability of Detection and Conversion on Close Control, P_{dc}--(1956)

The probability of detection and conversion for an element of close-controlled interceptors was taken to be the same as that for a single interceptor. This followed from the assumption that all interceptor crews other than the lead aircraft would be occupied with keeping station on the lead aircraft. As previously mentioned, all interceptors were postulated to be vectored into approaches from behind and parallel to the track of the bombers and flown with a closing speed of 50 knots. The distance normal to the bomber track at which the interceptors were able to position themselves (i.e., their lateral error) has previously been discussed as a measurement of accuracy. The distribution of this distance was assumed to be Gaussian, with a standard deviation (σ) of 6000 feet. The detection was assumed to be made by a visual contact, and the closure and firing by visual pursuit course methods.

For the detection criterion a step function was used, detection being considered certain within the maximum detection range and impossible beyond it. The maximum detection ranges employed were 6000 feet for the single-place F-86D and 8000 feet for the two-man F-89D. It was further supposed that an interceptor which detected a bomber could always maneuver into position for a firing pass by using pursuit-course tactics (barring pilot error, which is treated separately in the preceding section). For each type interceptor P_{dc} was then found by integrating the normal curve between the limits determined by the intersections of the detection circle and the scan barrier, the latter being taken as 70^{o} to either side of the nose of the interceptor. The values thus determined can be found in Table XIII.

Probability of Detection and Conversion on Close Control, P_{dc}--(1958)*

The probability of detection and conversion for an element of close-controlled interceptors was again assumed the same as that for a single interceptor. In the hypothesized nighttime attacks of 1958 all interceptors were again vectored to the bombers on overtaking courses with closing speeds of 50 knots. The same distribution and standard deviation of vectoring errors were assumed as for 1956. However, visual contact with enemy aircraft was considered very unlikely. Detection was limited to radar means, and closures were presumed to be radar-directed collision-course attacks. For ease in computing P_{dc}, and because of a lack of sufficient information to justify a more refined assumption, a step-function was again used for the detection criterion. Maximum detection ranges of 4000 feet and 8000 feet were postulated for the F-86D and the F-89D, respectively, but it was theorized that these interceptors would be unable to perform lock-on until they had closed to ranges of, in turn, 3000 feet and 4000 feet. A delay of six seconds was also stipulated following the interceptor's initial turn before the lock-on procedure could be completed.

The F-102 was envisioned as being equipped with a radar having a crude form of AMTI which, because of so-called platform motion, would give it a non-circular detection-range function. The following assumptions were used to define the AMTI performance:

*This section applies to all cases except one raid of IL-28's caught at high altitude by F-102's, for which P_{dc} was taken to be unity.

Table XIII

ESTIMATED VALUES OF P_{dc}, P_{kb}, and $P_{k\emptyset}$ FOR AREA WEAPONS

Year and Offense Tactic	Interceptor Type	Bomber Type	Number of Interceptors Attacking Bombers Simultaneously	P_{dc} (2)	P_{kb} (3)	$P_{k\emptyset}$ (3)
1956 Low Altitude Day	F-86D	IL-28	1	.65	.16	.20
			2	.65	.20	.13
			3	.65	.22	.09
			4	.65	.24	.07
		TU-4	1	.65	.37	.22
			2	.65	.45	.13
			3	.65	.50	.10
			4	.65	.52	.08
	F-89D	IL-28	1	.79	.24	.36
			2	.79	.35	.30
		TU-4	1	.79	.44	.33
			2	.79	.57	.26
1958 Low Altitude Night	F-86D	IL-28	1	.28	.13	.21
			2	.28	.16	.14
		Type-31	1	.29	.26	.22
			2	.29	.33	.18
	F-89D	IL-28	1	.72	.20	.28
			2	.72	.28	.21
		Type-31	1	.75	.43	.28
			2	.75	.55	.20
	F-102	IL-28	1	.92	.97	0
		Type-31	1	.95	.97	0
	F-102R	IL-28	1	.92	.35	.20
		Type-31	1	.95	.56	.20
1960(1) Snark High Altitude Night; B-47 Low Altitude Night	F-102	Snark	1	1	.97	0
		B-47	1	1	.97	0
	F-102R	Snark	1	1	.97	0
		B-47	1	1	.69	0
	F-99A	Snark	1	1	.52	--
		B-47	1	0	--	--
	F-99B	Snark	1	1	.97	--
		B-47	1	1(4)	.133(4)	--
	F-99C	Snark	1	1	.52	--
		B-47	1	1	.52	--

(1) In 1960 the parameter values for all weapons versus decoys were taken to be the same as those versus the accompanied carriers.

(2) Per element of interceptors.

(3) Per interceptor.

(4) See text.

1. The interceptors would fly at the same altitude as the bomber
2. The radar antenna would be pointed up 0.5°
3. The clutter-rejection capability of the AMTI would range from 5 db at 70° off the interceptor's nose to 10 db at 30° off the nose
4. Clutter signal strength would be such that a ratio clutter attenuation/target attenuation = 25 db would allow detection of a Type 31

Employment of the above assumptions led to the following contour for the detection-range step function:

vs. IL-28	11,400 feet for target 70° off interceptor's nose
	11,900 feet for target 50° off interceptor's nose
	12,700 feet for target 30° off interceptor's nose
vs. Type 31	12,700 feet for target 70° off interceptor's nose
	13,500 feet for target 50° off interceptor's nose
	15,000 feet for target 30° off interceptor's nose

Lock-on was thought to be feasible with this equipment immediately upon completion of the turn onto an approximate collision course. The scan limit was again taken as 70° to either side of the interceptor's nose.

In all cases a delay of 5 seconds was presumed for evaluation of the attack situation after detection. This was reflected in the graphical solutions used for determining P_{dc} by advancing the detection contour along the bomber's track (in bomber space) by a distance equal to 5 seconds times the overtake speed.

Following lock-on, minimum times were specified for:

Settling of steering presentation	3 sec.
Computer smoothing	18 sec.
Rocket time of flight	1 sec.
Additional time for interceptor to reach aim point	$\frac{r_F}{V_F}$ sec.

where r_F is the distance between the interceptor and bomber at the time of impact, taken to be 730 feet,[12] and V_F is the interceptor's speed. These times determined a minimum "time-to-go line" which was measured <u>from the aim point</u>. If lock-on has not occurred by the time the interceptor has closed to this line, conversion cannot take place.

A graphical construction was used to find the parallel path of maximum distance off the bomber track along which an interceptor could overtake a bomber and still detect and convert subject to the constraints discussed above. This "maximum distance" has been termed the "limit of interceptor distribution." The form of the graphical solution is shown in Fig. 12 for the F-86D and F-89D case, where the limit of interceptor distribution was determined by the intersection of the minimum time-to-go line and the lock-on range circle. For the F-102R, the limit of interceptor distribution was determined by the intersection of the interceptor radar scan limit and the detection line; while for the F-102 armed with atomic rockets (for which r_F was taken to be 4250 feet) it was determined by the minimum time-to-go line, the detection line, and the interceptor turn radius. It should be emphasized that Fig. 12 is drawn in bomber space.

P_{dc} was then determined from these graphical solutions by integrating the assumed normal curve of interceptor distribution (σ = 6000 feet) out to the "limit of interceptor distribution." The results are given in Table XIII.

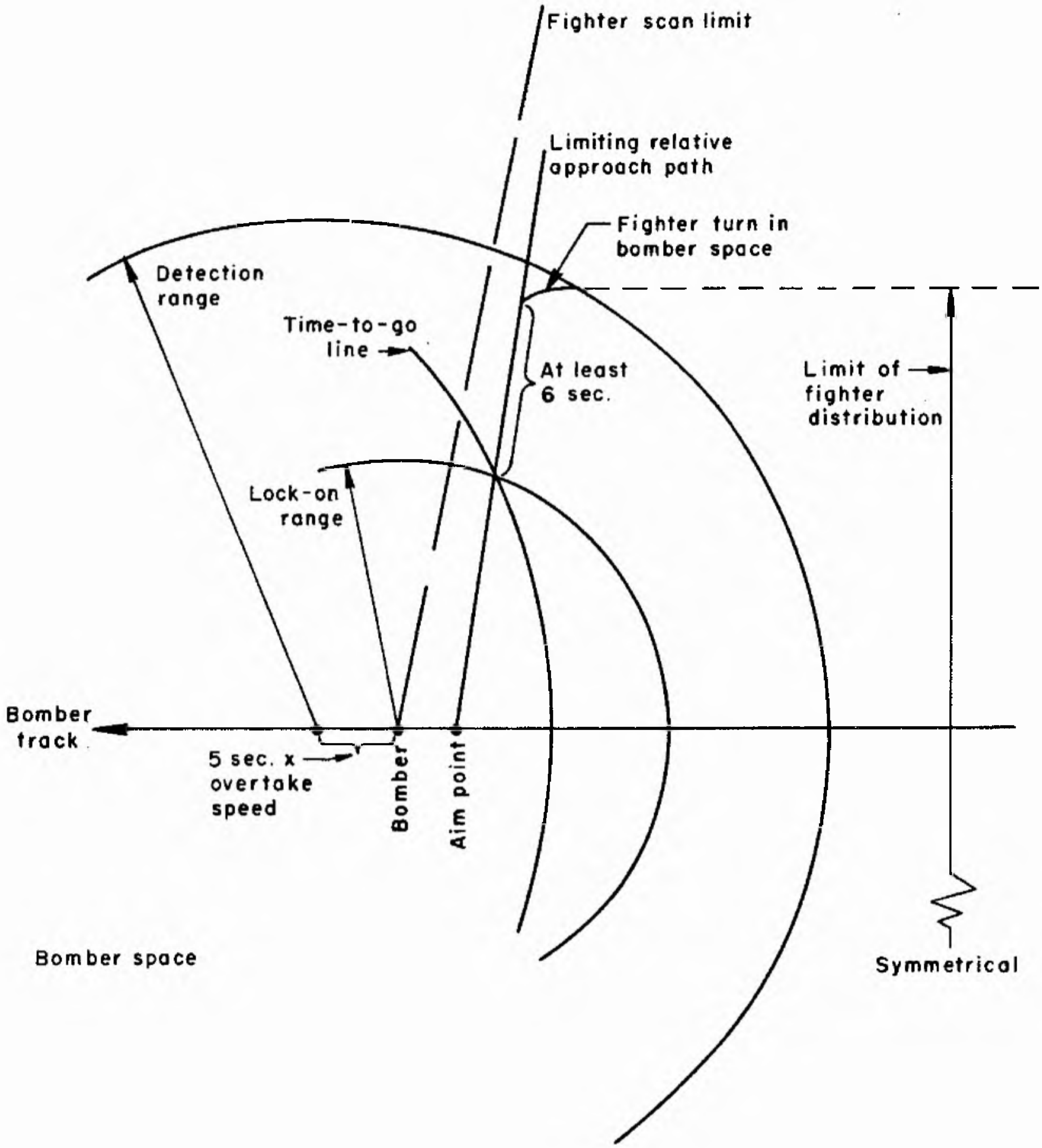

Fig. 12 — Graphical solution of P_{dc}

Probability of Detection and Conversion on Close Control, P_{dc}--(1960)

For the high-altitude attacks by Snark-type missiles in 1960, the performance of the F-102 was found to be very good if adequate time remained after detection to complete the closure on the missile (either Snark-type missile or decoy, the latter looking like the former to a radar). The assumed vectoring error of 3000 feet and the AI radar performance of approximately eleven miles' detection range on the missile were sufficient to allow all interceptors to detect their targets, so that the closing speed was the critical factor. In this regard it was found that the conversion could be completed by the F-102 if the attack angle was aft of about 60° off the missile's nose, and by the F-102R from any attack angle. Consequently P_{dc} was assumed to be unity, with the stipulation that vectoring should be aft of abeam.

Against the low-altitude B-47-type bomber attacks, essentially the same situation prevailed. Hence P_{dc} was again taken as unity, with the requirement of vectoring slightly aft of abeam.

Probability of Detection and Conversion on Broadcast Control, $\bar{P}_{dc}$--(1956, 1958, 1960)

It was postulated throughout this study that the F-89D would be the only interceptor used on broadcast control against the low-altitude raids. The F-86D, being a single-place interceptor without AMTI on its radar, was thought to be incapable of performing on this mode of control because the pilot would be too busy flying his airplane to do the extensive searching for targets which is required under broadcast control. In 1958 the F-102's and F-102R's were thought to be too effective to compromise their performance by using anything other than close control, so they were given first priority on control channels and, due to their limited number, never had to be used on any other method of control. In 1960 there was adequate control capability in the assumed Lincoln system to handle all of the interceptors individually so that broadcast control was not employed. In all three years, ground-to-air and air-to-air IFF was assumed to be available and to work well.

The same detection and lock-on criteria were used for the F-89D on broadcast control as on close control, these being stated in the preceding section. Interceptors on broadcast control were assumed to have been instructed to fly into the rear of the bomber formation and proceed in the same direction as the bombers with a 50-knot overtake speed. The bombers were assumed to be located randomly within the formation,* and $\bar{P}_{dc}$ was determined from the equation

$$\bar{P}_{dc} = 1 - \left[1 - \frac{A(t)}{A_o} \right]^{\beta}$$

where

t = time of search,

$A(t)$ = area searched by interceptor's radar in time t,

A_o = area of bomber formation,

β = number of bombers in the formation,

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*Two other models were investigated, one with the bombers located on the corners of a rectangular grid, the other with each bomber located within a rectangle of the grid with uniform distribution over the rectangle. The $\bar{P}_{dc}$'s resulting from these assumptions were very close to that obtained on the assumption of random location. The random model, being simpler, was used throughout the study.

and $\bar{P}_{dc}$ = probability of detecting at least one bomber upon which conversion can be accomplished while searching during time t through the bomber formation.

The time of search was considered to be ten minutes for each broadcast-controlled "pass," and A(t) was given approximately by

$$A(t) = \frac{\pi r_1^2}{2} + 2r_2 st$$

where r_1 = detection radius,

r_2 = "limit of fighter distribution" as found in solutions for P_{dc}

and s = overtake speed.

As an example, for a bomber formation coming in over sea* in the daytime,

A_o = 1025 square nautical miles (from Chapter I)

r_1 = 1.32 nautical miles

r_2 = 1.25 nautical miles

s = 0.833 nautical miles per minute

t = 10 minutes**

$$A(t) = \frac{\pi(1.32)^2}{2} + 2 \times 1.25 \times .833 \times 10 = 2.73 + 20.8 = 23.53 \text{ n mi}^2$$

and $$\bar{P}_{dc} = 1 - \left(1 - \frac{23.53}{1025}\right)^{\beta} = 1 - (.9765)^{\beta}$$

$\bar{P}_{dc}$ is plotted vs β for various conditions of attack in Fig. 13.

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*The value of $\bar{P}_{dc}$ for a given number of bombers differed for an over-water approach as opposed to an overland approach. This was because the permissible bomber formations (and hence A_o) differed in the two cases, mainly as a result of differences in the radar line of sight (for the bombers' station-keeping radars) corresponding to the approach altitude.

**Since most of the time would be spent in straight-and-level search (which usually carried the interceptors toward their bases), and because most F-89D's were not using their complete radius capability, F-89D's on broadcast control were given an extra range-free five minutes per pass.

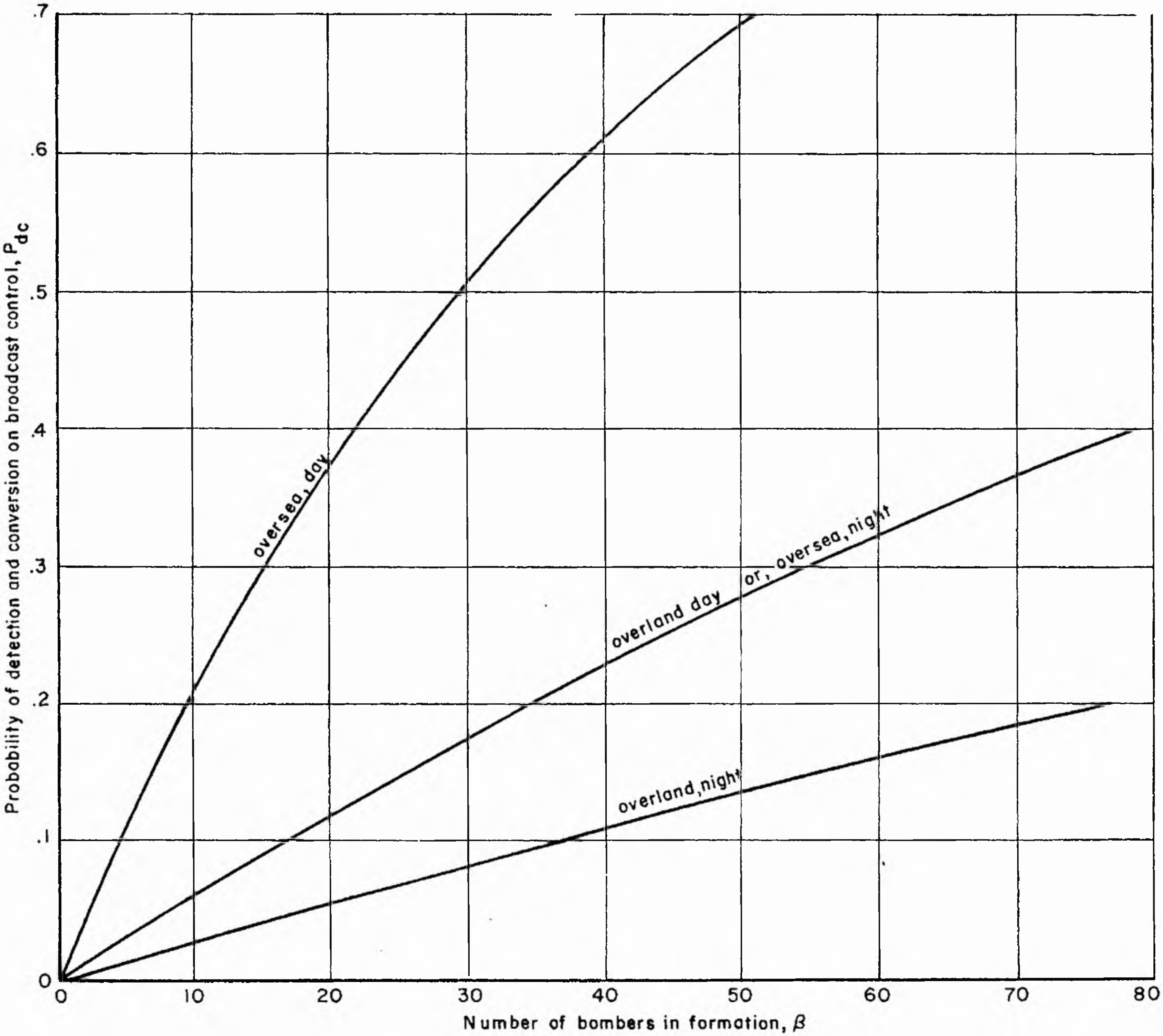

Fig. 13
Probability of detection and conversion on broadcast control vs number of bombers in formation

Probability of Detection and Conversion on Uniform Broadcast Control, $\bar{P}_{dc}'$--
(1956, 1958, 1960)

For the same reasons as given in the last section, only F-89D's were used on uniform broadcast control. The assumptions about performance of the fire-control system were the same as given above for close control, and the interceptors were again imagined to have been instructed to approach the bomber from the rear with a 50-knot overtake speed. The critical thing for this type of control was the assumption of the accuracy with which an interceptor could fly to a moving point in space. Since the interceptor was again allowed a ten minute search period per "pass," the positional error normal to the bomber path was the important parameter. This error was taken to have a normal distribution with $\sigma = 3$ miles for interceptions over land and $\sigma = 5$ miles for interceptions over the ocean. Integrating these distributions out to the "limit of interceptor distribution" as found for P_{dc}, the following figures were obtained for $\bar{P}_{dc}'$ for both night and day attacks:

$$\text{over sea,} \qquad \bar{P}_{dc}' = .20$$

$$\text{over land,} \qquad \bar{P}_{dc}' = .32$$

Probability of Kill of Bomber (P_{kb}) and of Interceptor ($P_{k\phi}$)—(1956)

An interceptor overtaking a bomber from the rear is subject to the full brunt of the bomber's tail-fire. The aerial engagement becomes a duel, with each plane attempting to shoot the other down without being first destroyed itself. The methods of RM-1067[13] were employed in this study to find the probabilities of kill of the bomber by each of the interceptors engaged in the duel and of each of the interceptors by the bomber.

F-86D: The F-86D was assumed to fire all of its 24 2.75 inch rockets in one pass. The 120 rounds of 23 millimeter ammunition which the bomber could fire during one duel were regarded as being divided equally among the interceptors making the pass. The standard deviations of the fire-control errors were postulated to be 27 mils for the interceptor and 12 mils for the bomber. The minimum range at which the interceptor would fire was taken as 1000 feet. The vulnerable areas used are given in Table XIV.

Two types of kill and their corresponding vulnerable areas were considered in all the kill-probability estimates, namely A-kills and C-kills. An A-kill is one in which the damaged aircraft crashes or falls out of control within five minutes. A C-kill is one in which the damaged aircraft cannot complete its mission in progress. In all cases the vulnerable areas employed for the bombers was that corresponding to an A-kill. For the interceptors at low altitude (the only case for which vulnerable areas were estimated for interceptor or manned bomber) the largest of the two vulnerable areas was employed. This was done to reflect the pilot's inability to parachute from low altitude. It was assumed that at the first indication of being hit the pilot would attempt to gain altitude, thus breaking off the engagement.

As an illustration of the procedure followed, consider two F-86D's attacking a TU-4. For this condition:

For the bomber

number of rounds, N_b = 60 (per interceptor)

vulnerable area, A_b = 167 sq. ft.

equivalent armament dispersion, σ_b = .012 radian

maximum rate of fire, ν_b = 26.7 rounds/sec.

Table XIV

BOMBER AND INTERCEPTOR VULNERABLE AREAS

Fighter	Bomber	Vulnerable Area in Sq.Ft.[1] Bomber	Vulnerable Area in Sq.Ft.[1] Fighter
	1956 (Low Altitude, Day)		
F-86D	TU-4	167	5
	IL-28	61	
F-89D	TU-4	167	23
	IL-28	61	
	1958 (Low Altitude, Night)		
F-86D	IL-28	52	12
	Type-31	122	
F-89D	IL-28	57	23
	Type-31	177	
F-102R	IL-28	78	11
	Type-31	173	
F-102	IL-28	78[2]	11
	Type-31	173[2]	
	1960 (Low Altitude, Night)		
F-102	B-47	335[2]	11
F-102R	B-47	335	11
F-102	Snark	(3)	
F-102R	Snark	(3)	

(1) The vulnerable areas are for the particular armaments assumed to be fired and for the particular type of firing pass assumed to be made. In each 1956 and 1958 case, a distribution of attack angles about the tail of the bomber was used which was felt to be consistent with the AI capabilities and the fighter maneuverabilities involved.

(2) These vulnerable areas are for the small rockets. See p. 90 for the assumptions regarding the atomic warhead rockets.

(3) See p. 92 for the assumptions about Snarks.

For the interceptor

number of rounds, N_f	= 24 (per interceptor)
vulnerable area, A_f	= 5 sq. ft.
equivalent armament dispersion, σ_f	= .027 radian
minimum range of fire, r_δ	= 1000 feet
closing speed, V	= 84.3 feet/sec.

From Ref. 13,

$$k_1 = \frac{N_f A_b/\sigma_f^2}{N_b A_f/\sigma_b^2} = \frac{24 \times 167/.027^2}{60 \times 5/.012^2} = 2.64$$

$$r_1 = \sqrt{\frac{N_f A_b}{2\pi\sigma_f^2}} = \sqrt{\frac{24 \times 167}{2\pi \times .027^2}} = 935 \text{ ft}$$

$$\delta = \frac{r_\delta}{r_1} = \frac{1000}{935} = 1.07$$

where k_1 is a relative armament effectiveness number and r_1 is the range at which the interceptor would expect one hit on the bomber. To find P_{kb} and $P_{k\phi}$, the two parameters k_1 and δ were then used in Figs. 2a and 2b, pp. 27 and 28 of Ref. 13, which show respectively the probability of kill of the bomber and the probability of kill of the interceptor as functions of these parameters for this duel situation. For the particular case in question,

$$P_{kb} = .45 \quad \text{(per interceptor)}$$

$$\text{and } P_{k\phi} = .13 \quad \text{(per interceptor)}.$$

These and all other kill probabilities used in this study are presented in Table XIII.

F-89D: The two-place F-89D was assumed to fire its 108 2.75 inch FFAR in two passes, using single salvos of 54 rockets on each pass. The assumptions of fire-control error and minimum firing range were the same as those given for the F-86D, as were those for the bomber. Vulnerable areas are again to be found in Table XIV and the kill probabilities in Table XIII.

Probability of Kill of Bomber (P_{kb}) and of Interceptor ($P_{k\phi}$)--(1958)

F-86D: The 48 small rockets carried by the F-86D in this part of the study were assumed all to be fired in one salvo on one pass. Since the interceptor armament was now more effective, a minimum firing range of 1500 feet was used, with a resulting decrease in the number of interceptors killed. The vulnerable areas are to be found in Table XIV. The other pertinent assumptions were the same as in 1956.

F-89D and F-102R: It was postulated that each of these planes would fire its 216 small rockets on two separate passes, using a salvo of 108 rockets on each pass. The other considerations, except those given in Table XIV were the same as for the F-86D.

F-102: The atomic-armed F-102 was envisioned as firing a single A-warhead rocket on each of two passes. The supposed firing range was 4500 feet, which provides adequate separation for the escape of the interceptor.(11) The atomic armament itself, according to the design criteria from Ref. 11,produced a probability of kill of the bomber approaching unity, even allowing the bomber maximum evasive maneuver. After including factors for reliability of the rocket, fuse, etc., P_{kb} = 0.97 was used for this interceptor and armament. The bomber fire was taken to be ineffective at this range, so that $P_{k\emptyset} = 0$.

Probability of Kill of Bomber (P_{kb}) and of Interceptor ($P_{k\emptyset}$)--(1960)

F-102R: The F-102, since it possessed a good AMTI radar, was assumed able to close on a collision course against all attacking vehicles employed at either high or low altitude. Although approaches from forward of the beam could have been performed by the F-102R, it was estimated that the F-102 with atomic warhead could not so operate. In order to make the general process of vectoring uniform, it was required that the F-102R make its passes back of the beam. The actual interceptor-bomber course difference assumed was 60°, which collision approach was envisaged as rendering ineffective the tail turret of the bomber. The interceptor-bomber encounter was therefore not treated as a duel.

The methods of RM-1147[14] and RM-1097[15] were used in determining P_{kb}. The range from the F-102R to the bomber at the time of firing was taken to be 2600 feet. The 216 2-inch rockets were regarded as being fired in two equal salvos and an "equivalent dispersion" of 27 mils was employed. Both the B-47-type bombers at low altitude and the Snark-type missiles at high altitude were assumed not to perform evasive maneuvers. Since they were designed to be indistinguishable from the accompanied bomb carriers, the decoys employed with the bombers and the missiles were also presumed not to perform evasive maneuvers.

Thus, for the low-altitude B-47:

bomber vulnerable area, $A_b = 335$

number of rockets in salvo, $N_r = 108$

equivalent dispersion, $\sigma_r = .027$ radian

present range, $r = 2600$ feet

$$\lambda = \frac{N_f A}{2\pi(\sigma_f r)^2} = \frac{108 \times 335}{2\pi(.027 \times 2600)^2} = 1.17$$

$$P_{kb} = 1 - e^{-\lambda} = 1 - e^{-1.17} = 1 - 0.31 = 0.69$$

In the case of the Snark-type missile attack there was the additional possibility (considered fairly probable) that the defense would know or be able to deduce that the attacking vehicles were passive--i.e., they would neither maneuver nor return fire. In such a case the interceptors might well adopt a policy of converting to a firing position in a tail chase, slowing down to the speed of the missile, and firing repeated salvos of a few rockets each until it was determined that the missile had gone out of control. More time would be required for this tactic, but the firing time would be spent at essentially cruise speed, thus conserving fuel and allowing the interceptor more battle time, and P_{kb} would be made very nearly unity for each pass. In addition, fewer rounds would be fired per kill, so that the F-102R could make more passes with the same number of rockets. The same tactic, naturally, could be employed against the decoys accompanying the missiles.

A compromise was adopted in the actual calculation of attrition for the missile (and decoy) attacks: P_{kb} was chosen to be 0.97, equal to that for the atomic-armed F-102, and the F-102R was limited to a total of three passes.

At low altitude the crudeness of the guidance and stabilizing systems used in the decoys should cause them to be much more vulnerable for their size than the B-47-type bombers but the small size of the decoys was felt to more than offset this fact. On the other hand, several ameliorating factors were involved in the analysis. First, no allowances were made for collisions between decoys, between decoys and bombers, nor, very important in the low-altitude strike, of decoys with the ground. Second, even barring collisions the decoys might at times be close enough together to have two or even more destroyed with one atomic warhead or salvo of rockets, which fact was not reflected in the analysis. Third, the possibility of a significant number of the decoys being recognized as such was not specifically considered.*

The result of these considerations was to simplify the analysis by assuming that the decoys had a vulnerability equal to that of the bombers which they accompanied. The same value of P_{kb} was therefore applied to the decoys as to the B-47-type bomber. It is to be noted that the F-102R kills comprised a small fraction of the total in both the missile and bomber attacks.

F-102: For the interceptor firing atomic-warhead rockets, the situation envisioned was much the same as for the 1958 strikes. Again, as explained in Ref. 11, the rocket speed, burst size, and firing range were picked such as to produce a P_{kb} approaching unity, even in the case of a maximum evasive maneuver. The reliabilities involved were considered to result in an overall value of $P_{kb} = .97$.

After firing its two atomic rockets, this interceptor was left with 108 2-inch rockets, which were presumed to be fired in one salvo against the

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*It was postulated throughout that there was no wholesale recognition of decoys, although a finite probability exists that the defense might accomplish this by some clever means. An attempt to avoid decoy-bomber collisions by programming them at different altitudes would enhance this probability substantially. Such recognition would, of course, not only nullify the use of the decoys, but make it a detriment because of the effort devoted to them which might have been put into more bombers.

low-altitude bomber or its decoys or in one extended pass against the missile or its decoys. The assumed condition was now the same as for the F-102R, and the same values of P_{kb} were used. The interceptor was allowed to make a total of four passes, fuel and armament permitting, launching atomic rockets on the first two of these which resulted in firing signals, and 108 2-inch rockets on the next.

Turn-Around of Interceptors--(1956, 1958, 1960)

It appeared that where the interceptor speed was high relative to the speed of the bombers some interceptors could probably be refueled and re-armed at their base after one sortie in time to make a second sortie against either the same or a different bomber stream. For this purpose it was assumed that up to four of a group of returning interceptors could be made ready for battle again, or "turned around," in twenty minutes from the time they arrived at the field. Any more which returned would be split into groups of four, and these groups could be scrambled in series, with 20 minutes between successive groups. When the times involved allowed turn-arounds to be used, the number of interceptors which were expected to survive the first sortie was computed and used as the number available for scramble on the second sortie.

AREA-DEFENSE MISSILES - (1960)

There were no area-defense missiles in the defense system assumed for 1956, and only one squadron of F-99A's was assumed for 1958. The low-altitude capability of this early form of the Bomarc weapon was regarded as being zero, and the presence of the one squadron was therefore neglected in the 1958 analysis.

Probability of Non-Abort, u_{ab}

It was presumed that the reliability of the Bomarc missile in all three of its forms--the F-99A, B, and C--would be fairly high by the time it got into production. A non-abort factor of $u_{ab} = 0.8$ was used for the complete missile in each form. In addition, the atomic warhead of the F-99B was assumed to give it some capability for destroying bombers when detonated by command from the ground without using the seeker for terminal guidance. A separate probability of non-abort of $u_{ab} = 0.9$ was therefore used for the F-99B in low-altitude attacks where its seeker was useless.

Probability of No Human Errors, D

Although no pilot would accompany the missile, so that there would be no "pilot aborts," it was felt that the missile would be much more subject than the interceptor to errors made by humans or by calculation and communication equipment in the ground system. The missile being a one-shot affair, nearly any error would result in a wasted missile. The same probability of no error, $D = 0.8$, was postulated as was used for the interceptors.

Probability of Detection and Conversion, P_{dc}

F-99A: The system vectoring errors and missile and seeker performance were presumed to result in a P_{dc} of unity at high altitudes. There was taken to be no provision for the elimination of ground clutter at low altitude, with a resultant P_{dc} equal to zero against low-altitude attacks.

F-99B: The high-altitude performance of this missile, and resulting P_{dc}, were the same as for the F-99A. Although the vectoring accuracy at low altitude was identical to that for the F-99A, the employment of an atomic warhead relaxed the limits describing a successful intercept and allowed a reasonable success probability on the basis of ground vectoring alone. The missile was visualized as being vectored to the vicinity of the target and the warhead being detonated by command from the ground network, without use of the airborne seeker. In this situation P_{dc} has no strict interpretation. However, in order to employ the same method of calculating effectiveness for all missiles, it was considered unity for the F-99B at low altitude also. The large miss distances resulting from no use of the seeker were accounted for in the calculations of P_{kb}, as discussed below.

F-99C: The pulse-doppler seeker hypothesized for the advanced model of the Bomarc missile was regarded as having performance at both high and low altitudes resulting in $P_{dc} = 1$.

Probability of Kill of Bomber, P_{kb}

F-99A and C: Both of these versions of the Bomarc were assumed to contain expanding-rod warheads. It was felt that not enough data existed to make accurate analyses of kill probabilities with this warhead, but preliminary work indicated a value slightly greater than 0.5. In this study P_{kb} was actually taken to be 0.52.

F-99B: At high altitude the same consideration was given the Bomarc with atomic warhead as was given the interceptor with atomic rockets: that the warhead was adequate to compensate for the miss distances expected with the seeker, and P_{kb} would approach unity. The warhead reliabilities involved led to a value of 0.97 for P_{kb}. At low altitude, where the seeker was of no use, the kill probability was based on the expected vectoring accuracy of the ground system, the lethal radius of the atomic burst, and the warhead reliability. With the assumed vectoring error of 3000 feet, a lethal radius of 1600 feet,[11] and the same reliability as was postulated at high altitude, the resultant low-altitude value was $P_{kb} = 0.13$.

LOCAL DEFENSES - (1956, 1958, 1960)

The remarks of this section apply to all three years, 1956, 1958, and 1960. It was assumed that the changes which occurred in the local defenses during this time were changes of types and numbers of missiles and missile systems rather than minor changes within any one system.

Radar Limitations

Nike: The Nike tracking radars were assumed to be incapable of adequate clutter rejection for use at low angles of elevation. It was theorized that they could track targets down to 15 mils above the horizon.

Talos: The Talos system, both in Talos CW and Talos W, was assumed to be usable down to the radar line of sight.

Probability of Target Acquisition

It was assumed that in all cases the data from the surveillance radar network was adequate to allow the radars of the local-defense weapons to find and acquire targets, within the limits described above. Thus the probability of target acquisition was treated as being unity whenever sufficient warning existed to bring the local-defense batteries into action, and as zero when the warning was insufficient.

Warning Time Required

The warning required to bring local-defense batteries into action was assumed to be fifteen minutes from the time a bomber crossed the detection perimeter until it reached the maximum firing range, R_M, which is defined below.

Probability of Non-Abort, u_{ab}

Nike and Talos W: These missiles which did not incorporate seekers were given reliabilities, or non-abort factors, of $u_{ab} = 0.9$.

Talos CW: This missile with its semi-active seeker was assigned a $u_{ab} = 0.8$.

System and Human Degradation, D

Because of the short times involved, a local-defense weapon is even more susceptible than an area weapon to any mistakes of commission or omission by the ground network. A degradation factor of D = 0.75 was used for all of the local-defense missiles.

Firing Ranges

A minimum firing range, R_m, of 5 nautical miles was postulated for all of the local-defense missiles. Maximum firing range, R_M, is defined as the distance from the missile battery to the target at the time of the first interception, and depends upon the altitude of the target and the missile characteristics. The R_M for each specific attack situation considered can be found in Table XV.

Time Interval Between Salvos, a

The time interval between salvos for a Nike battery was taken to be 12 seconds. For Talos CW and Talos W batteries it was taken to be 20 seconds.

Number of Salvos Fired per Battery, N_s or N'_s

N_s was defined as the number of salvos which could be fired prior to bomb-release line by one battery if a single bomber passed directly overhead of the battery. For this purpose it was envisioned that the bomb-release

Table XV

LOCAL DEFENSE EFFECTIVENESS

Year and Offense Tactic	Local Defense Weapon	Bomber Type	Bomber Speed (Knots)	Bomber Altitude (feet)	R_M (n.mi.)	a (sec.)	b (sec/n.mi.)	No. of Salvos N_s, N'_s	Missiles Per Salvo S	Missile Reliability μ_m	Kill Probability P_{kb}	Siting Factor: City Targets	Siting Factor: SAC Bases
1956 Low Altitude Day	NIKE I	IL-28	450	200	--	--	--	0	--	--	--	--	--
		TU-4	275	200	--	--	--	0	--	--	--	--	--
1958 Low Altitude Night	NIKE I	IL-28	450	500	6	12	4.22	1	1	0.9	0.50	0.18	1
		T-31	400	500	6	12	4.22	1	1	0.9	0.50	0.18	1
	TALOS W Single Simplex	IL-28	450	500	21	20	3.20	3.21	1	0.9	1	0.50	1
		T-31	400	500	22	20	3.20	3.59	1	0.9	1	0.50	1
	TALOS CW Single Simplex	IL-28	450	500	21	20	3.20	3.21	1	0.8	0.75	0.50	1
		T-31	400	500	22	20	3.20	3.59	1	0.8	0.75	0.50	1
1960 Snark: High Altitude Night; B-47: Low Altitude Night	NIKE I	Snark	515	50,000	21	12	4.22	2.84	1	0.9	0.50	0.50	1
		B-47	450	500	6	12	4.22	1	1	0.9	0.50	0.18	1
	TALOS W Dual Simplex	Snark	515	50,000	50	20	3.2	8.97	1	0.9	1	0.80	0.97
		B-47	450	500	21	20	3.2	6.31	1	0.9	1	0.50	1
	TALOS CW Dual Simplex	Snark	515	50,000	50	20	3.2	8.86	2	0.8	0.75	0.80	0.97
		B-47	450	500	21	20	3.2	6.05	2	0.8	0.75	0.5	1

line occurred within the minimum firing range of the battery so that N_s was the number of salvos fired at a single bomber headed directly over the battery, from maximum firing range to minimum firing range. For one guidance unit per battery*

$$N_s = 1 + \frac{3600}{bV_B} \ln \left(\frac{a + bR_M}{a + bR_m} \right) ,$$

while for two guidance units per battery (dual simplex operation of Talos CW and Talos W),

$$N'_s = N_s + 1 + \frac{3600}{bV_B} \ln \left[\frac{a + b\,(R_M - cV_B)}{a + bR_m} \right] ,$$

where b = reciprocal of effective missile speed in sec/n mi

V_B = bomber speed in knots

a = time interval between salvos in sec

R_M = maximum firing range in nautical miles

R_m = minimum firing range in nautical miles

c = launcher tie-up time, taken = 30 seconds for Talos CW

and = 10 seconds for Talos W.

Thus for a Talos CW single simplex defending against an IL-28 attacking at 500 feet (a 1958 strike),

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*The equations given for N_s and N'_s do not hold for small values of R_M, such as R_M = 6 nautical miles.

$$N_s = 1 + \frac{3600}{3.2 \times 450} \ln \frac{20 + 3.2 \times 21}{20 + 3.2 \times 5}$$

$$= 1 + 2.5 \ln \frac{87.2}{36}$$

$$= 1 + 2.21$$

$$= 3.21$$

The values of N_s or N'_s for each attack situation are given in Table XV.

Probability of Kill of Bomber by One Missile, P_{kb}

For Nike and Talos W, where no seeker is employed, the miss distance, and therefore the probability of killing the bomber, is a function of the range at which the intercept occurs. When the missile has a seeker for final homing, this is true only in a very minor fashion. For this study, only one value was employed for P_{kb} for each of the missiles involved, this being a value which was averaged over the range of intercept capability. These values are listed in Table XV.

Siting Factor, g

So far the discussion has dealt only with a battery which lies directly under the bomber's path. Batteries which are not so located have a reduced effectiveness because the bomber may be in range for a much shorter time before bomb release line, or may never come within range at all. The result of this is two-fold: the battery can fire fewer salvos, and the average salvo is fired at longer range, which may reduce P_{kb}.

The local-defense batteries around a city were pictured as being situated on a circle of ten miles' radius, while those around a SAC base were taken as on a circle of three miles' radius. A siting factor, g, was then computed which would adjust the average kill potential per battery for a bomber approaching from any direction. These siting factors are also listed in Table XV for each threat studied, and for both city and SAC targets.

CHAPTER III

STRIKE ANALYSIS TECHNIQUES

In order to determine the results of Soviet attacks on the U.S. under the various conditions discussed in the preceding chapters, an attempt was made to set up strike models which would be as realistic as possible. The method was to locate targets, bomber routes to targets, and the components of the defense system on a map of the United States and examine the air battles in the light of the actual geographical effects. In this way factors were included which could not easily be treated in a purely mathematical model. The air battles were simulated on the basis of the general offense and defense force assumptions discussed in Chapters I and II, in conjunction with a set of more detailed rules and on-the-spot decisions. These rules and decisions were intended to make each stage of the battle highly realistic. Tactics of both the defense and offense forces were represented on the map and will be referred to as "tactical decisions." The numerical results, in terms of bombers surviving the air battles, were calculated by a mathematical model which used the results of the tactical decisions as inputs.

The map exercise technology will be described in this chapter. The mathematical model of the air battle which was used to calculate the final results of the strikes will be discussed in Chapter IV.

The strike techniques which will be described below represent a continuous learning process. The methodology employed in the first few strikes was very crude compared to that used in the later strikes. As the sensitivities of the results of the strikes to various factors were discovered, changes and refinements were made. Because of the great variation in the strike techniques from one time period to another, this chapter will consist of a separate description of each strike. The conditions of each strike and the changes in techniques will be discussed.

The fact that several of the detailed discussions in this chapter describe strikes using the "vertical" attacks on petroleum and steel* does not imply that this was the primary target system for the entire study. These particular strikes were described in detail merely because changes in strike philosophy and methodology occurred at the time they were done. The strategy used in most cases and considered to be basic for the entire study was an attack on SAC bases, Washington, D.C., and urban industrial concentrations, in that order of priority. (Although Washington, D.C., appears high on the priority list of this target strategy, it could not always be attacked, as will be seen in the descriptions of the strikes which follow.) All of the 1956 and 1958 strikes in which offense force sizes, bomb sizes, and defense strength were varied were based on this strategy. The 1960 strikes were aimed primarily against urban industrial targets; SAC bases were not attacked, as will be discussed in the section on 1960 strikes.

The general procedure followed in analyzing the first four strikes can be outlined as follows:

A. Determination of offensive and defensive force sizes

B. Description of Soviet activity

   1. Selection of target strategy

   2. Estimate of expected attrition

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*A target system which included petroleum targets, steel targets and SAC bases. Often this strategy did not make use of all the bombers available and the remaining force was used on urban industrial concentration targets.

3. Selection of target complexes*

4. Assignment of bombers to targets**

5. Selection of bomber routes to targets

C. Determination of U.S. defensive actions

D. Tabulation of parameters to be used in the calculations of the strike results

In the first four strikes the primary purposes for the map exercise were to determine the routes for the Soviet bombers which would encounter the least amount of U.S. defenses and to determine the input parameters for the calculations of results.

For reference, a summary of the conditions of each strike will be given at the beginning of the section describing the strike. Unless otherwise stated, the offensive force assumed to be available for a strike is equivalent in cost to the "basic" force for that year as described in Chapter I.

1956 STRIKES (I, II, AND III)

Strike I

Offensive Force Arriving in ZI	188 TU-4's and 150 IL-28's.***
Bombs Arriving in ZI	290 100-KT bombs.

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*In the 1956 and 1958 strikes each city was a target complex. Each target could consist of one or more aiming points.

**The word "target" as used in the following descriptions infers target complex.

***The number of bombers and bombs arriving at the ZI are the numbers briefed minus the operational and refueling aborts. 20 percent of the total force was assumed to abort due to operational failures. The refueling aborts are described later. The TU-4's to which the IL-28's had been wingtip-coupled did not enter the battle zone.

Targets	SAC bases, petroleum targets, steel targets, and urban industrial concentrations.
Attack Type	Low altitude, daytime.
Defense Strength	Basic for 1956.
Estimated Attrition	15 percent.

Determination of Force Sizes

The basic offensive and defensive force sizes and the defense-weapon deployment for 1956 as given in Chapter I were used. The stockpile of 470 TU-4's was converted* into an equivalent TU-4 and IL-28 force briefed by the Soviets. Of this force 200** TU-4's and 150 IL-28's wing-coupled to TU-4 carriers survived the 20 percent operational aborts to reach the ZI. Of these bombers, 300** carried 100 KT bombs. The bombers not carrying bombs helped to saturate the defense, acting as decoys for the bomb carriers. The TU-4's to which the IL-28's were wing-coupled were assumed not to penetrate the defenses.

Soviet Activity

The strategy assumed on the part of the Soviets for this strike was an attack on SAC bases, petroleum targets, steel targets, and urban industrial concentrations.

In order to decide how many targets should be chosen for the attack, the

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*The conversion was made with the ratio, cost of one IL-28 (including portion of carrier cost)/cost of one TU-4 = 1.17.

**These numbers were later reduced to account for aborts resulting from the necessity to refuel. See p. 108.

"Soviet planners" needed an estimate of the total attrition which the Soviet force would suffer at the hands of the U.S. defenses. Since Strike I was the first strike to be analyzed, this estimate was based only upon experience gained from some earlier calculations of the same general type and was therefore a very rough guess. It was assumed that 15 percent of the Soviet force arriving at the ZI would be destroyed by the defenses before reaching bomb-release points. Thus the estimated number of bombs which could be delivered on target was reduced from 300* to 255.*

Then 255* aiming points were selected. The 29 SAC bases and 3 Washington, D.C., aiming points were given first priority. Since this was primarily a petroleum and steel strike, the 82 petroleum and 49 steel aiming points were considered next. The top 92* urban industrial concentration aiming points comprised the balance of the target list.

These aiming points were located on a large map of the United States which also showed the radar network and the location of interceptor bases. The targets with no radar cover or with insufficient cover to allow for defense action against approaching bombers were considered "free" targets; i.e., it was assumed that bombers attacking them would suffer no attrition. One bomb-carrying TU-4 was assigned to each such aiming point.

In assigning bombers to the defended targets, the different areas were considered separately. The aiming points in the areas of Los Angeles, San Francisco, Seattle, and St. Louis were assigned a number of TU-4's based upon the number of aiming points in the area plus an estimate of the number of bombers which would be destroyed while penetrating the defenses

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*These numbers were later reduced to account for aborts resulting from the necessity to refuel. See p. 108.

of the area. This attrition estimate was based on the number of interceptors which should attack the bombers and a guess as to their effectiveness.* The remaining bombers were assigned to the East Coast and Midwest areas simply in proportion to the number of aiming points in the areas, the selection of which is described above. The bombers which carried bombs were assumed to be distributed uniformly through the bomber groups. IL-28's were assigned to all Midwest targets and a mixture of IL-28's and TU-4's was sent to the East Coast targets.

The routes which might be taken by the bombers in reaching these targets were then considered, keeping in mind minimization of early-warning time to the defense, minimization of the time within radar cover, and, where detection was relatively early, saturation of the defense forces. An attempt was also made to coordinate the attack so that warning to defended targets would occur simultaneously in all areas of the country and so that the warning to SAC bases would be minimized, reducing their evacuation capability. These criteria indicated that most southern and southwestern targets should be approached from the Gulf of Mexico or Baja California. Such routes introduced the problems of additional support aircraft and aborts due to longer routes and extra refueling. Some bomber routes into other areas were also found to be of such a length as to introduce these problems. A total of 12 bombers were assumed to abort as a result of the relatively long bomber routes.** Of

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*It was assumed that the effectiveness of the F-89D was such that it would take 5 of them to kill one bomber. The estimate for the F-86D was 20 interceptors to kill one bomber.

**The refueling abort factor was assumed to be 7 percent. For flight routes from 4500-5500 nautical miles in length an additional abort factor of 3 percent was assumed. For those of 5500-6500 nautical miles length, the additional factor was 5 percent. See RM-1075.[2]

these bombers, 10 carried bombs. The number of bombs thus aborting was subtracted from the 300 originally assumed to arrive at the ZI, and the 15 percent attrition was applied to this revised number of bombs. The resulting final list of 247 aiming points was composed of 29 SAC bases, 3 Washington, D.C. aiming points, 82 petroleum, 49 steel, and the top 84 urban industrial concentration aiming points (in 45 cities).

The actual bomber routes from the periphery of the United States were then drawn on the map. Routes were determined on the basis of the above-mentioned criteria, plus the following rules. (Some of these rules were mentioned in Chapter I.)

1. All bomber groups would penetrate first detection lines simultaneously.
2. The size of the bomber formation was limited to a square no more than 60 nautical miles on a side if the approach was over land, or no more than 32 nautical miles on a side if the approach was over water. This restriction was due to the radar line-of-sight limitations on the bombers' station-keeping ability.
3. The number of bombers following any one route would be limited to 80 if they approached the ZI over land or 40 if they approached the ZI over water.
4. If it was necessary to send more than one group of bombers into an area by parallel routes, due to restriction 3, the distance between these routes should be no less than 70 nautical miles if they approached the ZI over land and no less than 40 nautical miles if they approached over water.
5. To reduce bomber losses, bomber routes were to avoid local defenses when possible, if in so doing they did not incur a serious range penalty.

6. On each bomber route there was to be an easily identifiable geographical point at a distance of from 60 to 100 nautical miles from the target.

The final bomber routes and targets which resulted from the use of these rules are shown in Fig. 16.

Action of the U.S. Defenses

The defensive action of the United States and Canadian forces in reacting to the bomber attack was simulated as described below.

The defense was assumed to have sufficient information to enable it to assign interceptors to the various bomber streams so that the kill potential in an area would be divided among the bomber streams in proportion to the initial numbers of penetrating bombers in the streams. Interceptors were assumed available for scramble, as a function of "time elapsed since first detection," according to Table XI. No interceptors could be vectored before the bombers entered contiguous radar cover, so in areas where early warning from the McGill Line occurred there was an accumulation of available interceptors. These were scrambled in one group as soon as the bombers entered cover.

For use in vectoring interceptors, transparent scales were made for each type of interceptor and bomber. These were calibrated in intervals of distance flown, to map scale, per interval of elapsed time. Each bomber scale was calibrated for two conditions, long-distance operation and maximum speed, both at low altitude. The latter calibration was used during the last hour before target for the TU-4 and the last 300 nautical miles before target for the IL-28. Each interceptor scale was also calibrated for the following two operating conditions:

	Condition 1	Condition 2
Climb power	Military	Military
Cruise-out altitude	Optimum	5000 feet
Combat power	Military	Military
Return to base	Long-range cruise	Long-range cruise

These interceptor scales included, in addition, a four-minute time delay from scramble order until the interceptor was airborne to allow for such things as taxiing and engine warm-up. An extreme radius was indicated on the F-86D scale which allowed for five minutes of combat. (Each attack by an interceptor on a bomber was assumed to last five minutes.) The F-89D scale indicated radius limitations for five, ten, and fifteen minutes of combat.*

The actual point at which each interceptor intercepted the bombers was found and indicated on the map, using the rules in Chapter II and the following method. On each bomber route the positions of the center of the bomber formation at ten-minute intervals** were marked, the zero point being at the position of this center at the time of first detection of the formation.*** The point of interception by any scramble could then be found by using the scales as follows:

1. The bomber scale was placed along the bomber route with the zero point at the location of the bombers at the time of the interceptor

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*The F-89D was assumed to be armed for two passes and fueled for three.

**These distance intervals corresponding to ten minutes of bomber flight were defined as "battles."

***This first detection occurred at the McGill Line for those routes from the north over Canada, and at the edge of contiguous radar cover for all others.

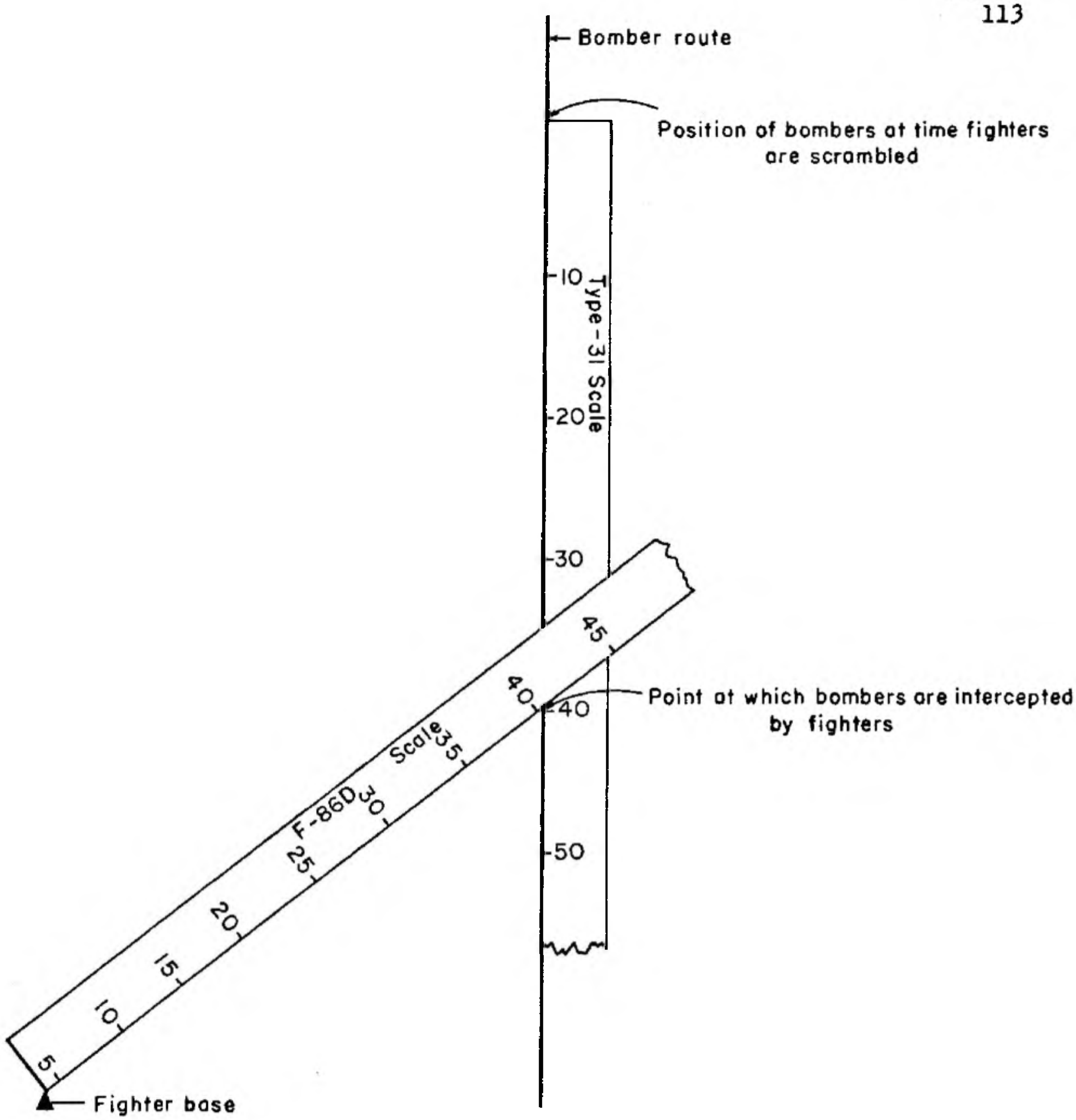
scramble. Each time on the scale then showed the location of the bombers at that time after scramble. (The scale was pivoted about turns in the bomber track if necessary.)

2. The zero point of the interceptor scale was placed at the interceptor base.
3. The interceptor scale was pivoted about its origin to the point on the bomber route at which the times on the two scales coincided. This was called the interception point.

Figures 14 and 15 demonstrate the use of the scales.

Because the time from first warning until the bombers reached target was so much longer in the Midwest than on the East Coast, it was found that many interceptors were able to attack bombers entering the East Coast area, return to base, and be reassigned to bombers entering the Midwest. This recycling of interceptors also occurred within the East Coast area itself, as a result of the differing speeds of the two types of attacking bombers. It was assumed that manpower limitations at the interceptor bases limited the number of returning aircraft which could be handled simultaneously. This number was taken to be four per squadron, and the "turn-around" procedure was presumed to require 20 minutes from touch down to availability for scramble for each group of this size. If more aircraft returned for reassignment they were delayed accordingly. The effect of these recycled aircraft had not been considered in the original estimate of attrition.

After the interceptors had been vectored, the number of control channels



The scales are marked off in terms of distance traveled for each interval of time

Fig. 14— Use of scales to determine point at which fighters intercept bombers

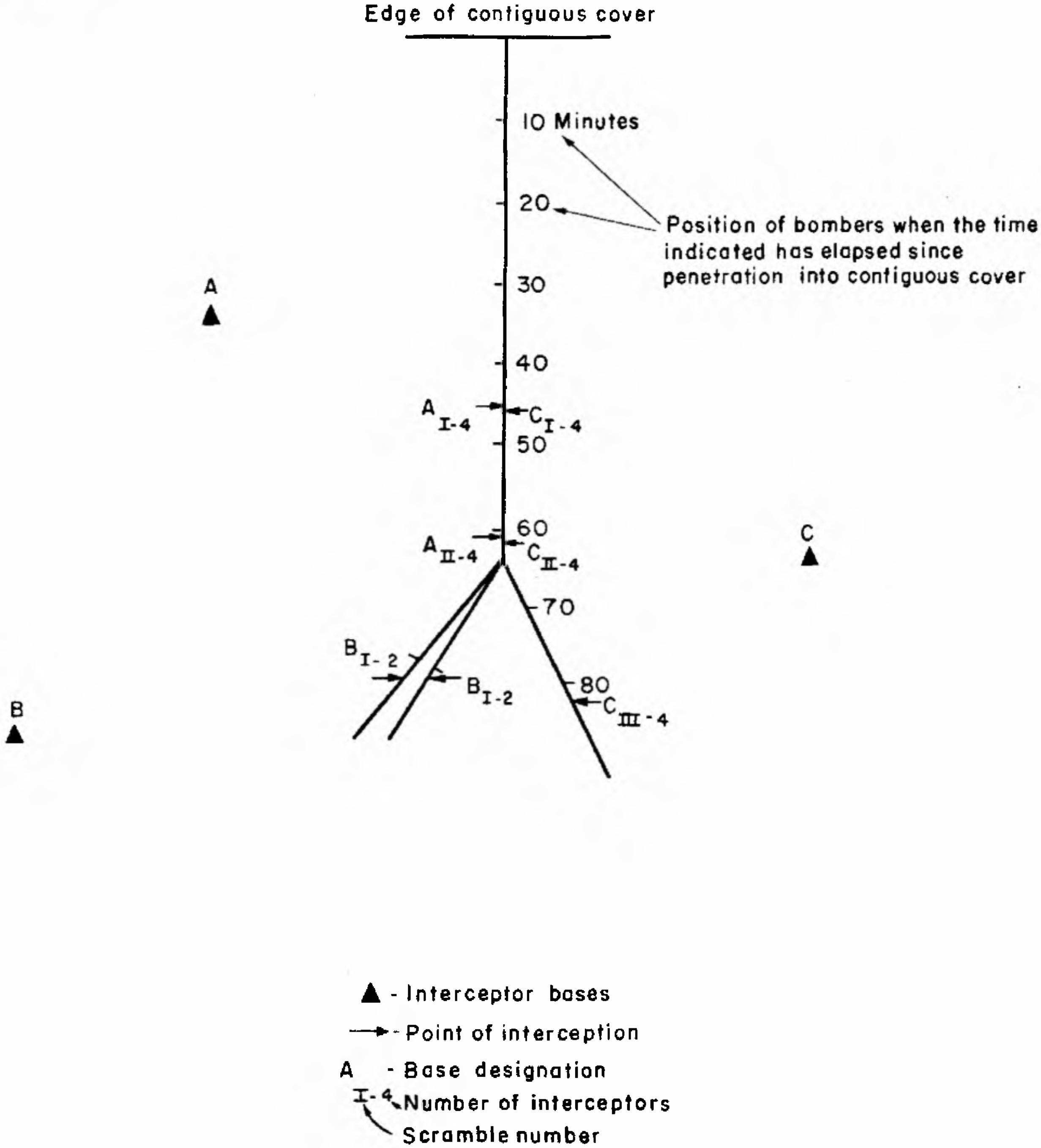
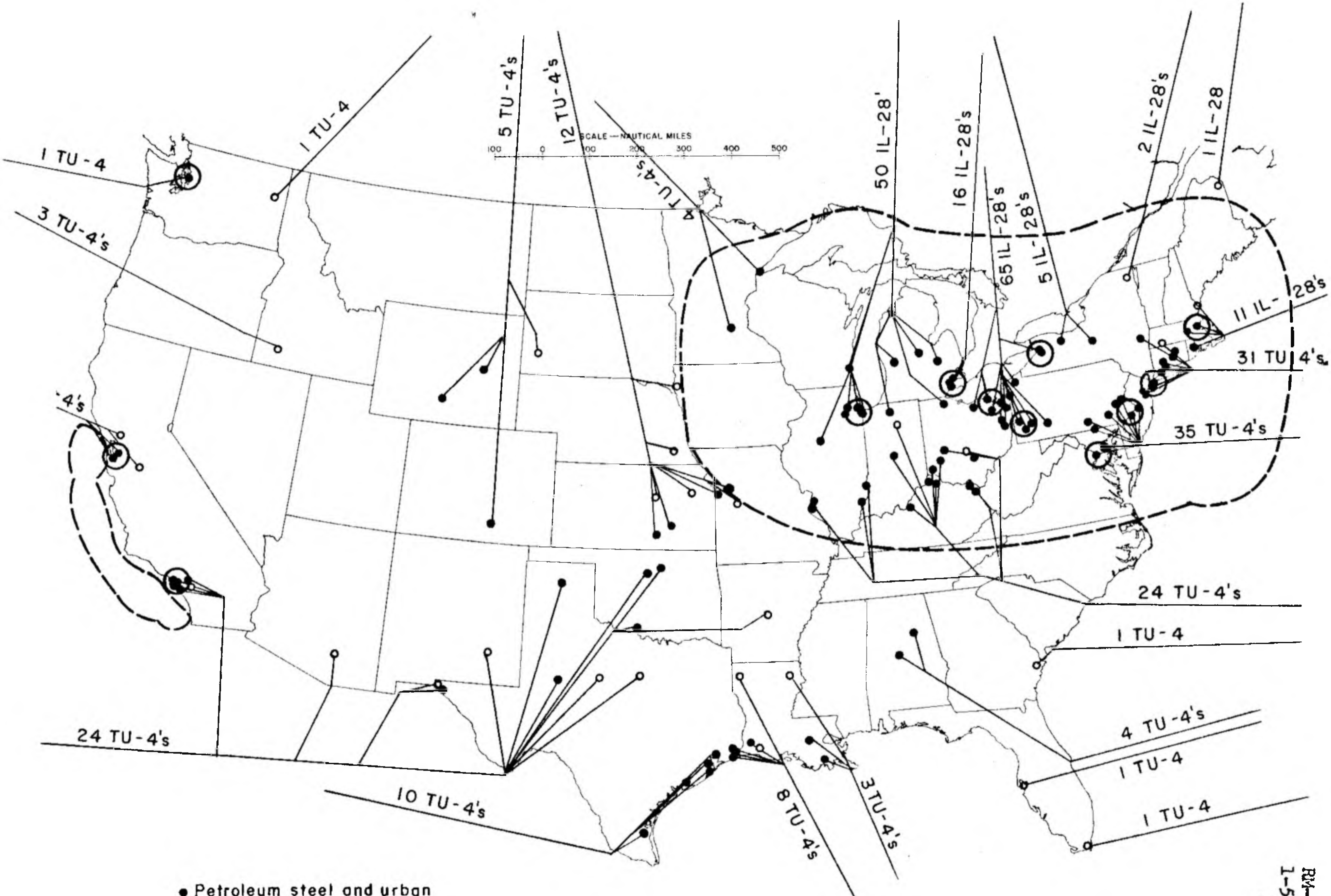


Fig. 15 — An example of a bomber track with points of interception indicated



● Petroleum steel and urban industrial concentrations
○ SAC bases
– – – Interceptor battle areas
—— Local defense battle areas

Fig. 16—Strike I 1956
Petroleum and steel (15% attrition assumed)

available for each "battle"* was read from curves** which estimated this number as a function of depth of penetration into contiguous cover. The number of control channels available determined the number of interceptor elements which could be controlled and also the type of control to be used. If enough control channels were available, all interceptors were assumed to be close-controlled. If not, all but one director were used for close control, this one being used to broadcast-control any superfluous F-89D's. The single-place F-86D's were never broadcast-controlled, but were held back until enough control channels were available for their close control.

Tabulation of Parameters

The following parameters were then tabulated for use in the calculations to be described in Chapter IV:

1. The number and type of bombers entering the ZI on each bomber path
2. The proportions of the bombers in each track which were briefed to follow each branch of a track split
3. The number of bombers originally briefed for each target
4. The total number of each type of close-controlled interceptor entering each battle

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*A distance interval corresponding to ten minutes of bomber flight was defined as a "battle."

**These curves were obtained by assuming, for each area, several typical bomber routes into the area and superimposing upon them a map of the areas of responsibility of each radar. Thus the control capacity available, per ten-minute battle, could be determined as a function of depth of penetration into contiguous cover. The values for the various routes within one area were averaged and the results used to plot the curves.

5. The number of F-89D's entering each battle on broadcast control or uniform broadcast control.

Strike II

Offensive Force Arriving in ZI	200 TU-4's and 150 IL-28's.
Bombs Arriving in ZI	300 100-KT bombs.
Targets	SAC bases, Washington, D.C., and urban industrial concentrations.
Attack Type	Low altitude, daytime.
Defense Strength	Basic for 1956.
Estimated Attrition	20 percent.

The assumed attrition for the second strike was raised to 20 percent in an attempt to include the effects of the recycled interceptors, better estimates of interceptor effectiveness, and better estimates of the number of aircraft actually engaging in combat. The bombers were assigned as before, except that in order to determine the effect, if any, of assigning pure or mixed forces, a pure force of IL-28's was assigned to targets on the East Coast. The number penetrating was based on the number of aiming points in the area and an estimate of the number of kills expected in the area. The remaining mixed force was assigned to sections of the Midwest in proportion to the number of aiming points in the section. The IL-28's were sent to the section around Chicago and the TU-4's were sent to the remaining aiming points. In some cases extra bombers were sent to those aiming points with a large amount of local defense. In other respects the strike technique was the same as for Strike I. The final attack list consisted of 209 urban industrial concentration aiming points in 66 cities, including Washington, D.C., and 29 SAC bases. The bomber routes and targets selected are shown in Fig. 17.

Strike III

Offensive Force Arriving in ZI	193 TU-4's and 150 IL-28's.
Bombs Arriving in ZI	294 100-KT bombs.
Targets	SAC bases, Washington, D.C., petroleum targets, steel targets and urban industrial concentrations.
Attack Type	Low altitude, daytime.
Defense Strength	Basic for 1956.
Estimated Attrition	25 percent.

Using the same method of allocating bombers as was used in Strike II, IL-28's went to the East Coast, a mixed force to the Midwest, and TU-4's to all other targets. The final attack list consisted of the top 48 steel aiming points, the top 82 petroleum aiming points, 29 SAC bases and 62 urban industrial concentration aiming points in 28 cities.

In this analysis it was assumed that the Soviets attempted to eliminate the additional attrition due to recycling of interceptors within the Midwest area and between the East Coast and Midwest. In order to accomplish this, bomber routes to both areas were timed so that they crossed the edge of contiguous radar cover, rather than the first detection line, simultaneously. Otherwise the technique was the same as for Strike I. The bomber routes and targets are shown in Fig. 18.

1958 STRIKES (IV, V, VI, VII, VIII, IX, X, XI)

Strike IV

Strike IV of the 1958 series was very similar to the 1956 strikes in

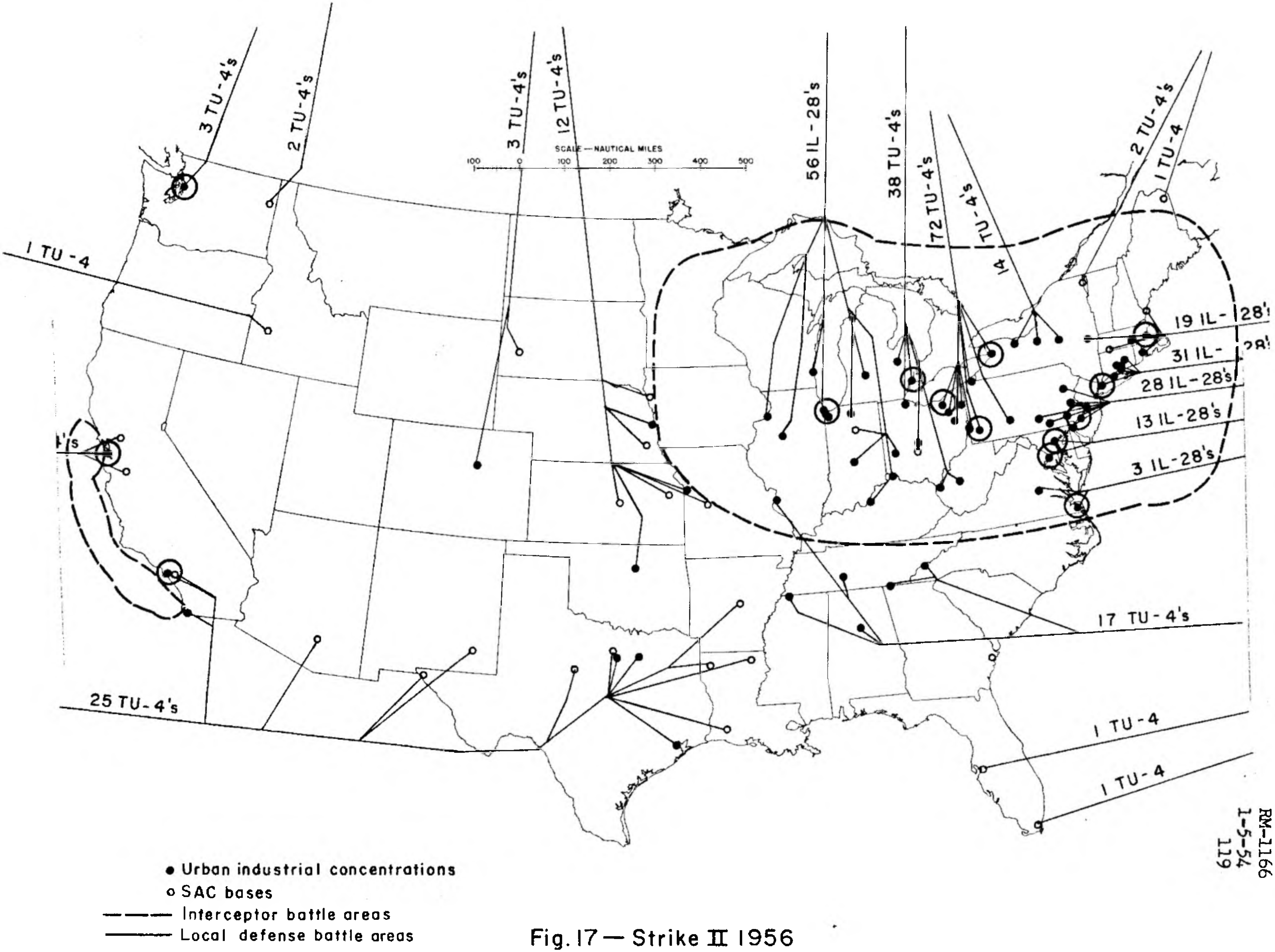

Fig. 17 — Strike II 1956
Urban industrial concentrations

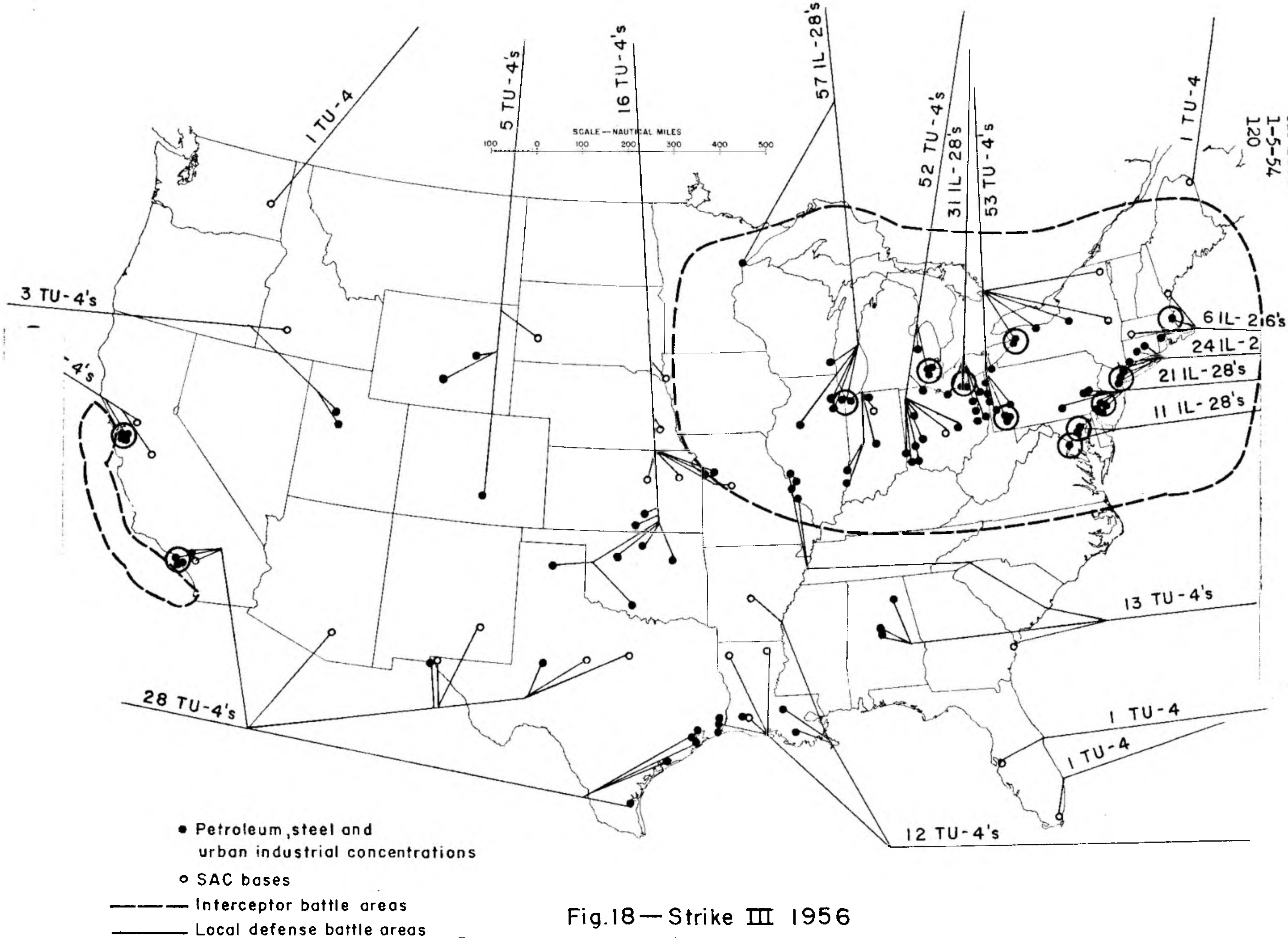

Fig. 18 — Strike III 1956

Petroleum and steel (25 % attrition assumed) method. In the following description, the sections dealing with method will describe only those aspects which differ from the 1956 strikes.

Offensive Force Arriving in ZI	40 Type 31's and 330 IL-28's.
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases, Washington, D.C., and urban industrial concentrations.
Attack Type	Low altitude, at night.
Defense Strength	Basic for 1958.
Estimated Attrition	50 percent.

Soviet Activity

The selection of the targets was done much the same as in the 1956 raids. An estimate of 50 percent overall attrition was made, which meant that 185 bombs could be delivered on target. These bombs were assigned to the 29 SAC bases, 3 Washington, D.C., aiming points, and 153 urban industrial concentration aiming points. In assigning bombers to the targets, an effort was made to avoid recycling of interceptors by sending bombers of only one type into each area and by timing all bomber groups going into a particular area so that they reached each fighter area simultaneously.

Assignment of Type 31's--All the SAC bases except Limestone were attacked with Type 31's either because the high cruise speed of the bomber at low altitude allowed less warning and thus less chance for evacuation or because the long range of the Type 31 was needed in order to reach the target. Since the Omaha area included some SAC bases which were attacked by Type 31's, the urban industrial concentration targets in the area were also assigned Type 31's.

In areas where attrition from interceptors was expected, 50 percent more bombers were assigned. Where local defenses existed, extra bombers were also assigned. The assignments described above made use of the entire force of Type 31's assumed available.

Assignment of IL-28's

Since the remaining targets could be attacked only by IL-28's the range limitations of the IL-28 became quite important. Coming into the ZI at low altitude instead of optimum cruise altitude reduced this maximum range from 1165 nautical miles to 530 nautical miles. Thus the total range of the system (TU-4 carrier plus IL-28) was 4365 nautical miles.*

Free targets within the low-altitude range were assigned one IL-28 per aiming point. Targets in the Los Angeles area were within this range and were assigned 25 IL-28's, to account for 11 aiming points and an estimated 6 kills by area defenses and 8 kills by local defenses.

Many of the deeper targets in the Midwest could not be attacked by the IL-28's. The early warning from the McGill line would have enabled interceptors to reach the TU-4's before they could get within 530 nautical

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*This range could be extended by flying the IL-28's some distance into the ZI at optimum cruise altitude using a lower fuel consumption rate, and then approaching the target at low altitude. However, the high altitude portion of the IL-28 flight would increase the attrition because of better interceptor radar performance at high altitude and consequent higher interceptor effectiveness. The formula used for the maximum distance, d, which could be flown by the IL-28 at low altitude was

$$d = \frac{1165 - p}{1.2}$$

where p = the distance in nautical miles from the uncoupling point to the target. This equation applied only when p was greater than 530 nautical miles.

miles of the target to release the IL-28's.* These targets were removed from the list and replaced by targets which were within the range of the bombers although less valuable.

On the East Coast all of the aiming points, except those around Washington, D.C., were within the range of the IL-28 bombers. Because Washington, D.C., had a high priority in the enemy's strategy, it was assumed that in order to reach it the IL-28's would fly some of the distance at optimum cruise altitude and then approach the target at low altitude. The penalty paid by the Soviets for this action would be an increase in attrition during the high altitude portion of the flight.** The final attack list for this strike consisted of 29 SAC bases and 156 urban industrial concentration aiming points in 48 cities. Bomber routes and targets selected are shown in Fig. 19.

Action by the U.S. Defenses

The action of the defense was simulated by the same methods as before, except for the following changes.

In attempting to vector interceptors to the various bomber groups, the actual number of control channels available during each ten-minute battle was considered. This information was obtained from a map of the "areas of responsibility" of the radars which was superimposed over the strike routes. When more than one bomber group was present in the same radar control area, the available control channels were divided between the groups in proportion

*It was assumed that the release of the IL-28's should take place at least 10 nautical miles before the first possible intercept by the defense.

**These IL-28's were attacked by F-102's only.

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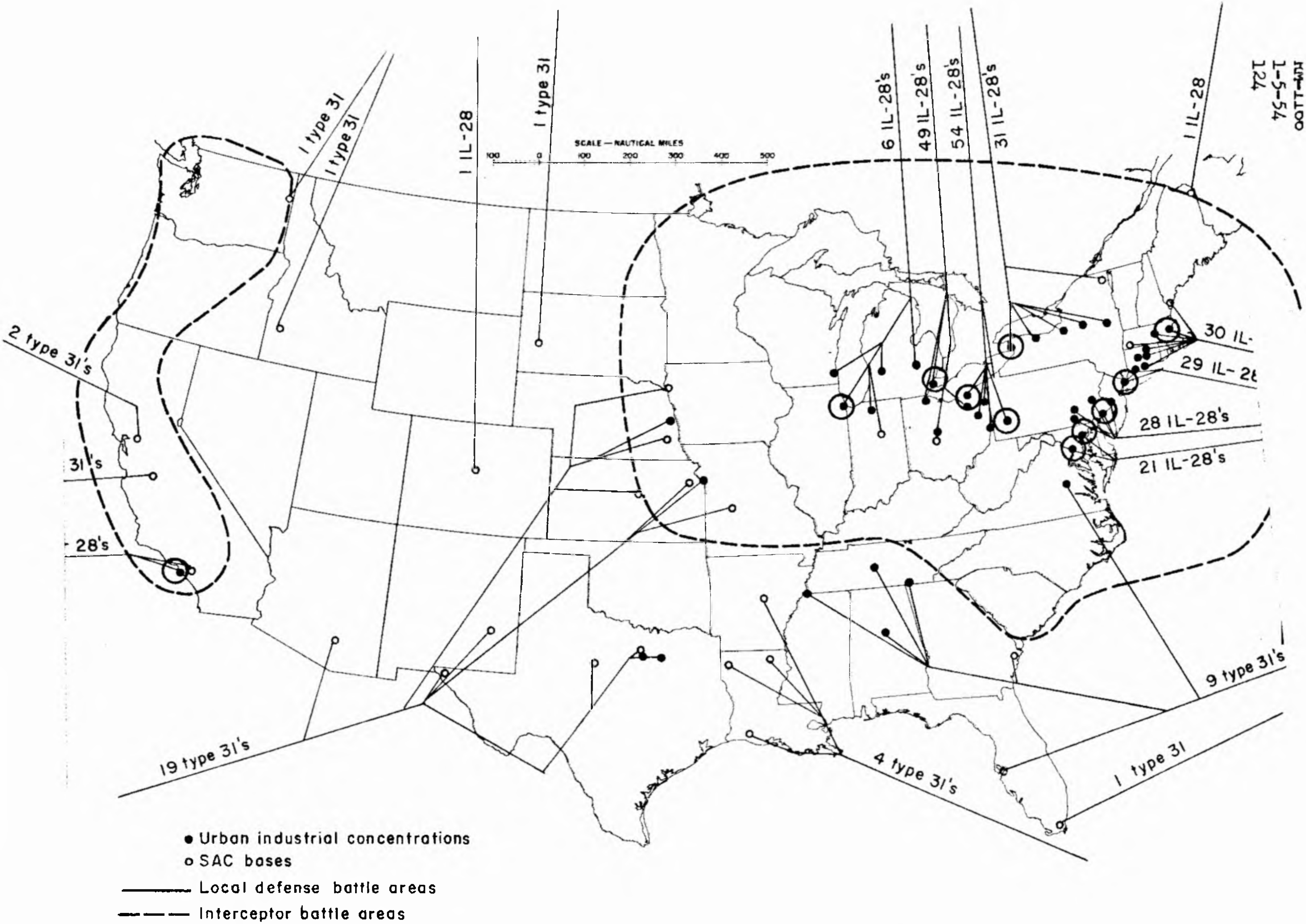

Fig. 19 — Strike IV 1958
Low attrition estimates

to the number of interceptor elements assigned to the groups. Interceptors which had been assigned to a particular bomber group were not scrambled until assured of available control channels at the intercept point. The F-102's which were armed with atomic warheads, because of their greater effectiveness, were given first priority in the use of control channels and were always sent on close control. F-102R's without atomic warheads had next priority, but, being the last two scrambles in each squadron, were usually not available in time to reach the bombers. F-89D's were not vectored until all the F-102's entering the particular battle segment had been or were being used and control channels were available, or until 15 or more F-89D's had accumulated. These latter F-89D's, for which there were insufficient channels to be close-controlled, were then broadcast-controlled.* Three units of control were needed for broadcast controlling any number of these interceptors. F-86D's had last priority on control channels.

Tabulation of Parameters

In 1958 the assumed effectiveness of the local defenses had increased enough to require that their effects be included in the calculations of results. A tabulation of kills due to local defenses was made for each target which was so defended. This tabulation was included in the tabulation of parameters which has been previously listed and which was used as an input to the calculations discussed in Chapter IV.

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*Fifteen F-89D's on broadcast control using 3 units of control were approximately equal, in effectiveness, to three F-102 passes, which required the same amount of control capacity.

Major Changes in Technology Philosophy

The results from the calculations of the first four strikes now became available. It was discovered that for these strikes the overall attrition estimates, upon which the target selections had been based, had been consistently too low. The estimate in the 1958 strike, Strike IV, had been especially low. The attrition had been guessed to be 50 percent but the final results showed that actually 86 percent of the bombers were destroyed before the bombs could be delivered on target.

This difference was due in part to the assumed lack of Soviet information on U.S. interceptor availability, interceptor effectiveness, and radar control capacity. However, the offense planners had, themselves, increased the attrition by selecting targets with the assumption in most cases that the percentage attrition which would be suffered by the bombers was the same for each aiming point attacked. On this assumption the aiming points had been selected in the order of their importance, with no regard for geographical considerations. The result was that the bomber force was too spread out. It was subjected to almost all the U.S. defense forces and suffered a high attrition rate. This high attrition on the Soviet force resulted in achievement of a relatively small amount of target damage.

For the later analyses it was assumed to be more reasonable that the Soviet information should include the three factors mentioned in the paragraph above. It was also decided that more careful attrition estimates and choice of targets, perhaps based on results of a set of map exercises similar to those described here, should be assumed on the part of the offense.

The fixed-force type of composition used in all previous strikes was also seen to have imposed a severe penalty on the Soviet offense force in terms of total value destroyed. In Strike IV, for instance, many important targets were not within the restricted range of the IL-28's and could not be assigned a Type 31 because of the limited number available. These targets had to be deleted from the offense target list and replaced by targets of lesser importance which were within range. It was assumed that if the Soviets had planned this particular raid some years ahead the same capability which had been used to build and maintain the 330 IL-28's and 40 Type 31's could have been used to build and maintain any mixture which was equivalent in cost* and more appropriate to the attack being considered. It was decided, therefore, that the strike force composition could be variable and should be based on the requirements of the particular targets under attack.

The rest of the 1958 strikes incorporated the changes described above, in addition to other refinements. The general procedure followed in analyzing these strikes is outlined below.

A. Determination of offensive and defensive force sizes

B. Soviet activity

1. Selection of target strategy

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*The conversion procedure was based on cost figures for building and maintaining the three types of bomber aircraft.

$$\frac{\text{Cost of Type 31}}{\text{Cost of IL-28 (including carrier)}} = 1.29$$

$$\frac{\text{Cost of IL-28 (including carrier)}}{\text{Cost of TU-4}} = 1.17$$

2.* Estimate of attrition

a. Division of the U.S. into geographical areas

b. Selection of bomber routes to representative targets in each area

c. Estimate, for each area, of expected kill potential due to both interceptors and local defenses

3.* Temporary selection of targets, assignment of bombers, and selection of bomber routes

C. Action of the U.S. defenses

D. Revision of target list to final form

E. Tabulation of the parameters to be used in the final calculations

Strike V

Offensive Force Arriving in ZI	280 IL-28's and 78 Type 31's.
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases, petroleum targets, and steel targets.
Attack Type	Low altitude, at night.
Defense Strength	Basic for 1958.
Estimated Attrition	66 percent.

Determination of Force Sizes

The sizes of the basic offensive and defensive forces and the defense weapon deployment for 1958 as given in Chapter I were used. The stockpile

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*Because of the assumption that the Soviets may have done similar map exercises previous to the attack, the results of step C were considered available for use in the final selection of targets. Steps B-2 and B-3 were therefore assumed to be only first steps in the selection of targets. The final target list resulted from step D.

of 556 TU-4's briefed by the Soviets was to be converted into an equivalent Type 31 and IL-28 force to fit the needs of the target strategy chosen. Each bomber carried one 100-KT bomb.

Soviet Activity

The strategy assumed on the part of the Soviets for this strike was an attack on SAC bases, petroleum, steel and some urban industrial concentrations.

The amount of information given to the offense commander to make his decisions was increased for this strike. It was assumed that intelligence sources available to the enemy would be able to give him, at least partially, information on:

1. Interceptor availability as a function of time after initial detection.
2. Estimates of interceptor effectiveness in destroying bombers.
3. The number of radar channels available for interceptor control.

The information listed above was included in the offense's estimate of attrition for this strike in the following way.

The defended region of the United States was divided into six areas; the Midwest area, the East Coast area, the St. Louis area, the Omaha area, the Los Angeles area, and the San Francisco area. Each of these was examined separately to determine the number of bombers which the defense forces could destroy if a group of bombers entered the area. This number, called the "kill potential," was determined by choosing bomber routes in each area leading to representative targets, then estimating the number and type of interceptors which could attack the bombers. An estimate of the number of interceptors from each base which could get into battle was made by actually vectoring some of the fighters. An attempt was made to include the effects of available control capacity in this estimate. The number of bombers expected to be killed, β_K, by a given number, ϕ, of a particular type of interceptor was given by the formula

$$\beta_K = \phi K_\phi$$

where ϕ = the number of interceptors attacking

K_ϕ = the effectiveness of the interceptor

Approximations of interceptor effectiveness, K_ϕ, were computed by the offense on the basis of the component effectiveness numbers given in Chapter II, using the following equation.*

$$K_\phi = u_{ab} P_{dc_1} DP_{kb} + u_{ab} P_{dc_2} DP_{kb} u_b (1-D_1 P_{dc_1} P_{k\phi})$$

$$+ u_{ab} u_b^2 P_{dc_3} DP_{kb} \Big[D_1 P_{dc_1} (1-P_{k\phi}) (1-D_1 P_{dc_2})$$

$$+ (1-D_1 P_{dc_1}) (1-D_1 P_{dc_2} P_{k\phi})\Big]$$

The equation above describes the case of an interceptor armed for two passes and fueled for three. All cases used in 1958 are included in this equation. The first term gives the effectiveness for the one-pass case. The first and second terms together describe the two-pass case. Where P_{dc_n} terms occur they signify the use of the value of P_{dc} corresponding to the type of control (close or broadcast) used for the n^{th} pass.

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*P_{kb} and $P_{k\phi}$ in this estimate were taken as averages of the values for one and two interceptors attacking a bomber.

Example: F-102R (without atomic warheads) vs IL-28 (two passes on close control)

$$K_{\phi} = (.86)(.92)(.8)(.35) + (.86)(.92)(.8)(.35)\left[1-(.894)(.92)(.20)\right] = .404$$

Type of Interceptor	Type of Attack	Effectiveness, K_{ϕ} vs IL-28	Effectiveness, K_{ϕ} vs Type 31
F-86D	One pass, close control	.028	.059
F-89D	One pass, close control plus two passes, broadcast control	.18	.38*
F-89D	Two passes, broadcast control	.081*	.17*
F-102R	Two passes, close control	.40	.67
F-102 (with atomic warheads)	Two passes, close control	1.22	1.26

The values of interceptor effectiveness in the above list were used to determine the number of bombers expected to be killed by interceptors. The kills by the local defenses were obtained directly from the local defense component effectiveness numbers shown in Chapter II, using the equations for local-defense effectiveness given in Chapter IV. The sum of the kills by both local and area defenses gave the total "kill potential" for each section of the country. The estimates for this strike were:

Area	Bombers Destroyed
Midwest	184
East Coast	119
St. Louis	15

*For estimates of broadcast control cases, average values of $\bar{P}_{dc}$ were used which depended upon the average size of the bomber formation under attack and whether the track was over land or water. The values listed here are typical.

Area	Bombers Destroyed
Omaha	4
Los Angeles	18
San Francisco	8

Although this concept of kill potential was independent of the various combinations of number of bombers, number of interceptors, and available control capacity possible in each battle, it was considered a reasonable assumption for the first try at choosing the targets.

These estimates were then used in the selection of targets and the resulting choice of bomber force composition. Such a large number of petroleum, steel, and SAC targets were located in the South, requiring Type 31's to reach them, that the remaining force of bombers was too small to enter profitably both the East Coast and Midwest. Upon comparison of the concentration of targets in the areas, the East Coast area was eliminated from the list of targets to be attacked.

A temporary assignment of bombers to targets was then made. Type 31 bombers were sent to the southern targets. They attacked from the south and thus minimized warning to the targets. One bomber was assigned to each aiming point in the petroleum, steel, and SAC target lists. For this strike, the SAC target list was modified to include only free SAC bases or those in areas which would be entered to attack petroleum or steel.

As the bombers were assigned to the aiming points, a running total was kept of the bombers used. The kill potential of an area was added to the list of bombers used at the time the first aiming point in the area was assigned a bomber. The assignment of bombers to petroleum, steel, and SAC targets did not make use of the entire bomber force. The remaining aiming points were chosen, in order of value, from those urban industrial concentration targets which were either free or in defended areas which had already been selected to be bombed because of the presence of either petroleum or steel targets.

The temporary bomber assignment described above resulted in a bomber force composition of 280 IL-28's and 78 Type 31's. The estimated attrition was 66 percent. The targets selected to be bombed included 63 petroleum aiming points, 17 steel aiming points, 24 SAC bases, and 19 urban industrial concentration aiming points in 7 cities.

The next step was to determine the number of bombers entering the ZI briefed for each particular target. For each target the number of aiming points under attack and the expected kills due to local defenses were determined. Their sum was taken to be the number of bombers required to enter the local defense region. Then, starting with this number and working from the target back along the bomber route, the expected kills due to interceptors in each track segment were added. At any specified point the total then represented the number of bombers which should survive all the air battles preceding this point. Whenever a segment of the route was shared by bombers of more than one group (i.e., going to more than one target), the kills expected along that segment were distributed (added) to the groups in proportion to the number of bombers in each group. The total obtained for each target after working back to a point before the first air battle was taken to be the total number of bombers which were required to enter the ZI briefed for that target.

The choices of bomber routes to the targets were done as in the preceding raid except that the bombers going to the Midwest were kept out of the sections controlled by the Lincoln Transition System as long as possible, because of the greater control capability of this system.

Action of the U.S. Defenses

The commitment policy and vectoring procedure used in this strike were identical to those used in the preceding strike.

Revision of Target List

After the assignment and vectoring of all interceptors was completed, a check was made to see if the number of interceptors and interceptor passes and the control capacity were actually the same as assumed by the Soviets in the original kill potential estimates listed on p. 131. The check on the estimate of the number of interceptors present was necessary because of the possibility of recycled interceptors and of additional interceptors from areas not bombed (East Coast) being sent to attack the bombers.

If any increase in kill potential due to these factors was found, it was to be accounted for by reducing the number of aiming points attacked. A number of the lowest-valued urban industrial aiming points equal to the total additional kill potential would then be removed from the target list. In this particular strike no additional kill potential was found. The target list remained as shown on p. 133. The targets and bomber routes selected are shown in Fig. 20.

Tabulation of Parameters

The results of this strike were tabulated as in the preceding strike.

The following raids in the 1958 time period were analyzed in the same way as Strike V. The variations between strikes were in the offense size, the choice of targets, and the strength of the defense. Only these differences are outlined for each of the remaining raids.

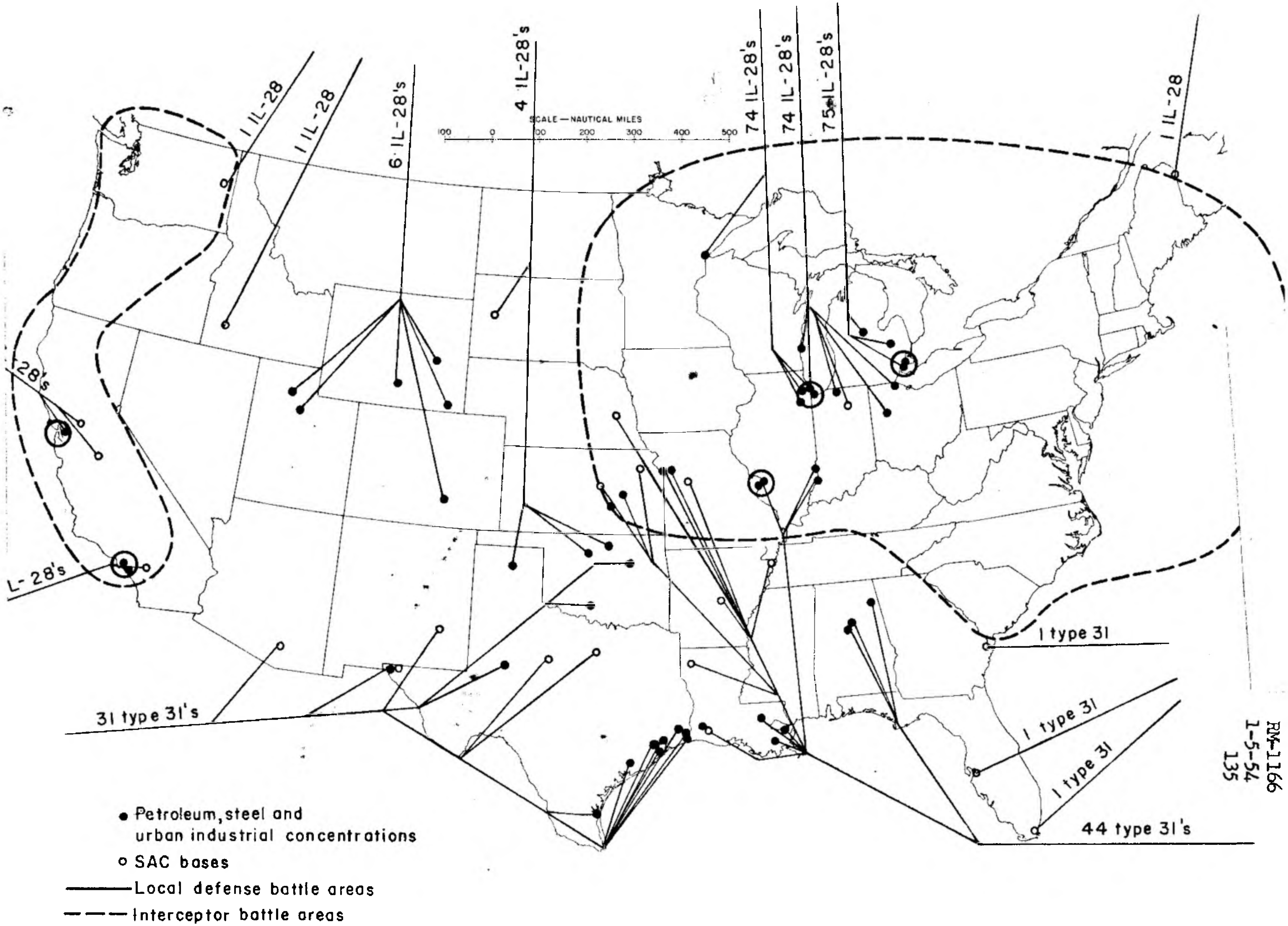

Fig. 20 — Strike V 1958
Steel and petroleum

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Strike VI

Offensive Force Arriving in ZI	239 IL-28's and 110 Type 31's.
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases and urban industrial concentrations.
Attack Type	Low altitude, at night.
Defense Strength	Basic for 1958.
Estimated Attrition	69 percent.

Strike VI is considered to be the basic case for 1958. The strategy used was to attack urban industrial concentration targets and those SAC bases which were either free or in defended areas which would be entered anyway because of the presence of the urban industrial concentration targets.

The procedure of selecting targets established a force of 239 IL-28's and 110 Type 31's arriving at the ZI. These bombers were assigned to 84 urban industrial concentration aiming points in 29 cities, and 25 SAC bases. Due to the large amount of attrition, the bombers could not enter both the East Coast and Midwest. The Midwest was chosen for the attack because of its greater concentration of high-valued targets. The bomber routes and targets selected are shown in Fig. 21.

Strike VII

Offensive Force Arriving in ZI	469 IL-28's and 228 Type 31's. (The force briefed was equivalent to double the basic force.)
Bombs Arriving in ZI	One 100-KT bomb per bomber.

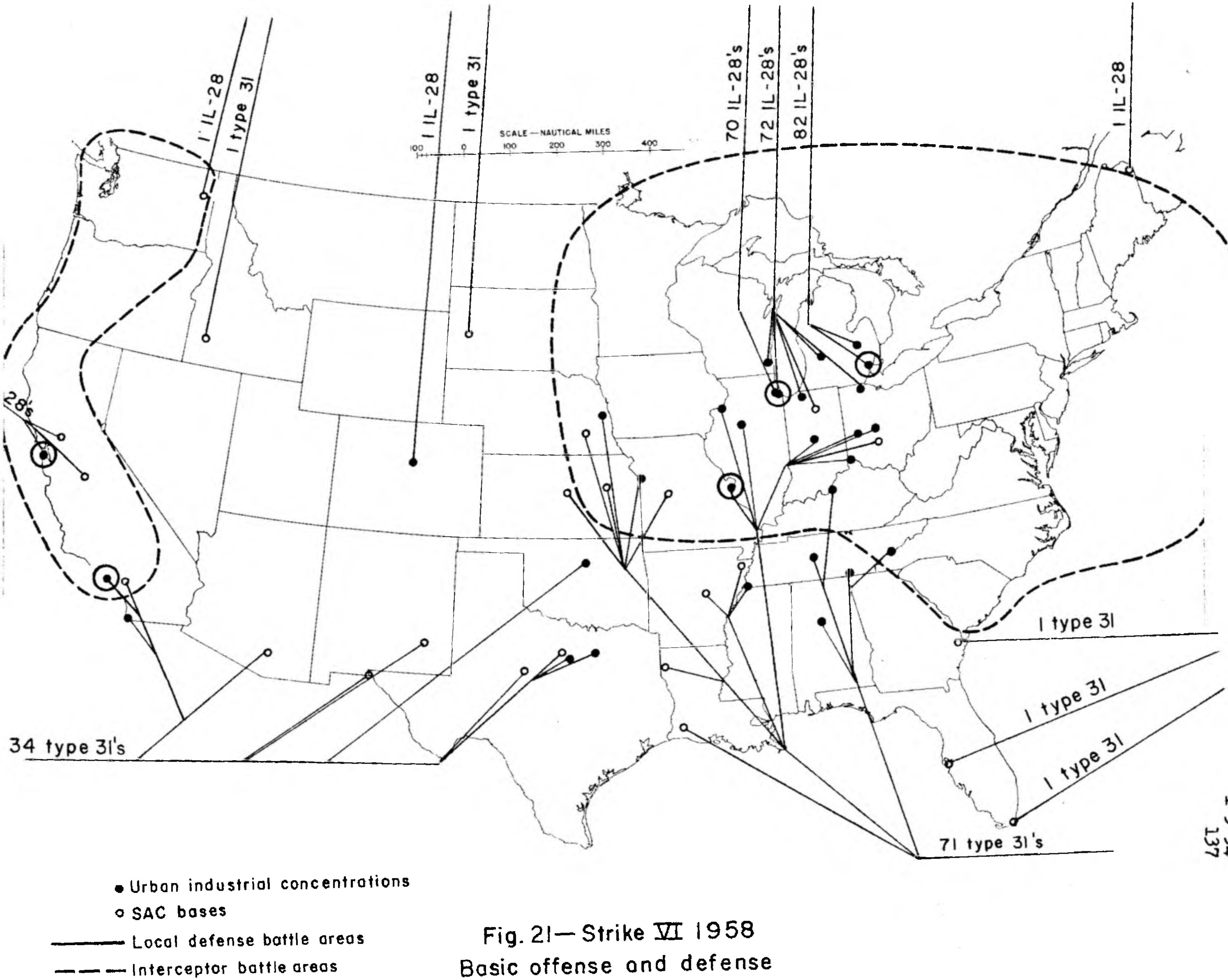

Fig. 21— Strike VI 1958
Basic offense and defense

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Targets	SAC bases and urban industrial concentrations.
Attack Type	Low altitude, night.
Defense Strength	Basic for 1958.
Estimated Attrition	66 percent.

The offense force in this case was large enough to permit the attack of both East Coast and Midwest. The targets selected were 28 SAC bases and 212 urban industrial concentration aiming points in 68 cities. The targets and bomber routes selected are shown in Fig. 22.

Strike VIII

Offensive Force Arriving in ZI	294 IL-28's and 68 Type 31's.
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases and urban industrial concentrations.
Attack Type	Low altitude, night.
Defense Strength	Double the basic force size for 1958.
Estimated Attrition	80 percent.

The targets selected were 17 SAC bases and 57 urban industrial concentration aiming points in 16 cities. The targets and bomber routes chosen are shown in Fig. 23.

Strike IX

Offensive Force Arriving in ZI	251 IL-28's and 101 Type 31's.
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases and urban industrial concentrations.

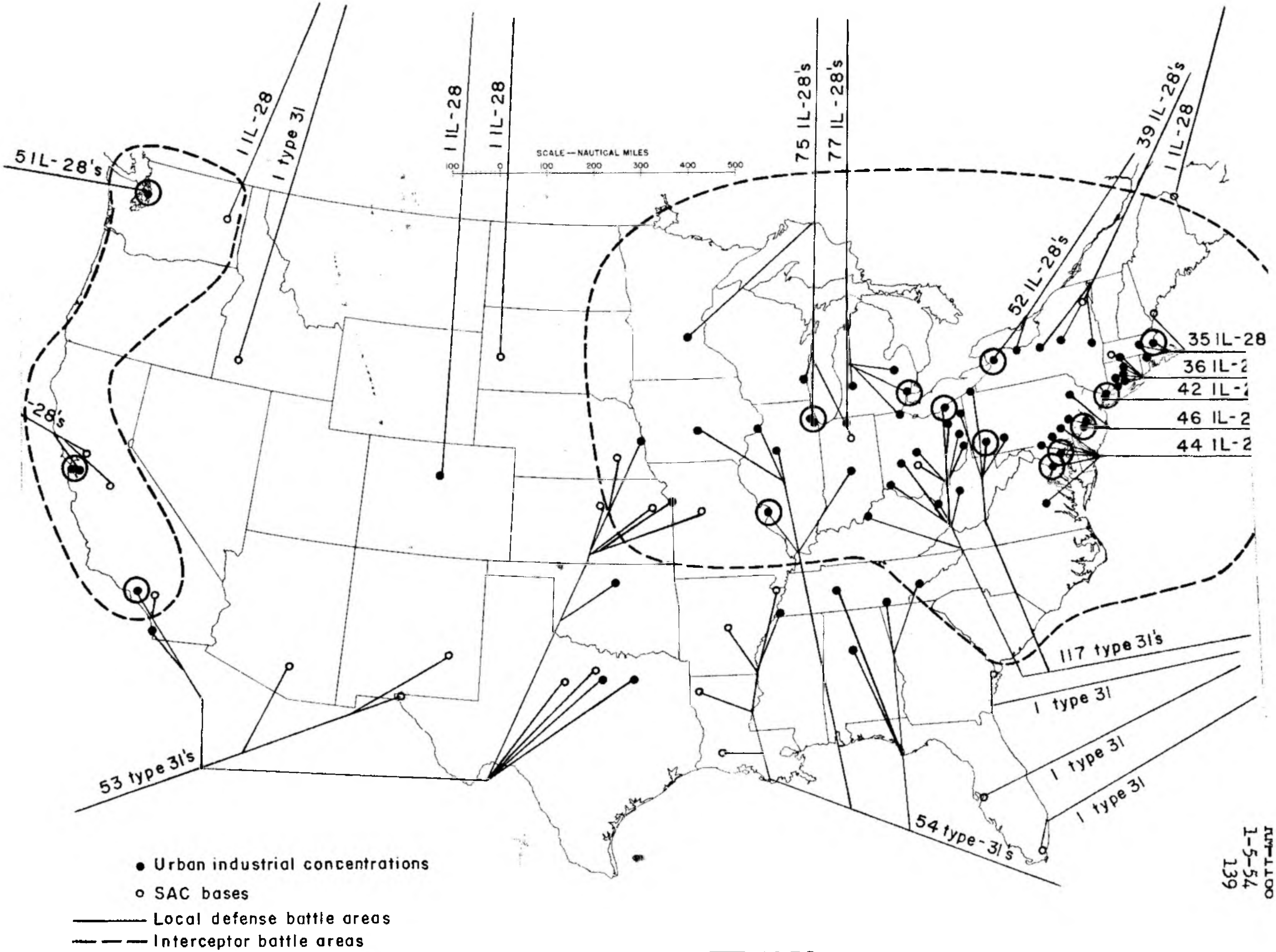

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Fig. 22 — Strike VII 1958
Double offense

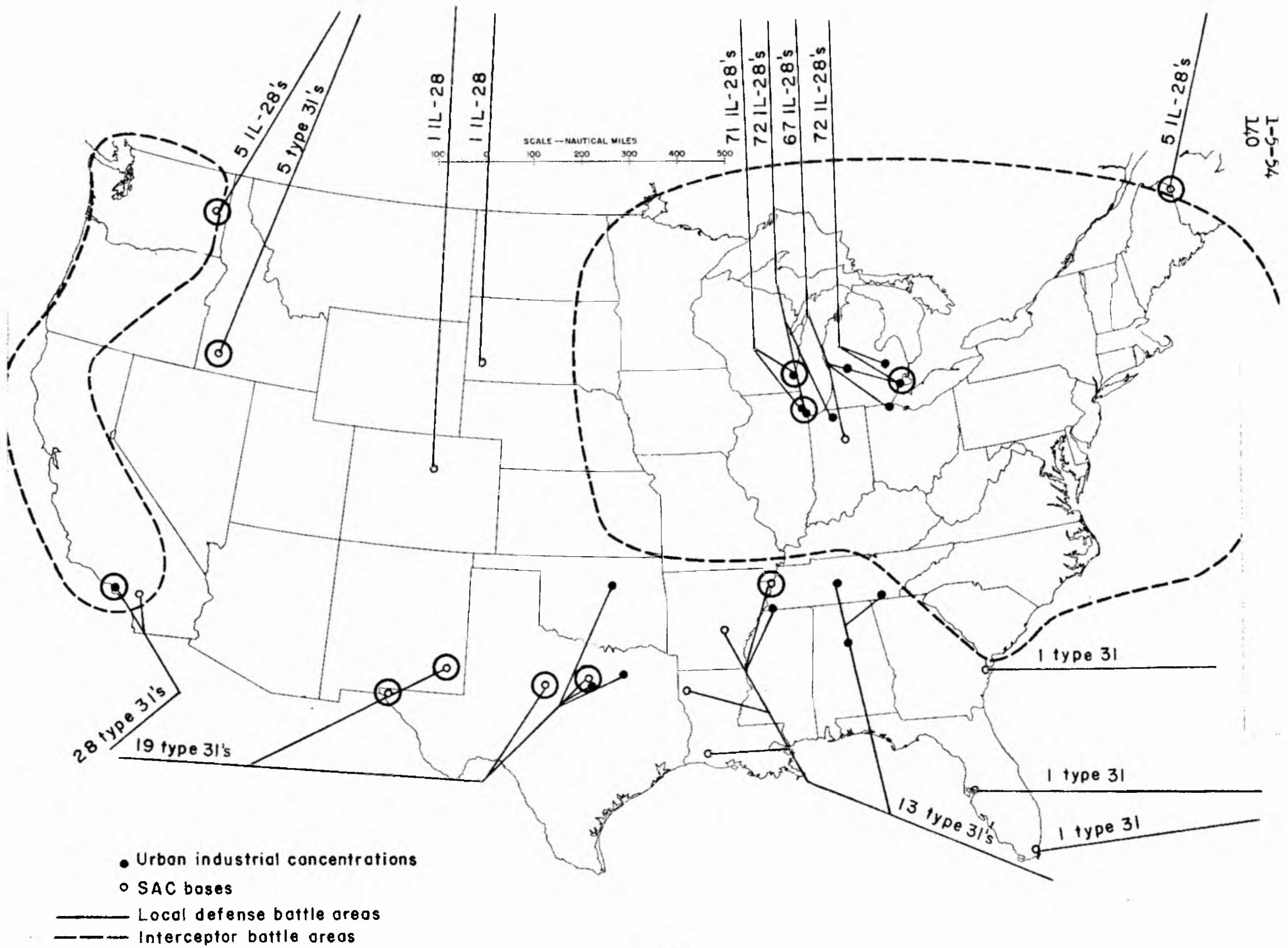

Fig. 23—Strike VIII 1958
Double defense

Attack Type	Low altitude, night.
Defense Strength	Basic size for 1958 with approximately 50 percent effectiveness.
Estimated Attrition	63 percent.

This calculation was made to determine the results of a strike in which the defense force was approximately half as effective as has been assumed for the preceding 1958 cases.

The bomber force attacked 22 SAC bases and 108 urban industrial concentration aiming points in 35 cities. Targets and bomber routes are shown in Fig. 24.

Strike X

Offensive Force Arriving in ZI	482 IL-28's and 218 Type 31's. (The force briefed was equivalent to double the basic force.)
Bombs Arriving in ZI	One 100-KT bomb per bomber.
Targets	SAC bases and urban industrial concentrations.
Attack Type	Low altitude, night.
Defense Strength	Double the basic force for 1958.
Estimated Attrition	81 percent.

Both offense forces and defense forces were doubled for this strike. The bomber force attacked 20 SAC bases and 112 urban industrial concentration aiming points in 38 cities. Figure 25 shows the selected targets and bombing routes.

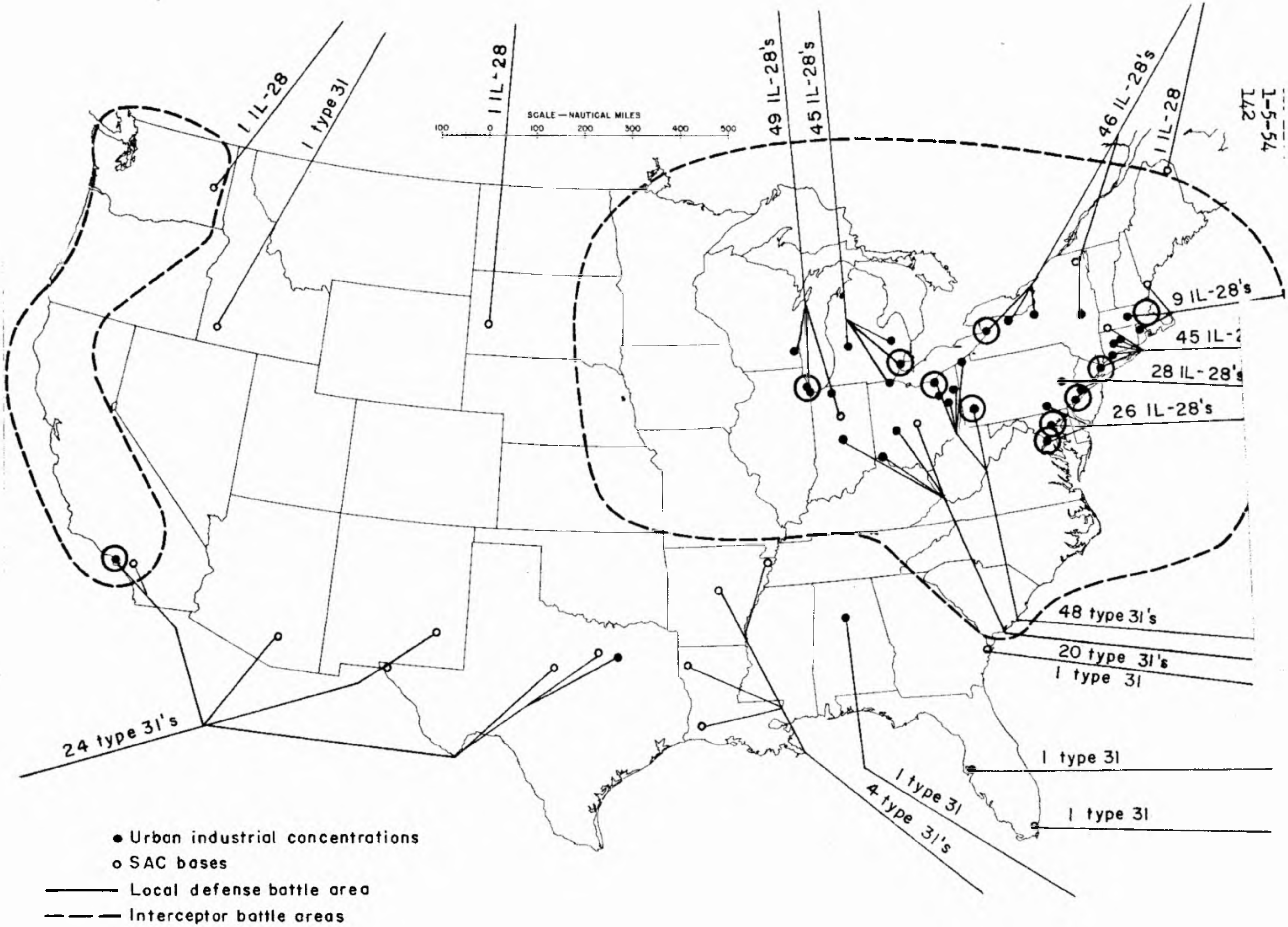

Fig. 24 — Strike IX 1958
Degraded defense effectiveness

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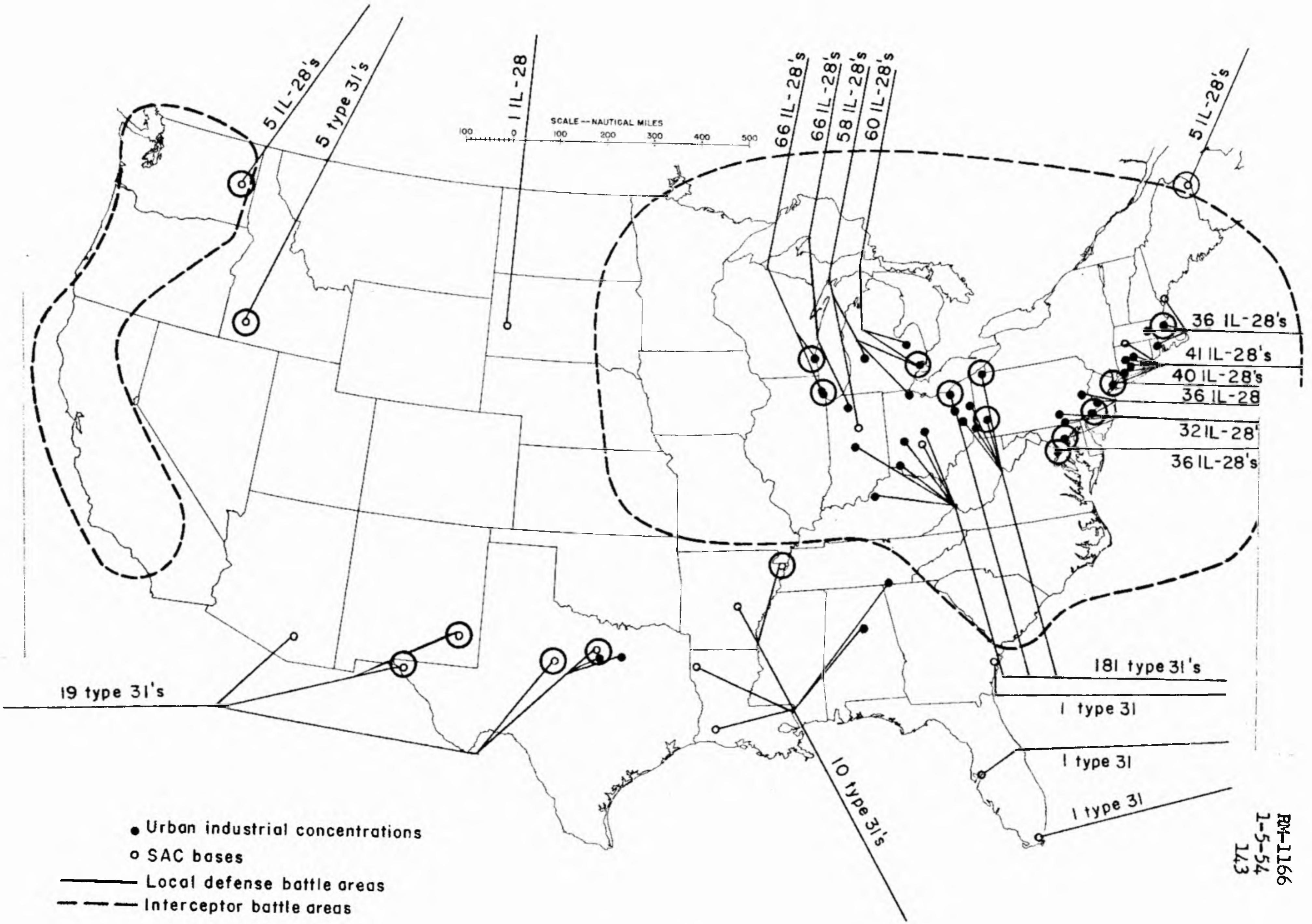

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Fig. 25 — Strike X 1958
Double offense and double defense

Strike XI

Offensive Force Arriving in ZI	215 IL-28's and 129 Type 31's.
Bombs Arriving in ZI	One 5-MT bomb per bomber.
Targets	SAC bases and urban industrial concentrations.
Attack Type	Low altitude, night.
Defense Strength	Basic for 1958.
Estimated Attrition	74 percent.

Strike XI was calculated in order to estimate results of using 5-MT bombs instead of 100-KT bombs. The targets attacked were 19 SAC bases and 71 urban industrial concentrations in 56 cities. The urban industrial concentration aiming points were from the target list for 5-MT bombs. The targets and bomber routes are shown in Fig. 26.

1960 STRIKES (XII, XIII, XIV, XV, XVI)

The Soviets were assumed to have available in 1960 a basic force of 1686 intercontinental subsonic guided missiles similar to the U.S. Snark. An alternate basic force of 574 manned bombers similar to the proposed long-range B-47 (B-47X) was also investigated in one strike, Strike XV. Each of these forces was regarded as equivalent in cost to 654 TU-4's. With either of these threats the Russians were considered capable of diverting part of their effort to decoy missiles (of the type described in Chapter I) and their carriers. These decoys would accompany the bomb carriers, and were presumed to be such that the defense forces could not distinguish them from the bombers except by visual recognition. It was postulated that, due to guidance limitations, only 50 percent of the decoys which survived the area defenses would penetrate the local defense regions

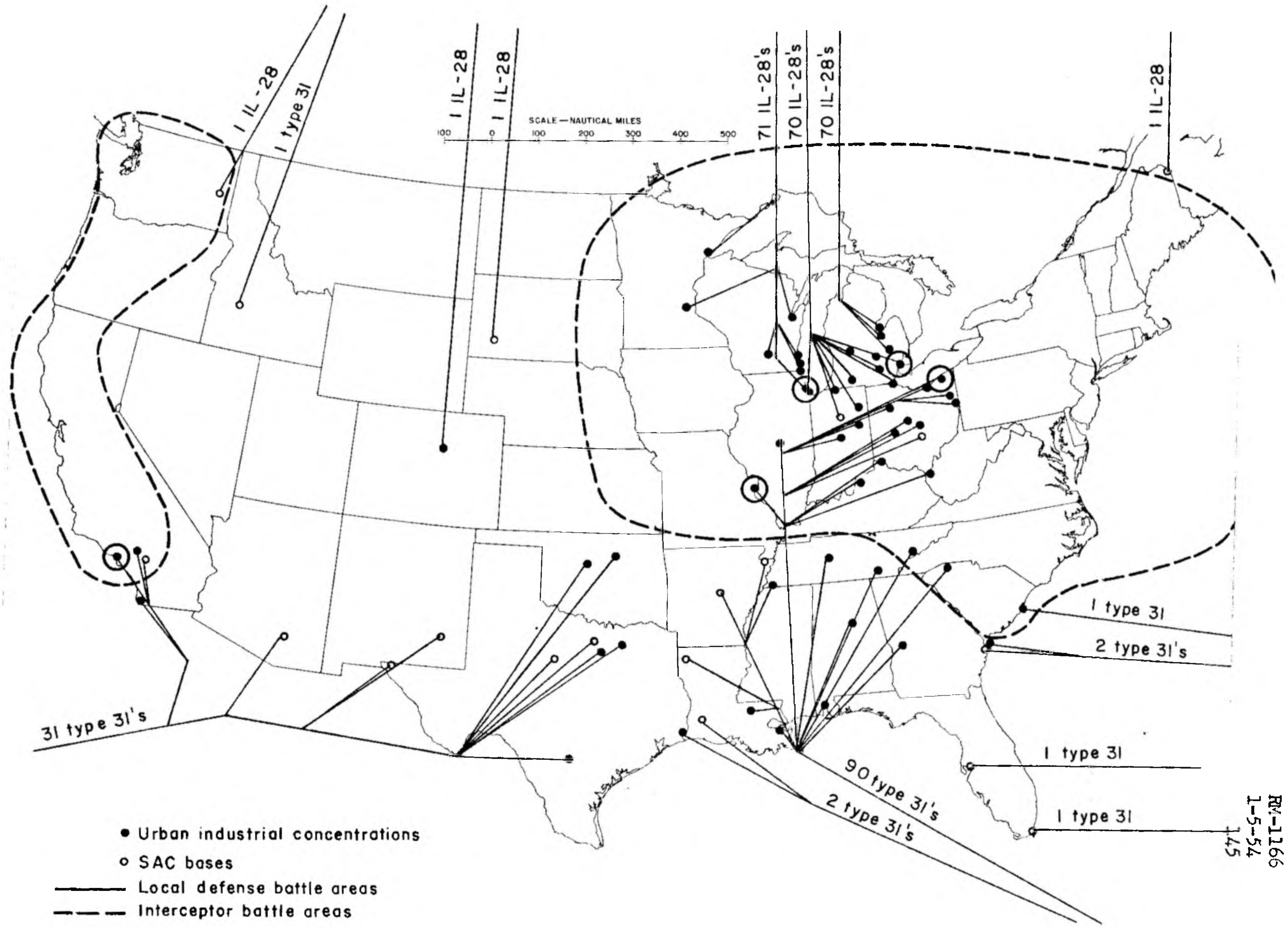

Fig. 26—Strike XI 1958
5 MT bombs

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for which they were intended.

An attempt was made to optimize the force composition for each strike so that each given target complex with a given defense strength could be destroyed at a minimum cost in bomb carriers and decoys. In this way a maximum number of targets could be attacked with the available force. This was done by the repetitive process outlined below.

A. Determination of offensive and defensive force sizes

B. Description of Soviet activity

   1. Selection, in order of worth, of an arbitrary number of aiming points
   2. Selection of missile routes to the target complexes
   3. Estimation for each target of the kill potential due to local defenses
   4. Estimation for each track of the kill potential due to area defenses
   5. Determination of the number of bomb carriers and decoys needed to be sent to target complexes so that the number of equivalent bomb carriers sent to each target complex would be a minimum
   6. Comparison of the required force with the available force
   7. Repeat steps 1 through 6 until the required force is approximately equal (within 5 percent) to the available force

Because of the anticipated improvement of SAC evacuation plans by 1960 and the larger amount of warning available from the assumed 1960 radar net, it was hypothesized that the Soviets would not include SAC bases in the ZI in an attack of this type in 1960. The SAC bases were consequently eliminated from the target list. The target strategy used in all 1960 strikes was an attack on the urban industrial or "value-added" targets.

The action of the U.S. defenses against the 1960 strikes is described in detail in the sections under Soviet activity. No other calculations of attrition were made since the estimates as assumed to be made by the offense in order to distribute missiles were found to be accurate enough estimates of the numbers of missiles surviving.

The same methods and procedures were used for all five strikes in 1960. Only the first strike will be described in detail. The ways in which the others differ will be discussed later.

Strike XII

Offensive Force Arriving in ZI	389 bomb-carrying guided missiles (similar to Snarks) and 2052 decoys.*
Bombs Arriving in ZI	One 5-MT bomb per bomb carrier.
Targets	Urban industrial concentrations.
Attack Type	50,000 feet, at night.
Defense Strength	Basic for 1960.
Estimated Attrition (Of bomb carriers)	85 percent.

*A comparison of costs to build and maintain bomb carriers and decoy systems, including carriers, gave the following ratio: cost of decoy/cost of missile = $\frac{1}{2.58}$. The ratio, cost of TU-4/cost of missile = 2.57 was used. Due to operational aborts, only 70 percent of the total committed force was assumed to arrive at the ZI. The force arriving at the ZI could have been any mixture between a pure force of decoys (some 3060) or a pure force of bomb-carrying missiles (some 1180).

Determination of Force Sizes

The basic offensive and defensive force sizes and the defense weapon deployment for 1960 as given in Chapter I were used for this strike. The stockpile of 654 TU-4's was converted into an equivalent force of guided missiles and decoys. The composition of this force was to be determined by the needs of the target strategy. Each bomb carrier carried one 5-MT bomb.

Soviet Activity

As a first guess, the top 50 urban industrial aiming points were selected from the 5-MT target list. Routes to these aiming points were then chosen according to the same criteria as was used in the preceding strikes. To insure destruction of the more valuable targets, bomber missiles over and above those necessary because of attrition were assigned to the aiming points using the following chart:

Value of Aiming Point (In millions of dollars)	Number of Bomb Carriers Assigned per Aiming Point
less than 370	1
between 370 and 1000	2
greater than 1000	3

The local defense kill potentials were then computed using the effectiveness numbers given in Chapter II and the equations in Chapter IV. When the kill potential was known, the optimum numbers of bomb carriers, β_ℓ, and decoys, D_ℓ, which should enter the local defenses so that a given number of bomb carriers, R_ℓ, would be expected to survive were computed from the following equations:*

*These equations were determined from a minimization of the total cost to the offense of attaining the expected number of surviving bomb carriers, R_ℓ.

$$\beta_\ell = R_\ell + \sqrt{\frac{R_\ell K_L}{a_1 - 1}}$$

$$r_\ell = -1 + \sqrt{\frac{(a_1 - 1)\ K_L}{R_\ell}}$$

$$D_\ell = r_\ell\ \beta_\ell$$

where K_L = expected number of missiles killed by the local defenses

a_1 = the ratio of cost of a bomb carrier to cost of a decoy (plus its portion of a decoy carrier)

r_ℓ = ratio of bomb carriers sent to decoys sent.

Because of the assumption that, due to navigational errors, only 50 percent of the surviving decoys would enter the local defenses, D_ℓ was then doubled. The resulting numbers of bomb carriers and decoys were summed for those which shared a common track through the area defenses. This gave the total numbers of missiles for each track, β_L and D_L, that should survive the area defenses.

The numbers of each type of missile which should enter the area defenses so that β_L and D_L would be realized were based on the attrition due to the area defenses. In order to determine the area kill potentials, the U.S. was divided into three parts, the East Coast, the Midwest, and the Los Angeles area, each of which was treated separately. When more than one track penetrated one of these regions, it was assumed that the defense could assign the area defense weapons in such a manner that the kill potential would be divided in proportion to the total numbers of missiles in each stream.

The F-102 and the F-102R were the only types of interceptors used against the 1960 strikes, but Bomarc missiles were included as area defense weapons. The Bomarcs which could reach the streams were dispatched as soon as the bombers entered the Lincoln system, and the interceptors were vectored by using elapsed-time-of-flight scales under the same rules that were applied in the 1958 analyses. When the interceptors and Bomarc missiles had been assigned the area kill potentials for each track were computed from the equation:

$$m_K = n_{\phi 102} K'_{\phi 102} + n_{\phi 102R} K'_{\phi 102R} + m_{Kb}$$

where

m_K = area defense kill potential against the track (i.e., the number of missiles and decoys destroyed by area defenses)

$n_{\phi 102}$, $n_{\phi 102R}$ = total number of passes against the track by F-102 and F-102R aircraft, respectively

$K'_{\phi 102}$, $K'_{\phi 102R}$ = probability that one pass by an F-102 or F-102R destroys a missile or decoy

m_{Kb} = expected number of offensive missiles and decoys in the track destroyed by Bomarc missiles

The value of n_ϕ per interceptor depended upon both the battle time available to the interceptor before bomb-release time and the distance it traveled in reaching the missile stream. The values of $K'_{\phi 102}$ and $K'_{\phi 102R}$ were computed using the assumptions listed in Chapter II and the following equation (where the parameter values for the respective interceptors should be inserted):

$$K'_{\phi 102} , K'_{\phi 102R} = u_{ab} P_{dc} D P_{Kb} .$$

This simple expression results, when the difference between the value of u_b and unity is neglected, because the interceptors were armed for all passes for which they were fueled and $P_{k\phi}$ was zero. K'_ϕ for the F-102 and F-102R was found to be 0.67.

Estimates of Bomarc missile effectiveness were made for each type of Bomarc, the F-99A, the F-99B, and the F-99C. For each Bomarc launched, the probability of destroying an offensive missile was calculated from the equations given in Chapter IV. Then m_{kb} was computed by summing these probabilities over all Bomarcs launched in the area.

It was assumed that the Soviets would expect the defense to assign area defensive kill potential in proportion to the number of missiles entering the ZI on each track and that they would determine the number of missiles to be sent per track accordingly. To do this they would calculate the number of missiles required to enter the local defenses for each target and assume that the ratio of missiles sent to missiles entering local defenses was the same for all tracks. This is equivalent to the assumption that interceptors are distributed against each track in proportion to the number of missiles entering the ZI. Since each track had both bomb carriers and decoys, the kill potentials in each track were spread between these two according to the ratio of the two types present. The following equations were used to compute the numbers of missiles which should enter the area defenses.

$$\beta_A = \beta_L \left[1 + \frac{K_A}{\beta_L + D_L} \right]$$

$$D_A = D_L \left[1 + \frac{K_A}{\beta_L + D_L} \right]$$

where:

β_A = number of bomb carriers entering the area defenses on a particular track

D_A = number of decoys entering the area defenses on a particular track

β_L = number of bomb carriers which should survive the area defenses on a particular track

D_L = number of decoys which should survive the area defenses on a particular track

K_A = area kill potential for the track

As a result of the procedure above it was discovered that if the first 50 aiming points were attacked the bomber force would be too spread out and would absorb most of the local and area kill potentials in the three areas of the country. By eliminating the East Coast and attacking more aiming points within the other two areas, more damage per equivalent bomb carrier could be achieved. The choice of targets was changed accordingly and the procedure for determining the equality between the "needed force" and the "available force" was repeated several times in successively closer approximations to a maximum damage potential. When the 1180 equivalent bomb carrier capacity was reached, the target complex attacked consisted of 48 aiming points in 28 cities, centered around four major cities, Chicago, Detroit, St. Louis and Los Angeles. The targets and missile routes selected are shown in Fig. 27.

As has been stated, no other calculations of the air battles were made for the 1960 strikes. The estimates assumed to be made by the offense in order to distribute missiles over the targets were found to provide sufficiently accurate estimates of the numbers of bomb carriers surviving.

<u>Strike XIII</u>

Offensive Force Arriving in ZI	411 bomb-carrying missiles and 1979 decoys.
Bombs Arriving in ZI	One 100-KT bomb per bomb carrier.
Targets	Urban industrial concentrations.
Attack Type	50,000 feet, at night.

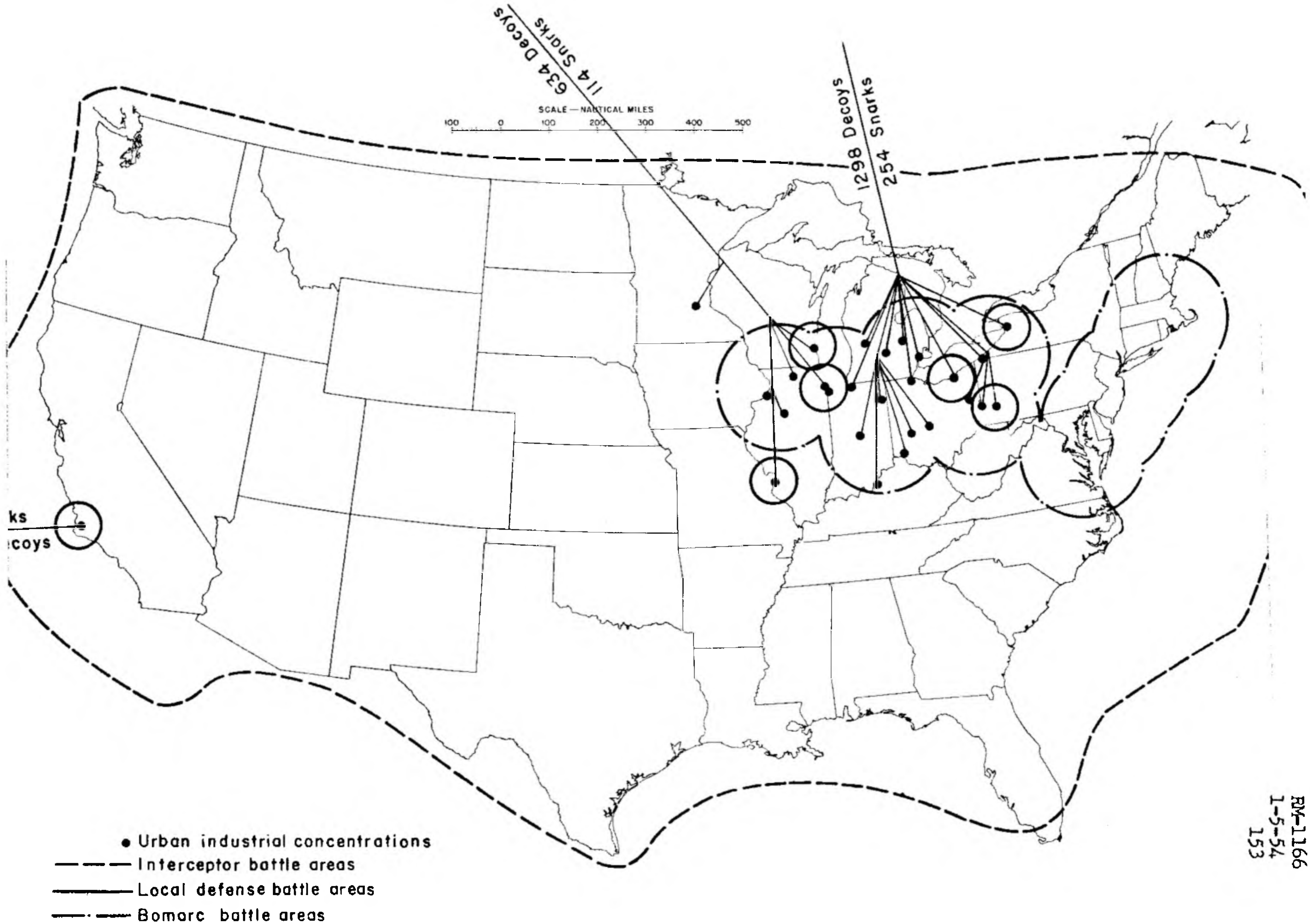

Fig. 27—Strike XII 1960
5 MT bombs basic offense and defense

Defense Strength	Basic for 1960.
Estimated Attrition (For bomb carriers)	84 percent.

The analysis methodology used for the second raid was identical to that of the first. The bomb size was changed from 5 MT to 100 KT and the target list was accordingly changed. The St. Louis area was omitted for the same reason that those targets on the East Coast were omitted in Strike XII.

A total of 63 aiming points located in 18 cities were attacked. The targets and missile routes used are shown in Fig. 28.

Strike XIV

Offensive Force Arriving in ZI	627 bomb-carrying missiles and 1417 decoys.
Bombs Arriving in ZI	One 100-KT bomb per bomb carrier.
Targets	Urban industrial concentrations.
Attack Type	50,000 feet, at night.
Defense Force	Basic size for 1960, with degraded (approximately 50 percent) effectiveness.
Estimated Attrition (For bomb carriers)	76 percent.

For the third strike a defense effectiveness degradation was applied to both local and area defenses, thus making it possible and profitable for the offense to attack targets in all three major areas using the 100-KT target list. In addition the San Francisco and Seattle areas were included in the attack against the West Coast. In this raid 152 aiming points in 46 cities were attacked. The targets and missile routes used are shown in Fig. 29.

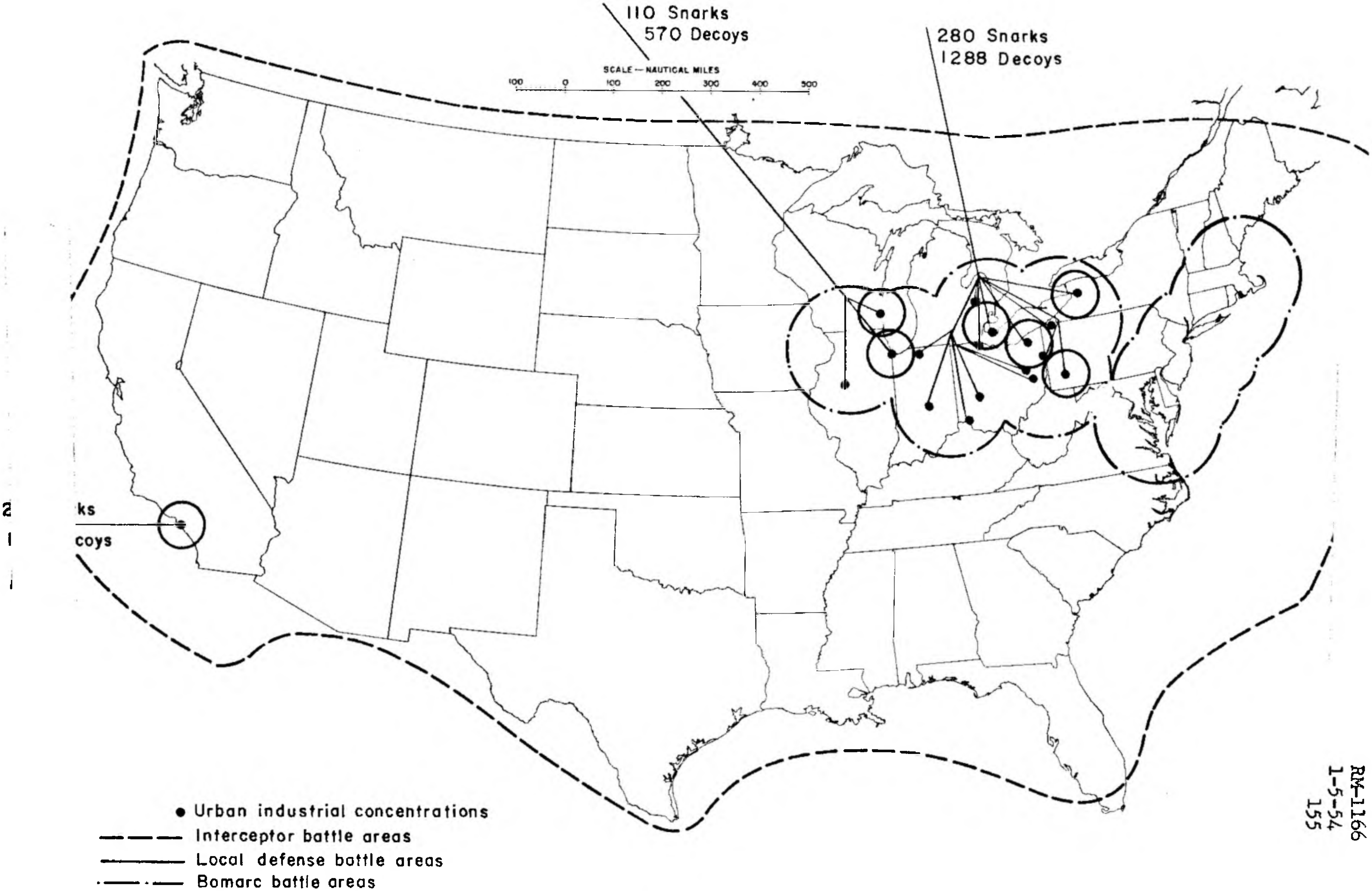

Fig. 28—Strike IV 1960
100 KT bombs basic offense and defense

RM-1166
1-5-54
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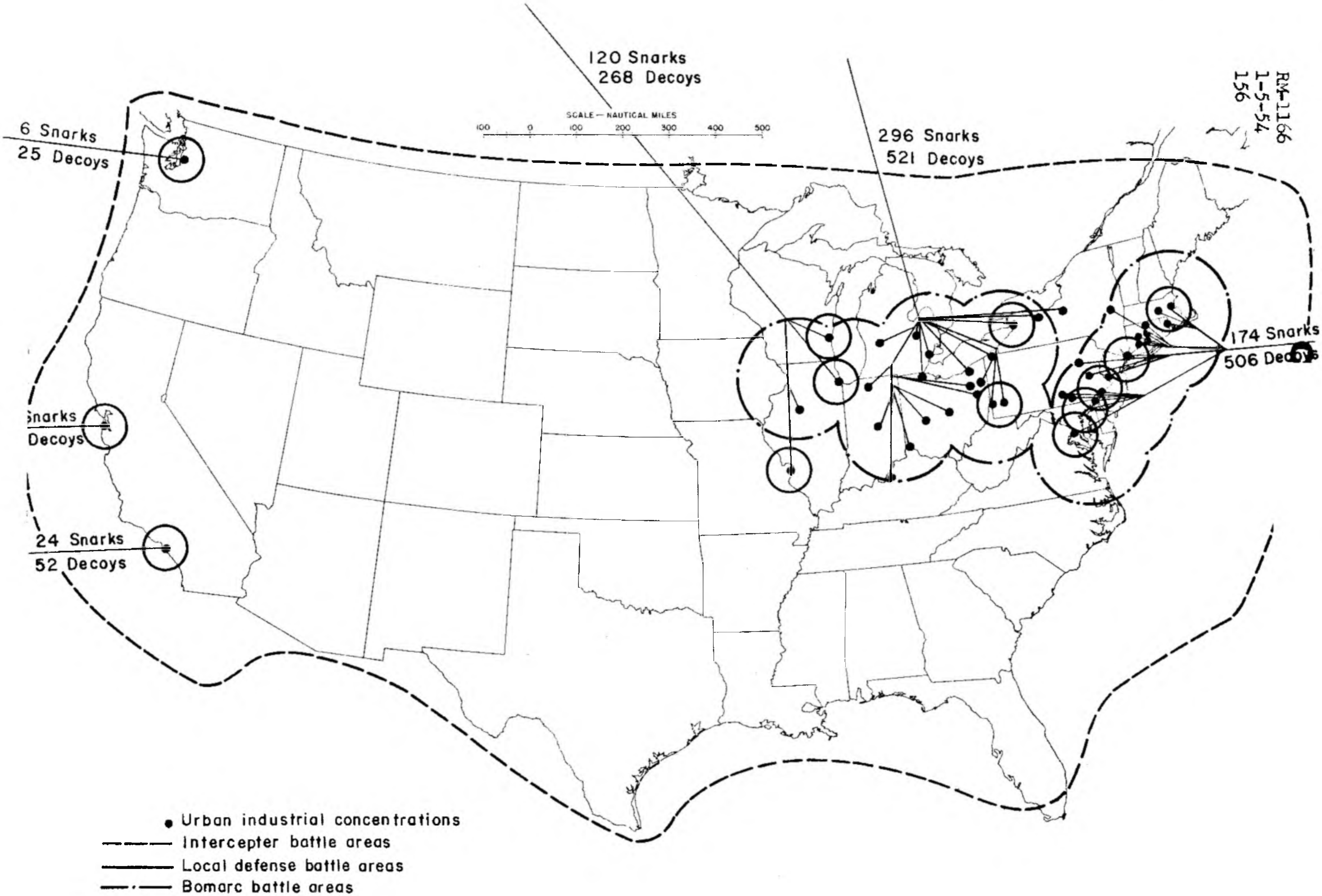

Fig. 29 — Strike XIV 1960
100 KT bombs degraded defense effectiveness

Strike XV

Offensive Force Arriving in ZI	213 B-47's and 1645* decoys.
Bombs Arriving in ZI	One 5-MT bomb per bomber.
Targets	Urban industrial concentrations.
Attack Type	Low altitude, at night.
Defense Force	Basic for 1960.
Estimated Attrition	92 percent.

Strike XV was the only attack in 1960 which considered the use of B-47-type bombers coming in at low altitude. The target selection methods used for this case were similar to those used in the other 1960 strikes. The following equation was used to calculate interceptor effectiveness for the F-102 (armed with atomic warheads).

$$K_{102} = u_{ab} D P_{dc} \Big[P_{kb_A} + u_b P_{kb_A} + u_b^2 \Big\{ P_{kb_A}(1-D_1^2 P_{dc}^2) + P_{kb_R} D_1^2 P_{dc}^2 \Big\} + u_b^3 \Big\{ P_{kb_A} \left[3D_1 P_{dc}(1-D_1 P_{dc})^2 + (1-D_1 P_{dc})^3 \right] + 3 P_{kb_R} D_1^2 P_{dc}^2 (1-D_1 P_{dc}) \Big\} \Big]$$

where

P_{kb_A} = probability of kill of an atomic warhead

P_{kb_R} = probability of kill of one salvo of 108 small rockets.

All other terms are as defined in Chapter II.

The equation represents the effectiveness of an interceptor armed for two passes with atomic rockets and one pass with small rockets, and fueled

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*The cost ratio assumed was cost of B-47/cost of decoy = 7.55. The numbers of bombers and decoys arriving at the ZI include a degradation for operational aborts. 25 percent were assumed to abort before reaching the ZI.

for four passes. The effectiveness of the F-102R armed for two salvos of 108 small rockets each and fueled for three passes was determined from the same equations by replacing P_{kb_A} by P_{kb_R}. The results were as follows:

Type of Interceptor	K 1 pass	2 passes	3 passes	4 passes
F-102 (atomic armament)	.67	1.33	1.83	1.97
F-102R	.48	.94	1.04	--

The East Coast was not attacked in this strike, but some targets which required southerly approaches were. A total of 52 aiming points in 38 cities were attacked. The targets and bomber routes selected are shown in Fig. 30.

Strike XVI

Offensive Force Arriving in ZI	597 bomb-carrying missiles and 1497 decoys.*
Bombs Arriving in ZI	One 5-MT bomb per bomb carrier.
Targets	Urban industrial concentrations.
Attack Type	50,000 feet, at night.
Defense Strength	Basic size for 1960, with degraded (approximately 50 percent) effectiveness.
Estimated Attrition (For bomb carriers)	76 percent.

This strike was analyzed by the same methods as the preceding strikes. The degradation on the defense forces allowed the Soviets to attack all three areas as in Strike XIV. A total of 131 aiming points in 91 cities,

*Because of operational aborts, only 70 percent of the total force was assumed to arrive at the ZI.

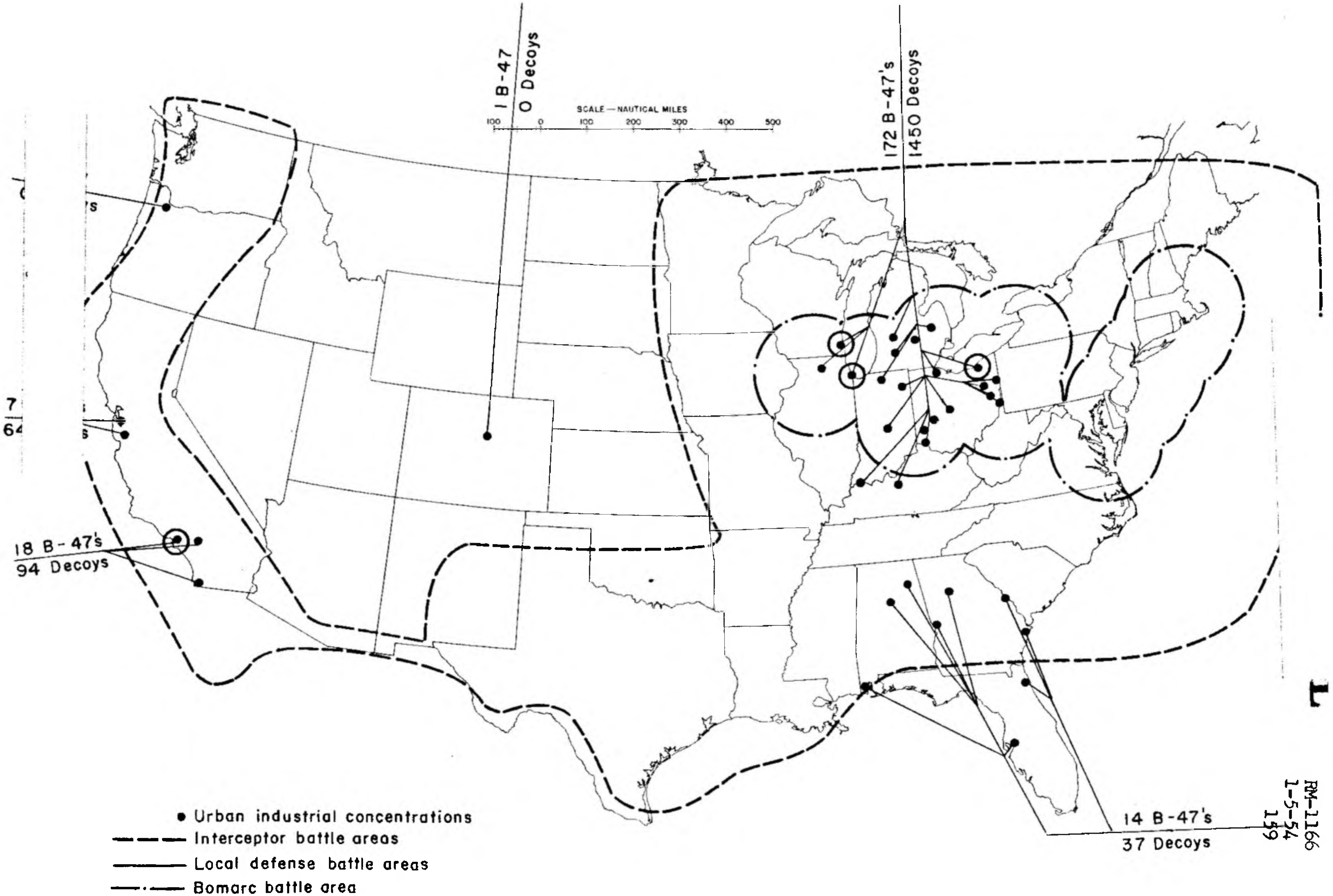

Fig. 30—Strike XV 1960
Low altitude B-47

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chosen from the 5-MT target list, were attacked. The targets and missile routes selected are shown in Fig. 31.

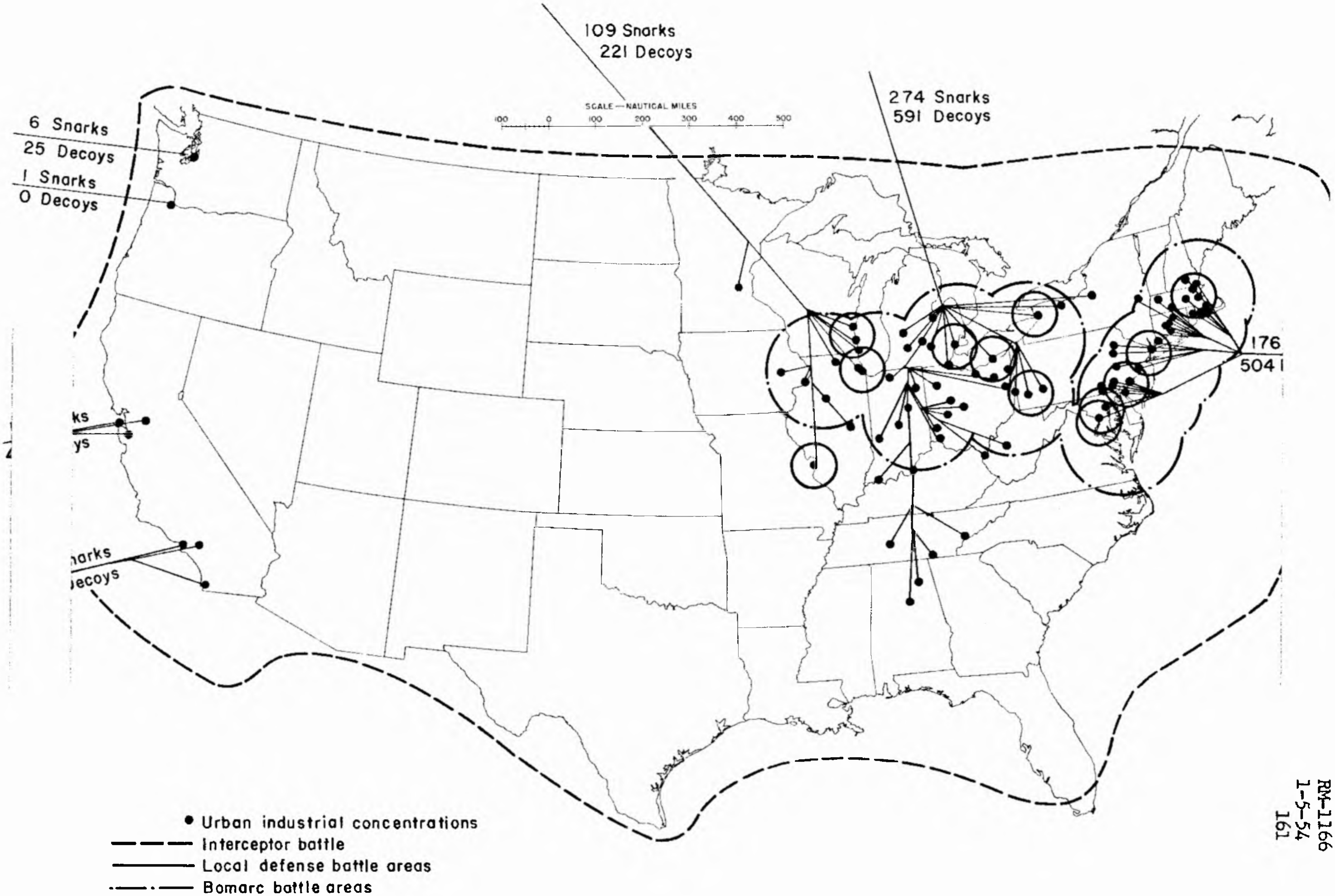

Fig. 31 —Strike XVI 1960
5 MT bombs degraded defense effectiveness

CHAPTER IV

ATTRITION AND DAMAGE CALCULATIONS

This chapter presents the methods and the equations employed in calculating the attrition to the bombers and the damage to the U.S. targets expected in these strike analyses. Numbers used in the mathematical models were derived from the map exercises described in the preceding chapter.

The outputs of the map exercises were:

1. The number of bombs and bombers briefed to each aiming point or target complex and the value of the aiming points.
2. The briefed bomber tracks (in geography and relative time) and the number of bombs and bombers briefed to fly on each track segment.
3. The number and type of interceptors and area missiles intercepting the bombers at each point along the bomber tracks.
4. The number of control channels and directors available at each point along the bomber tracks.
5. The types and amounts of local defense weapons defending the aiming points.

These outputs reflected not only the geographical constraints of components of the defense system, but also the constraints of time, vehicle performances, commitment policy decisions, and the many other assumptions discussed in the preceding chapters.

The attrition estimation was accomplished in two separate processes, the attrition due to area defense weapons being computed first and that due to local defense weapons being calculated as a second step. The complete order of events was, then: map exercise, area attrition calculation, local attrition calculation, damage assessment. The outputs of each of these processes were inputs to all of those which followed.

The area attrition model was almost entirely determined by the need to combine and reflect in an appropriate manner items 2, 3, and 4 above. The requirements were (a) to show bomber kills in a manner which allowed bombers that were killed to fall out of the attack within a realistic time after being hit, and (b) to allow each interceptor and each missile a kill potential commensurate with its share of the total control capacity available and its capability against the attacker in the given conditions. The methods used in approaching these two problems are discussed in detail below. However, some general remarks are in order here.

A desirable approach to the bomber fall-out problem, assuming that it were manageable from the point of view of labor, would be the Monte Carlo method. This approach demands a high degree of automaticity in the model manipulations if it is to be profitably employed. Because of the complex decisions to be made at many steps in such a calculation, and because of the lack of complete insight into the many interactions within an air defense campaign, it was estimated to be impossible to mechanize the process profitably. Hence each "play-through" of a Monte Carlo approach would have to be done manually, and the labor would prohibit the completion of a useful number of "plays." Instead of a Monte Carlo procedure, an expected-value model was devised. In this model the bomber paths were divided into equal time intervals, and each such interval considered as an air battle. The expected number of bombers dropped from a stream in a given battle was given by the equations presented below. The result of this procedure, applied in turn to all battle intervals over the length of a bomber track, was taken as the expected outcome of the area attrition.

This procedure has two major shortcomings. First, the final outcomes of the calculations may not coincide with those which would result from the Monte Carlo method. Second, the technique gives no indication of the distribution function of the overall attrition or bomb damage. Insight into both these factors may be had via studies such as those reported in RM-1094,[16] RM-1146,[17] and RM-1219,[18] where the result of an iterative procedure such as that under discussion is actually calculated via matrix multiplication, for specific types of attrition. However, no attempt has been made to determine either the expected error of the iterative technique employed, or the form of the distribution function of the attrition. It is felt, however, that the overall results, as discussed in the next chapter, are accurate enough to be used as the basis for conclusions of the type of interest.

Because all of the equations presented here follow in a straightforward manner from fundamental probability theory, no derivations will be given. The equations will merely be stated in the final form in which they were used. As in Chapter II, each section will be broken up into the year or years to which the specific procedures apply.

BOMBER ATTRITION

Attrition Due to Interceptors (1956)

As has been explained previously, the time during which the bombers in a particular track were under attack by interceptors was divided into ten-minute segments. This interval was picked because it was felt to be approximately the time required for nearly all of the bombers to fall which had been dealt fatal blows at the beginning of the interval. In other words, no bombers which had been fatally hit in one interval were ever carried into the next. All of the fighters which reached the bomber stream during each of these segments were considered as one group, and treated as though they all arrived simultaneously. Each segment was thought of as one complete "battle."

The results of the first such battle along a track were computed and the surviving bombers carried into the next battle. This iterative process was continued down the track until either the interceptors had to break off their engagements because of the presence of local defenses or the bombers reached bomb-release line.

When a split occurred along a bomber track, it was decided which battle was the first in which the defenses could recognize the split. This depended upon the nature of the split, but was generally taken to be the first battle after the centers of the groups of bombers were separated by about twenty miles. Immediately after the split was recognized, the bombers surviving the last battle before the split and any interceptors carrying over their attacks from that battle to the next were assigned to the separated groups in the same ratio as the bombers were originally briefed for those groups. Separate battles were then carried on for each arm of the track in the same manner as explained above for the main track.

The number of bombers entering a battle was defined to be (except for the case of splits):

$$\beta_{n+1} = \beta_n P_{BS_n}$$

where β_n = number of bombers entering n^{th} battle

and P_{BS_n} = probability that a bomber entering the n^{th} battle survives that battle.

In each battle, since there might be interceptors on close control and/or interceptors on broadcast control,

$$P_{BS} = \left[1 - \frac{1}{\beta} \left| \phi_{86}K_{86} + \phi_{89}K_{89} \right| \right] R_2^{\frac{\phi_2}{2}} R_3^{\frac{\phi_3}{2}} R_b^{\frac{\phi_b}{2}}$$

where ϕ_{86} = number of F-86D's on close control in the battle,*

ϕ_{89} = number of F-89D's on close control in the battle,*

ϕ_2 = number of F-89D's on their second pass in the battle, and hence on broadcast control, which had originally been on close control on their first pass,*

ϕ_3 = number of F-89D's on their third pass in the battle, and hence on broadcast control, which had originally been on close control on their first pass,*

ϕ_b = number of F-89D's in the battle which were on broadcast control all the time,*

nK_{86} = expected number of bombers shot down by an element of n (n = 2 or 4)** F-86D's on close control,

$2K_{89}$ = expected number of bombers shot down by an element of 2 F-89D's on close control,

R_2 = probability that a given bomber survives when the formation is attacked by one element of F-89D's on its second pass ($\phi_2 = 2$), the interceptors having been originally close-controlled,

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*The numbers used were the numbers of interceptors scrambled and not the number expected to reach the battle.

**In a given battle either elements of four F-86D's or two F-86D's were employed, not both.

R_3 = probability that a given bomber survives when the formation is attacked by one element of F-89D's on its third pass ($\phi_3 = 2$), the interceptors having been originally close-controlled,

and R_b = probability that a given bomber survives when the formation is attacked by one element of F-89D's which have been sent out on broadcast control ($\phi_b = 2$).

This expression is correct when the number of interceptor elements on close control is less than the number of bombers. This was nearly always the case in 1956, and created negligible error when it was not. The value of ϕ_2 was taken to be equal to the number of F-89D's which had been on close control in the preceding battle and the value of ϕ_3 was taken to be equal to the number of F-89D's which had been on close control two battles previous. In each case the fact that one or both interceptors in an element may have aborted, may have been killed, or may have committed some error which split the element was taken into account in the corresponding R factor, as can be seen below. Interceptors which were on broadcast control all the time had two passes, both of which were included in R_b, and both of which were assumed to be effective in the battle following the one in which they first reached the bomber stream. Thus ϕ_b was taken equal to the number of F-89D's originally on broadcast control which reached the bomber stream during the preceding battle.

The K's are interceptor effectiveness numbers and depended upon whether the interceptors were scrambled in elements of two or four. For the two-plane element of either F-86D's or F-89D's:*

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*Note that this equation holds only for F-86D's scrambled in elements of two and F-89D's on their first pass on close control and also scrambled in elements of two.

$$K_{86,89} = \frac{1}{2} \left[w_{11}P_{kb_1} + w_{12}P_{kb_2} + w_{22} \left[1 - (1-P_{kb_2})^2 \right] \right]$$

where w_{ij} = probability that two interceptors, having been scrambled as an element, attack a bomber so that bomber fire is split j ways, but only i interceptors fire effectively

P_{kb_j} = probability that an interceptor kills the bomber in a firing pass in which the bomber's fire is split j ways

(The other symbols are treated in Chapter II and are for the particular type of interceptor and bomber involved.)

The w_{ij} were found from the following equations:

$$w_{11} = 2u_{ab}D(1-u_{ab}D_1)P_{dc}$$

$$w_{12} = 2u_{ab}^2DD_1(1-D_2)P_{dc}$$

$$w_{22} = u_{ab}^2D^2P_{dc}$$

These symbols are also discussed in Chapters II and III; see the list of symbols as well.

When F-86D's were scrambled in elements of four, the resulting effectiveness equation became more complex because of the added combinations of ways in which the interceptors could attack the bombers. The effectiveness was given by:

$$K_{86(4)} = \frac{1}{4} \sum_{i=1}^{4} \sum_{j=1}^{4} C_{ij} \left[1 - (1-P_{kb_j})^i \right]$$

where the C_{ij} and P_{kb_j} are defined exactly as the w_{ij} and P_{kb_j}, respectively, above except that the interceptors were scrambled in elements of four, and the other symbols are as explained in Chapter II.

The C_{ij} were given by:

$$C_{11} = 4u_{ab}D\ (1-u_{ab}D_1)^3 P_{dc}$$

$$C_{12} = 12u_{ab}{}^2 DD_1(1-D_2)(1-u_{ab}D_1)^2 P_{dc}$$

$$C_{13} = 12u_{ab}{}^3 DD_1{}^2(1-D_2)^2(1-u_{ab}D_1)P_{dc}$$

$$C_{14} = 4u_{ab}{}^4 DD_1{}^3(1-D_2)^3 P_{dc}$$

$$C_{22} = 6u_{ab}{}^2 D^2(1-u_{ab}D_1)^2 P_{dc}$$

$$C_{23} = 12u_{ab}{}^3 D^2 D_1(1-D_2)(1-u_{ab}D_1)P_{dc}$$

$$C_{24} = 6u_{ab}{}^4 D^2 D_1{}^2(1-D_2)^2 P_{dc}$$

$$C_{33} = 4u_{ab}{}^3 D^3(1-u_{ab}D_1)P_{dc}$$

$$C_{34} = 4u_{ab}{}^4 D^3 D_1(1-D_2)P_{dc}$$

$$C_{44} = u_{ab}{}^4 D^4 P_{dc}$$

For F-89D's on broadcast control, the R's were determined as follows:*

$$R_2 = 1 - \frac{X_{11}}{\beta} P_{kb_1} - \frac{X_{12}}{\beta} P_{kb_2} - \frac{X_{22}}{\beta}\left[1-(1-P_{kb_2})^2\right] - X_{1-1}\left[1-(1-\frac{P_{kb_1}}{\beta})^2\right]$$

---

*As written here R_b is a linear approximation, in the $\bar{w}$'s and $\bar{x}$'s, to the previously defined R_b.

$$R_3 = 1 - \frac{Y_{11}}{\beta} P_{kb_1} - \frac{Y_{12}}{\beta} P_{kb_2} - \frac{Y_{22}}{\beta} \left[1-(1-P_{kb_2})^2 \right] - Y_{1-1} \left[1-(1-\frac{P_{kb_1}}{\beta})^2 \right]$$

$$R_b = 1 - \frac{\bar{w}_{11}+\bar{X}_{11}}{\beta} P_{kb_1} - \frac{\bar{w}_{12}+\bar{X}_{12}}{\beta} P_{kb_2} - \frac{\bar{w}_{22}+\bar{X}_{22}}{\beta} \left[1-(1-P_{kb_2})^2 \right]$$

$$- \bar{X}_{1-1} \left[1-(1-\frac{P_{kb_1}}{\beta})^2 \right]$$

where X_{ij} and Y_{ij} are defined precisely as the w_{ij}, but apply only to, respectively, the second and third passes of an element of two F-89D's which were on close control on their first pass.

X_{1-1} and Y_{1-1} = probabilities that an element of two F-89D's has split but each interceptor independently attacks a bomber (possibly the same one) on, respectively, the second and third passes of the interceptors,

$\bar{w}_{ij}$, $\bar{X}_{ij}$, and $\bar{X}_{1-1}$ are defined the same as w_{ij}, X_{ij}, and X_{1-1} except that they apply to an element of two F-89D's which is on broadcast control all the way

The equations from which the various X's, Y's, $\bar{w}$'s and $\bar{X}$'s were found are as follows:

$$X_{1-1} = u_{ab}^2 u_b^2 \bar{P}_{dc}^2 D^2 \left| 1-D-P_{dc} \left[2D_1(1-D_1)P_{k\phi_1} - D(1-D)(1-P_{k\phi_2})^2 \right] \right|$$

$$X_{11} = 2u_{ab}u_b\bar{P}_{dc}D \left| 1-u_{ab}u_bDD_1+P_{dc} \left[u_{ab}u_bDD_1-D_1P_{k\phi_1}+u_{ab}D(P_{k\phi_1}-P_{k\phi_2}) \right. \right.$$

$$\left. \left. -u_{ab}u_bD^2D_1(1-P_{k\phi_2})^2 \right] \right| \quad -2X_{1-1}$$

$$X_{22} = u_{ab}^2u_b^2\bar{P}_{dc}D^3 \left| 1-P_{dc}+P_{dc}D(1-P_{k\phi_2})^2 \right|$$

$$X_{12} = \frac{2(1-D_2)}{D_2} \quad X_{22}$$

$$Y_{1-1} = u_{ab}^2u_b^4\bar{P}_{dc}^2D^2 \left| 1-D^2+P_{dc} \left[D(1-D^2)(1-P_{k\phi_2})^2-D(1-D)-2D_1(1-D_1)P_{k\phi_1} \right] \right.$$

$$+\bar{P}_{dc} \left| D^2(1-D)(1-P_{k\phi_2})^2-2D_1(1-DD_1)P_{k\phi_1} \right.$$

$$+P_{dc} \left\{ DD_1(3DD_1-D_1-2)(1-P_{k\phi_2})^2 -2D(1-D_1)(1-2P_{k\phi_1}-P_{k\phi_1}{}^2) \right.$$

$$\left. \left. +2DD_1(1-D_1)P_{k\phi_1} \right| \right|$$

$$\left. +\bar{P}_{dc}{}^2 \left[D(1-D)P_{k\phi_1}{}^2+P_{dc} \left\{ D^2(1-D)(1-P_{k\phi_2})^2+2DD_1(1-D_1)P_{k\phi_1}(1-2P_{k\phi_1}) \right\} \right] \right|$$

$$Y_{11} = 2u_{ab}u_b^2\bar{P}_{dc}D \left| 1-u_{ab}u_b^2D^2D_1+P_{dc} \left[u_{ab}D(P_{k\phi_1}-P_{k\phi_2})-u_{ab}u_b^2D^3D_1(1-P_{k\phi_2})^2 \right. \right.$$

$$-D_1 P_{k\phi_1} + u_{ab} u_b^2 D^2 D_1 \Big]$$

$$+\bar{P}_{dc} \Big[u_{ab} u_b^2 D^2 D_1 - D_1 P_{k\phi_1} + u_{ab} u_b D^2 (P_{k\phi_1} - P_{k\phi_2})$$

$$- u_{ab} u_b^2 D^3 D_1 (1 - P_{k\phi_2})^2$$

$$+P_{dc} \Big\{ 2DP_{k\phi_1} - u_{ab} u_b^2 D^2 D_1 - D - u_{ab} D D_1 (1 + u_b D_1)(P_{k\phi_1} - P_{k\phi_2})$$

$$+2u_{ab} u_b^2 D^3 D_1 (1 - P_{k\phi_2})^2 \Big\} \Big] \Big] - 2Y_{1-1}$$

$$Y_{22} = u_{ab}^2 u_b^4 \bar{P}_{dc} D^4 \Big[1 - P_{dc} - \bar{P}_{dc} + P_{dc}\bar{P}_{dc} + D(P_{dc} + \bar{P}_{dc} - 2P_{dc}\bar{P}_{dc})(1 - P_{k\phi_2})^2 \Big]$$

$$Y_{12} = \frac{2(1-D_2)}{D_2} \quad Y_{22}$$

and $\bar{w}$'s and $\bar{X}$'s = corresponding w's and X's with all P_{dc}'s replaced by $\bar{P}_{dc}$'s.

When F-89D's were employed on uniform broadcast control, a slight modification of the R factors was necessary. The resulting equations were:

$$R_i' = 1 - S + SR_{i_S}^{\frac{\phi_1}{2}}$$

where S = lesser of 1 and $\frac{6}{\beta}$

and R_{i_S} = R_i as given on p.169 when computed for β equal to the lesser of the number of bombers in the battle and 6, and when the uniform broadcast control values for P_{dc} are substituted into the expression.

(The number six results because only one director was ever dedicated to uniform broadcast control, and he could handle six bombers.)

These R_i' were substituted for the $R_i^{\frac{\phi_i}{2}}$ in the equation for the probability of bomber survival given on p. 166.

Attrition Due to Interceptors (1958)

The presence of F-102's carrying atomic armament and F-102R's in the assumed 1958 defense system caused the bomber attrition to be considerably higher than it was in the 1956 strikes. In addition, the increase in control capacity allowed more interceptor elements to be close-controlled. The consequent decrease in the numbers of bombers in late battle stages and increase in the number of close-controlled fighter elements meant that at times there were more close-controlled fighter elements than bombers in a single battle. In the double-defense analyses for 1958 this situation was especially likely to occur.

The probability of bomber survival for the 1958 strikes was rewritten to be:

$$P_{BS} = \left[1-\alpha+\alpha \left| 1-\frac{1}{\Delta}\left[\phi_{86}K_{86}+\phi_{89}K_{89}+\phi_{102}K_{102}+\phi_{102R}K_{102R} \right] \right|^{\theta} \right] R_2^{\frac{\phi_2}{2}} R_3^{\frac{\phi_3}{2}} R_b^{\frac{\phi_b}{2}}$$

where α = probability that the ground system is tracking a given bomber, as explained in Chapter II,

Δ = greater of $\alpha\beta$ and γ,

θ = greater of 1 and $\frac{\gamma}{\alpha\beta}$,

and γ = number of close-controlled passes by interceptor elements in the battle,

$$(\gamma = \frac{\phi_{86}}{2} + \frac{\phi_{89}}{2} + 2\phi_{102} + 2\phi_{102R}),$$

and the other symbols are as previously defined for the appropriate types of interceptors.*

Since F-86D's and F-89D's were always scrambled in elements of two in the 1958 analyses, the single effectiveness equation as given on p. 168 was adequate for both of these interceptors. For the F-102's and F-102R's, each of which was scrambled singly and given two close-controlled passes which were both counted as being effective in the battle in which the interceptor reached the bomber stream, the effectiveness number was defined as:

$$K_{102} \text{ and } K_{102R} = u_{ab} P_{dc} D P_{kb} \left| 1 + u_b (1 - D_1 P_{dc} P_{k\phi}) \right|$$

where P_{dc}, P_{kb}, and $P_{k\phi}$ are for the appropriate fighter-bomber combination.

The F-89D's on broadcast control and uniform broadcast control were treated the same as in the 1956 portion of the study.

Attrition Due to Interceptors (1960)

In the 1960 analyses, the F-102 and the F-102R were the only interceptors used. They were always employed singly and were presumed to be equipped with improved AI radars incorporating good AMTI. The atomic-warhead rockets, which were the predominant form of armament, were assumed to produce instantaneous kills. The Lincoln system with its large control capacity was assumed to be operating in most of the areas where the interceptor density would be high, and the hypothesized strikes by bombers and

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*When θ is greater than one, this expression is an approximation for P_{BS} as defined previously.

decoys resulted in large and dense formations of attacking vehicles.

Consideration of all of these factors lead to two conclusions: first, that the interceptors would nearly always be used on close control, where the probability of doubling up on one attacking vehicle would be small; second, that even if broadcast control were necessary in the early battles, the capabilities of the AI radar and the density of the bombers and decoys would result in a P_{dc} of unity, and the numbers of bombers and decoys and quickness of kills would still make the probability of doubling up, or firing at previously "killed" vehicles, negligible.*

The net result was the supposition that all interceptors could be treated as though they were being close-controlled. This not only greatly simplified the equation for the probability of bomber survival, but allowed all interceptors which attacked one group of bombers (the main track from entry into the defended region until the first split, or a sub-track from one split to another) to be lumped into one air battle. The large number of decoys employed also prevented the number of interceptors from exceeding the number of attacking vehicles, further simplifying the survival equation to:

$$P_{BS} = 1 - \frac{1}{\beta+\delta} \left[\phi_{102}K_{102} + \phi_{102R}K_{102R} + M_{99A}K_{99A} + M_{99B}K_{99B} + M_{99C}K_{99C} \right]$$

where δ = the number of decoys entering the battle and the other symbols are defined as before, with the appropriate extension of the air battle definition. (See the following section for a discussion of the last three

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*A further condition favorable to the defense was the use of air-to-air IFF, which was assumed throughout this study.

terms of this equation.)

Since the armament load on the F-102 was a mixture of atomic weapons and small rockets, different expressions had to be written for the two K factors involved in the bomber survival equation. Thus:

$$K_{102} = u_{ab}P_{dc}D \Bigg[P_{kb_A} + u_b P_{kb_A} + u_b^2 \left| P_{kb_A}(1-D_1^2 P_{dc}^2) + P_{kb_R} D_1^2 P_{dc}^2 \right|$$

$$+ u_b^3 \left| P_{kb_A} \left[3D_1 P_{dc}(1-D_1 P_{dc})^2 + (1-D_1 P_{dc})^3 \right] + 3P_{kb_R} D_1^2 P_{dc}^2 (1-D_1 P_{dc}) \right| \Bigg]$$

and

$$K_{102R} = u_{ab}P_{dc}DP_{kb_R} \left[1 + u_b + u_b^2 + u_b^3 (1-D_1^3 P_{dc}^3) \right]$$

The four terms in the main parentheses in each of these equations refer respectively to each of four possible passes which the interceptor might make, P_{kb_A} and P_{kb_R} refer to the probabilities of kill of a bomber by an atomic rocket and a salvo of small rockets, and all other symbols have been previously discussed.

Against the Snark-type missile attacks, P_{kb_R} was taken to be equal to P_{kb_A}* and the F-102R was allowed a maximum of only three passes, so that the last term in the main parentheses of the equation for K_{102R} was never used.

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*See the discussion in Chapter II.

In the analysis of the B-47-type bomber attack the two P_{kb}'s were different, and each interceptor was allowed four passes if it had enough fuel. In both types of attack the amount of fuel remaining in each interceptor when it reached the bomber stream was calculated, and only that number of passes were used which would allow the interceptor to return to its own base with the proper reserves. The appropriate number of terms were deleted from the K equations in each case.

Attrition Due to Area-Defense Missiles (1960)

The area missiles, like the interceptors, were assumed to be controlled by the Lincoln system. Because of this and the large numbers of attackers (bombers plus decoys) involved, the missiles were postulated each to be vectored to a target different from that being brought under fire either by another missile or by an interceptor. Hence the symbols involved in the last three terms of the survival equation given in the preceding section may be defined as:

$M_{99A(B,C)}$ = number of F-99A(B,C) missiles fired which could reach the bomber stream during the air battle,

$K_{99A(B,C)}$ = expected number of bombers and/or decoys killed by the firing of one F-99A(B,C).

As can be seen from the survival equation, the attrition caused by the area-defense missiles was treated the same as and simultaneous to the attrition due to the interceptors.

The effectiveness for each missile was given by:

$$K_{99} = u_{ab} D P_{dc} P_{kb} \quad .$$

These symbols, treated in Chapter II, must be chosen for the pertinent missile, bomber, and altitude combination.

Attrition Due to Local-Defense Missiles (1956, 1958, 1960)

The bomber attrition caused by the local-defense missiles was treated completely separate from that produced by the area defenses. The procedure followed was to compute the number of bombers (and decoys) which were expected to survive the area defenses and enter each local-defense region. The expected attrition in each such local region was then computed and applied to the vehicles flying into that region.

Local defense performance against two different types of attack were examined. The first was a wave attack wherein all of the enemy vehicles were considered to enter the local defense region simultaneously. The second was one in which the attackers were assumed to be spaced in time (a mean spacing of two seconds was postulated) so that the firing units could possibly be recycled and more salvos fired. In the strikes studied for 1956 and 1958 the number of bombers entering the local defense area was found to be too small for the defenders to realize any significant gain under the second type of attack. In 1960 the presence of decoys changed this picture, since they greatly increased the number of vehicles simultaneously entering the local defense zones.

Another effect was considered, however, which ran counter to this. This was the effectiveness of the assignment of the local-defense salvos to the attacking vehicles. Whether they were assigned randomly, uniformly, or with some better coordination which would prevent wasting salvos on "dead" bombers would effect the total number killed. In 1956 and 1958 the number of salvos which could be fired was very small, while at the same time the presence of multiple aiming points within the locally defended regions required several bombers and kept them spread out to some extent. It was judged that in this situation the defense could achieve nearly perfect coordination of fire rather easily, since only very rarely would two salvos be fired at the same bomber.

In 1960, on the other hand, the number of possible salvos turned out to be very high, and the number of aiming points fewer than before. This would create a much tougher problem for the defenses in attempting to distribute their fire power, and perfect coordination would probably not be achieved.

As a result it was concluded that coordinated fire against a wave attack was a logical manner of estimating the attrition for the 1956 and 1958 strikes, and was also a reasonable compromise in 1960 between the effects of non-coordinated fire and the addition due to multiple firing from each battery. The number of bombers expected to arrive on target (β_{OT}) was found, for all three years examined, from:

$$\beta_{OT} = \frac{\beta_{\ell}}{V_{\ell}} \left[V_{\ell} - b_N K_N - b_{CW} K_{CW} - b_W K_W \right]$$

where β_{ℓ} = number of bombers entering the local defense region,

V_{ℓ} = number of vehicles entering the local defense region,

$b_{N(CW,W)}$ = number of batteries of Nike (Talos CW, Talos W) missiles in the region,

$K_{N(CW,W)}$ = expected number of vehicles killed by one battery of Nike (Talos CW, Talos W) missiles.

The K factors were found by substitution of the appropriate numbers into the equation:

$$K = gN_s D \left[1-(1-u_{ab}P_{kb})^{S_1} \right]$$

where S_1 = number of missiles per salvo. N_s' is substituted for N_s when appropriate.

TARGET DAMAGE

Expected Number of Bombs Arriving on Target (1956)

In the 1956 strikes it was postulated that the Soviet attacker was bomb-limited. Whereas about 350 aircraft were assumed to penetrate the ZI, they were considered to carry only around 300 bombs. Thus when the expected number of "bombers" which arrived at a target (β_{OT}) was found, it remained to determine the expected number of bombs delivered to the target (B_{OT}). This was given by the equation:

$$B_{OT_j} = \frac{\beta_{OT_j}}{\beta_{ZI_j}} \left[Z_j + (\beta_{ZI_j} - Z_j) \left(\frac{B_{ZI} - Z_{ZI}}{\beta_{ZI} - Z_{ZI}} \right) \right]$$

where B_{OT_j} = expected number of bombs arriving at the j^{th} target,

β_{OT_j} = expected number of bombers arriving at the j^{th} target,

β_{ZI_j} = number of bombers which entered the ZI briefed for the j^{th} target,

Z_j = number of aiming points in the j^{th} target,

B_{ZI} = total number of bombs entering the ZI (≅300),

β_{ZI} = total number of bombers entering the ZI (≅350),

Z_{ZI} = total number of aiming points for the particular strike.

Expected Number of Bombs Arriving on Target (1958, 1960)

In the 1958 and 1960 analyses it was assumed that there would be a bomb in each Soviet bomber. Thus the number of bombs expected to arrive at the target was always equal to the expected number of bombers which arrived at the target.

Probability of a Given Bomb Arriving on Target (1956, 1958, 1960)

In order to calculate the expected damage to a target, an overall probability of bomb survival, or the probability that a given bomb arrived at the target, p_j, was determined for each target from the equation:

$$p_j = \frac{B_{OT_j}}{B_{ZI_j}} \quad .$$

This probability was then applied as described below to arrive at an expected damage figure for the target.

Expected Damage to Single Aiming Points (1956, 1958, 1960)

A "single aiming point" was defined as a target consisting of only one aiming point, so that all bombs briefed for that target were also briefed for the one aiming point. In the case of such aiming points, as in the case of multiple aiming points discussed below, bombing errors were ignored and it was assumed that one bomb delivered would completely destroy an aiming point. Thus the probability that the j^{th} aiming point was destroyed, P_{D_j}, was taken equal to the probability that at least one bomb was delivered there, and was given by:

$$P_{D_j} = 1 - (1-p_j)^{B_{ZI_j}}$$

When the target was a SAC base, this P_D was also considered to be the expected fraction of the base destroyed, and was used to determine the expected number of SAC bases destroyed as outlined in the next chapter. For industry targets, the expected "value-added destroyed" was obtained from:

$$VAD_j = v_j \, P_{D_j}$$

where v_j = value-added destroyed by one bomb dropped on the j^{th} (aiming point) target.

In the case of oil or steel plants, the production capacity destroyed, C_{D_j}, as a percentage of the production capacity of the whole country, was determined from:

$$C_{D_j} = C_j \, P_{D_j}$$

where C_j = percentage of oil (steel) production capacity of the country contributed by the j^{th} plant.

Expected Damage to Multiple Aiming Points (1956, 1958, 1960)

A "multiple aiming point" was defined as a target which consisted of more than one aiming point. As outlined in the preceding chapter, the bombers which entered the defenses destined for such a target were not assigned to specific aiming points within the target when the strike was first constructed. Rather, this was left to be done during the damage calculations, and was done in such a manner as to maximize the damage achieved by those bombers.*

To accomplish this, a marginal value-added destroyed was calculated for each of a number of bombs on each aiming point in the target. This was obtained from:

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*In this process, it was assumed that each aircraft had to be briefed to a particular target prior to take-off. This is an important constraint.

$$VAD_{ij_n} = v_{ij} \left| \left[1 - (1-p_j)^n \right] - \left[1 - (1-p_j)^{n-1} \right] \right|$$

where VAD_{ij_n} = the marginal value-added destroyed by the n^{th} bomb assigned to the i^{th} aiming point in the j^{th} target,

and v_{ij} = the value added which would be destroyed by one bomb dropped on the i^{th} aiming point in the j^{th} target.

It can be seen from this equation that VAD_{ij_n} corresponds to the incremental increase in the expected VAD at the particular aiming point by assigning the n^{th} bomb to it after (n-1) have already been assigned to it, the assigning being done out of the population of B_{ZI_j} bombs briefed for the target as a whole.

As was said, this marginal value was calculated for each of a number of bombs assigned to each aiming point in the target. The largest B_{ZI_j} of these were then chosen to represent the actual assignment of the B_{ZI_j} bombs, and were summed to obtain the expected damage to the target as a whole.

CHAPTER V

RESULTS AND CONCLUSIONS

In this chapter a compilation is presented, in tabular form, of the results of all of the strikes which were conducted in this study. Some conclusions which are based solely on these results, and are therefore limited in scope, are stated.* Finally, there is a brief discussion of some of the more important assumptions and techniques which were used in these analyses and their bearing on the results obtained, and possibly on the conclusions derived from these results.

RESULTS--TOTAL DAMAGE FIGURES

In calculating the total expected damage to the metropolitan area or "value added" targets which resulted from any strike, it was necessary only to sum the expected damages at each such target for which bombs were assigned. The result was obtained as an amount of destruction in millions of dollars of value added by manufacture in war and war-connected industries. It should be borne in mind that this scale of values is to be thought of only as an index, and that the dollar destruction, as such, has meaning only on a relative basis. A perhaps more significant measure of overall damage was determined from these dollar values, which was the percentage of the total value scale to which this expected destruction corresponded.

The total expected destruction of SAC bases was determined as a number of bases which were expected to receive bombs. This was obtained by summing

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*A more comprehensive set of conclusions of the overall High Attrition Air Defense Study can be found in R-250.[1]

the probabilities of destruction* of all of the bases which were attacked in each strike.

In the strikes which were directed primarily at oil and steel targets, the percentage of the production capacity of the entire country which was expected to be destroyed was the resulting measure for each of these industries. This was calculated by summing the expected damages for all of the plants attacked, the latter being obtained as outlined in Chapter IV. Although the target lists used in these cases do not contain those facilities which have been recently completed or which may be built prior to the dates for which the analyses were conducted, it is anticipated that the results are representative of what might be achieved barring a sizeable change in the geographic distributions of these production capabilities.**

All of these measures of target damage are given in Table XVI for each strike which was analyzed. The strikes are listed in the order in which the analysis was done, which is also the order of presentation in Chapter III.

Table XVI also contains statements of the specific conditions of the offensive and defensive forces assumed for each strike. The offense budget level is indicated by the numbers of bombers sortied, with Strikes VII and X using a doubled offense effort. The defense budget level is indicated under the heading "Defense System," where Strikes VIII and X used a doubled defense weapons system corresponding to about an 80 percent increase in

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*Note that the calculation of the probability of destruction of an aiming point, as discussed in the preceding chapter, ignores CEP by assuming that one bomb delivered destroys all the value of the aiming point.

**The oil and steel target lists used are accurate as of January, 1950, and January, 1951, respectively.

TABLE XVI

STRIKE RESULTS

Strike	Bombers			Bombs			Targets Attacked: No. of DGZ's				
	Type (1)	Number Sortied	Number Arrived at ZI	Number Sortied	Number Arrived at ZI	Yield	SAC	Wash. D.C.	Urban Indus-trial Concen-tration	Oil	Steel
	1956 Strikes - Low Altitude Daylight Attacks										
I	TU-4 IL-28 (Car-riers)	250 188 (94)	188 150	375	290	100KT	29	3	84	82	50
II	TU-4 IL-28 (Car-riers)	250 188 (94)	200 150	375	300	100KT	29	3	206	—	—
III	TU-4 IL-28 (Car-riers)	250 188 (94)	193 150	375	294	100KT	29	3	59	82	48
	1958 Strikes - Low Altitude Nighttime Attacks										
IV	IL-28 Type-31 (Car-riers)	413 50 (207)	330 40	463	370	100KT	29	3	153	—	—
V	IL-28 Type-31 (Car-riers)	350 98 (175)	280 78	448	358	100KT	24	—	19	63	17
VI	IL-28 Type-31 (Car-riers)	299 138 (150)	239 110	437	349	100KT	25	—	84	—	—
VII	IL-28 Type-31 (Car-riers)	586 286 (293)	469 228	872	697	100KT	28	3	209	—	—
VIII	IL-28 Type-31 (Car-riers)	368 85 (184)	294 68	453	362	100KT	17	—	57	—	—

(See p. 190 for notes)

Defense System	Defense Weapon Perform. Degradation	% Attrition (3) Estimated	% Attrition (3) Calculated	Expected Target Damage: No. of SAC Bases Destroyed	P_D for each DGZ in Wash.	Value Added Destroyed: Millions of Dollars	Value Added Destroyed: % of U.S. Total	% Oil Refining Capacity Destroyed	% Steel Production Capacity Destroyed
1956 Strikes - Low Altitude Daylight Attacks									
As in Table V	D = .8	15	32.1	26	.81	8266 (4)	23.2	71.5	59.4
As in Table V	D = .8	20	35.8	26	.92	9759	27.4	—	—
As in Table V	D = .8	25	32.7	27	.74	8096 (4)	22.8	71.9	67.5
1958 Strikes - Low Altitude Nighttime Attacks									
As in Table V	D = .8	50	85.1	23	0	1670	4.7	—	—
As in Table V	D = .8	66.2	68.0	23	—	2903 (4)	8.2	53.5	19.0
As in Table V	D = .8	68.8	66.7	23	—	4822	13.5	—	—
As in Table V	D = .8	65.5	61.1	27	.28	10182	28.6	—	—
Double Defense (2)	D = .8	79.5	80.7	14	—	3412	9.6	—	—

TABLE XVI (Continued)

Strike	Bombers			Bombs			Targets Attacked: No. of DGZ's				
	Type (1)	Number Sortied	Number Arrived at ZI	Number Sortied	Number Arrived at ZI	Yield	SAC	Wash. D.C.	Urban Industrial Concentration	Oil	Steel
	1958 Strikes - Low Altitude Nighttime Attacks (Continued)										
IX	IL-28 Type-31 (Carriers)	314 126 (157)	251 101	440	352	100KT	22	3	105	—	—
X	IL-28 Type-31 (Carriers)	602 273 (301)	482 218	875	700	100KT	20	3	109	—	—
XI	IL-28 Type-31 (Carriers)	270 161 135	215 129	430	344	5 MT	19	—	71	—	—
	1960 Strikes - 50,000 Feet Nighttime Attacks (5)										
XII	Snark Decoy (Carriers)	557 2930 (293)	389 2052	557	389	5 MT	—	—	48	—	—
XIII	Snark Decoy (Carriers)	587 2830 (283)	411 1979	587	411	100KT	—	—	63	—	—
XIV	Snark Decoy (Carriers)	897 2030 (203)	627 1417	897	627	100KT	—	3	149	—	—
XV (5)	B-47 Decoy (Carriers)	280 2190 (219)	210 1645	280	210	5 MT	—	—	52	—	—
XVI	Snark Decoy (Carriers)	854 2140 (214)	597 1497	854	597	5 MT	—	1	131	—	—

(See p. 190 for notes)

Defense System	Defense Weapon Perform. Degradation	% Attrition(3) Estimated	% Attrition(3) Calculated	Expected Target Damage: No. of SAC Bases Destroyed	P_D for each DGZ in Wash.	Value Added Destroyed: Millions of Dollars	Value Added Destroyed: % of U.S. Total	% Oil Refining Capacity Destroyed	% Steel Production Capacity Destroyed
1958 Strikes - Low Altitude Nighttime Attacks									
As in Table V	D = .4	63.0	60.1	21	.08	7096	19.9	—	—
Double Defense (2)	D = .8	81.1	77.8	19	0	7189	20.2	—	—
Same as in Table V	D = .8	74.0	71.2	19	—	8666	24.3	—	—
1960 Strikes - 50,000 Feet Nighttime Attacks(5)									
Same as in Table V	D = .8	—	70.0	—	—	11263	31.7	—	—
Same as in Table V	D = .8	—	69.9	—	—	4694	13.2	—	—
Same as in Table V	D = .4	—	69.8	—	.69	8382	23.6	—	—
Same as in Table V	D = .8	—	75.1	—	—	8588	24.1	—	—
Same as in Table V	D = .4	—	69.9	—	.69	19886	55.7	—	—

NOTES FOR TABLE XVI

(1) The word "carriers" in 1956 and 1958 strikes refers to carriers for the IL-28's. These were TU-4's, each of which carried two wingtip-coupled IL-28's to the edge of the defended region. In the 1960 strikes, "carriers" refers to decoy carriers, which were C-132 type cargo aircraft in each of which were carried ten decoys. None of these carriers ever entered the air battle region.

(2) In the "double defense" system the number of each weapon in the U.S. defense system given in Table V was doubled and the number of controllers at each ground-based radar station, as given in Table VI, was doubled. The number of Canadian defense weapons and the number of controllers in the AEW and C aircraft were not doubled, nor were the other components of the complete defense system.

(3) The per cent attrition listed is an overall attrition which applies only to the total number of bombers entering the defended region. The attrition on each track was computed separately.

(4) These totals include the value of the damage to the oil refineries and steel plants in addition to that to the urban industrial concentrations.

(5) Strike XV was a low-altitude night attack by manned bombers, rather than an attack by missiles at 50,000 feet.

defense budget level. Two levels of defense-system efficiency were used, designated by D = .8 (basic efficiency) and D = .4 (approximately 50 percent of basic efficiency) in the column headed "Defense Weapon Performance Degradation." Strikes IX, XIV, and XVI are the cases in which the efficiency of the defense system was approximately halved.

Several other variations can be noted which had noticeable effects on the results of strikes for a given year. Among these are target strategy, (oil and steel were the primary targets in Strikes I, III, and V), bomb size (Strike XI used 5-MT bombs in 1958, while XIII and XIV used 100-KT bombs in 1960), estimated attrition as compared to that calculated (Strikes I and IV), and bomb-carrier type (B-47-type aircraft were used at low altitude in Strike XV).

CONCLUSIONS

The following general conclusions can be drawn from the results of these strike calculations:

A. If the Soviets maintain their strategic bombing force at about the level assumed for 1956 but continue to advance technologically, as was assumed in the analyses of Strikes II, III, VI, IX, XI, XII, and XVI--

1. The probable level of damage in the event of an attack during the 1956-1960 period--with the defense system proposed in this report, and if the components of that system function about as effectively as estimated--would be equivalent to the destruction of about 28 percent of the value of our metropolitan areas. (This conclusion is based on Strikes II, XI, and XII.) In the absence of extensive civil-defense measures, such as

evacuation or deep shelters, there would be an attendant loss of life of over 10 million people. Alternatively, a major portion of our oil refineries and steel plants could be destroyed. Strikes III and V give an indication of this possibility. In either event, a large number of our SAC bases could also be bombed.

2. It is possible that some of the factors which degrade the performance of the defense system might become so severe that the resulting damage from an attack would be equivalent to the destruction of 40 to 60 percent of the value of our metropolitan areas. (Note Strikes IX and XVI, but adjust Strike IX to account for the probability that megaton bombs would be available to the Soviets.) Wartime experience with complex weapons indicates that some of these degrading factors are increased human errors, increased equipment failures, decreased equipment accuracies, Soviet use of countermeasures without corresponding counter-countermeasures in the defense system, and the possible failure of key parts of the proposed system owing to its complexity. Although the 28 percent damage cited above corresponds to making allowance for these factors, they might become considerably more severe.

3. If a criterion of restricting damage to a level equivalent to 15 percent of the value of the metropolitan areas is accepted as a goal for the air-defense system, it appears that it would be very difficult to achieve this goal in the 1956 period, primarily because of the deficiencies of our weapons at low

altitudes.*

4. The calculations of this study indicate that the 15 percent damage criterion might be achieved in 1958 and 1960 with an augmented system requiring a total expenditure on active air defense in the 1954-1960 period of 40 to 80 billion dollars. The level required would be in the 40- to 60-billion-dollar region if the system components functioned as effectively as estimated, while 60 to 80 billion dollars would provide additional insurance against the degradations and failures mentioned above. The major portion of the increased budget in the later years should be spent for more weapons.**

B. It is possible that the Soviets will <u>expand</u> their bomber force in the later years, particularly if we embark on an enlarged air-defense program. Such an increase in bomber force can be offset by increases in defense effort. Because a large proportion of the Soviet effort is already being put into their bomber force, further <u>great</u> increases appear unlikely. However, suppose that the offense force is increased by 50 percent: the required matching air defense expenditures will then rise from the 40- to 80-billion-dollar region mentioned above to around 60 to 100 billion dollars for the 1954-1960 period.

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*Actually, RAND has been unable to establish a reliable estimate of the damage level beyond which U.S. war-making capability is decisively impeded. The 15 percent level is an interesting check point, however.

**This question of the required budget level for a given damage level is investigated in the current Air Defense Command study of 1960 requirements.

C. Even if we embark on an active air-defense program on a 60- to 100-billion-dollar scale, we cannot be completely sure of achieving a very high level of protection for several reasons. These reasons are enumerated in Chapter 2 of R-250.[1]

D. In view of these conclusions, our military and diplomatic plans should not be based on the assumption that our valuable ZI targets will be adequately protected from Soviet attack by an active air-defense system in future years. There is, however, enough chance that such protection can be achieved, particularly in the 1958-1960 period, that this possibility should not be ignored. Before about 1958 the low-altitude limitations of our system appear quite serious. After 1960 the ballistic-missile threat will probably become a reality, and the entire concept of air defense will have to be revised.

DISCUSSION

When viewed in retrospect, some of the particular assumptions which were made and techniques which were used in the course of these strike analyses stand out as having major effects on the results which were obtained. Although, as has been mentioned, an honest effort was made to adhere to realism in the methods and in the predictions of performance parameters in the assumptions, it is felt that some of the more important factors should be reviewed in the light of their effects on the damage figures and conclusions. Some of these factors tended to produce optimistic results, while others tended to produce pessimistic results. Because of these opposing effects, it is believed that the results in Table XVI are representative and the conclusions valid as stated. The following brief discussion, however, should help future evaluations when these assumptions can be made or disputed with more certainty.

<u>The Defense System--Factors Which Might Increase Damage</u>

The low-altitude limitation of 15 mils above the horizon which was assumed for the Nike tracking radars gave this missile system a marginal capability against a bomber attacking at a 500 foot altitude. Many U.S. cities, however, are situated in valleys, so that the Nike installations around them do not have a "flat" horizon. Unless the radars are located carefully, surrounding hills can raise this limitation by ten mils or more. In view of the very meager capabilities envisioned, however, this could not produce a drastic change in attrition or damage.

The "coordinated" assignment of local defense missiles of all types would be extremely difficult to achieve against certain types of attack involving large numbers of closely spaced attacking vehicles. (Such an attack, however, might be just as hard to achieve in view of the timing required, bomber interaction, and the action of the area defenses.)

The use of the present generation of interceptors at low altitude may be entirely infeasible. Certain problems of aircraft stability and development of proper AI radar procedures, although they appear surmountable, may impose more stringent limitations than employed in this study. This could have a great effect on the attritions calculated for 1956, but would produce a somewhat smaller effect on the damage totals.

In the 1958 analyses the F-102's were given a limited AMTI capability, while they were assumed to possess good AMTI by 1960. Should these predictions be in error, gross effects on both attrition and target damage would result.

In all three years the entire interceptor force was assumed to have adequate ground-to-air and air-to-air IFF equipment and procedures. The absence of such equipment and procedures could cause interceptors and area missiles to intercept other defense aircraft, thus wasting passes and reducing the weapon force. Since the Soviets could not rely upon this type of defense degradation, it would probably produce only moderate changes in the damage figures.

As has been previously mentioned, the numbers of directors which were assumed to be in the ground radar stations were considerably larger than those currently scheduled for those stations. Nevertheless, the limited number of directors assumed for the study was one of the basic limitations to the defense capability. In every strike analyzed for 1956 and 1958, many interceptors were delayed in their scrambles, many F-89D's were sent out on broadcast control, and some F-86D's were not used at all because of the lack of control facilities. Although the Lincoln SAGE (semi-automatic ground environment) alleviated this situation in the areas where it was postulated to be operative, even its facilities proved to be marginal in some cases. Should the control capacity be less than that used in this study, a decrease in attrition and increase in damage would result. Conversely, should some way be found to increase the control capacity over that used here, damage to our targets would be decreased. As mentioned before, the very interesting possibility of spending most or all of an increased budget upon increased close control facilities has not been examined.

The training of all of the working members of Air Defense Command is of fundamental importance to the system performance. In this study a high degree of training was assumed for both operating and maintenance personnel in the "basic" cases. Although the cases employing degraded defense effectiveness may reflect what happens when training is not made of prime importance, the situation could be much worse than pictured even in these cases. Fortunately the so-called "Systems Training Program" holds promise for improving the performance of the ground data-handling system by a sizeable factor, but much will remain to be done, particularly in training air crews for defense against low-altitude attacks.

Although attacks employing electronic countermeasures (ECM) on a large scale appeared to be less favorable to the offense than the tactics actually used, the omission of all forms of ECM may have been too optimistic from the defense point of view. The offense might possibly have gained something by using blinkers and towed sources against weapons without atomic warheads, and by employing barrage noise jamming and chaff against ground-based radars. The effects of such measures are felt to be included in the degraded-defense-effectiveness cases, but again could be worse if training were also bad.

The assumption as to the vulnerability of decoys, while reasonable for the atomic defensive weapons, may have been wrong for the more conventional types of armament. The result would be less decoy attrition, hence less decoys required, more bomb carriers used, and consequently more target damage. Since a large part of the weapons assumed for use against strikes including decoys had atomic warheads, this effect might have been of second order importance.

<u>The Defense System--Factors Which Might Decrease Damage</u>

Although the defense weapons were redeployed in an attempt to match the target system before the strikes were laid on, it now appears that even more redeployment might be feasible, and could result in a fair-sized increase in attrition in all three years examined. This redeployment would consist of shifting more weapons out of the Pacific Northwest and areas where adequate radar cover is lacking, and concentrating more strength around the valuable Midwest targets.

Some better weapon commitment policies could be adopted than were used in this study, particularly in the 1956 portion.

The selection of more of the most effective weapon types at the expense of lesser effective weapons would result in increased attrition, and hence less damage, for the same defense budget. For example, the damage to the target system could have been decreased by the use of more Talos and fewer Nike battalions than were actually selected for the doubled defense of 1958.

The kill potentials used for the local-defense missiles were taken from the calculations for a wave attack. Since there are considerable problems to be faced by the offense in getting vehicles into the local defense areas simultaneously, much recycling of missile launchers might be possible. This would make little difference in attrition in the 1956 and 1958 attacks, but in the 1960 attacks, when the use of decoys only worsens the offense's difficulties in this regard, the difference could be significant.

Some U.S. cities are situated so that the Nike should have had more than the marginal capability assumed against a low-altitude bomber. As mentioned above, this could not produce a drastic decrease in damage at these cities.

Should any kind of AMTI become operational on the F-86D's or F-89D's, a great improvement in low-altitude capability might be realized. In fact, the one thing which appeared most useful to the proposed defense system was a good AMTI capability.

The number of targets which were "free" to the offense (i.e., could be attacked without encountering defense action) was a significant factor in determining damage, particularly in the 1958 strikes employing doubled numbers of defense weapons. The reason these targets were free was the lack of sufficient low-altitude radar cover. If this deficiency could be alleviated, doubling the defense weapons would result in considerably less damage, and the damage in the "basic" cases would be somewhat decreased.

The Offense System--Factors Which Would Increase Damage

Although an attempt was made to distribute bombs assigned to the aiming points in such a manner as to maximize the expected damage within a given target, this was done only very crudely between targets. More refinement in the choice of target assignments could have given some increase in the total expected damage, although this is judged to offer only a relatively minor improvement (from the offense viewpoint) over the assignments actually used.

An effect which could have been somewhat larger, although difficult to achieve, would have been produced by assigning alternate aiming points to all bombers. This would have allowed bombers to proceed to other aiming points when more than one survived to bomb a given aiming point. The use of alternate aiming points was not permitted in this study.

The carriers which brought the IL-28's to the edge of the defended zone in 1956 and 1958 were assumed not to enter the battle region themselves. Had they entered this region, they would have served the purpose of decoys in diluting the defense fire power. Their limited range would have forced them out of the battle long before targets were reached, but some increase in target damage would have resulted. In 1960 the decoy carriers were too slow and too few compared to the decoys they carried to have produced much effect on damage by proceeding beyond the edge of the battle zone.

The Offense System--Factors Which Would Decrease Damage

All of the bomber streams which penetrated the defense system were assumed to be perfectly timed relative to one another in these strike calculations. This would be extremely hard to achieve with the flight distances involved, particularly in view of the variations in winds which would be encountered. Any deviations from this perfect timing would result in a build-up of the availability of weapons, possible recycling of area weapons, the possible employment of augmentation fighters, and other less effective increases in defense potential. The result could be large increases in attrition, with corresponding decreases in damage to the target system.

Alerting of the defenses through prior intelligence warning or early warning from other sources would produce many of the same results.

The effects of CEP on bomb damage, which were neglected throughout the computations of this study, would conceivably degrade the damage by a sizeable factor. Particularly is this true for SAC bases and the oil and steel targets. Although an estimate was made that bombing errors would be fairly small, this could be changed by such factors as bad weather in the daylight attacks of 1956, difficulties in low-altitude bombing (especially at night), and ECM against bombing radars.

In all of the 1960 strikes and all but the first (Strike IV) in 1958, the Soviet attacker was allowed to make an estimate of attrition which matched almost exactly the actual attrition which was computed as that expected for each strike. He was thus able to assign bombs, bombers, and decoys to targets in an optimum manner. An actual offense commander, in trying to obtain some foreknowledge of results, would be faced with many uncertainties, and might easily misjudge the capabilities and effectiveness of the many components of the defense. Strike IV presents a graphic example of the manner in which this misjudgment would affect the resulting damage. Notice that the offensive and defensive forces in Strike IV were the same as in Strike VI, which also used the same target strategy. The underestimate of attrition in Strike IV, however, led to spreading the bombers too thinly over too many targets; the result was that attrition was much higher than that encountered by the more optimal distribution of forces and damage was only a fraction of that achieved in the other strike.

Finally, in view of the high rate of attrition calculated for some of the strikes, the ability and willingness of the Soviet crews to press home such an all-out attack as that visualized may be questioned. The possibilities of increased aborts, increased gross errors, and other psychological effects caused by encountering high attrition were ignored in these analyses.

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