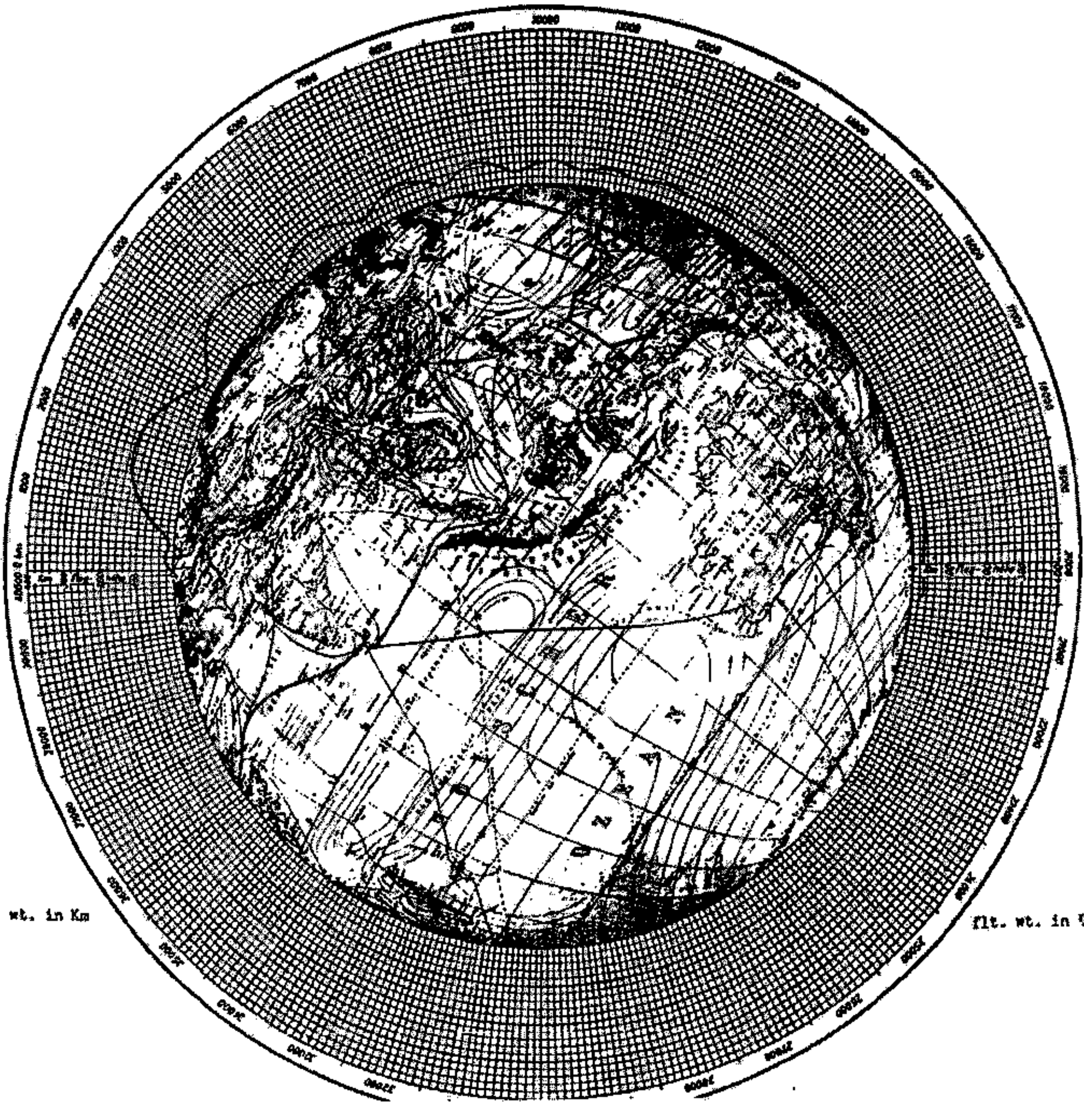

. wt. in Km

flt. wt. in Km

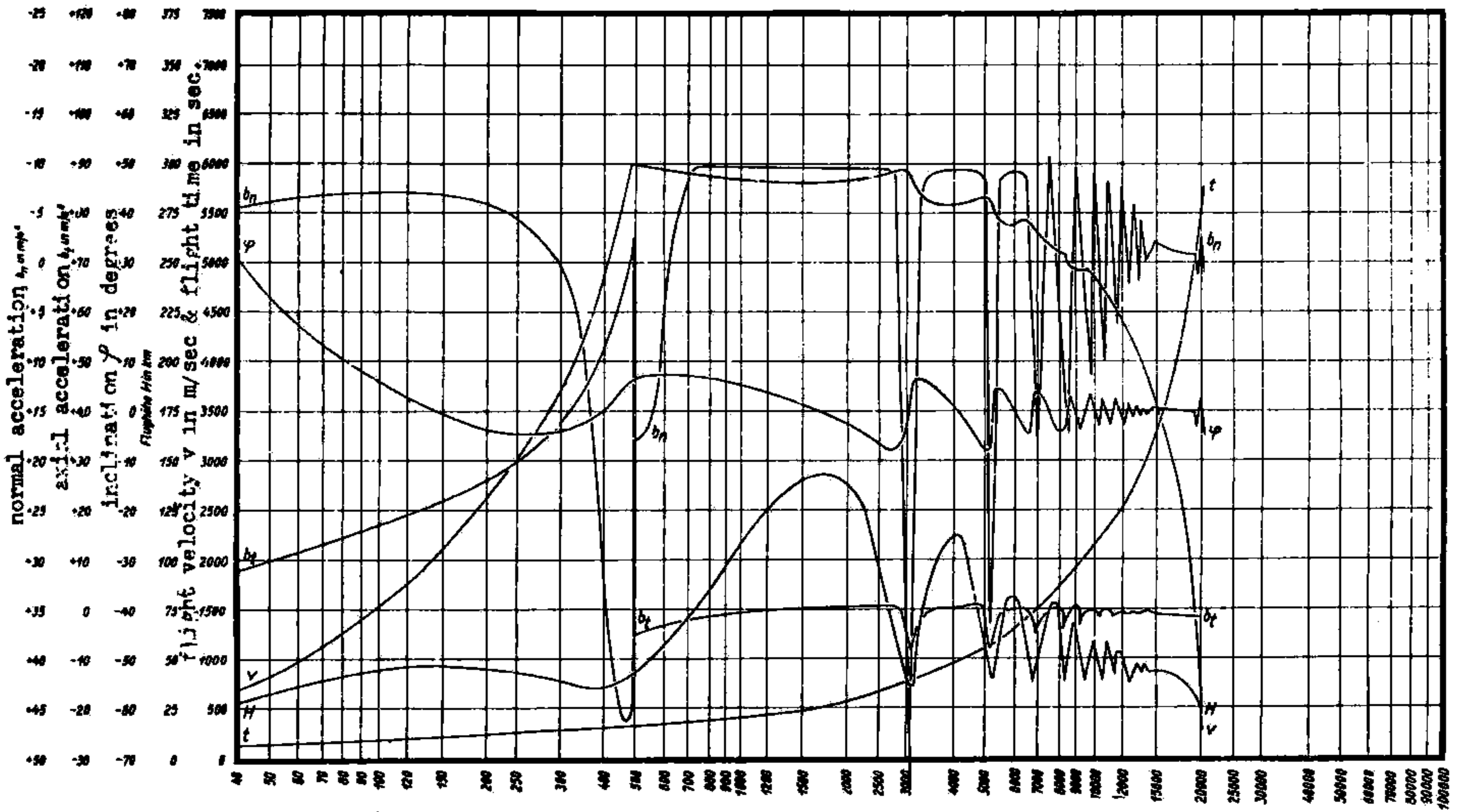

Fig. 74: Flight velocity v, altitude H, path inclination φ, tangential acceleration b_t, normal acceleration b_n and elapsed time t of the flight path of the Rocket Bomber with c = 3000 m/sec, v_o = 6000 m/sec and a bomb load of 0.3 tons.

C	V_0 in m/sec	Bomb load in tons	Flight path length in Km	Time of flight in seconds	Maximum flight height in Km	Maximum positive normal acceleration in m/sec.
3000 m/sec	1000	50,0	303	490	40	38,5
	2000	31,8	1528	1300	46	21,7
	3000	20,0	3639	2180	45	17,4
	4000	11,5	6692	2620	47	10,5
	5000	4,8	12171	4330	76	34,9
	6000	0,3	20371	5800	143	46,5
4000 m/sec	1000	58,7	295	530	34	28,7
	2000	43,3	1367	1160	37	15,2
	3000	30,5	3477	2100	49	26,0
	4000	20,0	6959	3040	80	35,6
	5000	13,3	12592	4400	104	45,3
	6000	8,0	21139	5820	160	48,8
	7000	3,8	39363	8840	283	50,3
	8000	1,0	91870	16015	1296	50,7
5000 m/sec	1000	65,0	291	455	30	22,0
	2000	51,7	1254	1120	31	19,2
	3000	37,5	3847	2225	68	37,3
	4000	28,1	7454	3200	87	37,0
	5000	20,1	12180	4290	102	46,5
	6000	15,0	21531	5990	111	35,9
	7000	10,5	42091	9120	128	36,3
	8000	6,5	293720	41600	778	2,5

Numerical characteristics of 22 various descent paths of the Rocket Bomber.

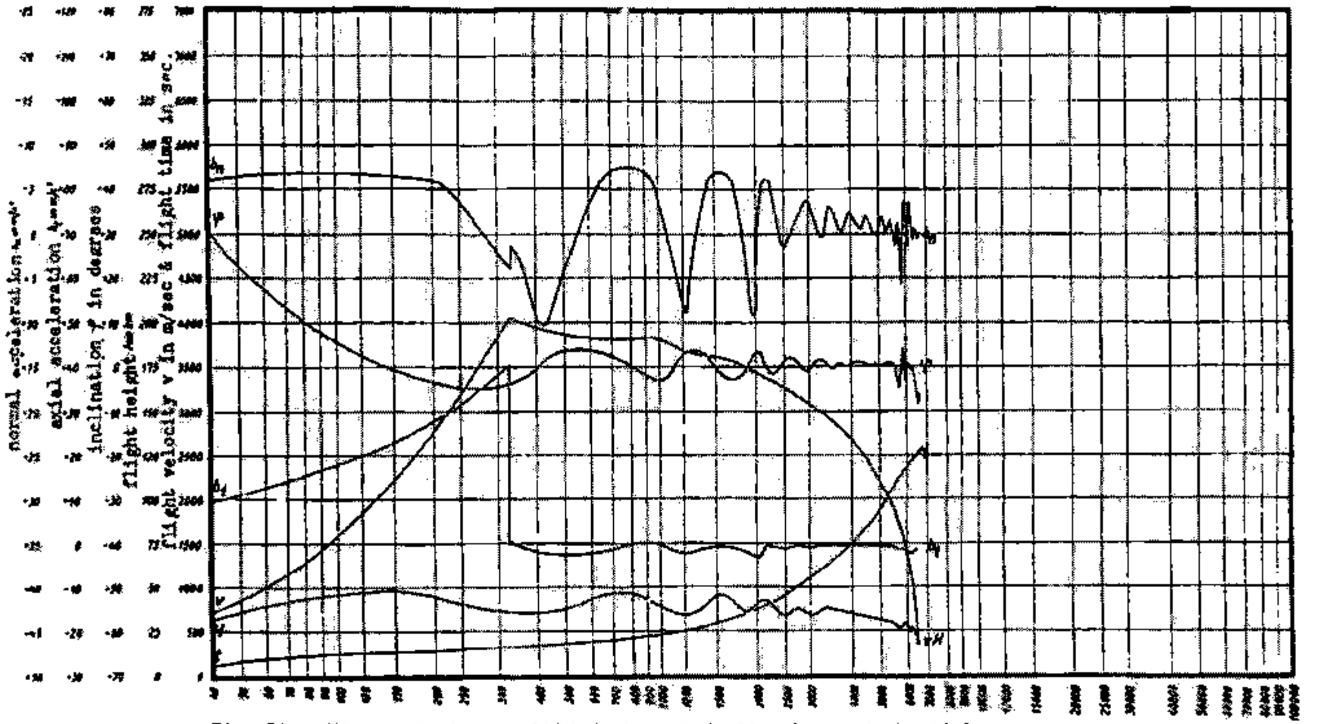

Fig. 73: Flight velocity v, altitude H, path inclination γ, tangential acceleration b_t, normal acceleration b_n and elapsed time t of the flight path of the Rocket Bomber with c = 3000 m/sec, v_o = 4000 m/sec and a bomb load of 11.5 tons.

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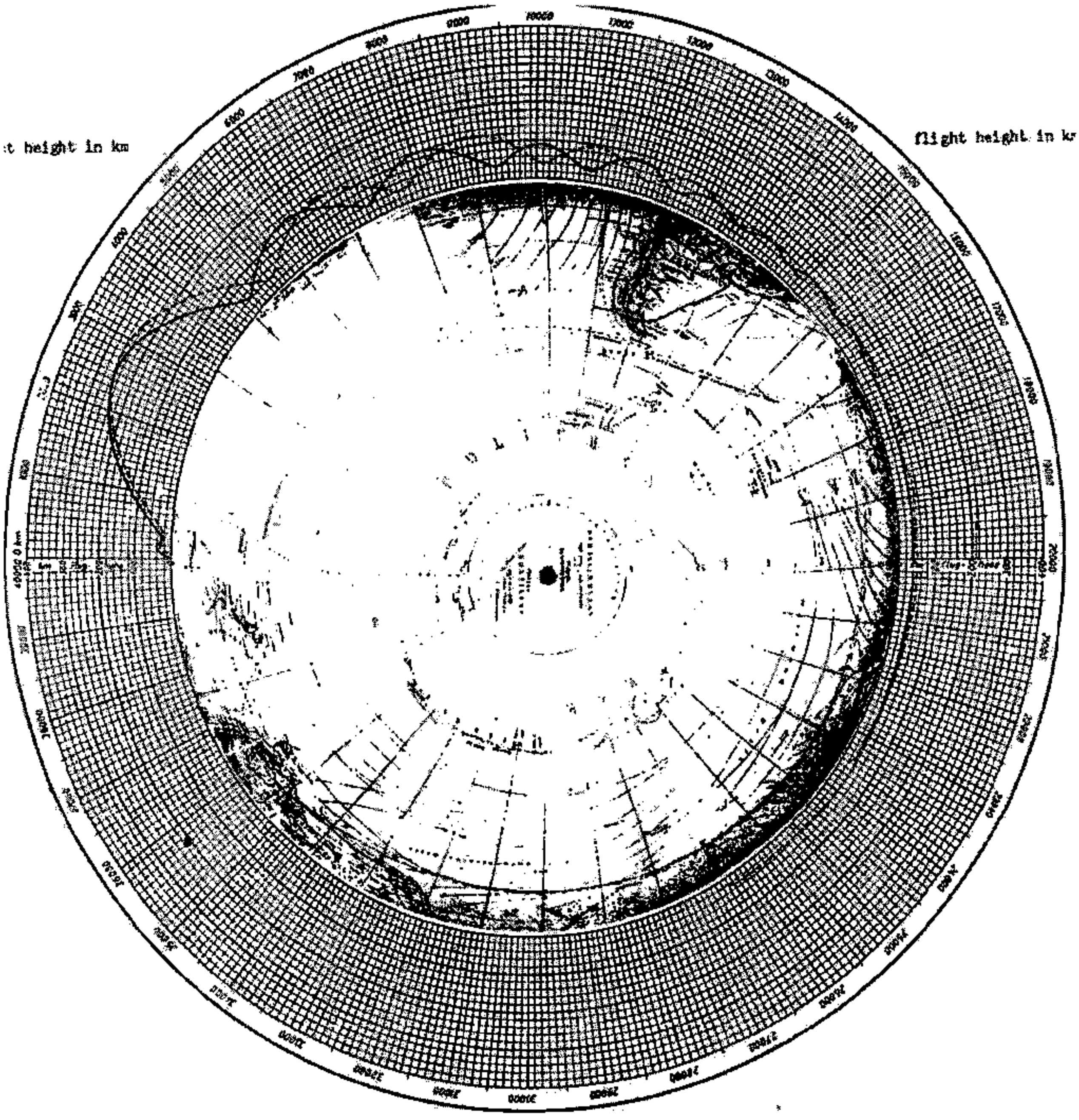
t height in km
flight height in kr
9000
10000
11000
12000
13000
14000
0 km
40000

[illegible]

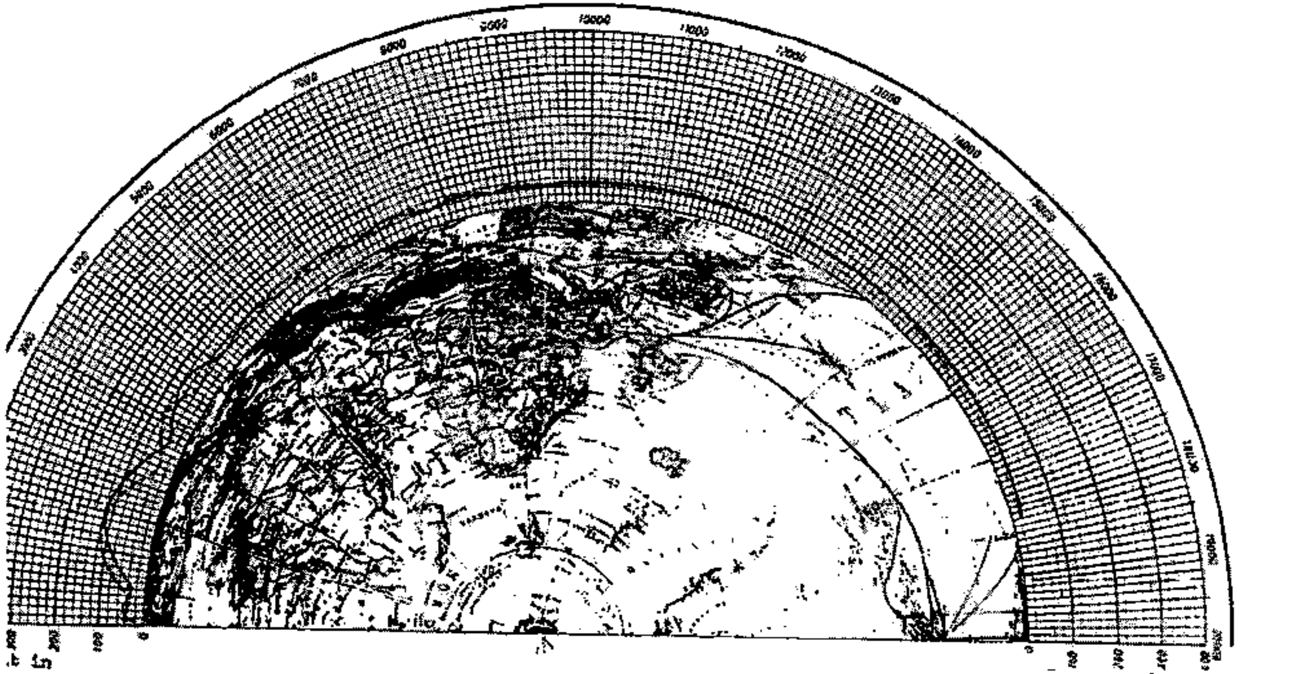

Fig. 76: Absolute (dashed line) and relative (solid line) flight path of the Rocket Bomber with $c = 3000$ m/sec, $v_o = 6000$ m/sec and a bomb load of 0.3 tons, in the case of a start toward the west from a point on the equator and including the effect of the Earth's rotation.

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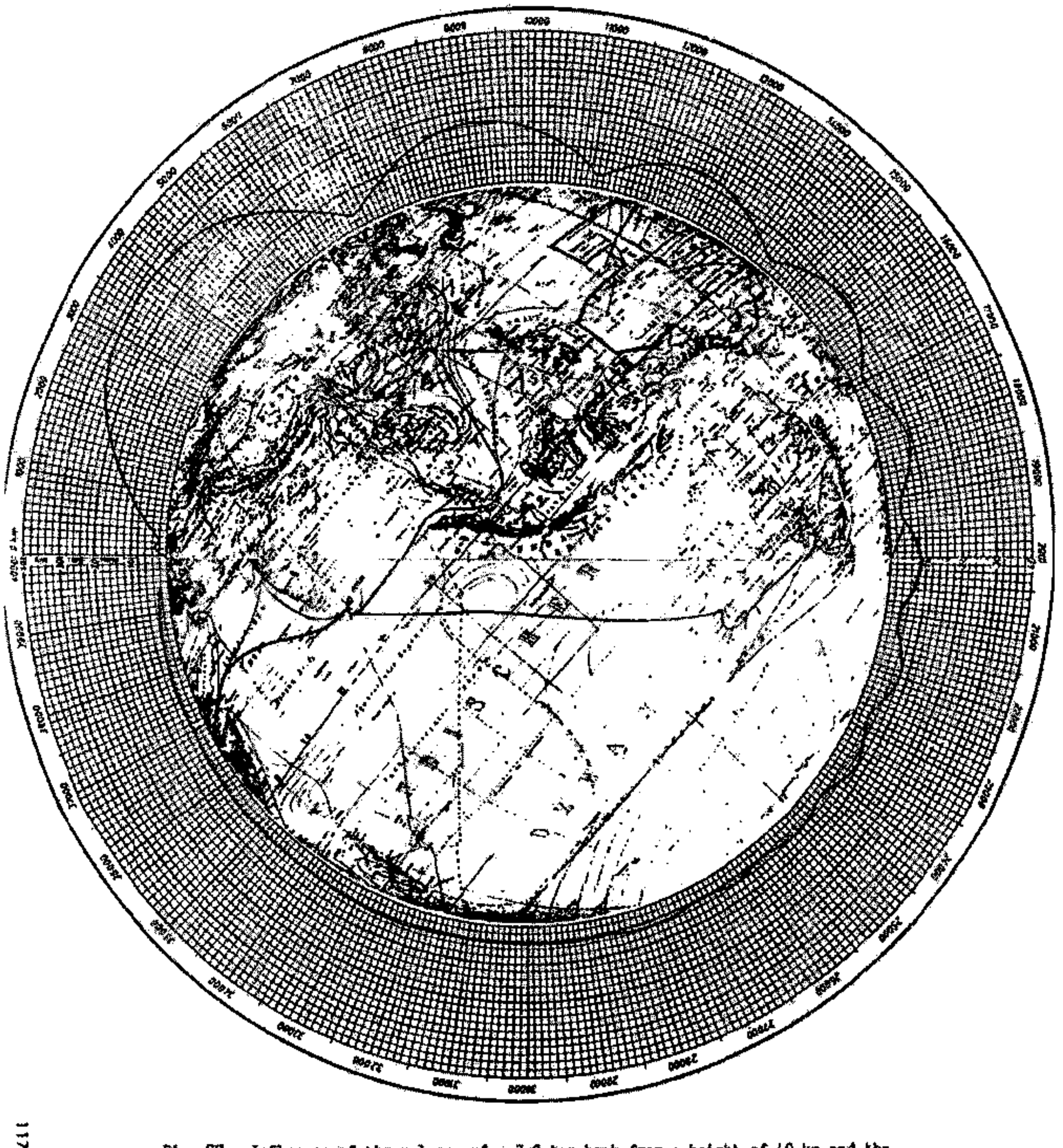

Fig. 77: Influence of the release of a 3.8 ton bomb from a height of 40 km and the velocity of 6060 m/sec on the flight path of the Rocket Bomber with c = 4000 m/sec, v_o = 7000 m/sec.

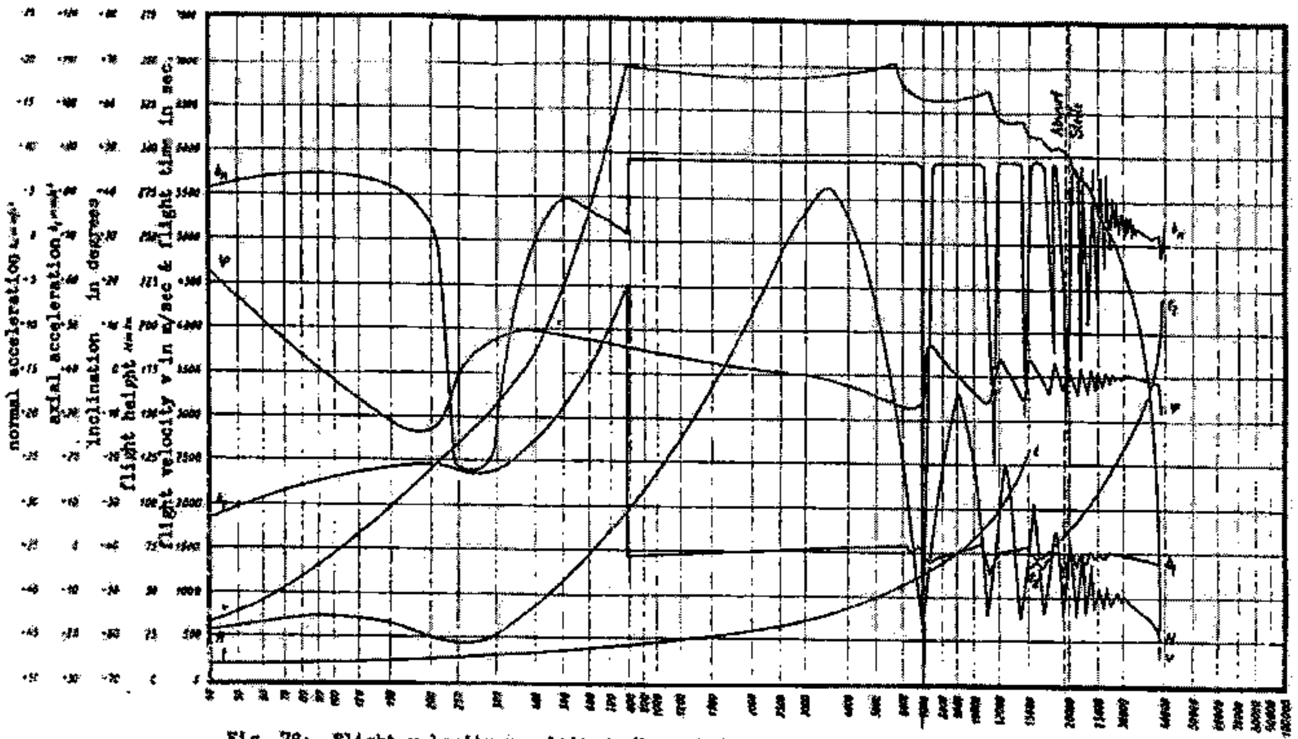

Fig. 78: Flight velocity v, altitude H, path inclination , tangential acceleration b_t, normal acceleration b_n and elapsed time t of the flight path of the Rocket Bomber and dropping of the bomb load B = 3.8 tons at 40 km height; also at 6060 m/sec flight velocity and 19 200 km distance from the starting point.

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This procedure is repeated at each jump which the rocket bomber makes toward its target, while the extreme values gradually die down and the flight becomes more and more smooth in the neighborhood of the stationary altitude. The total length of the projection of the glide path on the earth's surface is 20371 km, the duration of the flight is 5830 sec. In this manner various orbits were calculated; Table II gives the most important data - length of the orbit, glide-number, maximum altitude attained, and maximum positive normal acceleration.

All these orbit investigations were carried out neglecting the earth's rotation. For this reason Figs. 75 and 76 show the relative and absolute orbits for supersonic flight of the rocket bomber for $c = 3000$ m/sec and with the velocity at the end of the climb path $V_o = 6000$ m/sec, if the aircraft takes off in an exact easterly or westerly direction from a point on the equator. In the case of an eastward takeoff, the velocity of rotation of the takeoff point relative to the earth's center adds to the velocity of the aircraft relative to the takeoff point, so the centrifugal force increases. Because of this influence of the earth's rotation, the range $S = 20370$ km. in Fig. 72 is increased to $S = 23470$ km, more than 13%. This supersonic path relative to the earth's surface is shown in Fig. 75. The most interesting features are the much greater heights of the orbit peaks and the longer distance between peaks, compared to Fig. 72. The absolute path of the aircraft, as seen by an observer out in space, is shown dotted in Fig. 75; naturally the absolute path length is much greater ($S = 26410$ km.). In the case of takeoff to westward, the rotational velocity of the takeoff point is subtracted from the velocity of flight, the centrifugal force decreases and the range drops from 20370 km to 18200 km, i.e., more than 10%. At the same time the heights of, and intervals between, the first waves of the orbit decrease. These results are shown in Fig. 76; the absolute orbit is shown dotted for comparison. The effect of the earth's rotation on the range and height of the supersonic orbit becomes even greater if the maximum velocity of flight approaches the velocity due to the earth's rotation; on the other hand it decreases rapidly if the start is made from the equator in an intermediate, rather than in an easterly or westerly direction, or if the takeoff point moves from the equator toward the poles. For example, the ranges for $c = 4000$ m/sec and $V_o = 7000$ m/sec are 32430 km. for westward takeoff from the equator, 50440 km for eastward takeoff from the equator, and 39363 km for takeoff from the pole; the corresponding ranges for $c = 5000$ m/sec, $V_o = 7000$ m/sec are 32660 km, 58880 km and 42091 km.

When the bomb load is dropped during the supersonic gliding flight, the weight suddenly decreases by 10 tons from the value G, and the stationary altitude increases by $\Delta H = 6341 \cdot \ln G/10$. This decrease and the diminished ballistic loading of the aircraft produce an effect on the oscillating orbit, as shown in Fig. 77 for a definite case. It was assumed that, along the orbit for $c = 4000$ m/sec, $V_o = 7000$ m/sec, a 3.8 ton bomb was released horizontally at 40 km altitude and 6060 m/sec velocity, so that it struck the point on the earth opposite to the takeoff point. For a bomb throw of 850 km, the release must occur after 19150 km. At this point the plot of the orbit splits into three curves; the path of the falling bomb, the dotted path which the bomber would have followed if no bombs were released, and the solid line showing the orbit after the bomb release. In the last case the waves in the orbit are higher and broader, so that after several oscillations a definite phase shift is observable, the stationary part of the path lies 1670 m. higher, and the final velocity of 300 m/sec is reached a few dozen kilometers sooner. The difference in range is so slight that one need not make a special investigation of the orbit after the bomb release, but can use the approximate orbit calculated for full bomb load. Fig. 78 shows the elements of this orbit; it is interesting to note that at the point of release the normal acceleration jumps discontinuously from $+7$ m/sec^2 to $+19.5$ m/sec^2, because the aircraft was in a trough and before the bomb release (when it weighed 13.8 tons) it was in dynamical equilibrium with the buoyant forces of the air.

The range of the rocket bomber is largely determined by the length of the supersonic glide path. This important quantity can be estimated to a first approximation, without doing the exact orbit calculation, by setting the inertial force equal to the air resistance, $G/g \cdot dv/dt = -G\varepsilon$ from which

$$v = V_o - \varepsilon g t \quad \text{and} \quad s = (V_o^2 - v^2)/2\varepsilon g$$

This simple calculation is satisfactory up to $V_c = 2000$ m/sec. Above this, the centrifugal force due to the curvature of the bomber's orbit around the earth can no longer be neglected. In second approximation we may set $G/g \cdot dv/dt = -(G - Gv^2/Rg)\varepsilon$, from which (18):

$$v = \sqrt{Rg}\,\frac{\dfrac{\sqrt{Rg}+V_o}{\sqrt{Rg}-V_o} - e^{2\varepsilon t\sqrt{g/R}}}{\dfrac{\sqrt{Rg}+V_o}{\sqrt{Rg}-V} + e^{2\varepsilon t\sqrt{g/R}}};$$

$$S = t\sqrt{Rg} + \frac{R}{\varepsilon}\ln\frac{1+(\sqrt{Rg}+V_o)/(\sqrt{Rg}-V_o)}{e^{2\varepsilon t\sqrt{g/R}} + (\sqrt{Rg}+V_o)/(\sqrt{Rg}-V_o)}$$

$$t = \frac{R}{2\varepsilon\sqrt{Rg}}\ln\frac{(\sqrt{Rg}+V_o)(\sqrt{Rg}-v)}{(\sqrt{Rg}-V_o)(\sqrt{Rg}+v)};$$

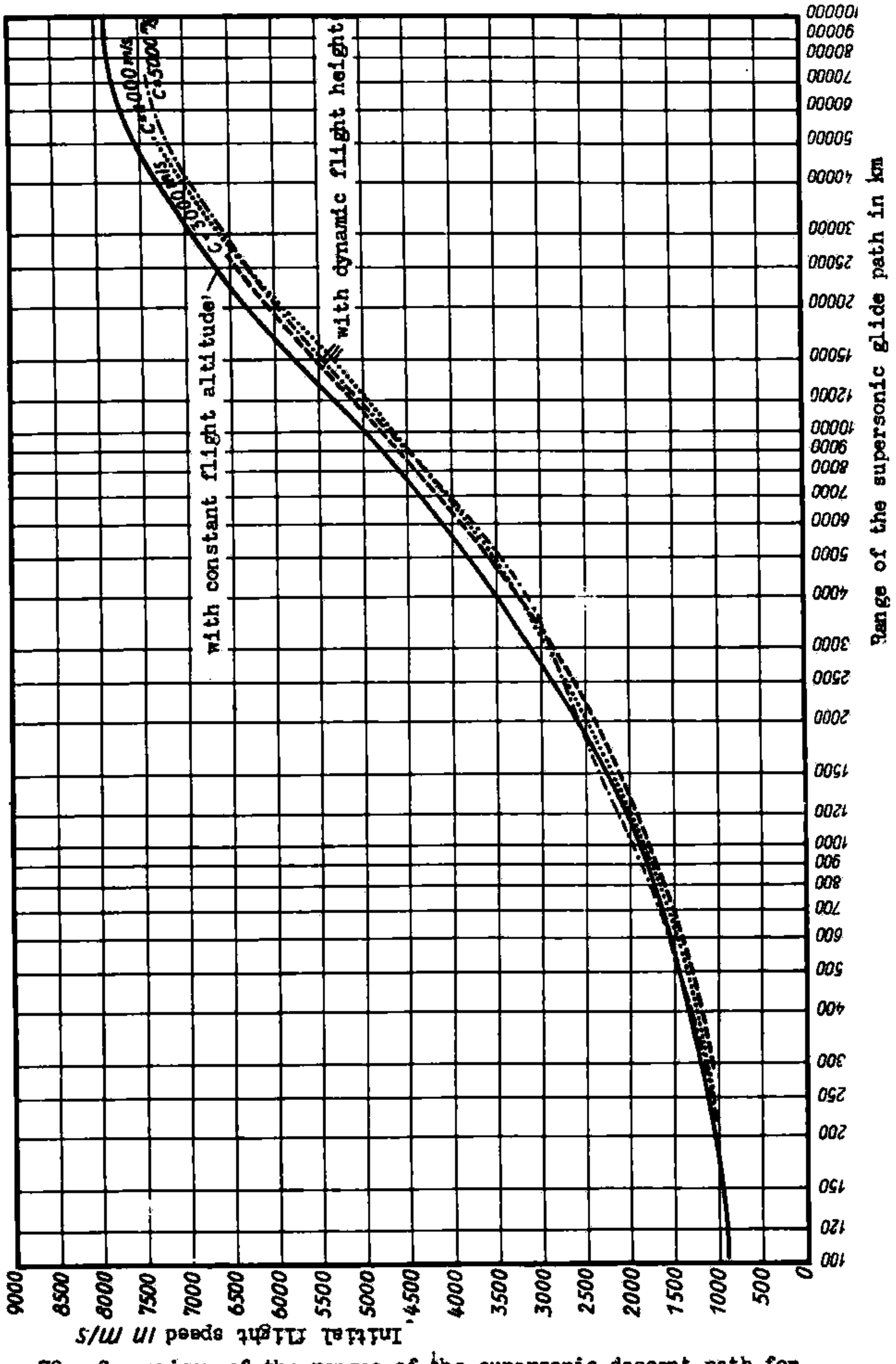

Fig. 79: Comparison of the ranges of the supersonic descent path for equal initial velocities computed by
a) Constant flight altitude
b) Graphical determined flight altitude
with c = 3000, 4000 and 5000 m/sec.

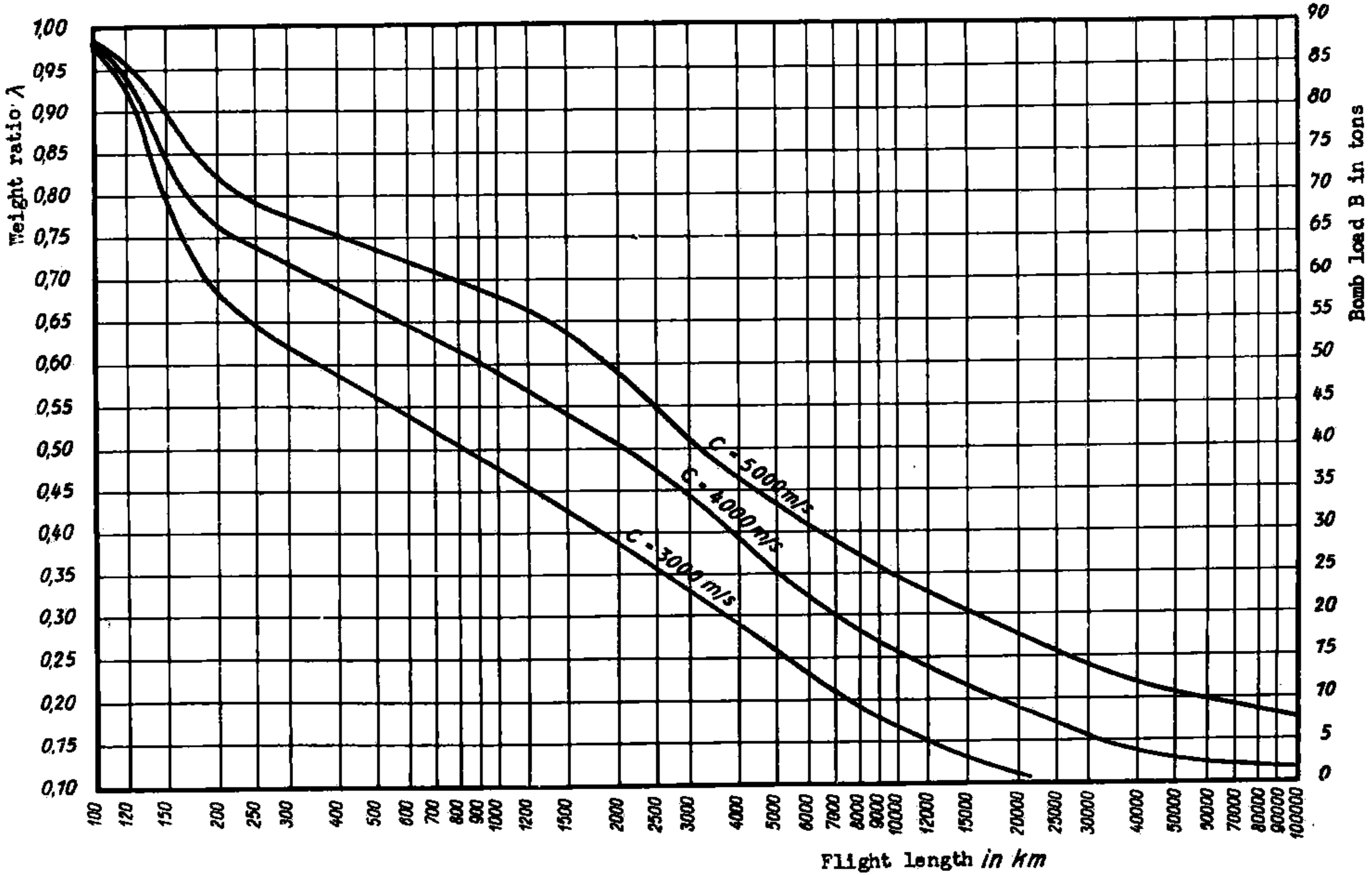

Fig. 80: Relationship between load ratio $\lambda = G/G_o$, bomb load B, and range of the Rocket Bomber for a "straight ahead path" and for exhaust velocities of c = 3000, 4000 and 5000 m/sec.

These equations give good results for the stationary flight paths until we approach the velocity of points on the earth's surface. With the aid of these equations we can also include the effect of the earth's rotation, and obtain values of V_a, t, and S_a for the absolute orbit, if in place of the relative velocity V_o we use the absolute velocity V_{ao} of the takeoff point, which is calculated from its velocity V_e and the compass angle ξ of the initial velocity V_o by the equation $V_{ao}^2 = V_o^2 + V_e^2 + 2V_oV_e \sin\xi$ The effect of the earth's rotation on the path length is greater than 1% in the most unfavorable case for $V_o = 2500$ m/sec, but decreases considerably when we change from absolute to relative path length. The path lengths calculated in this way can be compared to the ranges of fire for the same muzzle velocity V_o; up to $V_o = 6000$ m/sec and for the glide number $1/\varepsilon = 6.4$ used here, they are better by a factor 3.2, and as we approach the velocity of points on the earth's surface the factor increases rapidly; i.e., for the same initial velocity one can fly much farther than one can shoot.

Fig. 79 shows a comparison of the results of this second approximation with the stepwise calculation of the oscillating dynamical path. The reason why the dynamical paths are considerably longer than the stationary and for the same initial speed is mainly that whereas in the stationary gliding flight the energy consumption is distributed uniformly over the whole path, it is concentrated in the troughs of the dynamical path; the first (and also the longest) jump, which constitutes 15-30% of the total range, has a trough only at its end, and only loses there half of the energy which would be lost at the stationary altitude (this energy represents 15-30% of the total energy store). Other reasons for the greater range of the dynamical paths are that the regions of greatest energy consumption occur at low altitudes where favorable gas-dynamic glide-numbers at high Reynolds numbers exist, while the higher parts of the path, in which unfavorable gas-kinetic glide-numbers and low Reynolds numbers exist, occur in regions of rarefied air or practically empty space; finally, the process of turning out of the climb path, in the case of the stationary orbit, has to occur under unfavorable angles of attack, resulting in increased energy consumption for the same length of path. Even more clear is the plotting of the supersonic range of flight against bomb load or weight ratio, as in Fig. 80. The last two figures do not include the effect of the earth's rotation.

Also important for the use of the rocket bomber is the situation where, after release of bombs, the aircraft starts toward its home base. If the antipodes of the home base or other parts of the opposite hemisphere are being attacked, the bomber will return simply by continuing along its glide path after the bomb release and flying all around the earth. For nearer targets, there is the possibility of return by shifting course after the bomb release. Three possibilities are considered. First, instead of having the path be a great circle, after the initial propulsion, let it be a circle, lying on the earth's surface, with diameter $2r$ equal to the distance between takeoff point and target. For flight along this circular cap, the air resistance for a given velocity increases in the ratio $\sqrt{\cos^2[r/R.(1-2V^2/Rg)] + V^4/R^2g^2} / \cos[r/R.(1-V^2/Rg)]$

because of the oblique centrifugal forces, while the circular cap is shorter than the great circle only in the ratio r/R Flight along the circular cap will be more favorable than flight along the great circle only for velocities below 5600 m/sec, so this method of turning seems suitable for shorter distances of attack. However, in this range there is in most cases another favorable turning procedure - to reach the target along a great circle, to turn the aircraft at the target as sharply as possible, and return home along another great circle. If the bomber turns through a small angle $d\sigma$, then the ratio of the work done on the element of turn path of length $r\,d\sigma$ to the kinetic energy of the bomber at the beginning of this element is $2\varepsilon\, d\sigma \sqrt{1-g^2/b^2}$ which can drop to $b = V^2/r$ because of large centrifugal acceleration which can approach the permissible limit. The turning path then becomes a spiral along which the tangential and radial accelerations are constant. It is not integrable and must be computed step by step. From the equation, the relative loss of weight during the turn is independent of the velocity at the start of the turn, so it can be computed once and for all for all the spirals. It is shown in Fig. 81 for turn-spirals with tangential deceleration 1.75 m/sec^2 and centripetal acceleration 50 m/sec^2. After a 90° turn only 60% of the initial energy is left, after a 180° turn only 37% is left; i.e., the sharp turn still costs a great deal of energy. There are intermediate procedures for turning, which are a combination of narrow turn with non-great circles; these are characterized by less energy consumption than the last limiting case which only permits the use of oscillating flight paths.

A third turning method consists in the aircraft using only enough energy in the climb, to enable it to reach the target; there it turns at its small residual speed, and with the aid of a fuel store on board, gets another push to give it the energy for the return home. This method of using two driving periods has the feature that the aircraft travels slowly over the target at low altitude. So on the one hand the bombs can be dropped with great accuracy on the other hand, the fire power is less than for long range attack, and finally the bomber gets into the enemy zone of defense at the target. Fig. 82 shows the ranges of the rocket bomber when it is turned by the last two methods.

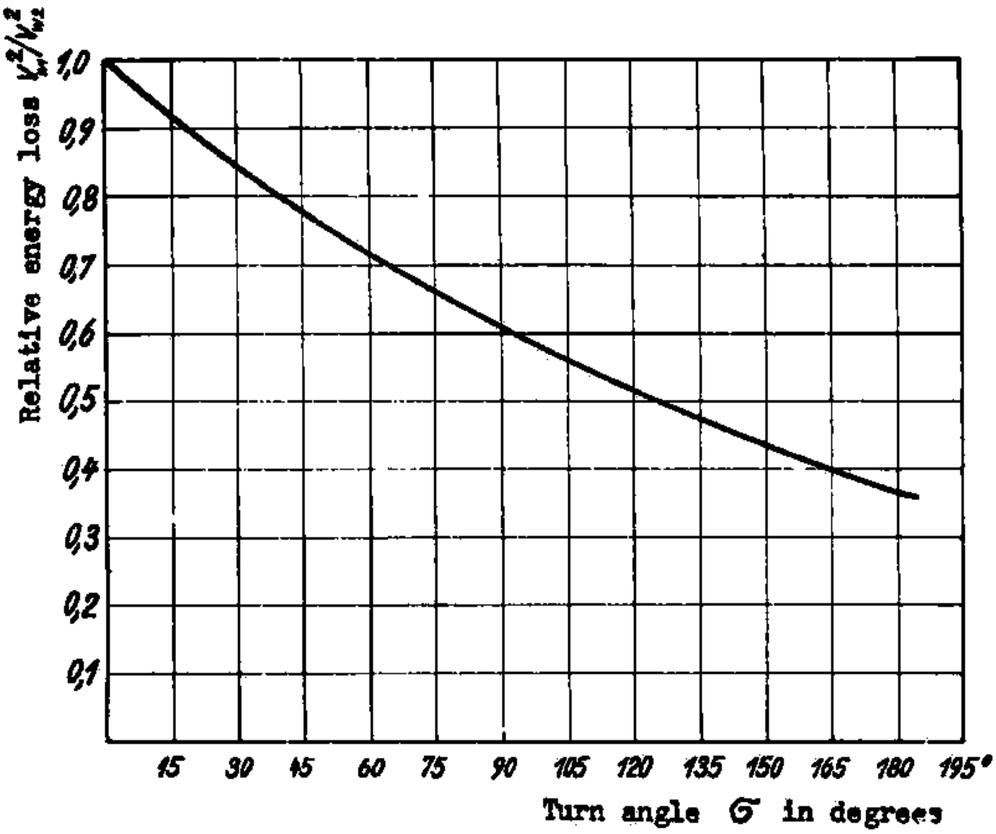

Fig. 81: Loss in kenetic energy during the turning through an angle along the spiral turn. (see p. 122)

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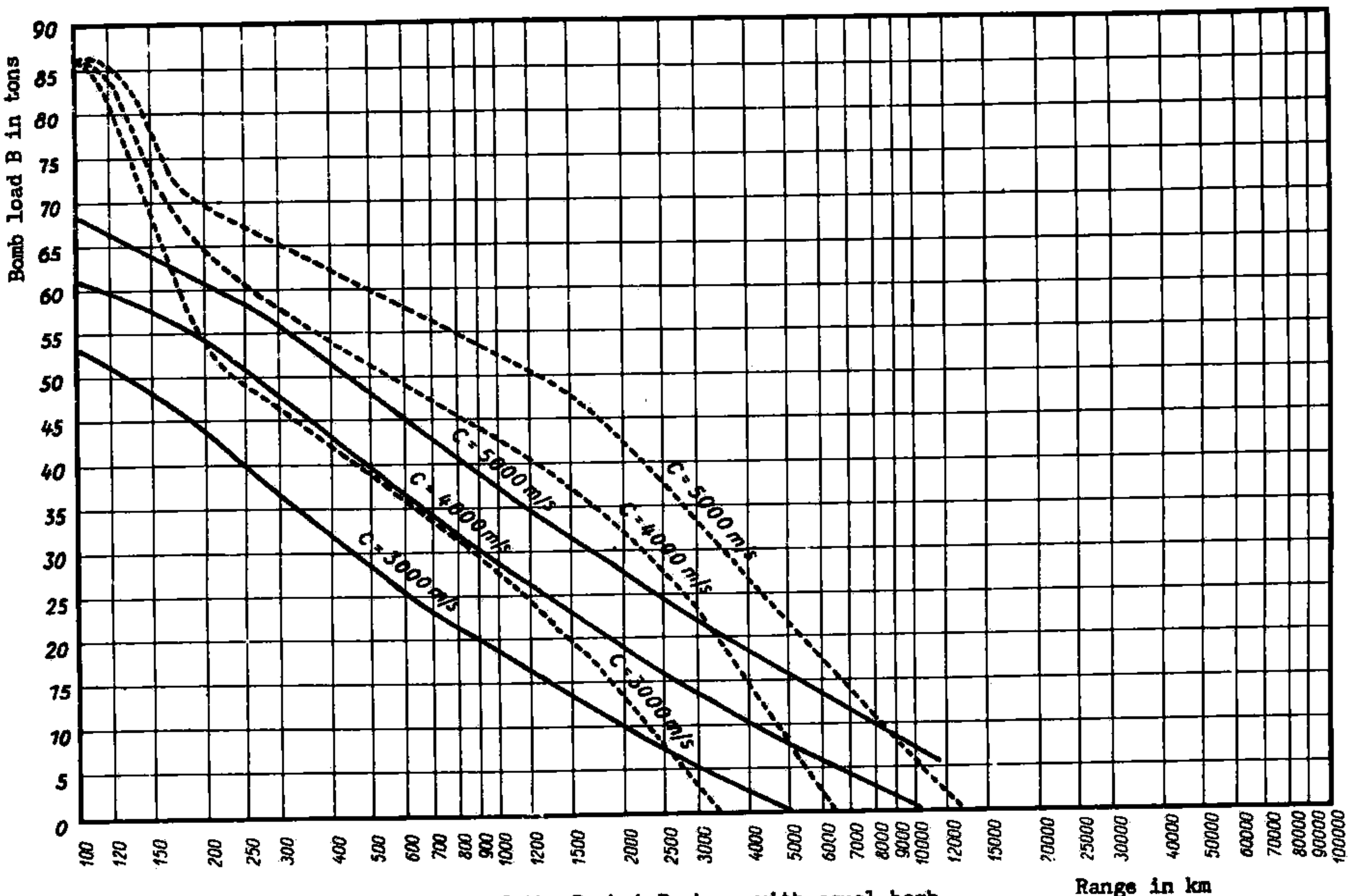

Fig. 82: Comparison of the ranges and of the Rocket Bombers with equal bomb loads for c = 3000, 4000 and 5000 m/sec. if the return to the launching point is effected by a full speed gliding turn (solid lines), or second, if there is a slower gliding turn, followed by a second rocket acceleration (dotted lines).

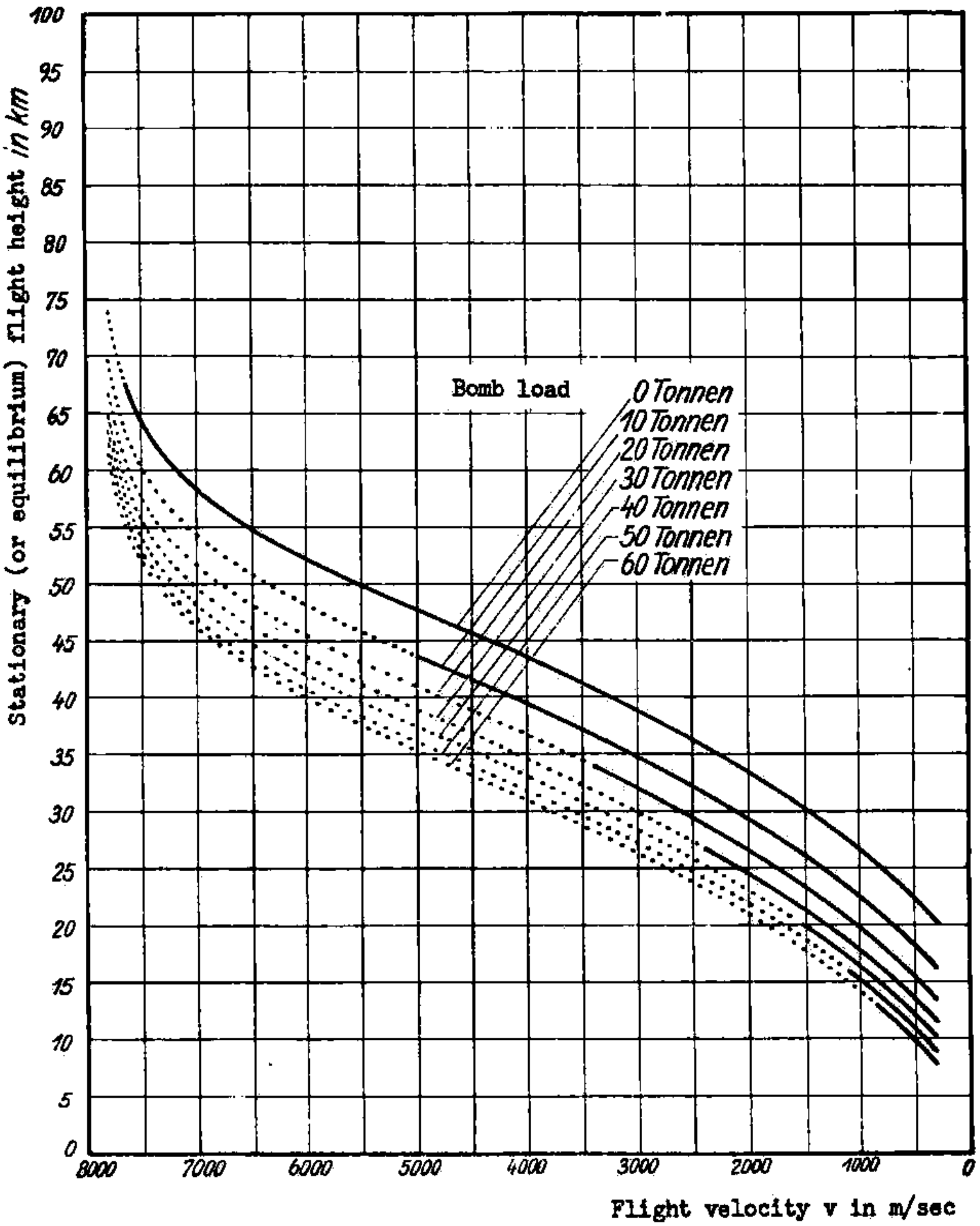

Fig. 83: Stationary flight altitudes of the Rocket Bomber during the supersonic glide with various bomb loads.

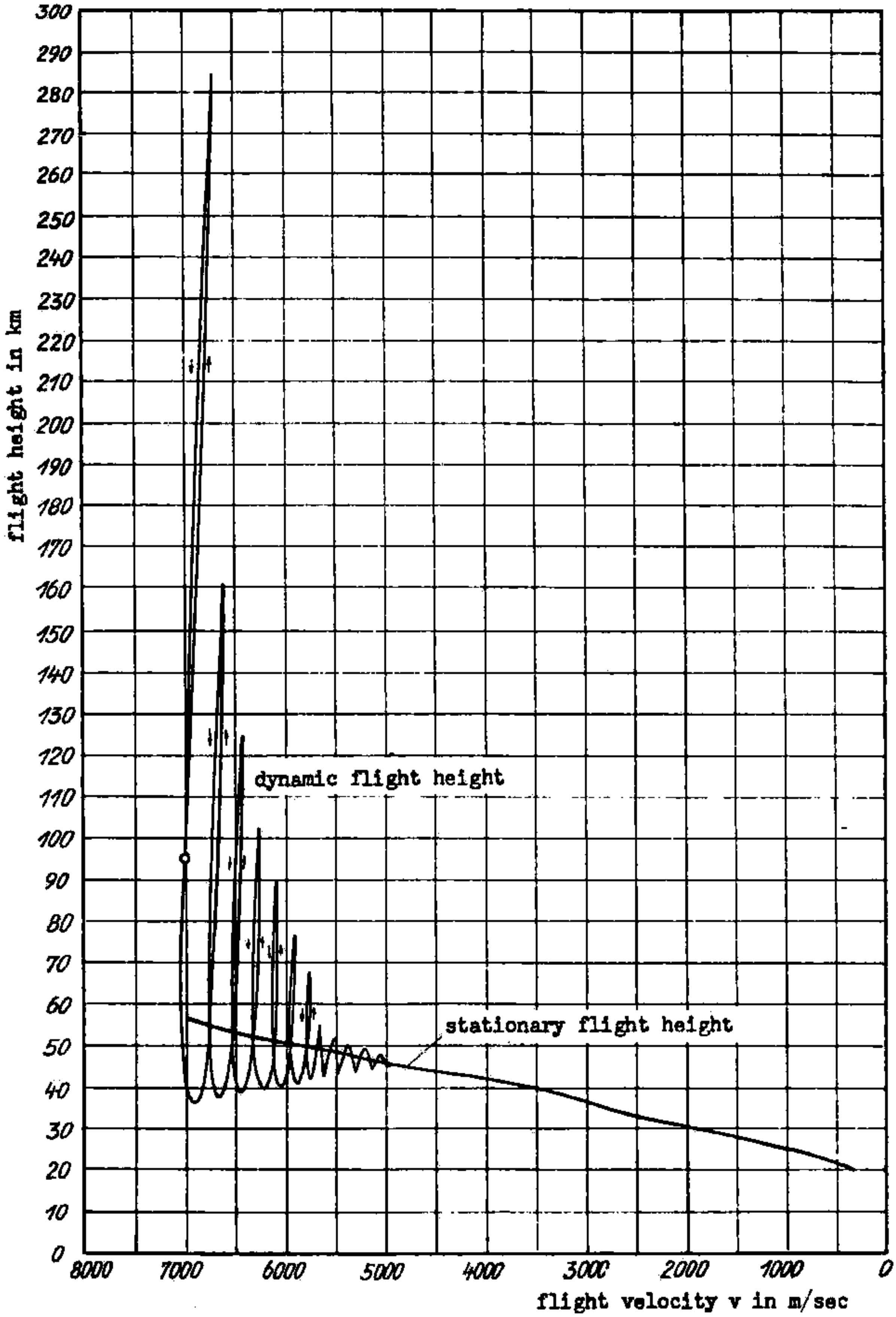

Fig. 84: Comparison of the actual and stationary flight altitudes of the Rocket Bomber during a supersonic glide path. (c = 4000 m/sec, v_o = 7000 m/sec.)

The same considerations apply to the altitudes of supersonic gliding flight as to the climb, especially as regards " stationary " and " dynamic " altitudes. The stationary altitudes, determined by the equilibrium between the constant flight-weight and the propulsive plus centrifugal forces (just as they were used for the second approximation to the length of the supersonic path), are shown in Fig. 83, where the curves are drawn solid out to the point actually attainable with the given bomb load and c = 4000 m/sec. The dynamical altitudes of flight, which result from the varying initial conditions for the dynamical orbit of supersonic glide flight, tend to approach the stationary altitudes of flight, as shown in Fig. 84 which shows the dynamical and stationary paths for c = 4000 m/sec and V_0 = 7000 m/sec.

2. Path of Subsonic Gliding Flight and Landing

The subsonic gliding flight, by its definition, begins at V = 300 m/sec with G = 10 tons. The lift coefficient for a favorable glide position is then about C_a = 0.2 and the corresponding height is H = 20 km. The supply of potential and kinetic energy is still 24580 kg m/kg, with which a distance of $24580/\varepsilon$ = 98200 m. can be travelled for an average subsonic glide-number ε = ¼. One can follow the descent in small velocity-steps V_1, V_2, V_3 . . . by using the result that the decrease in kinetic energy $(V_1^2 - V_2^2)/2g$ plus that of the potential energy $(H_1 - H_2)$ must always equal the work against air resistance $\Delta s . \varepsilon$; in the stratosphere we get
$\Delta s = (V_1^2 - V_2^2)/2\varepsilon g + 6341/\varepsilon \ln V_1^2/V_2^2$ or $\Delta H = 6341 \ln V_1^2/V_2^2$ in the troposphere
$$\Delta s = (V_1^2 - V_2^2)/2\varepsilon g + (H_1 - 44250)/\varepsilon \times [1 - (V_1/V_2)^{0.47}] \text{ or } \Delta H = (H_1 - 44250)[1 - (V_1/V_2)^{0.47}]$$
The subsonic glide path obtained from these equations is shown in Fig. 85. We see that the subsonic descent lasts 11 minutes, and ends near the surface of the earth at a velocity of 288 km/hr, whereupon the landing can occur. The actual variability of the subsonic glide-number can affect his path of descent.

The landing process begins at V = 288 km/h with C_a = 0.2. The behavior of the aerodynamic forces is given by the upper polar of Fig. 34, so that the velocity of the bomber can be lowered, by using landing-aids, to $288\sqrt{0.2/0.74}$ = 150 km/hr which is required for military glide-landings. With these polars we can determine the air resistance and the required angle of attack α for all velocities between 288 and 150 km/hr, for G = 10 tons, so the landing procedure can be followed by using the dynamical equations. It is shown in Fig. 86.

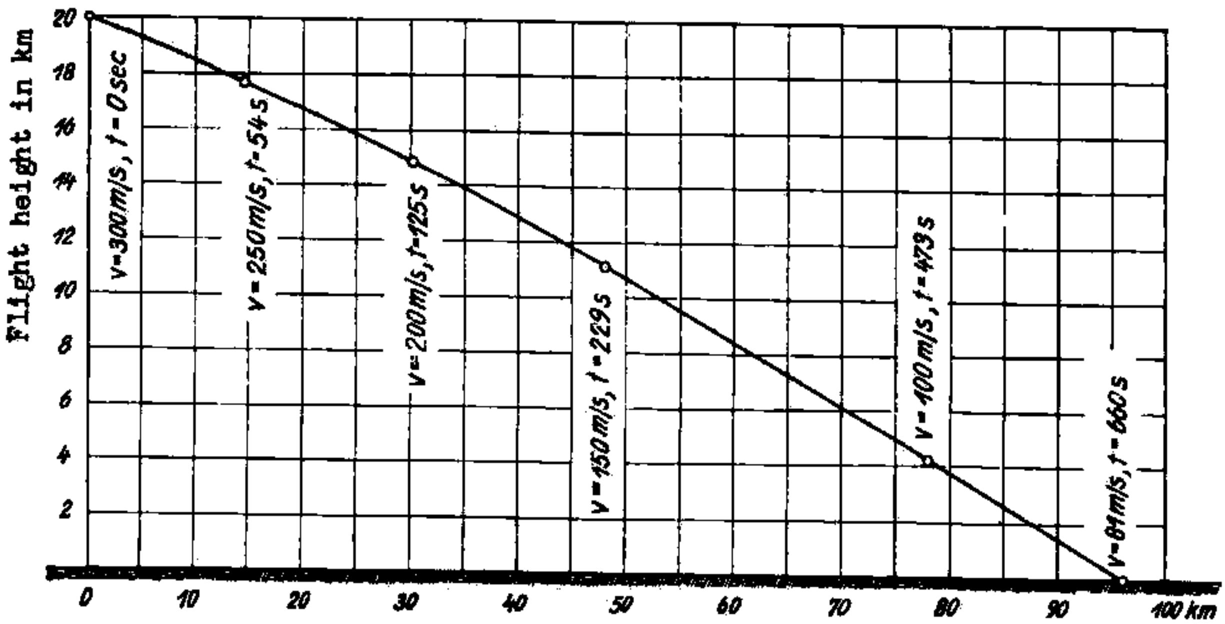

Fig. 85: Subsonic descent path of the empty Rocket Bomber assuming a constant average L/D of 4

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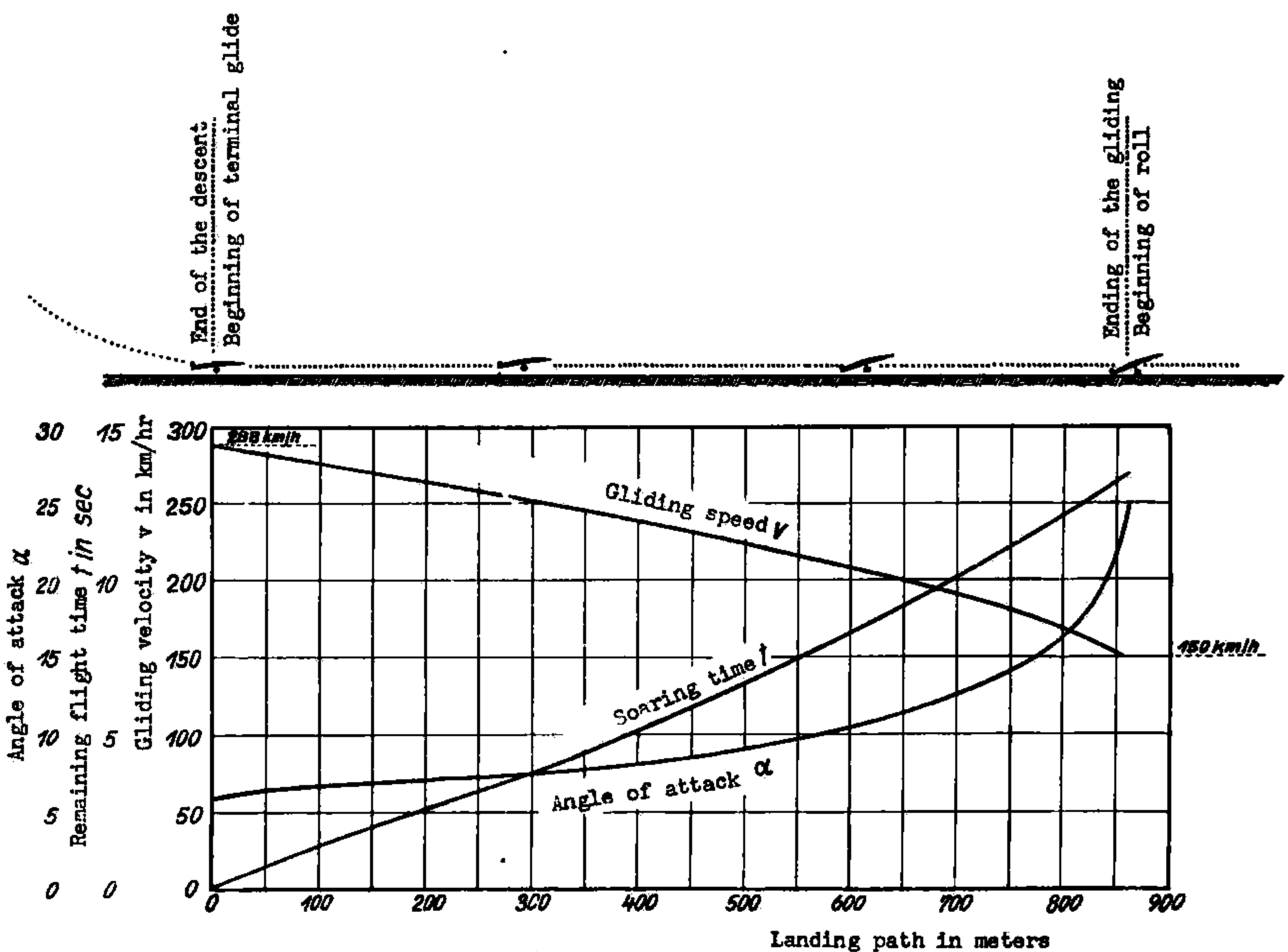

Fig. 86: The landing of the Rocket Bomber

V. PROJECTION OF THE BOMBS

1. Types of Projection

The rocket bomber has two different methods of attack: point attack and areal attack. The two procedures differ mainly in the manner and accuracy of the bomb release.

In the procedure of attack on a point, the bomb will be aimed precisely toward a "point"-shaped individual target, and released at moderate altitude and velocity under the same conditions as for ordinary bombers. In practice the same sub-types of bomb release are available to the rocket bomber as for other bombing aircraft, e g. bomb release during horizontal flight, dive bomb attack, bomb release during climb, low-altitude bombing, etc. The well-known conditions and difficulties of these types of release apply practically unaltered to the rocket bomber, especially as regards the accuracy attainable and the need for adequate visibility at the target, so nothing new can be said about these types.

Things are quite different for attack on an area. Here the bomb is thrown from great altitudes (50-150 km) and at very high velocities of flight (up to 8000 m/sec), i.e. under conditions far beyond those of long-range artillery fire. Since the target, for the distances involved, will not be visible, the release on an area will be aimed indirectly, e.g. by celestial navigation. Thus it is independent of weather and visibility at the target. Because of this, it does not reach the accuracy of release on a point, and we must expect spreads of several kilometers. So with areal bombing one cannot hit particular points, but rather a correspondingly large area, with sufficient probability. To achieve an anticipated effect on this whole surface, a single drop will not suffice, rather we will have to project several bombs toward the same target; these will distribute themselves over the surrounding surface according to the laws of chance. The distribution of hits inside the area will not be uniform; the bombs will strike more frequently in the neighborhood of the target than far away; there will also be unavoidable bomb-hits far outside the area being attacked. However, on the basis of laws of probability, the bomb distribution can be predicted well enough so that the goal of the attack can be achieved with the same or even greater accuracy than for point attack.

2. Flight Path of the Bomb

In order to make calculations concerning the bombs thrown from rocket aircraft, we must make some assumptions about the external shape of the projectile. Best suited to the existing conditions is a bullet-shape, with flat base, with a cylindrical tapered portion at the rear, with largest possible ratio of height h to caliber d. With say $\frac{h}{d} \doteq 8$ we get, from the well-known gas-dynamic laws for very high Mach numbers, a resistance coefficient of $C_w \doteq 0.014 + 1.43 A^2/v^2$, where in the friction contribution $C_{wr} \doteq 0.004$ we neglect the stabilizing surfaces, since they probably can only manage to set the projectile spinning about its axis in the initial part of the flight, before their thin walls are destroyed due to the temperatures developed by friction.

If one assumes that the explosive constitutes 50% of the bomb's weight, then bombs weighing 30 (or 5 or 1) tons have lengths of 11.20 (or 6.16 or 3.60) m., and cross-section loadings of 19.5 (or 10.7, or 6.2) tons/m^2. In a practical situation any bomb load could be made up out of these three sizes. The considerable space required for the projectiles will require an adjustment of the bomb-load-and tank-space to the purpose at hand, in the sense that larger fuel loads will be accompanied by decreased bomb loads and vice versa; i.e., the aircraft described earlier is best suited to the first case.

In estimating the path of flight of the bomb we can proceed in the same way as in determination of the ascending or descending path of the aircraft itself. The force picture differs from that for the climbing aircraft, since we have assumed that no aerodynamic lift forces act on the bomb and that the bomb can no longer be kept in a definite orbit plane by a pilot, so that it follows the tendencies to sideways motion due to atmospheric rotation (weather-vane action) and earth rotation (Coriolis-force), and describes a twisted orbit in space. As shown previously, the weather-vane action is caused by the fact that the bomb, as it flies over places of different latitude, continually moves through layers of air of different absolute speed (depending on latitude), and thus is acted on by a cross-wind, which produces horizontal transverse forces; these do not act at the center of mass of the projectile, but behind it, at least if the projectile has fins. This force as well as the Coriolis force was assumed, in the case of the aircraft, to be eliminated by transverse steering which develops forces equal and opposite to them. In the case of the bomb there are no controls; as a result of the weather-vane action it will not only drift to the side, but also as a consequence of the resultant torque, it will start to rotate about a vertical axis through the center of mass. The flight path of the bomb is thus determined by five external forces, of which four act at the center of mass and the fifth acts behind it: weight of the bomb, air resistance, transverse air force, Coriolis force, and d'Alembertian inertial force.

The transverse force is perpendicular to the tangent to the path, points the way the transverse wind is blowing, is proportional to the air resistance and the square of the angle under which the unperturbed air stream meets the symmetry plane of the aircraft. This angle in turn is determined by the strength of the cross-wind, i.e. by the course of the bomb and its velocity relative to the ground, by the magnitude of the moment of the crosswind about the center of mass of the bomb, and finally by the slowness with which the bomb responds to the crosswind and its torque, in turning its apex toward the crosswind. This inertia should be as large as possible, since the tendency to turn always exists except when the bomb is in the plane of a latitude circle. We can get an idea of the magnitude of this effect by considering the 300 km. long path of fall for a point of release over a pole of the earth. The difference in cross-wind between the point of release and the point of impact is, in this case, the absolute velocity of rotation 22 m/sec of the point of impact. Thus the angle of the cross-wind blowing against the projectile is 1/2 degree for a mean forward speed of 3000 m/sec. For such angles of incidence, in the Newtonian velocity region, the transverse force would be equal in magnitude to the resistance of the projectile; the projectile will thus carry out the deflection rapidly despite its large moment of inertia, so that the transverse force cannot increase to such magnitude.

The remaining forces, the Coriolis force and the d'Alembertian inertial force, can be given from our previous analysis. In doing this we should note that the system of forces acting on the bomb is generally a spatial system, i.e. it cannot be balanced by a single inertial force, but rather by a "screw".

If finally the bomb starts to rotate about its axis of symmetry, then gyroscopic, Magnus-, and Poisson- effects start, which affect the course of the bomb.

In order to obtain the path of the bomb, the force components along the principal directions of the compass and along the vertical must be determined and the equations of motion for the three directions in space must be written down. Integration of these would give an exact description of the twisted path in space. This extensive generalization of the well-known 'Fundamental Problem of Exterior Ballistics' is not directly soluble.

To get a preliminary picture of the path of projection, the range, final velocity of the bomb, time of fall, angle of impact, etc., we can use the well-known simple procedure of Poncelet and Didion for stepwise graphical construction of the path of fall. This procedure takes account of the earth curvature, convergence of verticals, and variation of air density and gravity with altitude, and is therefore the best suited of the usual ballistic procedures for the rocket bomb. In the actual calculation of the bomb path by this procedure, it turns out that the effect of air resistance on the path is extremely small, first because of the low air density along most of the path, second because of the small coefficient of air resistance for the slender bullet-shaped body. The paths can therefore be very accurately described as Kepler ellipses, and then the range and angle of impact can be determined from these. The actual velocity of impact of the bombs with the earth will be decreased by a few percent because of the air resistance.

The range of the bomb thrown horizontally and falling along a Kepler ellipse is given by $W = R \arccos\{1/\varepsilon \cdot [1-(R+H)/R(1-\varepsilon)]\}$ where $\varepsilon = 1 - V_o^2(R+H)/gR^2$ is the eccentricity of the ellipse. From these equations, the relation between the height at release H, the velocity at release V_o, and the range W, is plotted in Fig. 87. The duration of fall can be determined by integrating the path lengths or by a step-by-step calculation of the orbit, and gives values corresponding to those shown in Fig. 88. For large velocities of release, the earth rotation has a noticeable effect on the range. Since the release point is outside the earth's surface, one can insert for the velocity of release the absolute velocity of the bomb at the point of release, and then obtain the absolute length of the range from Fig. 88; the relative range on the earth can then be calculated in the usual manner.

One thing to be checked is how warm the bomb becomes in falling through the lower layers of air. In the case of the bomber, which has its high speeds in regions of rarefied air, so that it flies at moderate stagnation pressures, it was assumed that equilibrium between heat intake and radiation can be maintained by having a strongly radiating skin for sufficiently low wall temperatures, or that critical thermal stresses can be withstood in the troughs of the path by having a skin with sufficient heat capacity. During the fall of the bomb through more dense layers of air, the heat transfer per unit area of the bomb surface will increase greatly, but the bomb's fall lasts a much shorter time, so that one may compute using the heat capacity of the shell of the bomb. The stagnation- and also approximately the friction-, temperature can be

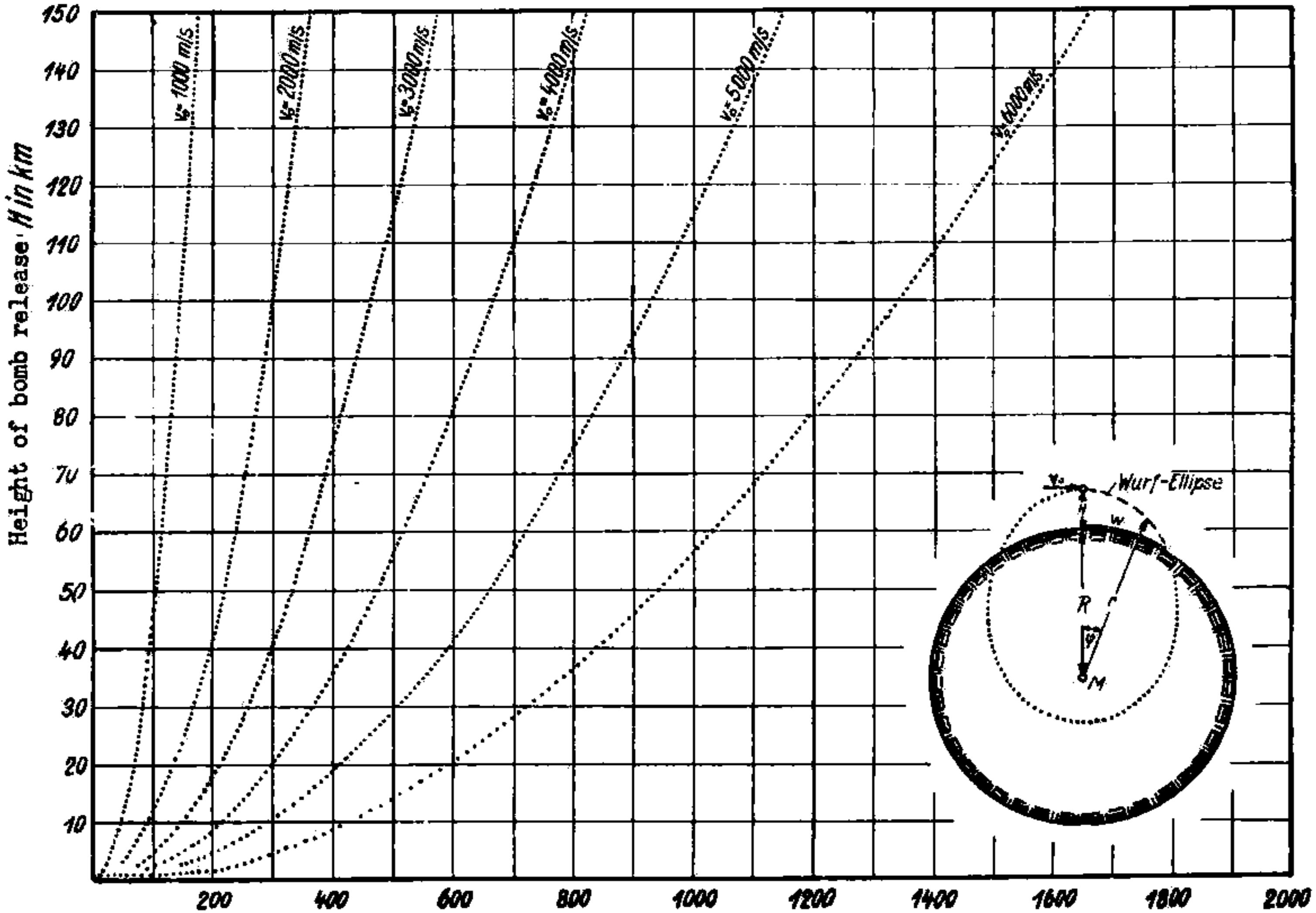

Fig. 87: Throwing distance of surface bomb according to second approximate calculation. (Path as a Keppler ellipse, taking into consideration the Earth's curvature, and also the approximate air resistance) See p. 130.

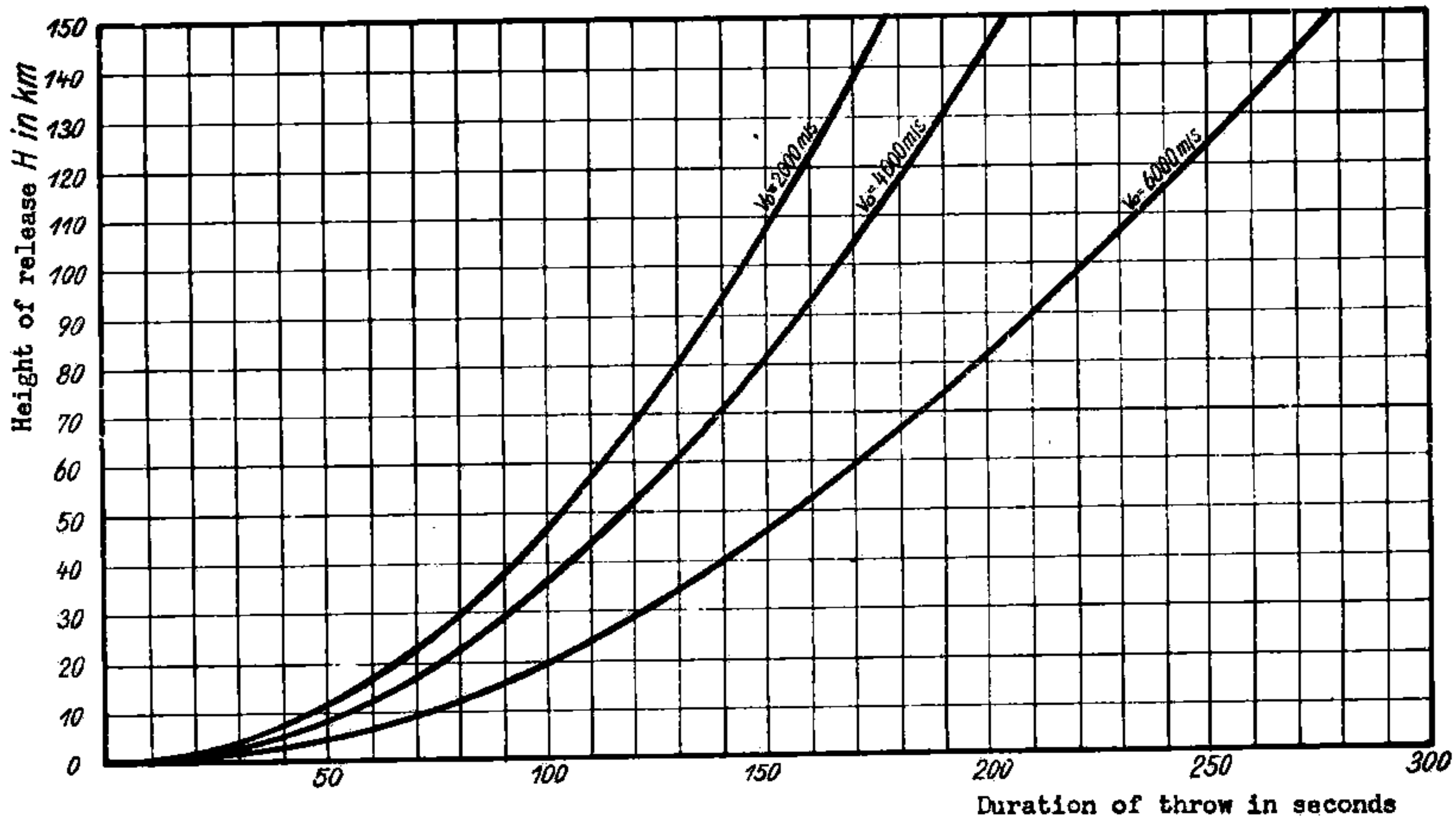

Fig. 88: Dependence of duration of throw as a function of initial altitude and velocity.

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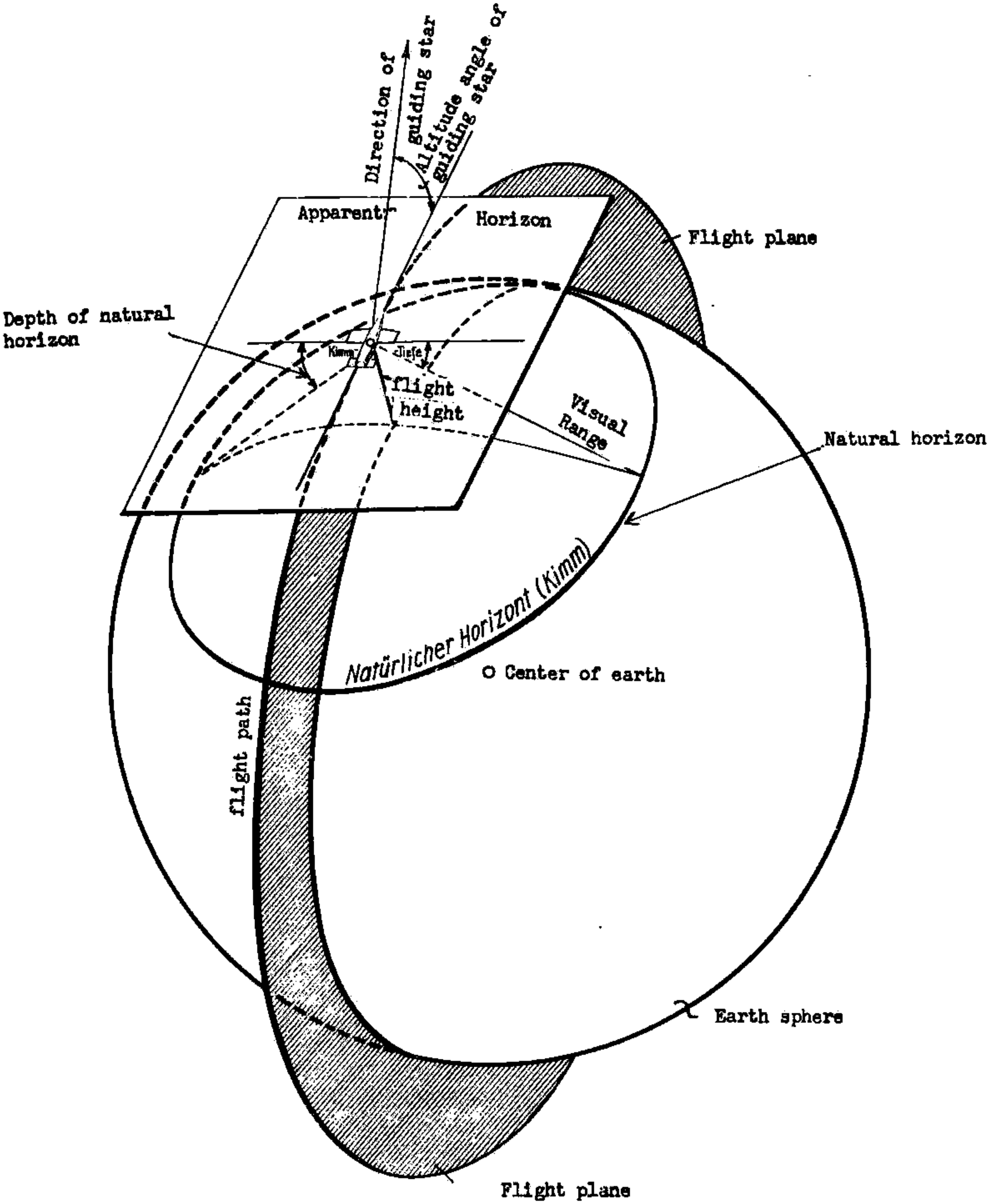

Fig. 89: The third aiming phase of bomb release (see p. 134).

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estimated from the gas-dynamic energy equation to be $\Delta T = V^2/2600$ if one assumes that for high temperatures of the boundary layer, the vibrational degrees of freedom of the air molecules are completely excited, but that no dissociation occurs in the boundary layer. The laws governing the transfer of heat from the heated regions of the boundary layer to the rigid wall are unknown, but one can set up a rough energy balance by using the estimated coefficient of laminar friction of the boundary layer $C_f = 0.0003$ to calculate the work of friction per unit surface per sec. as $\tau V = c_f \cdot q \cdot V = 0.5 c_f \rho V^3$; for V = 6000 m/sec at the earth's surface, this gives 5.4 hp/cm^2. If one assumes that a third of this heat goes to the wall, then one obtains the conditions of the jet throat of a powder rocket mentioned on page 8; i.e. an iron jacket only 2 cm. thick would only begin to melt after 10 sec. as a result of this heating. From more recent measurements of heat transfer at high Mach numbers, it appears to increase more slowly than the rate of frictional work, i.e. it goes like $\rho^{0.5} V^{2.5}$ this indicates that the bomb can go through the critical lower atmosphere even without the use of strongly radiating refractory protective layers for the outer covering.

Finally some general considerations are necessary concerning the accuracy of hitting for bomb release from great altitudes at high speed. In gunnery one assumes a diameter of the 50% circle equal to the range of fire. For the rocket bomber, the range of fire in this sense is the length of the path of fall of the bomb. For a mean length of say 600 km, the probable scatter would be 6 km, if one could release from the bomber with the same accuracy as one can fire from a cannon. The actual error will be the resultant of errors in release, which are determined by position-, velocity-, and direction- errors at the point of release, and of deviations during the fall, which are caused mainly by fluctuations in the density and flow of the air. The navigation of the rocket bomber to the release point is divided into three aiming procedures. The first phase consists in having the catapult apparatus lie in the direction of the target, if possible; because of its fixed installation deviations up to 90° may occur. The correction of this error occurs in the second phase right after takeoff, during the motorless flight or right at the start of the propulsion period, when the direction to the target can be set by means of the compass to within a few minutes of arc. During the glide, the aircraft must be steered very accurately, since systematic effects - rotation of the earth and atmosphere, and accidental influences, such as small asymmetries, errors in steering, fluctuations of air density, and movements of the air, continually tend to bring the aircraft out of its orbit. During the glide above the troposphere, the third phase, on which the accuracy of the bomb hits depends, is completed. In this one can think of using astronomical methods for pointing; this will be independent of the influence of the weather or the enemy; in the interference-free stationary glide path before release, it permits determination of position to an accuracy of a few seconds of arc, corresponding to position errors of little over 100 m. To determine the apparent horizon under the excellent visibility conditions available, one can sight on three points of the natural horizon; from the depth of the horizon the altitude can be determined. When the apparent horizon has been fixed, the maintenance of the prescribed orbit in space can be assured by choosing one or several stars in the plane perpendicular to the horizon through the position of the target, and following their apparent motion with a theodolite. If the guiding star, during the dynamic flight, stays in the plane of the orbit (i.e. on the vertical cross-hair) the pilot knows that he is in the prescribed orbit-plane. On the stationary flight path he can determine his absolute velocity from the apparent motion of the star along the vertical cross-hair, and his position and that of the bomb release from the altitude of the star. Whether the target is visible at the instant of bomb release is unimportant. The determination of the point of release involves only the small error in angle measurement, which corresponds to a few hundred meters. Fig. 89 is a pictorial presentation of the conditions during this third aiming phase. The errors arising during the fall of the bomb are more significant. If among the factors affecting the spread of projectiles: differences in propulsive charge, vibrations of the barrel, meteorological fluctuations, differences in the projectiles and errors in direction, only the last two are considered and each is given equal weight, then the spread would be about 2/5 of 1%, i.e. .6% (??), which for a range of projection of 600 km, gives a diameter of 3.6 km for the 50% circle. To this is added the error in navigation of the aircraft itself, so that one obtains for the probable deviation from the target of a single release, $W_w = 3$ km, with which we can make approximate calculations.

3. Ballistics of Impacts

The process of impact for point release and area release differ fundamentally in having very different velocities and angles of impact. The processes in point bombing are similar to those for ordinary bombing or heavy mortar fire, so that the necessary results can be written down; e.g. in dive bomb attack by the rocket bomber with 30, 5, or 1 ton bombs, for a final diving speed of 500, 300, <u>or</u> 260 m/sec, the penetrating power of bombs through the earth's crust is 100, 30, <u>or</u> 12 m., for reinforced concrete the values are 10% of the above; the corresponding penetrations through armor plate are 200 cm. (1.43 caliber), 60 cm (0.86 caliber) or 25 cm.

(0.55 caliber), in other words greater than the strength of all known ship's armor.

Entirely new conditions occur for the area bomb, which has a velocity of impact 10 times as great. The energy of impact is much greater than the energy content of the explosives in the bomb. The strength of the material of the bomb itself will permit it to penetrate a structure, or even to go through a city with numerous buildings, because of the small angle of impact; it will not permit penetration into the earth. The effect will thus be similar to that of a mine. The range of the explosion of a definite amount G [kg] of explosive can be estimated as $r = \sqrt{kG}$ under the assumption that the surface destroyed is proportional to the explosive charge; here r is the radius of destruction in meters, and k is a constant which gives the degree of destruction; for air pressures of about 20000 kg/m^2 which produce the worst effects on buildings and smash any except specially reinforced one, k is 3; for pressures of 5000 kg/m^2, k is 12, for which value slight damage to structures occurs, walls are overturned, and gables are destroyed; for k = 25 the safe distance of ordinary buildings from explosive storehouses is reached, and k = 200 gives the circle at which window panes and, partly, window frames are broken.

These effects are distributed uniformly in all directions from the point of impact of a very thin-walled bomb, and the result of impact of the rigid body of the shock wave moving with greater than sound velocity through the still air. The development of such shock waves in front of blunt projectiles flying at supersonic speeds is well known. The phenomenon of an explosion wave is quite similar, except that here the excitation comes only to a small extent from the bomb fragments thrown out of the bomb cover, and mostly from the combustion gases of the explosive, which for adiabatic expansion from the pressure and temperature of the explosion to a normal pressure reach radial velocities of $\sqrt{2gE/A}$ = 3400 $m/_{sec}$ for E = 1400 $kcal/_{kg}$ while individual portions of the gas can reach even greater velocities at the expense of other portions. If the explosive energy is also shared with the cover of the bomb (representing say 50% the total mass), then the velocity of the radial explosion wave drops to 2400 m/sec, a figure which checks well with actually measured velocities of fragments. The exploding material of the bomb collides with the surrounding still air at this velocity, and starts the powerful and far-reaching explosion wave in it.

From the mechanics of the explosion process we can get a clear picture of the effect of high impact velocity of an areal bomb on the explosive effect. In the following consideration we shall assume an impact velocity of 8000 m/sec, which we would get if the aircraft descended to the earth's surface at 8000 m/sec and released the projectile at short range. After detonation of the areal bomb on or above the earth's surface the mass of the resultant ball of fire has not only a radial velocity of 2400 m/sec, but also the convected forward speed of 8000 m/sec. The two velocities superpose as shown in Fig. 90 to produce a velocity relative to the surrounding still air. The front face of the explosion sphere collides with the air at a velocity of 2400 + 8000 = 10400 m/sec, and excites a shock wave as if the explosive had $(10400/2400)^2$ = 18.7 times as much energy content. The intensity of the explosion wave there is 18 times as great as for a bomb exploding at rest. The intensity drops rapidly for the sideward directions, and disappears completely at the rear.

Since the area of destruction by an explosive charge is proportional to the weight of the explosive, or more precisely to the energy available for the explosion wave, the area of destruction of an areal bomb is increased in the ratio of the sum of impact energy and explosive energy to the latter alone, i.e. in the ratio $(2400^2 + 8000^2)/2400^2$ = 12.1. At the same time the destroyed area loses its circular shape, and becomes a drop-like area along the direction of release whose outline can be calculated from the square of the resultant of impact- and explosive shock-velocities. The ratio of destroyed areas for the same bomb for point release and area release is shown in Fig. 90 for an impact velocity of 8000 m/sec. The destructive action of a bomb landing after areal release is much greater than that of an equal-sized normally-dropped bomb, is fan-shaped and points in the direction of release. Thus the effect of the bomb no longer depends only on the energy content of the explosive; the kinetic energy of the bomb also produces its full effect. The effect of the fragmentation of the bursting bomb-shell increases and distributes itself in the same manner as the intensity of the explosion wave. We get the instructive conclusion for the rocket bomber that, because of the additional energy of impact, the desired degree of destruction of a given surface can be accomplished by area bombing with much smaller bomb loads than for point bombing.

VI. Types of Attack

1. Basic Types of Attack

The type of attack procedure to be used by the rocket bomber in any specific case is determined by the nature of the target and its distance from the home base.

The extraordinary variety of targets is discussed in Section VI-9. There we discuss in greater detail the basic difference between point and area targets, according to which the types of attack can be subdivided into point-attack and area-attack procedures.

The individual types of point attack follow from the requirement that the bomber fly as slowly as possible over the target, so that it may have rather small residual energy there. If in spite of this, the bomber is to return to its takeoff field without a stop-over, then after dropping its bombs, over the target it must be propelled by its own rocket motor until it has acquired a sufficient speed to get home on the corresponding energy. Thus we arrive at a procedure for point attack involving two propulsions and return home, which consists essentially in having the bomber, after being catapulted at the home base, accelerated only till it acquires enough energy to bring it over the target. There it releases and turns at the lowest possible speed, then starts its motor with the residual store of fuel, to get up enough energy for the home trip, and lands back at its home base. Very large quantities of fuel are required for this double propulsion, so that this procedure can be used only for limited ranges of attack (up to 6000 km) and limited bomb loads. Point attacks over greater distances or with larger bomb loads than in this first procedure are possible if the bomber can land not too far from the target, and take on new fuel.

For the point-attack procedure with two driving periods, partial turning and auxiliary point, the bomber is again accelerated after catapult from the home base, until the acquired energy carries it just to the target. Then it releases, turns through the required angle at least possible flight speed, starts its motor with a small residue of fuel on board, to get the small amount of energy which carries it to the auxiliary field not far from the target; it lands there and takes on new fuel. With this, it takes off again in normal fashion and returns to the home base; it has the possibility of making further bombing attacks on the way home.

If a point attack is to be carried out over a larger distance or with very great bomb load and there is no possible auxiliary landing place fairly near the target, then rocket-technique, as seen at the present time, gives no possibility of retrieving the bomber and bringing it back to its home field. If attack on the target seems more important than the bomber itself (which has only a relatively small material value), then there is the possibility of sacrificing the bomber after the attack. This procedure of point attack with a single propulsion period and sacrifice of the bomber is, in principle, applicable to all points on the earth's surface. It is, naturally, to be applied to attacks and targets of very special significance, as for example the surprise destruction of a government building and the governing group assembled there, to the killing of a single, specially important enemy person, to sinking large enemy transports or warships, blocking of important avenues of commerce (say canals or straits), and to similar special cases; this is less because of the loss of the aircraft than for the more valuable pilot.

For procedures of attack on an area the need to fly slowly over the target disappears, so that one has more freedom in carrying out the procedure. The most obvious procedure for area attack, with single propulsive period and return home, consists in the bomber being catapulted from its home base, and then driven until it gets sufficient energy to get to the vicinity of the target, turn and get back home. The turn path uses up very large amounts of energy, so that this attack procedure remains limited to small distances and bomb loads.

Area attack over great distances is very much simplified, if an auxiliary field exists not too far from the target, so that the bomber can land and take on new fuel for the return trip. In this case the area attack goes as follows: after release the bomber makes a partial turn through an angle less than 180° (this requires smaller energy consumption than for a complete turn), then flies to the auxiliary field on its residual energy. This area attack with single propulsion, partial turn and auxiliary field is applicable to all distances on the earth; it assumes, however, that within at most a few thousand km. from the target there is a suitable auxiliary field, for landing, and which has a takeoff apparatus. In view of the large number of possible targets for area attack, this requirement can be fulfilled only in exceptional cases.

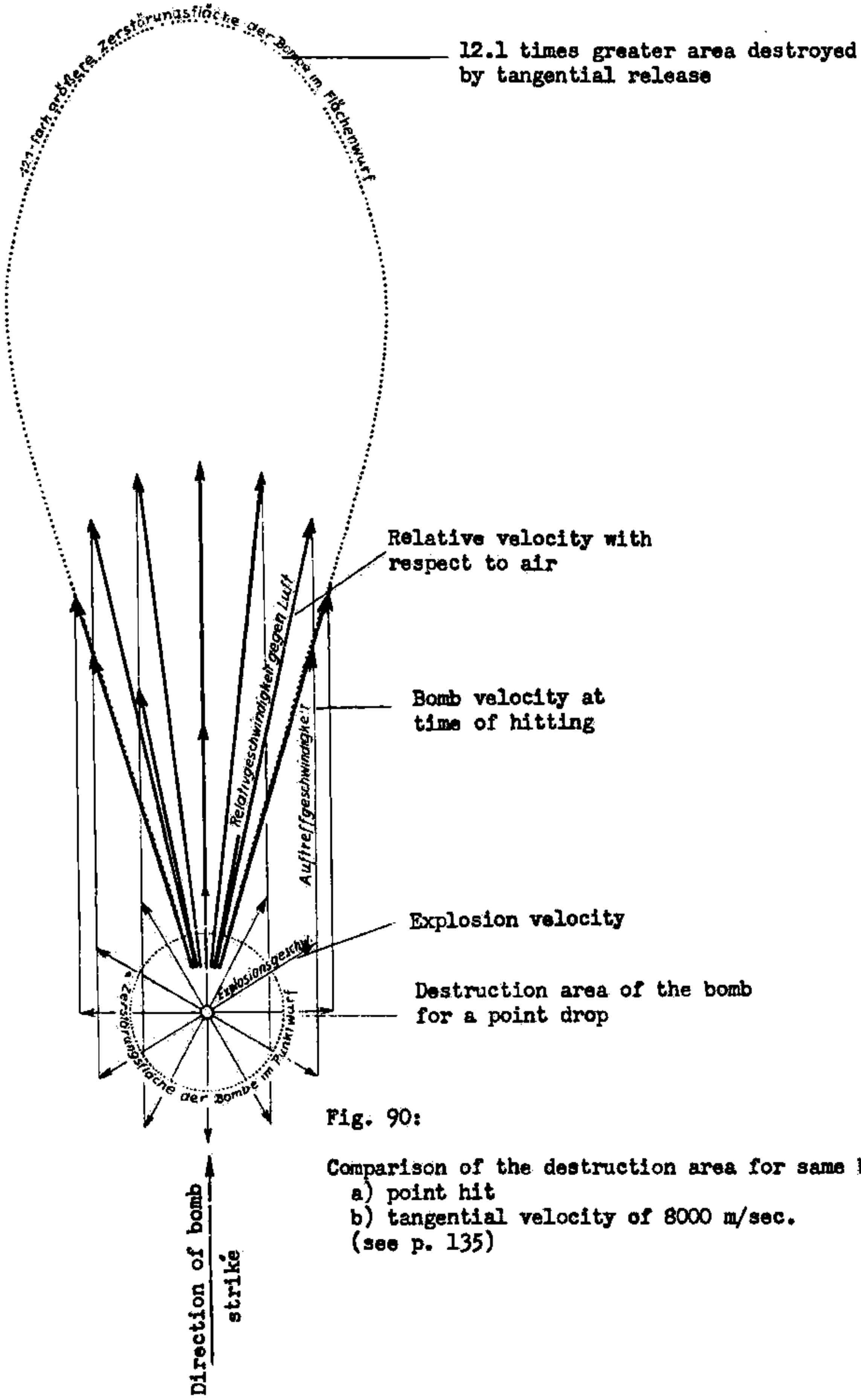

Fig. 90:

Comparison of the destruction area for same bomb
a) point hit
b) tangential velocity of 8000 m/sec.
(see p. 135)

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The value of the auxiliary point can vary considerably, not only according to its distance from the target, but also because of the size of the required angle of turn. Since large angles of turn are much more harmful than great distances, an obvious idea is to provide auxiliary points beyond all forseeable targets; e.g. beyond the two population concentrations outside of Europe (North America and S. E. Asia), say on the Marianas in the Pacific Ocean or on the islands of that ocean off the Mexican coast; or to secure a single auxiliary point at the antipodes of the home base, say in New Zealand or on the islands east of it. This auxiliary point at the antipodes can always be reached by straight flight without turning, no matter what point on the earth is attacked. Its distance from the target can be very large. On this discussion is based the method of area attack with single propulsion and auxiliary point at the antipodes. Such a single auxiliary point also has the advantage that it can easily be fully equipped to enable aircraft also to make bombing attacks on their journey back to the home base, and that its island location can be easily protected against enemy attacks; against the most dangerous attacks by enemy fleet units, this could be done by the rocket bombers.

If such an auxiliary point at the antipodes is not available, area attacks over large distances can be carried out by having the bomber, after release, fly a straight course all the way around the earth till it reaches the home base. This is the procedure for area attack with single propulsion and Circumnavigation of the globe.

Summarizing: all possible procedures for area attack coincide in what happens up to the bomb release; they differ only in the manner of bringing the bomber home after it releases its bomb load.

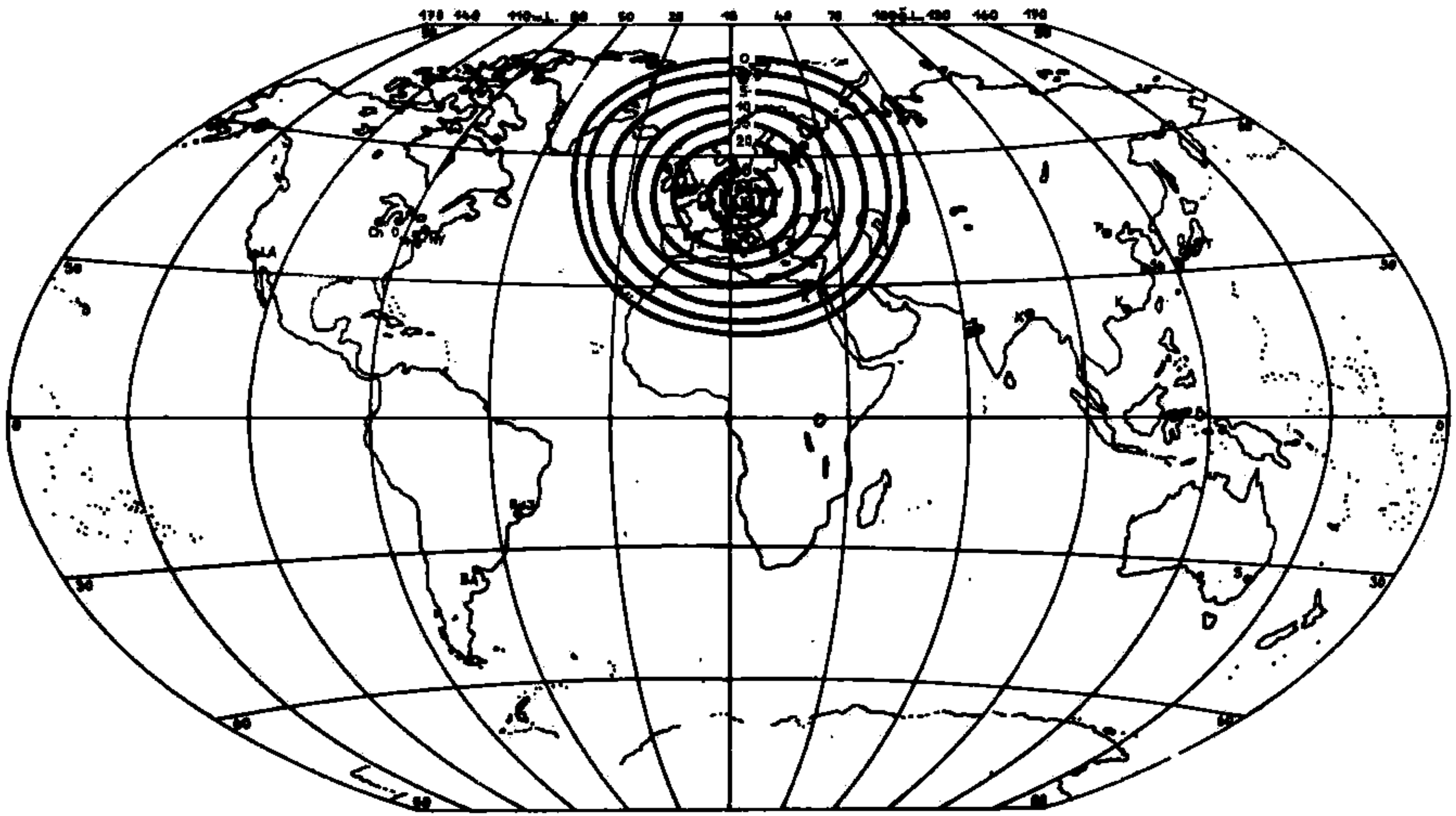
2. Point Attack with Two Propulsion Periods and Reversal of Path

If we denote the weight of the bomber in the separate phases of this attack procedure by G_o for the fully loaded bomber weighing 100 tons, G_1 after consumption of fuel for the outward trip, G_2 after bomb release, and G_3 the empty weight of 10 tons after consumption of the fuel for the homeward flight, then the identical distances of outward flight and return are determined by identical ratios G_1/G_o and G_3/G_2 according to Fig. 80, while the bomb load $B = G_1 - G_2$. Thus we obtain for each bomb load $G_1/G_o = G_3/G_2 = \sqrt{B^2/40000 + 1/10} + B/200$ and the relation between bomb load and range shown in Fig. 82, which also gives the range of this attack procedure. Figs. 91, 92, 93 show these ranges of attack, for three exhaust speeds C = 3, 4, and 5000 m/sec and with approximate inclusion of the earth's rotation, as contours of equal permissible bomb load, on a map of the earth's surface. The pictures show the effectiveness of the rocket bomber in a very persuasive fashion. Despite the unfavorable double propulsion the bomber, for the intermediate exhaust speed, is able to carry out point attacks within a radius of 2000 km., which includes all the strong points in Europe between Moscow and Madrid, Northern Sweden and Tripoli, Ireland and Ankara; these attacks can be carried out with extreme accuracy on any no matter how small object on land or sea, with a bomb load of 30 tons, which bomb load will stove in all except specially reinforced structures within 300 m; penetrate earth works 100 m. thick, and steel armor 1 meter thick; and <u>then</u> the bomber can return home without a stopover! With a smaller bomb load the same bomber can carry its attacks to over 6000 km; from Germany to Central Africa, Hindustan, Eastern Siberia, the North polar regions, to the east coast of North America and over the whole North Atlantic.

For C = 3000 m/sec, this range shrinks to Europe and the immediately adjacent regions; for C = 5000 m/sec it expands beyond the hemisphere with Europe as center. The procedure of point attack with two propulsion periods thus appears to have extraordinary practical importance, and is applicable to all actions inside Europe or in neighboring regions. In its favor is the fact that, though the bomber during a point attack comes into the enemy defense zone at the target at low velocity and altitude, the attack will generally be such a surprise that even a warship on the alert will scarcely have sufficient time to bother the bomber, much less to ward off the attack.

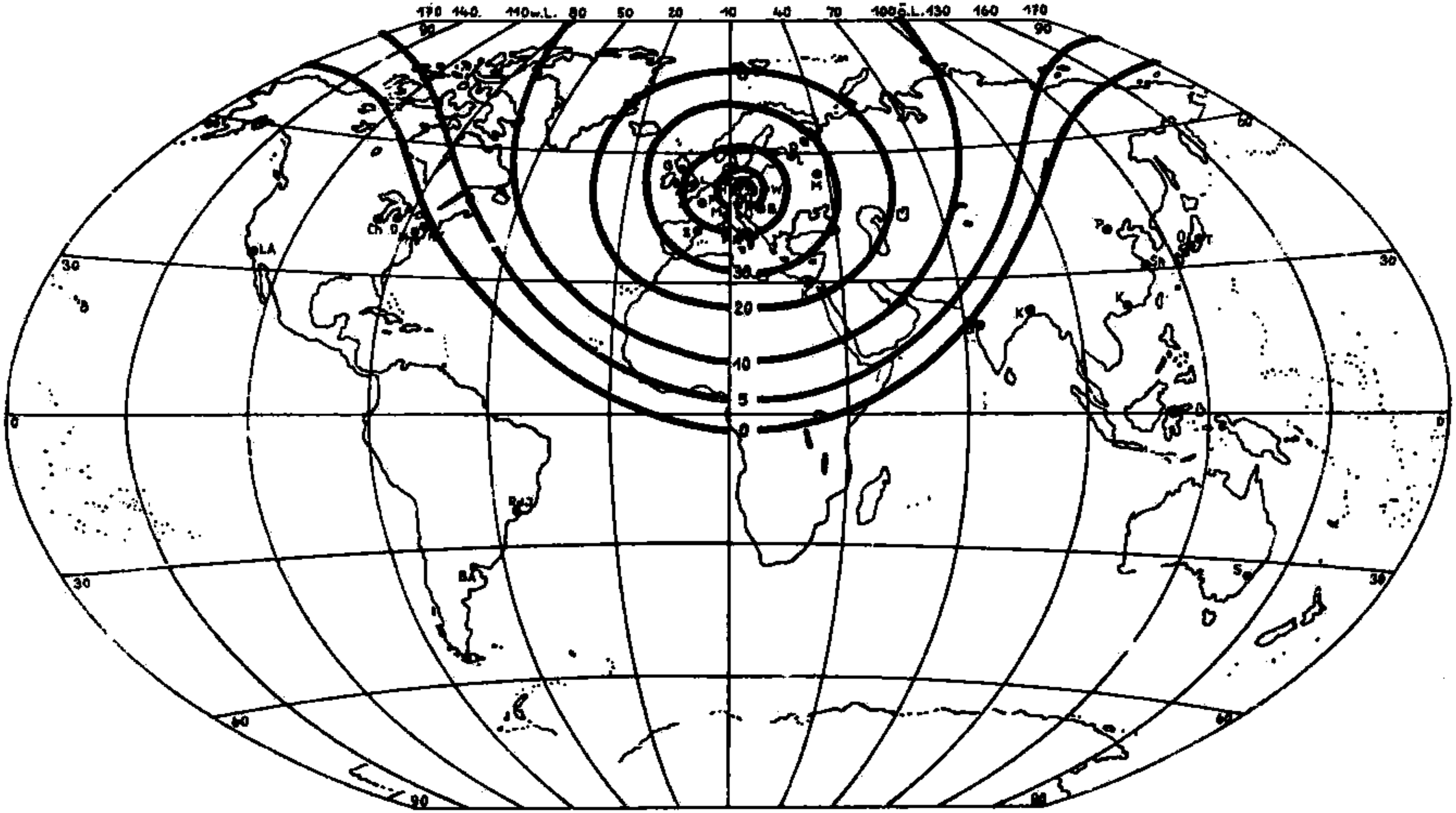
3. Point Attack with Two Propulsion Periods, Partial Turn and Auxiliary Point

This method of point attack differs from that of the preceding section only because the return flight can be shorter than the outward trip from the home base to the target since the landing is to be made at a suitable auxiliary location other than the home base. Because of the small kinetic energy over the target, the angle of turn is unimportant; the only important quantity is the distance from the target to the auxiliary point, measured as a fraction <u>k</u> of the distance <u>a</u> from takeoff point to target. With the notation of the preceding section, one has



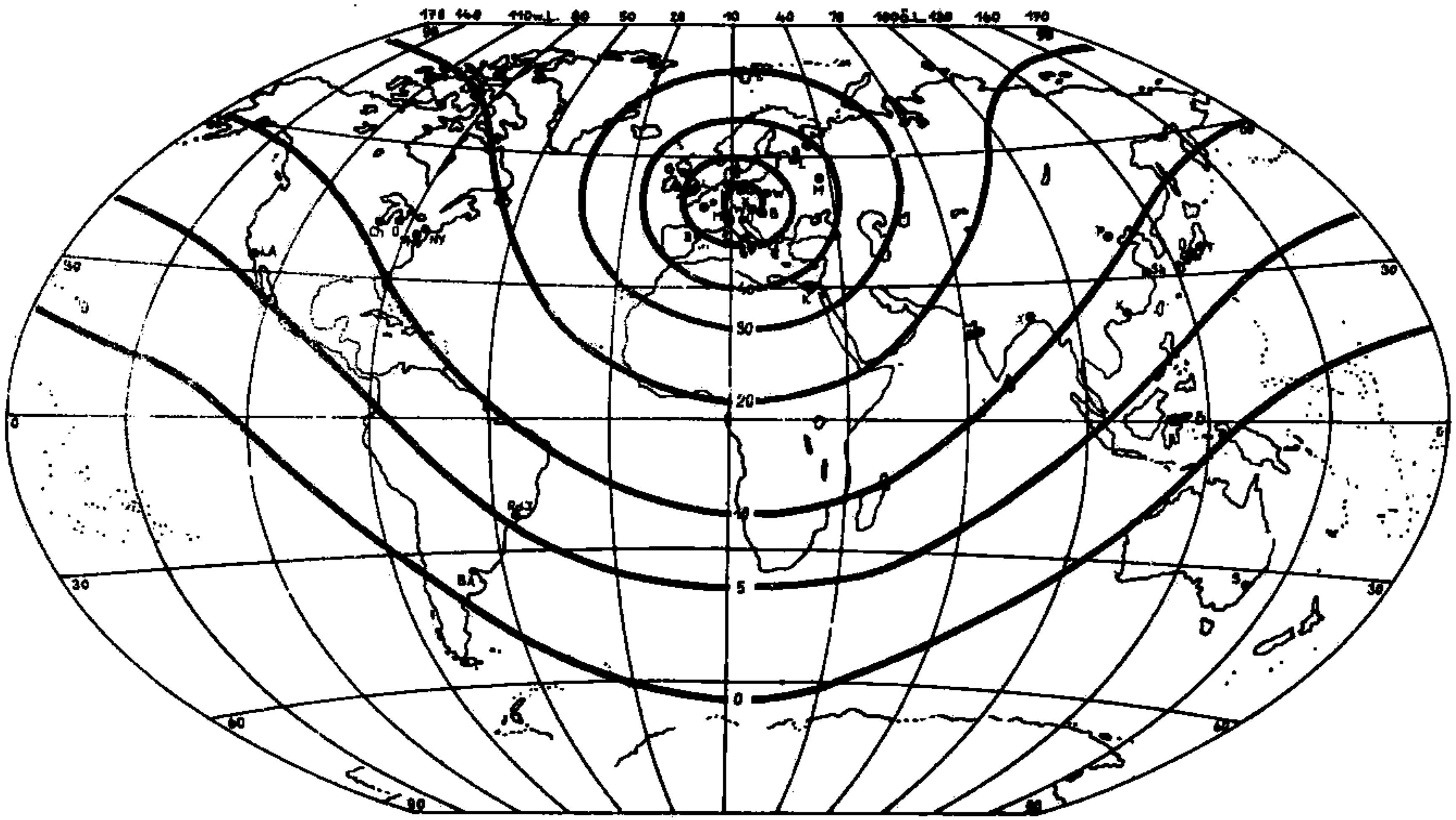
Cities of more than
• one million.
x Home base

Fig. 91: Bomb load in tons (i.e. percentage of the initial flight weight) of the Rocket Bomber in the case of point attack - double propulsion with intermediate turn around - and with exhaust velocity c = 3000 m/sec.



● Cities of more than one million
× Home base

Fig. 92: Bomb load in tons (i.e. percent of the initial flight weight) of the Rocket Bomber in the case of point attack - double propulsion with intermediate turn around - and with exhaust velocity c = 4000 m/sec.



● Cities of more than one million

✕ Home base

Fig. 93: Bomb load in tons (i.e. percent of the initial flight weight) of the Rocket Bomber in the case of point attack - double propulsion with intermediate turn around - and with exhaust velocity c = 5000 m/sec.

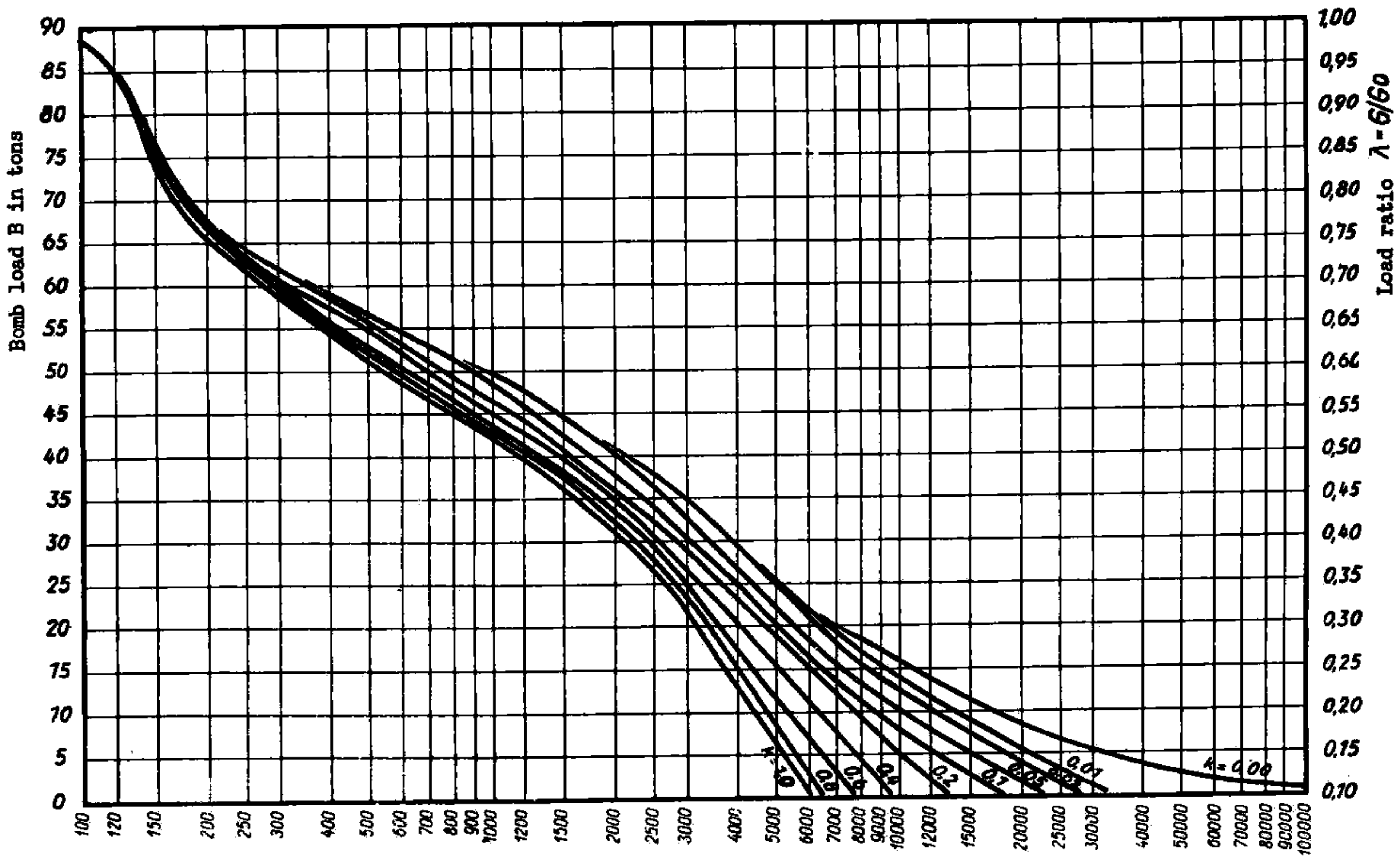
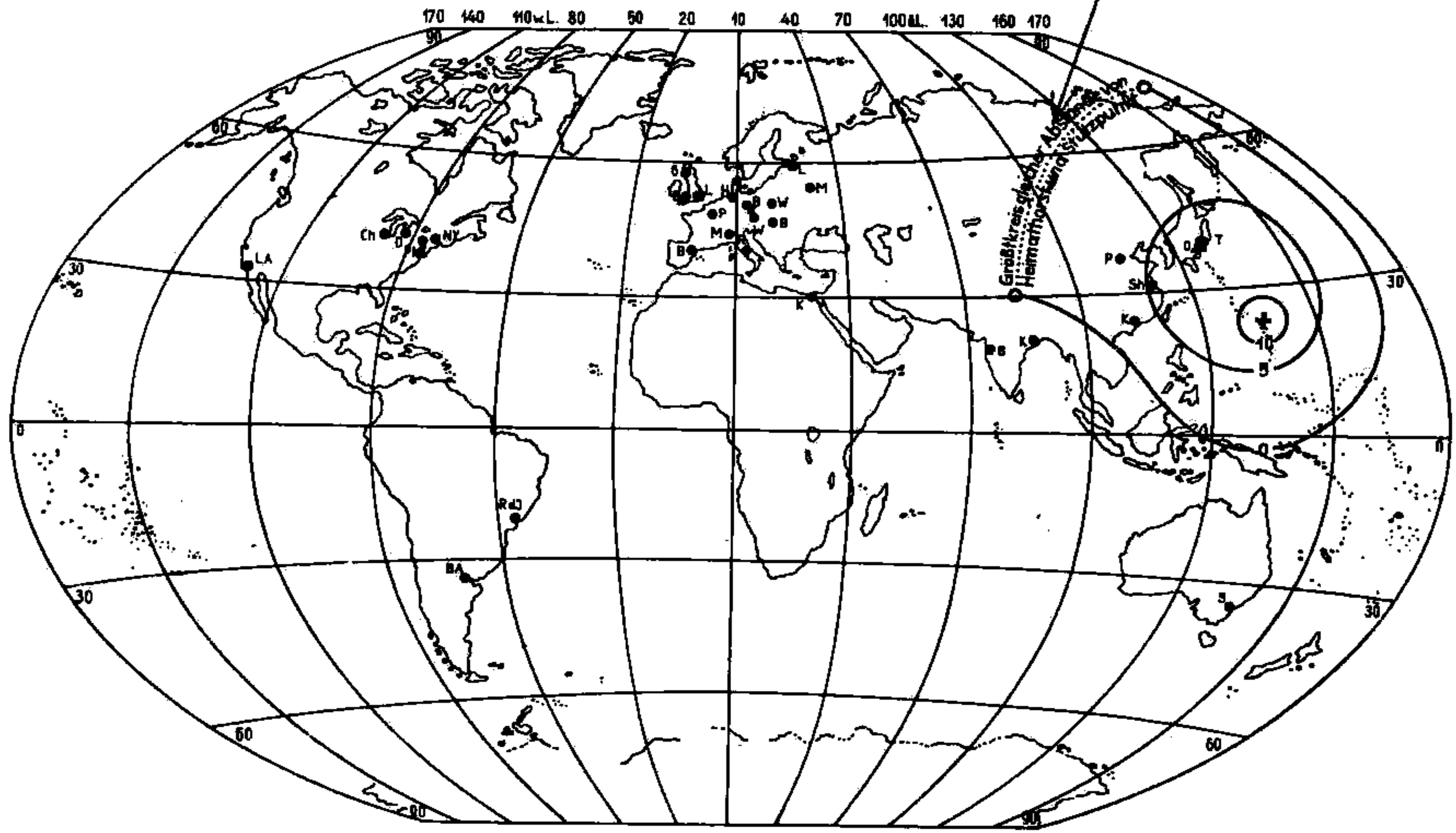


Fig. 94: Relationship between attack range a, and return range k.a and bomb load B, that is load ratio, in case of a point attack and a second propulsion at the knee of a dog leg path to a secondary base, c = 4000 m/sec. (see p. 138, sec. 3)

Largest circle equidistant from home base and secondary base.



Cities of more than
°one million
×Home base
+Secondary base in the
Marianas Islands.

Fig. 95: Bomb load of a Rocket Bomber in tons (percent of the take-off weight) in the case of a point attack, dog leg path, second propulsion at the knee, and a secondary base in the Marianas Islands. Exhaust velocity c = 4000 m/sec.

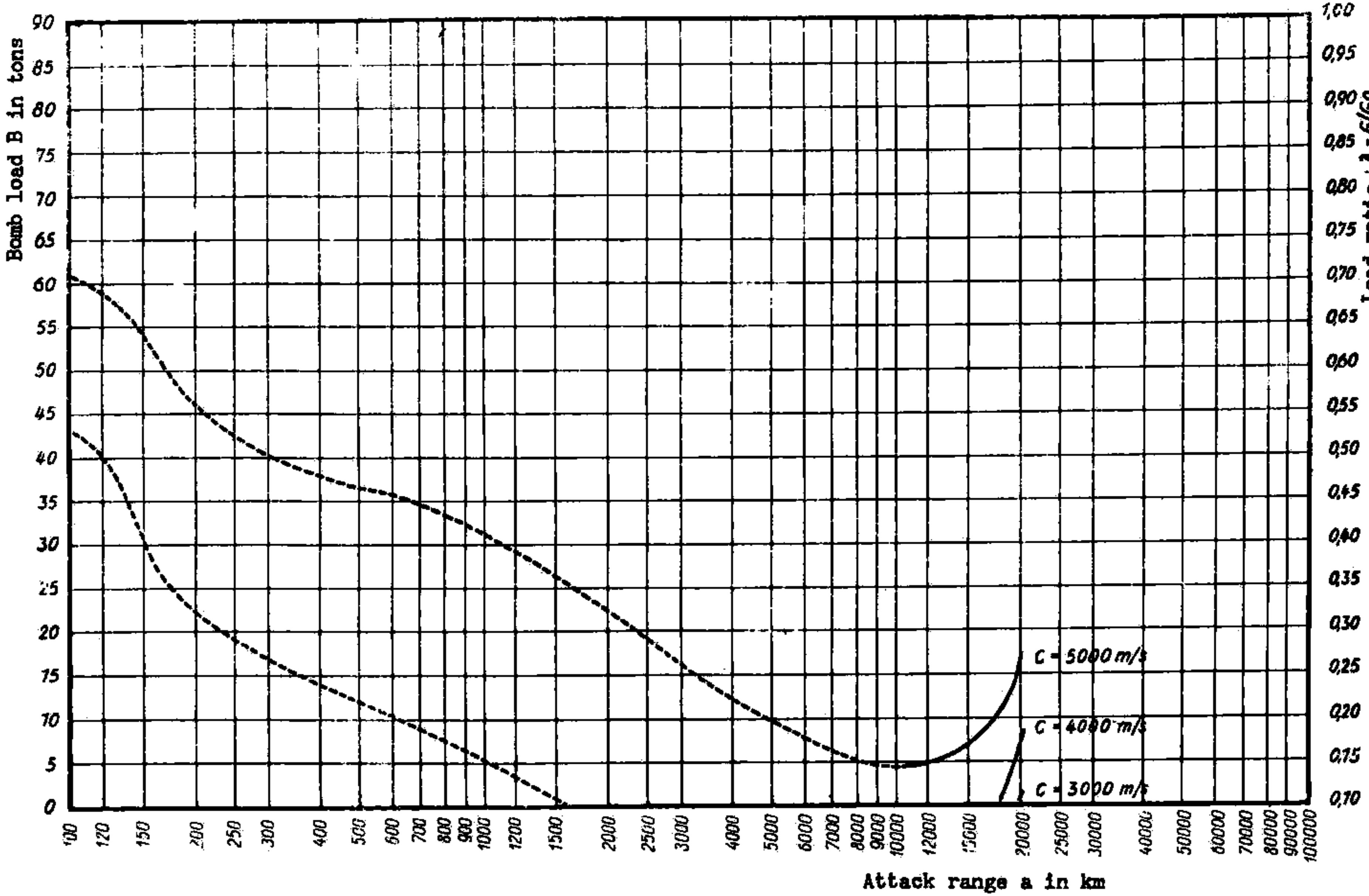


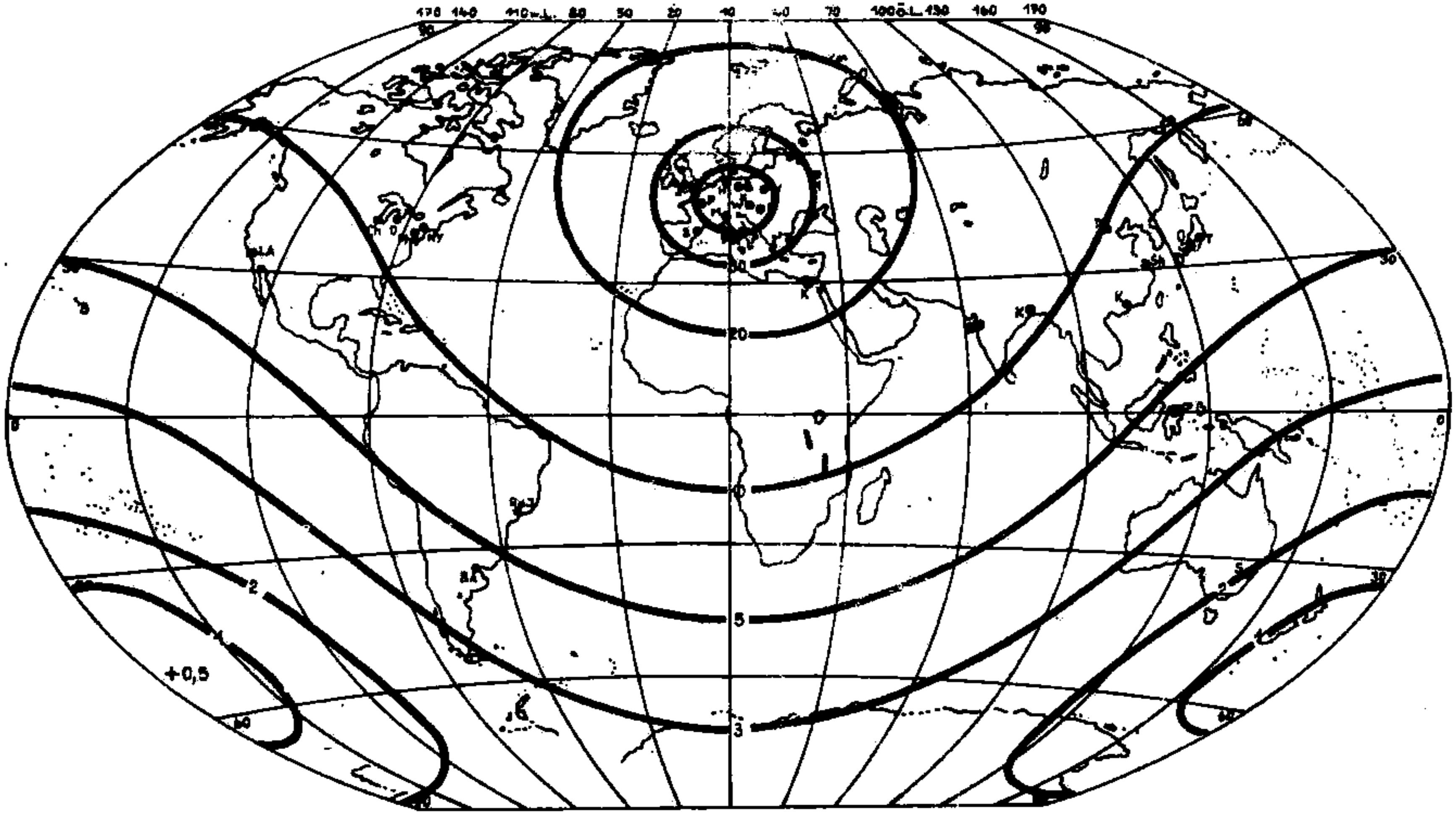
Fig. 96: Relationship between attack range a and bomb load B, i.e. load ratio , in the case of point attack with double propulsion and landing at the antipodal point for c = 3000, 4000 and 5000 m/sec.

two characteristic weight-ratios $G_1/100$ and $10/G_2$ for the outward-bound flight and the flight to the auxiliary point, respectively. Thus to each distance of attack _a_ and to the corresponding return distance ka, the required weight-ratios and the possible bomb load $B = G_1 - G_2$ can be gotten from Fig. 80. For k = o, we get the curves of Fig. 80; for k = 1, those of Fig. 82, and for all other values of k we get intermediate values, which for the case of c = 4000 m/sec, are shown in Fig. 94. Compared to the previous maximum possible range of attack of 5000 km, we now have unlimited ranges of attack up to 20000 km. if an auxiliary point is available sufficiently near near the target. Fig. 95 shows the contours of constant bomb-load in using an auxiliary point in the Marianas - i.e. when a landing is made at the auxiliary point after the attack. Since a point attack with two propulsions and use of an auxiliary point is sensible only for those parts of the earth's surface which are nearer to the auxiliary point than to the home base, the largest circle whose points are equidistant from home base and auxiliary point has been marked on Fig. 95. The bomb lines are limited to the region of the earth's surface beyond this. The possible range of attack in this case includes all of East Asia and a large part of the Western Pacific. For c = 3000 m/sec, the bomb-load curves shrink to small circles around the auxiliary point; for c = 5000 m/sec, they spread out over practically the whole hemisphere opposite Europe. When using an antipodal auxiliary point, a + ka = 20000 km, and the possible bomb loads have the values shown in Fig. 96. In this case bomb loads are possible only for quite large ranges of attack - for c = 4000 m/sec, only beyond 17,800 km, i.e. in a small circle around the antipodal point with a 2200 km. radius. Whereas an antipodal auxiliary point can be important for area attacks, it is of value for point attacks only when the point itself is to be protected (say against attacks by a fleet) by rocket bombers from the home field.

As an example of point attack with two propulsions and auxiliary point, an attack on the locks of the Panama Canal and landing at an auxiliary field on the American West coast will be described briefly. For c = 4000 m/sec, the bomb load is 2 tons; the characteristic numbers for the attacking flight are: Takeoff: time 0 sec, weight 100 tons, velocity 0m/sec, altitude 0 km, distance travelled 0 km; Climb from takeoff track to northwest; 11 sec. after takeoff; weight 100 tons, velocity 500 m/sec, altitude 0 km., distance 3 km. End of the motorless flight: time 36 sec, weight 100 tons, velocity 284 m/sec, altitude 3.7 km, distance travelled 12 km; End of Climb Period: time 332 sec, weight 26 tons, velocity 4560 m/sec, altitude 60 km, distance travelled 512 km; End of Supersonic descent: 3882 sec., weight 26 tons, velocity 300 m/sec., altitude 14 km., distance 9390 km. End of Subsonic Descent: the subsonic descent ends with the start of the diving attack; the final altitude is thus determined by the succeding dive. Since for an attack on the Canal-locks maximum accuracy of hits is more important than high impact velocity of the bomb, the end of the subsonic descent is chosen as 2 km. altitude. From this we get the other numbers: time 4162 sec, weight 26 tons, velocity 142 m/sec, distance travelled 9450 km; End of Dive-attack: the dive-attack goes from 2 km. to about 0.5 km. altitude; the final velocity of the dive is about 200 m/sec; then the bombs are released and the aircraft goes off with small loss in velocity, approaching to within negligible distances from the earth's surface. From this we get the values: Time 4172 sec, weight 24 tons, velocity 200 m/sec, altitude 0 km, distance travelled 9450 km;
End of the Second Climb Period: time 4405 sec, weight 10 tons, velocity 2800 m/sec, altitude 22 km., distance travelled 9710 km;
End of the Second Supersonic Glide-Flight: time 6125 sec, weight 10 tons, velocity 300 m/sec, altitude 20 km., distance travelled 12550 km;
End of the Second Subsonic Glide-Flight: time 6785 sec, weight 10 tons, velocity 80 m/sec, altitude 0 km., distance travelled 12648 km;
Landing: time 6810 sec, weight 10 tons, velocity 0 m/sec, altitude 0 km., distance travelled 12650 km.

4. Point Attack with Sacrifice of the Bomber

According to the previous considerations the rocket bomber with moderate exhaust speed can carry out attacks against small individual targets up to 6000 km. distance from the home base; if there is an antipodal auxiliary point, the range extends to 2000 km. from this point; for arbitrary auxiliary points distributed over the earth's surface, the range is the same distance from each of the points. If however the point attack is to be directed at a target in whose vicinity there is no auxiliary point, there is the possibility that the bomber proceeds exactly as described in the previous section, and lands at a corresponding point near the target even though the technical installations of an auxiliary point do not exist there. In this case it will no longer be able to take off from this point under its own power but will not in general be lost if the landing does not occur in enemy territory If there is no other possibility than landing in enemy territory, then we are left with a last, not to be neglected, way out-point attack with single propulsion and sacrifice of the bomber.

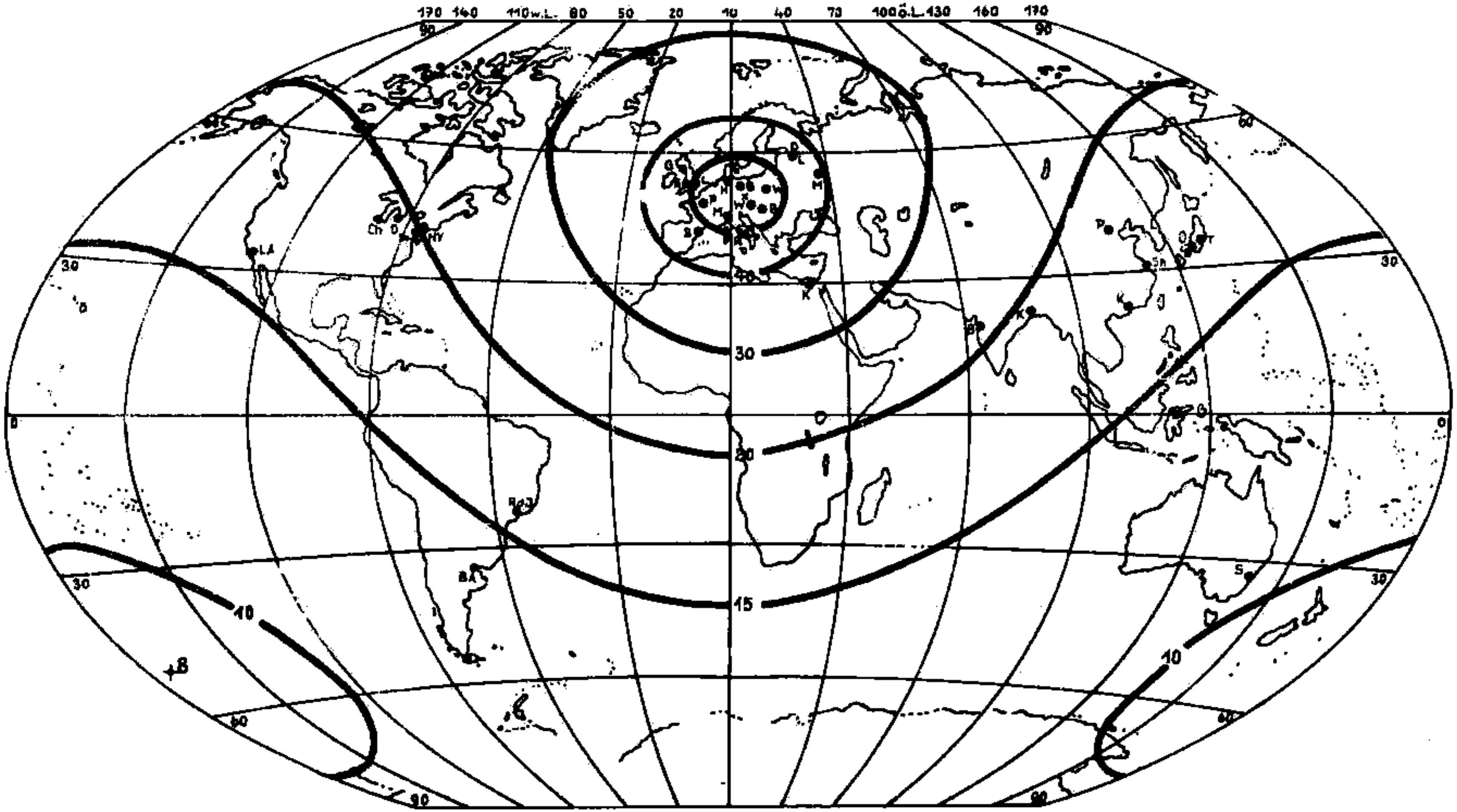


● Cities of more than one million

+ Antipodal base point

× Home base

Fig. 97: Bomb load of a Rocket Bomber in tons, that is percent of the initial weight, in the case of point attack with a single acceleration and sacrifice of the bomber and with exhaust velocity c = 3000 m/sec.



● Cities of more than one million
× Home base
+ Antipodal base point

Fig. 98: Bomb load of a Rocket Bomber in tons, that is percent of the initial weight, in the case of point attack with a single acceleration and sacrifice of the bomber and with exhaust velocity c = 4000 m/sec.

Since the aircraft gains altitude rapidly after bomb release in a point attack, the pilot can, at the end of this brief climb, parachute from the plane and destroy the empty aircraft to keep it from getting into the hands of the enemy. He will land a few km. away from the point of the impact of his bombs, and be captured. From the point of view of performance this procedure represents the limiting case of the point attack procedure described in the previous section, for which $k = o$, i.e. the return flight distance is zero. Figs. 97 and 98 show the possible bomb-loads for this method of attack. In all cases, the attacking range covers the entire surface of the earth; at $c = 3000$ m/sec. 0.5 tons of bombs can still be carried to points most distant from the home base; for $c = 4000$ m/sec. this figure increases to 8 tons, and for $c = 5000$ m/sec. to 17 tons. This procedure is naturally also suited to unpiloted use of the rocket bomber.

5. Area Attack with Full Turn

This first procedure for area attack corresponds to the first point attack procedure described, with the difference that the energy supplied at the start of the flight must suffice for the outward flight and the entire return trip to the home base; thus large kinetic energy is present over the target, and considerable fractions of this energy are lost in turning. An outline of the entire flight path including the path of the bomb is included as a sketch in Fig. 99. In order to calculate the relation shown between bomb-load B and range of attack a, one can proceed as follows: from IV 3, S_5, the length of the subsonic glide is known. From Fig. 79, we get the value of V_{w2} for $(a - S_5 - W)$; from Fig. 99 we get V_{w1}. Now the length of the climb, S_3, must be estimated by reading off from Fig. 64 a first value of G/G_0 for an assumed V_1, and then getting from this a first estimate of S_3. Then $(a - S_3 - W)$ is given from $S_5 + (a - S_5 - W) - S_3$. The initial velocity V_1 on the supersonic descending path, in order to have velocity V_{w1} after a length of glide of $(a - S_3 - W)$, can be obtained as described from Fig. 79. This value is to be compared with the estimated value and improved, if necessary. From Fig. 64 we now get the desired G and $B = G - 10$. From Fig. 83, the stationary altitude H_2 for given V_{w1} and G, is known, and finally the range of projection of the bomb, W, corresponding to V_{w1} and H, is read from Fig. 87. The range of attack, a, is thus $a = S_5 + (a - S_5 - W) + W$. This calculation contains a few assumptions which should be considered briefly. First, the assumption is made that relations between velocity and distance calculated for particular flight paths can be transferred, unaltered, to similar flight paths. More important is the assumption that the supersonic descending path, during the flight before bomb release and during the turn, is carried out at the stationary altitude, rather than in the strongly oscillating dynamical flight path. This is necessary for the decisive third phase of aiming, in order to attain the necessary aiming accuracy for the bomb release and in order to release the bombs during horizontal flight. Stationary altitudes of flight are also necessary for the period of turn in order to set up the aerodynamic turning-forces.

This last circumstance is connected with the fact that turning is possible only up to definite velocities of flight below the velocity of points on the earth's surface; for higher velocities, other methods of attack must be used. For this reason the procedure of area attack with single propulsion and full turn is limited to the ranges (up to 12000 km.) marked in Fig. 99. Inside this space it proves to be extremely effective despite the very costly turning process.

Figs. 100 and 101 show the lines of equal bomb-weight dropped at the target by this area attack procedure, for $c = 3000$ and 4000 m/sec. For the former value of exhaust speed, the domain of attack is bounded by a closed curve which deviates from a circle because of the earth's rotation, and whose periphery touches the North Pole, Newfoundland, Central Africa, and Central Asia. For $c = 4000$ m/sec, the ring expands so that now only Australia, the South polar regions, the South Pacific and the southern tip of South America do not lie within it. For $c = 5000$ m/sec. it would cover the whole surface of the earth.

As an example of area attack with single propulsion and full turn, we use the attack on New York at a range of 6500 km. For $c = 4000$ m/sec, the bomb load is 6 tons, and the detailed attack runs as follows: the motor starts to work 36 seconds after the take-off at 12 km. distance from the take-off point, and consumes the total fuel supply of 84 tons in the next 336 sec. At the end of the climb process, the aircraft reaches a velocity of 6370 m/sec, an altitude of 91 km, a distance of 736 km. from the point of take-off, and a weight of 16 tons. Using only its store of potential and kinetic energy, the bomber flies on to the point of bomb release, 5550 km. from the take-off point, and 950 km. in front of the target. At this point, which is reached 1150 sec. after take-off, the velocity has decreased to 6000 m/sec, and the stationary altitude to 50 km. After the bomb release the weight is 10 tons. Then the aircraft goes into a turn and in 330 sec. goes through a turn-spiral 1000 km. in diameter until it has reached the direction for the return flight to the home base. During turning, the altitude is greatly decreased in order to develop

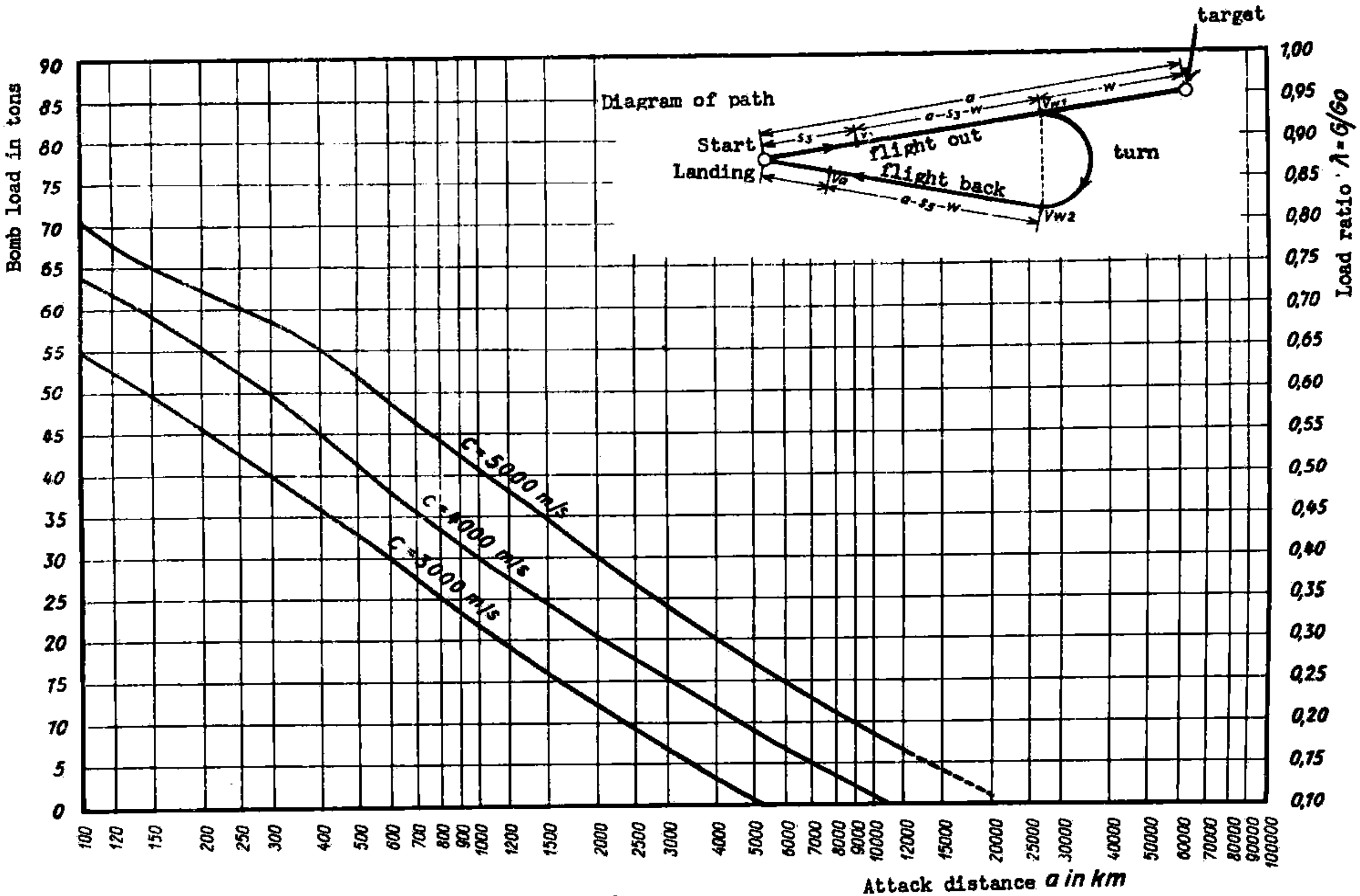


Fig. 99: Relationship between attack range a and bomb load B (i.e. load ratio G/G_o) in the case of area attack with turn around for the exhaust velocities c = 3000, 4000 and 5000 m/sec.

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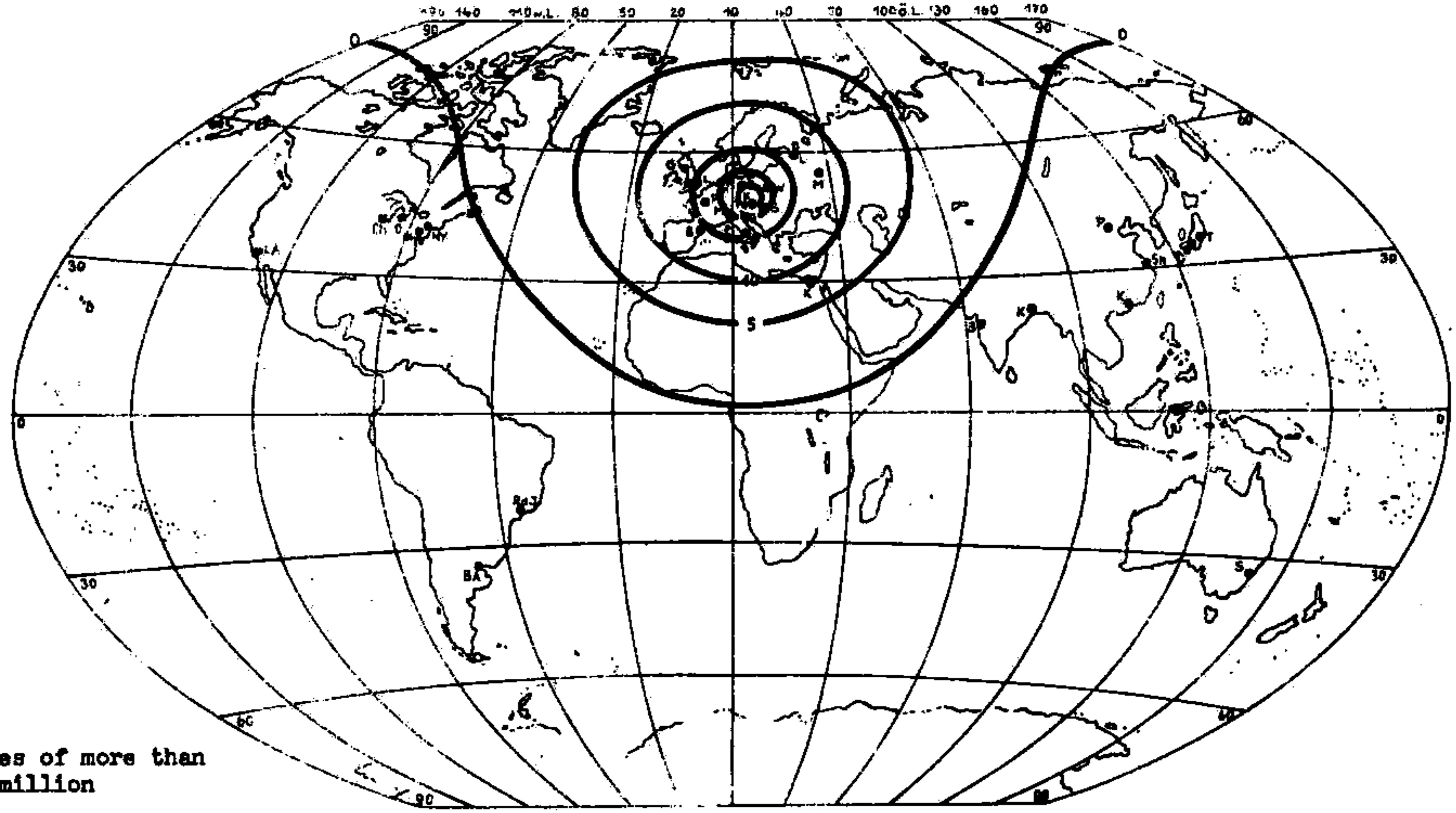
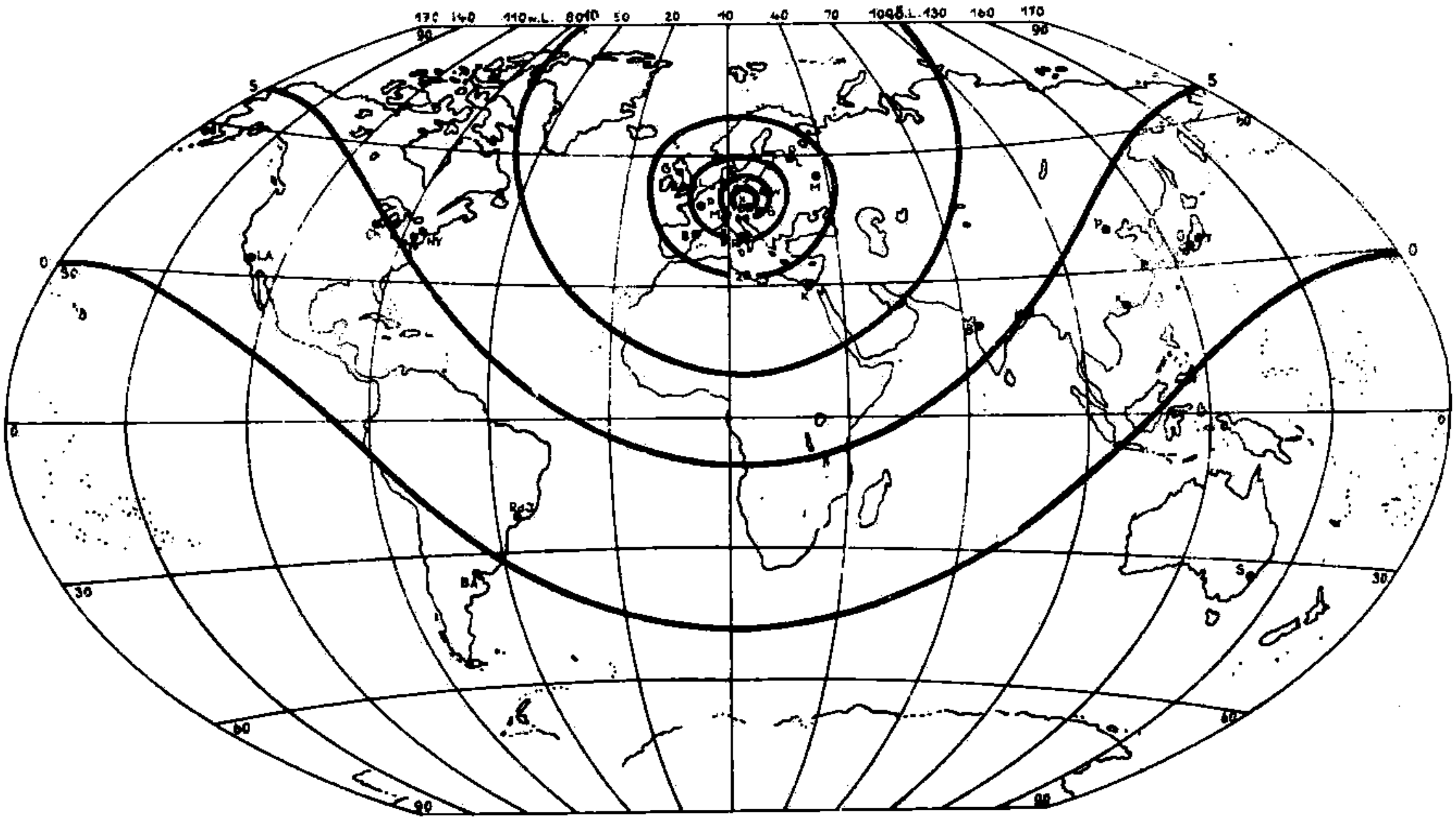


- ● Cities of more than one million
- x Home base

Fig. 100: Bomb load of a Rocket Bomber in tons (i.e. percent of the take-off weight) in the case of area attack with turn around and an exhaust velocity c = 3000 m/sec.



● Cities of more than one million

× Home base

Fig. 101: Bomb load of a Rocket Bomber in tons (i.e. percent of the take-off weight) in the case of area attack with turn around and an exhaust velocity c = 4000 m/sec.

the aerodynamic forces necessary for the turn. At the end of the turn path, the velocity is still 3700 m/sec. and the corresponding stationary altitude is 38 km. The supersonic glide-path in the direction of the home base goes over 5450 km. in 2600 sec. and ends 100 km. before the home base at an altitude of 20 km. and velocity 300 m/sec. Subsonic glide and landing are completed in customary fashion. The whole flight lasts 4755 sec.

6. Area Attack with Partial Turn and Auxiliary Point

This type of attack corresponds to the point attack with two propulsion periods, partial turn and auxiliary point. Like the latter, the area attack discussed here represents the most general case in its class, and includes all other procedures for area attack as special cases.

The course of an area attack with single propulsion, partial turn and auxiliary point consists essentially of first giving the bomber, during a single propulsion period, all the power which it requires until landing at the predetermined auxiliary point, having the bomber release its bombs in front of the target, at high altitude and flight velocity, as for area bombing, then carry out a turn at the existing high speed immediately after the bomb release, which takes it into the direction of the auxiliary point at which a landing is contemplated, and finally glides with its residual energy to this auxiliary point and lands there.

The first thing to determine is the relation between bomb load B and attack-range a. This relation is affected by the distance ka between target, and auxiliary point, the angle of turn σ through which the bomber goes after release, and the exhaust speed c. Because of the large number of independent variables, the relations are many-sided. For example, Fig. 102 shows the relation between a and B for a large number of distances of return flight, ka, and for a definite angle of turn, $\sigma = 60°$. The procedure of computation which gave these curves was the following: Assuming a definite c, a bomb-load B was chosen. To this there corresponds a mass-ratio $G/G_0 = (10 + B)/100$, a length S_3 of climb path, and from Fig. 59 a final velocity V_1. For this maximum velocity V_1, one can now choose various ranges of attack $a = S_3 + S_4 + W$ in such a way that before the bomb release, (i e. at the end of the outward flight over $S_1 + S_2 + S_3 + S_4$), a sufficient supersonic speed still exists. For this velocity and various turn-angles σ, we can, with the aid of Fig. 81, calculate the loss of speed and the distance S_w travelled during the turn, and from the residual velocity finally calculate the " distance of return " from release point to landing-point. By several repetitions of this procedure, and interpolation between the rough S_H - values found, the ka -curves of Fig. 102 were obtained.

Fig. 103 again shows the lines of constant bomb load for a rocket bomber using this procedure of attack, if an auxiliary point on the west coast of America is used. It should be pointed out that for turn-angle $\sigma = o$, there is a definite bomb-load with which the bomber reaches the auxiliary point and can release its load at any point enroute without altering the range, provided the release occurs after the motor is turned off. Thus for $\sigma = o$ the range of is anywhere between take-off point and auxiliary point. According to Fig. 103, this bomb load is 5 tons for $c = 3000$ m/sec. With smaller bomb loads the possible area of attack stretches over all of North America and considerable portions of South America and the Pacific Ocean.

7. Area Attack with Antipodal Auxiliary Point

A special case of the area attack described in the previous section occurs if the auxiliary point is at the antipodes of the home base. In this case the turn-angle is zero for all targets. Thus there are no energy losses due to turning at speeds above that of sound. The relation between bomb-load B and attack-range a can be obtained from the equations of the preceding section for $\sigma = o$ and a + ka = km. For a rectilinear flight with total distance $a (1 + k) = 20000$ km, with the present approximations it does not matter at what place on the glide-flight the bombs are released. Thus, within the 20000 km. range of flight, the range of attack is arbitrary and independent of bomb load. From Fig. 80, the possible bomb load is 0.7 tons for $c = 3000$ m/sec, B = 8 tons for $c = 4000$ m/sec, and B = 17 tons for $c = 5000$ m/sec.

8. Area Attack with Circumnavigation

Another special case of the general method of area attack discussed in Section VI 6 - the area attack with single propulsion period and circumnavigation - results for $\sigma = 0$ and a + ka = 40000 km. The relation between bomb-load B and attack-range a can be read off from Fig. 80,

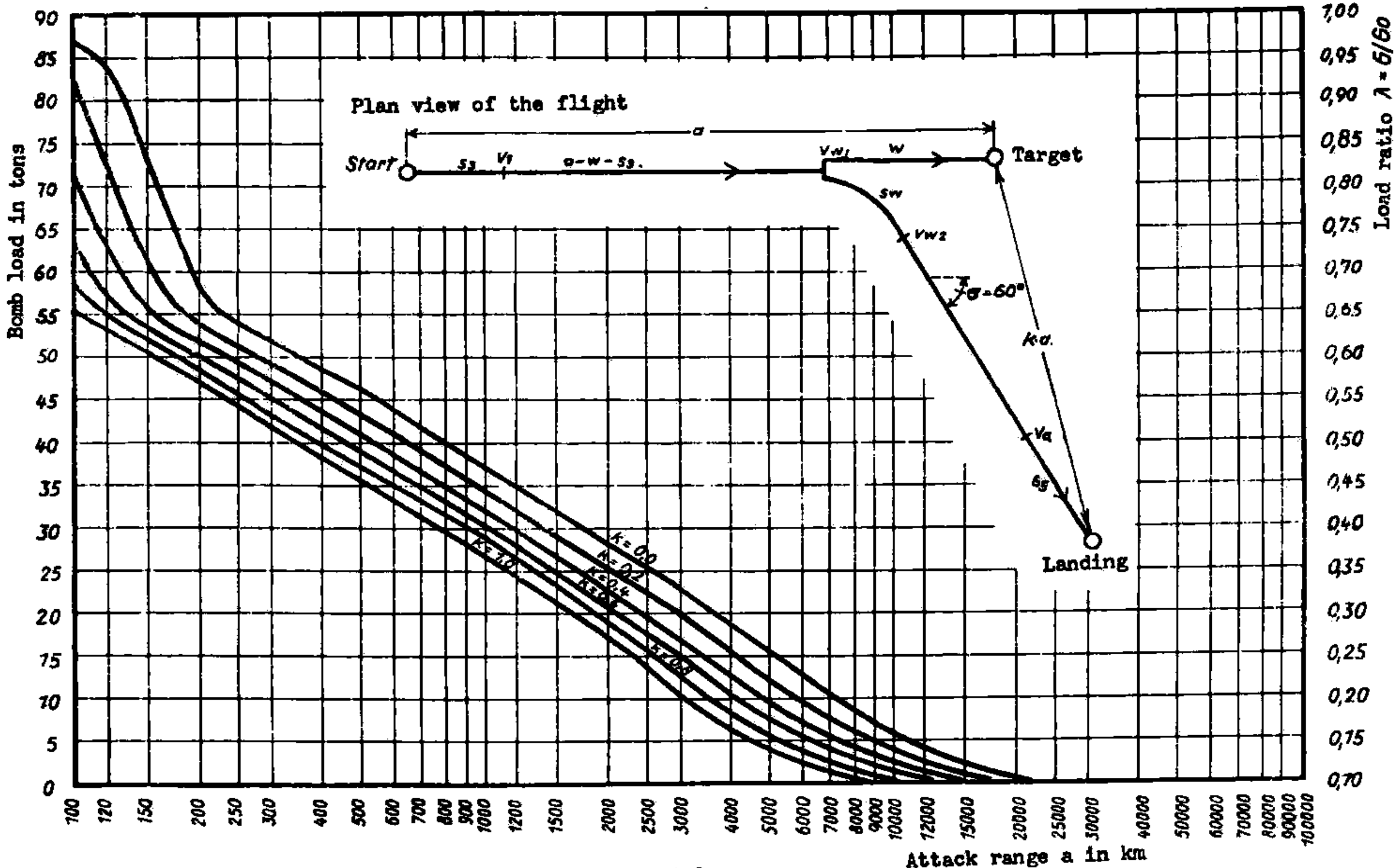
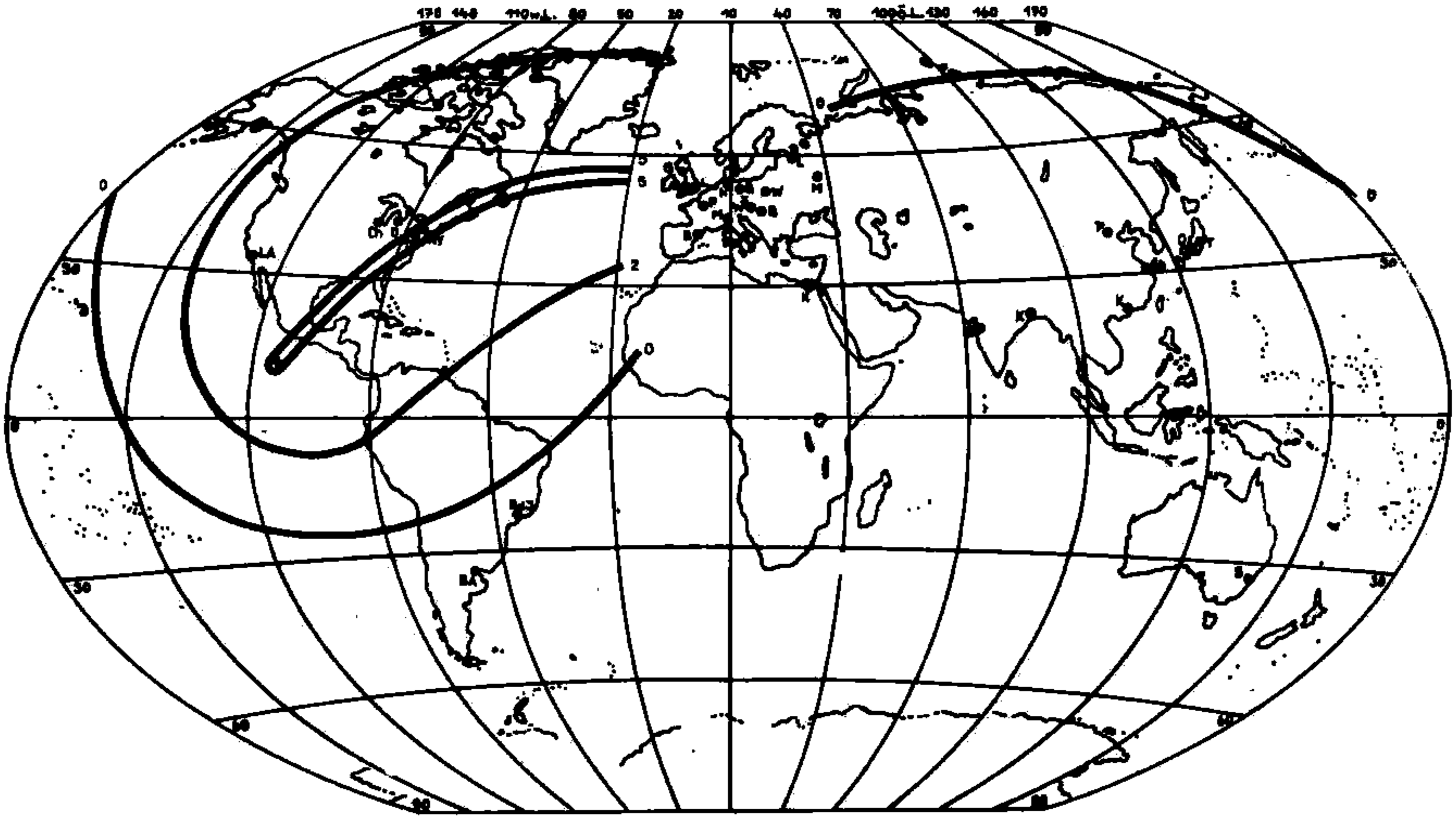


Fig. 109: Area attack - dog leg course - turning angle = 60°=constant. Return flight range, k x a, various fractions, k, of the distance a, to the target. Exhaust velocity = 3000 m/sec.



+ Secondary base on American West Coast

● Cities of more than one million

× Home base

Fig. 103: Bomb load of a Rocket Bomber in tons (i.e. percent of the initial weight) in the case of area attack using a secondary base on the American west coast and an exhaust velocity c = 3000 m/sec.

where the rule again holds that the place of bomb release has no effect on the range, so that the range of attack, a, is completely arbitrary and independent of the bomb load. From this figure, the largest bomb load with which circumnavigation is still possible is $B = 3$ tons for $c = 4000$ m/sec, $B = 12$ tons for $c = 5000$ m/sec, while for $c = 3000$ m/sec, circumnavigation cannot be achieved even without a bomb load. This method of attack shows most clearly the extreme technical superiority of the rocket bomber which with a size and empty weight equal to that of a medium military craft can, at moderate exhaust speeds, reach every point on the earth's surface with a bomb load of 3 tons, and flies 40000 km. all around the earth without an intermediate landing.

As an example of an area attack with single propulsion period and circumnavigation, we shall use the attack on the city with a million population most distant from Germany - Sidney in Australia. In this case the range of attack is 16500 km., the possible bomb load is 3 tons. The flight goes as follows: Take-off and motion after take-off do not differ from the same phases of previous examples. 36 sec. after take-off the motor begins to operate and consumes the 87 tons of fuel on board in the next 348 sec. At the end of this climbing process the velocity is 7200 m/sec., the altitude 101 km., distance from takeoff-point 815 km. and weight 13 tons. This very high initial speed drops to 300 m/sec. in the course of the supersonic descent which is 39185 km. long. After a 10000 km. journey, the strongly oscillating descent must be damped sufficiently so that at the release point, 15400 km. from take-off, it runs smoothly enough at the stationary altitude to enable accurate aiming for the bomb release. At the release point the altitude is 49 km., the velocity is 6400 m/sec., and the range of projection of the bombs is 1100 km. After release the bomber starts its supersonic glide with only 10 tons weight, during which the course which was previously in a plane has to be altered slightly in order to lead back to the home base. There the bomber lands 13060 seconds after take-off, having travelled 40,000 km.

9. Evaluation of Procedures for Attack

Procedures of point attack are directed against individual houses railroad stations and tracks, tunnel entrances, streets, bridges, dams, single ships, canals, dikes, breakwaters, gas-water-and oil-tanks, munitions depots, magazines, power stations, transformer stations, airdromes, harbors, factories, troop concentrations, etc; they are limited to a radius of several thousand km. around the home base, except for special cases where the bomber is sacrificed or flies on to an auxiliary field, when the range of attack can extend over the whole of the earth's surface.

Procedures of area attack can be directed against the entire earth's surface. The probable scatter of bombs over several kilometers limits them to target areas of this magnitude, e.g. cities with over a million population, large industries, fleets, etc. If in an area attack, the total energy Z in kcal is released against a single target with a probable scatter $W_r = 2$ km., then half the hits lie in a circle of 2 km. radius; the average density of hits on this unit surface is $\bar{z} = Z/2w_r^2\pi$ the actual density follows a Gauss error curve $z_r = 1.398\bar{z}\, e^{-0.694 r^2/w_r^2}$ has the value $1.4\,\bar{z}$ at the center, and is ½ of this at the boundary of the area 4 km. in diameter. Fig. 104 shows such a distribution curve of bomb hits over a map of New York. If larger connected surfaces than the unit surface described are to be attacked, several points of the target can be aimed at, so that the individual Gauss error curves partially overlap somewhat like those of Fig. 105, where the distance between aiming-points was chosen as $W_r\sqrt{2\pi}$ so that the average density over the whole surface is $\bar{z}$, while the local densities are shown as contour lines.

From the appropriate literature the following relations can be gotten between average density of destructive energy $\bar{z}$ in kcal/$_{km}$2 and the resultant destructive effect; $\bar{z} = 7\times10^6\ \frac{kcal}{km^2}$. puts industrial installations completely out of operation for several days. (Degree of destruction I)

$\bar{z} = 1.4\times10^8\ \frac{kcal}{km^2}$ destroys cities so that all except specially reinforced buildings collapse, and only cellars and foundations are usable (Degree of destruction II)

$\bar{z} = 1.4\times10^9\ \frac{kcal}{km^2}$ destroys cities so that cellars are also smashed in, all people inside the area are killed and only foundation walls remain standing (Degree of destruction III)

$\bar{z} = 7\times10^9\ \frac{kcal}{km^2}$ makes cities so flat that their location is no longer discernible against the background. (Degree of destruction IV).

If the energy content of the bomb at rest is assumed to be $E_0 = 700\ \frac{kcal}{kg}$, then with E =

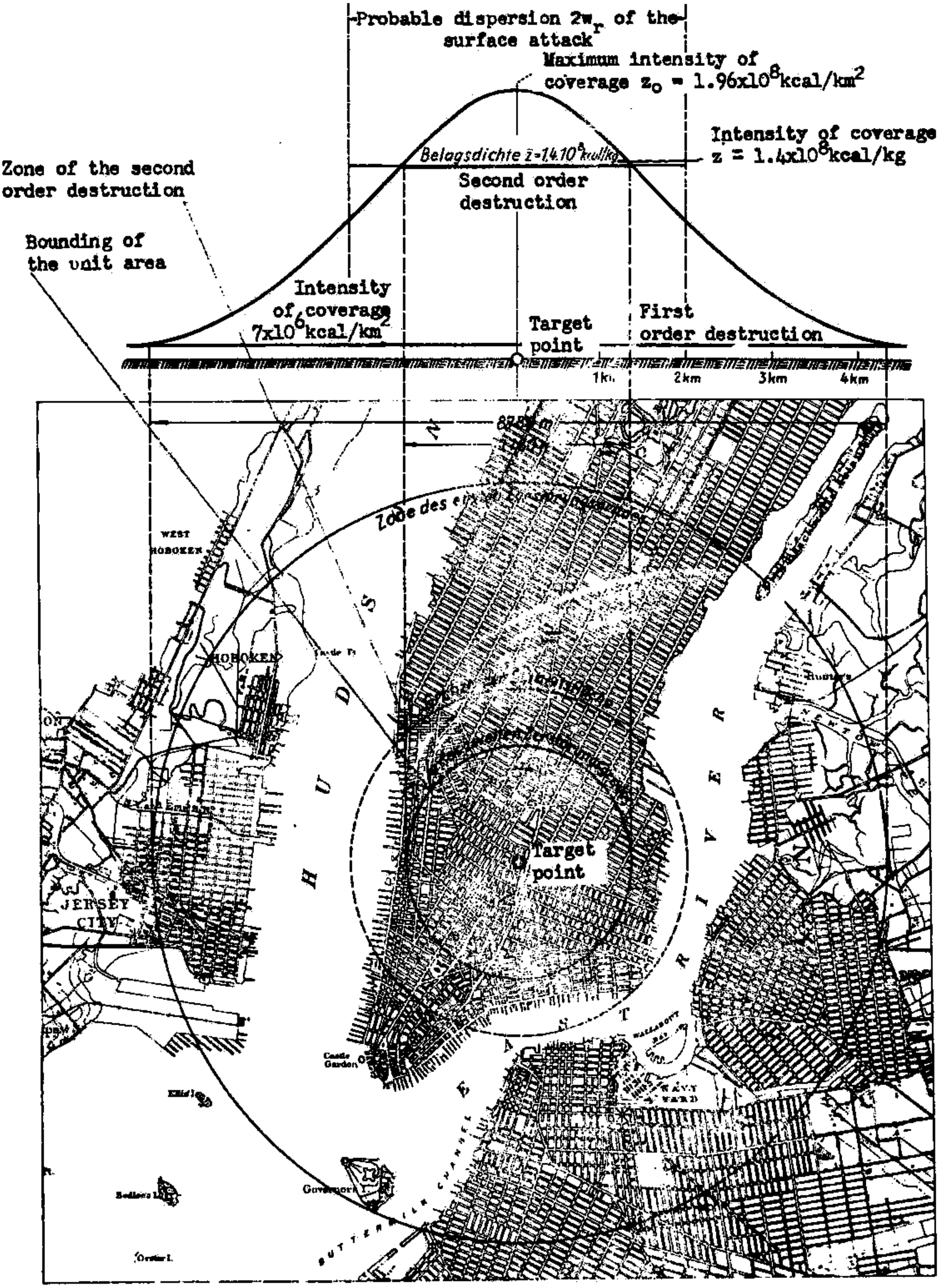


Fig. 104: Hit distribution in area attack against a target point in the center of New York.

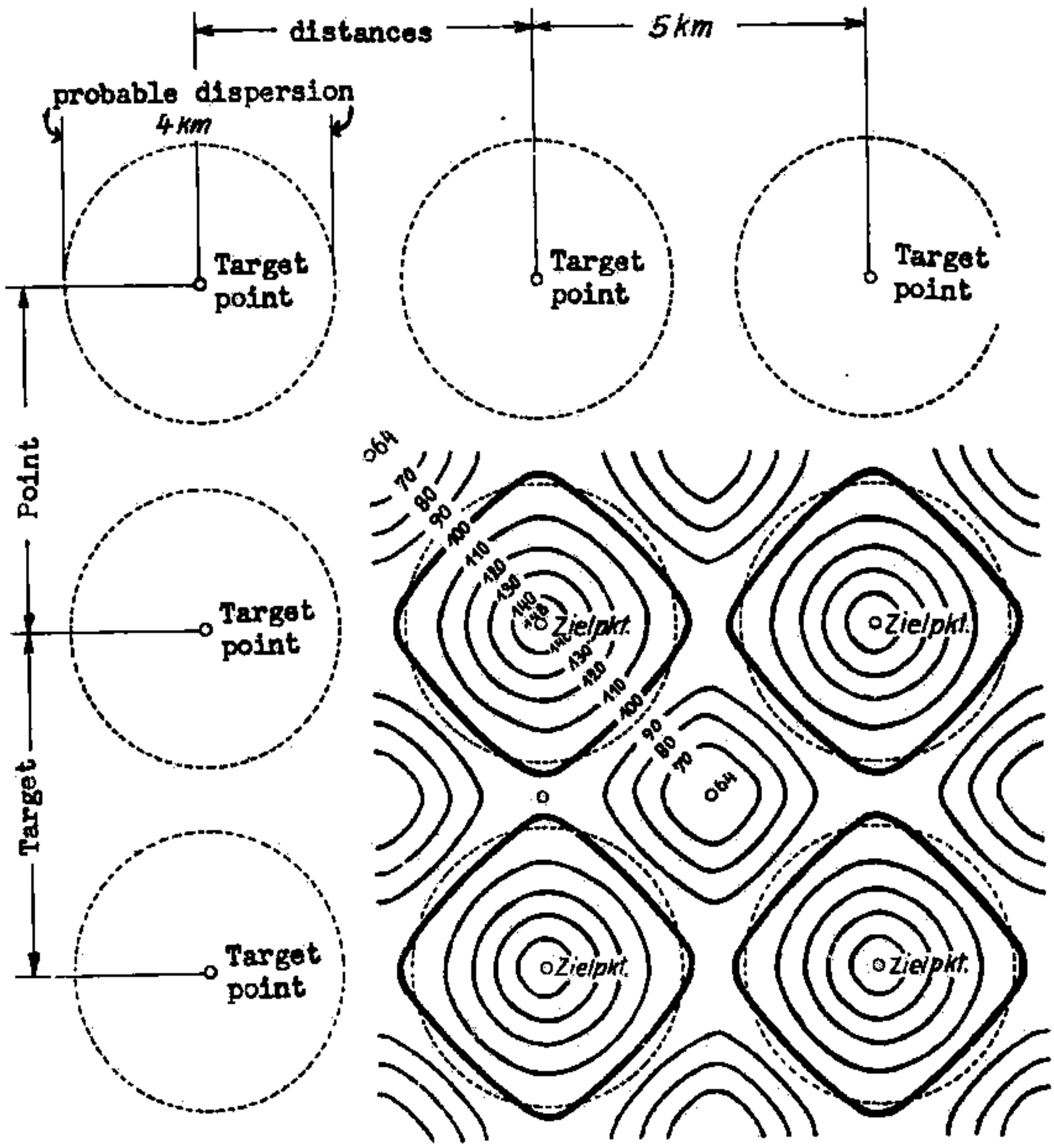


Fig. 105: Target distribution in the case of attack on very large surfaces and contour lines of equal bomb hitting density in percent of average value

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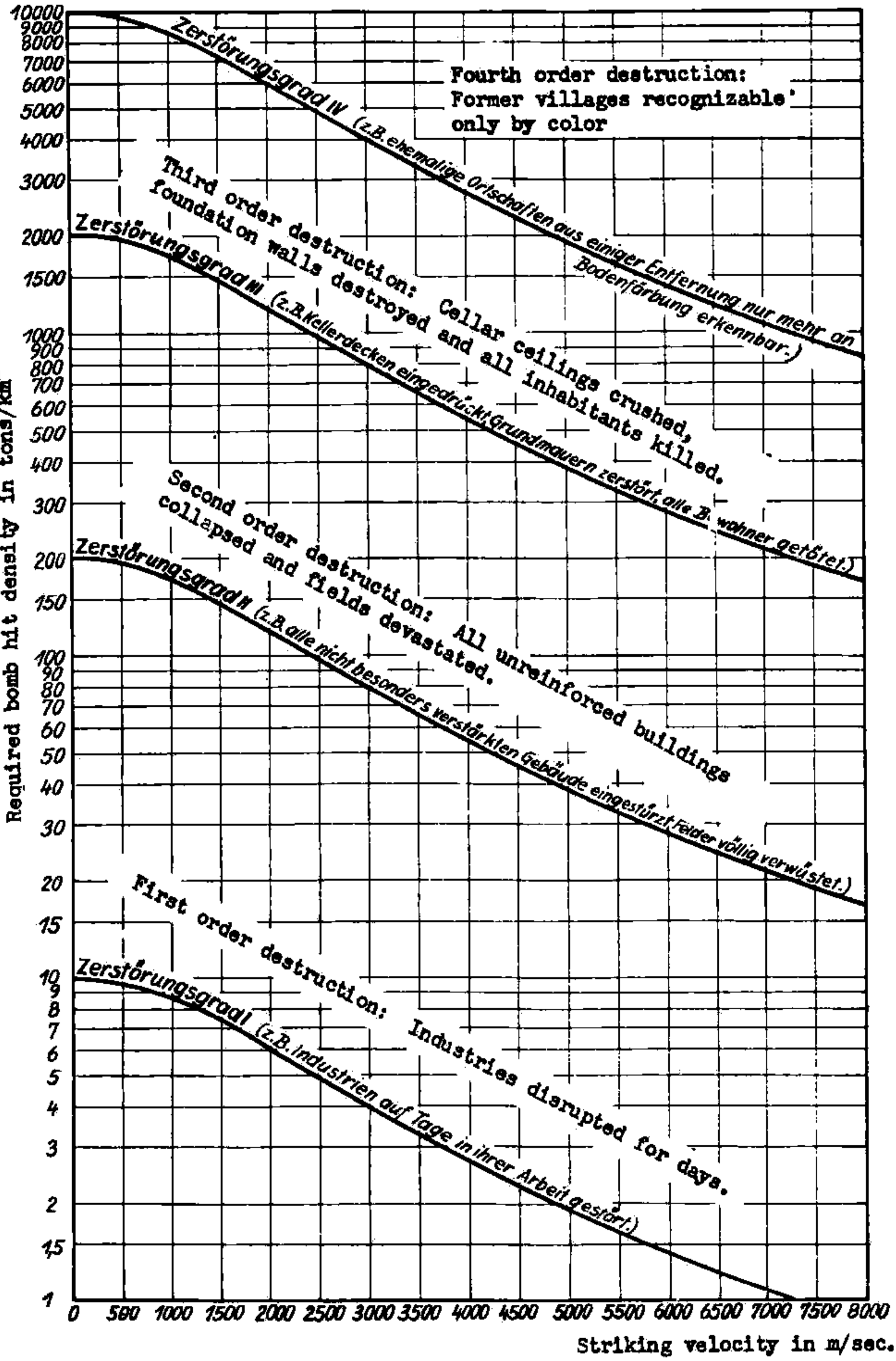

Fig. 106: Required bomb hit density to produce first to fourth order destruction as a function of the striking velocity of the bomb.

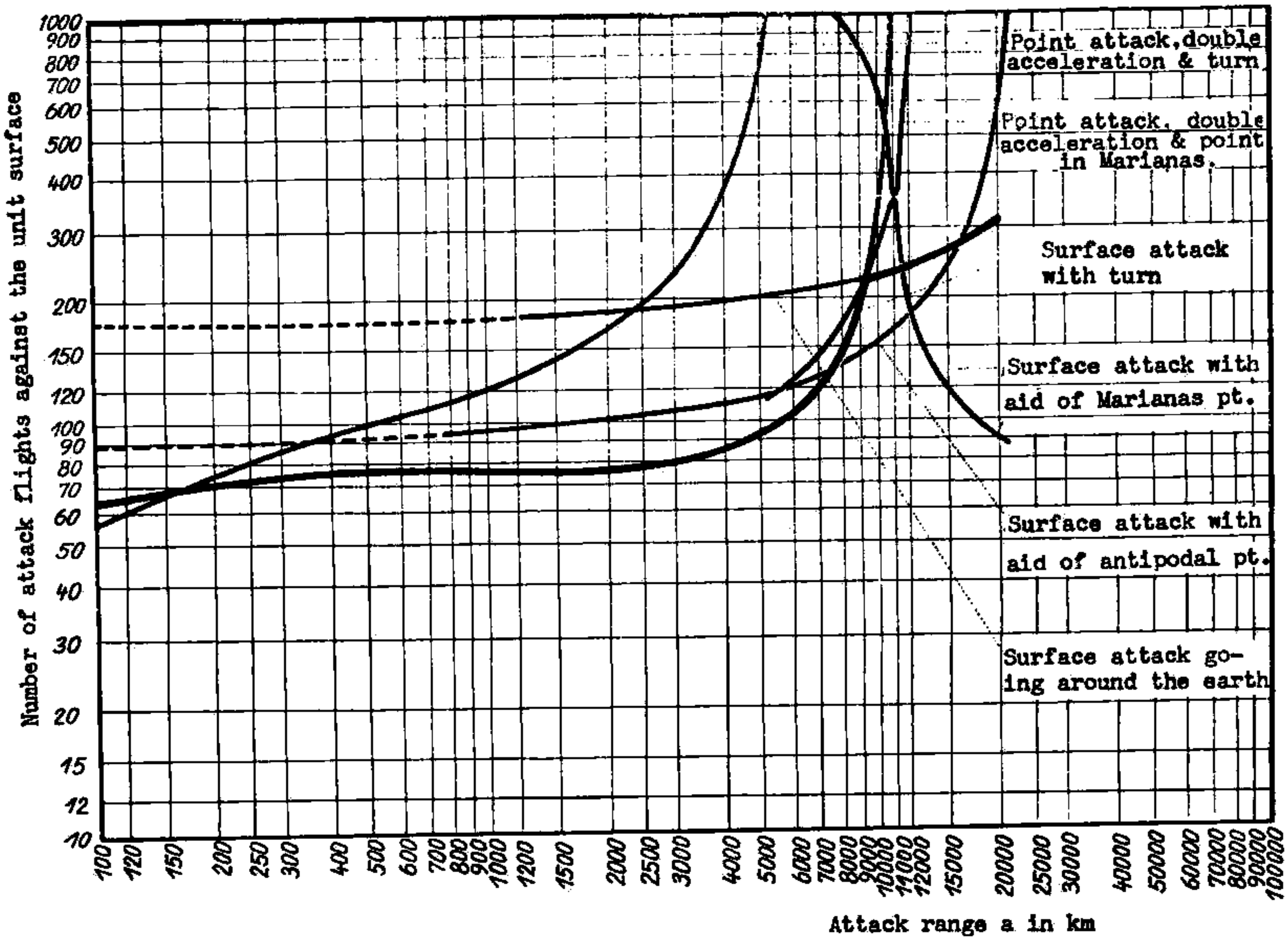

Fig. 107: Number of required sorties to cover the unit area and its surrounding, using various methods of attack, with a total of 3.52×10^9 kcal destructive energy, as a function of the attack range a.

$700 + Av^2/2g$, the density of bomb hits in tons/$_{km}2$, independent of the impact velocity V of the bomb is obtained from Fig. 106.

In order to destroy, to the 2nd degree, the surface of a city having an area equal to the previous unit surface, one must release against the target $Z = 2 \times 12.56 \times 1.4 \times 10^8 = 3.52 \times 10^9$ kcal of destructive energy, corresponding to 5000–420 tons of bombs depending on the velocity of impact. Then the concentration, as shown in Fig. 104, rises to $1.96 \times 10^8 \frac{kcal}{km2}$ near the aiming-points, is $0.98 \times 10^8 \frac{kcal}{km2}$ at the edge of the unit circle, and $1.14 \times 10^8 \frac{kcal}{km2}$ at 4 km. distance from the aiming point.

The number of flights necessary for dropping this amount, Z, of destructive energy on the unit surface is 84 if the bomb load is 60 tons and the impact velocity is low, or 420 if we assume the smallest bomb load - 1 ton -, and an impact velocity of 8000 m/sec. Fig. 107 shows plot of the number of attacks necessary against the unit surface, for various procedures of attack, against range of attack, for $c = 4000$ m/sec. If the unit surface is to be attacked with the minimum number of flights, then the procedure of point attack with double propulsion and full turn is best. If a single unit surface is to be bombed, this superiority is doubled, because then all the energy lies inside the unit circle, and only half as many bombs need to be dropped. For greater ranges of attack up to 8000 km., the procedure of area attack with single propulsion and full turn is far superior to all other procedures, especially since it does not depend on the use of an auxiliary point. A remarkable thing about the curve for this procedure is that the required number of flights does not increase mono onically with the range of attack, but rather that the decreasing bomb load is completely compensated by the increasing impact energy. Corresponding to the full curve, the number of flights actually required when using area attack with full turn or circumnavigation fluctuates between 64 at 1000 km. and 322 at 20000 km. range of attack. The evaluation of attack procedures shown in Fig. 107 assumes that the total consumption of take-off fuel, fuel for the aircraft, and of bombs, which together represent a constant amount of 133.7 tons per flight, shall be a minimum. Since the bombs are much more valuable per unit weight than the fuel, one can also set a requirement of minimum consumption of bombs. In Fig. 108 several procedures of attack are plotted from this viewpoint; we see that here the point attack procedures are very inferior while area attack procedures, which operate with high impact velocities of the bombs, are most favorable, especially area attack with circumnavigation and - at long ranges-, with full turn, which requires in this region the least total consumption as well as least consumption of bombs.

Fig. 109 shows an idealized distribution of hits, according to the laws of probability, over a city map of Berlin, where it is assumed that 84 bombs of 60 tons weight are dropped on the aiming point with low impact velocity; the half shown lies in the 50% circle; about each point of impact a circle of destruction of diameter 618 m results in which the energy density 1.4×10^8 kcal/$_{km}2$ required for degree II exists.

Fig. 110 shows the corresponding distribution of hits for 140 releases with 8000 m/sec. impact velocity and 3 tons weight per release; again the average energy in the unit circle is 1.4×10^8 kcal/$_{km}2$, but the area of destruction for the same energy per release is now drop-shaped and includes 180000 m^2, as previously derived.

VII. THE LINE OF DEVELOPMENT OF THE ROCKET BOMBER

The development of the rocket bomber project will follow roughly the sequence of 12 stages outlined below:

1. Development of the Combustion Chamber and Jet of the Motor

The main problems in this stage concern the introduction of the solid, liquid, or already vaporized fuel and the combustion-maintaining material, into a combustion chamber through injection nozzles; then the rapid distribution, mixing, heating and ignition of the fuel, its most complete combustion at more or less constant high pressure to a combustion gas at very high temperature; then the expansion of these gases in a jet to convert them to a beam of gas with as high streaming velocity and as low temperature as possible. The very high pressures and temperatures in the combustion space have the consequence that not only the tubes for the streaming process in the motor, but also the construction of all walls in contact with the flame, becomes a very serious problem, whose solution as regards choice of materials, methods of cooling, and constructional arrangement, should be a main point of study. Also important are questions of shape and relative size of combustion chamber and jet, choice of most suitable flame pressures, measurement of stream temperature and velocity, arrangements for rapid heating and mixing of the fuel, optical and acoustic phenomena, mixing of the jet with the surrounding air behind the motor, dissociation- and detonation-problems, and numberless others.

2. Development of Special Fuels for Rocket Motors

In many respects quite different requirements are to be set for rocket motor fuels than for the fuels of ordinary aircraft motors. In the first place, what counts is the available energy content per unit mass of the combustion mixture of fuel and, say, oxygen, and not the heating value of the fuel alone Thus a combustible material which has a lower heat of combustion than the usual hydrocarbons, but consumes much less oxygen in burning, can develop a far superior heat output of the mixture. In addition to the heat output of the mixture, other combustion characteristics such as ease of ignition, rate of combustion, tendency to detonate, degree of dissociation, state of aggregation of the combustion products, reaction temperatures, etc., are important. One must also consider properties not so directly connected with the combustion, such as procurement and cost, ease of storage in tanks on the aircraft, density, danger, ease of feeding of the fuel, etc. If one enumerates the problems of atomic hydrogen and nitrogen, of nuclear reactions and of takeoff fuels, then one has outlined in broad strokes the scope of fuel research which should lead to the development of new and more suitable rocket fuels.

3. Development of the Auxiliary Engines of the Rocket Bomber

Just as with ordinary aircraft motors, the rocket motor requires for its operation a few auxiliary engines, of which the most important are those for feeding fuel and coolant and the associated driving assemblies. These additional installations present some not-too-simple problems, since the feeding rates are very high, of order of magnitude 50-100 H.P. per ton of thrust, and the material to be conveyed can be in altogether unusual states, say a liquefied gas, a metallic suspension or even solid or liquid metal - and must be very accurately proportioned as well as being fed against very high pressures. A complication arises because the feeding installations must be designed under extreme limitations on weight of construction. In addition to these arrangements for feeding of fuel and coolant, ignition systems and in some cases intake and regulator systems require consideration.

4. Development of Test Model of Complete Rocket Motor

Even if the development of the previously enumerated most important parts of the motor had been achieved taking account of their interactions, putting them together into a ready-to-fly rocket motor and examining their interplay is still a separate and important step. Only now, on the apparatus ready for flight can a bench study be made of the mutual interactions of the combustion chamber, jet, fuel and auxiliary engines, so that by suitable adjustments the best results are obtained for exhaust speed, reliability of performance and construction weight. These bench tests of the complete rocket motor are especially important and thorough because they reproduce the conditions during flight very closely; this is in contrast to the ordinary aircraft motor where these conditions can be imitated only with difficulty and not even completely by altitude tests. This is mainly connected with the fact that the rocket motor accomplishes the jet formation, combustion and cooling only with its own fuels, and without use of the surrounding atmosphere, so that the differences of velocity, temperature and pressure of surrounding air between the bench test and actual flight can scarcely alter the conclusions. One of the few places where the rocket motor comes in contact with the surrounding air is the mouth of the jet. There the

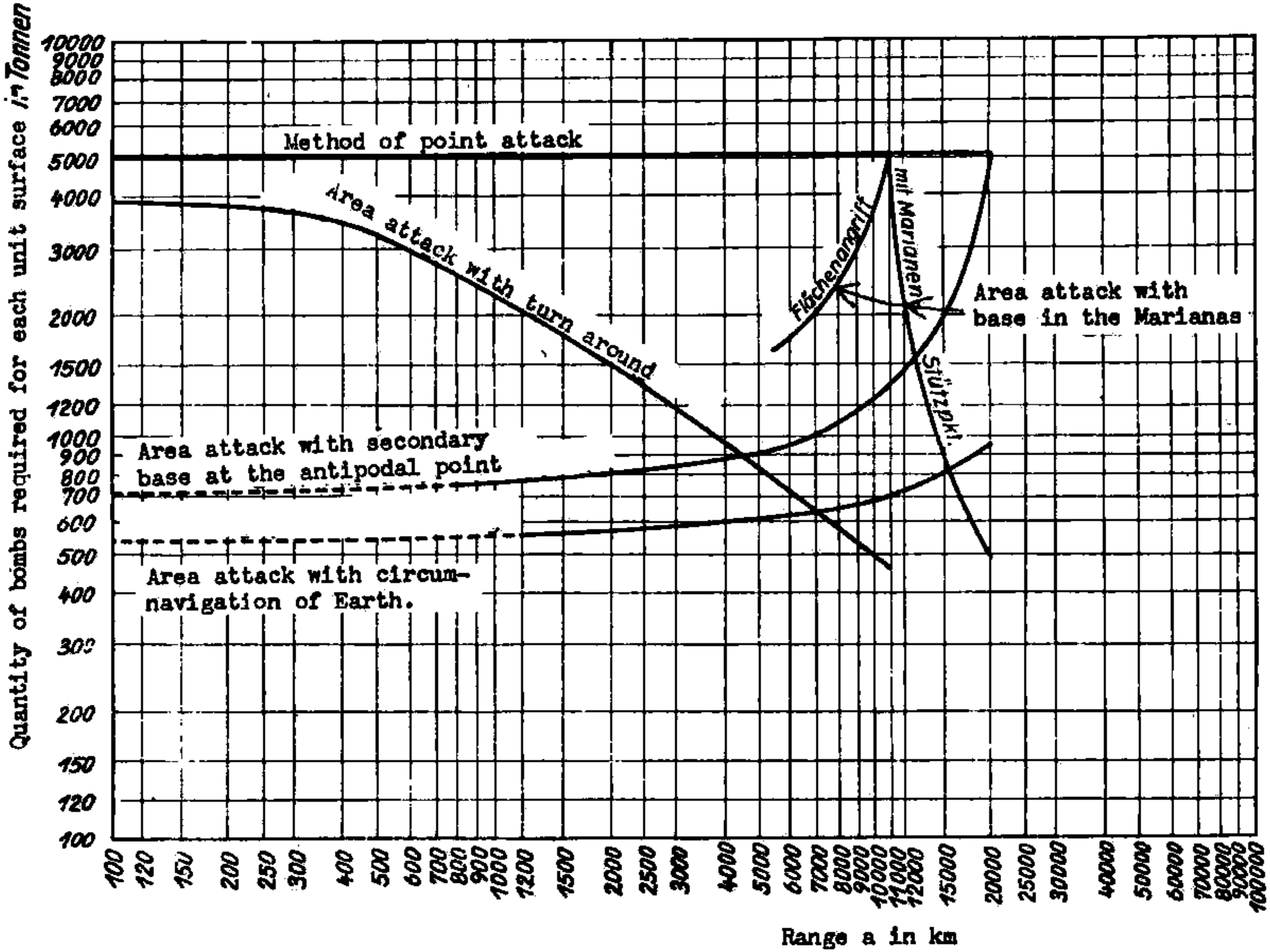

Fig. 108: Amount of required bombs in tons in order to cover the unit surface and the environment by various methods of attack with a total of 3.52×10^9 kcal destructive energy as a function of attack distance a.

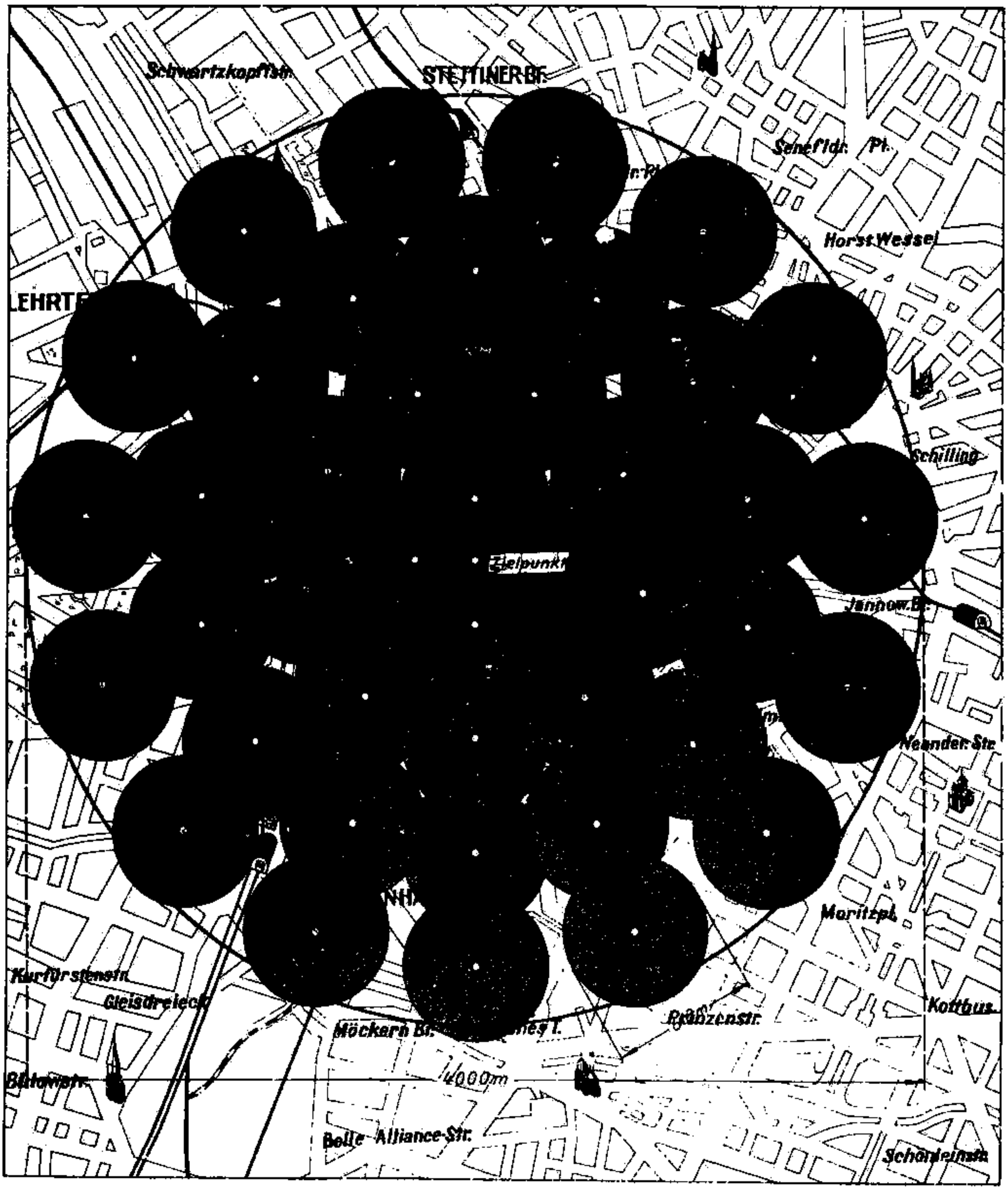

Fig. 109: Ideal Gaussian hit distribution of 42 hits, each of 60 tons of bombs, with small striking velocity in the unit circle in case of surface release against the target, and with area of destruction for each bomb (for example, bombardment of Berlin).

Fig. 110: Ideal Gaussian hit distribution of 70 hits, each of 3 tons of bombs, with small striking velocity in the unit circle in case of surface release against the target, and with area of destruction for each bomb (example, bombardment of Berlin).

combustion gas expands to the pressure of the air behind the aircraft; in flight this pressure is practically zero whereas in the open bench test the jet can expand only to the pressure of the still air around it. Still the differences are not very great, are largely amenable to calculation, and are moreover such that the bench test considers the more unfavorable case. A reaction of the slip-stream and the jet on the aircraft (in particular on the control surfaces) need not be considered for the rocket bomber, because operation of the motor and subsonic velocities of flight never occur together. Aside from the purely developmental and test studies on the model, a whole series of physical researches on the rocket motor can be carried out most advantageously during this phase of the development: more careful investigation of atomizing of the fuel, the actual behavior of the pressure in the combustion chamber, the temperature distribution in the combustion gas, the actual streaming speeds, the conditions of heat transfer from the combustion gas to the walls and from them to the coolant, the jet formation and sound emission in the furnace-jet, as well as numerous other questions. Only when in the course of these studies the motor has proven its complete reliability of performance, can one consider installing it in an aircraft. The development of this aircraft will have to be done alongside that of the motor, so that both may be ready for flight at the same time.

5. Wind-Tunnel and Tow-Tests on Models of the Air-Frame

The external shape of the rocket bomber is determined by the requirements that existing experience on screw-propelled aircraft shall be used as much as possible, that the special conditions of supersonic flight and rear installation of the motor must be considered, that the glide-number of the aircraft shall be as good as possible at very high Mach numbers, where the aerodynamic forces are proportional to the square of the velocity and angle of attack. Under these general requirements models of the rocket bomber can be designed; these cannot be tested in the most interesting region of very high Mach numbers, in the upper part of which actual chemical changes of the streaming medium are possible, because as yet such artificial air-blasts are not available; one can perform wind-tunnel tests in the range of Mach numbers from 0.08 to 4. In the range of velocities below that of sound, which is important for the landing process, using models of reasonable size one can carry out measurements on the aerodynamic forces, and especially on the maximum lift of the aircraft, and its improvement by the use of aerodynamic aids suited to the particular profile. In this range tunnel-tests on stability, vibration conditions and manoeuvrability of the vehicle are important. In the supersonic domain, aerodynamic forces, distribution of air pressure, stability and manoeuvrability, vibration conditions, air temperatures at the stagnation points, and heat transfer to the aircraft are of interest. A whole series of these tests on very small models can be carried out in a supersonic wind tunnel.

For tests on larger models the takeoff track of the rocket bomber is itself a very convenient towing-track; on it even very large models can be towed up to any desired high speed with the aid of rocket propulsion, and then studied. Such tow tests can be carried out at reasonable cost on a 15-30 km. long track, with models scaled 1:10 up to 1:1 at the original speeds of 800 up to 5000 km/hr, so that the Mach number is duplicated exactly and the Reynolds number approximately. Such tests would especially consider the general behavior of the aircraft in the neighborhood of the velocity of sound, i.e. between 800 and 1800 km/hr, for various shapes, angles of attack, arrangements and tilts of control surfaces, etc.; also the distribution of air pressure and temperature on the surface of the aircraft by means of taps, thermoelements, etc., for all velocities; measurement of the location and magnitude of the forces acting on the aircraft, direct tests of stability by means of a Cardan suspension of the moving model at its center of gravity, studies of the reaction of the jet on these conditions - especially on the aerodynamic forces and the stability investigation of the elastic properties on elastically-similar models; e.g. as regards vibration of the wings and control surfaces, etc.; takeoff and free-flight characteristics of self-stable or remotely controlled models especially during the passage of the velocity from values below the sound velocity to values above, and others. A special problem in such tow-tests, aside from the track itself, is the relative sliding behavior of lubricated surfaces at sliding speeds up to 5000 km/hr. For flight at arbitrary speeds in regions of very rare atmosphere, in which the so-called gas-kinetic laws are valid, and where neither tow tests or ordinary wind-tunnel tests are feasible, an extension of the theory is desirable, as well as its experimental justification, say by extension of the well-known molecular-beam methods to the present problem.

6. Constructional Development of the Vehicle

Once a preliminary decision as to the whole arrangement and shape of the rocket bomber has been made on the basis of wind-tunnel- and tow-tests, one can commence the construction of the fuselage, wings, control surfaces, and important installations such as the pilot's cabin, the tank installations and auxiliary equipment. In view of the fixed external shape, the decisive factor for the construction of the fuselage, wings and control surfaces is the fact the air pressures which occur are far greater than those on ordinary aircraft. The air pressures on the rocket bomber will certainly be in the neighborhood of 3000 kg/m^2, and will therefore lead to types of wing construction like those used in buildings or ships. The problem of the pressurized cabin has already been treated in other connections. The results assembled there can be made use of. There are no prototypes on which to base tank installations for large quantities of fuels like liquefied gases, metallic suspensions, etc., and these must be suited to the special conditions. An especially extensive group of apparatus requiring development is the auxiliary equipment of the rocket bomber, including velocity-, altitude-, and acceleration-meters, instruments for steering, navigation and aiming of bombs, optical instruments and many other apparatuses and instruments connected with the special characteristics of rocket flight.

7. Bench Tests on Interaction of Motor and Air-Frame

These tests represent the last stage before the first flight tests, and should check the satisfactory operation of the motor (which has so far only been bench-tested) under the conditions where all the parts have been assembled into a vehicle. The exact relation between the driving force and the centers of mass and air pressure of the aircraft should be checked to avoid instabilities caused by incorrect placement of the engine; and finally during these tests the pilot can become accustomed to some of the peculiarities of the new aircraft.

8. Development and Test of the Takeoff Arrangement

The several kilometers long takeoff path with its arrangement of rails represents a relatively simple engineering construction which presents no special problems. On the other hand, the takeoff sled, which under a load of several hundred tons must be accelerated in a very short time to 1 1/2 times the velocity of sound and then slowed down even more rapidly, requires special development. This will be concerned especially with the extraordinarily powerful takeoff rocket, the sliding contacts of the sled and the method of braking. Completely reliable operation of the takeoff track will have to be carefully tested by catapult trials on dead weights comparable to the weight of the aircraft.

9. Takeoff and Landing Tests on the Bomber

The takeoff tests begin with small fuel load on a taxi-strip which is as long as possible the practically empty bomber, after very brief operation of its own rocket motor obtains the velocity required to float, after which it rolls on its own landing gear. After a short hop it drops down again and carries out its first landing, which does not differ from the later landings after long flights. These takeoff tests should be carried out in such a large space that the landing can occur immediately after the takeoff without turning the aircraft, in order not to endanger the aircraft by manoeuvers near the ground when its flight characteristics are still uncertain. If after many such tests, the takeoff and landing characteristics are understood, then by using more fuel the aircraft can be brought to somewhat higher altitudes, say a few hundred meters, and then glided back to earth. Thus the essential flight characteristics at low speed will be determined, the arrangement of the control surfaces will be undertaken, the trimming, stability and manoeuvrability will be checked, and thus the airworthiness of the craft in all flight attitudes at not too high altitudes will be determined and eventually improved. If during these tests the aircraft acts reliably for the pilot, then the takeoff tests on the track can be repeated, by placing the empty aircraft on the takeoff sled, catapulting it and landing it. If these tests are satisfactory the trials can be extended to higher flight speeds. This phase of the trials will best begin by tow tests on a very long tow path, so that the aircraft doesn't get to fly but is only accelerated on the towing path and then immediately slowed down again. These tow tests on the actual aircraft at gliding speeds of 800 to 1800 km/h are to be devoted especially to the following individual problems: rechecking and refinement of the results of the tow tests on models concerning pressures, temperatures, aerodynamic forces, stability, vibrations, effects of the driving jet, etc.; studies of the behavior of instruments, apparatus and jet engines under the influence of high accelerations and velocities, development of suitable safety devices, e.g. special seats, getting the pilot accustomed to the new phenomena of high accelerations, high velocities, special engines and new arrangements of the aircraft.

10. Flight Tests of the Bomber

Finally one can go over to flight tests in which one catapults the aircraft with an initially small but gradually increasing supply of fuel, and lets the motor operate for longer and longer periods. Thus longer and longer climb paths will be traversed; one will soon surpass the velocities attained up to now by the fastest aircraft, and go up to altitudes never previously reached. The takeoff speeds also increase at the same time. Now begins the most difficult part of the flight studies, since the flight conditions depart farther and farther from any known at present and checked by experience; completely new aeronautical territory must be conquered. As far as can be visualized at present, the flight tests will extend to maintenance of requirements of life in the pilot's space taking account of the high altitudes, accelerations, and temperatures, the effect of the aerodynamic forces on the wings and controls of the aircraft, testing of the heating of the walls at many points of the aircraft, maintenance of stability and manoeuvrability beyond the velocity of sound, etc. This part of the flight tests will have to be done very circumspectly and with stepwise increase in velocity, since at very high altitudes, low air densities and high speeds, any slight accident can lead to a catastrophe since it is practically impossible to leave the aircraft by parachute. These tests of flight characteristics will be continued up to speeds not yet reached by projectiles, i.e. about 6 times the velocity of sound. Finally the actual trial flights will be completed with performance tests. They will serve first to determine simple performance data such as takeoff speeds, takeoff distances, landing distances, landing speeds, climbing performance, consumption of fuel, etc., and later to determine the maximum speed, ceiling and range of the rocket bomber. Since these three limiting performance figures are interdependent, they can be determined during the same flight. As the velocity is increased from the values attained during the tests of flight characteristics up to the maximum value, the temperature distribution on all windward surfaces will have to be carefully checked by means of a remote-reading thermometer system, in order to catch in time any dangerous heating as a result of air friction and stagnation. Too great heating, especially of projecting parts, such as the sharp end of the fuselage, the sharp wing edge, etc., is most dangerous because the slightest melting or other deformation of these carefully shaped critical points and their consequent blunting leads to instantaneous enormous increase of the stagnation temperature at those places and then in steadily spreading molten regions, and would result in immediate burning up of the whole aircraft. If the performance flights are carried out until these expected limiting values of 7000 m/sec velocity, 150 km altitude and 40000 km. length of flight are reached, then the flight studies can be considered completed.

11. Navigation Tests on the Rocket Bomber

The next important task of development concerns arrangements for navigation, which, after propulsion has ceased, give the rocket craft exact knowledge of its path, enable corrections of its course, and permit an exact calculation of the moment of bomb release. This precision navigation will have to be checked in a very large number of flight tests, since the success of any attack depends on its accurate and rapid performance.

12. Bomb Release Trials

These constitute the last phase of the research and development work on the rocket bomber and should give a practical verification of the preliminary theoretical work on the processes occurring during the fall of the bombs and their contact with the earth. So far as the relation between point of impact and point of release from the aircraft for various heights and speeds of flight is concerned, the oceans of the whole earth provide a suitably large testing areas. The study of impact of the bomb on land will be somewhat more troublesome, since very large uninhabited areas are required. However a few tests in the Arctic regions untrodden deserts or in our own possessions will suffice for this purpose.

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TABLE OF MOST IMPORTANT SYMBOLS

a.............attacking distance (m, km), sound velocity (m/sec)

a.............critical sound velocity (for example, in nozzle throat)

b.............acceleration (m/sec^2)

b_n............normal acceleration (m/sec^2)

b_t............tangential acceleration (m/sec^2)

c.............effective exhaust velocity (m/sec)

c_{max}..........maximum flow velocity of fire gases (m/sec)

c_{th}...........theoretical maximum flow velocity of fire gases (m/sec)

c_m............fire gas(exhaust) velocity at the mouth (of nozzle) (m/sec)

c_H............probable velocity of the air molecules before they strike a wall (m/sec)

c_R............probable diffuse rebound velocities of the air molecules from a wall (m/sec)

c_a............lift coefficient (C_L)

c_{ao}...........initial lift coefficient (C_{Lo})

c_{amax}.........maximum lift coefficient

c_{aF}...........lift coefficient of wings

c_w............drag coefficient (C_D)

c_{wr}...........frictional component of C_D, drag coeff.

c_f............surface drag coefficient

c_v............specific heat at constant volume ($kcal/kg^o$)

c_{vtrans}.......specific heat at constant volume, portion due to molecular translation ($kcal/kg^o$)

c_{vrot}.........specific heat at constant volume, portion due to molecular rotation ($kcal/kg^o$)

c_{vosc}.........specific heat at constant volume, portion due to molecular vibration ($kcal/kg^o$)

d.............wall strength, caliber, diameter (m)

d_m.............diameter of nozzle mouth (m)

d.............nozzle throat diameter (m)

f.............cross-sectional areas (m^2)

f.............cross-sectional areas of throat of fire nozzle (m^2)

f_m.............area of surface bounding mouth of nozzle (m^2)

g.............acceleration due to gravity (m/sec^2)

h.............length of projectile (m)

h_o.............smallest thickness of lubricating layer (m)

i_{pH}...........vertical shock impulse which in unit time is transmitted to surface of plate by impinging air molecules (kg/m^2)

i_{pR}...........vertical rebound impulse which in unit time is given by surface of plate to rebounding air molecules (kg/m^2)

i_r.............impulse parallel to wall, of the air molecules which impinge in unit time on a unit area of the wall (kg/m^2)

l.............free path length of molecules (m)

m.............mass ($kgsec^2/m$)

p.............air pressure, gas pressure, pressure (kg/m^2)

p_a.............external pressure of static air (kg/m^2)

p_o.............initial pressure, gas pressure in furnace, stationary gas pressure (kg/m^2)

p_m.............mouth pressure (kg/m^2)

q.............dynamic pressure, heat flow ($kcal/m^2sec$)

r.............trajectory radius of horizontal turning curves (m)

s.............flight distance (m,km) (pathlength)

s_1.............starting distance (m,km)

s_2.............length of partial distance after starting (m,km)

s_3.............length of accelerated climb (m,km)

s_4.............length of unaccelerated supersonic glide path (m,km)

s_5.............subsonic glide path length (m,km)

s_w............length of turning distance (m,km)

t.............time (seconds), wing depth, sliding slipper depth (m)

t_f............hot side temperature of fire wall(°C)

t_k............cool side temperature of fire wall (°C)

v.............flight velocity (m/sec)

$\mathcal{V}$ ....velocity vector (m/sec)

v_a............absolute velocity (m/sec)

v_o............initial flight velocity (m/sec)

V_e............velocity of a point on the earth's surface (m/sec)

v_{w1}...........flight velocity at beginning of turning arc (m/sec)

v_{w2}...........flight velocity at end of turning arc (m/sec)

w.............bomb range (m,km) (literally "throwing distance")

w_r............probable scattering of bomb trajectories (km)

$\bar{z}$.............average density of bomb hits for surface attack (kcal/km^2)

A.............mechanical equivalent of heat (1/427 kcal/kg), lift (kg)

B.............bomb load (kg)

C.............coriolis force (kg)

D.............dissociation energy (kcal/kg)

E.............reaction heat of fuels, upper mixture coefficient, total energy content (kcal/kg)

E_v............spacial energy concentration (kcal/Liter)

E_R............rebound energy of air molecules per unit time and unit wall surface (kcal/m^{2}sec)

E_W............energy of air molecules remaining in walls after impact (kcal/m^{2}sec)

E_A............energy carried by air molecules per unit time and unit surface to wall (kcal/m^{2}sec)

F.............aerodynamic supporting surface (m^2)

F_F ....carrying wing surface (m^2)

F_R............carrying fuselage surface (m^2)

G.............weight (kg)

G_o.............initial weight (kg)

G_1.............weight of bomber after using up fuel required in approach of target (kg)

G_2.............weight of bomber after release of bombs (kg)

G_3.............empty weight of bomber (kg)

G_s.............starting weight (kg)

G_{os}...........initial starting weight (kg)

H.............flight altitude (m,km)

J.............heat content (kcal/kg), impulse (kgsec)

J_o.............heat content in state of rest, state of furnace, initial state (kcal/kg)

J_m.............mouth impulse (kgsec)

K.............evaluation number of rocket fuels

M.............molecular weight

P.............effective thrust, load on one of a sliding slipper (kg)

P.............free thrust measurable by dynamometer (kg)

Q.............quantity of heat (kcal/kg)

R.............individual gas constant (m/°), radius of earth (m)

R_e.............Reynold's number

R_{io}...........internal height of evaporation at 0°K (kcal/kg)

T.............temperature (°K), d'Alembert's inertial force (kg)

T_o.............initial temperature, furnace temperature, static temperature (°K)

T_m.............mouth temperature (°K)

T_G.............temperature of air molecules before impact with wall (°K)

T_W.............temperature of a wall surface struck by air molecules (°K)

T_R.............temperature of air molecules after rebounding from wall (°K)

U.............internal energy (kcal/kg)

V.............specific gas volume (m^3/kg)

V_o............furnace volume (m^3)

W.............resistance (kg)

W'............resistance measured in wind tunnel (kg)

Z.............total energy thrown at a target (kcal)

α............angle of attack (°), coefficient of accommodation

α_s...........angle of attack of leading edge of a curved surface

γ............specific weight (kg/m^3)

γ'...........specific gas weight at the critical velocity (kg/m^3)

γ_o...........specific gas weight at rest, or in the neighborhood of Earth's surface (kg/m^3)

ε............glide number, numerical eccentricity of a Keppler ellipse

ε_a...........optical absorption coefficient

ξ............compass rose angle (i.e. "heading") (°)

η............viscosity ($kgsec/m^2$)

η_a...........maximum efficiency, external efficiency

η_D...........nozzle efficiency

η_i...........internal efficiency

η_o...........furnace efficiency

η_{therm}.......thermal efficiency

κ............adiabatic exponents

$\bar{\kappa}$............average adiabatic exponents

λ............thermal conductivity (kcal/mh°)

μ............coefficient of friction

ρ............density, radius of path, ($kgsec^2/m^4$) (m)

$\bar{\rho}$............mass of gas striking unit surface area of a plate each second ($kgsec/m^3$)

ρ_m...........gas density at the mouth ($kgsec^2/m^4$)

ρ_o...........gas density in furnace, initial state, rest state ($kgsec^2/m^4$)

σ............strength, turning angle (kg/cm^2) (°)

τ............tangential stress due to air or gas drag (kg/m^2)

φ............path inclination (°)

ω............ angular velocity (1/sec)

Δ............change in a quantity

θ............characteristic temperature of vibrational excitation of a gas molecule (°K)