UNCLASSIFIED

AD NUMBER
AD422571
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited. Document partially illegible.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 25 JUL 1960. Other requests shall be referred to Department of Defense, Attn: Public Affairs Office, Washington, DC 20301.**
AUTHORITY
RAND ltr, 31 Mar 1966

THIS PAGE IS UNCLASSIFIED

5 739280 0

AD No. 422571

DDC FILE COPY

[redacted]

DDC
NOV 13 1963
TISIA A

422571

NO OTS

⑤ 739 280

⑥ ON THE PROBLEM OF BALLISTIC MISSILE DEFENSE,

⑩ by R. D. Holbrook and/
J. F. Gross.

Engineering Division
The RAND Corporation

P-2046-ARPA

July 25, 1960

Reproduced by

The RAND Corporation • Santa Monica • California

This paper is based on research supported and monitored by the Advanced Research Projects Agency under Contract No. AF 49(638) 710.

⑨

I. Introduction

In the long contest between offense and defense few events have changed the rules quite so comprehensively as the coming of age of the ICBM. The situation is that the United States has an active defense system in operation, which was designed to cope with manned bomber attacks to some degree. This system has no capability against missile attacks and some many years must pass before any effective system can be deployed.(1) Thus, both the civilian U.S. and its military forces have rather suddenly and dramatically lost whatever benefits active defense could guarantee.

The greater part of this paper~~, and the entire issue,~~ discusses technical problems and the questions of whether active missile defense can be technically, economically, or operationally feasible. These questions are likely to have different answers depending on what segment of the United States is to be defended (cities; airfields; hard missile sites; hardened command posts; etc.), the purpose for which defense is undertaken (to prevent or limit damage; to buy time; to raise enemy force requirements; etc.), and how well the defense system is supposed to perform under the variety of circumstances which could arise. It is important to understand that defense in one form or other is an essential element in our national posture and that it can take many forms. We invest in defense not only to save lives or property in the unhappy event that thermonuclear war should occur but because it is a tool of national policy in peace as well as war. In this sense it is clearly improper to talk of national objectives served by active defense without at least a brief word on passive defense in relation to the same objectives. In addition, careful and explicit definition is necessary before a statement such as defense against ballistic missiles is feasible (or infeasible) has any meaning.

We can define active defense to include all those direct measures which could be taken to prevent successful completion of an attack, or to lower its intensity. Passive defenses modify the nature of the target attacked so as to reduce or nullify the effects of successfully delivered weapons. Passive defenses may be divided into warning; passive military defenses such as hardening, mobility, dispersal and concealment; and civil defenses such as shelter programs, preparations for evacuation and for recuperation, etc.

Defense is undertaken for something; in the broadest sense to contribute to some national objective, and is seldom thought of, professionally, in black-and-white terms. The question at issue is rather that of what mixture of the various types of defense and offense goes furthest toward achieving national objectives, with the most efficient utilization of resources.

It must be admitted at the outset that defense against the ICBM is extraordinarily difficult, technically. There are important differences of feasibility between defending certain kinds of military targets and defense of population and property. For example, defense of a small, localized military unit is certainly much simpler than defense of a city. We know of, and expect to find, no perfect defense which is proof and shield against all attacks, but even an imperfect defense can be worthwhile.

II. Why Defense is Important

Other than limiting damage and helping people to stay alive defense may be worth a considerable investment for a number of reasons, depending on circumstances. Let us describe two rather different national attitudes toward, and degrees of preparation for, thermonuclear war with respect to their defense implications.

At one end of the scale is Minimum Deterrence in which the United States maintains an invulnerable offensive force of retaliatory weapons. The central philosophic content is that a few modern weapons on enemy cities would wreak such intolerable damage that the enemy must be deterred from ever starting a central war. There are no serious preparations for limiting damage since the war is never going to start. In this posture any action which reveals that the United States is taking the possibility of central war seriously is considered to be destabilizing and in a sense provocative. For this reason, no counterforce capability is sought, and no special attempt is made to secure warning or obtain reconnaissance and surveillance information. A simple execute order is all that is required in terms of command and control and there are no general active or civil defenses. It is very important, however, that the retaliatory force be invulnerable, implying defense of this force by concealment, hardening, active defense, etc., as required for credible deterrence. Hence, even in this strategy in which all would be risked on deterrence, certain kinds of defense of the military forces are important. These defenses do not have to be perfect but only good enough to secure deterrence.

At the other end of the scale are postures which still seek deterrence but in which the national attitude is one of grim realism. In spite of the best intentions central war may occur anyway through accident, miscalculation, or catastrophic crisis. In this event, the United States would like to survive as nearly intact as possible and fight the war to a tolerable conclusion. In such postures all kinds of defense are important since all elements of the national strength are designed for survival. Deterrence is reinforced by procuring a wide spectrum of well-protected offense weapons. The capability to attack the enemy's military forces (Counterforce capability) is sought as the war would not likely occur as a spasm but might be protracted over several days with a high value attaching to enemy forces destroyed before use. There is a strong effort in warning, reconnaissance, and surveillance and command and control with systems designed to function during and after the war. Military forces are separated from civilian targets where possible to give the enemy at least the option of not attacking civil targets. Civil defense preparations for population survival, including measures for strategic evacuation of cities, are undertaken. Bomber defenses are maintained and modernized and every effort is made to secure effective anti-missile defenses.

The question of which kind of posture the United States should have is controversial and not yet settled. Many people sincerely favor minimum deterrence, sometimes because they believe the other kind of posture is not feasible. Many technicians including the authors believe in war-fighting capabilities because they see so many ways in which an all-out war could start with neither side desiring it. This belief carries with it a recognition of the importance of active defense. Some of the reasons are (1) as time passes the power and precision of the attack which could be laid on this country is such that passive military defenses would have great difficulty to protect the offense force, for example we are interested in active defenses for hardened missile sites and key control points. Such defenses need not be perfect against attack and are useful in peacetime since they increase the enemies' force requirements; (2) people and property (e.g., cities) are easily destroyed and civil defenses alone cannot provide the desired protection; (3) passive defenses can do little to alleviate the effects of an increasingly hostile environment due to successfully delivered weapons. Therefore we are interested in active defenses to limit immediate and long-term damage, to make our civilian targets less attractive, and to improve the possibility for recuperation. These defenses, also, do not have to be perfect to be worthwhile.

III. General Difficulties

While anti-missile defenses are worthwhile even if imperfect, the difficulty has been to find one which could be guaranteed to work at all. As discussed later, a ballistic missile attack may be expected to contain *in the simplest case* a large number of objects which can be quite easily mistaken for an enemy warhead. With some effort, an attacker can provide objects designed to look like warheads and, at considerably greater cost could also deliver objects which *are* warheads or which are of the right size, shape and weight to qualify as warheads. In short, having solved his basic delivery problem, the enemy, if he has sufficient payload capacity, can design his attack so that his chances of penetrating the defense system are optimized, merely by varying payload design to contain the proper number and kind of objects. These objects can be delivered as a compact group, a diffuse cloud, a trail of objects several hundred miles long or in whatever spacial and arrival sequence is desired.

Generally speaking, schemes to attack such collections of ballistic objects, as a whole, have seemed promising only for special cases of attack. Individual interceptions seem necessary and for this reason the problem of selecting the objects to intercept (discrimination) has been of paramount importance to the defense designer. In judging the kinds of discrimination capability which would be most useful we can adopt the following crude rules; more or less in descending order of desirability.

- Mass measurement--so that light objects cannot serve as decoys (relative mass data also useful).
- Size measurement--large objects more likely to be dangerous than small ones.
- Shape measurement--very irregular objects less likely to be warheads.
- Ballistic parameter measurements (W/C_DA)--which relate mass to shape and size are useful to determine reasonable limits for warhead parameters.

Ballistic missile defense discrimination may be defined as the ability to classify the individual objects in a collection that exhibits the characteristics of a ballistic missile. The point along the trajectory where this collection is first observed, the total number of objects in it, and the location of the defense will in general influence the method of classification.

An object may be classified by its dynamic behavior, the radiations it emits or reflects, and its interaction with the surroundings through which it passes. This information will make it possible to separate the objects into categories of weight, shape, and character. The character of a body is identified independently of apparent weight and shape, from data related to surface characteristics, for example. The categories of weight, shape, and character, will enable the defense to identify the objects as nose cones or decoys.

The discussion will concern itself first with a brief statement of the discrimination techniques which are of present interest. A comment on the nature of the collection of objects will follow. Then the mid-course and re-entry portions of the collection trajectory will be examined to determine which discrimination techniques appear most attractive in each. Finally, there will be some general remarks on the use of integrated discrimination systems. These discussions will not be concerned with the problem of detection of the objects.

IV. Discrimination Techniques

The dynamic behavior of an object leads to an obvious discrimination method, and it was the first to be investigated. The dynamics that a body experiences during re-entry into the atmosphere are determined by its velocity variation with altitude. This velocity-altitude relationship has been shown to be a function of the ballistic parameter, W/C_DA. Heavy, low-drag bodies (nose cones) decelerate at quite low altitudes, whereas light, high-drag objects (chaff) decelerate higher in the atmosphere. Figure 1 shows the deceleration of the objects as a function of altitude with the ballistic coefficient as a parameter.(2) It should be noted that (1) the curves are similar, (2) deceleration occurs in a layer about 50,000 ft thick, and (3) the ballistic coefficient W/C_DA increases logarithmically as the maximum deceleration altitude decreases linearly.* If range-time information is available, such a plot may be made for each object and fitted to a particular ballistic-coefficient curve. Eventually all the objects may be classified in this way. If the area of an object is known from other considerations (the drag coefficient C_D is not a strong function of altitude or surface character but is a strong function of shape), then a mass classification is possible. It will be observed here that bodies whose ballistic coefficient $\beta = W/C_DA$, is about 100 will not be identifiable by velocity change until they descend to altitudes of about 250,000 ft. At this point the velocity of the object will be about 20,000 ft/sec, which gives the defense roughly three minutes to identify, launch an interceptor, and kill at a reasonably high altitude.

Each object in the collection will, of course, emit radiations throughout its entire flight trajectory. The spectral region in which strong emissions occur will depend upon the portion of the trajectory. Immediately after separation and in midcourse flight, the object will emit primarily in the far-infrared part of the spectrum. As the object begins to enter the

---

*This latter property makes it increasingly difficult, but not improbable or impossible, to lower the altitude of maximum deceleration.

atmosphere, its kinetic energy is rapidly converted to thermal energy, which is distributed in the following modes: (1) the surface of the vehicle is heated, perhaps to the sublimation temperature, (2) the heat content of the gas in the shock layer changes, and (3) the surface and the shocked gas radiate energy into the surrounding atmosphere. The conversion of kinetic energy is a function of the dynamic behavior of the body; Fig. 2 shows this conversion as a function of the ballistic coefficient. Since the re-entry velocities of the objects will generally be the same, the amount of energy that will be released as the object decelerates will, of course, depend on its mass. The altitude and rate of this release depend on the ballistic coefficient. Finally, the distribution of the energy into the several modes is a function of the body shape and size. Both the gas in the shock layer and the surface may radiate energy in the infrared and visible regions of the spectrum. The hot gas from the shock layer, together with ablative material from the surface, spews into the wake of the object so that the wake may also radiate in these regions. The careful measurement of the radiation emitted by each object can lead to estimates of the weight, shape, and surface characteristics of the object. The total radiant intensity will be a measure of the mass of the object; the spectral distribution of the energy will yield information on the apparent surface temperature and body shape; and, finally, spectral analyses will indicate the constituents present in the shock layer and the body surface.

The use of reflected electromagnetic radiation in the wavelength region from UHF to X-band to track and identify objects has been a well-known technique for two decades. Radar is the most important element in present defense systems, and an enormous amount of effort has been expended on the development of more sophisticated radars with shorter pulse widths, greater range, multiple-frequency capability, etc. In addition to the usual range-time data, the radar echo as a function of time (or altitude) may be examined for absolute cross-section variation and scintillation frequency in an effort to obtain the "signature" of an object for some region of the trajectory. The signatures of objects may then be compared with one another and with previously obtained signatures to sort out those that are of interest to the defense. In general, signature information is useful only for identifying shape, and not for mass determination.

There are, in addition, a host of induced ionospheric effects as well as possibly emitted microwave radiations that could add unique inputs to the classification scheme. Some of these are particularly interesting because they are induced effects in which the energy deposition would be indicative of the mass of an object, as distinct from information that could be useful only with a priori assumptions of shape, ballistic coefficient, etc.

V. Threat

The nature of the moving collection may roughly be predicted if an assumption is made concerning booster capability. It is not unreasonable to expect that an operational payload weight of 10,000 - 20,000 lb will be achieved in the near future (the Saturn vehicle, with a 1,500,000-lb thrust, will have a payload-delivery capability of over 25,000 lb). The payload designer, then, has two choices: he may elect to surround the weapon with a series of objects whose behavior in the various stages of flight resembles that of the weapon in the different phenomena modes used by the discrimination sensors; or he may choose to design a very sophisticated weapon, a "non-detectable" nose cone. The latter will not be discussed here since it is a problem of detection and not discrimination.

The collection of objects, then, consists of weapons and decoys. Assuming a weapon weight of a ton or so, the decoys can either be very numerous or very sophisticated, depending on whether one wishes to saturate or confuse the discrimination sensors. Since there is a weight limit, however, the increase in the number of decoys will result in a higher "unmasking" altitude, i.e., the altitude at which apparent differences occur in re-entry phenomena of weapons and the lower-weight, less sophisticated decoys.

The decoy complex might be expected to consist of light mid-course decoys, such as balloons and chaff; heavy re-entry decoys, such as darts, cones and rings; and booster tank fragments. It seems logical to explode the booster tank because it is available anyway and may be used as a crude attempt to saturate the defense system. The mid-course decoys will probably be balloons whose shape is similar to that of the weapon; however, these will not survive re-entry. Therefore, heavy cones or rings with a ballistic coefficient W/C_DA equal or close to that of the warhead are necessary. It can be seen then that if a mid-course decoy weighs 5 lb and a re-entry decoy weighs 100 lb, a typical collection could consist of one or two warheads, tens of re-entry decoys, and hundreds of midcourse decoys. Such a threat package would probably include, in addition, radar frequency jammers and, at a later date, several multiple warheads. This is, in general terms, the kind of threat that might be expected.

VI. Midcourse Discrimination

Figure 3 shows the trajectory of an ICBM, indicating the region of interest to the defense. It illustrates the time advantage available if a discrimination technique could be achieved in this region. The time during which the object is in midcourse is about 20 minutes, so the defense may reckon in minutes for this phase, as compared to seconds for the re-entry phase. This advantage is countered by the disadvantages of long range and the low-energy output of warheads in this regime. Since this portion of the trajectory is outside the sensible atmosphere, no drag or other re-entry-phenomena discrimination techniques may be used. Radar may be used to differentiate between chaff and very small fragments, but a lightweight balloon could be used to simulate the shape of the nose cone exactly with effectively no weight penalty. These balloons would be destroyed at a relatively high altitude, but their purpose--to make identification of the warhead impossible until it had begun the re-entry phase (with the consequent reduction of the time constant)--would have been accomplished.

It has been pointed out that the balloons had a mass several orders of magnitude below that of the weapon. This implies a difference in the surface temperatures of these objects because the ρc_p products are different and the rate of cooling will be different. Since these temperatures are not particularly high (heating rate at ascent is one hundredth of re-entry heating), detectors in the far infrared should be employed. It might be observed that these temperature differences can be eliminated without great penalty to the offense.

There are, in addition, a number of complex electromagnetic effects induced in the ionosphere as a result of body-ionosphere interaction.

In general, these effects will be useful for detection rather than for discrimination.

VII. Re-entry Discrimination

The re-entry regime offers many possible discrimination techniques, primarily because of the enormous energy loss of an object as it decelerates within the atmosphere. The amount, as well as the mode and rate, of deposition of this energy will permit the defense to make some general classifications of weight and/or shape.

An object, traveling about 20,000 ft/sec will begin to experience the initial effects of the atmosphere at about 300,000 ft (see Fig. 3). As the body enters the continuum-flow region, a bow shock is formed, behind which a high-temperature compressed mass of air is present. This shocked gas may reach temperatures of several thousand degrees Kelvin and hence will consist of products of dissociation, electrons, and ions. The hot gas radiates into the atmosphere and to the surface of the re-entry vehicle. A wake is formed, also, which contains the products of the ablating surface and shock-layer gas. As the body moves to lower altitudes, the surface heating rate drops radically and the effects mentioned above are dissipated.

The atmosphere provides a natural filter that separates the objects according to their ballistic coefficients. This becomes a very powerful tool when used in conjunction with some other methods that yield C_DA estimates. Decoys whose ballistic coefficient matches that of the warhead exactly can certainly be imagined. The problem arises when an attempt is then made to simulate other phenomena.

There are several ways in which radars may be employed to discriminate.

They provide, of course, the range-time information used in the ballistic-coefficient classification. The radar will also give cross-section data, which could, as indicated previously, be used to obtain a signature. However, the deposition of electrons in hot gas in the shock layer will result in a plasma which will react with the electromagnetic waves from the radars. This will influence the apparent cross section of the body. If the illuminating frequency is f_i, the radar will be observing the body itself as it re-enters until an electron concentration builds up in the plasma sheath whose equivalent plasma frequency f_p is equal to f_i. When $f_i < f_p$, the illuminating waves will be reflected from the sheath surface instead of the body. A typical re-entry body would have a stagnation-point plasma frequency of about 900 Mc at 275,000 ft. This would increase, perhaps by an order of magnitude or more, before 200,000 ft and then decrease. In the region where $f_p \sim f_i$, the electromagnetic waves react with the plasma and the radar return may be enhanced.

The plasma formed in the shock layer expands into a wake, which may result in a trail having a length of many body diameters. Since the length and electron concentration of the wake are a function of energy deposition and hence of the mass of the body, a multiple-frequency scan of the wake length could provide a powerful discrimination technique.

It appears reasonable that some of the lighter objects could be designed (with a W/C_DA consistent with the warhead) to simulate some of the characteristics indicated above. In Fig. 4, some measurements by Keys and Primich show cross section as a function of wavelength for two cones and a wire loop. These are shown as a simple example of cross-section simulation.(3)

There are other techniques, such as polarization sensitivity and cross-section aspect-angle variation, that could be employed for discrimination purposes. To counter these, however, the weapon may be camouflaged by coating it with radar-absorbing material.

The kinetic energy transformed during re-entry is a function of the mass of the body (velocities being similar). The formation of the shock layer generates a hot gas and a heated surface which emit in the visual and infrared portion of the spectrum. Calculations indicate that the temperatures in the shock layer can reach 8000°K at about 100,000 ft. The surface temperature will depend upon the nature of the ablation material. Measurement of the surface-radiation intensity as a function of altitude can be related to W/C_DA.(4) Such a curve is shown in Fig. 5. Radiation-intensity curves could be obtained for several spectral regions of observation. These regions could then be combined to determine a color temperature. The radiation rates of the surface and in the hot gas are also different, and the simultaneous variation of these rates may be used as a classification technique. Just as in the case of atmospheric filtering, this technique becomes more powerful as the unmasking altitude is reduced. The energy required to simulate the nose cone must come from the mass of the decoy, and this is, of course, limited except for the multiple warhead.

The wake will contain radiating species and, although the radiant intensity is far less than in the shock layer, the wake radiation is not negligible because of the enormous wake volume. Feldman(5) has calculated that for a sphere with a nose radius of 100 cm at 100,000 ft and a velocity of 25,000 ft/sec, the total thermal radiation emitted by a laminar wake is about 10^9 watts. The optical radiation is less by an order of magnitude, and the nose-cap radiation is approximately four orders of magnitude lower. These ratios will change with altitude and velocity, but they are quoted here as an example of re-entry radiation characteristics.

VIII. Integrated Discrimination

It has been stated previously that no one method is sufficient to discriminate the objects exactly. The most important classification category is mass. This is based on economic considerations; every pound of payload has a constant delivery cost regardless of its destructive ability. The purpose of a decoy is simply to aid penetration. Economic considerations require that decoys achieve their purpose without imposing a severe weight penalty on the offense. The perfect decoy (in the sense of phenomena simulation) is an exact replica of the nose cone. On the other hand, balloons or chaff, which are very light, only simulate a particular phenomenon over a portion of the trajectory. The optimum decoy will be somewhere between these two extremes.

Time is the other important factor. It would be possible to let atmospheric filtration, together with radar-echo information, classify the objects. However, it might then be too late for the information to be useful. It is advantageous for discrimination to be not only early but versatile. As the number of required phenomena that the decoy must simulate increases, the decoy must become more sophisticated (and heavier). The altitude at which light decoys fail to simulate the same phenomena properly is higher, with a corresponding increase in the reaction time available to the defense.

The problems of data transmission and coordination for integrated discrimination systems are complex, particularly if some of the sensors are airborne. The optimum discrimination system will obviously comprise those methods that will yield the most information at a point when the available time is still reasonable.

IX. A Spectrum of Possible Defense Systems

We have discussed some of the problems of ballistic missile defense explicitly but have necessarily left much of the over-all difficulty to be implied. It is hoped that some remarks bearing on particular system possibilities will be helpful in this regard.

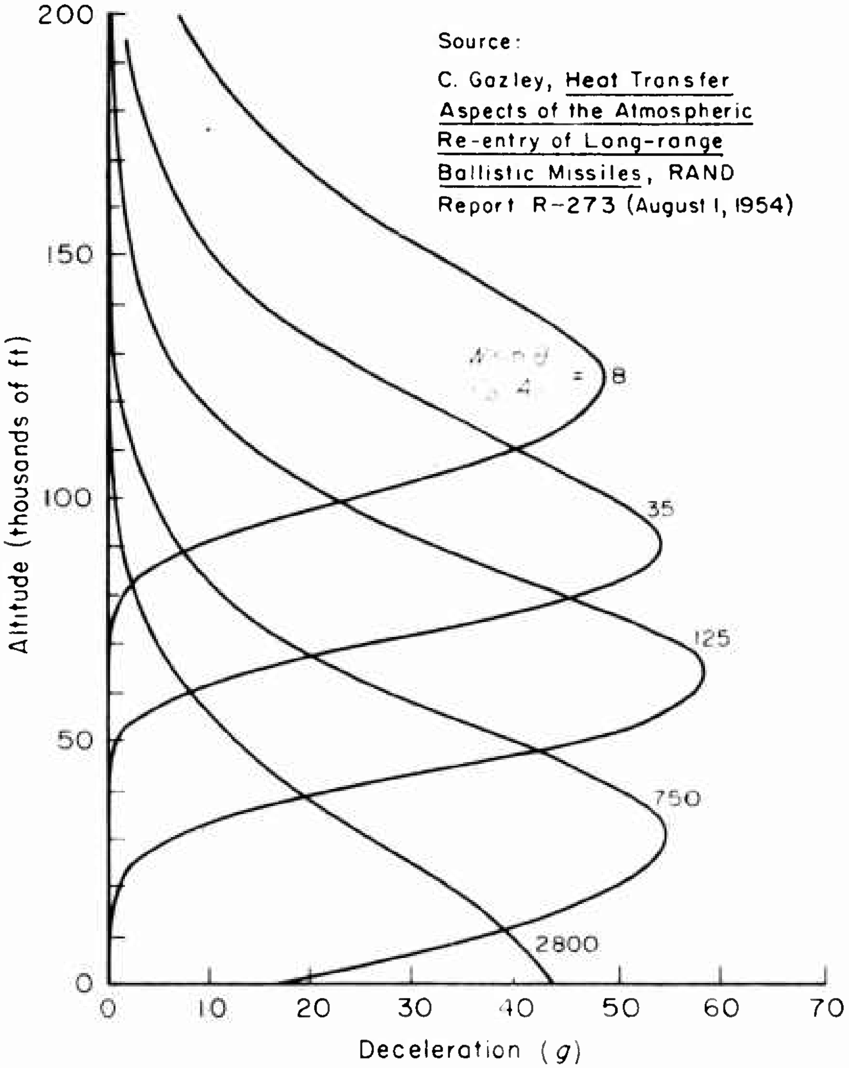
The conditions of attack, during midcourse and re-entry as we have seen imply that defense systems require instruments of unparalleled sensitivity and precision if significant discrimination is to be achieved. Further, even in such a case, the attacker can require the system to have a very high rate-of-fire and the capacity to engage a large number of objects. The root of the trouble is that such systems are exceedingly expensive in the absolute sense and the cost per interception is high. The defense designer is concerned to be in a situation where it costs the enemy significantly less to deliver an object than it costs the defense to intercept it.

A. Hardened-Point Defense.

Certain elements of the military forces may be hardened to withstand some tens to hundreds of psi overpressure meaning that even high yield thermonuclear weapons must detonate quite close to cause destruction (e.g., for 100-psi 10 megatons within about 8000 ft; 1 megaton within 4000 ft). It is apparent that systems defending such points can risk interception at quite low altitudes. Further, the range of the defensive weapons need not be great and certain performance requirements are minimized.

generally. In this connection, defense designers have, rather wistfully, many times pointed out the vulnerability of the ballistic missile during its short launching phase. Here it is most easily detected, may represent a locally unique event, and is most easily damaged. Unfortunately, this phase is generally accessible only to satellites which operate under laws that keep the majority away from the target area. However, if some means could be worked out to intercept ballistic missiles from satellites, it would offer great possibilities for defense.

In other papers, some of the details pertinent to ballistic missile active defense are given. In this paper, the authors have tried to convey a notion of the complexity of the problem by drawing a kind of silhouette. They feel that after this beginning of an entire issue devoted to missile defense, it will be important to have much more public discussion of this important problem.



Source:
C. Gazley, Heat Transfer Aspects of the Atmospheric Re-entry of Long-range Ballistic Missiles, RAND Report R-273 (August 1, 1954)

Fig. 1 — Deceleration and path during re-entry of a long-range ballistic missile (5500 n mi range)

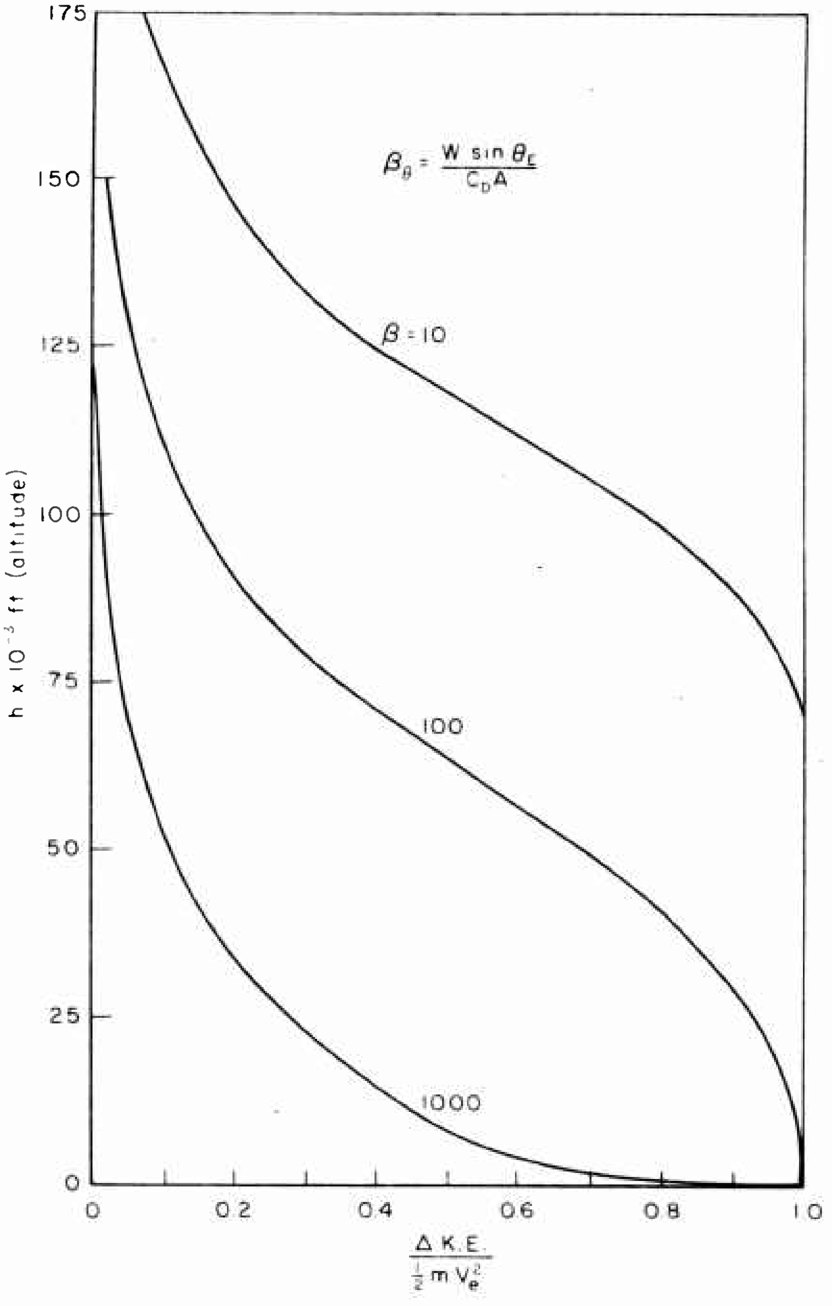


Fig. 2—Conversion of kinetic energic during atmospheric re-entry

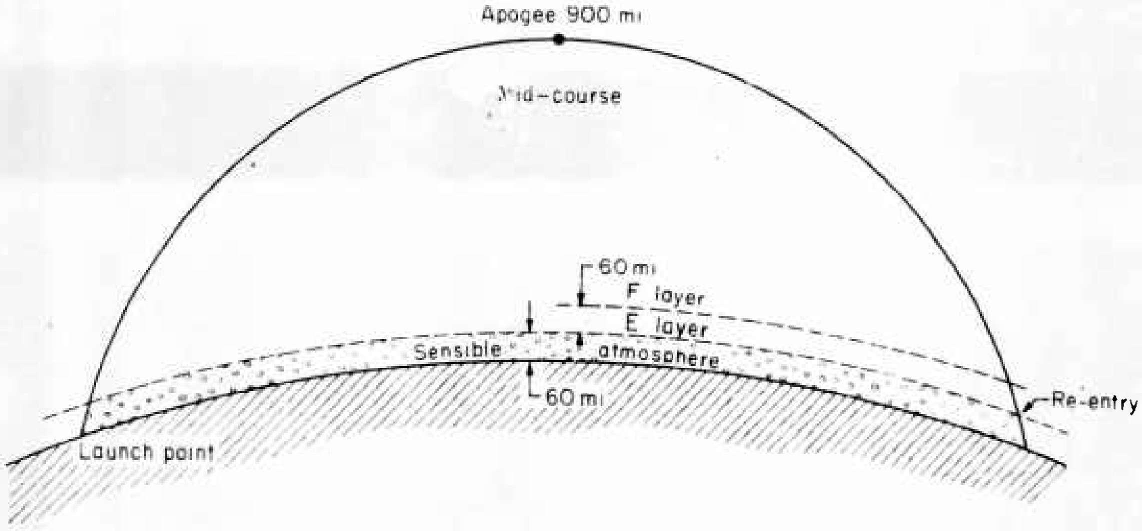


Fig. 3 — Typical trajectory of an intercontinental ballistic missile

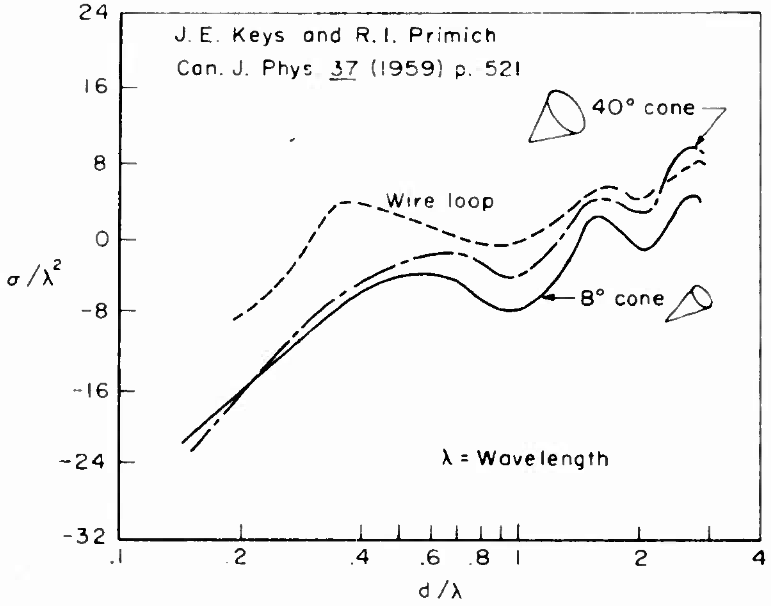


Fig. 4—Nose-on radar cross-section of right circular metal cones

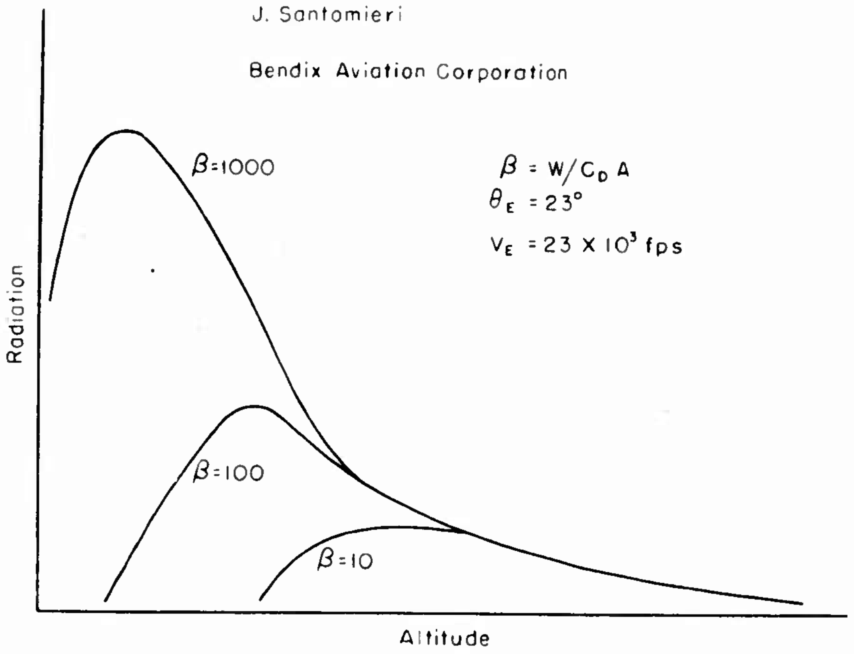


Fig. 5 — Nose radiation for a zero heat sink re-entry body

REFERENCES

1. Testimony of Dr. Herbert York before the Committee on Science and Astronautics, June 4, 1959 [Hearings "Basic Scientific and Astronautic Research in the Department of Defense", No. 45].

2. Gazley, C. Heat Transfer Aspects of the Atmospheric Re-entry of Long-range Ballistic Missiles, The RAND Corporation Report R-273, August 1, 1954.

3. Keys, J. E. and R. I. Primich, The Nose-On Radar Cross Sections of Conducting Right Circular Cones, Can. J. Phys. 37, (1959), p. 521.

4. Santomieri, J., ASM-161, Bendix Aviation Corporation, (SECRET).

5. Feldman, S., Trails of Axi-symmetric Hypersonic Blunt Bodies Flying through the Atmosphere, AERL Research Report 82, AVCO Corporation, December, 1959, p. 84.