DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC

18 November 2009

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John Greenewald
[redacted]

Dear Mr. Greenewald

This is in response your 8 July 2009, Freedom of Information Act request for Accession Number: AD0089238 Title: Preliminary Design Approach. Air-to-Surface Missile Strategic Weapon System.

The Air Force Plans and Requirements office provided the attached document responsive to your request.

Please direct your questions to Naida I. Rhoades (703) 692-9960 and refer to Case #2010-00132. There are no assessable fees for processing your FOIA request in this instance.

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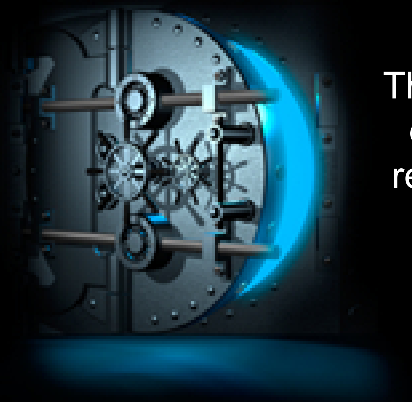

AD089238

PRELIMINARY DESIGN APPROACH. AIR-TO-SURFACE MISSILE STRATEGIC WEAPON SYSTEM

MICHIGAN UNIV ANN ARBOR

13 MAY 1955

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PRELIMINARY DESIGN APPROACH
AIR-TO-SURFACE MISSILE STRATEGIC WEAPON SYSTEM

BY: R. E. GREENEWALD

UNIVERSITY OF MICHIGAN
AERONAUTICAL ENGINEERING COURSE #102 LECTURE
MAY 13, 1955

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Preliminary Design Approach

(Air-to-Surface Missile Strategic Weapon System)

In a recent lecture period, Dr. Welmers discussed the methods employed in an operational analysis. Theses analysis techniques are particularly valuable when conducting a study program to define a system possessing optimum characteristics for accomplishing a certain job, since the factors used in the analysis can be applied uniformly to each of several desirable systems in an expeditious and economic manner to determine the relative merits of each system.

Today I would like to consider this application of operational analysis; a study program designed to define an optimum weapon system. As a specific example I will take a study program recently completed at Bell Aircraft.

In June of 1953, Bell undertook a study program for the Air Force to investigate and define an optimized air-to-surface missile weapon system. This system was to be centered around a B-47 bomber, but was to be so defined as to be useable with a B-52, and was to be limited to those components, technologies and systems which were sufficiently advanced to permit operational use in 1958. A broad approach was desired indicating the necessity for study of families of missile designs, guidance methods and operational tactics.

It is apparent that any such study must be started by determining the objectives to be accomplished. There probably is no system which is truly optimum with respect to all possible parameters. Such a system would cost almost nothing to procure, have infinite accuracy, be completely reliable, and completely destroy all targets without loss of human life. This of course is practically impossible, but we can select some of these parameters and optimize the system with respect to these selected parameters.

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For our particular study the parameters selected were minimum carrier and crew losses and minimum missile expenditures. As you will see later, this also results in minimizing the cost of the campaign conducted. Having selected the objectives of the study, the next step was to select and organize the variables to be considered into a compact plan of attack.

The objectives determined, we must pick an enemy we wish to destroy, locate his military or strategic targets, and from either intelligence reports, comparison with our own defense capabilities, or sheer hypothesis, assign probable defense levels. To conduct this war we must have bases of operation, and these must be selected.

We have said that we must study families of missile designs, guidance methods and operational tactics. These are obviously interrelated since the guidance method may limit the maximum practical range, which of course will affect the routes to the target and ultimately the losses and campaign cost. The desired missile and carrier ranges will be suggested by the target complex and bases selected. The guidance system and warheads selected will determine the kill probability for those missiles reaching the target.

The guidance system may also be an important factor in determining the missile design and carrier equipment. The complete missile installation, derived from these considerations and the enemy defense capabilities assumed will enable determination of the missile and carrier vulnerability, penetration routes and optimum tactics for the campaign. Studies of missile and carrier reliabilities will be necessary to determine the attack required to destroy the target complex.

These data can then be used to figure the number of sorties required, the expected carrier losses and missile expenditures for the campaign, and the total campaign cost.

This approach is used for each of the several families of missile designs, guidance methods, and operational tactics. The results of these separate investigations are then compared, and the best features of each system used to define an optimum system. These characteristics are then reinserted into a specific system preliminary design to combine as many of them as possible into a specific design. Evaluation of this single (or potentially several) specific designs eventually leads to a satisfactory definition of our optimum system. Now, since the carrier has been defined in our study objective, the system characteristics are readily converted into missile characteristics.

In our analysis we considered an enemy target complex of 152 targets in 68 cities in Soviet Russia, considering certain warheads and warhead effectiveness criteria. These targets lie within an assumed defense perimeter established at or near the boundaries of the Soviet and Soviet satellite countries. The bases assumed for this operation were based on the B-47 range capabilities and are London, Dharan, and Tokyo. The graph shows the amount of penetration into this defended area required to attack a given percentage of the targets selected. You will note that full target coverage requires penetration slightly in excess of 800 nautical miles.

We were assisted in establishing the target complex and defense levels by consultations with various Air Force agencies.

The enemy defense levels considered in this study were of two major categories: first, each of the targets was assumed to be highly defended locally by anti-aircraft guns, rockets and missiles clustered about the target. The remainder of the area within the defense perimeter was assumed to be protected with area defenses including interceptors, GCI radar systems, etc. It was assumed that the level of the area defenses was uniform throughout the defended areas. Various levels of defenses were considered for both the local and area networks. Incidentally, these networks were assumed to be discrete, that is, no area defenses in local defense zones and vice-versa.

From these assumptions of defense levels, calculation of carrier and missile survival is computed.

You will note that various sizes of bomber groups were assumed to determine the effects of defense saturation, and that the survival per aircraft does increase for increasingly large flights. Unfortunately, this increase is not proportional to the increase of carrier force. Similarly, the missile survival can be computed for the multiple launching case. It will be noted that the probability of at least one missile surviving under local defense conditions is almost 100% for two missiles/target. Note the reduction in probability that a particular missile survives, which must be considered if the method, or tactic of attack is to use decoy missiles.

Having established missile and carrier survival probability (or inversely their vulnerability), we defined missile reliability as the probability that the missile would travel the required distance with the accuracy specified without accident caused by malfunction of any of its components. Similarly carrier reliability was defined as the probability that the carrier will travel both inbound and outbound legs without component failure. The initial missile reliability is assumed to be .70. Once the launching is satisfactorily accomplished, the probability of component failure during the time the missile is required to operate is small. Thus the decrease of reliability with increasing range is gradual, to a value of about .65 at 800 nautical miles.

For carrier reliability, we assumed that 3% of carriers used in each mission were lost due to normal hazards as take off, landings, etc. It is of interest that in flight refuelings will decrease carrier reliabilities.

Detail consideration of tactics employed and penetration routes is dependent on the characteristics of the missile system selected, and will, therefore, be deferred until after consideration of the various missile parameters.

From the consideration of the target complex and enemy defense levels expected you will recall that a missile range of slightly over 800 nautical miles would require no carrier penetration of the defended areas. This would seem to be a logical initial criteria for missile range. I have used the terms initial criteria intentionally, for we will see that although carrier losses due to penetration decrease linearly with increasing missile range up to about 800 nautical miles, another factor should be considered. As the missile range increases, the accuracies of most types of guidance systems deteriorate. This decreasing accuracy lowers the kill probability for each strike, and required more and more return (or duplicate) missions to insure target destruction. By flying return missions the carriers survival probability again decreases, indicating that the optimum missile range from standpoint of carrier losses will be a compromise dependent on the guidance accuracy, target complex and enemy defenses.

In considering the guidance systems available we compiled a list of desirable characteristics.

The factors we considered important are listed here: good accuracy at extended range, immunity to jamming in the vicinity of the target where jamming will probably be most severe, a low altitude approach capability, a limited capability for indirect bomb damage assessment andreconnaissance, the ability to employ human judgement after launch, and finally requirements for carrier equipment which was available and practical to install in the selected carriers.

Next we surveyed the guidance systems which were either completely developed or which would be completed within the required time period. These included the multi-axis inertial system, a multi-axis inertial plus missile doppler radar system, an automatic map matching system (ATRAN), three type of Rascal type systems; a simple autopilot with radar steering, a single axis (range computing) inertial system with radar steering and a radar monitored single axis inertial system, a loran or shoran system, and finally a radar monitored multi-axis inertial system. To compare these systems, we merely checked each system for which a particular characteristic existed.

The multi-axis systems and components available today will not provide for necessary accuracy at the long ranges desired. The system is jam proof, and possesses a low altitude approach capability, but since it has no eyes, does not provide any IBDA or reconnaissance information. It is not controllable after launch. The carrier equipment which would be required for launching with suitable initial heading and velocity data is not available today, but can be developed and this is further complicated by the lack of adequate map data for an appreciable percentage of targets in the complex.

When a doppler (or ground speed measuring) radar is added in the missile, the stringent carrier equipment requirements are relaxed, and available carrier equipment will suffice. This system, however, still does not have adequate accuracy at long ranges and suffers in the reconnaissance department as well.

An automatic map matching system (ATRAN) offers good accuracy at long ranges, low altitude approach capability and will operate satisfactorily with presently available carrier equipment. It can be jammed, possesses no reconnaissance and IBDA capability and cannot utilize human intelligence after launch.

Further, this system again suffers severely from lack of sufficiently accurate map data - data which would have to be gathered on reconnaissance missions prior to operational employment. This is a serious defect when a "quick war" is contemplated.

The three Rascal type systems which have been demonstrated and proven in the present Rascal Objective I and II flight test are all adequate from the standpoint of IBDA and reconnaissance capability, possess excellent opportunity for employing human judgement after launch and present no problems with regard to carrier equipment. They do not, however, have adequate accuracy at long ranges.

Loran and Shoran systems provide low altitude capability and have a minimum of carrier equipment, but are extremely limited as regards the other desired characteristics, and are considered unsuitable for the application.

From these foregoing investigations, an approach of combining several of the best features of several systems was adopted, and the Radar Monitored Multi-axis inertial system was proposed. As shown here, this system meets all of the desired characteristics stated. This system possesses the jamming immunities and low altitude capabilities of the multi-axis system, but utilize a radar system to extend the range without affecting the accuracy and in addition satisfy the remaining desire characteristics. It was synthesized in this way.

Now at the altitudes envisioned - that is launch at about 40,000 feet and missile flight at 60 to 70,000 feet, earth curvature will determine the maximum radar relay link range for dependable operation. This is about 400 to 500 nautical miles. This would limit the maximum range to considerably less than 400 nautical miles to permit a radar steering type system (such as Rascal) be tracked down to a reasonable altitude.

A multi-axis inertial system on the other hand possesses suitable accuracies (with the present state of the art) only to 300 to 350 nautical miles with the accuracies of initial conditions which would be available.

It immediately becomes apparent that a radar system useable to 400 nautical miles could be employed to monitor the first part of the flight and also be used to enable a human operator in the carrier to introduce flight path corrections.

Further investigation showed that drifts and errors occurring during the radar monitored portion of flight could be effectively cancelled, resulting in a range extension for the multi-axis inertial system of about 300 nautical miles with very little degradation in accuracy.

Reference to our target complex analysis shows that 91% of the enemy targets can be reached with a 700 nautical mile missile range without requiring penetration. This was adjudged a suitable compromise, since for the warheads considered, 91% of all targets could be destroyed with a kill probability of 90% or better, a probability adequate to minimize the number of repeat missions.

In operation then, initial conditions of carrier position, velocity and heading are computed by the carrier navigation equipment and transmitted to the missile multi-axis inertial system. The missile is then launched up to a maximum range of 700 nautical miles from the target at an altitude of about 40,000 feet. During the first 400 nautical miles of flight, the search radar may be turned on to make position checks of known points, and flight path corrections introduced by the guidance operator. During the flight the missile follows a brequete flight path, climbing from 60,000 to about 70,000 feet as the fuel load is reduced. After the last missile radar position check the missile continues on as an all inertial flight, and may dive on the target in two preset manners; either a direct 60° dive on the target or by means of an alternate low altitude approach. When the terrain surrounding the target permits, the low altitude approach has the advantage that the missile remains undetected long enough so that its survival probability due to local defense action is almost unity.

It is important to note that although the missile would have a range capability of 700 nautical miles, it can be used at any range up to the maximum, thus accruing the advantage of increased accuracy at the shorter ranges.

Having proposed a guidance system and knowing the missile range required, the next step in the missile design is logically a power plant investigation to determine the best system for the proposed application. This is a logical step since the power plant and fuel space requirements will ultimately have a large bearing on the size of the missile airframe. One approach here is a comparison of weight requirements for the various propulsion systems for various ranges.

In the short range missile designed to have a given Mach No. carrying a given warhead (here shown as either 1500 or 2800 lbs) it is apparent that a liquid rocket power plant has weight advantages, due to the relatively light engine. As the range increases to about 150 nautical miles the weight of the liquid oxidizer which must be carried overcomes the low engine weight, and air breathing engines provide a lighter installation. Although not shown here in the 100 - 200 mile range for purposes of graphical clarity, the Turbojet will be superior for ranges of from about 150 nautical miles to 500 nautical miles. Beyond this range the ramjet is theoretically superior. As a point of interest you will note a considerable difference in the shape and slope of the curves for ramjet and turbojet operation. This is largely due to the fact that with existing turbojets, available engines have capabilities in discrete steps. In general, when additional fuel must be carried for longer ranges, additional thrust must be provided to both carry the larger mass at the same speed, and also to counteract the increased drag due to the larger tankage - volume required. In the ramjet case, these effects are not as pronounced, since the ramjet airframe is the engine, and increases in fuel volumes necessary for long ranges increase the size of airframe and hence also change the size of engine resulting in a configuration which can be designed to be near optimum for all ranges.

From these curves the ramjet has definite superiority for our 700 mile missile. Unfortunately, our restriction to use of components which are presently or will shortly be available legislates against Ramjets in favor of the more common, more available and better known turbojets.

A very important consideration beyond the missile range alone is the effect of the various propulsion systems on carrier radii, and ultimately on Weapon System radii.

Here the carrier radii are shown as dotted lines, and the Weapon System radii are shown solid. For the case of liquid rockets it is readily apparent that carrier radius falls off very rapidly with increasing missile range due to increase missile weight. This results in only a small increase in total Weapon System range for the increasing missile ranges. The characteristics of the turbojet and ramjet missiles are sufficiently similar to be lumped together. For these two configurations the carrier radius decreases quite slowly with increasing missile range due to the weight/range advantages inherent in the air breathing jet engines. This of course results in greatly increased weapon system radii with increasing missile ranges.

In order to arrive at this power plant summary, it is obvious that, we did more than study specific propulsion system characteristics. Actually we performed a rough preliminary analysis on some 55 possible missile designs. Only fourteen of these showed sufficient promise to consider further and two missiles of each type were finally picked for detailed study. These were all designed primarily for the 2800 pound special warhead. Before describing any of these missiles in detail it would be appropriate to describe the general characteristics of the entire family:

First of all, missiles are of the body-wing type in both the pitch and yaw plane. This arrangement was chosen over the more conventional tail aft or canard configurations for the following reasons:

1. Interference between fore and aft surfaces is eliminated. This results in linear static stability characteristics in both pitch and yaw planes up to high lift values as well as reduced rolling moments in combined plane maneuvers. The demands on the autopilot and servo system are eased substantially with this arrangement.

2. Structural flight loads on the body are much smaller since the main lift is close to the center of gravity. This results in substantial structural weight savings. In addition, non-structural (quickly removable) access doors become quite practical under these favorable conditions.
3. The number of parts are reduced considerably, e.g., surfaces, fittings, actuators, etc. This results in decreased weight and cost.

In order to minimize the drag in trimmed level flight, the missiles were designed to near neutral static stability. This is also an aid in simplification of the control system because only small control moments are required to maneuver the missile. The type of design is particularly well justified in non-piloted missiles of this category because provision of a significant amount of aerodynamic stability only reduces performance and neither provides simplicity nor increases the reliability of the system. It should be mentioned here that this very important phase of the study was investigated in detail using a representative missile as a model.

Roll and pitch controls are provided by balanced wing elevons; yaw control is provided by the upper vertical surface which is pivoted at the aerodynamic center. Because the missile is designed for a low value of directional stability, the rolling moment produced by the proposed surface arrangement is very small and, therefore, easily handled by the elevons.

The missiles shown herein are designed to accommodate a 48-inch diameter rotating double pill-box antenna, installed in a near horizontal position, either forward or aft of the wing. An alternate side-looking antenna, 10 feet in length, can be installed on most of the designs shown.

To facilitate comparisons of the turbojet and ramjet designs, the configurations and data I will give correspond to missiles designed for the same range.

The two turbojet missiles selected use the J-73 and J-65 jet engines. Although a number of turbojet engines proved suitable for use, such as the J-57, J-71 and J-67, advanced versions of the J-73 and J-65 appeared to be most favorable in regard to over-all missile performance and weight. In regard to availability, each of the basic engines is operating at present, and in each instance the development programs, for these engines, appear reasonable in regard to performance and weight, and compatible with the operational date required.

Both missiles were designed for 500 nautical miles range, launch at Mach 0.8 at 40,000 feet. They accelerate without auxiliary boosters and climb to cruise at Mach 1.8 at 60,000 feet.

Each horizontal surface has 35 square feet, an aspect ratio of 2.5 and a taper ratio of .5. The horizontal surfaces are a 4% modified double wedge airfoil section.

The vertical surfaces have 11 square feet of area each. The upper surface is movable and the lower surface (containing the guidance relay antenna) is fixed.

The J-73 missile has an overall length of 475 inches; a body diameter of 45 inches; a wingspan of 203.5 inches, and an overall height of 147 inches. Its weight empty is 6842 pounds and launch weight is 13,507 pounds.

The J-65 missile has an overall length of 457.5 inches, a body diameter of 45 inches, a wingspan of 203.5 inches and an overall height of 148 inches. This missile is slightly heavier than the J-73 version, having an empty weight of 7486 pounds and a launch weight of 14,726 pounds.

The missiles described require the use of afterburning, although cruise is usually at less than full reheat. One non-afterburning engine-missile configuration was investigated in an effort to conserve length. Since the thrust with full afterburning is more than twice the non-afterburning thrust, at high speed, a high capacity engine is essential if afterburning is to be eliminated. Rough preliminary results indicated that a J-67 powered configuration would provide satisfactory cruise performance. However, the performance of this particular missile was degraded considerably, due to several additive factors, in a recheck of the more promising configurations. The basic idea is practicable, nevertheless, provided an engine with higher thrust output were available.

The performance characteristics given for these missiles are based on the use of fixed inlets and outlets, which are compromised between the two extremes of transonic acceleration and high speed cruise. Two-position throw away types of inlets, or variable inlets, and variable nozzles do not seem practical for this application; calculations show that an increase of only about 15 per cent in fuel load is required to compensate for the omission of such more complicated and less reliable items.

Since the turbojet engine is started before launch it would be used to drive the alternator and hydraulic pump required for missile guidance and control components. Here again, pre-launch malfunctions could be observed and suitable action taken. It should be noted that neither ramjet nor rocket missiles provide such desirable characteristics in regard to engine starting and accessory drives.

The engine, of course, uses the same type of fuel as the bomber, thus relieving the logistic problem considerably. Engine reliability is enhanced significantly also, since the engine can be ground tested easily, under static conditions, whenever desired. Further, engine maintenance crews are already quite familiar with turbojet power plants, thus making checkout and maintenance a much simpler problem as well as eliminating the ground crew training which would be necessary for other engine types.

Two basically different type of ramjet missiles have been investigated in some detail.

These are the annular ducted body single burner type and the twin ramjet type with a non-ducted body. From weight and performance standpoints, neither missile has a particular advantage over the other. Accessibility to warhead and guidance components is better on the non-ducted body configuration, but on the other hand there are disadvantages inherent in twin engine operation even though they have a common fuel and control system.

Again both missiles were designed for 500 nautical miles range, and launch at Mach 0.8 at 40,000 feet. You will note that external boosters are required to accelerate the missiles to Mach 1.6, where the ramjet engines take over for the acceleration and climb to cruise at Mach 2.25 at about 70,000 feet.

The area of the horizontal surfaces is increased to 32.5 square feet per surface, but the 4% modified double wedge airfoil maintains its 2.5 aspect and .5 taper ratios. Both the all-movable upper and fixed lower vertical surfaces remain at 11 square feet per surface.

The annular ducted body configuration engine is 50 inches in diameter and is based on a 48 inch engine developed by the Wright Aeronautical Corporation. The overall missile length is 324 inches, body diameter 53 inches, wingspan 207 inches and overall height is 142.5 inches.

The twin ramjet engines are based on 28 inch diameter Marquardt Engines scaled up to 35 inches. The missile has an overall length of 340 inches, a body diameter of 45 inches, a wingspan of 220 inches and an overall height of 142 inches.

The optimum cruising Mach number was determined to be about 2.25 for these partially self-accelerating ramjet missiles. Higher cruise Mach numbers require the use of larger rocket boosters since the ramjet take-over speed is higher. The increase in weight due to this item is greater than the reduction in cruise fuel; consequently, missiles which cruise at M = 2.75 are about 500 pounds heavier. This phenomenon is due mainly to the fact that ranges in the order of 500-700 n. mi. are rather moderate for ramjet powered missiles. Increasing the range substantially would shift the optimum Mach numbers to higher values since the cruise portion of the flight would become increasingly important.

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An advantage of the ramjet missiles, in general, is that they are very compact and can be carried semi-submerged in the bomb bay, if desired. On the other hand, a rather extensive investigation of the present and future status of ramjet engines indicates a strong possibility that new ramjet engines, which would be required for these missiles, cannot be developed within the required time scale.

The necessity for rocket boosters to accelerate the missile to the ramjet take-over Mach number results in additional logistic, maintenance, and storage problems as compared to the turbojet power missiles, which do not require boosters.

As mentioned before, ramjet missiles do not provide practical low altitude approach. For example, an approach of 40 n. mi. at low altitudes will cause a range loss of approximately 200 n. mi. This occurs mainly because the characteristics of ramjet engines are such that flight Mach number must be kept to a high value - the minimum is about M = 1.6 for the missile shown. This results in unfavorable combination of Mach number and altitude, insofar as range is concerned. The low altitude approach results in more severe inlet instability, temperature, and structural problems.

Only one rocket propulsion system will be mentioned here, although several schemes and systems were considered in the original analysis. This missile was designed for a range of 100 nautical miles, from launch at 40,000 feet at Mach 0.8. The boost-glide flight profile includes a boost to Mach 3.7 at 71,500 feet, glide to Mach 1.3 at 63,000 feet and dive to detonation altitude.

Also of the wingbody configuration, its maximum dimensions include 315 inches length, 179 inches wingspan, 46 inch body diameter and 121 inch overall height. It has slightly smaller wing areas.

The liquid propellant rocket missiles investigated in this study were all of the boost-glide type. The use of this flight path, coupled with thrust-weight ratios of 2, refinements in aerodynamic design, and use of a ram air turbine for auxiliary power, provides a near optimum design for these missiles.

Missile length was kept to the length shown in order to make a bomb bay installation possible. For an external (Rascal type) installation a small reduction in weight could be obtained by increasing the body fineness ratio.

Although the boost-glide missile type represents a significant improvement when compared to the boost-cruise type of rocket missile, it is shown, in material which follows, that the improved rocket missile do not satisfy the performance requirements for an optimum missile system.

The rocket missiles would provide satisfactory low altitude flight characteristics except that the range reduction for a 100 n. mi. high altitude missile is so great that carrier penetration into the local defense would be required.

From these studies, it is apparent that the air breathing engines have definite superiority over liquid rocket missiles for the long ranges desired. Further, as previously stated, the ramjet developments are not sufficiently advanced to make these engines available in the time scale required. For these reasons the J-65 and the Advanced J-73 turbojet engine configurations were proposed.

For purposes of clarity, I'm going to briefly depart from the exact chronology of the study. A later extension of this study program investigated turbojet performance in considerably greater detail. It was determined from mechanical differential computer studies that for given fuel loads, the J-73 configuration had about 50 n. miles greater range than the J-65 configuration.

Characteristics of other turbojet engines were investigated. In addition to the J-73 and J-65, the J-79, J-71 and J-57 engines were considered.. To facilitate ready reference to manufacturers data, the manufacturers designation is given here. The engine parameters at sea level and 35,000 foot altitude and two Mach numbers are compared. The values shown are corrected for inlet losses and are for a convergent-divergent nozzle of 1.6 area ratio. It is apparent that from a size-weight-thrust standpoint, the J-79 is very attractive. At the time of this study, however, the J-79 did not look to be available within the time span. Even so, a comparison of these engines was made for typical Mach 1.8 cruise 800 nautical mile flights to determine the amounts of fuel required for each of these airframe power plant combinations.

Again it appears that the J-79 has advantages of both fuel requirements and launch weights. Comparisons of this type, even though the components are currently unavailable, point out considerable advantages in growth potential of given designs and are valuable from this standpoint. Indications of the versatility of the basic missile design is also highly desirable, both from a development and a production view point.

A more detailed basic missile design was made for the J-73 engine configuration. The multi-axis inertial guidance equipment is shown installed in the nose and rear of the warhead compartment. The fuel tank is located to coincide with the missile center of gravity to minimize C.G. travel during the flight. The horizontal wing is located approximately at the center of the fuselage so that the C.G. - center of lift locations insure a near neutral stability. A single inlet duct with a modified 4% boundary layer control wedge is provided. The possibilities of using variable or several throw-away ducts were considered, but deemed of insufficient value to justify the added complexity and cost.

The search radar antenna is located just aft of the wing carrythrough. As we've said before, this antenna is used only during the midcourse - constant angle of attack portion of flight and does not need to be pitch stabilized. The particular configuration shown here shows the growth potential capability of using an ATRAN monitored multi-axis inertial system when suitable ATRAN components become available. For the radar monitored multi-axis system this unit is replaced with the command package which decodes and transfers guidance operator correction commands.

The J-73 turbojet is mounted slightly below the forward body centerline, inclined slightly nose down, the hydraulic and electrical power supplies for the missile guidance and control equipment are mounted on the engine accessory pads in the normal manner. The lower vertical wing is hinged to fold parallel to the horizontal wing to provide the necessary ground clearance when the missile is mounted on the carrier aircraft.

Although the original study dealt mainly with the 2800 and 3000 pound warheads, this later study indicated the desirability of having a capability of using the 6400 pound special warhead. This capability was incorporated by installing the lighter warheads in the forward end of the warhead compartment and the heavier warhead in the rear of the compartment. When the 2800 or 3000 pound payload is installed, a removable fuel tank is installed in the aft end of the compartment, to provide the balance of the fuel needed for the 800 n. mile mission. The size of the 6400 pound warhead is sufficient to require the entire warhead compartment, and the resulting missile range is 400 nautical miles.

Initial structural design work was concerned with the study of certain structural problems, pertinent to the selection of optimum missile structure. Effort was concentrated on the center portion of the body since it appeared that this portion would dictate the most promising structural arrangement for the entire body.

Five center bodies were designed, including aluminum alloy structures of pure monocoque and semimonocoque, and a plastic structure of sandwich construction. From a comparison of the weight of these designs, together with a consideration of fabrication costs and difficulties, fuel tank sealing problems, structural development programs, etc., the pure monocoque, aluminum alloy shell was selected.

Studies were also made of the forward end of the intake duct where problems arise from the large pressure loads on thin, flat surfaces. A satisfactory structural configuration was ultimately achieved by using longitudinal cantelever beams, rather than frames, in this section.

The various problems of thermal stress, creep, creep buckling, and other phenomena resulting from high temperature operation have been examined generally, and is considered that no serious difficulties exist with the proposed missile.

Following the afore-mentioned general studies, a structural configuration was developed for the basic missile. Sizes and thicknesses were established for the primary structural material and a supporting preliminary analysis was written. A brief description of the missile structure is given in the following paragraphs.

The wing is typical of thin, highly loaded supersonic surfaces in that it has its primary bending structure of multiweb construction with machined, tapered, aluminum alloy skins. The skins extend in one piece from the rear beam forward to the leading edge, and from the missile centerline to the tip. The shear webs are channel-section members of aluminum alloy, and three channel-section ribs are also included, one at each aileron hinge and one at the body attachment.

The aileron is a simple, three-piece structure consisting of a single aluminum casting of the internal beam and ribs, to which are bonded the two skins of 1/8 inch aluminum alloy sheet.

The fuselage is primarily a ring-stiffened, pure monocoque shell, circular in section except over the center portion where it is deepened and given flat sides to accommodate the intake duct. Aft of the leading edge, the intake duct rises into the fuel tank and changes gradually from a semirectangular to a circular section. Internal duct pressures are resisted by channel section frames which also extend up into the fuel tank to carry fuel tank pressures. The wing carry-through structure and the search antenna are positioned beneath the duct, and the resulting cut-out in the fuselage shell is bridged by channel-section longerons. Large structural doors are provided for warhead and engine installation, and most of the fuselage structure is formed from 24S-T6 aluminum alloy.

The upper vertical surface is all-moveable, and is pivoted on a 2 1/4 inch diameter alloy steel shaft, carried in bearings in the fuselage. This shaft extends up into the vertical surface where it changes to a rectangular section, forming the main beam. The remaining upper surface structure consists of two one-piece aluminum alloy skins, separated by solid magnesium ribs.

The lower vertical surface is fixed in free flight, but is hinged on two root fittings to facilitate storage of the missile on the carrier. The primary structure is of multiweb construction, using aluminum alloy skins which are machine-tapered in thickness and three channel-section spanwise beams. The front and rear beams pick up the root hinge fittings, while the skins are one piece from root to tip and from leading to trailing edge.

To permit a comprehensive examination of the structural aspects of the various configurations, an analysis of basic criteria and resulting major design loads had to be made. A representative configuration was used as the example, and actual preliminary design loads were derived for use in stress analysis and subsequent weight estimation. For other configurations, loads were obtained by applying the ratios of gross weights and/or moments of inertia.

The selection of the design criteria is goverened by the target accuracy and associated maneuver requirements, probable gust loads, and captive flight conditions. Data provided are: structural design weights, limit load factors, and definition of critical condition combinations. Maximum load factors of 3.0g in pitch and 1.5g in yaw were selected for missile free-flight-condition design.

It is interesting to note as an aside that about the time this second study was completed, it became apparent that the J-79 engine was coming along much faster than the advanced J-73 engine, and that today we think almost entirely in terms of the J-79.

The missile installation as determined in the original study has not been appreciably changed.

Studies to date of various carrier-missile configurations have shown that the body mount arrangement (similar to the present Rascal) is the most promising for missiles over 340 inches length for the B-47 and 420 inches for the B-52 aircraft. A typical installation of this type is shown here.

An arrangement whereby the missile is mounted on the wing in place of one of the wing tanks has some merit for present B-47B and B-47E models in that the elimination of one wing tank does not reduce the amount of fuel that can be carried. This location possesses a further advantage in that existing attachments function adequately as a missile mount. On the other hand, longer range versions of the B-47 are being considered by the USAF; these airplanes take off at, and refuel, to higher gross weights than present B-47 models and would require all available tankage for maximum radius. On these models, therefore, the loss of a wing tank would constitute an important disadvantage.

Wing mount arrangements on the B-52 do not appear very satisfactory. The wing tank is much further outboard and further aft, compared to the B-47. Mounting the missile in place of the wing tank presents, consequently, more severe lateral and longitudinal balance problems as well as increased alignment troubles. As with the B-47, inboard, pylon-type wing mounts are inferior to body mounts on many scores and have no outstanding advantages.

Another possibility serious disadvantage of wing mounted missiles, in general, is that on an aborted mission it may be necessary to jettison the missile to prevent excessive landing loads on the outrigger landing gear and subsequent loss of the aircraft. For testing purposes, missile weight can be reduced to 4000 pounds or less and would not present the same problems.

For missiles falling within the length limitations mentioned previously (short range rocket missiles and short or long range ramjet missiles), a semi-submerged bomb bay location is possible. A small advantage of this arrangement is found in its greater similarity of appearance to the usual gravity bomber than is found when wing or body mounts are employed. On the other hand loading the missile aboard the carrier is more complicated, because of the rather small ground clearance. The upper fin (as well as the lower fin) will have to be either foldable or readily removable, otherwise pit loading will be required.

Modifications to the carrier are also greater; the bomb bay fuel tank, the small fuselage fuel tank under the wing, the shear deck, and bomb bay doors will require modifications. Although certain carrier modifications could be of a permanent nature, reconversion back to gravity bombing missions is more complicated than for the external mount arrangement.

Towing the missile behind either the fuselage or the wing presents many serious problems compared to the arrangements mentioned previously. Because preliminary calculations indicate that no important advantages have been discovered in the tow arrangement (probably because this weapon system make useof an existing airplane), less effort has been expended on this type of design.

The external body mount arrangement, as contrasted with other arrangements, offers the most satisfactory compromise to the over-all installation problem. To sum up:

1. The drag is low on both legs of the carrier flight.
2. The disturbance to longitudinal and lateral balance is small.
3. Modifications to aircraft structure and fuel tankage are small.
4. Loading the missile on the carrier is simple.
5. Access to the missile, when placed on the carrier, is good.
6. Access to the carrier relay antenna and other equipment which is located in the free bomb bay area is excellent.
7. Similarity in mount to Rascal will permit the use of much of the existing ground support equipment and techniques.
8. The least configurational demands are placed on the missile.
    a. Body length and fineness ratio are not predicated by any arbitrary constraint, e.g., bomb bay length. Instead, a near optimum fineness ratio, considering both drag and structural weight, can be used.
    b. The upper fin is not required to be easily removable or foldable.

It should be noted here that a bomb bay installation of the relay antenna is preferable, for long range missiles, to more aft locations, for two reasons. First, it provides forward as well as rearward vision. The result is that the communication link can be maintained with the carrier headed both towards and away from the target. This feature is very desirable for long-range missiles preliminary calculations indicate that no important advantages have been discovered in the tow arrangement (probably because this weapon system make use of an existing airplane), less effort has been expended on this type of design.

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In regard to other guidance equipment on the carrier, the intent is to use Rascal techniques and development wherever profitable. For example, it appears possible to use the B-47 navigator-bombardier station in its entirety, as devised for Rascal. The remaining guidance equipment can be installed in a capsule mounted in the bomb bay, similar to Rascal, or it may be preferable, because of the severe cooling problem for capsule-contained equipment, to mount the components on racks.

Looking back at our study plan, we have pretty well completed the missile design and installation, determined our target complex, possible bases of operation and hypothesised the probable enemy defense levels. We have spoken briefly of carrier and missile reliabilities and vulnerability. The remaining areas of consideration are therefore those of tactics and the actual weapon analysis.

At the risk of some slight repetition let's review the significant factors affecting each of the various phases of such an operation and then consider our specific problem. We have done several such analyses; the latest was under a continuation of the original study program, in which major consideration was given to the B-52 as carrier, and the proposed missile I have developed for you. The numbers I'll give you today will be based on this latest analysis.

A. MISSION SUCCESS

Consider a weapon system consisting of a warhead, a container for the warhead, and a carrier to deliver this warhead package. The container may be either an air-to-surface missile or a gravity bomb; - the carrier is a B-52 bomber. The ability of the weapon system to destroy enemy ground targets is dependent on (1) survival of the carrier to a release point for the warhead package, (2) survival of the warhead package from launch to a suitable detonation point and (3) detonation of the warhead, and destruction of the target.

(1) Survival of carrier to launch (P_{SL})

Three factors should be considered in determining the probability that a carrier will arrive at a designated launch position, namely, the effects of enemy defenses, non-combat hazards and carrier reliability. The encountering of non-combat hazards, (e.g. extremely unfavorable weather conditions, failure to receive adequate refueling subsequent to take-off, etc.) or failure of carrier components to function reliably may result in an aborted mission or, in the extreme case, actual loss of the carrier. Evaluation of air abort rates and carrier survival of non-combat hazards is a difficult problem, due to the high degree of unpredictability associated with the occurrence of causes leading to these effects. In particular, it is difficult to anticipate the psychological reaction of carrier crews to indications of equipment malfunction when faced with the prospect of flying for a considerable length of time through enemy defended territory prior to release of a high yield payload. Another problem that becomes pertinent when attempting to evaluate abort rates is the distribution of aborts with respect to the amount of time that has elapsed between takeoff and actual occurrence of the abort. It is reasonable to assume that a high per cent of all carrier component malfunctions will occur relatively soon after takeoff. This is based on the philosophy that a great number of failures are initial failures that result when a component is first called upon to operate, and that a large majority of carrier components are initially operated shortly after takeoff. For carriers that function reliably over this initial time interval, component failure rates are expected to increase gradually as the operating time is increased. From a psychological point of view, however, detection of minor failures by a pilot will not result in aborted missions as often after the cell has penetrated considerably into enemy territory as they will during initial entry into defended regions. In an analysis of weapon system effectiveness, it becomes necessary to define an operational factor "po" to represent the probability that a carrier will abort. For any cost analysis it is necessary to evaluate carrier losses $\bar{p}o$, therefore, will be used to designate the probability that an aborted mission will result in loss of the carrier. "po" is primarily a function of time of flight "t_f where $t_f = \sum_{n} t_i$ with: t_1 = time of flight from takeoff to entry into enemy defended territory

t_2 = time of flight during which carrier is exposed to area defenses prior to release of warhead package.

t_3 = time of flight during which carrier is exposed to local defenses prior to release of warhead package.

t_4 = time carrier must loiter, subject to area defenses subsequent to release of warhead package. Despite the increase in carrier vulnerability caused by loitering in regions covered by the enemy's defensive forces, it frequently becomes necessary to accept this penalty in order to obtain damage assessment data or to provide accurate guidance of the warhead package to its detonation point.

t_5 = time carrier must loiter subject to local defenses subsequent to release of warhead package. Since the terms "local defense" and "area defense" are usually employed to designate mutually exclusive areas, $t_4 = 0$ when $t_5 \neq 0$, and $t_5 = 0$ when $t_4 \neq 0$.

t_6 = time of return flight, subsequent to release of warhead package and loiter time, during which carrier is exposed to local defenses.

t_7 = time of return flight, subsequent to release of warhead package and loiter time, during which carrier is exposed to area defenses.

t_8 = time of flight between exit from enemy defended territory and return to home base.

The enemy is expected to surround each prime target with a network of local defense weapons including anti-aircraft guns, unguided barrage rockets and guided missile installations. This chart shows the capabilities of each type of weapon system in terms of maximum altitude and maximum horizontal range. These contours were derived on a basis of existing and estimated future performance characteristics of U.S. weapon systems. In order to evaluate the effectiveness of a local defense network, in combatting any particular threat it becomes necessary to ascertain:

a) the quantity and employment of each type of weapon;

b) The rate of fire attained by each installation, i.e. the number of rounds that can be fired and the time duration of a single round; and

c) the kill probability per round for each weapon type.

When this information is combined with data defining the pattern of the attacking force, the probable success of the defense in countering the attack can be determined. From this it is possible to determine the probability that any carrier entering the local defense zone will arrive successfully at its designated launch position.

Outside of those areas defended by local defense weapons, the enemy is expected to provide some measure of national defense through a variety of weapons systems.

A major portion of this effort will be accomplished by interceptors armed with conventional armament (guns, cannon and unguided rockets) with future improvement provided by air-to-air guided missiles. In evaluating the effectiveness of an interceptor that has been committed against a group of attacking bombers, it is necessary to evaluate: (1) the probability that the interceptor will be successfully vectored into a position where it is capable of detecting the bombers; (2) the probability that detection will be accomplished; (3) the probability that detection can be converted into a firing pass; and (4) the probability that the firing pass will result in a bomber kill. These probabilities are primarily dependent on the capabilities of the interceptor and its equipment. While successful vectoring is heavily dependent on accurate ground tracking of the target and successful relaying of this data to the interceptor the ultimate success or failure of this phase is directly related to the performance characteristics of the interceptor, e.g. its rate of climb, cruising speed, maximum altitude, etc. Detection is of course dependent on the capabilities of the interceptor's AI radar. Once having accomplished detection of the bomber group, the interceptor must be capable of maneuvering into a position where it is capable of firing its armament against the bomber. Achievement of a bomber kill is then dependent on the accuracy and lethality of the particular weapon employed. After an evaluation of this nature has been made it becomes necessary to analyse the geometry of the attack in terms of: (a) the bomber track; (b) the size and deployment of the bomber group; (c) the location of the early warning detection line; (d) the location of interceptor bases and the numbers and types of each interceptor (plus armament) available to each base, and (e) the commitment rate for each base against the bomber strike. Combining this information with the probabilities previously described, it is then possible to evaluate the probable success of the bombers in penetrating the interceptor defenses. Other weapon systems could be employed for area defense (e.g. AA guns and barrage rockets) but due to the vast amount of territory requiring some measure of defense unreasonable quantities of these weapons would be required to provide adequate coverage. The only other weapon that can be presently envisioned as capable of providing a level of defense sufficiently high to warrant consideration is a long range surface-to-air missile of the Bomarc type. Due to the complexities inherent in establishing an operationally reliable and accurate system of this nature, it is felt that until about 1965 interceptors must be relieved upon to provide virtually all of the area defense.

Strengthening of this area defense can be accomplished by:

a) increasing the number of interceptors available for combat;

b) improving the accuracy and lethality of the armament; and

c) providing interceptors with greater performance capabilities and improved AI radar eqipment.

Thus, it is seen that in order to evaluate "P_{SL}", the probability that any given carrier survives to its designated launch position, it is necessary to evaluate a large number of factors including performance criteria, and operational availability of defense weapon systems, and the geometry and strategy of both the attacking and defending forces. In general P_{SL} is a product of three probabilities:

$$P_{SL} = (1 - P_o)\, P_{SAD}\, P_{SLD}$$

$(1 - P_o)$ - probability that the carrier will not abort

P_{SAD} - probability that the carrier survives through the area defense

P_{SLD} - probability that the carrier survives through the local defense

A number of cases may arise in which the carrier is not subjected to either the area defenses or the local defenses. In these instances, the appropriate survival probabilities are defined to be equal to unity.

(2) Survival of Warhead Package from Launch to Detonation (p_{wps})

Assuming that the carrier has successfully reached a launch position the next phase requiring analysis is that of release of the warhead package and passage of this package to a desired location for a detonation of the warhead. As previously indicated the container for the warhead may be either an air-to-surface missile or a gravity bomb.

If a gravity bomb is used the probability that it will arrive at an intended location for warhead detonation is dependent on the accuracy and reliability of the bomb sight, accuracy of the input data, and reliability of the release mechanism. The bomb is invulnerable to enemy countermeasures during its drop from release at altitude to detonation.

When an air-to-surface missile (ASM) is employed to deliver the warhead, the problems of missile system reliability and vulnerability become critical. An analysis of ASM reliability in particular is difficult to perform due to the complexity of equipment required to perform guidance, control and propulsion functions for the missile.

In general, missile reliability is a function of time-of-flight. As in the case of the carrier, most of the missile system components are called upon to operate during the initial phase of the missile flight pattern, and hence a majority of equipment malfunctions are expected to occur early in the flight. Since some components may not be in operation until the latter portion of the flight due to the special nature of their function, e.g. mechanisms required to initiate the terminal dive phase in the flight program, missile failures due to non-reliable operation are expected to increase as time of flight is increased. It is expected, however, that the number of reliability failures experienced initially will be very large as compared to the number of failures experienced during the remainder of the flight. Although the supersonic speed and high altitude capabilities of an ASM render it invulnerable to interceptor weapon systems, surface-to-air guided missile systems of the Nike-type are effective in combating an attack by ASM's. It thus becomes necessary to re-evaluate the effectiveness of the local defense network in combating an attack by ASM's.

Thus, if "r_{wp}" is used to represent the reliability of the warhead package from launch to detonation and "p_{sd}" is the probability of surviving enemy defenses, then "p_{wps}", the probability that a warhead package is successfully launched and arrives at a detonation point is a product of these two factors thus:

$$p_{wps} = r_{wp} \, p_{sd}$$

The success of a single mission at this stage is a product of carrier survival probability and success of the warhead package in reaching a point of detonation, or, if "P" represents success of the mission:

$P = P_{sl} \, P_{wps} \, P_d$ where P_d is the probability that warhead detonation and target destruction are accomplished.

Hence

$$P = (1 - P_o) \, P_{sad} \, P_{sld} \, r_{wp} \, p_{sd} \, P_d$$

(3) Warhead Detonation and Target Destruction ("P_d")

The problems associated with detonation of the warhead and destruction of the target may be roughly divided into four categories:

I. reliability of detonating mechanism (fuzing system);

II. location of the burst;

III. lethality of the warhead; and

IV. the nature of the target and the amount of damage required to effect target "destruction".

The probability of obtaining proper detonation of the warhead is dependent on reliable functioning of the fuzing mechanism ("r_f"). Of the esveral types of fuzing that may be employed, the one ultimately selected for use is dependent on its compatability with the type of warhead that is used and the operational characteristics of the vehicle employed to deliver the warhead.

In order to completely evaluate the effectiveness of a burst, it is necessary to know the ground zero (g.z.) and altitude at which the warhead detonates. In addition to this data, the latitude and longitude of the target must be specified in order to determine an intended aim point to relate the burst location and the target position. Because the enemy will undoubtedly attempt to conceal "target" locations, it is often necessary to rely upon intelligence reports and secondary data as a basis for estimating target positions. Hence, it becomes important to assess the degree of accuracy with which these positions are reported. In evaluating a given weapon system the burst pattern or distribution of burst about an intended aim point, should be determined. In a guided missile, this pattern is determined by the accuracy of the guidance system. Knowledge of this probability distribution of burst locations about an intended aim point when combined with warhead lethal radius, i.e. the maximum distance at which an overpressure sufficient to destroy the target is produced by the warhead, can be used to determine the probability of "killing" the target ("P_k") for those warheads which have reliably detonated. In general, two categories of warheads may be considered, single stage and two stage warheads. For each of these categories a distinct method of target destruction is considered. The single stage warhead is used to achieve a high level of overpressure against a structural or near point target. When two stage warheads are employed, the concept of destruction is changed. It now becomes feasible to "destroy" a target, i.e., nullify its usefulness to the enemy, by crippling or destroying supporting facilities for the target that exist in the surrounding area. It is seen, therefore, that it is most important to completely define the target objective. If it is a structural target and a single stage warhead is used, target toughness must be assessed and the amount of overpressure required to destroy the target can then be determined. If a two stage warhead is employed and the concept of indirect target destruction is accepted, the size and shape of the area on which sustenance of the targets usefulness is dependent, must be specified. It is then necessary to specify a minimum overpressure that should exist over a certain per cent of the area, this per cent dependent on the extent to which supporting facilities must be disrupted in order to halt the targets output and usefulness to the enemy.

Thus, the probability that a warhead that has reached a detonation point will destroy its target objective is a product of "P_k" defined above and the reliability of the fuzing mechanism, "r_f".

$$P_d = r_f P_k$$

Hence, "P", the success of a mission (i.e., accomplishment of destruction of the target objective) is given by:

$$\begin{aligned} P &= P_{sl} P_{wps} P_d \\ &= (1 - P_o) P_{sad} P_{sid} r_{wp} P_{ad} r_f P_k \end{aligned}$$

From the crew's point of view, the mission is, of course, not a success until they have returned safely to home base. If:

P'_{sld} = outbound carrier survival probability through local defense

P'_{sad} = outbound carrier survival probability through area defense

$1 - \bar{P}'_o$ = probability that the carrier does not suffer a fatal abort on its outbound leg

then for the outbound survival probability

$$P_{so} = P'_{sld}\, P'_{sad}\, (1 - \bar{P}'_o)$$

The total carrier survival probability, "P_s" is given by:

$$P_s = P_{sl}\, P_{so} = (1 - \bar{P}_o)\, P_{sad}\, P_{sld}\, P'_{sld}\, P'_{sad}\, (1 - \bar{P}'_o)$$

B. OPERATIONAL FRAMEWORK

The term "operational framework" is used here to represent:

(i) the target system,

(ii) the defense network for that system,

(iii) bases of operation for the attack forces,

(iv) amounts of equipment (initial stockpile) available for use at inception of attack,

and

(v) replacement rates and buildup of striking power following initial strike.

1. Target System

In the event that hostilities should break out, attacks will be required against at least two categories of target objectives; (i) those which represent the enemy's immediate striking potential, e.g. strategic air command bases, warhead depot and surface-to-surface missile installations and, (ii) those representing locations of facilities vital to the national economy, e.g. industrial plants, power supply sources, transportation and communication centers.

While reconnaissance and intelligence reports are expected to provide most of the necessary data concerning targets prior to the outbreak of hostilities, some provision must be made for attacking locations vital to the enemy discovered subsequent to the beginning of the war. Target complex, as used here, shall be used to refer to only the known fixed sites. In addition to specifying the locations of the targets, it is desirable to obtain data concerning the physical structure and economic relationship of the areas immediate to those locations. This information is necessary in order to evaluate the effectiveness of using the two stage warheads and in selecting aim points. Where two or more targets exist in the same area, this data takes on added significance since in these instances, a single two-stage warhead strategically placed may produce the same effect as two or more single stage warheads.

With the advent of high yield warheads of great destructive potential and the intercontinental capability of the enemy's long range bomber force for delivering such payloads, time becomes increasingly significant as a parameter in the overall campaign analysis. Since it is anticipated that only a portion of the targets in the complex will be capable of being successfully attacked on the first strike, it is necessary to evaluate the relative importance of all targets in the system and plan the campaign accordingly.

2. Defense Network

Once the target system has been established, an assessment must be made of the enemy's potential for defending this system. In order to define the defense pattern it is necessary first of all to establish the location of the early warning radar line. This is, of course, dependent on the type of radar equipment available and the locations of radar systems relative to the target complex. The next step is to determine the sites of interceptor bases (and, in the future, Bomarc type surface-to-air missile installations) and the relation of interceptor control to early warning detection. From this information, it is possible to establish the locus of points at which the attack force first becomes amenable to enemy countermeasures. The territory enclosed by this locus is defined as the target area. The two types of defense (area defense and local defense) existant in this area have been previously discussed (Section A, 1). Once the area and local defense patterns have been established, the routes to be used by the attacking forces are selected.

3. <u>Bases</u>

In conducting a campaign against the target complex, an attempt is made to select attack routes which require the least amount of carrier exposure to enemy countermeasures. The ability to accomplish this against all of the targets in the system is dependent on the effective operating radius of the weapon system and the locations of bases from which this weapon system may operate.

Suitable sites for bases of operation may be selected from a number of overseas locations. The vulnerability and logistics problems associated with the use of overseas bases, however, suggests the desirability for investigating the potential of an intercontinental weapon system with bases located on the mainland of the United States. A minimum of operational complexity would result through the use of continental bases exclusively. Should the radius of the weapon system, however, prove to be a limiting factor, a "shuttle type" mission might be employed. In this type of mission the attack is initiated from a base in the U.S., the payload is dropped on the target and then the carrier proceeds to an overseas refueling base prior to returning to the U.S. In this manner, the operating radius of the weapon system may be effectively extended to permit the selection of less vulnerable attack routes.

4. Stockpile

In the evaluation of a particular weapon system, it is necessary to estimate the number of active units which may be called upon to provide the striking power at any specified time period. A time is then selected to designate initiation of the campaign and using the stockpiles of carriers, warhead containers and warheads available at this time it is possible to determine the structure and size of the initial strike. At this stage of the analysis, it is important to formulate some guess as to the nature of the conflict and the time period available during which counterattacks may be made against the enemy. This will in some measure dictate the size of stockpile and the rate of buildup required to establish this stockpile at the outbreak of hostilities. If the period of attack and counterattack is expected to encompass a reasonably long interval of time, it may be desirable to study the possibility for replenishing depleted stockpiles following the initial phase of the campaign.

C. STRATEGIES AND COST ANALYSES

"Strategies" as employed in this section shall be used to refer to the structure and size of the striking force required against each target. This is, of course, dictated by the number of targets requiring attack, the extent of damage desired against each target and the amounts of equipment available to "do the job". Within this framework, then, strategies are selected which result in a minimum of loss of human lives (crews) and the least cost in expenditure of equipment. Furthermore, this optimization must result in strategies which will accomplish the campaign objective within the allotted time period.

The complete costing of a campaign involves a complex analysis which should take into account:

(i) the actual cost in terms equipment expended during the campaign,

(ii) the maintenance costs entailed in keeping the system in state of readiness, and

(iii) the initial cost of establishing the system (including such items as establishment of bases and supply lines, stockpiling of necessary equipment and training of personnel).

In many instances a sufficient measure of the cost of a given system may be obtained from (i) alone. To evaluate the merits of a given weapon system, the cost of the system should be compared with the "kill potential", or amount of damage that the system is capable of inflicting on the enemy. Another item entering into an evaluation of system merit is its flexibility, i.e., its capability for adapting to changes in such items as target locations, enemy defense strengths and the size of the payload required against a target. Finally, the growth potential of the system should be considered, i.e. improvements in the system which can be incorporated to increase the reliability and reduce the vulnerability of the weapon system.

A. THE MODEL

In order to compare the merits of a B-52/gravity bomb weapon system with B-52/Air-to-Surface Missile weapon systems, a simplified model was constructed. 152 target objectives located in 70 urban areas of the USSR were selected to form the target complex. A defense border representing the locus of positions where GCI (Ground Controlled Intercept) supervised interceptor planes can first engage attacking forces of B-52's was assumed, thus defining the target area. This chart shows the distribution of the 70 urban areas with respect to their depth behind this defense border. It is seen from the graph that about 50% of the areas are within 300 n.m. of the defense border. The distribution of the 152 target objectives is almost identical to that for the 70 areas. Table II-A gives a breakdown of the 70 areas in terms of the number of targets (from the 152 objectives) in each area. It is notable that 31 areas or 44% of the total number of target areas contain only one target objective. Destruction of these target objectives (structural type targets) may be accomplished in either of two ways:

Number of Targets In Area	Number of Areas	% of Total Number of Areas
5	4	6
4	9	13
3	13	18.5
2	13	18.5
1	31	44

TABLE II-A

(a) by destroying the target directly with an overpressure of about 10-12 psi on the target structure, or

(b) by covering a "vital" area adjacent to the target with an overpressure of about 6 psi. (In brief, the reasoning is that the effectiveness of a "structural type target" may now be destroyed by causing destruction and havoc over a sufficient portion of an area adjacent to the target containing a major portion of supporting activities for the target.)

In this analysis the vital area described is assumed to be circular in shape with a radius of 2 1/2 n.mi.

The levels of area and local defense assumed to exist within the defense border are expected to represent the enemy's capabilities about 1960. To simplify the analysis it is assumed that interceptor bases are distributed in a pattern so as to provide uniform coverage of the defended area. This means that the amount of opposition encountered by an attacking B-52 force is a function of the amount of enemy territory traveled over by the B-52 force. The level of area defense selected for the analysis may be interpreted as crediting the enemy with 3000 interceptors with a kill probability per interceptor of .10 ready for instantaneous use in combating an offense directed against the targets. Estimated capabilities of this defense against a group of 50 B-52's penetrating 500 n. m. into defended territory are summarized in Table II-B.

	Inbound	Outbound	Total
Survival Probability (Each B-52)	0.825	0.891	0.735
Expected Losses	8.75	4.50	13.25

Initial B-52 cell size - 50
Depth of penetration - 500 n. mi.

TABLE II-B SUMMARY OF AREA DEFENSE CAPABILITIES

The dominant factor in the local defense network is assumed to be a Nike-type surface-to-air missile system. The defense level assumed in this model is obtained by providing each area with three SAM installations. Table II-C summarizes the capabilities of this local defense against cells of air-to-surface missiles attacking a target with a speed of Mach = 2.0 from an altitude of 60,000 ft.

Cell Size	Prob. A Given ASM Survives	Prob. At Least One ASM Survives
1	0.240	0.240
3	0.630	0.954
5	0.760	1.0

TABLE II-C SUMMARY OF LOCAL DEFENSE CAPABILITY AGAINST AIR-TO-SURFACE MISSILE

The capabilities of this local defense against cells of B-52's are given in Table II-D.

Initial Cell Size	Prob. That at Least One B-52 Reaches Bomb Release Line	Expected Losses
4	0.720	3.59
5	0.963	4.12
6	0.973	4.38

TABLE II-D SUMMARY OF LOCAL DEFENSE CAPABILITY AGAINST B-52's

Characteristics of the missile systems examined are described in Table II-E. Primary interest is centered about the long range (700 n. mi. max. range) ASM's. For purposes of comparison, the 100 n. mi. and 400 n. mi. maximum range missiles are studied.

Maximum Range	Type of Guidance	Inflight Surveillance of Missile
100 n. mi.	All inertial	None
100 n. mi.	RASCAL type	To detonation
400 n. mi.	Multi-axis inertial with North seeking platform and K-4 plus Doppler (20 min. leveling)	None
400 n. mi.	Multi-axis inertial with North seeking platform and K-4 plus Doppler (20 min. leveling)	To initiation of dive or end of relay link
700 n. mi.	Multi-axis inertial with North seeking platform and K-4 plus Doppler (20 min. leveling)	None
700 n. mi.	Multi-axis inertial with North seeking platform and K-4 plus Doppler (20 min. leveling)	To initiation of dive or end of relay link
700 n. mi.	Radar monitored MAIG with North seeking platform and K-4 plus Doppler (fine leveling)	To initiation of dive or end of relay link

TABLE II-E MISSILE SYSTEM CHARACTERISTICS

The guidance system capabilities of each system in terms of CEP as is function of range are summarized here. The reliability of each system is assumed to be 0.60 and constant with range. Perfect accuracy and 100% reliability are assumed for the B-52/gravity bomb system. All missiles are assumed capable of carrying either of two warhead types, single stage and two stage warheads. The lethal radius of the single stage warhead is about 5700 feet while several two stage warheads are considered. As previously indicated, the target can be destroyed by achieving a high level of overpressure against its structure or by covering a large portion of a defined vital area with a fairly low level of overpressure. P_k, the probability of destroying the target as a function of missile range is shown for the various warheads. It represents for

(i) single stage warheads - the probability of covering a point target, and

(ii) two stage warheads - the probability of covering at least 60% of a circular area (radius = 2 1/2 n. mi.).

The relative efficiency of each of the weapon systems is measured on the basis of the expected number of B-52's and crews lost as well as the expected "cost" in destroying the given target complex. An attempt to get a measure of cost was made by use of the following assumptions:

Cost of B-52 and crew - 1 unit
Cost of Missile without warhead - 1/40 unit
Cost of single stage warhead - 1/40 unit
Cost of two stage warhead - 3/40 unit

Using simple probability theory, each target in the complex, depending on the post launch reconnaissance or monitoring capability of the weapon system, was attacked until it was destroyed or until its survival probability from a number of attacks was reduced to 0.10.

For each weapon system, various tactics (that is, number of missiles, or gravity bombs, assigned against each target, number of targets to be attacked simultaneously, flight path of the carrier, etc.) were tried against each target. The cost of destruction for a given target using a given attack tactic was found and the tactic resulting in the least cost selected. After this had been done for each target, the campaign cost was found by summing the costs for each target. The entire process was repeated for each of the weapon systems considered.

Preliminary investigations indicated that because of the 3:1 cost ratio assumed between two stage and single stage warheads, it was more economical to use the single stage warhead in the 31 areas each of which contains but one target objective while the two stage warheads are employed in areas containing more than one target. In this analysis, it was assumed that a base system had been established permitting carrier access to a target through any point on the defense border. In general, the cells of attacking B-52's were chosen to be numerically large enough to saturate the enemy defenses. In doing this, several discrete targets were attacked by a force which remained together as a single cell as long as possible.

This analysis constitutes the mathematical model for our study. It is apparent that one must start from here and plug numbers into the formulas developed, considering in turn each of the several variables in tactics, attack routes, mission sizes and the rest in order to determine the most economical methods of conducting the campaign. As you are aware, we are currently building the Rascal weapon. You may well ask why we now recommend this new system. Let's look at the bases for both of these systems. When the Rascal system was conceived, the prognosis of enemy defense capabilities was primarily centered about the local target defenses through which a gravity bomber must fly to deliver its payload. Accordingly, the Rascal system was designed to eliminate carrier exposure to these high level local defenses. It was believed that the facilities required to protect an area the size of the target complex considered would not be available during the time period considered.

Today, looking forward into the future, we anticipate that area defenses will be vastly improved by 1960 and subsequent, thus raising the cost of conducting a campaign with a Rascal weapon system. It should be noted that the gravity bomber losses will also rise an amount greater than the Rascal system, and for the same reason. From our study we determine that an increased missile range will greatly reduce these losses, and from the families of missiles considered, determined that 700 nautical miles range was about the payoff point. Having done this, we can next logically ask of our proposed system -

Now what does this weapon give us? -

First, the 700 n. mi. missile extends the radius of action of the weapon system, and in the case of the B-52 gives it an intercontinental capability.

To attack the Russian target complex shown on this chart, the mission can be activated at ZI bases in northern United States allowing fissionable-material storage to be maintained in the U.S. proper. In destroying the various targets, varying techniques may be used. Prestrike refueling will yield minimum penetration for some targets. Post-strike staging and refueling will yield best results for other targets. The intercontinental capability is here. Prestrike staging areas could be located in the Alaskan-Greenland-Iceland areas. Post-strike areas could be in either the northern Africa-southern Arabia-India area, or in the Japan-Okinawa-Philippine Island area.

On the following charts, I will summarize a comparative analysis of the use of five strategic bombing systems to destroy this target complex. This complex was assumed to include 70 targets in 68 cities located in Russia proper and in adjoining satellite countries. An analysis made for each strategic weapon system was based on destroying all 70 targets with a probability of 90%.

In each case, the weapon systems were assumed to operate against the same network of both area and local enemy defenses which have been predicted for the 1960 and subsequent period. I would like to state that the effectiveness of this defense network has been optimistically chosen. For example, the local defense effectiveness assumed is approximately as effective as we state for our own Nike defenses, but the number of installations per target is about one-half the number we are planning in our own defense network.

As will be shown, the long range air-to-surface missile weapon system appreciably reduces the cost of destroying a given enemy target complex compared to a gravity bombing offensive with either B-47 or B-52 aircraft.

On this next chart we have plotted the relative campaign costs required for each of five strategic systems to kill the given target complex. These five strategic bombing systems are:

1. A B-52 gravity bomber.
2. The present emanating Rascal weapon system.
3. A 400 n. mi. all-inertial-guidance missile weapon system based on the configuration presented here.
4. A 700 n. mi. all-inertial-guidance missile of the same configuration.
5. A 700 n. mi. radar-monitored inertial guidance missile that has been proposed by Bell Aircraft and summarized in this presentation.

On the left side of the chart we have plotted the total relative cost, compared to the gravity-bomb B-52 offense. This total relative cost includes the cost of the carrier aircraft lost and their crew, and the missiles and warheads expended in doing the job. It is readily apparent that any air-to-surface missile strategic system greatly reduces the total costs. We see that the present Rascal system reduces costs to approximately one-third that required when using only a gravity bomber. With increase missile range this cost is even further reduced, as can be seen for the 400 n. mi. all-inertial system, and the 700 n. mi. inertial system. Minimum costs are obtained with the proposed weapon, the 700 n. mi. radar-monitored MAIG guidance system which reduces total costs to less than 10% as compared to the B-52 gravity bomber.

On the right side of this chart we have plotted a comparison of the carriers, or lives lost in killing the target complex. Once again all missile weapon systems show an appreciable reduction in losses. Of primary interest here is the fact that over 50% of the gravity bomber losses are due to exposure to local defenses, even at the optimistic level of effectiveness assumed here. Once again, the present Rascal system has reduced losses to about one-third and as the missile range increases, these costs are further reduced until we reach a minimum again with the recommended system of about 4% compared to the gravity bomber.

A comparison of the two guidance systems applied to the 700 n. mi. missile shows a 25% reduction in both total costs and carrier loss for the recommended radar-monitored MAIG system over the all inertial system.

The following features were found to be highly effective in minimising the campaign costs for the proposed weapon system:

A. The system is capable of delivering either high or low yield warheads. This flexibility in payload allows the selection of a warhead which best meets the operation requirements with minimum cost and also presents a safety factor with regard to the warhead stockpile.

B. The missile is capable of both high and low altitude operation. A low altitude approach into the target within the local defense area makes the enemy GCI almost useless and the missile is practically invulnerable. However, because of varying terrain at some targets, flexibility in missile terminal flight is very desirable.

C. The system has satisfactory kill probabilities at all ranges of the missile. This is extremely important since any long range missile will be used a large percentage of the time at ranges less than maximum. As previously stated, this is done to maximize accuracy while minimizing carrier penetration into enemy defenses. This is clearly illustrated here for the weapons being compared. Here we have plotted the total number of sorties required to kill the given target complex. For the missile weapon systems, we have segregated by blocks of 100 n. mi. range the means in which the various weapons would be used in the offensive operation. In the case of the present Rascal system, the missile would be utilized at essentially its maximum range. As we continue to the longer range missiles, the 400 n. mi. missile is still used at its maximum range a great portion of the time. However, in going to the 700 n. mi. range missiles, the use of the missile is more evenly distributed, particularly in the case of the more accurate radar-monitored MAIG weapon system.

D. There are several reasons for the decreasing number of sorties required to destroy the target complex. First, the longer missile ranges increase the carrier survival probability by decreasing the penetration required, and in the case of the missile systems requires fewer repeat missions. Second, the radar monitoring system provides assessment of the missile in-flight operation and in many cases furnished some degree of bomb damage assessment.

E. More pertinent from the standpoint of cost than the number of sorties, however, are the total number of hours the carriers must fly over enemy defenses, both local and area, to destroy the total complex. I might mention that throughout the entire cost analysis the most effective gravity bombing techniques such as optimum number of bombers per target have been employed, so that no repeat missions have been required. For purposes of simplifying the study, optimistic assumptions have been used for gravity bombers. For example - in this case, 100% gravity bomber system reliability has been assumed, as well as 100% gravity bombing accuracy. In contrast, the previously stated CEP accuracy figures and a system reliability of .6 were used for all the missile weapon systems. This time spent over enemy defenses, of course, correlates directly with the average bomber and crew survival probability. For the gravity bomb mission 628 sorties are required, 100% requiring penetration, resulting in a survival probability of only 10%. Once again I would like to point out the assumed defense effectiveness is optimistic.

All missile weapon systems have greatly increased this average survival probability of the carrier aircraft and its crew. This is true even though the total number of sorties required have not been decreased appreciably. For the present Rascal system, 455 sorties are required, but only 85% of these missions require carrier penetration (only into area defenses, as is the case for all missile weapon systems) resulting in an improvement in carrier survival to over 60%. Once again as the missile range increases, the percentage of sorties requiring penetration reduce, which results in improved carrier survival. The 400 n. mi. missile system requires more sorties tha the present Rascal, but requires only 47% to have carrier penetration and results in a survival probability of 80%. The 700 n. mi. all-inertial system has reduced the sorties to 475 and appreciably reduced penetration of the carrier to 16% resulting in a carrier survival of 93%. The more accurate radar monitored MAIG missile system further reduces the total number of sorties to 390 and requires only 12% to have carrier penetration which again gives a carrier survival of 93%, over nine times better than the gravity bomber.

We believe these results conclusively show why we recommend the weapon system summarized in this presentation. A recent trip to the Strategic Air Command Headquarters and to the Rand Corporation has indicated another reason why the radar-monitored MAIG missile system is extremely desirable. It was pointed out that of prime importance and of first priority are targets comprised of enemy SAC installations, both bombing aircraft bases and surface-to-surface missile installations. The destruction of such bases is felt to require "cratering" type of damage. Such damage can be carried out only with highly accurate bombing systems, even with the largest of high yield warheads.

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