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RESEARCH MEMORANDUM

A COMPARISON OF THE MANEUVERING PERFORMANCE OF A MONOWING VERSUS A CRUCIFORM MISSILE

By Howard F. Matthews and Stanley F. Schmidt

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
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INTRODUCTION

As is well known, the guided antiaircraft missile is of relatively recent origin, the design of those now becoming operational being started about ten years ago. At that time the selection of design criteria was mostly a conservative guess since few substantiating data were available. In particular this conservatism led, in practically all instances, to specifying such a rapid response that the additional lag due to rolling-to-turn inherent in a monowing configuration was considered unacceptable, and thus missiles were designed with a cruciform arrangement of the main lifting surfaces. Inasmuch as the design of future missiles will certainly use what has been learned with present missiles, it seems proper to reassess the importance of the additional lag of the monowing for two reasons: First, there exists potential advantages of the monowing type of configuration such as less drag and better stowage. Second, the heavy filtering found necessary to cope with noise is usually added in the guidance and control loop ahead of the missile so that it appears that the additional lag of the monowing would be masked to some extent. It is the purpose of this paper, therefore, to present the results of a simulation study made to compare the maneuvering performance of a cruciform and a monowing missile.

MISSILES AND COMPARISON CRITERIA

To make the results of the study more meaningful, an actual missile, the Sparrow I, shown in figure 1, has been chosen as the cruciform configuration and the Sparrow with the yaw wings removed, as the comparative monowing.

The comparison of these two missiles will be based on two factors: first, the beam-riding qualities near intercept when tracking a maneuvering target with "glint" noise present; and second, the minimum launch range which is established partly on the time required for beam capture after boost for a dispersion error. These comparisons will be made within the restriction that identical basic components of the guidance and control system as well as the mass characteristics of the Sparrow are retained for the monowing, with system modifications limited to those necessitated by its "bank-to-turn" operation.

CONTROL SYSTEMS

Consider first the beam-rider geometry. Illustrated in figure 2 is a head-on or tail chase of a target accelerating laterally, with the plane of the figure being perpendicular to the beam. The beam is positioned with respect to the target by the tracking radar of the interceptor, the differences between the beam and target being due predominantly to glint noise. The two errors shown between the missile and the beam are those measured by the radar receiver in the missile.

Consider now some pertinent facts about the control systems of these missiles with the aid of figure 3. Shown in this figure are two voltages, v_p and v_y, whose magnitudes represent in the Sparrow I control system the resolved missile-beam errors of figure 2 after passing through the stabilizing lead-lag network. These signals, respectively, drive a pitch-control loop and, for the cruciform, a yaw-control loop identical to that of the pitch system, to produce missile accelerations in these planes. The acceleration voltage limiter shown in figure 3 is used to prevent the maximum acceleration developed from exceeding the missile's design limit. The altitude and Mach number gain changer compensates for the reduction in the aerodynamic gain with altitude and lower speed. The rate-gyro feedback is, of course, used to provide additional damping.

The Sparrow I also has a loose roll system in which the roll-command signal is proportional to the difference between v_p and v_y. The purpose of this system is to place the resultant lift vector between the cruciform wings for maximum acceleration, but it is relatively ineffective when the missile is riding the "noisy" beam. Due to the limited computer capacity, however, the cruciform missile had to be assumed not to roll.

For simplicity and since v_p and v_y were successfully used in the Sparrow roll system, they were also taken as the input signals to the monowing roll-command computer, even though it was recognized that other signals may have been better suited for this purpose. In order to develop a resultant acceleration of the missile exactly toward the apparent position of the beam (see fig. 4), the missile must roll through an angle somewhat less than φ_ϵ due to gravity. A simpler roll-angle computer results, however, if gravity is neglected, the effect being that now the missile will be commanded to point its lift vector directly at the beam. An approximation for φ_ϵ that can be easily mechanized is shown in figure 5 as well as the exact trigonometric function, v_{φ_ϵ} being the roll-command voltage and k the proportionality constant. As can be seen from the plotted curves of the two expressions, the approximation, which was used in this study, closely matches the exact. The signal v_p denotes that the sign of v_y is switched according to the sign of v_p so that theoretically the missile will roll through the minimum angle. On the REAC the dividing was done by a servo and the switching by relays. In an actual missile, however, the same operation can be accomplished by changing the bias on a tube for the dividing and using diodes for switching.

RESULTS AND DISCUSSION

Beam Riding, h_p = 5,000 Feet

Consider now at an altitude of 5,000 feet the beam-riding qualities of the two missiles at intercept when tracking a maneuvering target with glint noise present. At this altitude identical time constants and gains of the pitch-control system were used for both missiles; these values differed from those of the Sparrow I only in an increase in the lead-time constant of the lead-lag stabilizing network to reduce the step response overshoot which improved the beam-riding performance. The effect of the glint noise was simulated by using an actual 14-second radar tracking record taken during a tail chase of a nonmaneuvering F6F. The target motion taken was an alternating 3 g lateral acceleration. Time histories of these inputs to the missile control system are shown in figure 6. It was further assumed that the missile is constantly at intercept at a Mach number of 1.5 so that the root mean square miss can be obtained from one run. This assumption is contrasted to the time-consuming, more precise, and complex method of making a large number of runs from launch to intercept, taking proper account of the change in aerodynamics with Mach number and computing the rms miss at intercept from the ensemble. It is believed, however, that the method used is adequate for comparative purposes. For these conditions the monowing and cruciform motions with respect to the center of the target are plotted as time histories in space coordinates in figure 7. As is evident from these curves, the monowing performed nearly the same as the cruciform. This is reflected also in the rms miss distance, that of the cruciform being about 27 feet and the monowing 28.5 feet.

Minimum Launch Range, h_p = 5,000 Feet

It is to be recalled that a second criterion of comparison was also stipulated - that of the minimum launch range which depends partly on the time required for beam capture after boost. This range is defined herein as the distance at which the missile can be launched and still be able to return to within 10 feet of the beam center before the target is reached.

Shown in figure 8 are the assumed representative errors of the missile with respect to the beam after boost. These errors are a 50-foot displacement error and a relative velocity of the beam of 50 feet per second away from the missile in a direction along the radius at orientation angles of 0° to 180°. As is obvious from the figure, an orientation angle of 0° means that the missile starts directly above the beam and, similarly, for 180° the missile is initially below the beam. For these two angles it is also evident that both missiles will perform the same since the monowing need not roll. At an orientation angle of 90°, however, the monowing must roll 90° since it is assumed to start with control wings horizontal, so that here we may expect to find the greatest effect of the lag due to roll of the monowing on the minimum launch range. Note also that the lift capabilities of the cruciform are identical to that of the monowing only at angles of 0°, 90°, or 180°; at all others it is larger, being the vector addition of the horizontal and vertical lift potential. Thus at orientation angles of 45° and 135°, the maximum lift of the cruciform will occur and is about 1.4 times that of the monowing.

Figure 9 shows a plot of the percentage change in the minimum launch range versus the orientation angle of the two missiles for a tail approach with the target and interceptor velocities being the same. The top curve is that of the monowing missile, the increase between 0° and 180° being due to gravity. The bottom curve is that of the cruciform missile and the form of the curve is due to the increased lift potential at orientation angles other than vertical or horizontal. The difference between the two curves has been separated into that due to the acceleration advantage of the cruciform and that due to the lag associated with rolling the monowing. As can be seen, the maximum roll effect is small, being only about one fifth of that possible due to acceleration. However, the total maximum difference between the two missiles is still relatively small, being about 5 percent. Thus from the aspect of miss distance or minimum launch range it appears that at low altitude the performance of the monowing is essentially equivalent to that of the cruciform.

Beam Riding, h_p = 50,000 Feet

Some results were also obtained at an altitude of 50,000 feet where the potential maximum accelerations of the missiles have been reduced to 40 percent of their values at low altitude, and operation will be in the region where the aerodynamics are nonlinear. The important nonlinearities were included, of course, in the simulation. At this altitude, the target acceleration was reduced to 1.5 g with the glint noise remaining the same. The results are summarized in figure 10. First, the significance of the inequalities is that they indicate the amount of limited control deflection, due in the case of the cruciform to mechanical interference of the control wings. For the monowing the same pitch control limit δ_p was used, but an additional 5° of differential wing deflection

δ_a was allowed for more roll control. The system changes in going from low to high altitude referred to as minor are a reduction of the roll-system gain and the pitch-gyro gain by one half and a reduction in the level of the acceleration voltage limiter (shown in fig. 3) to a value that would not saturate the controls and compromise the damping operation of the rate gyro. The major changes include the addition of normal-acceleration feedback, and increasing the lead term and removing the lag term in the stabilizing lead-lag network immediately behind the radar receiver. The results show that if but minor changes are made, the miss distance of both missiles is near the same and is 60 percent greater than that at low altitude. If major changes are made, the miss distance improves and is about 20 percent more than that at low altitude. The time histories of the response of the two missiles with the major changes are shown in figure 11. In both instances the monowing has an equal or slightly lower miss distance than the cruciform missile. Note the greater difference in the beam-riding qualities of the two missiles at low altitude (see fig. 7 for comparison), particularly near the beginning of the run, although the rms miss is the same. This is due to the monowing acting as an additional filter; that is, the missile tends to ignore the faster beam motions which, if followed, would probably give larger miss distances.

CONCLUSIONS

As a result of a simulator study made to compare the maneuvering performance of a monowing versus a cruciform beam-rider missile, the following remarks may be made for the conditions analyzed:

1. At an altitude of 5,000 feet, the additional response lag due to roll for the monowing missile had small effect on the beam-riding qualities and the minimum launch range, despite the unfavorable restrictions placed on the mass characteristics, wing area, and allowable system modifications of this missile.

2. At an altitude of 50,000 feet, the lag of the monowing is more pronounced in that it cannot follow the beam motions as rapidly as the cruciform missile. However, this filtering action by the monowing is not detrimental since the miss distances for the two missiles are essentially equal.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Apr. 13, 1955

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THE SPARROW MISSILE

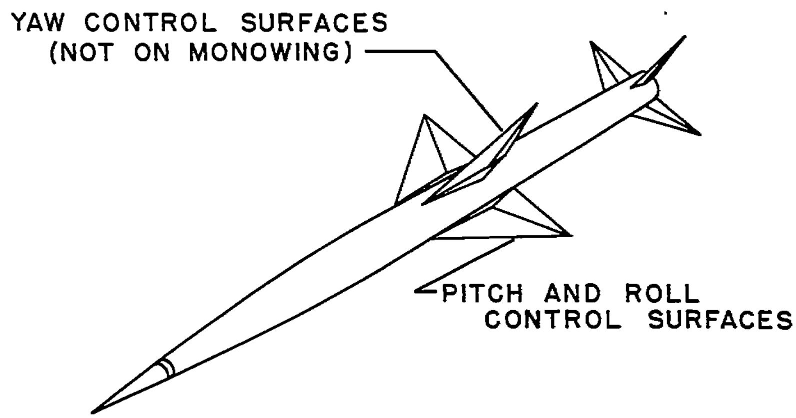

Figure 1.

BEAM RIDER GEOMETRY

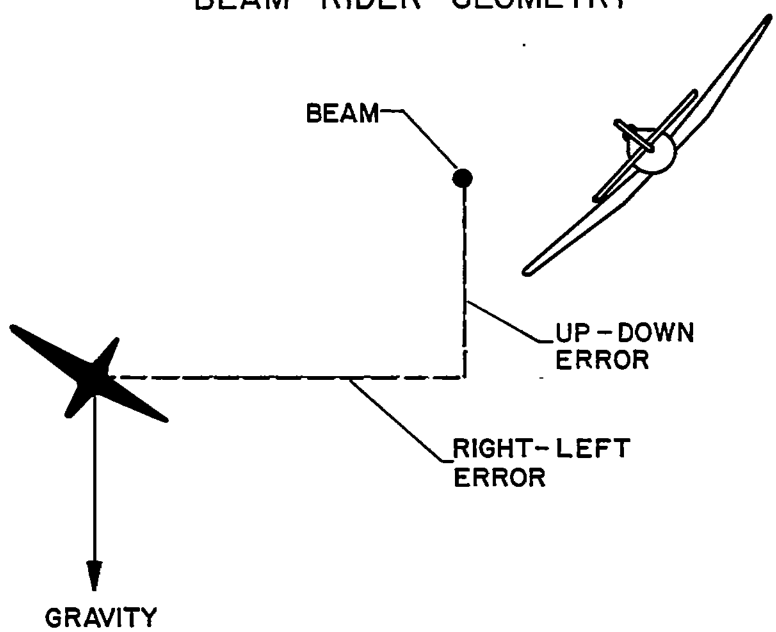

Figure 2

THE CONTROL SYSTEM OF THE MONOWING MISSILE

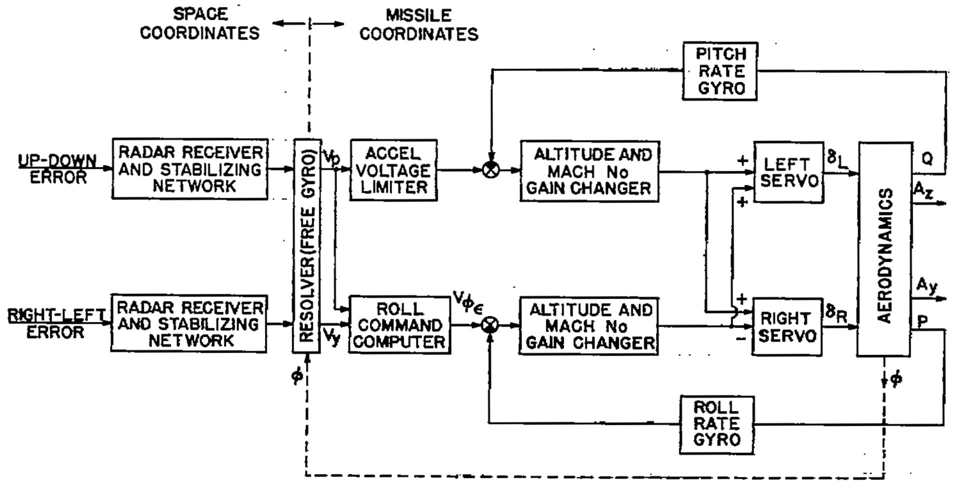

Figure 3

MISSILE CONTROL SIGNALS

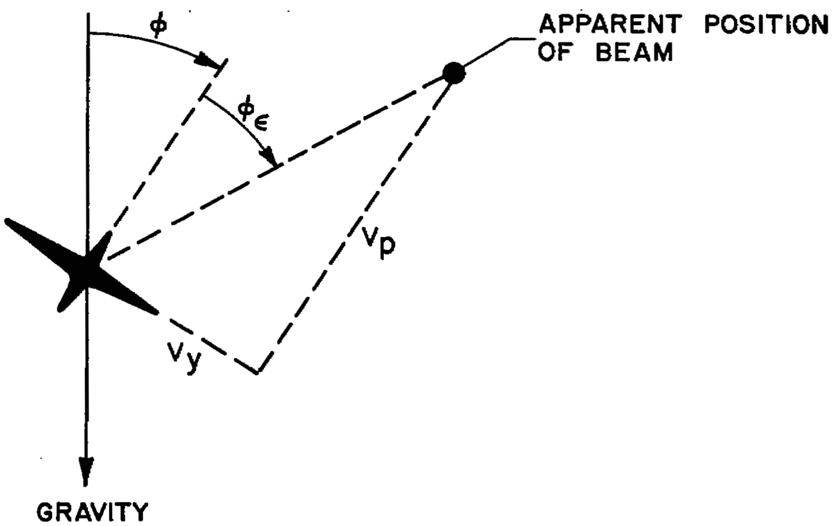

Figure 4

ROLL COMPUTER CHARACTERISTICS

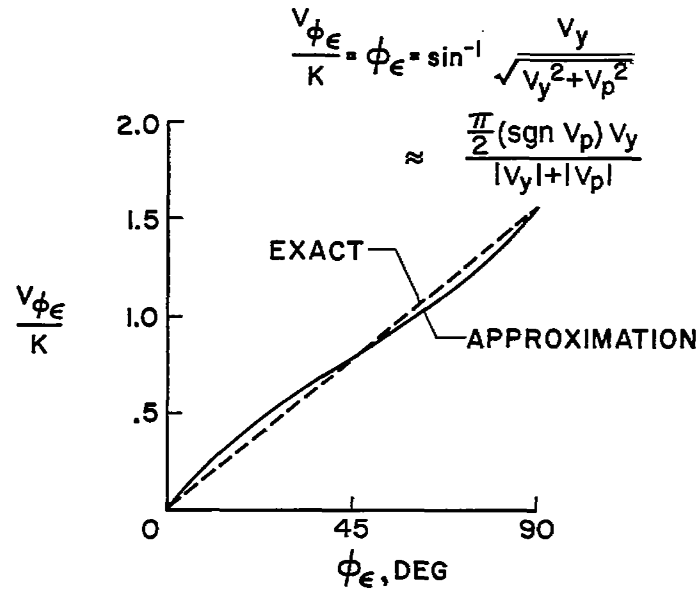

Figure 5

BEAM INPUTS

$h_p = 5{,}000$ FT

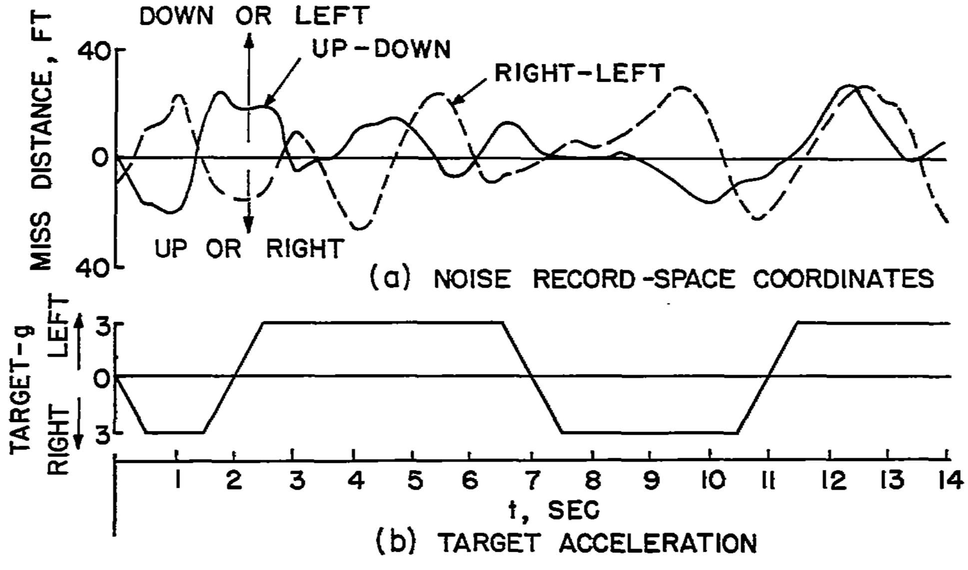

Figure 6

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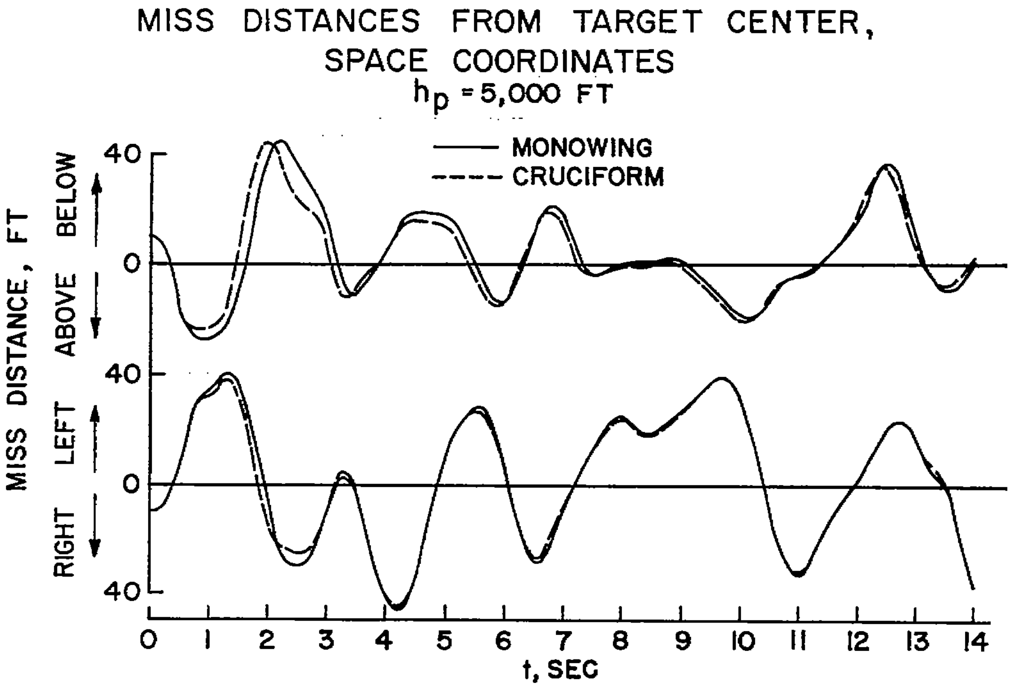

Figure 7

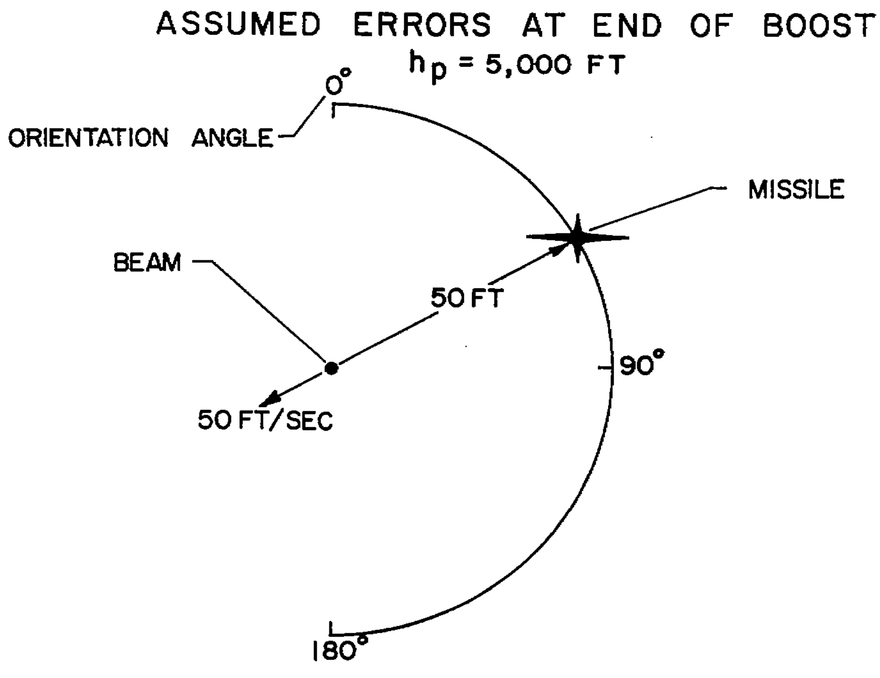

Figure 8

MINIMUM LAUNCH RANGE-TAIL APPROACH

h_p = 5,000 FT

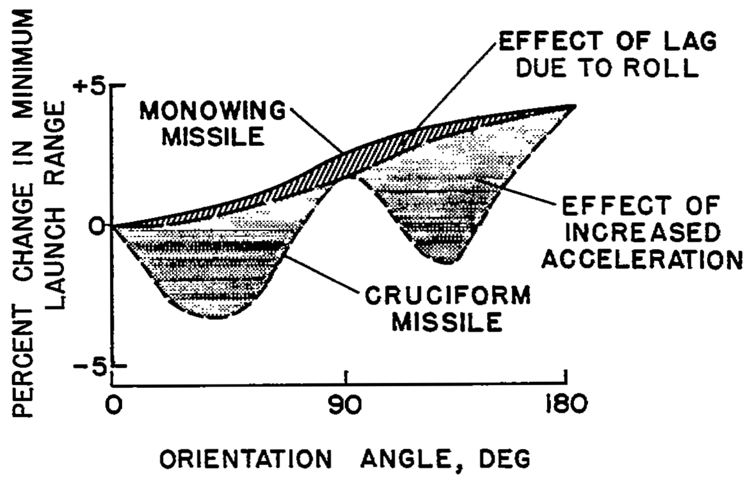

Figure 9

RMS MISS DISTANCE

TARGET ACCELERATION = 1.5 g , h_p = 50,000 FT

	SYSTEM CHANGES	
	MINOR	MAJOR
1. CRUCIFORM, $\lvert\delta_p\rvert \leq 17°$	44 FT	33 FT
2. MONOWING, $(\lvert\delta_a\rvert + \lvert\delta_p\rvert) \leq 22°$ $\lvert\delta_p\rvert \leq 17°$	43 FT	33 FT

Figure 10

[redacted]

MISS DISTANCE FROM TARGET CENTER
SPACE COORDINATES

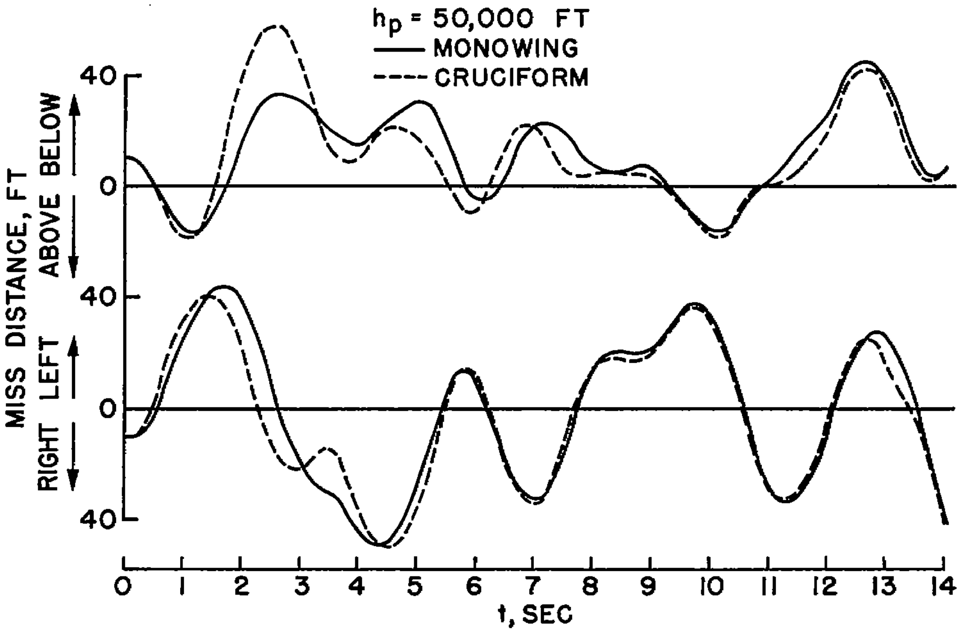

Figure 11