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SUBJ: Orbiter Post-Blackout GCA Simulation - Pilot's Report

The Pilot's Report from the CPES simulation of the Post-Blackout GCA is enclosed for your information.

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Post-Blackout GCA Simulation - Pilot's Report

1.0 SUMMARY

Nominal entries and GRTLS's were flown on the CPES to determine the feasibility of using ground voice commands to control energy versus range from post-blackout down to the preflare. It was found that with good ground data, the voice commands were sufficiently accurate to reliably arrive at the correct preflare state, the voice traffic was minimal and the demands of the flying task were well within acceptable limits.

2.0 INTRODUCTION

In addition to the use of only onboard navigation data, pilots of both high and low performance aircraft accept the GCA as a reliable and often preferred method of arriving at the runway threshold. The use of the GCA as one of the methods of controlling energy versus range in the X-15 program showed that its extension into the hypersonic and unpowered flight regimes is both feasible and useful. It is natural to ask if the GCA can also be feasible and useful in the Orbiter return.

The study accomplished here concentrates on the question of practicality rather than utility. That is, the tasks of the pilot and ground controller were simulated and judged in terms of effectiveness and feasibility. The usefulness of the GCA, that is, the probability and types of situations which could arise that would make the GCA the prime mode of controlling the Orbiter return, where not investigated.

During December 1977, 25 runs were made on the CPES; 17 were nominal entries with dispersions and 8 were GRTLS's. The nominal entries picked up at the post-blackout point at approximately Mach 10. The GRTLS started at the end of the pullout phase at Mach 5 with $\dot{h}$ slightly positive. Willis Bolt (CF3) was the ground controller and Edward Gibson (CB) was the pilot.

Ground control used CRT displays with overlays that gave ground track, ranging capability, and in the final approach phase, glideslope information as well. Wind information was available and sometimes used by the ground but not definitely required. The minimum required onboard displayed information was stability roll (ϕ), KEAS, g and a pitch reference. When entry pitch was flown in manual, Mach and α were also required. Voice communication was accomplished without headsets which made the task slightly more difficult than if they had been available.

The results of each run were judged in terms of the ability to reach the nominal preflare state, any $\bar{q}$, g or α limits which were exceeded, the volume and intelligibility of the voice traffic and the degree of difficulty of the piloting task.

The pilot's impressions are presented in this report. A similar report giving the ground control aspects of the exercise is in preparation.

3.0 ASSUMPTIONS

For proper management of Orbiter energy versus range and for adequate flight control, the following conditions are required.

3.1 Ground Knowledge of Orbiter Coordinates

The ground must know the Orbiter's range and bearing to the field. That is, it must have a radar fix on the Orbiter. Since the Orbiter does not have a transponder, it may prove difficult for the ground to pick up the Orbiter on C-band immediately post-blackout, especially if the ground's knowledge of the Orbiter's state vector is significantly degraded.

3.2 Ground Knowledge of Orbiter Energy

The ground must have reasonable knowledge of the Orbiter's energy. This requires good knowledge of primarily the kinetic energy in the hypersonic regime, of both kinetic and potential energy in the supersonic and transonic regimes and of primarily potential energy in the subsonic regime (see Appendix A-1). Radar information should be adequate.

3.3 Onboard State Vector

The onboard state vector and platform must be adequate for flight control. That is, the onboard knowledge of Mach (M), ϕ and α must be within reasonable bounds (yet to be defined) but field bearing and range are not required. Also, although not very sensitive, h is sent to flight control from NAV and used in the calculation of $\bar{q}$ before air data is available. The displays which are required onboard for the piloting task are g (limit monitoring), $\bar{q}$ (limit monitoring and drag control in TAEM), a pitch reference (θ), ϕ and, if pitch is flown in manual, α and M.

3.4 Voice Communication

Voice communication is available. It is believed that except for the final phase, the relay of commands via a capcomm is sufficient although the delay which would be introduced was not simulated.

These assumptions define the situation in which a GCA is both feasible and useful. That is, the onboard state vector and platform are adequate for flight control but not navigation and ground has sufficient information to supplement the deficiency. The likelihood of this situation as well as the feasibility of other recoveries (e.g., shipping up a new state vector) were not but should be addressed.

4.0 NOMINAL ENTRIES

4.1 Initial Conditions

Each run was started at the following conditions:

Bearing/Range = 250^{o}/392nm from runway 17

Heading = 59^{o}

h = 170K ft.

M/Velocity = 9.68/10,425 fps

EAS = 150 Kts

$\gamma/\dot{h}$ = -1.23^{o}/-224 fps

$\alpha = 38^{o}$

$\phi = -45^{o}$

Orbiter Weight = 183K pounds with a mid CG

The dispersions which were introduced were:

Down Range - ±60nm

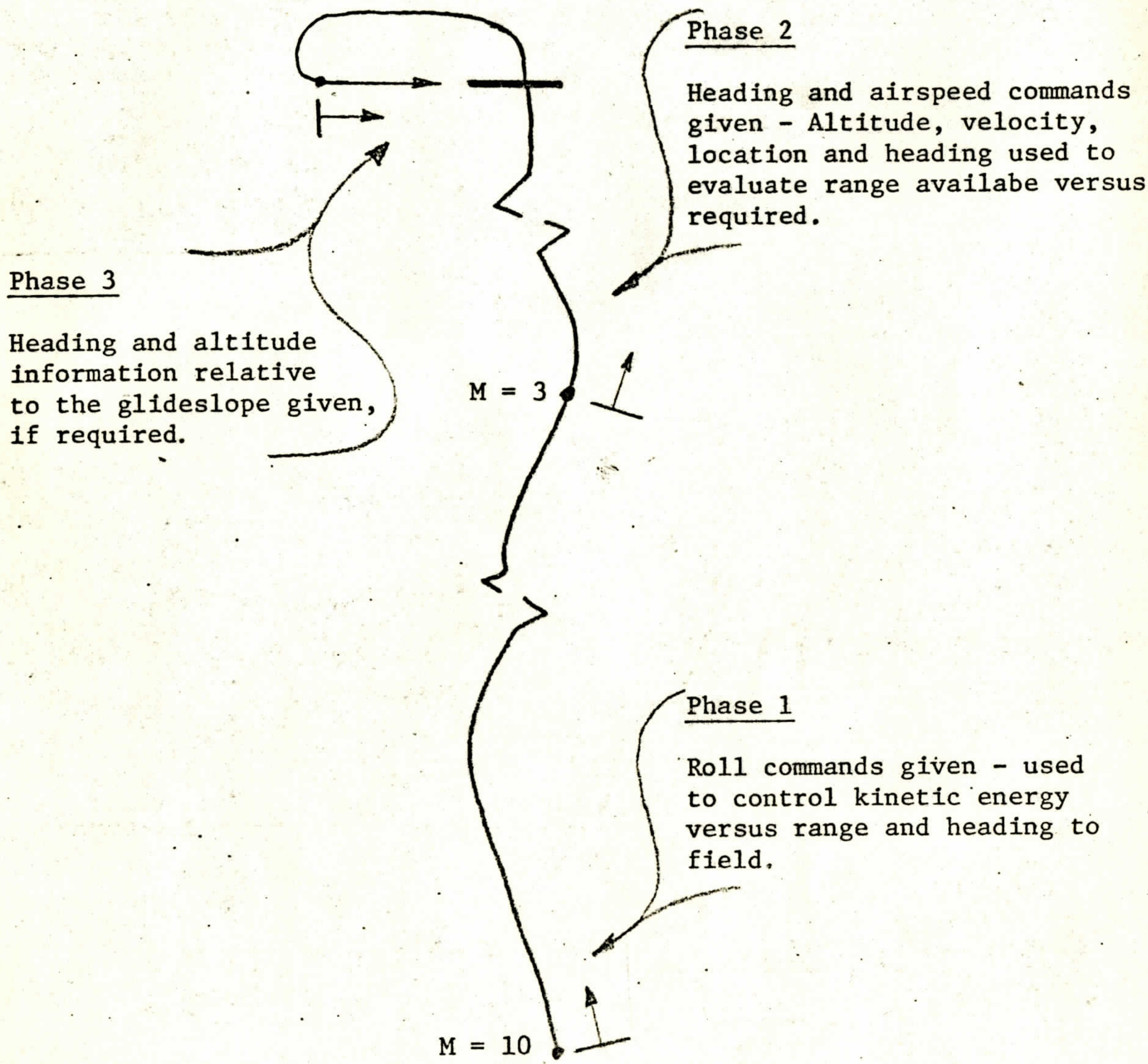
Cross Range - ±30nm

C_D - +10% (3σ), -5%

Wind - up to 85% of the wind model (225 Kts at 90K ft with no twist) from 210^{o} to 250^{o}

4.2 Flight Profile

The energy versus range is controlled differently in the three phases shown below.



4.3 Phase 1

The objective in Phase 1 is to continually work toward a nominal schedule of kinetic energy versus range in order to arrive at 55nm out from the field at Mach 3.0. ϕ is used to control drag. Bank reversals are required when the difference between the heading and the direction to the field is greater than approximately 15°. For the nominal Mach versus range schedule, the ϕ is 60° at Mach 10 and decreases to 35° at Mach 3.

The speedbrake and body flap are flown in auto. Pitch should also be flown in auto although, because of the low crew workload in the simulation, it was flown manually using the schedule $\alpha = 4M$ which is close to that flown by auto guidance.

For a nominal run, the <u>total</u> voice traffic might consist of the following after blackout and the decision is made to fly a GCA:

Ground	Crew
	"I have a roll of left 45
"Roll to left 60	Roger, left 60
Roll to right 55	Roger, right 55
Roll to right 45	Roger, right 45
Roll to left 35	Roger, left 35"

Clearly, the voice traffic required is concise and minimal.

The data used by the ground to issue the roll commands is derived from the position versus Mach plot shown in Appendix A-2. The ϕ magnitude is varied about a nominal value versus Mach depending upon the actual range relative to the nominal range. Thus, some judgement is required on the part of the controller in issuing the commands. However, since the correct preflare state was reached in all but one run, including some with sizeable dispersions, it is a self-correcting and workable system. The precision could be increased by use of a table like that suggested by Appendix A-3. Also, if advantageous, drag itself could be commanded and the pilot would roll accordingly. Use of the proposed phugoid damper could make this task easier. At first sight, however, it appears best to keep the crew workload to a minimum and have only the actual control command given by ground.

Two extreme cases exist which required different approaches.

The first one is the "short" case in which the range is considerably larger than the nominal; e.g., in the simulation it reached 450nm rather than the nominal 370nm at Mach 10. When this is encountered, the ϕ is kept small and only used to get pointed directly at the minimum entry point. The nominal α/Mach schedule was always flown. It is clear that this is not optimum for this case. The degree to which α should be reduced below nominal toward $(L/D)_{max}$ must consider the total integrated profile and trade off the C_L (α) required to avoid buildup of excessive $\dot{h}$, $\bar{q}$, or g and thermal and stability constraints.

The second case is the "long" case in which the range is considerably smaller than nominal; e.g., in the simulation it was as small as 330nm rather than 370nm at Mach 10. Obviously, the drag has to be ramped up quickly and maintained at as high a value as feasible. A maximum roll of 70^{o} was used. This is the most challenging case in that a good technique must be used to avoid large negative values of γ leading to over $\bar{q}$ and/or over g. It was found that the roll of 70^{o} can be maintained until smaller values (40 to 60^{o}) are required in order to keep $|\dot{h}|$ no larger than approximately 400 fps and $\ddot{h} \simeq 0$. The value and rate of movement of the $\dot{h}$ tape can be controlled in these bounds easily with roll as long as the rapid buildup of negative $\dot{h}$ is anticipated. Once arrested at approximately -400 fps ($\gamma \simeq -3^{o}$ at Mach 8), $\bar{q}$ and g are monitored and roll used to keep them within limits (300 Kts and 2.5). This is continued until the nominal Mach range schedule is approached. It requires judgement on the part of the controller to know how far the heading can be allowed to deviate from the direction to the field (nominally $\pm 15^{o}$) since the drag is considerably reduced during a bank reversal.

Profiles other than that shown in 4.2 were not used. That is, it was not attempted to significantly extend the groundtrack or optimally place the location where subsonic maneuvering becomes available by heading away from the field. For small misses the effect of passing abeam of the field at greater than Mach 2 is essentially the same as passing over the field. That is, the large turning radius at high velocity limits the trajectory so that it cannot be bent around to get back to the field. It is conceivable that a large miss and a resultant large-radius high-Mach 90 to 270^{o} turn on to final might be feasible (see Appendix A-4). This possibility deserves further investigation.

4.4 Phase 2

The objective of Phase 2 is to transition from Mach 3 at approximately 55 miles from the field to the proper conditions for final approach of approximately 15K ft. at 7 miles from the threshold. The overhead profile flown will of course depend upon the approach headings to the field relative to the runway heading. Anything between a 180^{o} downwind (direct entry to downwind) and a 360^{o} overhead is possible. The 270^{o}

overhead case was flown in all runs and others are not considered further here.

Two intermediate objectives are used in this phase. First, the kinetic energy is reduced so that Mach 0.9 is reached when passing over the field. This makes available the higher lift to drag ratios of subsonic flight and the smaller turning radii. The overhead approach is flown in order to add approximately 15nm to the footprint, as is the case with the optional TAEM targeting concept which is currently being considered for OPS 3. Second, potential energy becomes the prime consideration and a minimum of approximately 30K ft (no wind) is required when passing over the field for a 270° overhead. The mode of energy management shifts to one where ϕ is used to control heading and $\bar{q}$ and speedbrake are used to control drag and thereby energy versus range.

The speedbrake and body flap remain in auto until Mach 0.9 is reached where the speedbrake is taken over manually and fully closed. Selection of a partially open speedbrake in the nominal case would give additional energy reserve and may be needed for stability. α is flown to get the required $\bar{q}$. All turns are made at a ϕ of 40°, close to the optimum for subsonic maneuvering.

For a nominal run, the total voice traffic might consist of the following:

Ground	Crew
"Come to a heading of 080 and fly 250 Kts	"Roger 080 and 250
Heading now 070	Roger 070
Turn downwind to a heading of 350 and fly 230 Kts	Roger 350 and 230
Turn base to a heading of 260	Roger, 260
Turn final to a heading of 170"	Roger, 170"

The data used by the ground to issue the airspeed and heading commands evaluates the range available versus the range required. Range available is derived from the plots shown in Appendix A-5.

An alternate to these plots, useful for onboard monitoring and perhaps ground use as well, is shown in Appendix A-6. It does not include relative velocity and is similar to VERT SIT 1 and 2. The range required is derived from a position plot like that shown in Appendix A-7. For monitoring purposes, it was found that numerically the altitide (K ft) should be approximately twice the range to go (nm) in this phase. (As a reference, in a nominal descent in a T-38, this value is 1/2 rather than 2; that is, a glide ratio of 1 to 3 rather than 1 to 12.)

If the short case is encountered in Phase 1, it is followed up here by making a 90° turn on to short final rather than making the 270° overhead. An α of 10° is flown for maximum glide angle. The turn is made at 45° ϕ and 15° α to minimize energy lost (see "Maneuvering Capability in TAEM" by V. Brand, 4/12/77). The decision to use or not use the 270 overhead was made at Mach 2.5. If the range available was not 30nm or more greater than the straight line distance to the threshold, the overhead was not used.

The long case is encountered, when the Mach crossing the field is closer to 2 rather than 1. All effort must be directed at reducing the Mach to subsonic by a 2.5 g turn to downwind (perhaps smaller for OFT-1) and trading velocity for altitude if required. It now appears that if the Mach is greater than approximately 2 over the field, the only major decision left is whether to over g or land short. It is suggested that until subsonic, the best course of action is to continue the reduction of velocity by 100 percent speedbrakes, continue the 2.5 g turn and remain high until 200 Kts is approached and a tight turn back to the field can be completed.

4.5 Phase 3

Once final approach is reached, the GCA becomes very much like that which is flown routinely by instrument pilots. Headings to acquire or remain on centerline and the position relative to the glideslope are given. The airspeed is maintained at 285 Kts by use of the speedbrake. The displays used by the ground are the standard ones used by final controllers (Appendix A-8).

Other alternatives to flying a GCA final, and perhaps more preferable, are out-the-window if VFR, MLS if operative or via a TACAN generated centerline and glideslope when available.

5.0 GRTLS

5.1 Initial Conditions

Each run was started at a reset point which was generated by flying in auto from MECO to the end of the pull-out phase.

The conditions at MECO were:

Range = 274nm

Heading relative to R/W = 100^{o}

h = 230K ft

$\dot{V}$ = 7448 fps

$\dot{\gamma}$ = +1.25

The conditions at the generated reset point at pullout used to start all of these runs were:

Range = 88nm

Altitude = 110K ft

M/EAS = 5.08/280 (decreasing rapidly)

$\gamma = +0.8^{o}$

$\dot{h}$ = +75 fps.

No dispersions from these conditions were introduced.

5.2 Flight Trajectory

These GRTLS runs were very similar in character to the "long" case in the nominal entry. However, the positive $\dot{h}$ had to be reversed first by banking to ϕ of approximately $\pm 70^{o}$. Once the $\dot{h}$ approached -300 fps, $\ddot{h}$ was killed off. This could be adequately led if the rate of travel of the $\dot{h}$ tape was monitored. ϕ and α were then varied so as to not exceed $\bar{q}$ and g limits.

To a degree the start of these runs was artificial and the total RTLS should be flown rather than starting in the middle. For example, it would have been preferrable to stop the pullout at a slightly negative γ and immediately begin an S turn. Nevertheless, it did show that the same GCA procedures were applicable as in the nominal entry.

6.0 CONCLUSIONS

6.1 GCA Accuracy

Voice commands are sufficiently accurate to reliably arrive at the correct preflare state assuming that the ground data is sufficiently accurate and timely. Relatively simple procedures proved to be sufficiently accurate for all of those cases between the extremes of being either short or long. That is, the system is relatively insensitive to error between these extremes by being self-correcting. The extreme cases require set procedures which should be followed until some margin is gained. That is, for the short case, point at the field, roll wings level and fly the max range α/M schedule. For the long case, follow the prescribed procedures to get as negative a γ as possible without exceeding allowable $\bar{q}$ or g.

6.2 GCA Voice Traffic

The voice traffic required is minimal. The voice commands, as illustrated in section 4, are concise and infrequent enough that they could easily be relayed by a capcomm, except possibly in Phase 3.

6.3 GCA Piloting Task

The demands of the flying task are well within acceptable limits. In Phase 1 only, roll is pilot controlled unless pitch is also flown in manual. In Phase 2, heading and airspeed are pilot controlled. In Phase 3, if a full GCA is used, heading, altitude relative to the glideslope and airspeed are pilot controlled.

The most challenging tasks occur in GRTLS and the short case. Set procedures need to be developed to decrease the dependence on judgement and cross-check.

It is clear, however, that the CPES is not real-world, both in terms of the total workload as well as the physical and psychological environment.

7.0 RECOMMENDATIONS

7.1 GCA Usefulness

Evaluate the possible usefulness of a GCA in order to determine the priority given any future simulation, procedures development and training.

7.2 GCA Feasibility

Evaluate the task in the more realistic environment of the OAS with L/D variations, air data errors, 95% of the Edwards wind model (head and tailwinds) and larger dispersions in initial location.

7.3 GCA/Auto-Guidance Commonality

Develop profiles which are as similar as possible to the auto-guidance profiles in order to have common conditions for recognition, monitoring, and training, to make use of common onboard data and to facilitate transitions between the auto and GCA modes of flight. For example, fly the GCA using the heading alignment circle if the optional TAEM .

targeting becomes baselined.

7.4 Simple Procedures for Extreme Cases

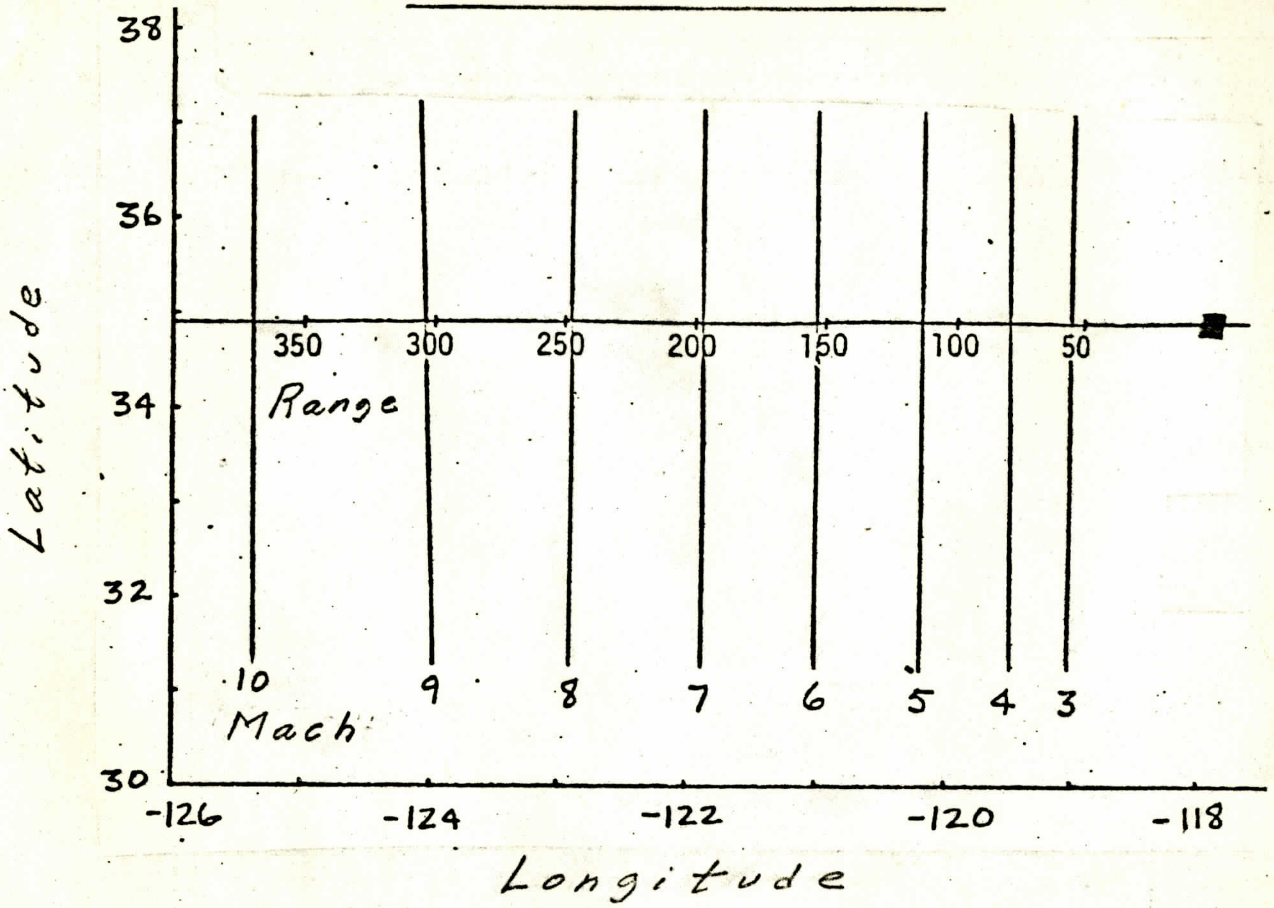
Develop set procedures for the short and long cases which are effective, simple, and easily accomplished in a high-workload high-stress environment. In particular, determine the optimum groundtrack for the close in case given range, M and h.

APPENDIX A

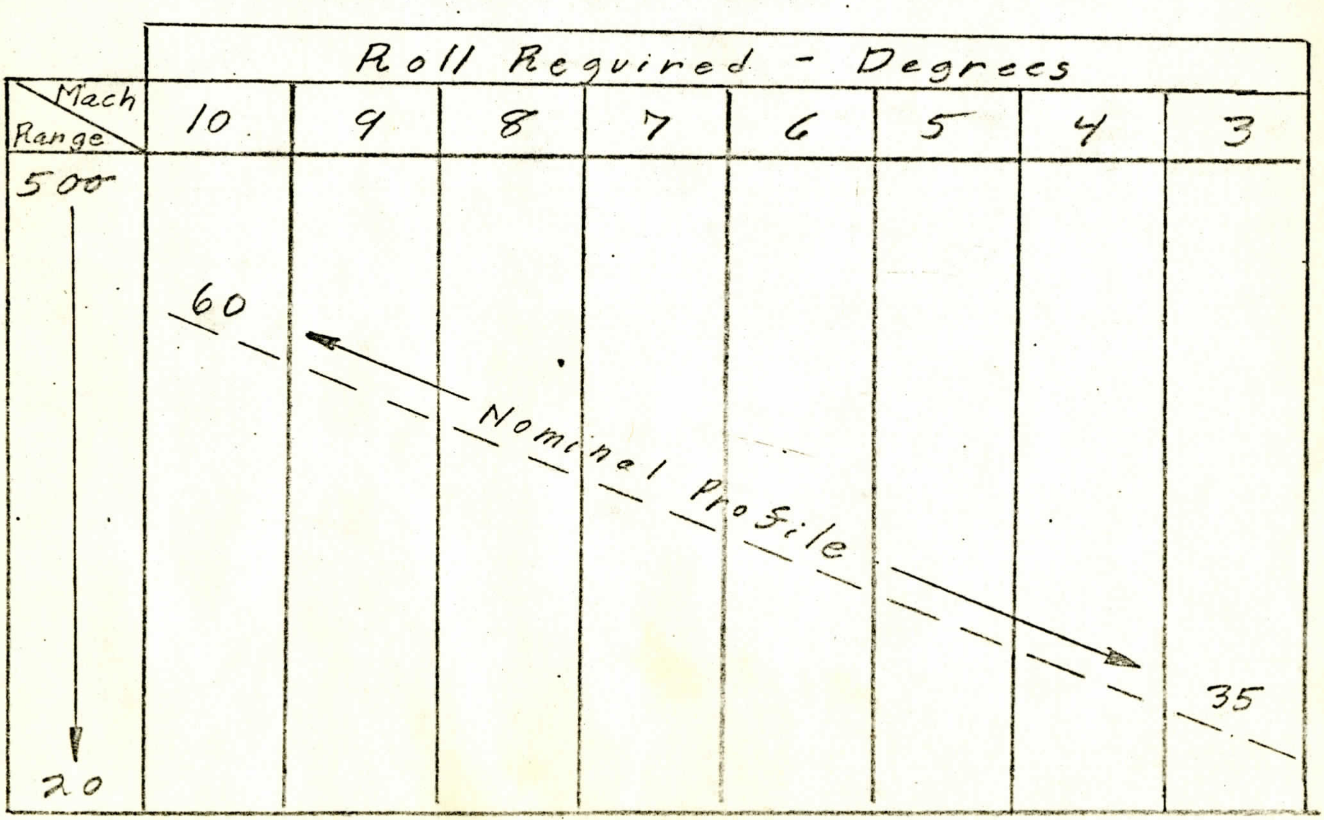
A-1 Orbiter Potential and Kinetic Energy

The ratio of kinetic to potential energy is approximately $M^2/4h$ where M is the Mach number and h is the altitide in units of 100K ft. Thus, kinetic energy is dominate in the hypersonic regime where h is approximately 100K to 200K ft. At Mach 2.5 and 82K ft, this ratio is 2. At Mach 0.9 and 40K ft it is 1/2. Thus, potential energy becomes important at the beginning of TAEM and is dominate in the subsonic TAEM region. Kinetic energy, which is again dominate at preflare, does not become larger than potential energy until an altitude of approximately 6K ft. That is, at Mach 0.5 and 6K, the above ratio is approximately unity.

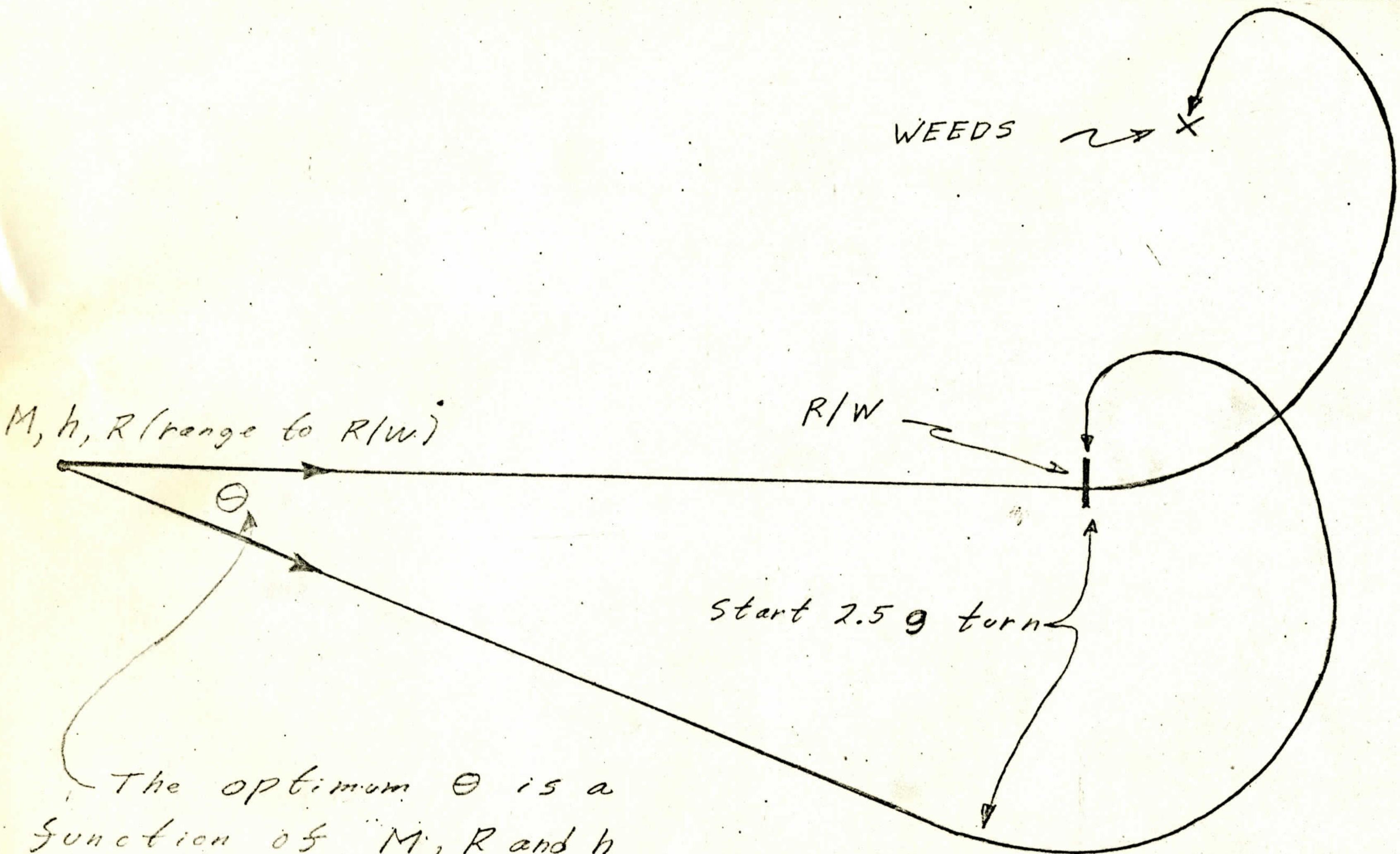
A-2 POSITION VS. MACH



A-3 ROLL REQUIRED VS. MACH/RANGE



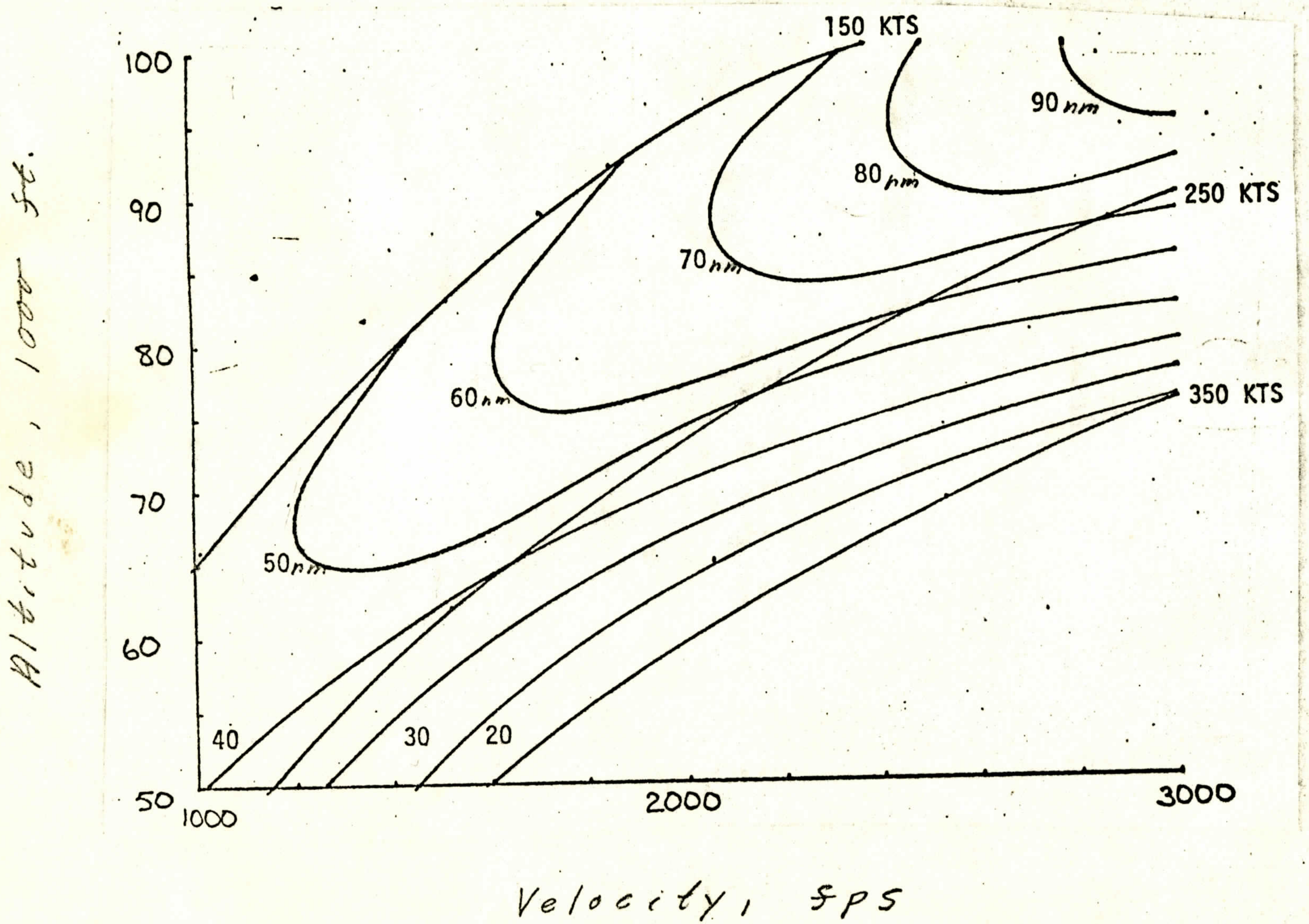
A - 4 OPTIMUM MISS ANGLE FOR CLOSE-IN CASE



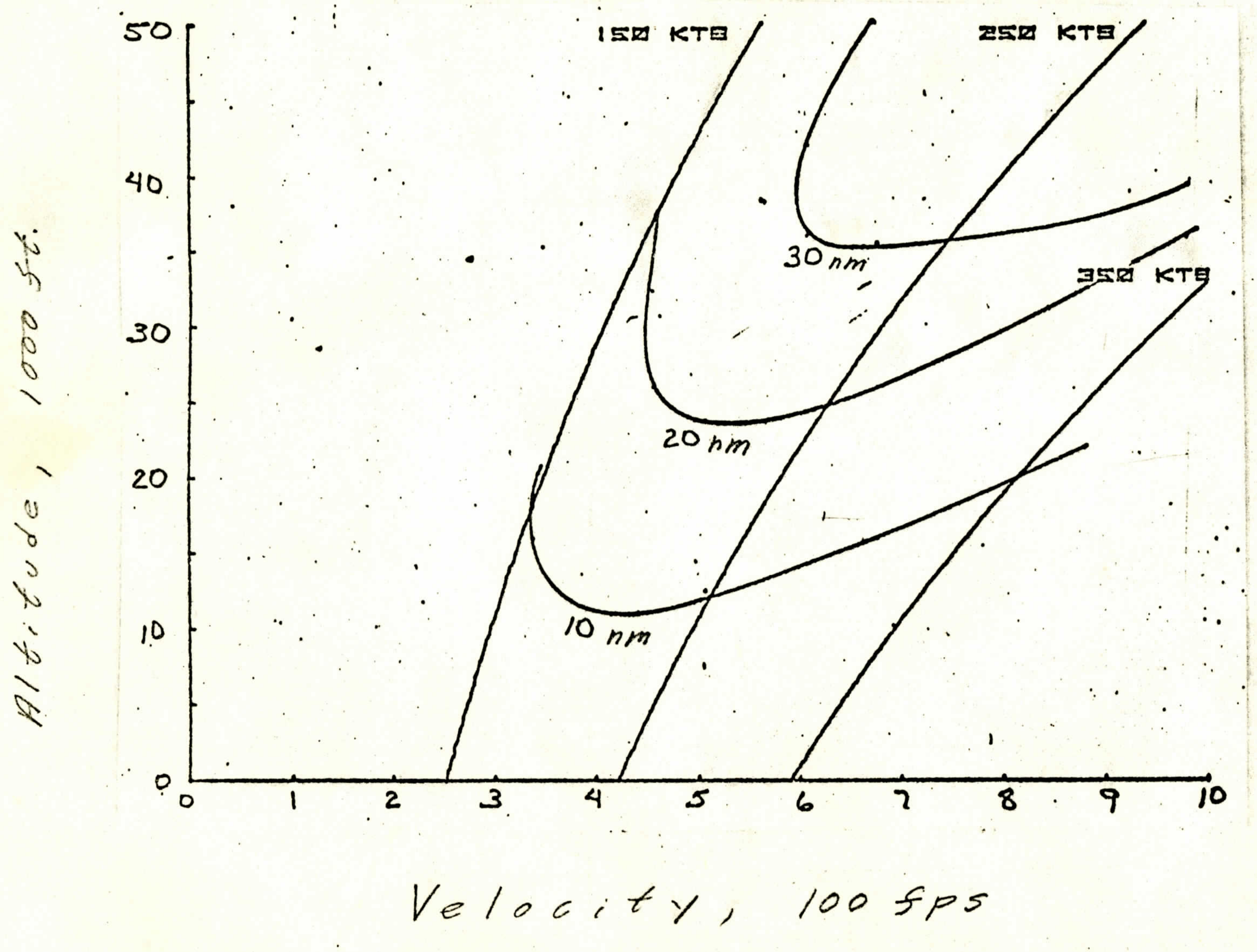
The optimum θ is a function of M, R and h to first approximation.

A limit set of M, R and h exist for which it is no longer possible to make the R/W for any θ.

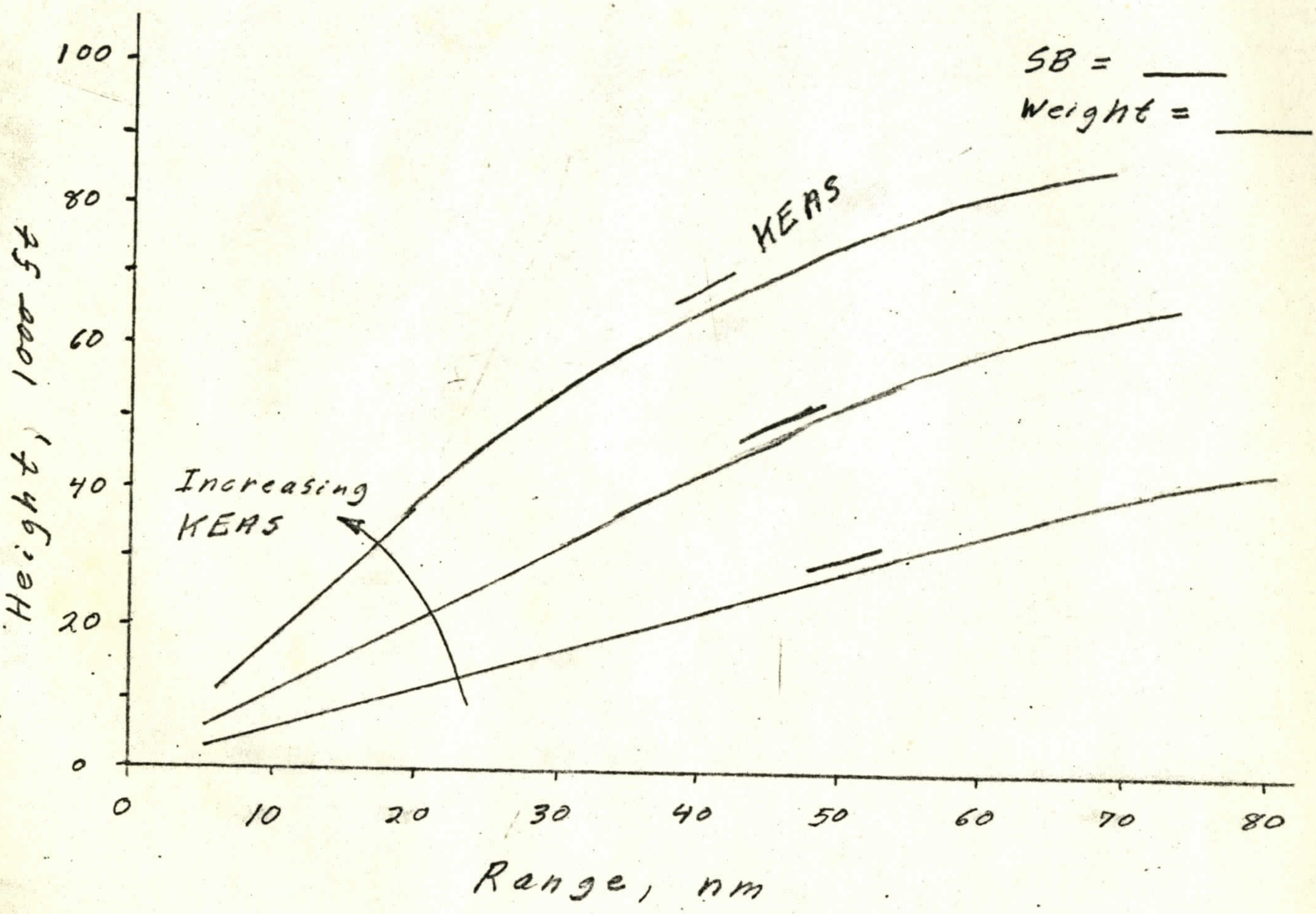
A-5(a). ALTITUDE VS. RELATIVE VELOCITY



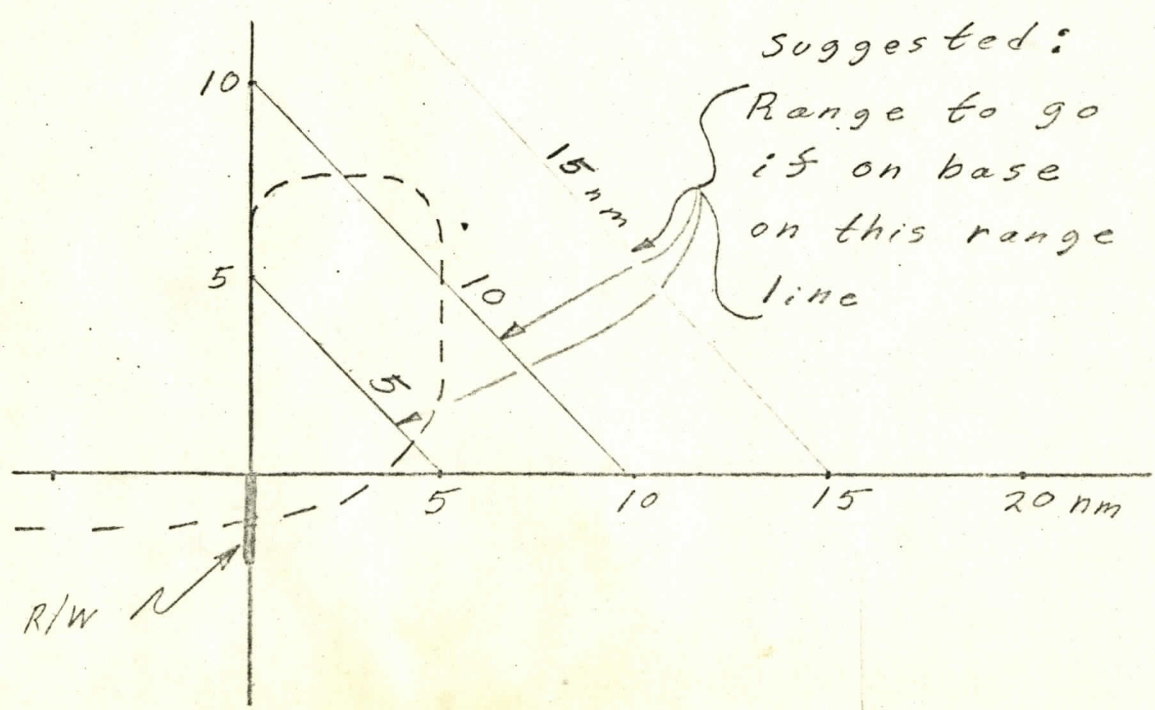
A-5(b) ALTITUDE VS. RELATIVE VELOCITY



A-6 HEIGHT VS RANGE



A-7 RANGE REQUIRED VS. LOCATION



A-8 FINAL CONTROLLER DISPLAY