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Remotely Piloted Vehicle (RPV) Kamikaze Study

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SEPTEMBER 1975

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ABSTRACT

~~MITRE performed~~ a study ~~for the Army's Aviation System Command (AVSCOM)~~ to identify preferred technical concepts for an Army RPV kamikaze capability. The study included consideration of the RPV, communications, warhead and sensors with emphasis on variations in communications relay platforms (balloon, RPV, parachute) and types of communications (microwave, laser, fiber optics, wire). Onboard autotrackers for the terminal phase are also considered. Preferred configurations are identified.

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EXECUTIVE SUMMARY

In response to a request from LTC Davies Powers, Weapons System Manager in the Army's Aviation Systems Command (AVSCOM), MITRE identified and evaluated a number of concepts for the Army RPV kamikaze project. The scope of the study included kamikaze RPVs which utilize TV for target surveillance, identification and designation under control of an operator at the Ground Control Station (GCS) with terminal guidance being provided by either ground steering (TV aided) or by an onboard autotracker.

The kamikaze concept introduced a complication not present in other current RPV scenarios, namely, control of the RPV while it is below line-of-site from the GCS. This complication occurs during the kamikaze dive when the GCS-to-kamikaze range can be up to 30 km with intervening terrain causing masking and thus loss of communications.

After considering numerous approaches such as communications relays deployed from the kamikaze just prior to diving, high frequency communications (not line-of-site limited) and autotrackers which lock on the target and guide the kamikaze within the communications shadow area, several preferred systems were identified. In order of preference they are:

- Microwave communications between the GCS and the kamikaze with an autotracker in the kamikaze for final homing within the communications shadow area.

- Microwave relay in an RPV platform placed between the GCS and the kamikaze.

- Parachute relay deployed from the kamikaze with microwave transmission between the relay and the GCS. Optical communications (fiber optics) would be used between the relay and the kamikaze.

Promising alternative configurations outside the scope of the current study were also identified. These configurations did not require either TV or autotrackers in the expended kamikaze and were, therefore, attractive because of their lower cost. Further examination of these other alternatives is contingent on AVSCOM's evaluation of their overall kamikaze program.

1.0 INTRODUCTION

1.1 Background

At short ranges, out to about 3 km, hard point targets such as tanks can be visually observed and effectively attacked by existing (or developmental) missiles, e.g., TOW, Dragon and Shillelagh. [1,2] At longer ranges (e.g., 3-30 km), artillery can be used with the aid of a Forward Observer (FO) but the fire is basically area coverage (although localized) rather than being specifically targeted on individual tanks. The high hardness of tank targets, however, affords them good survival likelihood against moderate-rate conventional artillery fire. Moreover, manned aircraft which either act as FOs, or deliver projectiles directly, are physically vulnerable (and costly) as they operate near, and in, enemy territory.

The use of RPVs with onboard sensors extends, in effect, the visibility range with less potential cost penalty than the use of manned aircraft. Not only can the RPV be used for reconnaissance, surveillance and FO for artillery, but it may allow precision tracking of moving targets and may either launch a guided projectile against the target, or may itself be guided into the target (kamikaze style) bearing onboard munitions.

A weapon system which uses an RPV, in some key role, to attack a target will be referred to as an RPV attack system. There are numerous possible configurations, and options, for an RPV attack system. [3] The RPVs may carry imaging equipment such as TV, Low Light Level TV (LLLTV), Forward Looking Infrared (FLIR), or possibly even Synthetic Aperature Radar (SAR). Of these options, TV is limited to daytime use but LLLTV and FLIR can be used at night. SAR can be used under poor visibility conditions (i.e., "all weather"). Another conceivable approach, which is all-weather like SAR but non-imaging, may involve the use of monostatic MTI radars or multistatic range-only radars; however, these are limited strictly to moving point targets. Moreover, a projectile, or kamikaze RPV, which directly attacks the target may be either actively guided toward the target or may passively home in on the target with an autotracking (image tracking) TV sensor, an IR seeker, an anti-radiation device or even, possibly, an acoustic homing device.

The intent of this study is to concentrate on a specific sub-class of systems in which Service interest has historically been high. These particular systems employ a kamikaze approach in which the RPV itself, rather than a projectile, directly impacts the target. The term "impact" is understood to include the use of a mass-focus type of warhead which propels a heavy mass at the target, destroying the bearer RPV in the process. The other major type of munition suitable for anti-tank use is the shaped charge.

The kamikaze is assumed to include a video sensor (TV) rather than an IR, SAR or other type. A central problem of this particular sub-class (i.e., kamikaze) is that of maintaining communications down to low altitude during the homing phase.

The question of whether or not the specific sub-class of kamikaze systems being studied here is the best approach to destroy a moving tank, relative to either other types of kamikaze systems (IR passive homing, etc.) or non-kamikaze types of RPV attack systems (laser designator systems, projectile fired from RPV, etc.), is not being addressed within the present scope of effort. Also, the more general question as to whether an RPV attack system is the best approach relative to artillery or manned-aircraft delivery systems is not considered in this study. This does not preclude later consideration of the other types of systems and does not imply a prejudgment that the kamikaze approaches identified are necessarily the best approaches for moving-tank destruction.

1.2 Study Approach

This study is covered by the U.S. Army Aviation System Command/MITRE Technical Objectives and Plans (TO&P) for Project 8370, Army RPV Analyses, dated 10 April 1975. The study approach included the following steps:

- Basic elements (components) of the system were characterized;
- A representative scenario considering the needs for general surveillance, target classification, weapon control and damage assessment (desired) was prepared;
- Candidate systems compatible with the scenario were configured;
- Alternatives deemed impractical were eliminated;
- Each remaining alternative was evaluated considering cost, technical feasibility, compatibility with current RPV designs and general operational performance;
- Preferred alternatives were rank-ordered with advantages and disadvantages highlighted;

- Representative alternative candidate approaches which were not within the scope of this study were identified for consideration at a later date.

2.0 CONCEPTS AND ANALYSES

There are numerous possible operational concepts with attendant options in communications techniques, relay platforms, autotrackers, etc. To facilitate discussion of the various concepts, they have been categorized as being either closed control (man in the loop until impact and requiring communications all the way) or modified closed control (man in the loop until terminal phase requiring communications until handover to some terminal guidance such as a linear predictor or an autotracker).

For the closed control concepts there are several options to be considered for providing the complete communications required. Figure 1 shows a direct link to the RPV from the Ground Control Station (GCS) which is one option. Another option is to provide a communications relay deployed from the RPV. Such a relay suggests further options in terms of the type of relay platform (RPV, balloon or parachute) and the type of communications (microwave (MW), fiber optics, laser, etc.). Figure 2 shows the various combinations included in the study and some alternative concepts not within the scope of the study. Alternatives are shown as "LGP", "Non-Imaging," and "Rendezvous Approach" under the "Weapon Without TV Camera" block. Also, the "Projectile With IR Homing" block is in this category. These options are described in Section 2.4.

Elements common to all concepts (basic RPV, TV camera with its controls and warhead) are described in Section 2.1, Basic Elements. Also, autotrackers are described in this section to provide some background for the succeeding sections. Descriptions of communications, relays, etc., which are unique to the various concepts are included in the descriptions of Section 2.3, Candidate Systems.

A basic scenario is developed in Section 2.2, Targets and Scenarios. The scenario provides a general framework for evaluating the various system concepts and it assumes tanks as the prime targets.

Section 2.3, Candidate Systems, contains a summary of each system including operational concept, equipment requirements and descriptions, costs, and evaluation. Some factors considered in the evaluation are: targeting accuracy, range (from GCS to target), warhead size, weight budgets, system simplicity, size, overall system cost, manpower requirements, vulnerability (to destruction and countermeasures), day/night/weather capability, development risks and ability to perform damage assessment after attack. Clearly all of the systems and all of the above factors could not be treated exhaustively in the two and one-half month contract period, and the depth of treatment was tailored to the time schedule. When a critical element of any concept was deemed unsatisfactory

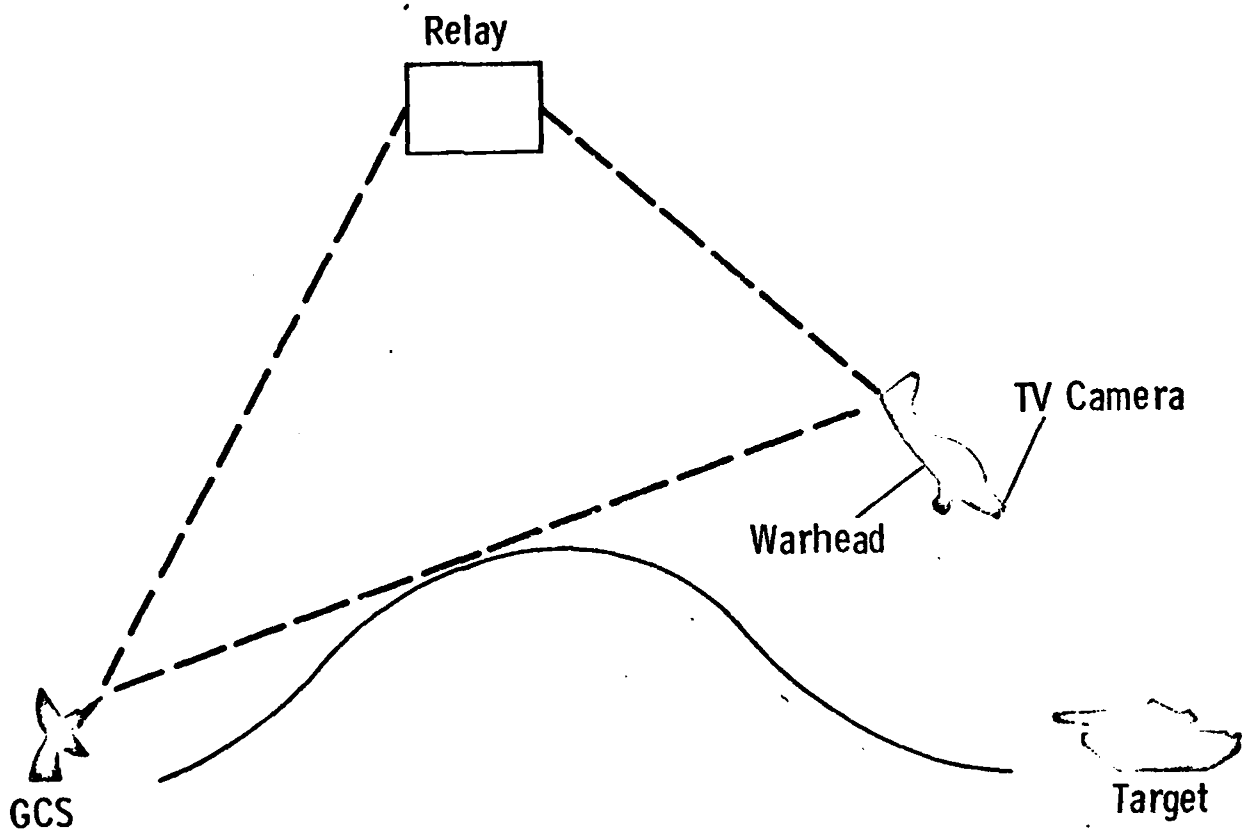

FIGURE 1
GENERAL KAMIKAZE GEOMETRY

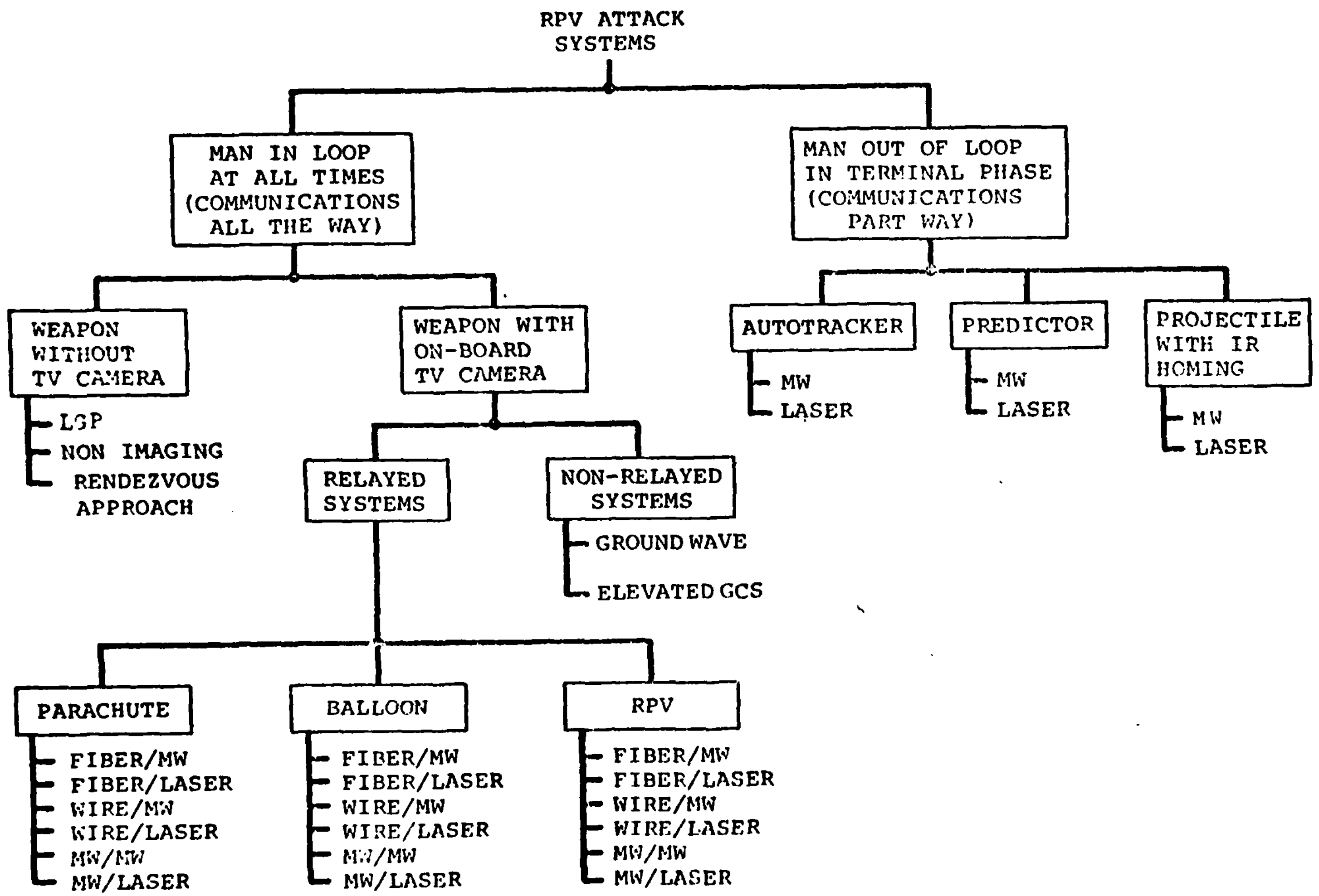

FIGURE 2
COMMUNICATION AND PLATFORM RELAY OPTIONS

in the system sense, analysis on the affected configuration and the associated hardware was discontinued. The schedule did not permit detailed independent examinations of all technical details in all areas; therefore, professional judgment was applied to make maximum possible use of data and analysis already available through various government laboratories and industry. Costing is more relative than absolute and should be used primarily for comparative purposes.

2.1 Basic Elements

Three basic elements are defined for this study - (1) RPV, (2) stabilized TV camera and (3) warhead. The following assumptions and estimates regarding their characteristics (cost, size, weight and performance) were made for this study. Autotrackers are also described to provide background information.

2.1.1 RPV (2, 4, 5, 6, 7)

An RPV weighing about 120 pounds fully loaded was assumed with approximately 30-50 pounds available for payload. The payload includes sensors, warhead and any supplementary electronic equipment that may be necessary in a particular kamikaze application beyond that of the normal flight configuration (i.e., the specific payload weight allotment is above that of the normal communication, navigation and autopilot equipment).

The overall wingspan is assumed to be roughly 10-12 feet and the speed 75-120 knots. Flight endurance time is about two to four hours with the assumed payload weights. Maximum cruise altitude is taken as 15,000 feet MSL. Radar cross-section of the RPV is assumed to be on the order of .1 m^2 at C-band. Time to reach an altitude of 10,000 feet is about 10 minutes. Cost (5) in production is assumed to be $7K.

In principle, the RPV is assumed to be observed (e.g., by radar) and controlled from the GCS. In this report, whenever the GCS controller guides an RPV into a target in the homing phase it is understood that a ground-based autotracker could be employed as an assist. The flight control system would command altitude, speed and heading rate and onboard servo control would provide both response to the flight-control orders and stabilization.

2.1.2 TV Camera (6,8,9,10)

A shock-mounted and separately stabilized TV camera (as in Phase III of the Aquilla[1] program) with a stabilization of 50 ur rms and a variable Field of View (FOV) capable of remote adjustment from 4° to 20° is assumed. These FOV limits are consistent with current equipment and provide a reasonable range of values between the wide coverage (but adequate resolution) needed for surveillance (20°) and the higher, but localized, resolution needed for recognition (4°). Static resolution is assumed to be 500 lines/frame and dynamic resolution 250 lines/frame. Image derotation and automatic brightness control are assumed.

The need for separate camera stabilization was inferred from References 8, 9, 15 and 16 based on test flights with a Cessna aircraft carrying a stabilized Praeire sensor. A rough analytical estimate of the required degree of stabilization can be determined as follows. In a typical surveillance scenario (see Section 2.2), the RPV may be flying at an altitude of 3300 ft. looking forward with its 20° FOV between depression angles of 30° and a 50° with a maximum target range within the FOV (at 30° depression angle) being at 2000 m. A ground resolution of about 10 ft may be barely adequate to detect a 20 ft tank, which corresponds to a required angular resolution at the RPV of

$$\frac{10 \text{ ft} \times \sin 30^\circ}{2000 \text{ m} \times 3.28 \text{ ft/m}} = 760 \text{ ur.}$$

If the 20° FOV is divided into 500 lines (assumed static resolution), this corresponds to an angular resolution of

$$\frac{20^\circ}{500} = .04^\circ = 698 \text{ ur,}$$

which is adequate, although the assumed dynamic resolution of 250 lines would be marginal for the most distant targets. At any rate, to prevent further degradation of the 760 ur desired resolution, the camera should be stabilized to a fraction of the 760 ur, perhaps on the order of 80-100 ur which is understood to be at a level where separate camera stabilization is required.

---

[1]Formerly called Little "r"

Lack of separate camera stabilization does not necessarily negate the system, but tends to transfer the limiting system resolution to the stabilization rather than the TV line granularity and forces the RPV to operate at a lower altitude than that assumed in this report. Further confirmation of the above conclusions is, of course, highly desirable since it is mainly based on the limited experimental data taken to date. In summary, the 50 ur of stabilization assumed in this report is desirable for long-range target detection and recognition, and is understood to be roughly at the present state-of-the-art.

The payload weight for the TV camera and stabilization equipment is assumed to be about 30-33 pounds, with stabilization equipment accounting for about 90% of this weight allocation (gimbals, motor, gyro and electronics).

The production cost of a stabilized TV camera system will be assumed to be $14K-16K, with the TV camera and zoom lens being about $2K-4K, and the stabilization accounting for about $12K.

2.1.3 Autotracker[8,9,10,11,12,13]

Autotrackers can be effective passive seekers and have been incorporated in operational air-to-surface missiles such as Maverick (Air Force); Walleye (Navy); Condor (Navy), and HOBO (KMU-351, Air Force). The programmed Hellfire missile (Army) is also expected to have an autotracker as one of the guidance options. The auto-tracking unit is basically a signal-processing adjunct to a standard digital TV system. In a typical application, an operator can place a visible rectangle on the TV display at any desired location and with a selectable size. Assuming the rectangle has been placed around a target, such as a tank, the video signals within the rectangle are extracted and subjected to a centroid determination (of the intensity pattern). As the centroid moves relative to appropriate display coordinates, an error signal can be generated for control of missile direction, etc. There are various types of autotrackers, e.g., (1) trackers which follow a contrast edge (actually a "corner" in two dimensions), (2) pseudo-centroid trackers which follow the centroid of everything within the visible rectangular gate, (3) true-centroid trackers which follow the centroid of only the target shape within the visible rectangular gate and (4) area-correlation trackers which follow a particular image configuration (not appropriate for target tracking unless the target occupies a major part of the picture).

Autotracking electronics may be small and lightweight. It is assumed that the incremental autotracker weight is about 2-4 pounds and that it has a size of roughly 6" x 6" x 7". In production quantities, it is assumed that the incremental cost of an autotracker would be on the order of $4K-9K, depending on quantity and supplier. The high cost limit is for quantities of about 1,000 and the low-cost limit is for quantities of about 10,000.

2.1.4 Warhead

Shaped-charge warheads previously used[1] in anti-tank missiles vary from about 4-14 pounds, with the greater destruction capability being, of course, at the higher weights. For purposes of weight budgeting, 10 pounds is assumed.

Incremental cost of the warhead should be relatively low, e.g., $100. (The entire German Cobra anti-tank missile has a unit cost of $600, with 5.5 pound warhead.)[1]

An alternative type of anti-tank warhead is the mass-focus device in which a heavy projectile is propelled (by explosives) at a tank from a standoff distance of 100-200 ft. It is believed that this type of kill mechanism has less penetration capability than a shaped charge, but may do more internal damage if it penetrates.

2.2 Targets and Scenarios

2.2.1 Detection and Recognition Ranges

The prime target is considered to be a tank, although trucks, armored personnel carriers (APC), bunkers, bridges, etc., are also of interest. Tanks, of course, are very mobile and capable of some evasive maneuvering, at least in an open field. Maximum target speed is assumed[14] to be 80 km/hr (50 mph) which includes most APC but not necessarily high-speed trucks on open road.

Based on some preliminary field results,[15,16] and other references[6] it will be assumed that an RPV, performing surveillance with a 20° FOV can detect a prime target (e.g., tank or APC) on a road at a mean range of about 3500 m and, by zooming to a narrow FOV of 4°, can recognize the target at a mean range of 2,000 m. For a target off-road, in moderately sparse low-brush terrain, a mean detection range of 2,000 m with a 20° FOV and a mean recognition range of 2,000 m with 4° FOV is assumed. These results are based on: (1) a silicon vidicon type of TV camera, which has a spectral band extending up to about 1 um, (2) good stabilization of about 50 ur, and (3) mean values rather than high-probability results. In general, the given ranges (based mainly on Ref. 16) tend to be substantially longer than other field results (Ref. 15) using different TV equipment. The above assumed ranges are summarized in Table I.

TABLE I

ASSUMED MEAN DETECTION & RECOGNITION RANGES

	Detection Range (m) 20° FOV	Recognition Range (m) 4° FOV
On road	3,500	2,000
Off road	2,000	2,000

It should be recognized, however, that different equipment and/or procedures such as FLIR, MTI video, narrow FOV during surveillance, higher detection probability, etc., will yield different operational ranges than those shown in Table I. The assumed ranges are, therefore, treated only as illustrative values to obtain first-cut "ballpark" results.

2.2.2 Surveillance

This section treats the geometry and cruise conditions which exist during the surveillance period prior to the kamikaze dive. The geometry is illustrated in Figure 3. During the surveillance phase it is desirable that the RPV fly at the highest possible altitude, consistent with the ability to detect and recognize targets in order to reduce physical vulnerability, increase ground coverage and maintain good communications. By fixing $R_{s(max)}$ (in Figure 3) equal to 2,000 m, the required detection (20° FOV) and recognition (4° FOV) capabilities are obtained over the FOV. Figure 4 shows how altitude, H, varies as a function of depression angle, α, for a constant value of

$$R_{s(max)} = 2000 \text{ m}$$

and with the 20° surveillance FOV.

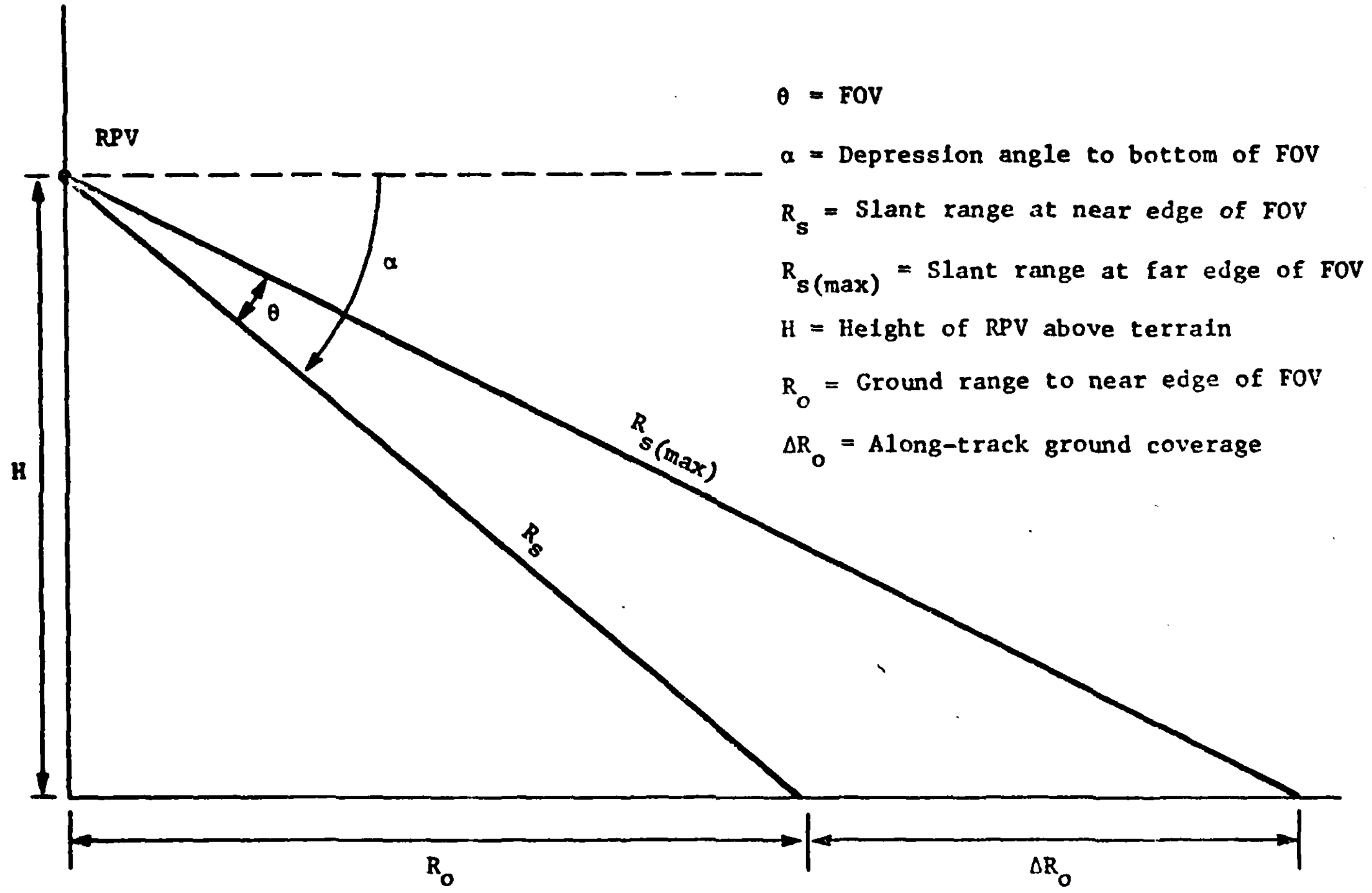

FIGURE 3
GEOMETRY FOR SURVEILLANCE

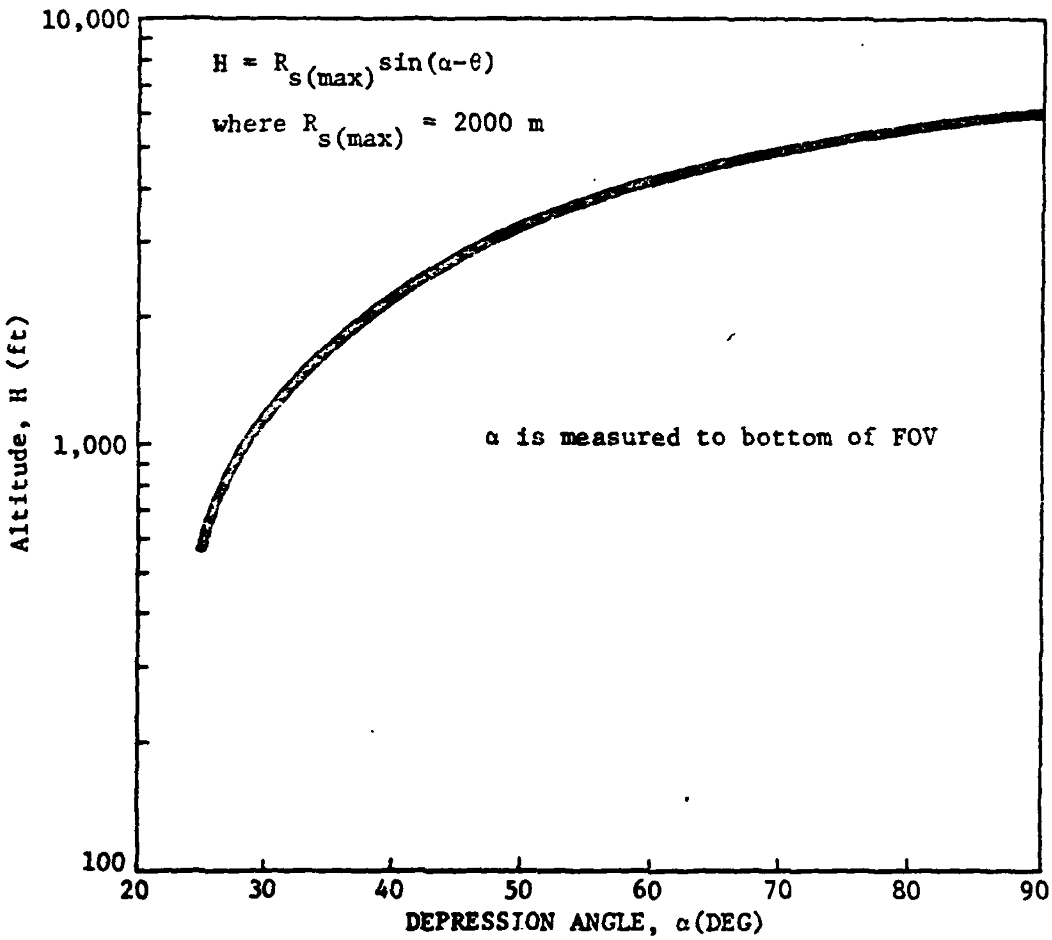

FIGURE 4
ALTITUDE FOR A MAXIMUM SLANT RANGE OF 2000 m

Varying α, as a parameter, and using the value of H from Figure 4 (maximum H for required ground resolution), the following important parameters as a function of α are plotted in Figure 5.

(1) A masking factor $S_F = \cot(\alpha - \theta)$, which is the length of the masked distance (or shadow) of a terrain object of unit height; the subscript F indicates that it is evaluated at the far end of the FOV.

(2) Along-track ground coverage, ΔR_o.

(3) Cross-track ground coverage at center angle $(\alpha - \frac{\theta}{2})$ of FOV, ΔD.

(4) Transit time for a target to pass through the FOV, $T_F = \frac{R_o}{V}$, where V = RPV ground speed.

(5) Lead time, $T_L = \frac{R_o}{V}$, which is the time required for the RPV to go from its present position to a position directly over the target, assuming the target is currently at the near edge of the FOV; this time is usable for direct pitchover into a kamikaze dive.

It can be seen from Figure 5 that the optimum depression angle, α, for surveillance is a compromise between better masking properties plus higher cross-track ground coverage at high values of α, on the one hand, and higher along-track coverage plus longer transit times at lower values of α. Note that lead time T_L peaks near 40°-50°, which is selected as a reasonable compromise. Specifically α = 50° is selected as the illustrative operating point, giving the following surveillance parameters.

FOV: $\alpha = 50°$, $\alpha - \theta = 30°$

H = 3,300 ft

ΔR_o = 2,800 ft

ΔD = 1,700 ft

S_F = 1.7 sec

T_F = 17 sec

T_L = 16 sec

V = 100 knots

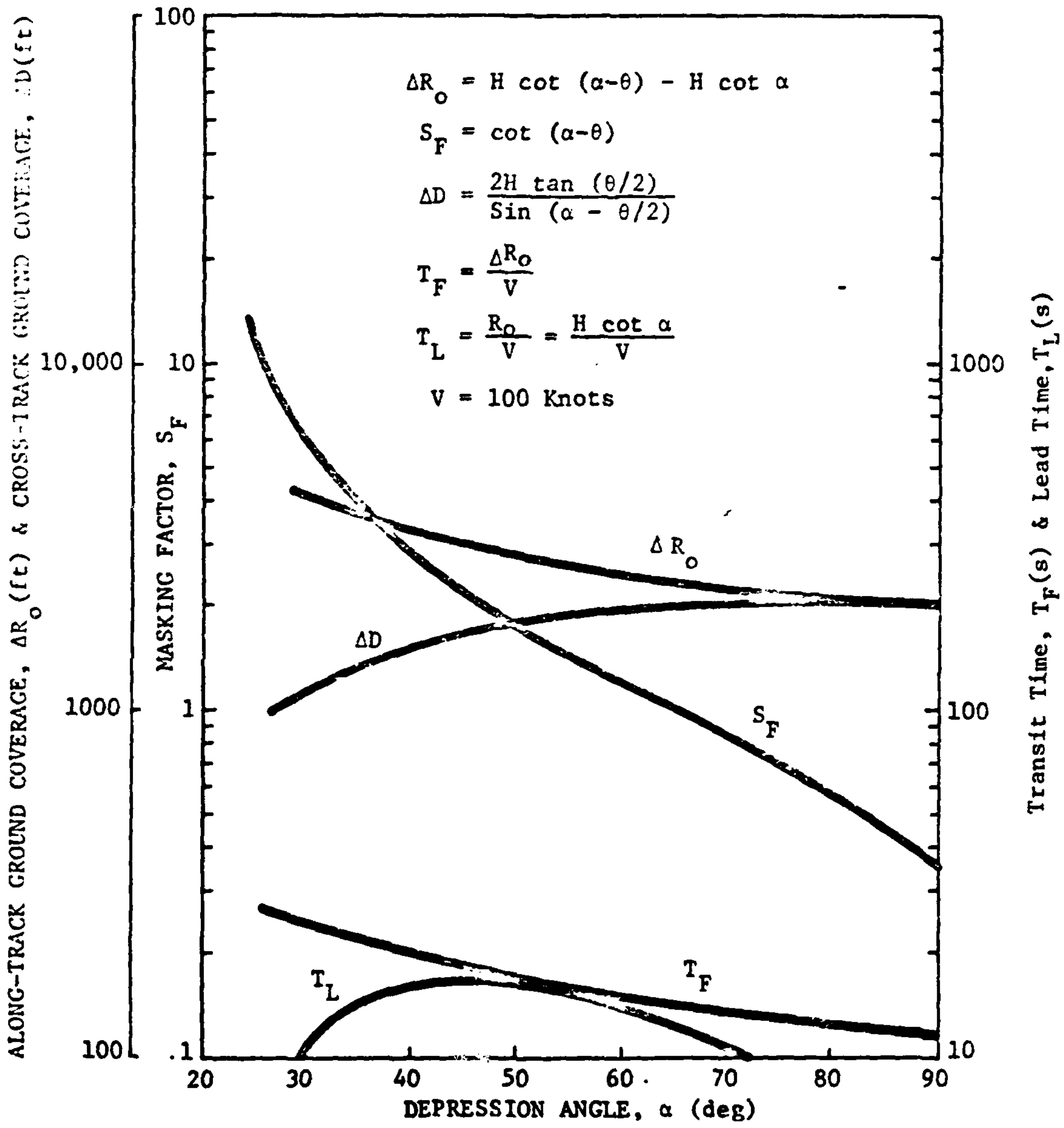

FIGURE 5
SURVEILLANCE PARAMETERS AS A FUNCTION OF DEPRESSION ANGLE, α, AT BOTTOM OF FOV

2.3 Candidate Systems

This section describes candidate systems and comments on their suitability for the kamikaze task. Closed control (communications all-the-way) concepts are considered first. They include: (1) the basic elements as defined in 2.1 with some inherent Line-of-Site (LOS) limitations; (2) ground wave link (no LOS limitations); and (3) three relay platforms (parachute, balloon and RPV) with their associated GCS/RELAY/KAMIKAZE links. Next, a modified closed control (communications until terminal phase) concept using an onboard autotracker is described. Finally, alternatives which are not within the scope of the study are described briefly.

2.3.1 Basic System

It is possible to utilize only the basic RPV, stabilized TV and warhead described in Section 2.1 to form the simplest attack configuration. These elements, coupled with autopilot control, proportional navigation and a simple linear predictor for the homing phase could provide significant coverage where flat terrain exists and an advantageous site location could be provided for the GCS.

For example, it is possible to maintain communications to an RPV flying at only 75 ft altitude at the 30 km range if the GCS is elevated 20 ft. and the terrain is flat (see Figure 6).[2] Thus, the kamikaze could dive under direct operator control except for the last 75 ft (less than one second prior to impact). Communications during this terminal phase are probably not essential, particularly if autopilot control, proportional navigation and a simple linear predictor are incorporated in the RPV.

Complete studies of this basic system were not undertaken at this time to determine how well it would perform under various terrain conditions. This would require a considerable effort including communications masking studies (involving typical terrain, etc.) and a determination of the maximum "no communication" time allowable in the terminal phase during which the RPV operates autonomously.

[2] Although Figure 6 shows only (LOS) limitations, calculations of altitude limitations due to multipath (Fresnel lobing)[17] showed comparable results as detailed in the Appendix.

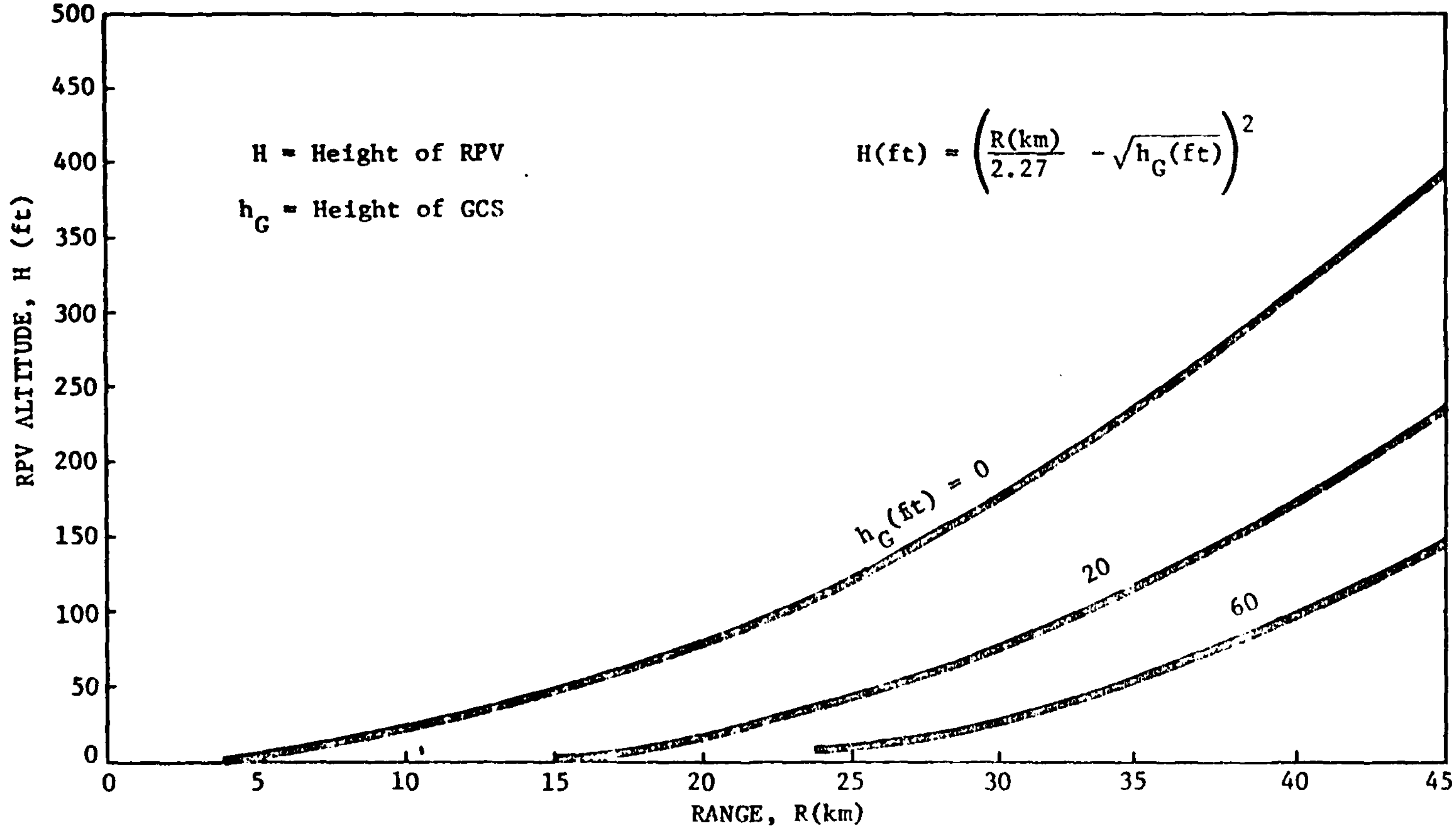

FIGURE 6
MINIMUM RPV ALTITUDE FOR LINE-OF-SIGHT CONDITION

2.3.2 Ground-Wave Link

Closed control may be obtained using ground-wave communications which do not have the LOS limitations of microwave or laser communications. The ground-wave link would, of course, permit closed control only if both forward-link commands and back-link TV signals can be continuously transmitted between the GCS and the kamikaze.

It was known early in the study that the ground-wave link was not an acceptable alternative because the relatively large conventional bandwidth required for the video link was not likely to be allocated[3] in the crowded high-frequency (2-30 MHz) spectrum. Further, jamming vulnerability and EMI problems are also severe. Nevertheless, the minimum required bandwidth was determined to establish technical feasibility, on the chance that there might be some means of accommodating a narrower-band ground-wave link. Such design alternatives did not lower the bandwidth requirements enough to make the ground-wave link practical. Although the pursuit of ground-wave links for this application was dropped, the video link analyses and design alternatives are described as follows for future reference.

The major problems to be considered in the design alternatives are TV-bandwidth related, specifically:

(1) What is the minimum imagery bandwidth required during (a) surveillance and (b) homing?

(2) What carrier frequencies are appropriate for the required bandwidths and range of 30 km.

(3) Can appropriate carrier frequencies and bandwidths be obtained from frequency allocation managers?

Although a normal TV bandwidth is on the order of 4-6 MHz, refined digital processing and communication techniques such as (1) sending the coefficients of optimum transforms and (2) sending differences in gray-scale amplitude rather than absolute values have been used(20)

---

[3] Although a final determination of frequency allocation requires official consideration by responsible agencies, checks with the working groups involved (including Mr. Charles Runyon of the Army Communications Command, C&E Services) confirmed that chances of getting clear, worldwide assignments of proper bandwidth in the low-frequency band are essentially nil.

to reduce the bit rate to about 500 kb/s for a frame rate of 4 frames/s. This assumes a 250 x 250 cell image with an average of 2 bits/cell after transform techniques have been applied. Resolution and gray-scale are said to be roughly equivalent to a good household TV. Required electrical bandwidth may be expected to be about twice the bit rate for a digital communication system, or 1 MHz at 4 frames/s. It should be noted, however, that in the kamikaze application there are several quality factors that may be exchanged for bandwidth; namely, (a) frame rate, (b) "communicated FOV"[4] and (c) resolution. For example, during the surveillance (target search and detection) phase of the engagement, a large communicated FOV and fine resolution are required but a low frame rate may be acceptable. However, during the homing phase, high frame rate is required but a small communicated FOV and coarse resolution may be acceptable.

In general, the ground-wave link would be a communications supplement to ICNS,(19) the latter still being required for RPV location, navigation and control. Possibly, however, the ICNS communication functions (in contrast to the radar functions) could be substantially reduced to avoid redundancy with the ground-wave link.

In the work which follows, note that only basic bandwidths are being estimated without spectrum spreading for anti-jam purposes. Anti-jam techniques such as spectrum spreading would require 10 to 1,000 times that required to transmit the basic data.

2.3.2.1 Bandwidth Required for Surveillance. In Section 2.2 it was seen that a reasonable cruise height for an RPV during the surveillance phase is 3300 feet, with a depression angle of 40° at the center of a 20° FOV. Under these conditions a target nearly beneath the ground track passes through the FOV in about $T_F = 17$ seconds. If we allow the GCS observer a display with persistence, or refresh, and guarantee (somewhat arbitrarily) that he gets four looks at a target as it passes through the FOV, then the time between frames is:

$$\frac{17}{4} = 4.3 \text{ sec/frame.}$$

Scaling from the 1 MHz bandwidth stated earlier for 4 frames/s, it may be estimated that a minimum bandwidth of 60 kHz is required for RPV surveillance. This assumes a suitably wide communicated FOV (20°)

[4] The "communicated FOV" is defined to be the portion of the overall optical image that is actually communicated back to the GCS.

and fine resolution adequate for target detection at the stated cruise altitude. Also, the frame period of 4.3 s/frame is arbitrary and may, or may not, be adequate.

2.3.2.2 Bandwidth Required for Homing. After detection of a target at an altitude of about 3300 feet, a depression angle of 40° at the center of the FOV and a slant range of 2 km at the far end of the FOV, we assume that the RPV narrows its FOV to about 4° for target recognition as it continues cruise flight toward a position nearly over the target where it will commence its dive, guided by the ground-wave link. This position will be reached at $T_L = 16$ s after the target would ordinarily leave the surveillance FOV. However, before the target leaves the FOV, presumably a GCS observer would start steering the camera's FOV to follow the target of interest, while the RPV would be guided toward a flight path passing directly over the target.

Figure 7 shows the kamikaze vertically above the target, at the start of its dive. In reality, the dive would not be exactly vertical but this approximate model should be sufficiently accurate for estimation purposes.

The ground resolution is given by

$$r = \frac{d}{\overline{TVL}} = \frac{2\ H \tan \frac{\Theta}{2}}{\overline{TVL}}\ , \qquad (1)$$

where

d = distance covered by optical FOV

$\overline{TVL}$ = number of TV lines (assumed to be about 250 under dynamic conditions).

Note that, with a 20° FOV, and H = 2,000 m (altitude hypothetically set equal to the assumed detection range), the ground resolution is $\hat{r} \approx 9$ feet, which is roughly what would be expected for detection of a tank that is about 20 feet long. If this is set as a fixed resolution during the homing phase,[5] the required optical FOV from Eq. (1) is:

[5]Better resolution is not required since it is sufficient for guidance purposes to guide toward a "dot". Trajectory smoothing (in the absence of large disturbances) gives a hit accuracy better than the resolution cell size.

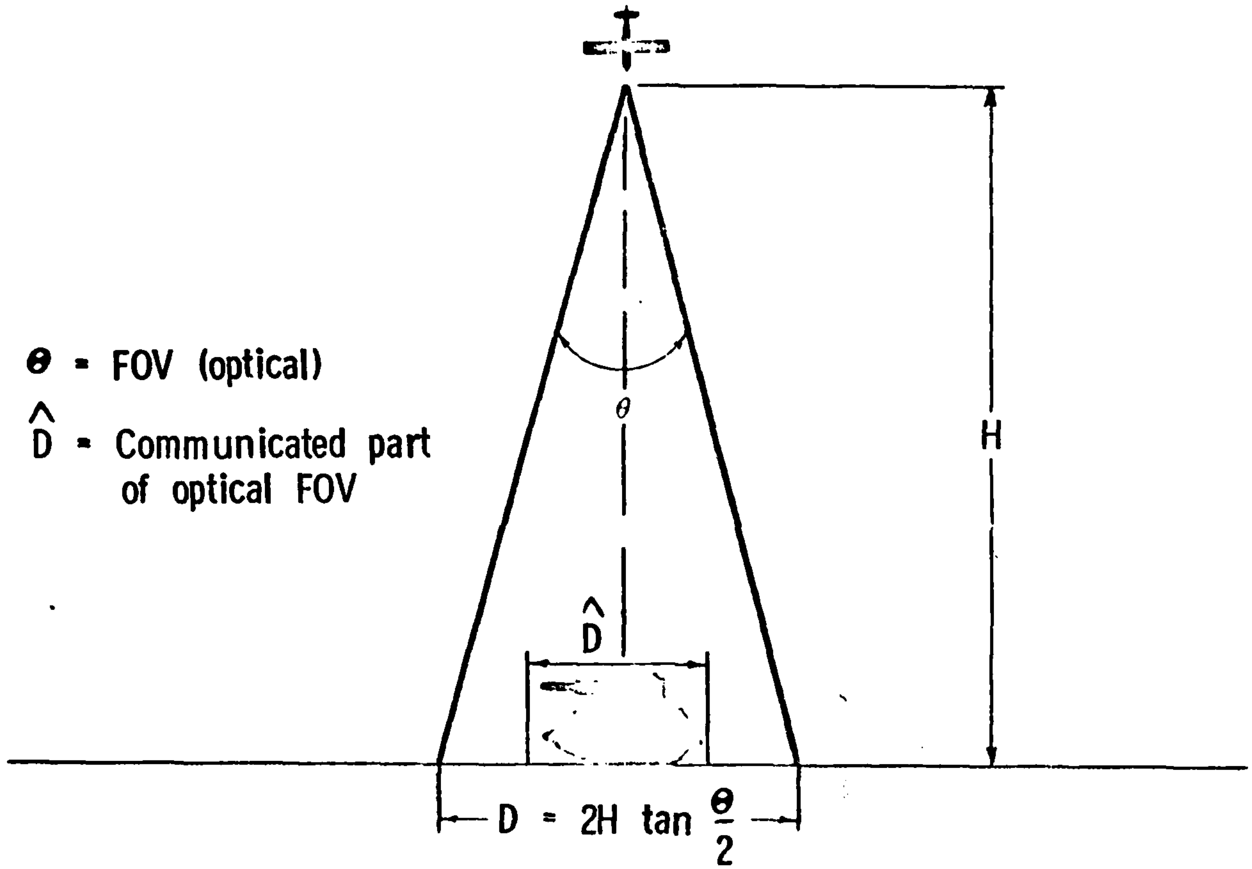

FIGURE 7
GEOMETRY FOR HOMING PHASE

$$\Theta = 2 \tan^{-1}\left(\frac{\hat{r} \cdot \overline{TVL}}{2H}\right) \qquad (2)$$

as plotted in Figure 8. As H decreases, the required optical FOV increases for constant ground resolution.

As this variable FOV is maintained during the descent, it is seen from Eq. (1) that the quantities d and h tan $\Theta/2$ remain constant since r is being maintained constant. The constant value of d is:

$$d = 2\ H \tan \Theta/2 \simeq 2{,}300\ \text{ft}.$$

But this is far in excess of the display needed for a GCS observer to guide in the kamikaze; he may need approximately 200 feet, just sufficient for the tank to remain in the display. Thus, the communicated FOV need be only about

$$\left(\frac{200}{2{,}300}\right)^2 \simeq .008$$

times the optical FOV.

Setting the frame rate at 4 frames/s, consistent with an operator's reaction time of 1/4 s, the minimum required bandwidth during homing is

$$.008 \times 1\ \text{MHz} = 8\ \text{kHz}.$$

Even with an increased frame rate, a finer resolution and/or a larger communicated FOV, the bandwidth during homing can be much less than 60 kHz. The maximum bandwidth is therefore dictated by the required surveillance bandwidth of 60 kHz.

In the above approach, wide-angle, variable-zoom optics are assumed. However, an alternative method of varying the resolution may be designed into the TV camera itself. Cameras exist with variable resolution capabilities, measured in lines per frame, and variable readout rates for the image. Such a camera is being used in connection with at least one approach to solving the kamikaze communication problem by means of a groundwave link.[20]

In general, it may be concluded that about 60 kHz is required for surveillance and substantially less than that for homing. These bandwidths are compatible with hardware operating at frequencies above 1 MHz, where ground wave communication occurs. The upper limit on carrier frequency would be determined by the total losses acceptable over 30 km range on a ground wave link. This is now considered.

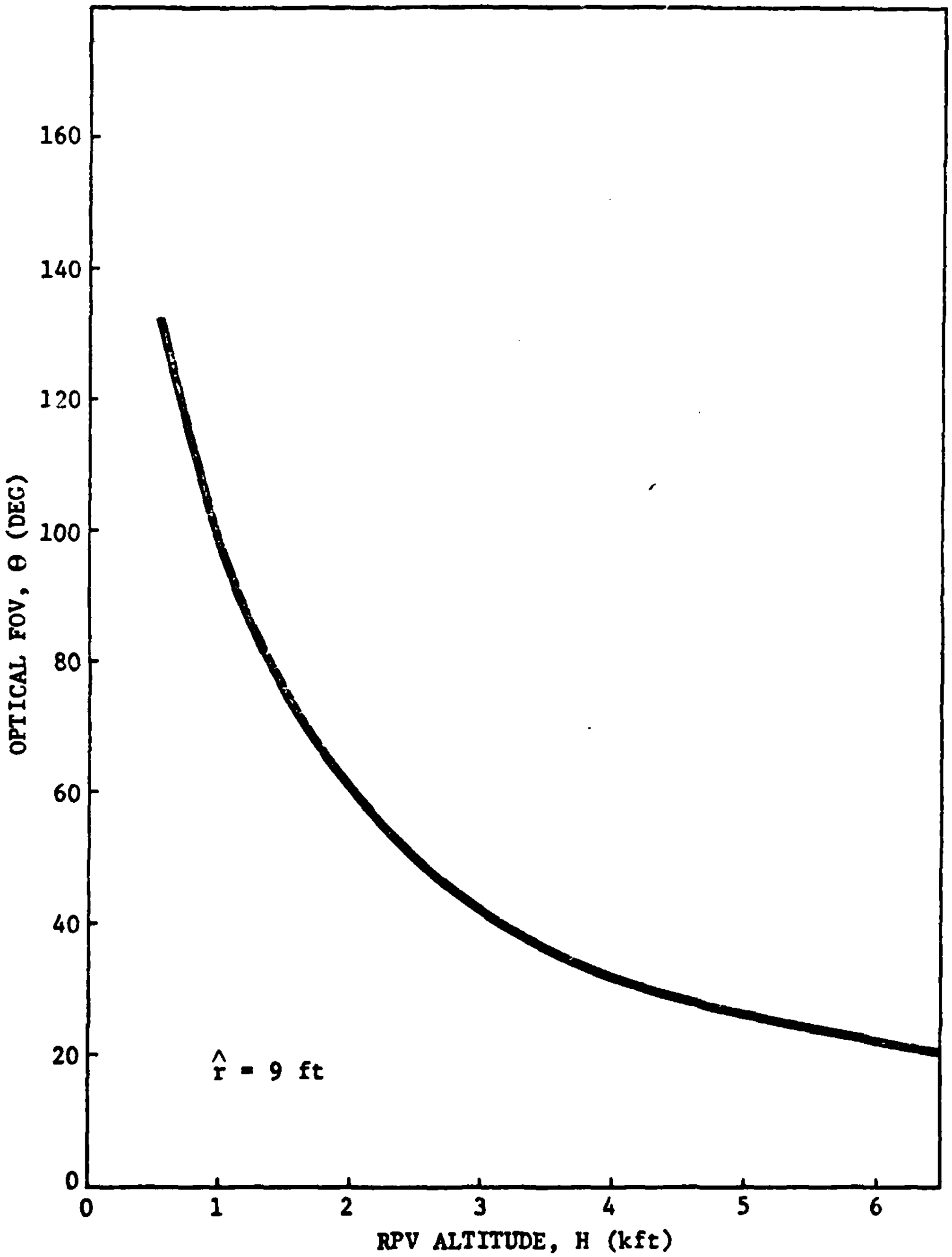

FIGURE 8
REQUIRED OPTICAL FOV, θ, AS A FUNCTION OF ALTITUDE
FOR CONSTANT GROUND RESOLUTION, $\hat{r}$

2.3.2.3 Choice of Carrier Frequency. Choice of carrier frequency is basically dictated by the need to have about 60 kHz of video bandwidth allocated (per kamikaze) at some carrier frequency where propagation losses in the ground-wave mode are tolerable. Received signal-to-noise ratio is given by

$$SRN = \frac{P_R}{k\ TBF} = \frac{P_T\ G_T\ G_R\ L}{k\ \ TBF}, \qquad (3)$$

where

P_T = transmitted power

G_T = transmitting gain

G_R = receiving gain

L = loss factor due to spreading and terrain

k = Boltzmann constant = 1.38×10^{-23} J/°K

T = noise temperature

B = receiver bandwidth

F = noise figure

Figure 9 shows some typical values of expected transmit and receive gains for the link from transmitting RPV to receiving GCS, as a function of carrier frequency. Assuming those plotted values and the additional parameters

B = 60 kHz

P_T = 10 W (on kamikaze)

T = 300° K

F = 5 dB (at GCS)

SNR = 30 dB (allowing for a 20 dB fade margin),

it is found that the acceptable level of attenuation, $1/_L$, is that plotted in Figure 10 (dashed line). Figure 10 also shows (family of solid curves) the ground-wave attenuation as determined from the Longley-Rice computer program,[22] for one illustrative case with

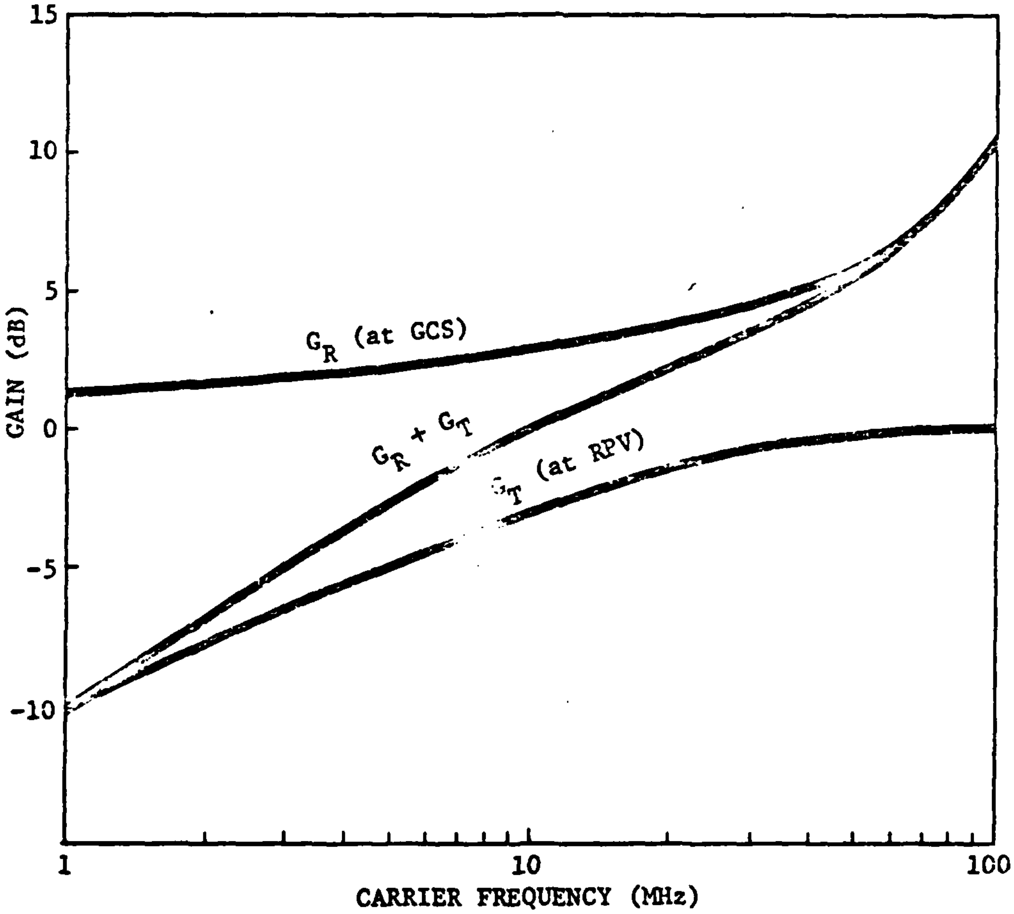

FIGURE 9
TYPICAL VALUES OF TRANSMIT AND RECEIVE GAINS

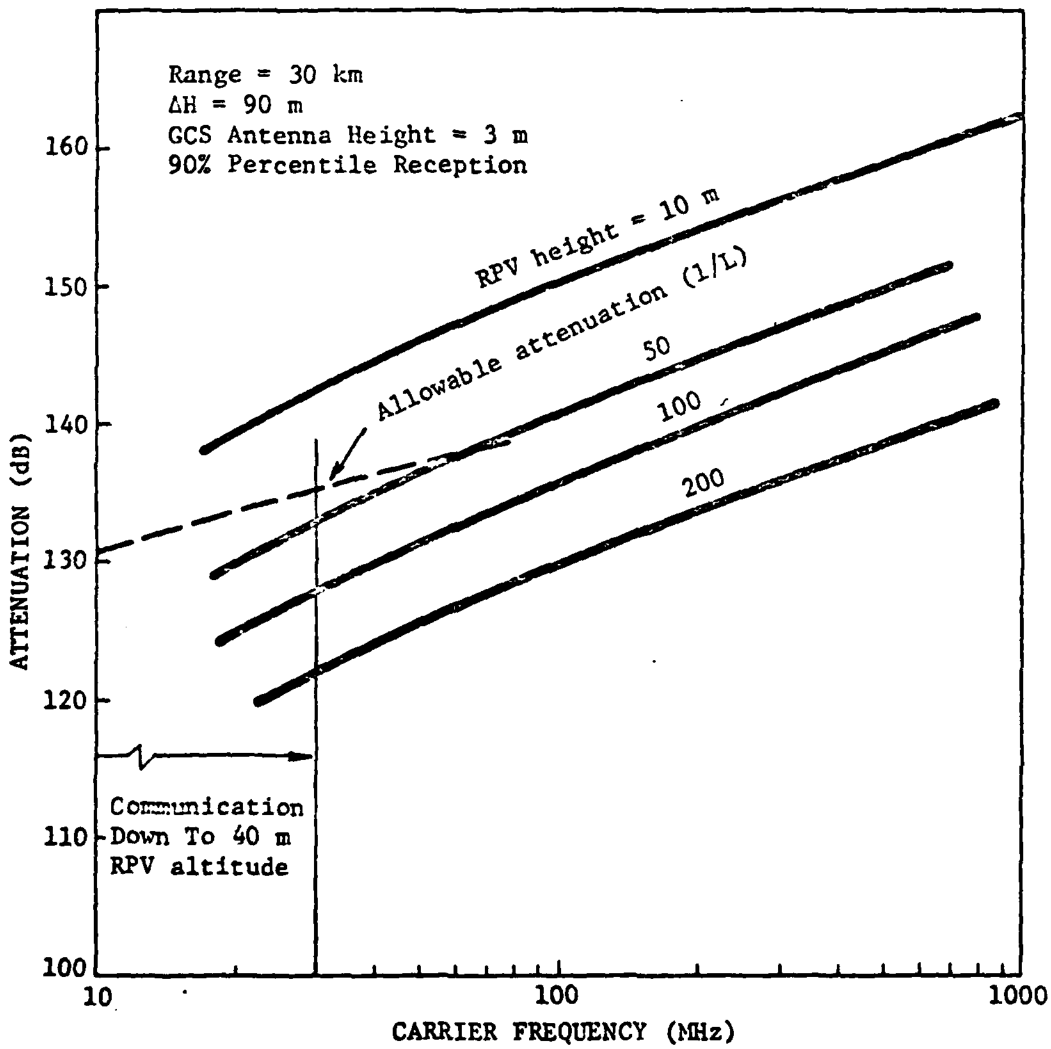

FIGURE 10
GROUND-WAVE ATTENUATION FOR ONE SAMPLE CASE

terrain variations[6] being on the order of $\Delta H = 90$ m. It is seen that frequencies up to about 30 MHz can be used from a loss standpoint for RPV heights down to about 40 m and frequencies below 10 MHz are required for RPV altitudes down to 10 m. The near-horizontal trend of the curves, however, make the results very sensitive to minor changes in attenuation or in the validity of the Longley-Rice model. Nevertheless, there is no large favorable margin for operation above 10 MHz, particularly since other sources of noise (atmospheric, etc.) and interference have been neglected.

2.3.3 Relay Communications Options

Six combinations of wire, fiber optics, microwave communications and laser communications were considered for the links between the GCS and the relay platform and between the relay platform and the kamikaze. These combinations have been shown in Figure 2 and are:

	GCS and Relay	Relay and Kamikaze
1.	Microwave	Fiber Cable
2.	Laser	Fiber Cable
3.	Microwave	Wire
4.	Laser	Wire
5.	Microwave	Microwave
6.	Laser	Microwave

Combinations 2, 4 and 6, using lasers in the GCS-to-relay link were eliminated from further consideration for several reasons: (1) only one RPV could be serviced by each GCS laser; (2) range limitations in weather preclude reliable communications at 30 km (since the signal must be propagated through the atmosphere) (3) new ground station equipments are required since it is not compatible with Aquila/Little Scout; and (4) there is technical risk involved since it is relatively new compared to the microwave approach, although promising laboratory results have been obtained.[18]

The laser does have a major advantage in anti-jam (AJ) potential which results from the use of narrow laser beams. In turn, the narrow laser beams would require precise acquisition and tracking of the RPV from the GCS. Acquisition could be by visible means and tracking could be by means of a quadrant detector which is analogous to a four-horn radar monopulse tracker.

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[6] ΔH is defined as the height difference between the 10% point and the 90% point on a curve of cumulative probability for height, H.

The incident angle of the laser beam may be $\pm$ 40° to $\pm$ 60° for a single retromodulator,[7] necessitating either pointing control of the retromodulator or multiple retromodulators (for 360° of azimuthal coverage). Also, no part of the relay platform (wing of an RPV, etc.) can mask the laser-to-relay line of sight.

The following cost information is from Reference 18. With a 1-5 kw laser, the GCS may cost $30K-50K, could fit on a small truck or jeep and may have a range of about 20 km even under relatively poor visibility conditions. In a system having a laser retromodulator link between GCS and relay plus a fiber optic link between the relay and kamikaze, the components in the relay platform may cost $500 and the components in the kamikaze may cost $300, in production quantities of 1000.

The use of wire between the relay and kamikaze is impractical because a wire line is bandwidth limited and subject to RFI; a coaxial cable is too heavy. Therefore, combinations 3 and 4 are not useful and only combinations 1 and 5 remain to be considered with the various relay platforms.

2.3.4 Relay Platform Options

The three relay platform options which were studied are parachute, balloon and RPV as shown in Figure 2. Of these three, only the parachute and RPV were judged to be viable relay platform alternatives. Other means of relaying data such as satellites and manned aircraft were dismissed because of cost and complexity. Also, a tethered balloon at the GCS was dismissed because it could be easily jammed and would also divulge the location of the GCS.

A balloon platform deployed from the RPV prior to the kamikaze dive presents serious mechanical, weight and deployment problems. For example, a titanium bottle approximately 11 inches in diameter, 20 pounds in weight and containing compressed helium at 3000 psi is required to inflate a 75 cubic foot balloon support for the 5 pound (estimated) microwave relay package. Actual deployment would

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[7] A retromodulator is a device (to be placed on the RPV) which reflects the laser beam directed at it from the GCS.(18) In addition to reflecting the beam, it modulates the return signal to the GCS.

probably have to be accomplished by dropping the balloon, gas bottle and valves, most likely with a slow-down parachute, and then separating the balloon and valves/bottle after inflation. These techniques have been used successfully in the past. However, the complexity, sizes and weights involved are unwieldy for mini-RPVs. For these reasons the balloon vehicle was not considered to be a competitive alternative.

The surviving communications and relay platform options are shown in Figure 11. It is noted that the MW/MW option for the parachute is not included because it has no cost or other discernable advantage over the MW/MW RPV configuration.

2.3.5 Parachute Relay With Fiber-Optic and Microwave Links

The parachute relay platform option (see Figure 12) is attractive since the added equipment and hardware are cheap, lightweight and reliable (considering it is a mechanical device) and it is not susceptible to jamming from the target area. The need to deploy the parachute and maintain the umbilical fiber connection places some obvious operational and deployment restrictions on this option.

It is envisioned that the parachute with a microwave relay package (for the relay-to-GCS communications) and the electronics for the fiber optics would be deployed from the kamikaze prior to its final dive. The fiber optics would be played out from a spinner-type reel in the kamikaze.

Assuming the scenario in Section 2.2, the dive from 3,300 feet would require less than 20 seconds; the relay would drop only a few hundred feet in this period so communications could be maintained until impact.

Fiber optics technology is still in a developmental stage, although encouraging progress has been made. A major obstacle at the present time is the high cost of good optical fibers. Strong, low-loss (<6 dB/km) optical fibers exist[18] which have exhibited payout speeds in excess of 300 ft/s with 10-20 MHz of bandwidth, permitting video communication over distances of 5-10 km. Although the current cost is several thousand dollars per km, suppliers are working on new fibers which may bring the cost down below $100/km in the next few years, and possibly $10/km later. Optical modulation and demodulation equipment was described as being relatively simple and low cost.

Cost estimates for this relay concept are outlined in Section 2.3.8.

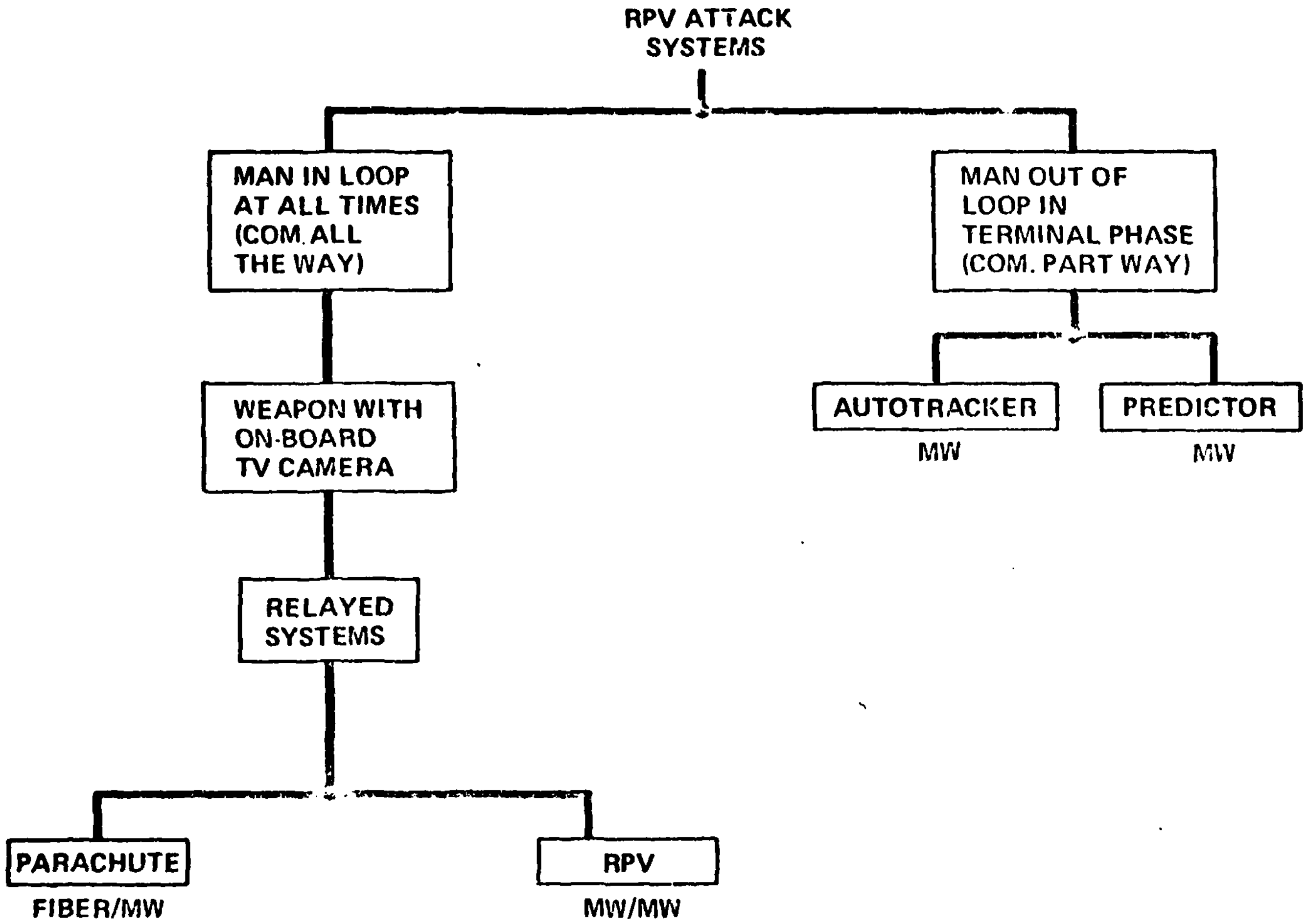
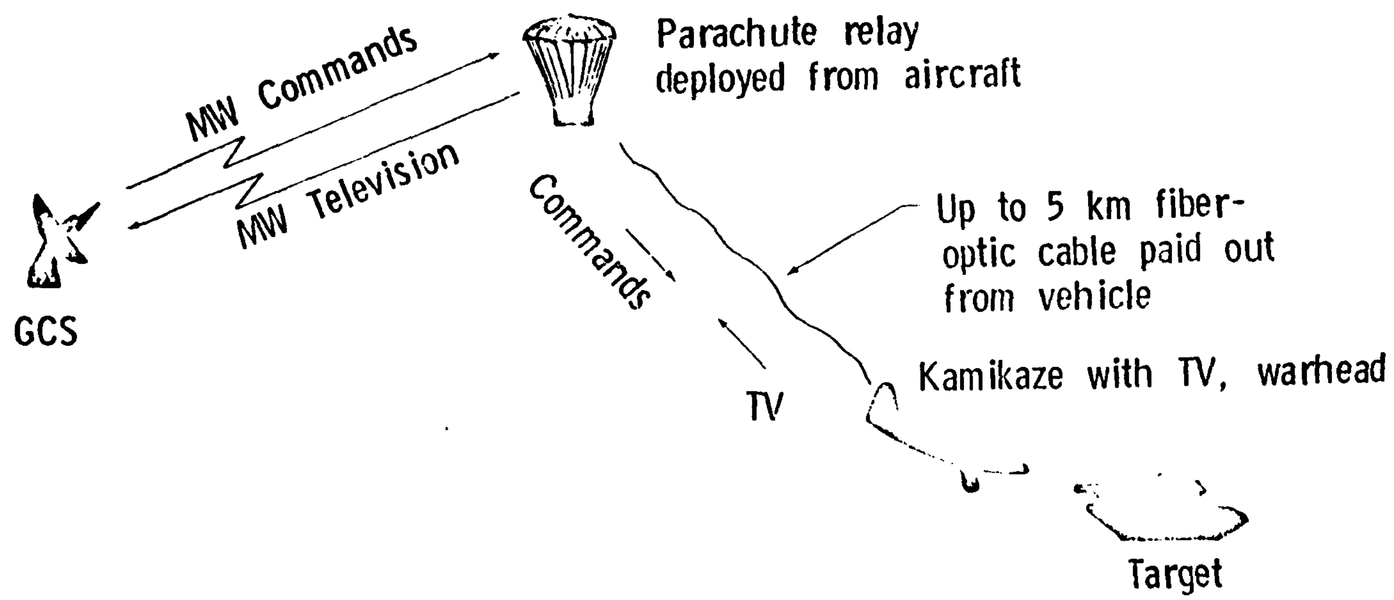


FIGURE 11
SURVIVING SYSTEMS



OPERATIONAL PROCEDURE

1. GCS operator locates target with kamikaze communicating directly with GCS.
2. GCS operator commands deployment of parachute and dive maneuver. Relayed sensor data is maintained via fiber optic cable up until point of impact. Once parachute deployed, the mission must be completed in a short time (no loiter).
3. Damage assessment by some other system.

FIGURE 12
PARACHUTE RELAY
(FIBER/MW)

2.3.6 RPV Relay

An obvious and viable alternative is the use of an RPV platform equipped with a two-way relay as shown in Figure 13. It has operational advantages over the parachute relay since the kamikaze would not be restricted to a high altitude flight profile to deploy the parachute. Also, the RPV relay can be used in the damage assessment role. Another benefit of this option is the chance to abort the mission after committing to the dive and trying again if necessary.

However, the RPV microwave relay is vulnerable to ECM, especially to jammers located on or near the targets. The probability of jammers being located on the targets is unknown at this time, but such jammers are certainly feasible. A mitigating factor is that null tracking antenna can be placed on the RPV to resist off-target jammers.

Estimates of cost are presented in Section 2.3.8.

2.3.7 Onboard Autotracker

The onboard autotracker approach is shown in Figure 14. A standard microwave technique (e.g., ICNS[19]) is used to communicate with the kamikaze until the GCS observer designates the target. This designation action by the observer identifies for the autotracker the target to be attacked. The autotracker then guides the kamikaze to the target without further direction from the observer. The autotracker is described in Section 2.1.3.

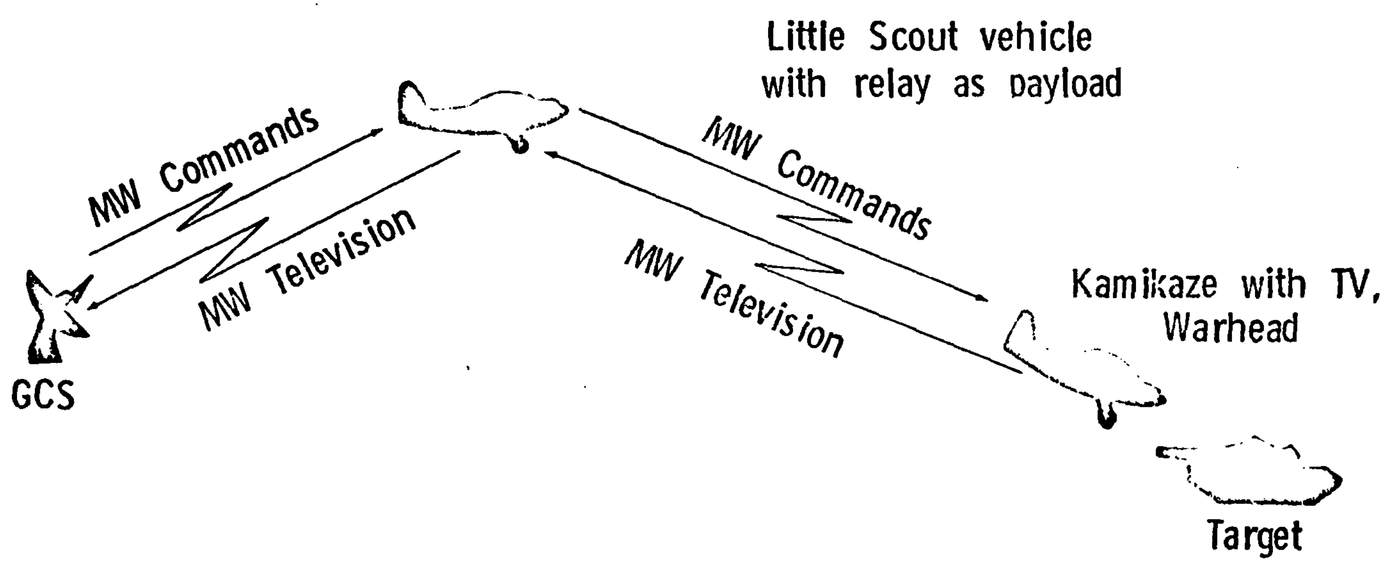
Several problems associated with this approach are:

(1) The tendency of an autotracker to be pulled off track by terrain features adjacent to the target such as trees, shadows, etc.;

(2) The need for an adjustable rectangular gate and probably adjustable FOV, to handle closing distances to the target; and

(3) Cost of the expendable autotracker.

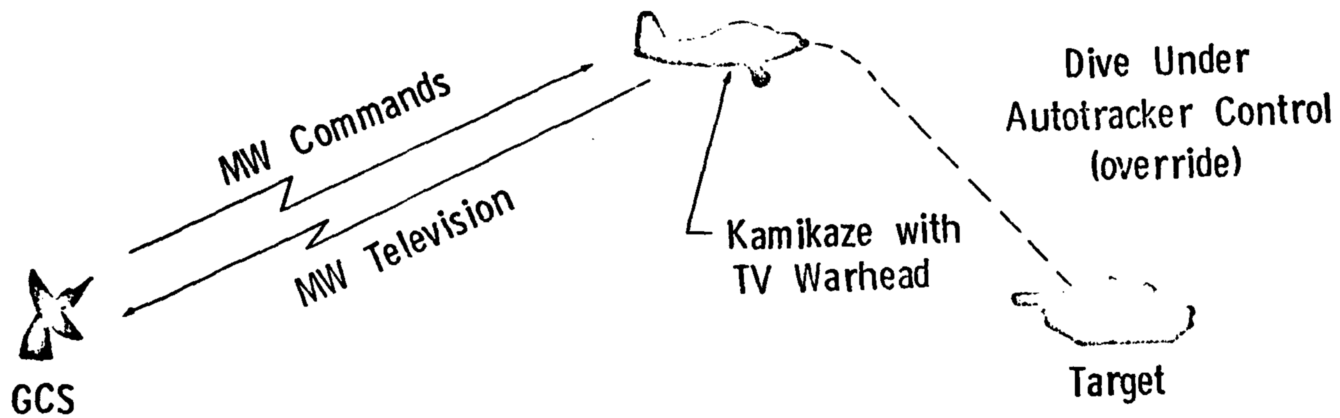
With respect to Item (1), it is advisable to keep the GCS operator potentially in the engagement as long as possible, probably out of the loop but capable of intervention if the kamikaze is pulled off track. Another useful feature, apparently not in current autotracker systems, would be a coast mode whereby a moving tank



OPERATIONAL PROCEDURE

1. GCS operator locates target with kamikaze communicating directly with GCS.
2. GCS operator commands communications through relay and dive maneuver. Relayed communications are maintained until impact. Abort may occur any time; kamikaze may be recovered.
3. Damage assessment by Little Scout vehicle.

FIGURE 13
RPV RELAY
(MW/MW) APPROACH



Operational Procedure

1. GCS operator locates target using on-board sensor and communications system.
2. Commands on-board autotracker to lock on target and dive.
3. Operator uses communications only to abort or redirect mission. Local terrain will determine how far he can hold communications during the dive. Vehicle can be recovered.
4. Damage assessment by some other system.

FIGURE 14
AUTOTRACKER APPROACH

which passes under a tree (for example) would be picked up again as it emerges on the other side. This requires a rate memory, combined with a criterion for detecting the fact that the centroid motion has suddenly stopped concomitantly with a sudden change in the target's apparent shape. In connection with Item (2), the adjustable gate size is understood to be a feature available in current autotrackers but the variable FOV may have to be added (if found to be required). The fact that the autotracker is destroyed in this approach (Item (3)) makes its cost more of a prime consideration here than in the other types of alternative systems.

Smoke countermeasures (CM) could cause the autotracker to be pulled off track. The mitigating factors are that the observer can stay in the loop until LOS conditions cause loss of communications. Also, autotrackers may be improved to provide an indication of "target" shape change occurring simultaneously with apparent sudden stop of target motion and thus permit an automatic abort.

2.3.8 Costs

The three preferred options (autotracker, RPV microwave relay and parachute relay with fiber optics) were costed by estimating relative R&D costs, relative unit production costs and 100 mission costs.

2.3.8.1 R&D Costs. The R&D costs are shown in Figure 15. Since the autotracker option doesn't require relay modifications (indicated by "Not Required", N.R., in the figure) the only R&D costs are in the modifications to the weapon (or RPV kamikaze) for $200K and the autotracker for $200K. Thus an estimated $400K total is required for the autotracker R&D. The ICNS and Aquila-ICNS designations note that R&D is already being covered by those programs.[8]

The RPV relay option requires a modification to the vehicle to accommodate the relays ($200K) and relay development is required ($400K) for a total of $600K.

For the parachute option, the RPV kamikaze must be modified to house and deploy the parachute and to accommodate the fiber optic reel ($200K). Also, it must have a relay for laser communications capability to the relay ($100K). In the relay, the parachute and fiber optics are estimated at $300K with the $400K allotted to the relay electronics for a total R&D cost of $1,000K.

[8] The GCS R&D costs are also being covered by the Aquila-ICNS programs.

	PREFERRED OPTIONS		
	AUTOTRACKER	RPV RELAY (MW/MW)	PARACHUTE RELAY (FIBER/MW)
WEAPON			
Basic Vehicle	200K	200K	200K
Command Receiver	ICNS	ICNS	100K
Sensor Transmitter	ICNS	ICNS	
Autotracker	200K	N.R.	N.R.
Subtotal	$400K	$200K	$300K
RELAY			
Media	0	0	300K
Platform	N.R.	Aquila-ICNS	
Sensor Receiver	N.R.		
Sensor Transmitter	N.R.	400K	400K
Command Receiver	N.R.		
Command Transmitter	N.R.		
Subtotal	0	$400K	$700K
GRAND TOTAL	$400K	$600K	$1000K

FIGURE 15
RELATIVE R&D COSTS

2.3.8.2 Relative Unit Production Costs. Production costs are summarized in Figure 16 for the three options. Under WEAPON, the basic vehicle costs are common to all three and are composed of:

Airframe, engine, avionics (but no communications)	7.0K
Sensor, stabilized TV	16.0K
Warhead	.1K
	$23.1K

(Rounded to $23K in Figure 16)

The command receiver in the weapon consisting of a command adaptive array and modem is estimated at $4K and would be used in the autotracker and RPV relay. For the parachute relay, the rough cost of fiber interfacing transducers in the weapon and relay is $.25K as obtained from Optelecom.

The sensor/telemetry transmitter consisting of a telemetry modem ($1K) and video modem/encoder ($1K) is estimated at $2K total for the autotracker and RPV relay. The fiber interfacing transducers are estimated to be $.25K for the parachute relay.

The autotracker estimate of $6K is an average obtained by reviewing cost data from Hughes, Martin, Honeywell and DBA.

Under RELAY, the media cost is for 5 km of fiber optic cable at $.5K.

The platform cost for the RPV is:

Airframe, Engine, Avionics	$7K
Command and Telemetry Communications (no video)	$5K
	$12K

Costs for the parachute platform and fiber/MW link include:

Parachute and Parachute Deployment Mechanism	$1.5K
Fiber Cable Payout Mechanism	$1.0K
Power Supply (Battery)	.5K
	$3.0K

The two transmitter and two receiver costs totaling $6K in the RPV relay assume an existing Command-Telemetry Modem and are costs to add a relay capability. For the parachute relay, the sensor receiver and command transmitter require only fiber optics interfacing transducers at $.25K each ($.5K total), a command receiver at $4K and a sensor transmitter at $1K.

	PREFERRED OPTIONS		
	AUTOTRACKER	RPV RELAY (MW/MW)	PARACHUTE RELAY (FIBER/MW)
WEAPON			
Basic Vehicle	23	23	23.
Command Receiver	4	4	.25
Sensor/Telemetry Transmitter	2	2	.25
Autotracker	6	NR	NR
Subtotal	35	29	23.5
RELAY			
Media	0	0	.5
Platform	N.R.	12	3.
Sensor Receiver	N.R.	3	.25
Sensor Transmitter	N.R.	1	1.
Command Receiver	N.R.	1	4.
Command Transmitter	N.R.	1	.25
Subtotal	0	18	9
GROUND STATION			
Multi-Beam Antenna			
Command Transmitter			
Sensor Receiver	1000	1000	1000
Display Console			
Computer			
Subtotal	1000	1000	1000

FIGURE 16
RELATIVE UNIT PRODUCTION COSTS (THOUSANDS $)

The production GROUND STATION costs are grossly estimated at $1,000K for each of the three options.

2.3.8.3 <u>One-Hundred Mission Costs</u>. Since some items are not expended, and some configurations are useful with only partial complement of equipment, a 100-mission model was provided to determine the cost differential for the three systems with the results shown in Figure 17.

As a general rationale, it was assumed that there were good LOS conditions for 25 of the 100 missions and no special equipment (such as a relay or onboard autotracker) was required beyond the basic system (Sect. 2.3.1). In the 75 remaining missions, wherever a recoverable relay was used, relay attrition was assumed to be 10%.

With the autotracker, for the 25 missions that could be accomplished within LOS, it was assumed that there would be enough modularity in the design to permit removal of the autotracker prior to these missions. Thus, a 100-mission cost of $3,350K applies to the autotracker case as shown in Figure 17.

For the RPV-relay case, all 100 weapons would be expended; however, relay attrition would be such that 7.5 relays, on the average, would be lost. With this rationale, the RPV relay concept costs $3,035K for 100 missions.

All 100 weapons would be expended in the parachute relay case; however, the assumption that 25 attacks would be within LOS requires that only 75 parachute relay assemblies be used. In their stead, a simple ($5.5K) LOS kit would be substituted. This kit would contain ICNS-type command/telemetry and video modems. The total cost for the 100 missions would be $3,163K.

2.3.8.4 <u>Summary</u>. A summary of the above costs are presented in Figure 18. Considering the gross cost estimates used, there is no significant cost differential for the three alternatives.

2.3.9 <u>Weights</u>

The basic RPV itself, with normal communications equipment for command reception and status transmission, is assumed to weigh about 60-80 lbs and be capable of carrying a payload weight of roughly 30-50 lbs.

	COST (THOUSANDS)
AUTOTRACKER	
75 Weapons with Autotracker @$35K	$2625
25 Weapons without Autotracker @$29K	725
	$3350
RPV RELAY (MW/MW LINK)	
100 Weapons @$29K each	$2900
7.5 Relays @$18K each	135
	$3035
PARACHUTE RELAY (FIBER/MW LINKS)	
100 Weapons @$23.5K each	$2350
75 Parachute Relay Assemblies @$9K	675
25 LOS Kits @$5.5K each	138
	$3163

FIGURE 17
OPERATIONAL SYSTEM COST FOR 100 MISSIONS

	AUTOTRACKER	RPV RELAY (MW/MW)	PARACHUTE RELAY (FIBER/MW)
WEAPON COST	$35	$29	$23.5
RELAY COST	0	$18	$ 9
100 MISSION COST	$3,350	$3,035	$3,163
RELATIVE R&D COST	$400	$600	$1,000

FIGURE 18
COST SUMMARY (THOUSANDS)

For the three preferred systems, the payload weight on the kamikaze RPV is estimated as follows:

Onboard Autotracker System

Stabilized TV camers	30-33
Autotracker	2-4
Warhead	8-12
	40-49 lbs

RPV Relay System

Stabilized TV Camera	30-33
Warhead	8-12
	38-45 lbs

Parachute Relay System

Stabilized TV Camera	30-33
Warhead	8-12
Parachute and Relay	5-8
Optical Fiber with Dispenser	.5-1
Optical Components	.5-1
	44-55 lbs

It can be seen that the estimated payload weights are high relative to the assumed maximum payload capacity of 50 lbs, but appear to be marginally acceptable.

2.3.10 General Summary

Following is a general summary of the operational concepts and the relative evaluations of the three preferred alternative systems.

2.3.10.1 Operational Overview. The GCS operator has several options available in the employment of the kamikaze. The surveillance and identification functions could be followed by either an immediate attack during the "first pass" over the target or an attack on subsequent passes (with the attendant risk of enemy retaliation). The operator might also prefer to wait until the target is in a more opportune position (no LOS communication restriction, lighter foliage, etc.).

With the many variations in operator options and enemy countermeasures (CM), only a qualitative review of the alternatives is possible within the scope of this study. The scenario outlined in Section 2.2 is assumed for a general discussion of the surveillance, detection and recognition functions.

During the kamikaze surveillance period, prior to the homing dive, an RPV having a TV camera with a 20° FOV might reasonably cruise at an altitude of about 3300 ft. with the 20° FOV ranging between depression angles of 30° and 50°. The surveillance (without panning) would cover a cross-track dimension of about 1,700 ft. and a target would pass through the in-track dimension of 2,800 ft. in about 16 seconds for an assumed ground speed of 100 knots. During the surveillance-cruise phase, targets judged to be of interest with the 20° FOV could be inspected more carefully with a 4° FOV, which should be adequate for target recognition. If the kamikaze mission is completed in the "first pass," the GCS pilot would have about 16 seconds (after the target passes the near edge of the FOV) before the RPV passes over the target. During this 16-second interval, he would yaw the kamikaze toward the target and transition to a dive mode keeping the target in view until impact or until handover to a seeker. If a "second pass" is acceptable, moré time is available to prepare for the kamikaze dive since the target identity and position would already be known.

All three alternative systems could accommodate either a "first pass" or "second pass" dive situation with varying degrees of flexibility. ECM for the communications link directly from, or to, the GCS is common to all systems since each employs such a link. CM such as smoke (which was not evaluated in detail in this study) could affect all three systems to some degree since a tank is a very "hard" target and targeting accuracy is extremely important. It is estimated that smoke could be most effective against the autotracker design; however, this design is amenable to operating procedures (careful preselection of target, operator intervention, etc.) and onboard logic improvements (automatic detection of track loss) which permit adjustments during the mission and mission aborts when CM is encountered. These factors make the autotracker approach competitive with the other two even though somewhat more susceptible in the smoke CM area.

The autotracker design is not highly vulnerable to ECM during the terminal phase since it relies on the autotracker for optical guidance. Other types of CM (such as smoke) then become the serious factor, along with the natural obstacles such as trees obscuring the view of the target. The mitigating factors are that the operator can follow the dive as long as LOS conditions prevail, and abort if satisfactory lock-on by the autotracker is not sustained. Further, automatic detection of radical changes in the target shape (caused by smoke CM or foliage) could be programmed to abort the mission and recover the kamikaze for another attempt. Finally, an automatic "coast" feature could be implemented to handle possible track loss due to target background feature changes occurring just prior to impact.

This "coasting" would cause the kamikaze to follow a linear rate established prior to confusion of the autotracker.

The parachute relay alternative is unique in that the fiber optics communication link from the kamikaze to the relay is essentially impervious to ECM. However, an attack profile must be used which releases the parachute at a height that maintains LOS to the GCS and keeps the kamikaze within several kilometers (length of the cable) of the target. Also, no reasonable abort alternate is envisioned after deploying the parachute,

The RPV relay option provides a larger degree of operational flexibility. For example, the relay can remain distant from the kamikaze and control it during a low-altitude attack. The weakness in this approach is the ECM vulnerability on the kamikaze-to-RPV relay communications link because of the downward looking receive beam on the relay. However, the kamikaze would operate over a very large operational area and there is some question as to the practicality of jamming this link (e.g., a jammer on every tank or group of tanks). Such jammers (particularly those on tanks) could then be used to advantage for homing. The RPV relay also has damage assessment capability since the relay could contain a TV sensor.

In summary, the parachute relay alternative has excellent ECM characteristics with some restrictions in operational flexibility because of the optical fiber. The RPV-relay alternative has excellent operational flexibility, damage assessment capability and a possible weakness in the ECM area. The onboard tracker has good ECM characteristics, some operational restrictions imposed by LOS restrictions and a possible higher vulnerability to smoke CM. None of the characteristics noted above were marked enough to warrant definite rejection of any one of the systems.

2.3.10.2 Technical Risks. No insurmountable technical risks were noted for any of the three alternatives. The state-of-the-art is different among the various techniques and improvements would be required as noted below to meet the designs postulated.

In the parachute relay case, optical fiber communications are still developmental and fiber costs are currently high. However, the technology appears to have good potential for high AJ capability and eventual low cost. This case also has a degree of mechanical complexity (due to the fiber and parachute) which is not present in the other systems. Thus, there is a chance for less operational reliability but not necessarily a larger technical risk.

In the onboard-autotracker case, technology has been proven in other programs and requires only adaptation for the kamikaze mission. Improvements would be required to make operation more reliable in heavily wooded areas and under smoke-CM conditions.

The RPV-relay design is straightforward unless considerable ECM protection is included in the design. To provide ECM protection commensurate with the ICNS communications presents a serious technical challenge which is currently being addressed in the ICNS program.

In relation to the RPV and its terminal dynamics, it is noted that, on the basis of studies reported in Reference 23, a kamikaze-RPV diving into a target is best controlled in yaw and pitch with roll stabilized. Thus an RPV design using elevons, which require a roll action to produce yaw, is not expected to be effective for kamikaze homing. This does not necessarily represent a technical risk area; however, it is a factor to be considered in the kamikaze design.

In summary, there seems to be no overriding technical risk areas which distinguish between the three system alternatives or preclude their implementation.

2.3.10.3 Costs. Operational costs for a 100 mission capability were very similar for all three systems (autotracker - $3,350K; RPV Relay - $3,035; and Parachute Relay - $3,163K). The costs were dominated by the $16K cost of the stabilized TV sensor. Considering the accuracy of the cost estimating process, there appears to be no strong reason for preference among the three systems based on cost.

2.3.11 Parallel Backup Studies

The following studies would provide additional design insight for the three preferred systems.

2.3.11.1 Onboard Tracker. An important factor in the onboard autotracker system design is the overall operating range (GCS-to-target distance) determined by the LOS communications considerations. Hence, statistical terrain studies would be useful in determining LOS coverage and, in turn, the operating range of the system. The terrain studies, coupled with an examination of the kamikaze/target kinematics, could also show how and when the kamikaze could operate with only simple predictor circuitry and would not require the autotracker. Such techniques could also be studied as they apply to the cases where smoke or foliage intervenes to obscure the target but the mission continues based on predicted kamikaze and target performance. Another area for study is the target-shape monitor modification to the tracker wherein digital techniques can be used to identify the apparent target shape and monitor it as the kamikaze dive progresses. Significant changes in apparent target shape due to foliage, smoke, etc. could be monitored and used to abort the mission, thereby recovering the kamikaze.

2.3.11.2 RPV Relay. The current ICNS design does not include a relay capability. The conceptual design of such a relay could benefit both ICNS and the kamikaze program.

2.3.11.3 Parachute Relay. A low-cost demonstration program showing parachute deployment and optical fiber payout would be useful.

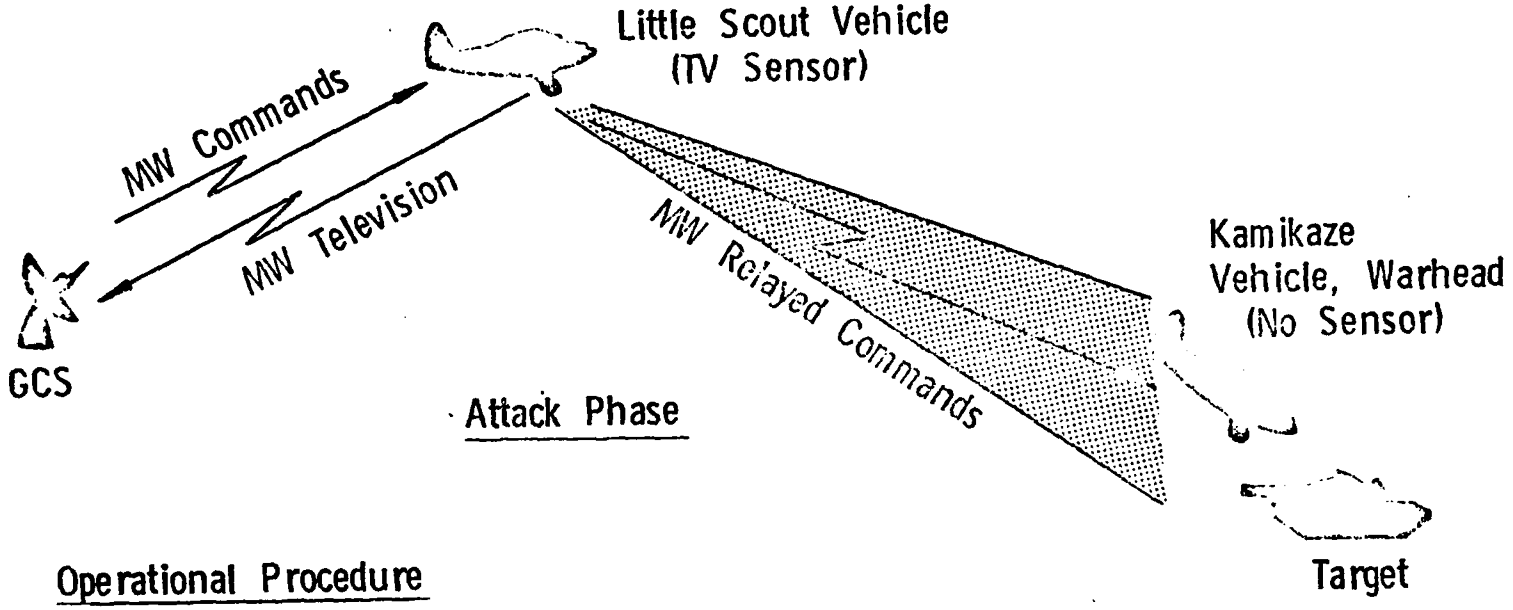
2.4 Alternative Concepts (Out of Scope)

The sensor (a stabilized TV system estimated at $16K) is a significant portion of the kamikaze cost and is expended when used with the concepts considered within the scope of this study. Other approaches have been suggested which do not expend the sensor and thus have a good potential cost advantage. Three such approaches are discussed in the following sections. The intent is to identify some of these alternatives realizing that they are only a sample of what might be available. Also, no analysis has been made to determine cost, operational performance, etc., of these sample ideas. The three alternatives noted in Figure 2 are the rendezvous approach, non-imaging approach and guided projectile.

2.4.1 Rendezvous Approach

The rendezvous approach was conceived in discussion with MICOM representatives. The concept is relatively simple as shown in Figure 19. The kamikaze (with a warhead but no sensor) and the target are kept under surveillance by an RPV equipped with communications (including a relay for kamikaze commands) and TV sensor. The observer at the GCS monitors the kamikaze dive and controls it to impact using the command relay and TV in the sensor-equipped RPV.

This approach has substantial operational advantages in that there is freedom in locating the RPV relaying the data and the relay-RPV can also be used for damage assessment. The elements of the system are very similar to, and compatible with, the present RPV designs. A warhead must be added along with the command-relaying capability to make up the kamikaze RPV. A major question remaining is the ability of the ground observer to control the dive from the TV data relayed back to him, considering the dynamics (relative speeds, positions, orientation, etc.) of the two RPVs and the need to keep both kamikaze and target in the FOV simultaneously.



Operational Procedure

1. Little Scout locates target.
2. Kamikaze vehicle launched and rendezvous with Little Scout while communicating directly with GCS. Kamikaze carries no video sensor - the vulnerable video back-link is thereby eliminated.
3. GCS causes kamikaze vehicle commands to be relayed through Little Scout as kamikaze is guided into target using Little Scout TV sensor data.
4. Damage assessment by Little Scout vehicle.

FIGURE 19
RENDEZVOUS APPROACH

2.4.2 Non-Imaging Approach

As shown in Figure 20, it is possible to deploy a projectile from an RPV.[9] The projectile can be guided to the target by one of several means (i.e., wire communications, microwave link, etc.) using the TV sensor in the RPV to monitor the projectile's travel to the target. The projectile would not contain a sensor, thereby minimizing system costs.

This approach has advantages in that the expendable projectile is relatively cheap and there is an inherent damage assessment capability.

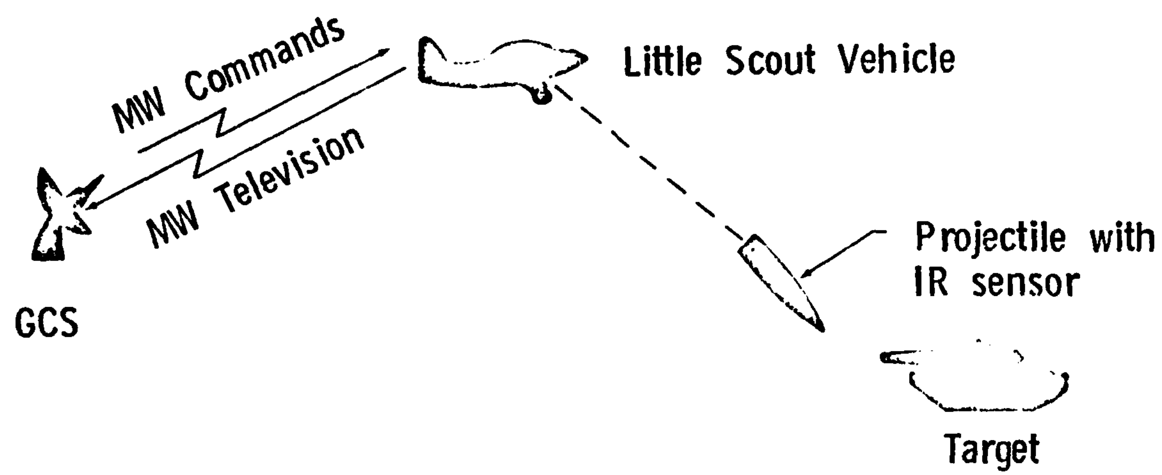
2.4.3 Laser Guided Projectile

The third alternative employs the RPV's laser to designate the target. The designated target is then attacked by a laser-seeking weapon employed from an airborne vehicle or from the ground (cannon launched projectile, etc.). Again, damage assessment is inherent. Operationally, there is a lot of flexibility in positioning the RPV but coordination procedures with the source of firepower could be a limitation.

2.4.4 Other Alternatives

Another technique for possible cost reduction, which could be used with either the in-scope or out-of-scope systems, involves the use of aerodynamic stabilization. This approach, suggested by Teledyne-Brown,[21] employs a trailing vane on a gimballed unit and is intended to replace the more costly gyroscopic stabilization.

[9] If the projectile, itself, were a smaller RPV, the arrangement would be of the "mother-daughter" type.



1. Little Scout locates target.
2. Projectile with IR (or other non-imaging) sensor released from Little Scout.
3. Damage assessment by Little Scout.

FIGURE 20
NON IMAGING APPROACH
(PROJECTILE)

3.0 CONCLUSIONS

Three preferred kamikaze systems within the scope of the study were identified:

- Onboard autotracker with microwave communications
- RPV relay with microwave communications for both GCS/Relay and Relay/Kamikaze links.
- Parachute relay with microwave communications for the GCS/Relay link and fiber optics for the Relay/Kamikaze link.

These systems are all considered to be feasible with no insurmountable technical risks.

The study results are heavily influenced by the inclusion of a stabilized TV in the design since it is a costly item ($16K) and is expended with the kamikaze RPV in each case. Further human-factor studies are required to better determine the requirements for the TV sensor stabilization. If a cheaper TV sensor is acceptable for surveillance, identification and terminal homing, the study should be updated to reflect that change.

A few other system approaches (i.e., rendezvous, non-imaging and laser guided missile) were identified which are outside the scope of this study, but do not result in the destruction of the TV sensor. These (and others which might be postulated) could provide capabilities equivalent to those of the three preferred alternatives with significant potential cost savings.

Finally, an interesting alternative for cost reduction which deserves consideration is the use of aerodynamic stabilization as suggested by Teledyne-Brown. It could be used with any of the systems (in-scope or out-of-scope) described in this report.

APPENDIX

ALTITUDE LIMITATIONS DUE TO MULTIPATH

In accordance with the results of Section 2.2.2 we assume an RPV cruising at a speed of 100 knots at an altitude of 3300 feet using a 20° FOV and a depression angle of $\alpha = 50°$. The horizontal field swath on the ground is $\overline{HF} = 1700$ feet. After flying a (straight or serpentine) surveillance path over a localized area where secondary intelligence has pinpointed enemy activity, we assume that a target is detected and recognized (by zooming to 4° FOV) at a range of 2,000 m.

At the assumed cruise altitude of 3300 feet, geometrical line of sight is no problem between the GCS and RPV, as shown in Figure 6 which gave minimum LOS RPV altitude H vs Range R for different values of GCS antenna height h_G. Figure 6 was based on a simple 4/3 earth model and did not allow for local terrain variations. However, it is presumed that advantageously high local terrain would be selected for the GCS whenever possible. Basically, Figure 6 showed that, except for intervening hills, geometric LOS was not an inherent problem up to 30 km range unless the RPV altitude is below about 75 feet for $h_G = 20$ ft. Below 75 ft there is less than a second of kamikaze flight to go and maintenance of communications is not essential, particularly, if the following are incorporated in the homing phase:

(1) Autopilot control
(2) Proportional navigation
(3) A simple prediction of target motion.

However, a communication problem may occur at low RPV altitudes because of ground multipath reflections. It is well known [17] that, in the presence of a perfectly reflecting earth surface, one-way signal power is characterized by a lobe structure of the type illustrated in Figure 21. At low altitudes and long ranges, which we are dealing with, the free-space one-way signal power is modified by a factor of

$$B = 4 \sin^2\left(\frac{2\pi H\, h_G}{\lambda R}\right), \tag{4}$$

which is a particularly useful formula at, and below, the center of the lowest lobe. The center of the lobe is characterized by the condition

$$\sin^2\left(\frac{2\pi \hat{H}\, h_G}{\lambda R}\right) = 1, \tag{5}$$

$$\frac{2\pi \hat{H}\, h_G}{\lambda R} = \frac{\pi}{2}$$

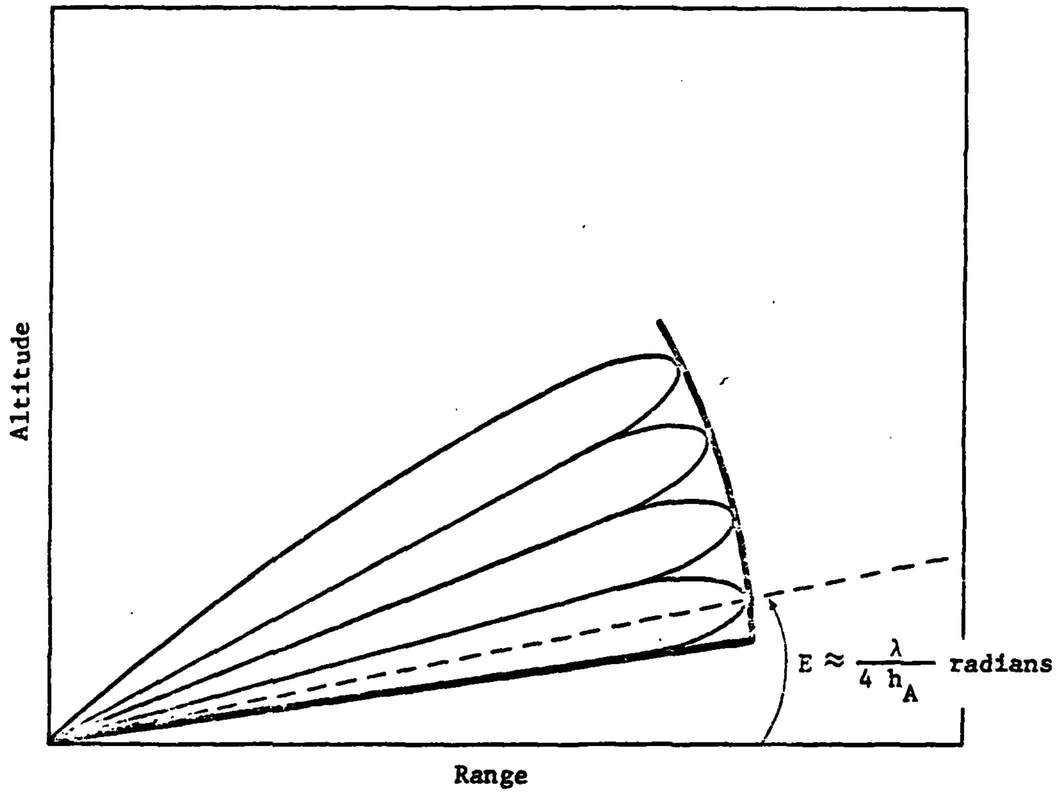


FIGURE 21
MULTIPATH LOBING OF ANTENNA PATTERN

Defining

$$E = \frac{\hat{H}}{R} \tag{6}$$

as the elevation angle (in radians) at the center of the lowest lobe it is seen that

$$E = \frac{\lambda}{4\,h_G} \text{ radians} \tag{7}$$

as shown in Figure 21. Assuming a wavelength of 6 cm (for the Aquila frequency of 5 GHz), Figure 22 shows the RPV altitude, $\hat{H}$, versus range, R, corresponding to the center of the lowest lobe for different values of GCS antenna heights, h_G. Below the altitude $\hat{H}$ of Figure 22 (at any specific range, R), one-way power deteriorates in a manner determined by the factor B of Eq (4). Thus we can write

$$\begin{aligned} B &= 4 \sin^2\left(\frac{2\pi H\, h_G}{\lambda R}\right) \\ &= 4 \sin^2\left(\frac{2\pi H\, h_G}{\lambda R} \cdot \frac{\hat{H}}{\hat{H}}\right) \\ &= 4 \sin^2\left(\frac{2\pi \hat{H}\, h_G}{\lambda R} \cdot \frac{H}{\hat{H}}\right) \\ &= 4 \sin^2\left(\frac{\pi}{2} \frac{H}{\hat{H}}\right) \end{aligned} \tag{8}$$

where Eq (5) was used in the last step of Eq (8). Eq (8) is plotted in Figure 23. It can be seen from Figure 23 that the altitude can decrease to about 1/5 of $\hat{H}$ before the power is reduced 3 dB below the free-space value. Thus, for example, at a range of 30 km and a GCS antenna height of $h_G = 20$ ft., Figure 22 shows that the center of the lowest lobe is at $\hat{H} = 240$ ft. Therefore, the RPV altitude can decrease to $1/5 \times 240 \approx 50$ ft. before the power drops to 3 dB below the free-space power.

All of the above assumes a flat perfectly conducting earth. However, for other (more realistic) conditions where the lobing structure is not as well pronounced, communication down to near-zero altitudes may be better than that resulting from the lobe limitations. Thus, the lobe analysis tends to be a limiting worst-case analysis, except for the possible inclusion of intervening hills which has been neglected above. In certain situations where the

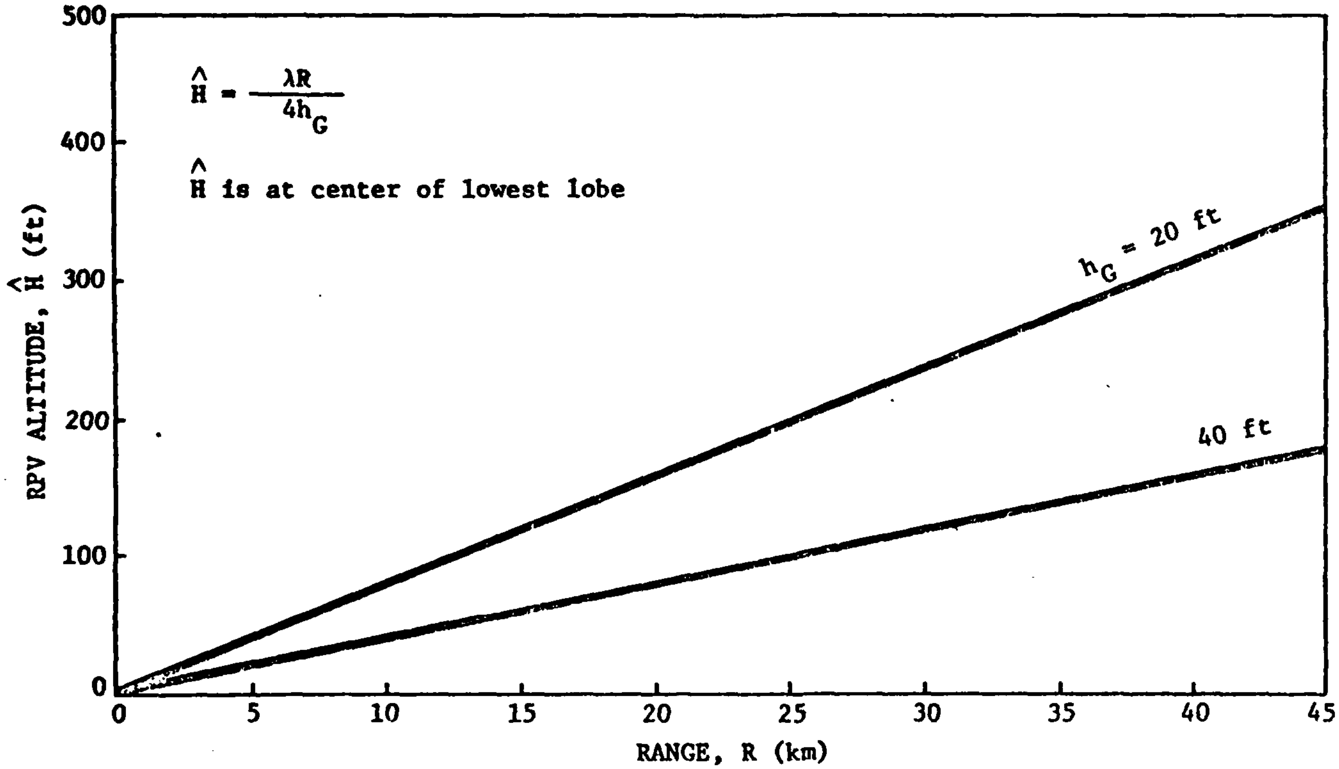


FIGURE 22
RPV ALTITUDE, $\hat{H}$, BELOW WHICH COMMUNICATION STARTS TO DEGRADE

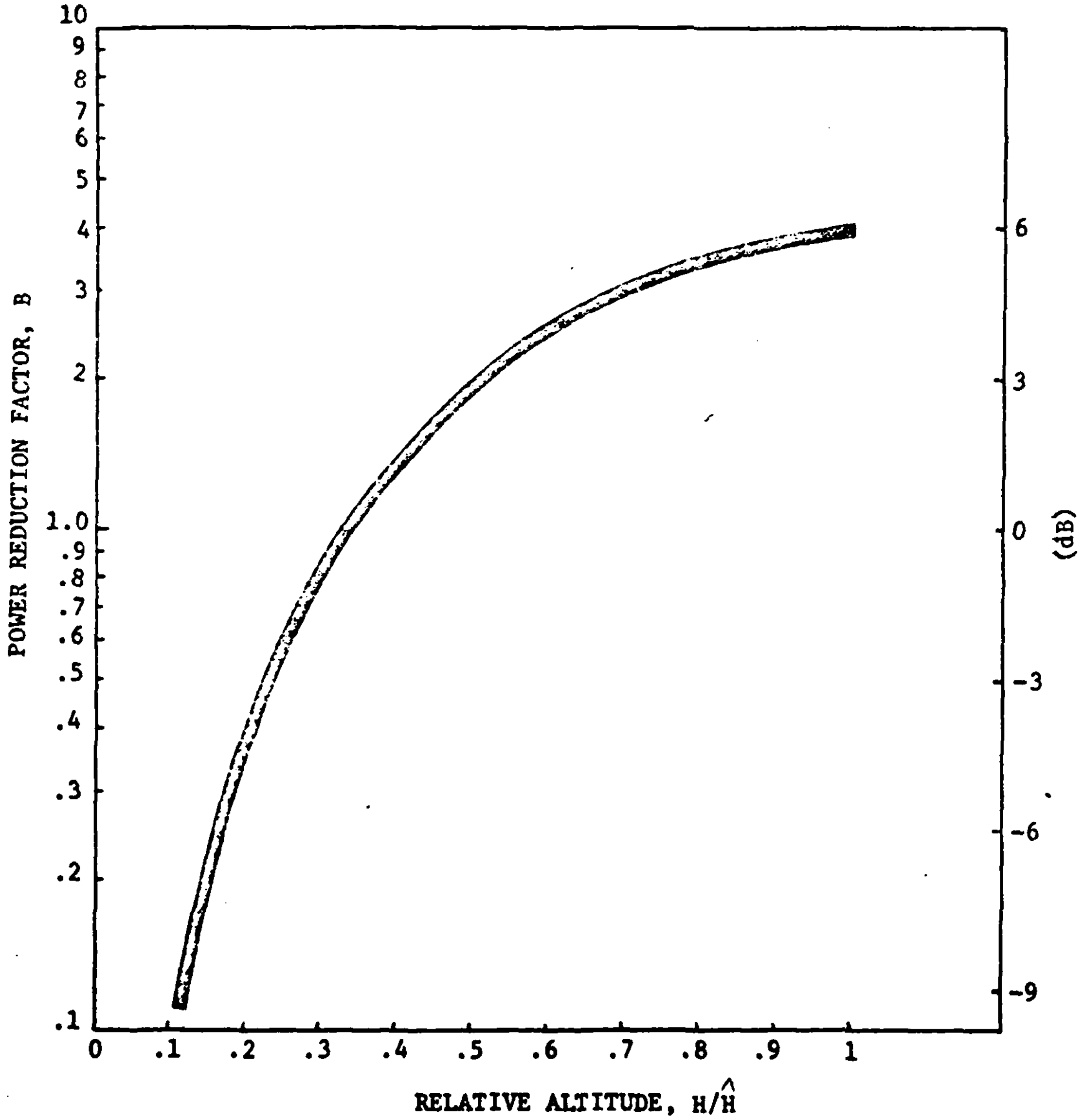


FIGURE 23
ONE WAY POWER REDUCTION FACTOR FOR ALTITUDE
BELOW CENTER OF LOWEST LOBE

GCS can be well sited on a local hill and the intervening terrain to the battle area is relatively flat, it seems likely that C-Band communications (and higher frequencies) would continue quite strong down to low altitudes (<50 ft. at 30 km range). However, intervening hills would pose a problem for the kamikaze. Also, a GCS on a hill would make the system relatively susceptible to jamming. Thus, the good low-altitude communications (determined above) between the GCS and RPV also imply high jamming susceptibility between an enemy ground jammer and the GCS. Consequently, from the tactical standpoint, it may be advisable to avoid placing the GCS on a high hill and also to purposely operate over intervening hills, if possible. But under these circumstances communication to low altitudes becomes more difficult with the straightforward approach described in this section, motivating consideration of the alternative system concepts discussed in the body of the report.

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