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HIGH ALTITUDE RADIO RELAY SYSTEMS

SEMI-ANNUAL REPORT

BY

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UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH, N.J.

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PAGE COMMUNICATIONS ENGINEERS, INC.

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ABSTRACT

A. High Altitude Radio Relay (HARR) Study. This is the first semi-annual report on the work being performed under the High Altitude Radio Relay (HARR) study contract. The HARR program is an applied research study effort in support of the Advanced Research Projects Agency requirements for Remote Area Conflict communications (Project AGILE). The theoretical and analytical investigations are aimed at determining the key characteristics and parameters of a system to enable the use of military communications equipment over difficult paths. The technique being investigated is the use of a radio relay installed in a high-altitude platform, for the purpose of extending the range of remote area radio communications. (U)

B. HARR Parameters. The operational parameters being considered are: traffic, transmission range, terrain, foliage, frequency range, modulation, and types of relay capabilities. The equipment parameters being considered are: relay control, transmission modes, size and weight, radio frequency power levels, receiver sensitivities, power requirements, operational life, interference, jamming, platform performance, platform payloads, compatibility, basing, availability, and costs. (U)

C. HARR Program. The goal is to define the best relay-platform configurations for extending jungle communications ranges over difficult terrain. Within this context, the effort is one of synthesis, study, and selection of appropriate configurations, finalizing in a system design plan for implementation of the selected systems. In performing the analytical investigations, the study teams have been task-oriented. The following four major tasks have been performed in the first half of the study: communication mission requirements, propagation analysis, relay analysis, and platform analysis. (U)

FOREWORD

This research was sponsored by the Office of the Secretary of Defense, Advanced Research Projects Agency (Project AGILE), and was monitored by the U.S. Army Electronics Command under Contract DAAB07-67-C-0006. The study is being conducted by Page Communications Engineers, Inc., and its two subcontractors, Telcom, Inc., and Northrop-Ventura. This report covers the work that has been performed during the first six months of this twelve-month contract.

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SECTION 1

SUMMARY

1.1 GENERAL

T is the first semi-annual report on the work being performed under the High Altitude Radio Relay (HARR) study contract. The HARR program is an applied research study effort in support of the Advanced Research Projects Agency requirements for Remote Area Conflict communications (Project AGILE). This research program is under the contractual and technical direction of the United States Army Electronics Command (USAECOM), Fort Monmouth, New Jersey. The theoretical and analytical investigations are aimed at determining the key characteristics and parameters of a system to enable the use of military communications equipment over difficult paths. The technique being investigated is the use of a radio relay installed in a high-altitude platform, for the purpose of extending the range of remote area radio communications. The operational parameters being considered are: traffic, transmission range, terrain, foliage, frequency range, modulation, compatibility, basing, availability, costs and types of relay capabilities. The equipment parameters being considered are: relay control, transmission modes, size and weight, radio frequency power levels, receiver sensitivities, power requirements, operational life, interference, jamming, platform performance, and platform payloads.

1.2 OBJECTIVES

The primary objective of the study is to develop a number of recommended equipment configurations for extending jungle communications ranges via airborne-type repeaters. The following detailed objectives have been established:

a. To prove, by means of propagation analysis, that relay modes of operation will achieve significant increases in radio range over difficult paths in a jungle environment.

b. To make optimum selections of equipments suitable for both relay and platform operations, on the basis of all modes of performance.

c. To combine selected repeaters and platforms and to perform a cost-effectiveness trade-off analysis of the various system configurations.

d. To prepare a system design plan for implementing the recommended hardware configuration solutions.

1.3 RESULTS TO DATE

Although the results of the study are not yet finalized, there have been some findings of significance. The conclusions that follow are presented as the interim results of the first half of the study.

1.3.1 The results of the propagation analysis have demonstrated that relay modes of operation will achieve significant increases in radio range over difficult paths in a jungle environment.

1.3.2 Certain relay and platform equipments have been subjected to trade-off analysis and interim selections have been made where possible.

1.3.2.1 The relay trade-off analysis has been inconclusive, thus far. The review of candidate systems has demonstrated that there is no completely satisfactory equipment currently available in the inventory. This is due to the necessity for satisfying the combined requirements of channel capacity, range, ground equipment compatibility, and platform compatibility.

Subject to the above finding, for use during the initial time frame (1968), the best solution to the relay equipment problem is the adaptation of the AN/PRC-25 (or the improved version, the AN/PRC-77), the AN/ARC-114, or the AN/ARC-89(V). The characteristics of repeater candidates have been examined in order to find other equipments readily adaptable to the relaying requirements. The discussions in section 3.4 describe the relay limitations of each equipment and identify those equipments which, in addition to the above, have some capability for repeater functions.

1.3.2.2 The platform trade-off analysis has yielded the following results:

a. The use of manned platforms is considered necessary for multichannel operation, in order to handle the problems of channel control and frequency management.

b. The use of unmanned platforms is recommended under conditions detrimental to performance of manned platforms. A desirable unmanned platform is the QM-50D DASH (Drone Anti-Submarine Helicopter).

c. For use during the initial time frame, the repeater platform recommendations in order of preference are:

   1. For platoon operations, the UH-1D helicopter, the U-6 single-engine utility aircraft, the O-1 single-engine observation aircraft, and the QM-50D DASH.

   2. For battalion operations, the LOH-6 light observation helicopter, the U-6, the UH-1D, the CV-2 Caribou, and the C-123 Provider.

   3. For division operations, the UH-1D, the CV-2, and the C-123.

d. The use of tethered balloons is not recommended, due to the combined disadvantages of required logistic support in the field, payload limitations, and environmental constraints.

e. The use of synchronous satellites is not recommended with low-powered man-pack radio sets.

f. Initial results of the platform cost analysis show a wide variation in anticipated cost per channel hour of operation. In addition to cost, the significant parameters are platform payload capacity in number of channels, and platform flight endurance in hours.

1.4 SCOPE OF WORK

The intent of the program is to define the best relay-platform configurations for extending jungle communications ranges over difficult terrain. Within this context, the effort is one of synthesis, study, and selection of appropriate configurations, finalizing in a system design plan for implementation of the selected systems.

1.4.1 In all ways the study is parametric in nature. Three time frames are being considered, as follows:

a. Initial (1968), requiring the use of existing inventory equipment.

b. Interim (1969-1972), requiring the use of existing equipment with improvements.

c. Long-range (post-1975), requiring the use of developmental equipments.

1.4.2 A complete set of communication mission requirements has been postulated and an evaluation tool has been developed based on these requirements. Within each of the three time frames the availability of inventory equipments has been predicated for use on the ground.

1.4.3 On the basis of the communication mission requirements, relay and platform equipments have been selected prior to marrying them into a number of system configurations. The various configurations will be subjected to performance cost effectiveness trade-offs in the second half of the program, in order to make final configuration selections.

1.4.4 The following separate analyses are being performed as necessary in order to support the primary objective:

a. The propagation study has been a continuing task since the inception of the program. Within the established environment, a complete set of parametric path loss curves has been generated to validate the relay modes of operation.

b. The Viet Nam random aircraft sortie distribution study is a special task that has evolved since the start of the program.

c. The canopy treetop configuration study is also a special task and is part of the continuing search for new ideas which can be applied to the program.

1.5 STUDY APPROACH AND METHODS

In performing the analytical investigations, the study teams have followed the Technical Guidelines of 14 April 1965. As such, the analysis has been task-oriented. There have been four major tasks performed in the first half of the study, as follows:

1.5.1 Task I: Communication Mission Requirements. This task has included the following activities:

a. Communications missions
b. Channel requirements
c. Communications link criteria
d. Ground ranges
e. Ground terminals
f. Ground equipment performance

1.5.2 Task II: Propagation Analysis. This task has included the following activities:

a. Mathematical propagation model
b. Effects of foliage
c. Effects of terrain
d. Programming of math model
e. Path loss analysis
f. Sets of parametric path loss curves

1.5.3 Task III: Relay Analysis. This task has included the following activities:

a. Relay system identification and tabulation
b. Parametric evaluation of candidate equipments
c. Recommendations for relay systems
d. Preparation of relay power budgets
e. F_1-F_1 vs F_1-F_2 transmission modes
f. Multiple access
g. Channel loading
h. Design criteria to optimize relay performance
i. Novel repeater concepts

1.5.4 Task IV: Platform Analysis. This task has included the following activities:

a. Platform system identification and tabulation
b. Parametric evaluation of candidate equipments
c. Recommendations for platform systems
d. Payload and relay interface
e. Delivery systems
f. Logistics
g. Cost model
h. Cost analysis
i. Random aircraft sortie distribution
j. Design criteria to optimize platform performance
k. Novel platform concepts

SECTION 2

COMMUNICATIONS REQUIREMENTS AND MISSION MODELING

2.1 GENERAL

The purpose of this section is to develop the communications mission based on the Army Tactics applicable to a Viet Nam environment. These mission requirements form the basis for the platform-relay analysis tasks being performed on the HARR study program.

The section has been prepared in three parts:

a. General tactical concepts in remote and terrain-restricting areas of conflict to include Viet Nam.

b. Network configurations and problem definition.

c. System recommendations.

The investigation to date has been directed at units relying totally on manpack and vehicular forms of FM radio equipment during their assigned missions. Subsequent study will pursue the multi-channel semi-fixed means of communications.

2.2 GENERAL TACTICAL CONCEPTS

Communications requirements and equipment emphasis has changed considerably over the past two decades. During World War II, the battlefield in Europe was one of total commitment and troop units were dispersed across the width and breadth of continents. Troop displacement was generally continuous along a front, and terrain once occupied or passed through was retained and held secure.

In contrast with the tactics and terrain of World War II is the war in Viet Nam. Unlike war on a major political and tactical scale, the battlefield there can more accurately be described as continuous in terms of the enemy with small pockets of friendly forces operating alone on missions of short duration. The war has often been described as a battalion, company, and platoon leaders' war. Brigade-sized units, and often battalion-sized units, operate on search and destroy missions many miles from the friendly stable rear areas. Airlifted in by helicopter, these units move forward through enemy terrain, destroying small pockets of resistance, village terrorists and equipment depots; and once the friendly forces pass through and no longer occupy an area, it is likely to again become enemy territory. Combine this tactical dispersion with the dense tropical jungle or mountainous terrain and a situation prevails that taxes the range and performance of existing small unit radio equipments.

British fighting units experienced similar communications difficulties in the late 1950's as evidenced by documents* describing the limitations which jungle conditions impose on radio communications as normally practiced in a tactical area.

Vegetation, terrain, and the heavy reliance placed on tactical radio communications have placed severe support demands upon the present generation of tactical radio sets.

Combat operations in remote areas of conflict utilize tactical units that are highly mobile and dispersed over broad areas of widely varying terrain. The degree to which such mobility and dispersion can effectively be attained will bear to a large measure on the means to maintain command and control. The achievement of these means depends on the adequacy of the communications.

2.3 NETWORK CONFIGURATIONS AND PROBLEM DEFINITION

2.3.1 General. To precisely what degree relay schemes should support ground tactical units is one of the problems to be considered in the study. To arrive at some collective discrete means extending $\underline{n}$ channels $\underline{x}$ miles is to a large extent imposing tactical doctrine. On the other hand, considering all combinations of 1 through $\underline{n}$ channels extended from 1 to $\underline{x}$ miles provides too little in the form of definitive objectives to those faced with the task of providing specific relay and platform configurations.

Since it is extremely difficult to relate systems engineering concepts to the flexibility of battlefield demands, it is hoped that the following considerations will provide a concept of battle and a sufficient understanding of tactics and communications procedure to provide solutions wherein tactical units possess the internal capability of range enhancement in areas where existing radios do not adequately support the tactical mission.

2.3.2 Tactical Network Configurations. Tactical radio nets are typified by the structure shown in Figure 2-1. A net will consist of two or more transmitters and receivers operating on the same frequency. The operating mode is "push to talk"; that is, the transmitters are only activated when a

*Memo from U.K. Delegate, Ministry of Defense, May, 1958.

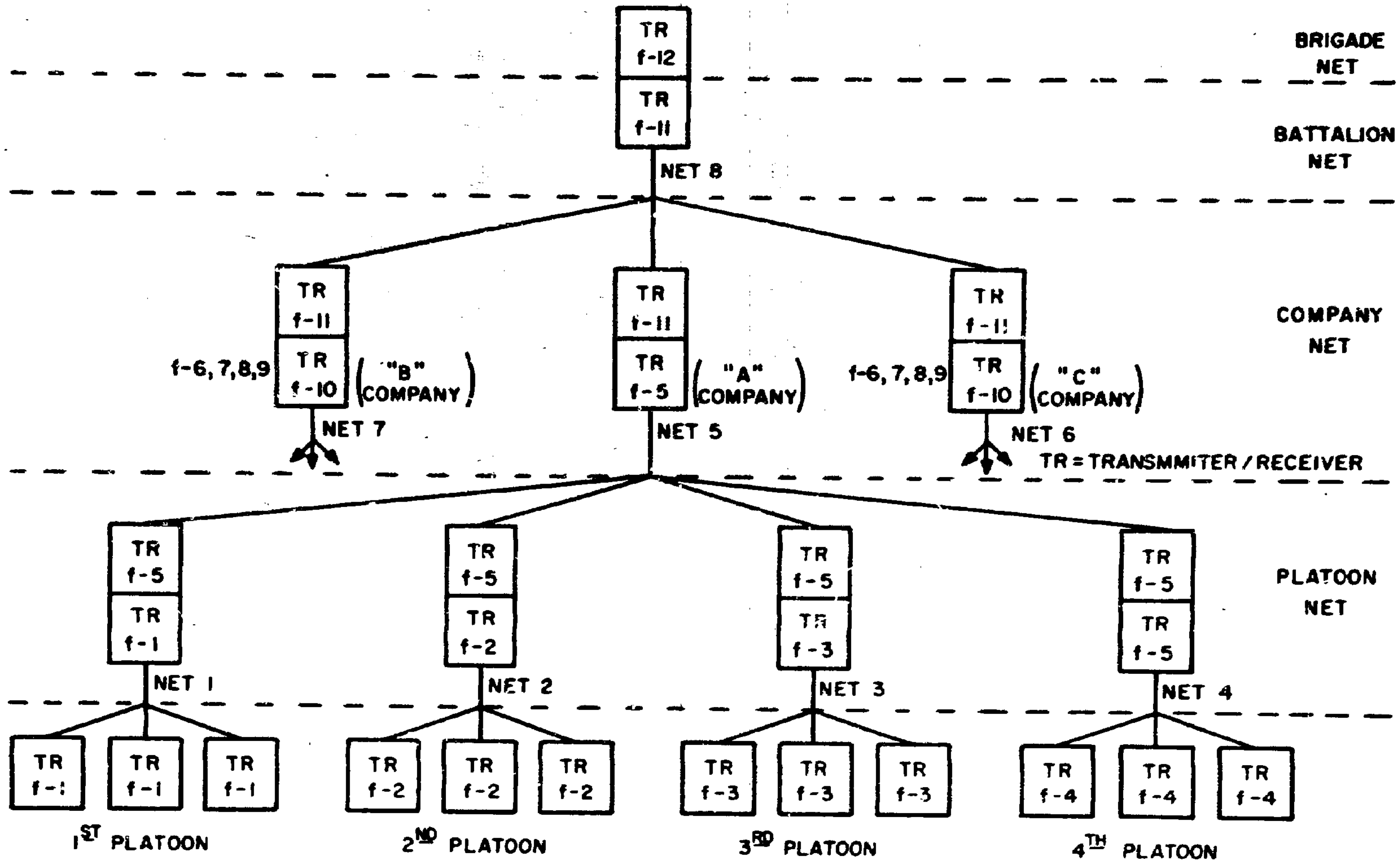

Figure 2-1. Typical Net Structure

person wishes to speak. For all other conditions, only the person's receivers are on. No more than one transmitter in a net can be active at any given time. In accordance with tactical echelons of command, the commander in one net is also a member of the next higher echelon net. For example, a platoon leader is a member of a net consisting of the other platoon leaders and the company commander. The company commander is in turn a member of a net with the other company commanders plus the battalion commander.

As the level of command responsibility increases, so does the talking range of the assigned radios used by that command. In general, all voice tactical radio sets below brigade level are FM-VHF. Frequency assignments are shared among users who are geographically separated to such an extent that the energy from one transmitter does not normally affect the other user. As the number of channels increases corresponding to more units being assigned a given sector, separation decreases, and the probability of mutual interference becomes greater.

Voice radio communications between stations in a tactical net can fail under three conditions, with the exception of the obvious equipment breakdown. The first is that the radio terminal is well within its nominal design range but the path loss incurred by either terrain masking or ground foliage or a combination of both is in excess of the capabilities of the set. This can be described as obstacle limiting.

The second condition is that tactical deployment may have exceeded the nominal design range of the set. This can be termed path length limiting.

The third factor contributing to failure is interference from from other radio frequency sources. Although this contributes indirectly to failure, the correlation between troop unit density, radio spectrum availability, and interference warrants its consideration as a significant parameter.

These then constitute the three fundamental propagation problems occuring in the military application of VHF-FM voice tactical radio sets. The differences, though subtle, seem to warrant serious attention to the manner of solution ascribed to each, particularly in view of the most recent reports regarding frequency spectrum congestion* and the role of VHF-FM tactical radio sets in Viet Nam.

In an obstacle limiting condition the most useful solutions, in consonance with tactical VHF radio, would be those which overcome the near-in path restrictions and reestablish reliable communications to only that tactical area of immediate concern to the unit or units committed.

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*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam," Booz-Allen Applied Research, September 1966.

In path length limiting situations, solutions should include the possible integration with other forms of long distance communications such as platform to platform UHF or ground to ground troposcatter.

The solutions to both are of equal concern to the tactical commander, however, the imposition of easily attainable long range solutions upon a tactical environment requiring only limited range enhancement largely negates the role of VHF tactical radio and contributes to severe crowding of the 30-76 MHz spectrum (see Figure 2-2).

2.3.3 <u>Terrain Limiting Tactics and Resulting Communication Needs.</u> When assessing tactical communication needs, there are sufficient similarities between jungle and mountain operations to state that communications support adequate for one would be equally responsive to the other. Tactical operations in both yield to the commitment of small and often isolated units operating independently. Useful radio distances are often limited to less than one mile. Tactical deployment, i.e., fire and maneuver, or movement is greatly hindered and adjacent unit support is often not possible. Rapid employment and the shifting of reserves is difficult. Although deliberate tactical maneuver prevails, its prosecution will occur at a slower pace than conventional open battlefield combat. Radio traffic would be minimum and used more as an emergency means than to exercise continuous and rapidly changing control over supporting maneuver elements. Typical net traffic would include the call for and probable direction of close-in air support, medical evacuation, and the reporting of imminent overrun or ambush. It seems reasonable, therefore, that one or two reliable channels per company would provide adequate means as opposed to the 6 to 8 channels normally employed in the commitment of an infantry rifle company in conventional conflict.

As an extension of this hypothesis, it is not unlikely that several companies could be performing entirely independent missions in areas ranging from one to thirty miles and the communications needs would increase correpondingly. Precisely how many channels are required is not of great concern so long as it is possible to effect a modular approach and enable the appropriate command level to tailor the means to the needs. In order that such schemes be compatible with existing frequency management practice, it is essential that a reasonably accurate assessment of anticipated ground coverage be provided the implementing command.

Once the means are available, a likely operational practice would be to assign one or two channels to each company in the service area and one or two channels to groups of these companies as alternate or emergency nets. Additional channels would be assigned for the direction of air support, medical evacuation, logistics and area command functions.

In unmanned stations, the channels could be altered on a prearranged basis during platform downtime in accordance with standard operating instructions.

Assuming that airborne relay means can be provided to reestablish, over limited distances, VHF-FM radio reliability through highly restrictive paths, significantly more benefit can be derived from the VHF-FM spectrum committed to short-range tactical communications. The same degree of

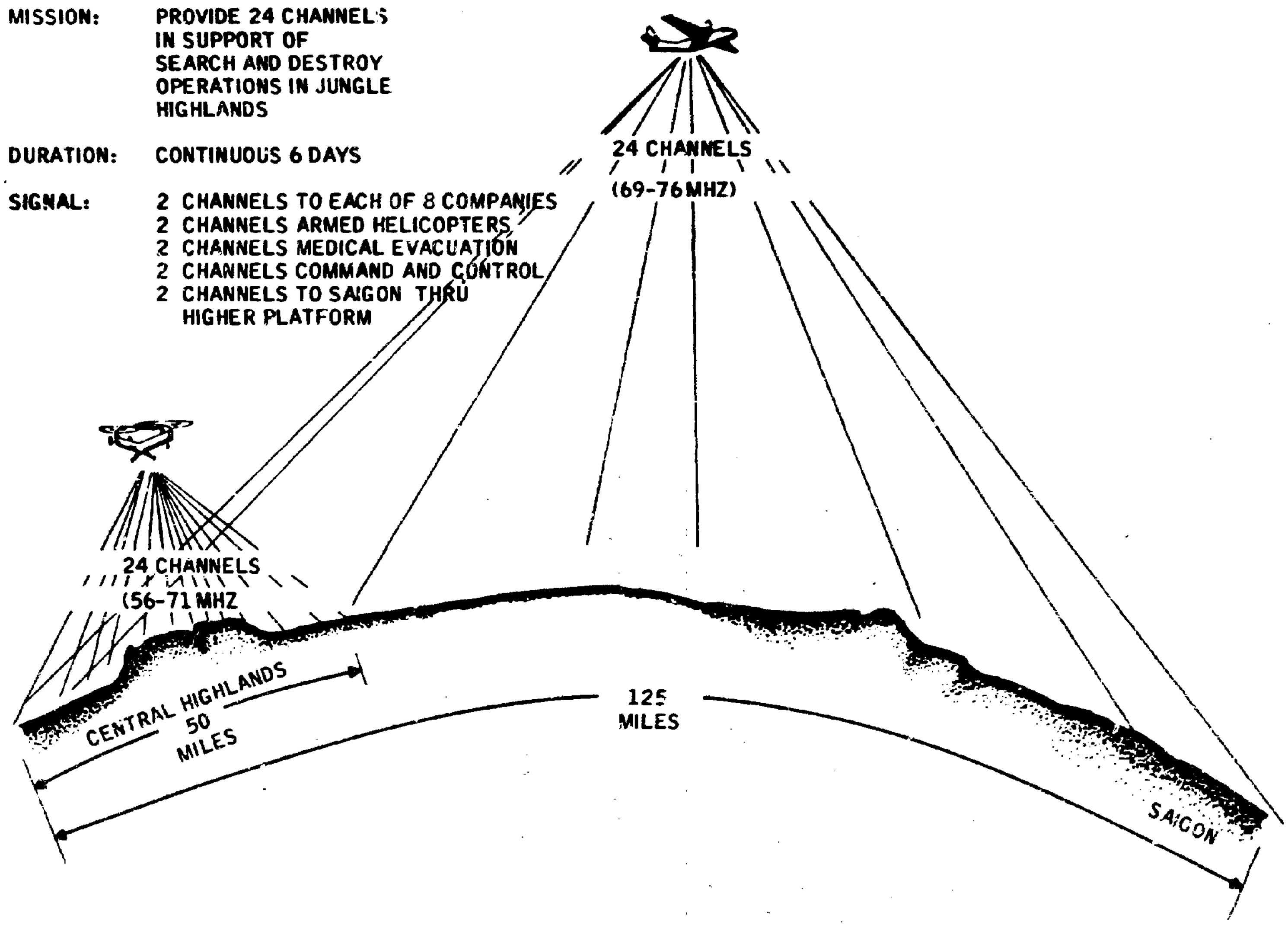

Figure 2-2. A Typical Mission Utilizing a Short and Long Range Platform

freedom in frequency allocation normally afforded the lower tactical echelons can be preserved and obviously more units can receive concurrent support.

Other advantages to reduce geographic coverage are that it permits local control in responding to the effects of enemy jamming. Locally initiated action, such as changes to S.O.I., more responsive channelization, and the use of alternate frequencies, would be permitted thus reducing the vulnerability of the relays.

2.3.4 Tactical Communications Extension Requirements. The ability to quickly deploy troops over large distances to areas of enemy concentration constitutes a major tactical advantage of the ARVN, U.S., and Free World Forces in Viet Nam. By the use of helicopters well supported by artillery and tactical air, commanders are able to achieve surprise and shock action. Such actions can generally be described as airmobile operations. It places long-range communications demands on existing VHF ground equipment and is presently employing airborne relay to a limited extent. The command elements in many airmobile tactical commitments utilize aerial command posts operating between the staging area and the landing zones (LZ) where helicopters discharge the troops into the combat area. Displacement distances vary considerably from 10 or 15 miles to 150 miles. Early operations of this type were limited to the range of supporting artillery; however, recent actions have provided for the airlift of artillery units thus permitting deeper penetration.

The present command and control practice is to place the commanders and observers aloft and includes typically three to five command elements. Radio nets are usually effected from this airborne command post to medical, fire support, armed and troop lift helicopters as well as with the units committed on the ground. Communications to the staging area, which is the longest distance requirement, usually employs VHF/AM/SSB means. Generally the air-to-air and air-to-ground paths in the vicinity of ground fighting is VHF. An O-1E aircraft provides radio relay and performs forward observer and forward air control activity.

These missions typify the need for long-distance communications between the command elements of isolated fighting units and other supporting arms. The isolated unit may be as small as 20 to 30 men on a patrol mission committed for periods of several days, or it may be a brigade deployed into a province for sustained operations over two to four week periods.

The following conditions emphasize the need for range enhancement through such means as: air-to-air UHF, air-to-ground integration with long-haul fixed-plant relays, or directive VHF means as opposed to nondirective wide geographic coverage utilizing the VHF spectrum (30-76 MHz) (see Figures 2-3 and 2-4).

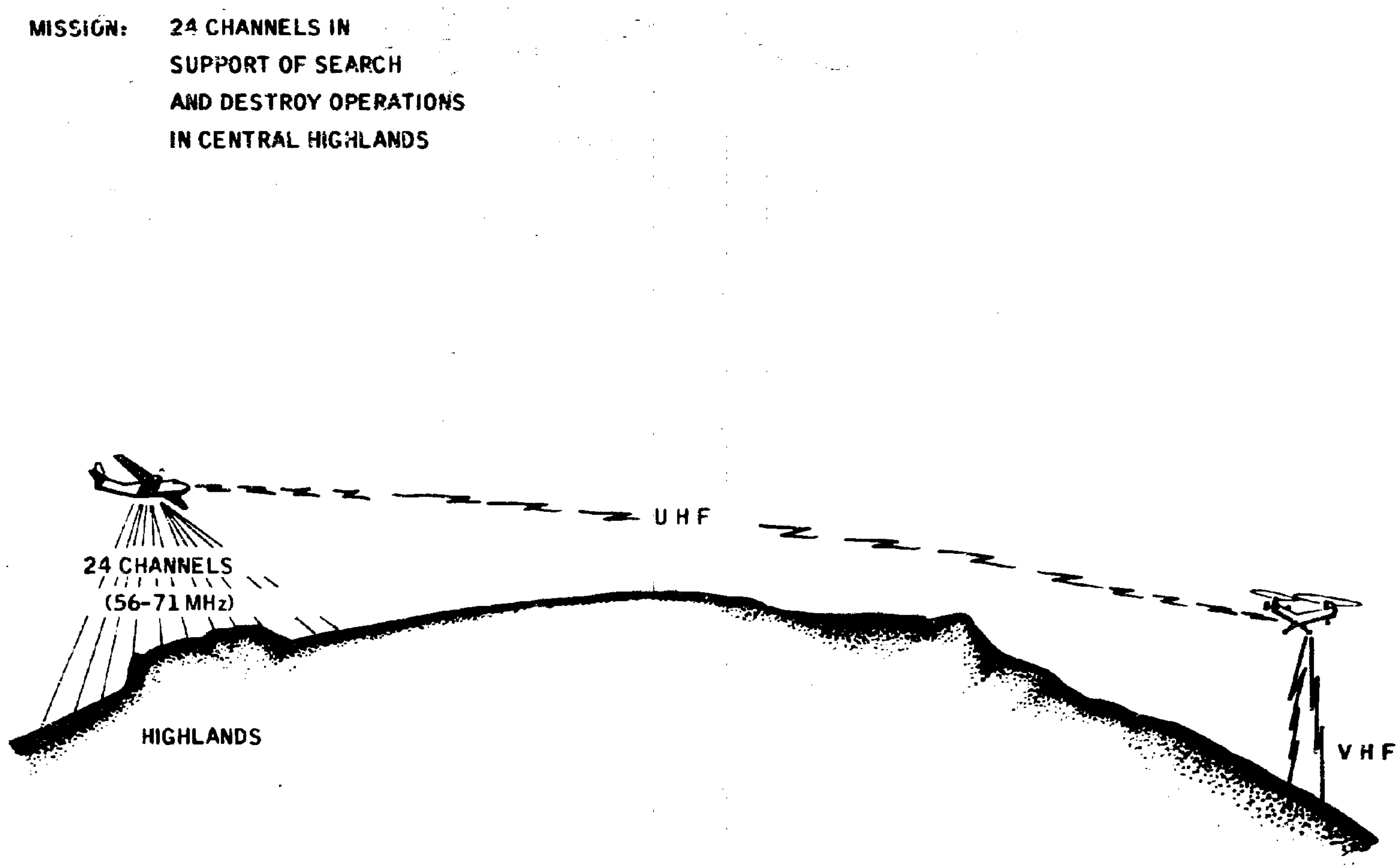

Figure 2-3. A Typical Mission Utilizing Platform to Platform Links

MISSION: PROVIDE 24 CHANNELS IN SUPPORT OF SEARCH AND DESTROY OPERATIONS IN JUNGLE HIGHLANDS NEAR DALAT

DURATION: CONTINOUS FOR 6 DAYS

SIGNAL: 16 CHANNELS SUPPORTING 8 COMPANIES
2 CHANNELS ARMED HELICOPTERS
2 CHANNELS MEDICAL EVACUATION
2 CHANNELS COMMAND AND CONTROL
2 CHANNELS RWI THRU DALAT TROPO TO SAIGON

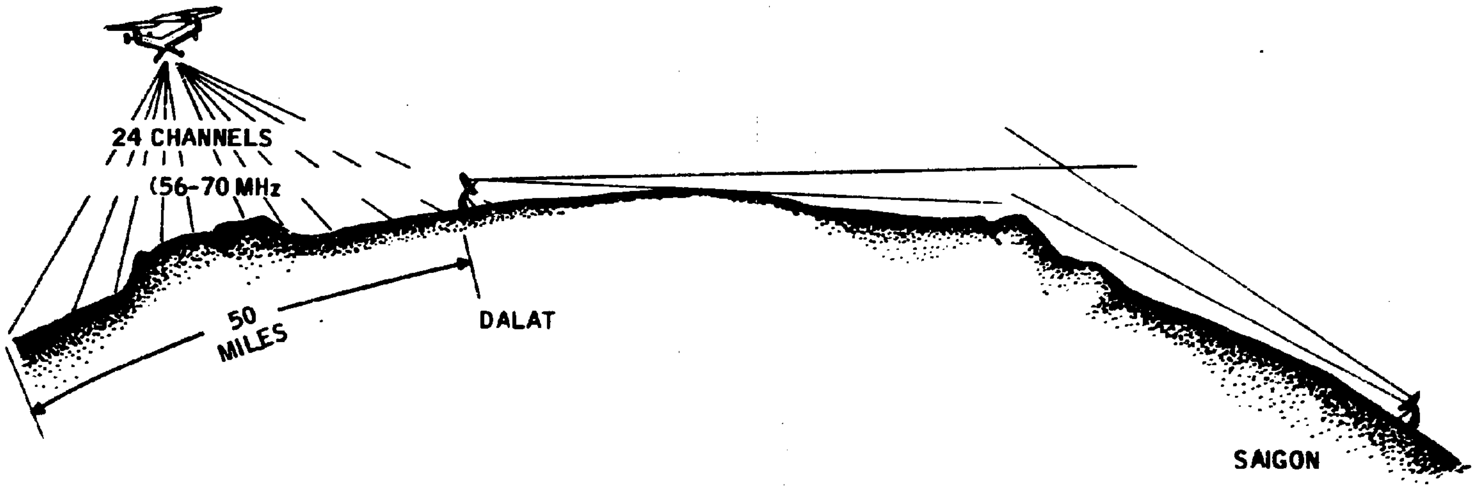

Figure 2-4. A Typical Mission Utilizing RWI to Fixed Ground Station

a. Limited 50 KHz channel resources estimated at 500 for all U.S. and Free World tactical units in Viet Nam of which approximately 120 are presently dedicated to relay activity. *

b. Heavy reliance on portable VHF terminals for both short and long-range communications.

c. Increased field activity directed at extending ranges of VHF tactical radio terminals.

d. Conflicting communication needs resulting from a sharply contrasting terrain environment. The delta region suffers from mutual interference problems while in areas immediately to the north, radio paths can be restricted to fractions of a mile because of the terrain and jungle environment.

Table 2-1 illustrates the characteristics of communications equipment associated with military operations in the Viet Nam area.

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*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam," Booz-Allen Applied Research, September, 1966.

Table 2-1. Characteristics of Communication Equipment

Nomenclature	Type	Frequency Range (MHz)	Modulation	Power (watts)
Village-Hamlet Radios				
HT-1	R-T	30-40	AM	0.5
TR-5	R-T	30-40	AM	5
TR-10	R-T	3-12	AM	5
TR-20	R-T	30-40	AM	20
TR-35	R-T	2-9	AM	30
National Police Radios				
FM-1	R-T	152.8-162.0	FM	1
FM-5	R-T	152.8-162.0	FM	5
Motran	R-T	152.8-162.0	FM	30
Tactical Radios (Manpack)				
AN/PRC-6	R-T	47-55.4	FM	0.25
AN/PRC-9	R-T	27-38.9	FM	1
AN/PRC-10	R-T	38-54.9	FM	1
AN/PRC-25	R-T	30-75.95	FM	1.5-2.0
AN/PRC-28	R-T	30-42	FM	1
AN/PRC-35	R-T	30-68.95	FM	0.4
AN/PRC-41†	-	-		-
AN/PRC-47‡	R-T	2-12	SSB	100 PEP
AN/PRC-62	R-T	2-30	SSB	Replaces AN/GRC-9
AN/PRC-64	R-T	2.5-6.0	AM	*
AN/PRC-65	R-T	*	*	Paratroopers and Forward Air Controllers
AN/PRC-66	R-T	*	*	Paratroopers and For ward Air Controllers
AN/PRC-70§	R-T	2-76	CW, SSB FM, AM	20
AN/PRC-74	R-T	2-12	SSB	*

*Unknown at this writing
†Backpack version of AN/VRC-24
‡75 lbs
§To be introduced in late 60s

Table 2-1. Characteristics of Communication Equipment (Continued)

Nomenclature	Type	Frequency Range (MHz)	Modulation	Power (watts)
Tactical Radios (Not Manpack)				
AN/GRC-5	R-T	27-38.9 47-58.4	FM	16 0.5
AN/GRC-6	R-T	27-38.9 47-58.4	FM	16 0.5
AN/GRC-9	R-T	2-12	AM	CW-15, V-7
AN/GRC-26, A, B and C	T R	2-18 0.5-32	AM	CW & FSK-400 V-300
AN/GRC-38	T R	2.0-18 0.54-54	AM	CW-400 V-300
AN/GRC-41	T R	1.5-20 0.5-32	AM	V-450 CW-450
AN/GRC-87	R-T	2.0-12	AM	CW-15, V-7
AN/GRC-106	R-T	2.0-30	SSB	400 PEP, CW-200
AN/GRC-109	T R	3.0-22 3.0-24		CW 10-15
AN/GRC-125	R-T	30-76	FM	1.5
AN/VRC-9	R-T	27.0-38.9	FM	16
AN/VRC-10	R-T	38-54.9	FM	16
AN/VRC-12	R-T	30-76	FM	35
AN/VRC-46 AN/VRC-47 AN/VRC-48 AN/VRC-49	Variations of the VRC-12			
AN/VRC-24	Vehicular version of the PRC-25			
AN/VRC-15	R-T	38-54.9	FM	16
AN/VRC-17	R-T	27-38.9	FM	16
AN/VRC-18	R-T	38-54.9	FM	16
AN/VRC-34	R-T	2-12	AM	CW-15, V-7

Table 2-1. Characteristics of Communication Equipment (Continued)

Nomenclature	Type	Frequency Range (MHz)	Modulation	Power (watts)
Tactical Radios (Not Manpack)				
AN/VRC-38	T	1.5-20 0.5-32	AM	100
AN/VRQ-2	R-T	27-38.9	FM	16
AN/VRQ-3	R-T	38-54.9	FM	16
SCR-193	R			
BC-312 BC-191	See Transmitters and Receivers below			
SCR-188	Same as SCR-193 except AC powered for fixed installations			
Radio Relay Equipment				
AN/TRC-1	Radio relay set	70-100	FM	40
AN/TRC-3	Radio relay tml	70-100	FM	40
AN/TRC-4	Radio relay repeater	70-100	FM	40
AN/TRC-24	Radio relay set	50-upwards	FM	50-120
AN/TRC-35	Radio relay tml	50-upwards	FM	50-120
AN/TRC-36	Radio relay repeater	50-upwards	FM	50-120
AN/TRC-29	Radio relay set	1700-2400	FM	10
AN/TRC-38	Radio relay tml	1700-2400	FM	10
AN/TRC-39	Radio relay repeater	1700-2400	FM	10
Transmitters				
BC-191	T	1.5-6.2	AM	CW-75, V-40
BC-610	T	2-18	AM	CW-300, V-400

Table 2-1. Characteristics of Communication Equipment (Continued)

Nomenclature	Type	Frequency Range (MHz)	Modulation	Power (watts)
Receivers				
R-390/URR	R	0.5-32	-	-
R-388/URR	R	0.5-30.5	-	-
BC-312	R	1.5-18	-	-
BC-342	R	1.5-18	-	-
Aircraft Radios				
AN/ARC-1	R-T	100-156	AM	6
AN/ARC-3	R-T	100-156	AM	8
AN/ARC-12	R-T	0.19-0.55 116-148	AM	2
AN/ARC-36	R-T	100-156	AM	8
AN/ARC-44	R-T	24-51.9	FM	6-8
AN/ARC-45	R-T	225-400	AM	2
AN/ARC-27/55	R-T	225-400	AM	9
AN/ARC-54	R-T	30-69.95	FM	10
AN/ARC-60	R-T	228-258	AM	0.5
AN/ARC-73	R-T	116-149.95	AM	20-25
AN/ARC-302A	R-T	118-136	AM	-
AN/ARC-302H	R-T	118-136	AM	-
Navy Radios				
Transceivers				
TCS-12	R-T	1.5-12	AM	CW-5, V-45
TCS-13	R-T	1.5-12	AM	CW-25, V-15
TCS-14	R-T	1.5-12	AM	CW-25, V-15
TCS-15	R-T	1.5-12	AM	CW-25, V-15
SCR-694	R-T	3.8-6.5	-	CW-25, V-7
Transmitters				
TDE	T	0.3-18.1	AM	100A1
TED	T	225-400	AM	10

These tables were extracted from Table A-1 of "The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam" - Booz-Allen Applied Research Inc.

2.3.5 Geography and Its Effect on Military Tactics

2.3.5.1 Operations in the Central Highlands.

2.3.5.1.1 General. The Central Highlands area constitutes almost 50 percent of the South Viet Nam land mass. It is a rugged, mountainous area with maximum elevation ranging from 4500 to 7000 feet in the vicinity of Dalat and from 3000 to 8000 feet in the area west of Quang Ngai. The area slopes steeply down to the coastal plain on the east and more gradually on the western plateau, resulting in a strong contrast between the short, swift, eastward flowing streams with their steep-walled, narrow valleys and the more sluggish westward-flowing streams with their broad flat valleys. All streams are swollen and difficult to ford during the rainy season. Operations in this area differ greatly from those in the Delta and coastal plains because of the differences in terrain, weather and population.

2.3.5.1.2 Terrain. Steep slopes, sharp crests and narrow valleys characterize the mountainous areas. Numerous razorback ridges run in all directions and it is virtually impossible to follow them in any one direction for more than a few hundred yards. The forested areas of the foot hills up to 3000 feet have an unbroken continuity of tall trees that form a dense, closed canopy over the ground. The undergrowth is very thick, comprising an almost impenetrable mass of smaller trees less than 10 feet high, intermingled with thorny shrubs and vines. Most streams are bordered by high, steep rocky banks and are generally swift with rapids and shallows common. Fording is possible in many places except during the flash floods which occur during the rainy season.

2.3.5.1.3 Weather. In the highlands, the southwest monsoon season lasts from May to October. During this period low clouds and ground fog limits observation and seriously restrict aerial activity. Cloud ceilings are less than 3000 feet about 80% of the time. Average monthly rainfall is approximately 13 inches. The average high temperature is 88 degrees with an average low of 55 degrees.

2.3.5.1.4 Movement. The steep terrain and dense jungles reduce foot mobility. Rate of march is usually from one-half to two kilometers per hour with frequent rest stops. Experience shows that there is a tendency to overestimate the rate of advance of columns. The amount of rations and equipment carried by the individual soldier must be carefully considered to prolong his effectiveness.

Wheeled and track vehicles will be restricted to the existing roads and trails. Bridges in this region are not capable of supporting heavy loads.

The limited number of suitable landing zones requires careful and detailed reconnaissance in order to conduct heliborne operations. Open areas are sometimes covered with stakes and tree stumps, which may prohibit helicopter landings. The high altitude and small landing zones result in a reduction of helicopter lift capability.

2.3.5.1.5 Combat Support Considerations

a. Artillery. Limited road nets or complete absence of roads restricts movements of artillery. Suitable positions are difficult to find, and sometimes clearing and leveling is necessary prior to positioning artillery pieces by helicopter.

b. Air support. Dense jungle, low clouds and ground fog restrict air support. The locations of friendly forward elements are frequently difficult to determine from the air, limiting the delivery of close supporting fires. Units should plan the use of pyrotechnics, panels and other devices to mark their forward positions.

2.3.5.2 Operations in Swampy and Inundated Areas. Operations in swampy and inundated areas in Viet Nam are generally associated with the Mekong Delta--that region of Viet Nam which lies south and west of the city of Saigon and is laced with rivers, streams, and canals. However, some of these conditions exist along the northern coastal plain in small delta areas. Rice paddies comprise most of the Delta. Two other types of areas within the Delta, the Plain of Reeds and the Mangrove Swamps, are treated separately below.

2.3.5.3 Rice Paddy Areas of the Delta

2.3.5.3.1 General. The rice paddy land of the Delta is the most heavily populated rural area in the Republic of Viet Nam; dwellings are found along nearly every waterway. Streams, canals and rivers interlace this area; trees and other vegetation along the waterways sometimes extend 300 meters on each side. The land between the waterways is covered by rice paddies, and during the rainy season these paddies are covered with water to a depth of one foot or more. In the dry season these same rice paddies dry up and crack open.

2.3.5.3.2 Movement.

a. Routes. There is an extensive network of rivers and canals usable throughout the year, and generally capable of supporting craft as large as landing craft, mechanized (LCM). River craft are confined to the major canals and to the rivers. Overhead bridge clearance and depth of water at high and low tide must be considered in planning use of river boats. Assault boats can operate freely on minor canals only during high tide. Native sampans operate at all times.

b. Troops. Troops can maneuver in the paddies on foot the year-round. Foot movement during the dry season averages three to four kilometers per hour during the day and one and one-half kilometers per hour at night. During the wet season foot movement may be slowed by difficulties in crossing canals; a combination of deep water and steep muddy banks may result in insufficient traction. Consideration of the tide is necessary, even far inland, as high tide favors boat movement, while low tide favors wading across canals in most search operations. Several large-scale operations have failed or have been aborted because the effects of the tide were not considered.

c. Helicopters. Most rice paddies in both the wet and dry season are potential landing or loading zones.

d. Airborne. Airborne forces can be employed year-round with few limitations on the size of the force dropped. During the wet season the water depth of the rice paddies should be considered when selecting drop zones. If the situation requires it, drop zones can be successfully selected immediately prior to the drop.

2.3.5.4 Plains of Reeds Area of Delta

2.3.5.4.1 General. The sparse population is scattered throughout the small hamlets at canal or stream junctions and along the banks of these waterways. During the rainy season when the entire area is inundated, the people live in elevated houses or in sampans. Even during the dry season, the area is continuously covered with water varying from ankle to shoulder depth and blanketed by reeds and grass one-half to four and a half meters high. There are trees scattered along the small number of canals and streams in the area. During the dry season many parts of the area resemble the midwest prairies from the air. In the wet season it looks like a sea or large lake.

2.3.5.4.2 Movement

a. Routes. There are only two major canals and a single road cross the area. Inhabitants normally travel by boat and sampan, often directly across flooded fields.

b. Troops. The average rate of travel cross-country by foot in the dry season is 1.5 kilometers per hour. During the wet season foot travel seldom exceeds one kilometer per hour and in many places is not possible at all. Armored personnel carriers are most valuable in this area, although frequent stops are necessary to cut the reeds and grass from the tracks and drive sprockets. River force craft are limited to larger streams and canals. They are sometimes used to carry troops to the general area of operations but can seldom be utilized to support an assault operation.

c. Helicopters. Helicopter landing zones in the Plain of Reeds are limited. In the dry season, canal and river banks may be used for landings, but in the rainy season troops must be loaded and unloaded from hovering helicopters. Care must be taken not to offload troops in water reaching over their heads. Small boats can be lashed to the skids of helicopters and used to disembark troops.

d. Airborne. Airborne troops can be employed effectively throughout most of the area depending upon the depth of the water and the season of the year.

2.3.5.4.3 Combat or Fire Support. Moving artillery into position to support operations requires boat or helicopter transportation and usually compromises security. Heavy mortars and artillery which can be delivered by helicopter still possess the disadvantage of limited range for the usually large-area operations conducted in the Plain of Reeds. Naval guns can support operations within range of the Mekong River. Tactical air support and armed helicopter support are most useful. Assault boats or sampans may be used to carry heavier crew-served weapons and ammunition.

2.3.5.5 Mangrove Swamp Area of Delta

2.3.5.5.1 General. Population is very sparse and is concentrated along the shore line or at river and stream junctions. Most houses are built on stilts because of the wide variations of the tides. Few people actually live in the swamps. Trees, vines, exposed roots and dense undergrowth are marks of the Mangrove Swamps. Swamp depths, depending on the tide, vary from one meter of mud to one meter of mud covered by two meters of water. Tides cause river current to reverse direction as the tide changes.

2.3.5.5.2 Movement

a. Routes. There are no roads in the Mangrove Swamps. Boats traveling into the area during high tide can be stranded at low tide and may have difficulty reaching shore. Sampans can enter the area from the sea only during high tide. Although these conditions hamper tactical troop landings, several successful landings have been made. LCM's and LCVP's can get close to shore only by following river channels.

b. Troops. Foot movement is very slow. The average rate of foot movement is one kilometer per hour, and may be only a few hundred meters per hour. Armored personnel carriers can operate in only a few parts of the Mangrove Swamps, generally around the edges. Sampans and SSB's are limited to the few streams and are likely to be stranded at low tide.

c. Helicopters and Airborne. Helicopter and airborne forces can be employed in mass only on the fringe areas of the Mangrove Swamps.

2.3.5.5.3 Combat or Fire Support. The planning considerations for the use of artillery, mortar and air support are similar to those necessary for operations in the Plain of Reeds. Naval gunfire can be used. Consideration should be given to the use of assault boats or sampans to carry heavier crew-served weapons and ammunition.

2.3.6 Operational Considerations. Throughout most of the Delta the terrain is such that small forces are employed to develop the situation, with mobile reserves for commitment as required.

Most operations are aimed at encircling a suspected Viet Cong force in a given general area. Often the lack of definite intelligence leads to the selection of terrain objectives rather than Viet Cong locations as control measures. All forces must be quick to follow the Viet Cong, to keep pressure on them if possible, in order to rapidly develop the situation and fix them in a killing zone. Secondary forces are assigned blocking positions on both sides of wooded canal lines leading into the suspected Viet Cong area. These forces must be strong enough to withstand a Viet Cong breakout attem[illegible] particularly at night. Maneuver elements usually advance along wooded c[illegible] lines, which offer very limited frontages (generally limited to platoon size on each bank of the canal). For this reason it is often difficult to bring large forces to bear on Viet Cong positions on both sides of the canals. The use of screening smokes laid by aircraft or artillery may permit flanking movements through the open rice fields.

2.3.7 Frequency Management Considerations. In attempting to determine small unit radio requirements hence platform loads and relay packages, efforts to affix channel requirements to corresponding unit strength on the basis of classical tactical net structures results in a large concentration of channel frequencies in a relatively small area.

Consider Figure 2-1 which is typical of the frequencies found within an infantry rifle company. Typical distances between the internal elements of command within a rifle company are likely to range from 0.5 to 8 kilometers. On the basis of typical company frontages, units displaced laterally along the forward edge of a battle area would permit the reassignment of identical blocks of frequencies in every second or third company sector. Such is generally the case and is a distinct advantage in the application of VHF tactical radio sets on the small unit level (see Figure 2-5).

Figure 2-5 is an extension of the netting principle shown in Figure 2-1 as applied to an infantry brigade. For purposes of discussion and clarity, only the FM voice nets occupying the 30-76 MHz spectrum are shown. Considering normal areas of battalion occupancy or approximately a rectangle three miles wide and two miles deep, there would exist no less than 43 separate nets utilizing 23 separate frequencies. If no frequency sharing were permitted at the platoon and company levels, then 43 separate frequencies would be required.

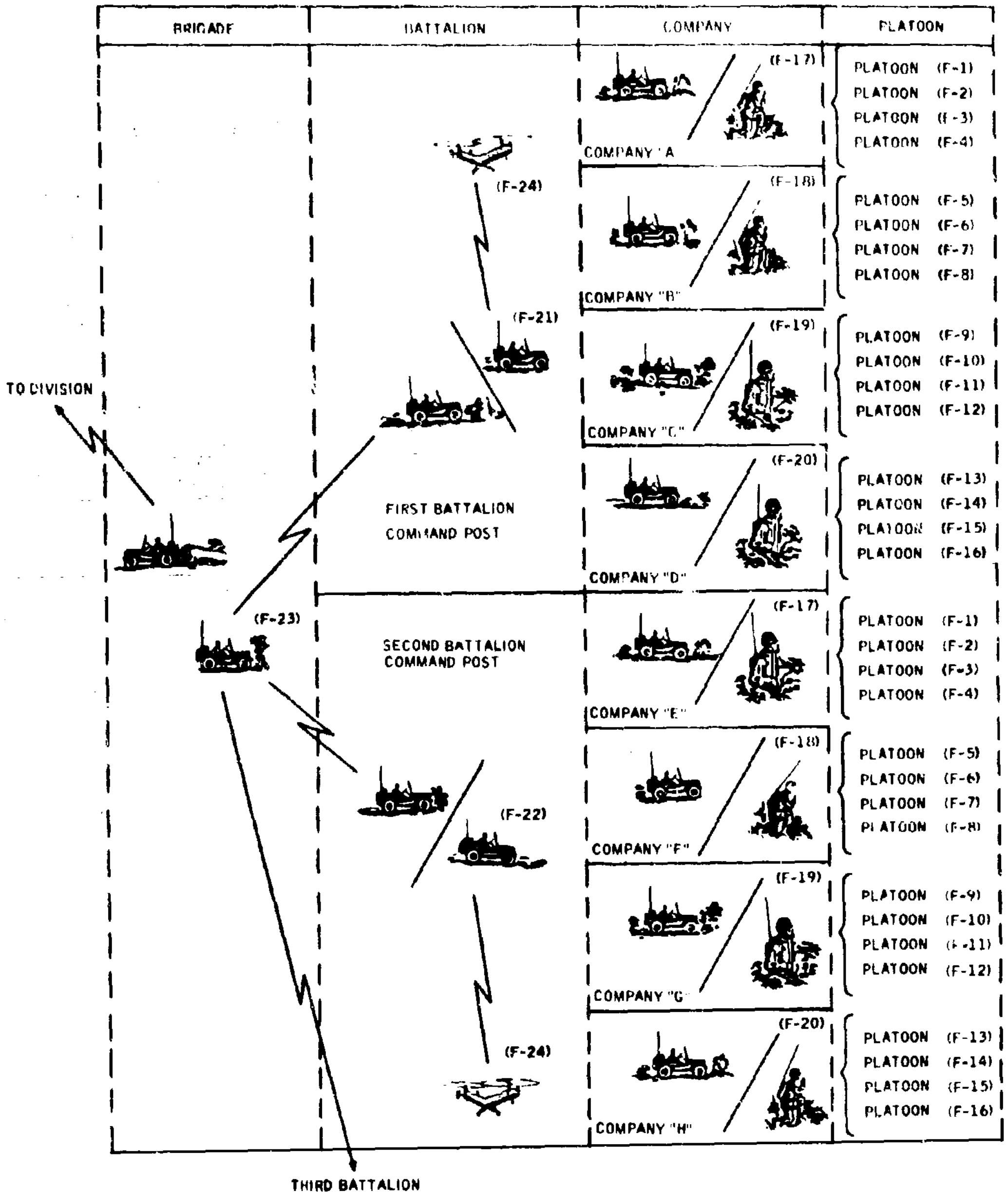

Figure 2-5. An Example of Typical Brigade Voice Radio Netting

Extrapolating these figures to a brigade comprised of three battalions and assuming frequency sharing as a function of range attenuation as in the first case above, then only one additional frequency would be required--the battalion/company command net. If no sharing were permitted, 20 additional frequencies or an aggregate of 63 would be required for a brigade made up of three battalions.

Concentrations to this extent are permitted in routine operations characterized by non-restrictive channel availability and terrain wherein there exists no large scale efforts to extend the design range of radio equipment.

Spurious signal or "on-site" interference does occur in such situations with the manpack and vehicular equipments when command elements employing these sets are co-located no more than several yards apart. This frequently happens and is reported to be a problem in Viet Nam. Frequency selection in accordance with the interference charts that accompany the radio sets' appropriate TM would help alleviate this problem to some extent; however, the geographically random location likely with tactical sets and the limited channel availability estimated at 460 (30-70 MHz) does not permit exclusive interference-free geographical assignments. In view of the large number of users and limited availability of channels, optimization of channel assignment appears to be the only means by which interference can be reduced. As is often the case, however, time and a constantly changing tactical environment does not permit a statistical and probabilistic approach to these assignments at the small unit command levels.

Far site or co-channel interference resulting from the increased use of airborne command posts and airborne radio relay has been described* as a second area of concern to Viet Nam frequency coordinators. It is being used principally by the U.S. and Free World Forces as opposed to the Vietnamese. Relay support often takes the form of merely relaying a command message between two ground units experiencing difficulty.

There are also difficulties arising from the increased reception of numerous ground terminals by airborne receivers. Units have reported that large portions of a corps area appear on airborne command nets. The present means to combat the problem appears to be exclusive frequency assignment (FM-VHF) from airborne command posts to battalion level units.

The preceeding illustrates the need for judicious application of relay schemes into the present communications structure in Viet Nam.

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*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam," Booz-Allen Applied Research, September, 1966.

The limiting constraints and considerations include:

a. Tactical FM frequencies (VHF) are reported to be allocated in the following manner:*

Vietnamese

1. 27.0-54.9 MHz or 270 channels of 100 KHz spacing. The Vietnamese are not presently using equipment with 50 KHz channel spacing.

U.S. and Free World Forces

1. 20-26.9 MHz or 138 channels of 50 KHz spacing. This band is used principally by armored units.

2. 55-75.95 MHz or 418 channels of 50 KHz spacing. Approximately 120 of these channels (69.9-75.9 MHz) are committed to radio relay transmission (airborne or other means).

3. 84 additional channels between 27.0-54.9 MHz have been obtained from the Vietnamese spectrum and are allocated by the Military Assistance Command--Viet Nam (MAC-V).

b. Strict regard for platform height and power output to limit interference with allocation schemes based upon range limitation.

c. Maximum selectivity in the airborne receivers employed in retransmission systems.

*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam," Booz-Allen Applied Research, September, 1966.

Table 2-2.* Number of Frequencies (30-70 MHz) Assigned Within the Four Corps Areas of Viet Nam (Maximum Power Not to Exceed 25 Watts)

MHz	I	II	III	IV	Total
30 - 31	2	2	2	2	8
31 - 32	11	11	11	11	44
32 - 33	23	23	23	23	92
33 - 34	9	8	8	8	33
34 - 35	15	11	12	11	49
35 - 36	15	7	11	14	47
36 - 37	4	4	8	13	29
37 - 38	17	17	19	23	76
38 - 39	33	19	19	19	90
39 - 40	36	17	24	22	99
40 - 41	26	1	11	8	46
41 - 42	13	2	10	4	29
42 - 43	20	2	7	6	35
43 - 44	26	2	11	9	48
44 - 45	25	1	12	7	45
45 - 46	20	3	12	11	46
46 - 47	17	4	14	9	44
47 - 48	18	12	8	-	38
48 - 49	15	9	6	-	30
49 - 50	13	-	5	-	18
50 - 51	16	2	6	-	24
51 - 52	16	9	6	-	31
52 - 53	11	10	6	-	27
53 - 54	11	10	6	-	27
54 - 55	7	10	4	-	21
55 - 56	11	-	3	3	17
56 - 57	5	1	1	4	11
57 - 58	8	1	1	5	15
58 - 59	5	1	1	5	12
59 - 60	-	-	-	4	4
60 - 61	-	-	-	3	3
61 - 62	1	1	1	4	7
62 - 63	1	1	1	5	8
63 - 64	-	-	-	1	1
64 - 65	1	1	1	1	4
65 - 66	-	-	-	-	0
66 - 67	1	1	1	1	4
67 - 68	1	-	-	-	1
68 - 69	2	-	-	2	4
69 - 70	-	-	-	-	0

*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam (Extracts from Military Assistance Command--Viet Nam J-6 Records)," Booz-Allen Applied Research, September, 1966.

This table reflects typical MAC-V assignments of the channels within the four corps areas.

It is assumed that the assignments in the 30-54.9 MHz region were made using only the 84 channels obtained from the Republic of Viet Nam Armed Forces and clearly illustrates frequency duplication or sharing on a non-interfering basis within each corps area.

2.3.8 Conclusions and Recommendations. Combat operations in Viet Nam and indeed elsewhere are complex and to a large extent unpredictable. The development of system concepts to support such activity must exhibit a compatability with the existing equipment technique and doctrine. Once the means are provided, the application rests with tactical commanders.

The recommendations contained herein reflect an assessment, within the limits of security, of the present situation regarding the application of VHF tactical radio means in Viet Nam. They are intended to allow a broad appraisal of capabilities and means in the pursuit of realistic applications with potential benefit to a wide range of tactical activity.

2.3.8.1 Short-Range Support of the Lower Tactical Echelons

a. Provide the means whereby tactical commanders at battalion level can effect relay support of limited channel capability within his area of tactical influence to include consideration for the modular assembly of from 2 to 8 channels with effective ground coverage not to exceed 75 miles.

b. Simultaneous compatibility with AN/PRC-25 and AN/VRC-12 transceivers (output power difference).

c. Ground coverages considerably less than 75 miles would prove a distinct advantage. Increased effectiveness would result if the equipment were equally responsive in both manned or unmanned platforms. Manned platforms should consider the inclusion of command subscriber elements.

2.3.8.2 I, III, and IV Corps Areas

a. Provide the means whereby support can originate within a corps area of influence. This should include consideration for configurations of 12, 24, and 48 channels compatible with existing VHF FM ground radio terminals.

b. Ground coverages not exceeding 100 miles should be considered. With the exception of the II Corps area ground coverages of this magnitude would approximate each corps commander's area of command jurisdiction.

2.3.8.3 II Corps Area

a. Provide the means whereby support can originate within the II Corps area of influence. This should include consideration for configurations of 12, 24, and 48 channels as in paragraph 2.3.8.2, with ground coverages up to 250 miles. As discussed earlier, long-range means should include consideration by other than VHF means once the ground interfaces with VHF terminals are established.

2.3.8.4 Distress or Warning Nets

a. Consideration towards providing continuous 24-hour coverage of 2 to 12 channels with effective ground coverage of at least 300 miles. In accordance with present frequency plans in effect in Viet Nam, consideration should be directed at spectrum characteristics in the 70-76 MHz region.

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SECTION 3

RELAY SYSTEMS

3.1 RELAY ANALYSIS AND SELECTION

3.1.1 Objectives and Requirements

This section of the report pertains to the investigation and study effort to date that was performed to determine the characteristics and parameters required of the relay package to be carried by selected platforms.

The relay study task was grouped into sub-tasks as follows:

a. Propagation Path Loss
b. Relay System Identification and Tabulation
c. Parametric Evaluation of Selected Equipments
d. Recommendations for Relay Systems

3.1.1.1 Propagation Path Loss. The objective of this study area is to formulate a mathematical model of ground-to-air radio propagation which may be used to define relay coverage area and radio equipment specifications. This model is to be programmed for a digital computer, and parametric curves for path loss for representative terrain and foliage are to be prepared for use in analyzing the selected relay configurations. Required end products are the programmable propagation models and path loss analyses.

3.1.1.2 Relay System Identification and Tabulation. Relay systems compatible with existing or proposed Field Army ground terminals meeting the requirements for relaying up to 48 voice channels will be identified and their performance tabulated. Later study will encompass advanced relay systems with automatic switching and retransmission using RADA techniques.

3.1.1.3 Parametric Evaluation of Selected Equipments. The relative performance of the equipment selected for relay use in the previous task will be evaluated based on communications system requirements.

3.1.1.4 Recommendations for Relay Systems. Using the results of the previous task, a family of relay systems corresponding to the requirements previously generated will be recommended. In the event that no existing system can be recommended for a particular requirement, recommendations for hardware development will be made. If more than one equipment is available for a particular requirement, data will be furnished for use in a cost-effectiveness comparison. Trade-off studies as required to support the above recommendations will be performed.

3.1.2 Study Results. The paragraphs which follow describe briefly the results of the relay study effort at the present time.

3.1.2.1 Propagation Path Loss. An idealized mathematical model of jungle foliage effects has been combined with experimentally determined jungle electrical parameters, and power safety margin requirements have been determined by the use of experimental path loss deviation from loss predictions based on the idealized model.

Parametric curves of ground-to-air path loss have been prepared for various values of jungle physical and electrical characteristics. Variability data have been used to estimate margin requirements. The path loss predictions and variability data have been combined to predict the service range of particular repeater configurations. Paragraph 3.5 of this report presents the path loss analysis and resulting parametric curves for representative sets of parameters.

3.1.2.2 Relay System Identification and Tabulation. The characteristics of military and commercial radio equipment potentially capable of serving as high altitude relay components have been examined and tabulated. Paragraphs 3.4.2 and 3.4.3 of this report contain tabulations and review of single-channel relay system candidates, and paragraph 3.6.3 contains tabulations and review of multichannel relay candidates.

3.1.2.3 Parametric Evaluation of Selected Equipments. In reviewing the tabulated data on existing radio equipment, a limited number of suitable equipments has been found. The results of this selection of prime candidate systems are presented in paragraphs 3.4.2, 3.4.3 and 3.6.3.

3.1.2.4 Recommendations for Relay Systems. In the review of candidate systems for the relay functions, no completely satisfactory systems have been located for the channel capacity, range, ground equipment, and platform compatibility requirements. Several configurations combining existing and readily developed equipment have been recommended as the best solutions to the relay problem for the initial and interim time frames. Studies in particular areas of repeater compatibility, reported in paragraphs 3.3 and 3.4.5 have provided guidelines for recommendations for the long-range time frame.

3.1.3 Plans for Further Study. Several areas of the relay study program remain to be completed. It is evident that many of the specific areas investigated will not be definitely resolved within the scope of the present program, and preliminary recommendations for expansion or extension of some study efforts will be made in paragraph 3.1.4.

3.1.3.1 Propagation Path Loss. It is anticipated that data from the Stanford Research Institute's airborne Xeledop path-loss measurements in Thailand will be analyzed in the next few weeks and the results made available. Comparison with the preliminary variability data will indicate the revisions of margin allowances which will be required. Additional parametric curves of path loss will be prepared for the revised estimates of jungle foliage permittivity noted in paragraph 3.5.2.7.

3.1.3.2 Relay System Identification and Tabulation. This study effort is substantially completed for conventional modulation systems. Some additions to the tabulated data may be made in the next few months, particularly in the multichannel relay area. Preliminary work has begun in the RADA study area, and review of RADA documents and exploration of potential RADA-HARR interfaces will proceed in the following months. A limited review of passive and semi-active repeaters will continue.

3.1.3.3 Parametric Evaluation of Selected Equipments. This study effort is substantially complete, although further candidates may be introduced and additional output data requested for platform and overall system trade-off analyses.

3.1.3.4 Recommendations for Relay Systems. This task includes the major unfinished items, particularly developing in further detail the recommended configurations of repeaters for the initial time frame. Further cost-effectiveness input data and platform interface data must be generated. A major area requiring further definition is that of antenna systems for relay platforms.

3.1.4 Action Recommended. Preliminary recommendations may be made for the initial time frame relay systems and for specific work items beyond the scope of the present contract.

3.1.4.1 Recommended Relay Systems. In the following paragraphs, we are basing our recommendations on technical considerations only. Whether these preliminary conclusions will be borne out by cost-effectiveness studies remains to be determined.

3.1.4.1.1 FM Network Relay. In view of the interface problems which accompany $F_1 - F_1$ repeater operation, we feel that use of $F_1 - F_2$ relaying is the only immediately available method with an appreciable chance of success. The 6- or 12- channel repeater system would be assembled using AN/PRC-25 transceivers in the conventional relay configuration, with outboard preselector and diplexing filters, hybrid summation of PRC-25 transmitter output, and a manual patch panel for supervisory control. Augmentation of pack-sets with AN/PRR-9 receivers will be necessary in areas where repeaters are deployed.

3.1.4.1.2 Multichannel Relay. The severe physical interface problems at the relay platform suggest that the use of the AN/ARC-89(V) airborne relay equipment is the best interim solution to the relaying problem, providing 12 four-wire full duplex channels per equipment set.

3.1.4.2 Recommended Study Items

3.1.4.2.1 Common Frequency Repeater. Continuation of evaluation of F_1 - F_1 repeaters is recommended, with attention to multipath interference, low-speed switching, and compatibility with pack-set receivers.

3.1.4.2.2 Diversity. Experimental evaluation of space, frequency, and polarization diversity in air-to-ground configuration and jungle environments is recommended with the reduction of margin allowances as an objective. This may be particularly significant for multichannel relay systems carrying digital modulation formats.

3.2 RELAY REQUIREMENTS

3.2.1 Ground Terminal Compatibility. For each of the time frames for relay implementation, various constraints on relay design are applicable. The following paragraphs discuss the problem of compatibility with single-channel tactical radio equipment as it affects both the relay and the pack-set or vehicular radio equipment. More specific details of the compatibility of relay design with FM VHF radio equipment are contained in paragraph 3.4.6. The multichannel tactical relay problem is addressed in paragraph 3.6.

3.2.1.1 Initial Time Frame. For the initial time frame, it is necessary that the relay be compatible with tactical radio sets now in operation. This implies compatibility with FM net operation in the 30 to 76 MHz frequency range, with 50 KHz channel spacing, 10 KHz deviation, and 0.3-3 KHz audio bandwidth. Push-to-talk operation is used, with no provision for automatic break-in. While the AN/PRC-25 is the contemporary equipment in general use, several earlier and later sets are generally compatible except for more limited tuning ranges and/or 100 KHz channel spacing. These sets are characterized by low power and electrically short omnidirectional whip antennas in the man-pack configuration. In fixed stations or vehicular operation, higher power and higher antenna gain may be employed.

Beyond the limitations due to the electrical capabilities of radio sets in the 30-76 MHz frequency range, the problems of frequency availability in this range severely restrict the operating frequency choice. In general, the band will be shared with friendly and opposing military or para-military services using similar equipment and with a variety of civil and military communications services. Interference both from and to these competing services in the 30-76 MHz band restricts the frequency assignment flexibility in a given theater of operations, but requires an ability to change the operating frequency for compatibility with other theaters.

3.2.1.2 Interim Time Frame. For the interim time frame, it is to be anticipated that the present inventory of equipment will remain in service with some phasing-out of older pack-set equipment (e.g. the AN/PRC-10). New equipment including the AN/PRC-77, AN/ARC-114, etc. will be placed in operation, generally improving the effectiveness of tactical communications, without changing its philosophy. Modification of existing tactical sets is not desired. In the worst case, only very limited modification of existing tactical radio sets for relay compatibility could be contemplated, for example, provision for squelch disable or time constant modification, signaling tones for relay activation, or issuing supplementary receivers (e.g., the AN/PRR-9) for frequency translator compatibility.

3.2.1.3 Long-Range Time Frame. In the long-range time frame, it is possible that digital modulation modes will be provided as an alternative to the FM analog mode, for digital data entry, and eventual message routing control. Relay equipment for this time frame must therefore be compatible with both the digital modulation formats and the conventional FM mode. In this time frame it is feasible to plan tactical radio requipment for compatibility with relay systems, if this study program indicates the value of such redesign. In the area, one might envision synchronous common-frequency (F_1-F_1) operation or offset receive-transmit tuning for frequency translator compatibility.

The development of transceivers equipped for UHF operation (e.g., the AN/PRC-72) may provide a means of moving relay operation out of the already crowded 30-76 MHz band, while maintaining a degree of compatibility with FM net operations in this band. The use of UHF in a jungle environment may necessitate very high altitude platforms, and may require use of portable directive antennas.

3.2.2 Relay Performance Requirements. Requirements for relay performance include range under various terrain constraints, channel capacity, multiple access, and channel quality.

3.2.2.1 Range Requirements. The basis for the range requirements for various relay configurations was established in Section 2 of this report. The constraints implied by terrain, propagation through jungle foliage, and platform performance have been combined with these requirements to some extent. It is anticipated that mutually compatible relay configurations will be established in the next few weeks. Path loss computations indicate that the range objectives of Section 2 may be met with reasonable reliability in jungle covered terrain even with the PRC-25 output power limitations.

The propagation studies undertaken thus far have dealt with smooth-earth terrain, except for approximate evaluation of required platform heights in mountainous terrain as noted in Section 4 of this report. Further attention to the mountainous terrain problem is planned for the following months.

3.2.2.2 Channel Capacity. Channel capacity requirements based on the probable number of FM nets in a nominal relay service area were described in Section 2 for various relay applications. An alternative interpretation of channel capacity requirements is currently under discussion between the team members.

Previously, we assumed that if a repeater were available it would be used to improve performance of all FM nets in the service area. This establishes requirements for large numbers of channels, with resulting frequency allocation and interference problems, and complicates the physical and fiscal aspects of the repeater platform.

There is also the consideration that if troops are regularly deployed over distances such that they must depend on the repeater for ordinary communication, then the repeater reliability becomes a critical aspect of system design, particularly in regard to maintaining platforms on station during unfavorable weather conditions.

It is apparent that not all of the FM networks will need repeater augmentation. It is only when an occasional detachment becomes too far separated or enters foliage too dense for satisfactory communication that the repeater is required.

As an extension of this argument, it is unlikely that all of the FM nets in the repeater service area would need augmentation simultaneously. Therefore, there can be some sharing of backup channels and repeater subsystems at the platform.

Since the use of the net with the emergency-only philosophy is based on repeater operation only when direct communications fail, it is presumed that a relatively small number of repeater channels would be required. The exact number is probably not too critical. As an example, the activity factor for a net is substantially less than 50% (5 "subscribers" each with 5% activity factors result in a net activity factor of 22.6%) and the probability of an unsatisfactory link in the net is probably less than 10%, so the probability of a particular FM net needing the repeater would be less than 5%.

If a single n[illegible] a 5% probability of needing the repeater, we may then compute from [illegible] binomial or Poisson distributions the number of repeater channels required to accommodate the requirements of N nets for a particular fraction of the time. If this fraction (the probability of instantaneous availability of a repeater channel) is 95%, then for N = 10 three repeater channels would be required*, four for N = 20, five for N = 50, and eight for N = 100. This is plotted in Figure 3.2-1.

The preceding argument has not included the delay in establishing circuits in computing the necessary number of channels. If the delay in completing circuits is comparable to the average message length, the fraction of useful time on a given channel will be reduced. This point will be explored further.

There may be some correlation in the usage of a number of separate FM nets, as military operations (on either side) may be synchronized in a number of areas so the required number of channels may be larger

*From a table of the cumulative terms of the binomial distribution (N = 10, 20) or the cumulative Poisson distribution (N>20).

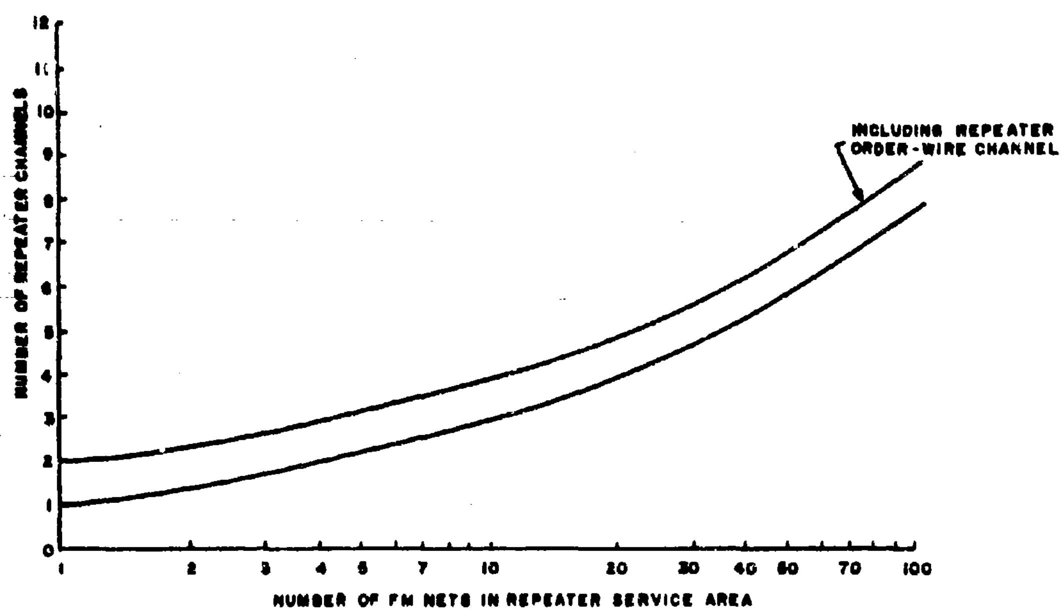


Figure 3.2-1. Number of Repeater Channels for 95% Probability of Instant Availability

than indicated above. The consequence of not having enough channels is that low priority calls may be delayed, but this is a relatively minor problem in comparison with a subscriber's having no communications at all.

3.2.2.3 Multiple Access. A basic requirement is that the repeater be available either full-time or on short notice to the net requiring its service. Since the cost of the repeater platform is less per channel hour if it may carry a number of repeater channels, it is expected that a number of nets will be provided with repeater service by a single platform. As indicated in paragraph 3.2.2.2 above, the number of repeater channels may actually be somewhat less than the number of nets served.

There is a choice of autonomous control of the repeater or supervised control. Autonomous control of access is compatible with unattended platforms, such as drones or balloons, but may require modification or augmentation of pack-sets to provide control functions. Otherwise, separate relay channels may be required for each network in the service area. Attended control requires a repeater orderwire channel, on which the subscriber needing repeater service would call the operator to request augmentation of his net. Attended control is applicable to either common frequency or frequency-translating repeater systems.

3.2.2.4 Channel Quality. For the three time frames under consideration, the basic channel quality requirement is that of intelligibility. The long-term time frame will also require suitable digital error rates and distributions.

A number of factors enter into the determination of the intelligibility for a repeater-equipped link, some of which are only partially predictable.

a. Background noise at speaker's and listener's locations.

b. Effect of band-limiting, clipping, and handset response in transceivers.

c. Internal and external noise at repeater and ground receiver.

d. Interference or jamming at platform and at ground receiver.

e. Repeater intermodulation in amplifiers common to multiple-access channels.

f. Effects of repeater switching in F_1-F_1 mode, including interaction with squelch.

g. Fading due to motion of platform through spatial signal irregularities due to jungle inhomogeneity.

h. Fading due to atmospheric effects.

i. Fading due to repeater antenna pattern irregularities, including pattern modulation by rotor blade interaction.

j. Rotor blade modulation interaction with receiver squelch and agc.

Clearly, we are not able to predict the net effect of all of these terms, as only a few of them relate to channel disturbances which produce predictable and repeatable effects on intelligibility. Thermal noise, paragraph 3.5, and squelch interaction and repeater switching are considered in paragraph 3.4.6. Repeater intermodulation has been considered briefly. The progress in estimating repeater loading in terms of the distribution of differences of signal levels is described in paragraph 3.5.3.3. No attention has been given to rotor blade modulation of helicopter antenna patterns, but this will be included in the development of recommendations for platform antennas in the following months.

The channel intelligibility is also related to the time allowed for transmitting a message, since the speaker may add redundancy to the message by repeating himself, and verification of the message may be exchanged with the listener. To avoid the necessity of defining a message delay criterion, we have simply used a 10 db signal-to-noise-plus-distortion ratio in a 3 KHz bandwidth as a criterion for minimum satisfactory service. It is noted, of course, that the time-varying nature of the signal, noise, and interference as detailed above may produce a degradation of intelligibility comparable to that introduced by thermal noise and distortion.

3.3 PLATFORM-RELAY INTERFACES

3.3.1 Introduction. There are a number of areas in which the relay and the platform designs interface. One of the output products from the relay study program is the information necessary to perform platform selection and optimization. This information relates to the platform's location, and the resulting effects on system performance, to the physical and electrical characteristics of candidate repeater equipment configurations, and to the costs associated with repeater alternatives.

The following paragraphs describe some of the physical, environmental, operational and maintenance considerations pertaining to the platform-relay interfaces.

3.3.2 Altitude. From the standpoint of the relay designer, the platform altitude necessary for satisfactory operation of the high altitude radio relay is determined by the required service area, reliability, and interference generation and vulnerability. The example which follows assumes that the three-foot vertical whip antenna ($\sim\lambda/4$ at 76 MHz) is used with AN/PRC-25 pack set transceivers located in the jungle. The PRC-25 output power is assumed to be 1 watt at 76 MHz. The PRC-25 is further assumed to provide useful communication capability with a carrier input level of -113 dbm. The pattern and corresponding gain of the $\lambda/4$ whip antenna supported above ground is assumed to resemble a half-wave center-fed vertical dipole 1.5 meters above the ground surface. The repeater is electrically similar to the PRC-25, and again has a half-wave vertical dipole antenna pattern.

Computation of the median path loss and margin requirements from the relay platform to a point in the jungle is detailed in paragraph 3.5 of this report. For a 90% probability of a satisfactory circuit, a power margin of 9.5 db must be provided on both the uplink and the downlink. Combining this figure with the PRC-25 parameters above, a median path loss of 133.5 db will provide a 90% probability of usable service.

The required platform altitude may then be obtained from Figure 3.5-35 for values of required ground distance. One of the service requirements defined in Section 2 called for a 100-mile range. Interpreting this as the diameter of a circular service area, a ground range of 50 miles (80.5 km) is required. From Figure 3.5-35, this range may be realized for platform altitudes from 0.6 to over 100 km (2000 to 320,000 feet). For the maximum range requirement of 300 miles (taken as a ground range of 150 miles from transceiving to repeater), an altitude of greater than 9 km (29,500 feet) is required.

The curves of Figure 3.5-35 indicate that above a minimum usable altitude the repeater performance continues to improve in the useful range of platform altitudes. Interference and jamming vulnerability demand, however, that a minimum altitude consonant with range, obstacle clearance, and platform safety and performance be used.

3.3.3 Horizontal Motion. An idea of the effect of horizontal motion on relay operation may be obtained by estimating the changes in range for an allowable path loss variation of ±3 db. This path loss change will include, in general, a free space component and a component due to change in foliage attenuation as a result of changed penetration angle; in an extreme case, the change in ground distance may even put the up or down-link beyond line of sight. Hence, the allowable variation in repeater location will be strongly dependent upon the total range being utilized and the repeater height. For any specific case, numerical results may be readily scaled from the appropriate curves of adding (in terms of contributed noise power) the loss difference terms contributed by the two paths.

For the special case where the repeater platform is between the ground transceivers and two paths from ground-to-air and air-to-ground are about equal, the changes in free-space attenuation for one path will nearly cancel the changes in free-space attenuation for the other path. Therefore, for paths not too near the radio horizon relatively large changes in radial distance may be made with little effect on repeater performance. If the changes in range are roughly proportional to the median range, so that angular variations remain fairly constant, the attenuation changes will also remain about the same.

If operation outside of the above limits is desired, the change in attenuation may be determined from Figure 3.5-26 by using the slant ranges from the ground station to the relay vehicle positions to determine the attenuation change.

3.3.4 Platform-to-Platform Relay. The three-path relay system, from ground-to-air to air-to-ground, may be useful in some circumstances, especially mountainous terrain. The range may be extended without the use of an extremely high repeater altitude if two airborne repeaters are used. Major disadvantages, operationally, of the two-repeater paths are the requirement for additional frequencies and for an additional platform. The interference range for both of the repeater transmitting frequencies is also quite large, but the interference range would be much greater at the transmitting frequency of a single repeater at the extremely high altitude that would be necessary for the same ground range and at the same elevation angles at the ground terminals. The initial cost of the second platform (with equipment) and the operating costs are serious disadvantages.

There would be little advantage in using two airborne relays for a ground-to-air-to-air-to-ground path in a jungle environment. The ground elevation angle required for satisfactory clearance of the jungle canopy is only from 2° to 10° so that adequate range could be obtained from a single airborne relay at moderate relay platform altitudes.

The payload differences are dependent on the necessary relay platform altitude and not as much a function of the number of links in the relay path. The length of the separate links will be reduced to some extent by using two airborne relays but the payload weight would change very little with a moderate change in the power of the transmitter. It would be more efficient to use a single airborne platform over a somewhat larger path. The required increase in transmitter power would increase the weight of the payload no more than 10 or 15%, including the requirement for an increase in primary power.

3.3.5 Costs. The costs for several alternative six-channel relay systems have been worked out and include the original equipment cost, the cost of 10% spares, and the maintenance cost per year. The calibration cost should be negligible and is not included and the cost of primary power is also not included since it will probably be supplied by the aircraft power supply or by engine-driven auxiliary generators on the manned aircraft. The cost figures for the first year are as follows:

AN/PRC-25	\$ 9,888 (Production)
AN/ARC-114	\$28,368 (Development)

Single-channel repeaters are not considered economically feasible for the general situation, since the capabilities of the airborne platform, which is more expensive than the relay equipment, are not well utilized, and normally considerably more than one channel is required, operationally, in a given service area.

If the platform is lost, the dollar cost is as given above for the repeater equipment. The maintenance cost may be subtracted from the total dollar cost since this cost is associated only with the operation of the relay equipment. The cost of the platform is normally much greater than the above equipment costs.

The "battlefield" cost of the loss of the relay may be very high if it results in the complete loss of communications for a tactical unit. For example, if this loss of communications were to result in the failure to warn the unit of an enemy ambush, the loss of the relay could result in the loss of the entire tactical unit (especially if this tactical unit is unable to obtain timely reinforcements due to loss of communications).

3.3.6 Physical Characteristics

3.3.6.1 Weight. The total weight of a multiple repeater "package" of AN/PRC-25 transceivers for six channels is given in Table 3.4-1 as 163 pounds. To this we must add the weight of mountings, housings, connecting wiring, etc.. An additional 20%, or 32 pounds, should be adequate to cover these items, making a total of 195 pounds.

A 12-channel "package" of 24 AN/PRC-25 transceivers would then weigh about 390 pounds.

The weight of a multiple repeater "package" made up of 12 AN/ARC-114 transceivers, for 6 channels, is shown in Table 3.4-2 of relay equipment types as 96 pounds. An additional 20% for mountings, housings, connecting wiring, etc., would add 19.2 pounds to make a total weight of 115.2 pounds. The weight for a 12-channel "package" of 24 AN/ARC-114 transceivers would be twice as great or 230.4 pounds.

The use of a broadband translator (Table 3.4-1) with a power amplifier, similar in size to the AM-4306, would result in a very lightweight piece of equipment. The two units would only add up to 6.25 pounds, but added mountings, housings, wiring, etc., of about 5 pounds would add up to 11.25 pounds. All these weight figures are exclusive of the primary power supply, which could be supplied by the vehicle. The broadband translator is not an inventory item and must be developed.

Another alternative system, that is listed with the multi-channel relay equipment type, makes use of a set of six AN/ARC-114's with six R-1297 ( )-/ARC receivers. This system is limited operationally to receiving on one single frequency and transmitting on a second frequency (F_1-F_2). As a result, the system is not completely compatible with the normal ground station; and either two separate transceivers or one transceiver with an additional receiver must be used at each ground station. There is a weight and cost advantage for the airborne relay alone, but the requirement for additional equipment at each ground station makes the overall system cost much greater. The weight of the six channel system, described above, is 60 pounds. An additional 20% for mountings, housings, wiring, etc., would add 12 pounds, making the total weight equal to 72 pounds. If a 12-channel system is desired, the weight would then be doubled to 144 pounds.

3.3.6.2 Volume. The volume required for some of the more promising relay "packages" of 6 and 12 channels is as follows:

First, the six channel "package" made up of 12 AN/PRC-25 transceivers requires about 3.4 cubic feet of volume. Another 100% should be added for housings, shock mountings, etc., or another 3.4 cubic feet, making a total volume of about 6.8 cubic feet. The overall dimensions of each AN/PRC-25 transceiver are 11-1/2" x 4-1/16" x 10-7/16". One practical arrangement would be to group three transceivers together, stacked on top of each other, with two groups of three on one side of the aircraft cabin and the two other groups of three on the opposite side of the cabin. The probable dimensions of the group would be 18-3/4" high by 12" deep by 12" wide. This would represent a volume of 2700 cubic inches or 1.56 cubic feet. The total volume would then be about 6.25 cubic feet for these four stacks of three units. If the units are stacked up in piles of two instead of three, there would be less heat build-up and the units would run cooler. This might avoid the use of forced air ventilation systems for cooling.

The systems, or "packages," made up of AN/PRC-77's would require the same volume as those for the AN/PRC-25's, since each individual AN/PRC-77 has the same dimensions as each AN/PRC-25.

The system "package," made up of 12 AN/ARC-114's would require 0.9 cubic feet of volume for the transceivers. An additional 100% of volume should be added for housings, shock mountings, etc., or another 0.9 cubic foot, making a total of 1.8 cubic feet. The best arrangements of units would probably be a side-by-side arrangement, since the normal aircraft avionics equipment has a height over 2 times its width. The equipment is small enough so that a row of six units would not be too wide to fit into most aircraft cabin arrangements. One row of six units could then be mounted on one side of the cabin and the other row of six on the other side of the cabin.

The system "package," made up of six AN/ARC-114 transceivers, and six R-1297 ( )-/ARC receivers saves some space, weight, and cost over the system made up entirely of AN/ARC-114's. Unfortunately, it requires separate receive and transmit frequencies, so that each ground station must have two transceivers instead of one. The receivers and transceivers require 0.6 cubic feet of space and, as before, an additional 100% should be allowed for the housings, mountings, etc. This makes a total of 1.2 cubic feet required for this six-channel system. A 12-channel system would then require about 2.4 cubic feet, total volume. The receiver, the R-1297( )-/ARC, is also quite limited in frequency range (only 48 to 50 MHz) which thus limits the flexibility of the system. In fact, it is only rated for 20 channels at a 100 KHz spacing between channels.

The broadband translator would presumably require much less volume than any of the above systems which use a combination of many single-channel equipments. Since it is still in a conceptual stage, it is difficult to estimate the exact space requirements. The figure given in the relay equipment list is 0.24 cubic feet for the equipment and an added 100% for housings, mountings, etc., bringing the total space requirement up to 0.48 cubic feet. This volume is for 12 channels, so that it may be compared with the higher figures given for other system "packages."

3.3.6.3 Modularity. In scaling repeater physical parameters to a particular channel capacity, it is evident that the designs employing multiple transceivers will have common equipments which do not change in weight and dimensions with each increment of channel capacity. Common equipment in the repeaters may include diplexing filters, receiving preamplifiers, and power splitters transmitting summing networks, power regulators and supervisory equipment. Of these, the diplexing filters are the only significant items which will not increase strictly in proportion to channel capacity, since the filter requirements are substantially as stringent for any number of channels. As a rough estimate, it is anticipated that diplexing filters will weigh 10 pounds or less and require less than 1 cubic foot of volume.

3.3.6.4 Spares. The use of 10% spares should be adequate for equipment, such as the AN/PRC-25, with a 2000-hour meantime between failures (MTBF). For a system made up of 12 transceiver equipments and for missions averaging 10 hours in duration, a failure should occur once per 17 missions, on the average. The more modern all-solid-state equipments have a much longer MTBF and the AN/PRC-77, which has an MTBF of 25,000 hours, should require no airborne spares at all. A 6-channel system, using 12 AN/PRC-77 transceivers, should have a failure occurring only once per 208 missions of 10 hours duration. Since one failure would only reduce the capability by one-sixth, to 5 channels, it should not be necessary to carry any spares at all in the vehicle. In summary, the number of spares is proportional to the number of channels, the mission duration, and inversely proportional to the meantime between failures per equipment.

3.3.7 Environmental Factors

3.3.7.1 Vibration and Shock Limits. The vibration and shock limits of the relay packages should conform with the requirements of other airborne electronic equipment, such as the avionics equipment installed in the aircraft chosen for the airborne platform. The requirements for a recent avionics equipment, the Collins AN/ARC-111 radio set, designed for similar military use, are as follows:

Vibration	-	10 to 55 cycles at 0.06 inches, total excursion on power supply.
		10 to 55 cycles at 0.02 inches, total excursion on transceiver.
		Both units vibrated for 90 minutes in 3 mutually perpendicular planes.
Shock	-	12 shocks of 15g each operation. Crash safety test of 30g, non-operational.

The aircraft radio set, AN/ARC-51A and 51BX, made by Admiral Corp., Government Electronics Division, specifies MIL-E-5400, Curves II and IV for vibration characteristics. The shock characteristics are not specified.

The Collins 618M-2B/D VHF transceiver (the 619A-13 is the commercial version of the AN/ARC-111 described above) gives the following specification for shock:

Rigid mount - 6g operational

3.3.7.2 Specification and Adequacy of Mountings. Since the AN/PRC-25 and the AN/PRC-77 transceivers were designed for ground use, no specifications have been used or planned for aircraft mountings. The broadband translator equipment would also have no established specifications for mountings. The AN/ARC-114 transceivers, however, have been designed for use in the light observation helicopter and should have adequate specifications for mountings may be given. Since this equipment is still in development and, thus, does not have sufficient data on operational performance and life.

3.3.7.3 Effect of "Power-on" or "Power-off." Since the equipment being considered for relaying purposes is almost completely solid state (one tube in the AN/PRC-25), there should be very little effect on the relay equipment if it is powered or not, even during maximum vibration and shock conditions as during aircraft landings. There is no need to operate the repeater equipment when the platform is not on-station.

3.3.7.4 Limits of Temperature, Altitude, etc. The temperature limits specified for the AN/ARC-114, a prime repeater candidate, range from -25° to +145°F with full performance and from -55°F to -25°F and from +145°F to +165°F with a 2 to 1 performance degradation allowable. The manufacturer, Sylvania Electronic Systems Division, says that their preliminary test results show a reduction in performance to only 70 to 80% of the normal performance rather than to 50%, for the extreme temperature limits. The altitude limits that were specified for the AN/ARC-114, were from sea level to 15,000 feet. The Sylvania preliminary test results show satisfactory performance from sea level to 50,000 feet.

The temperature limits specified for the AN/PRC-25 and the AN/PRC-77 should be about the same as for the AN/ARC-114 (which are found in SCL-4662A), but the altitude limits for this ground equipment may be somewhat restricted.

The humidity limits for both ground and aircraft equipments should require operation at up to 100% humidity. The humidity limits for a similar piece of avionics equipment, the Collins AN/ARC-111 radio set, range up to 95 to 100% humidity for 48 hours at 122°F ± 5°F.

There has been no information given on icing problems for antennas. If the antennas do accumulate a layer of ice, the major effect would be to detune the antenna and reduce its efficiency. Icing should not be a problem for the immediate time frame for use in Southeast Asia.

3.3.7.5 Sheltering Requirements. There are several factors which tend to reduce the severity of the sheltering requirements for the high altitude radio relay equipment, partially due to the high efficiency and very low minimum power requirement of the transistors and other solid state devices used in the modern equipment being considered for this purpose. This factor may make it unnecessary to use forced air cooling for the equipment, thus avoiding dust problems with air filters, etc. The second factor in its favor is the low voltage requirements of solid state devices. This alleviates the moisture and humidity problems associated with exposed mounting (as under a drone helicopter, etc.). If the equipment could be completely enclosed because of the low power requirements discussed earlier, the moisture and humidity problem would be negligible. The AN/PRC-25 and the AN/PRC-77 were both designated for ground, man-pack use and thus must certainly be designed to withstand occasional immersion in water. The AN/ARC-114 transceiver was designed for use in the cockpit of a light observation helicopter; therefore, it may not be able to withstand exposed mounting (as under a drone helicopter) without additional protection.

Since the broadband translator discussed previously is in a very early stage of development, a suitable housing may easily be designed to meet the environmental requirements.

3.3.8 Housing Considerations

3.3.8.1 Mounting Limits. Most of the housing considerations discussed in the section on sheltering requirements were quite extreme and would not be encountered in most cases The most likely vehicle for the airborne platform is a helicopter, such as the UH-1D, which has ample room in the cabin to mount a large number of transceiver equipments on suitable shock mounts, in this fairly well protected area. The heat dissipation problem is not a serious one, as discussed previously, so that special provisions need not be made for forced air cooling, etc. Neither is maintenance a serious problem, since in para. 3.3.6.4 the number of spares was discussed and it was shown that the number of failures per mission should be very low, even for relay systems made up of AN/PRC-25 radio equipments (an average of 1 failure per 17 missions). With the use of the AN/PRC-77 radio equipment, which has a mean time between failures of 25,000 hours, in-flight failures would be virtually non-existent.

3.3.8.2 Fast Mounting or Relocation. Although little in-flight maintenance should be necessary, as previously explained in paragraph 3.3.8.1, the initial system design would probably make use of fixed mounting for both active and spare equipments, with the use of switching to substitute spare equipment for active equipments that have failed. This method of maintenance has the advantage of rapid substitution of a failed unit, as well as the convenience of repair on the ground near the maintenance facility.

Later equipment development may make in-flight maintenance unnecessary. The complexity of the system and the component equipment may also be reduced substantially in the future, further increasing the life of the overall system and reducing the maintenance requirements correspondingly.

3.3.9 Antenna Specifications

3.3.9.1 Polarization and Orientation. The polarization of the antenna on the platform should be primarily vertical, since most of the ground equipment in use on the tactical battlefield will have predominately vertical polarization. However, the ground equipment will be operated at all angles to the vertical, as, for example, when a man-pack equipment is operated from a prone position. There will also be many reflections from surrounding objects that will tend to cross-polarize the combined waves. A third factor to be considered is the broadness of the antenna directivity pattern in the vertical plane. This means that tilt angles up to 30 degrees may be neglected and that the gain at greater tilt angles is not seriously affected.

The antenna orientation may thus be determined by the best arrangement for the vehicle. It may be most practical in the case of the UH-1D helicopter to use the tail boom antenna normally associated with the AN/ARC-54 VHF transceiver.

3.3.9.2 Antenna Location and Mounting. The detailed specifications for the antenna to be used on the relay vehicle cannot be determined before the relay vehicle is chosen from the group of prime candidates. Prime candidates for the antenna choice would be either a three-foot whip or a ten-foot whip antenna, similar to those in use on the ground for the AN/PRC-25. The AN/PRC-8, 9, and 10 radio sets use either the AT-272/PRC, which is the 36-inch steel tape antenna, or the AT-271/PRC, which is the 10-foot multi-section whip antenna. Both antennas should weigh less than 5 pounds, but the AT-272/PRC probably does not have the stiffness necessary for operation on an aircraft. A Collins VHF/FM blade antenna, their 437S-1, would be suitable for use on a high-performance aircraft (up to Mach 0.95) and it weighs only 6-1/2 pounds. It provides an automatic tuning capability which would not be required but might be quite useful. A source of 28 volts dc power must be connected to this antenna to operate the servo system, but the 35-watt power drain occurs only momentarily (2 to 5 seconds duration) during the tuning cycle.

An additional problem occurs on a rotary-wing vehicle (helicopter) due to modulation of the antenna pattern by the rotor blades. This results in amplitude modulation of both transmitted and received signals.

Another possible location for the antenna is underneath the fuselage. While this would provide some shielding of the antenna from the rotor blades, it might interfere with landing and take-off operations, although it might be possible to mount a flexible whip or retractable antenna in this location. This position would also be good with respect to radiation in the predominantly downward direction to the ground stations.

3.3.9.3 Homing Loop Antennas. The AT-784/PRC homing loop antenna is a standard accessory for the AN/VRC-12 and the AN/PRC-25. The antenna itself weighs approximately three pounds and is 4" by 2-9/16" by 7" in size. It covers the frequency range from 30 to 76 MHz and is intended primarily for use with portable and vehicular FM receiver-transmitter equipment. It will fulfill the basic requirements for a single-unit homing facility for a system of combat area FM radio communication equipment.

The normal homing loop for aircraft use is usually mounted on the top of the fuselage and may be either rotated by hand or servo-driven. For the Collins DF-203 automatic direction finder system, the 137A-4 fixed-loop antenna is mounted flat on the top or bottom of the fuselage. It weighs 3.8 pounds and is 16 inches long, 12 inches wide and 7/8 inches thick and has no moving parts. It is probably connected to a phased rotatable transformer in the ADF set, so that the actual antenna does not need to be rotated. A sense antenna is usually provided, such as their 437M-2, used with a 179J-5 servo antenna coupler. The sense antenna is used to resolve the 180° ambiguity in the loop pattern.

3.3.9.4 Relay Aspects of Rotatable Antennas. The use of a tracking antenna on the airborne platform would be desirable only at the higher frequencies where an appreciable gain may be obtained from a directional antenna. For example, in the UHF band, at 225 MHz, a six-foot diameter parabolic reflector antenna would only have a gain of 10 db. This amount of gain would not improve the system enough to warrant the added expense, weight, and complication.

For the case of the AN/TRC-29 radio relay equipment, which operates at frequencies between 1700 and 2400 MHz, a six-foot dish antenna would give a gain of about 28 db at 1700 MHz. This amount of power gain might justify the increase in system complexity necessitated by the use of tracking antennas, within a randome. Even a three-foot dish antenna at 2400 MHz would result in an antenna gain of almost 25 db.

This increased antenna gain would substantially reduce the transmitter power requirements for the airborne relay equipment, but complicated and highly expensive acquisition and servo control systems and air frame modifications would be necessary. The overall value is therefore highly questionable.

Further work on retrodirective antenna arrays, with amplifier and modulators to transfer subchannel modulation signals from one path to another, may present a practical solution to this problem for the long-term time frame, since these are self-directive and thus require no acquisition and steering systems. A promising directive antenna approach is to use an antenna exhibiting vertical directivity but no azimuthal directivity (for example, a collinear array of vertical dipoles). This arrangement is being investigated to extend horizon coverage at some sacrifice of signal power on short paths.

3.3.10 In-Flight Operation

3.3.10.1 Facilities for Repeater Control. If a multichannel repeater system is set up in manned aircraft using multiple sets of single-channel radio equipments, an operator should be available to perform simple supervisory procedures. Spare equipment will probably be provided when sets of AN/PRC-25 radio sets are used. The operator could easily switch in a spare equipment to replace one that has failed. He could also retune the spare unit to the frequency of the unit to be replaced. Retuning of operating units might also be necessary if the channels are being interfered with, either intentionally by enemy jamming or by channel overloading. This could also be done by the operater without too much difficulty. In all cases supervisory equipment must be set up to permit the operator to monitor all the channels, in order to determine whether the operation is satisfactory.

Since the AN/PRC-25, the AN/PRC-77 and the other radio equipments that are being considered as suitable candidates for the airborne relay equipment provide synthesized frequency control, there is no requirement for in-flight frequency calibration.

The use of a data link to telemeter supervisory information and control may be possible and desirable with unmanned aircraft.

3.3.10.2 Message Monitoring and Recording. While traffic monitoring may be performed, as part of the supervisory control function, there have been no plans to record or to playback the messages being handled by the airborne relay. The equipment to be used for the traffic monitoring purpose itself should be limited to switching circuits and simple audio circuits when the supervision is done by an operator on board the manned aircraft. If an unmanned aircraft is used, the traffic monitoring may be done at a ground station in conjunction with the supervisory control. A simple data link system may be used to telemeter both supervisory information (such as "system status monitoring" - including fault detection) and the supervisory control information, back to the unmanned vehicle. The ground station may monitor the relay channels directly by switching a ground receiver from channel to channel. Since an F_1-F_2 system will probably be in use, both frequencies should be monitored. The location of the ground station must be chosen to be within easy range of the airborne relay platform. Monitoring will not be possible on circuits using digital encoding for privacy or security.

The simple type of airborne relay equipment is intended solely for tactical communications on VHF frequencies and thus would not have facilities for switching from VHF to UHF and vice-versa. Some additional equipment to translate channels from VHF to UHF may be desirable. A limited number of channels may be set up, using standard single-channel UHF equipment (such as the AN/ARC-116 or the AN/ARC-45), for liaison between U.S. Air Force forces and U.S. Air Force aircraft. If a long transmission path is involved for a communications channel and the UHF band is not fully utilized, the channel may be translated from VHF to UHF in one airborne relay transmitted to a second airborne relay (high gain directional antennas may even be used, on a large manned aircraft), retranslated down to VHF and transmitted to the second ground station.

3.3.11 Power Supply. The use of platform power, when available, is believed to be the most efficient method to supply primary power to the repeater equipment. Even if the quality of the power supplied by the platform is poor, adequate voltage regulators, filters, etc., are readily available. A satisfactory regulator for 500 watts, which should be ample power for a 6- to 12-channel repeater system, should weigh less than 10 pounds and require less than 0.1 cubic foot of volume. Any suitable secondary or auxiliary power supply would require substantially more weight and volume. For example, a secondary battery supply capable of supplying 10 watt-hours per pound would require 50 pounds to supply 500 watt-hours, although lithium-copper fluoride primary batteries having a capacity of 80 watt-hours per pound are in the development process.

Most airborne vehicles have some primary power available, with no additional weight required. If added primary power is required, the added weight required for a larger generator may be at a rate as little as 10 pounds per horsepower, or 74.6 watts per pound. Even this value is based on present designs for generators which can be improved substantially in the future.

3.3.12 EMI Compatibility. The conceptual design of the multi-transceiver repeater package is predicated on the assumption that the interference between the repeater and platform avionics equipment and the interference between adjacent transceiver equipments may be held to satisfactory levels. Further investigation of the interference generation and susceptibility of the AN/PRC-25 and AN/ARC-114 is needed before a specific repeater package is designed. The results of such an investigation may indicate necessary filtering, shielding, power supply decoupling, tuning range limitations, and in general, the suitability of the transceiver equipment for multiple repeater service.

3.4 RELAY CANDIDATES

3.4.1 Introduction. One of the major tasks of the relay study was to list all existing radio equipments, including developmental as well as production, that could be used for an airborne repeater equipment. Although compatibility with existing VHF FM tactical radio equipments was considered essential for the initial solution of this study, other types of radio equipment, such as commercial and/or developmental equipment types, may be considered for the interim solution or for the long-range solution. This means that frequency ranges other than the VHF range may be considered and that even other types of modulation may be studied. The relay equipment compatible with AN/PRC-25 ground sets is shown in Tables 3.4-1 through 3.4-3.

This equipment list is not intended to be comprehensive and is directed primarily at the initial solution from the present time up to the 1968 fiscal year. While this equipment list is primarily a comparison of technical factors, economic, logistic and availability factors are also included.

A description of several useful repeater configurations should help in a better understanding of the problems associated with the development and application of high altitude radio relays. Since it is very difficult to prevent coupling from two antennas that are close to each other, and hybrid networks or duplexers with isolation values of over 100 db have not been developed for the VHF band, it is necessary to transmit from the repeater at a different frequency than the incoming received signal. This difficulty is avoided at the ground stations because the receiver and transmitter are switched on and off alternately with the push-to-talk button on the handset. Even if the receiving and transmitting frequencies of the repeater are separated enough in frequency for proper isolation, the F_1-F_2 arrangement only permits transmission in one direction. Since each ground station should be able to receive and to transmit on the same frequency, the repeater must be set up so that it can alternate from F_1-F_2 to F_2-F_1 (the first ground station operates on F_1 and the second ground station operates on F_2). A single channel repeater system, such as one operating a pair of AN/PRC-25 transceivers back-to-back, may use the receiver squelch system to turn on the receiver of this other transceiver. The squelch of this receiver releases several milliseconds after the received signal ceases. The second receiver (on F_2) can then receive the signal from ground station No. 2 and the receiver on F_1 is shorted, transmitter F_1 is activated, while transmitter F_2 remains off.

This time-sharing arrangement cannot be used for a broadband translator (F_1-F_2) equipment since there is no sharp transition from the no-signal to the signal condition. In this case, a separate receiver on F_2 must be used at each ground station. This could be avoided if the normal AN/PRC-25 ground transceiver could tune its receiver to a different frequency channel than its transmitter. This cannot be done with the AN/PRC-25 because a single-frequency synthesizer is used to supply the frequency control signal to both receiver and transmitter of each transceiver. If a simple modification could allow each ground transceiver to receive and transmit on different frequencies, repeater designs could be simplified considerably.

In order to make use of a high altitude radio relay platform in an economical manner, the repeater payload should permit operation on several channels. One multichannel configuration utilizes parallel pairs of AN/PRC-25's connected back-to-back through the retransmission cable kit MK-456/G, which includes a junction box, cable connection and a handset connection. The handset connection may be utilized for supervisory control, although demodulation and subsequent re-modulation is not essential in an F_1-F_2 repeater. The basic block diagram of two parallel pairs of single-channel transceivers is shown in Figure 3.4-1. The parallel receiver inputs must be connected together through a preamplifier and dividing networks to prevent spurious responses to oscillator radiation, etc., of one receiver from interfering with another receiver and to prevent loss of receiver sensitivity. Similarly, the transmitters should be isolated from each other by combining networks, such as hybrids, to prevent interaction. A single antenna may be used for both reception and transmission by insertion of a suitable diplexing filter between the antenna and the transceivers and preamplifier (which is broadband). A common power supply derived from a battery pack, or from the platform power source (perhaps with the addition of a regulator) should be used to operate the equipment.

The only way that the repeater can operate straight-through, on F_1-F_1, is to switch from receive to transmit at a rate that does not affect the intelligibility of the voice modulation. The system used is shown as a block diagram in Figure 3.4-2. This system will operate satisfactorily at several switching rates for voice modulation but is generally unsatisfactory for digital data modulation. These factors are described in greater detail in paragraph 3.4.5.2.2. This system has the additional advantage that only a single transceiver is required per channel. Much of the weight saved in this manner may be required for the commutation timer, the memory, and the other switching equipment that is required.

Another useful repeater configuration has been described in a later portion of this section of this report. This repeater type is the broadband translator of paragraph 3.4.2.7. A suitable preamplifier, that is available as a catalog item, is the RHG Electronics Lab. model FMT 6020. A suitable main amplifier is the RHG model EMT 6020 and a suitable power amplifier is the RHG model EHT 6020.

This power amplifier has a power output of only about one watt, so that another type having a higher power output would be more suitable. A good balance between the uplink and the downlink system gain would be obtained if the power amplifiers had a power output of about two watts per useful channel, or about 24 watts (12 channels).

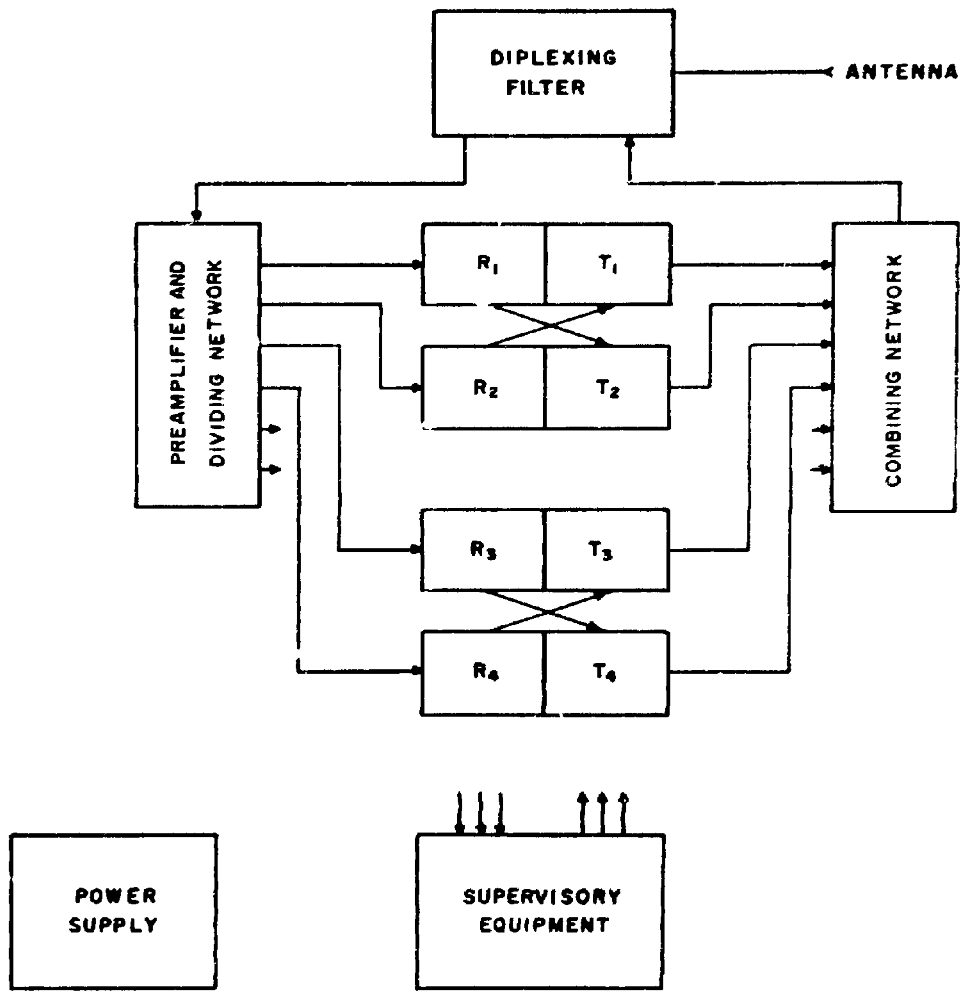


Figure 3.4-1. Frequency Translating Repeater Configuration (F_1 - F_2)

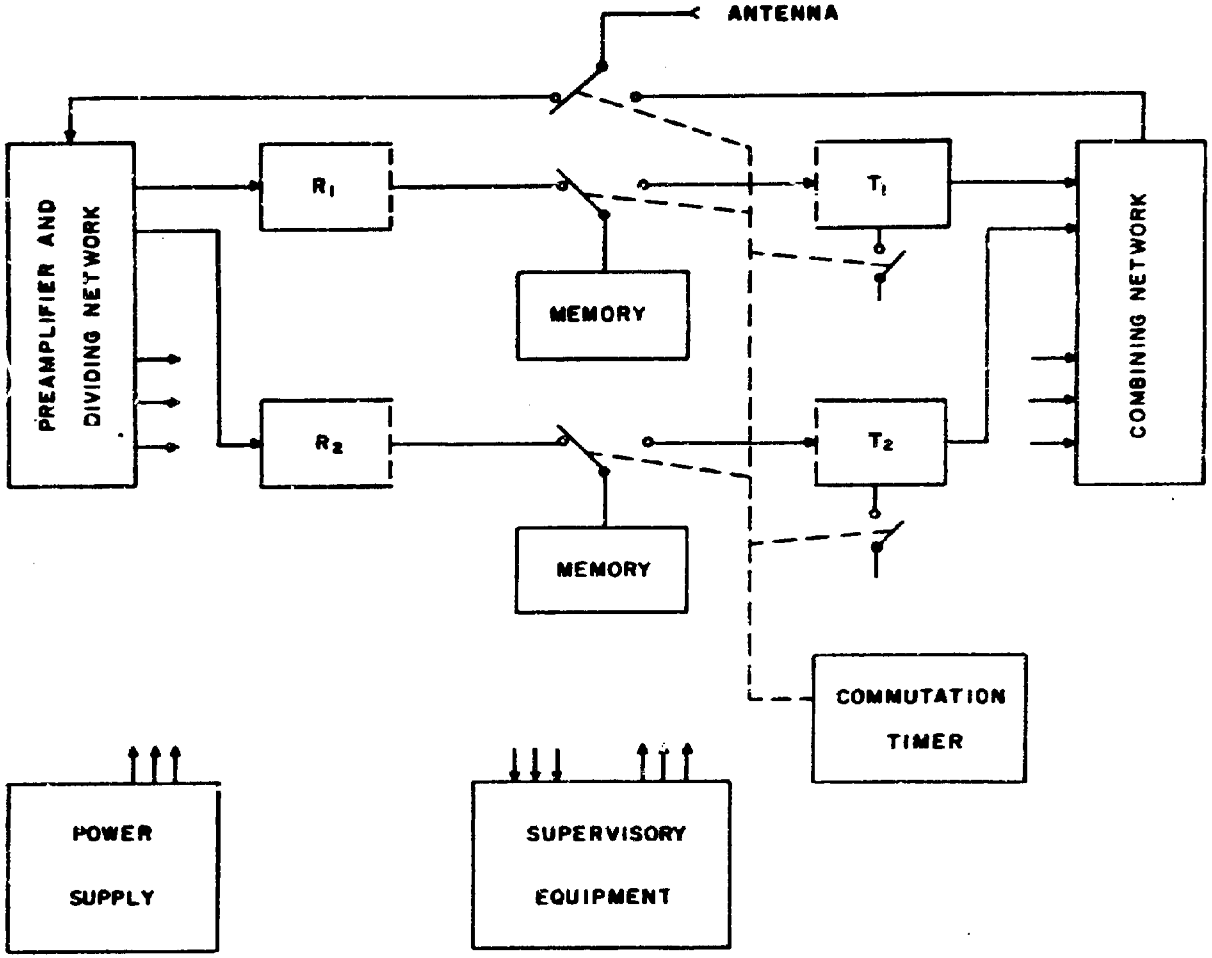


Figure 3.4-2. Common Frequency Switching Repeater (F_1 - F_1)

The preliminary selection of the best candidate relay system consists mainly of the elimination of the less suitable candidate relay systems. The selection of the best system for the initial period limits the choice to systems presently being supplied to the armed forces.

In some cases, modifications of candidate relay systems may be made that would improve the system performance enough to change their relative standing for this selection. Some of these modifications might be rather drastic and would entail substantial changes in the operational system. Several of these major changes in system design, primarily intended for the interim or the long-range time period, include the use of power control, the use of supervisory control, the use of F_1-F_1 switched systems, and the use of random access discrete address (RADA) systems.

The list of candidate relay systems is discussed first and begins with VHF equipments that are compatible with the present VHF tactical ground radio equipment. Next are listed the UHF equipments that are compatible with existing Air Force UHF aircraft equipment and with U.S. Army ground liaison equipments. Next are listed the equipments that would be compatible with the existing UHF and microwave point-to-point multichannel relay terminals. Finally, an assorted list of passive and semi-active equipments is given.

3.4.2 <u>VHF Repeater Types</u>. The first portion of this list of candidate relay equipments shows a number of equipments that are compatible with the existing VHF tactical radio equipment that is in extensive use. Important technical, logistic, economic, and availability factors are listed in Tables 3.4-1 through 3.4-3. AN/PRC-25 radio equipment was assumed to be used on the ground, since it represents a modern design that is in production and also quite extensively deployed. The allowable loss in Tables 3.4-1 through 3.4-3 is simply the difference between the transmitter output power and the receiver input power required for a 10 db audio signal-to-noise ratio. This difference must then include antenna gains, feed system losses, jungle losses, free space path loss, variability allowances, and system margin allowances.

3.4.2.1 <u>AN/PRC-25</u>. The first relay equipment being considered is the AN/PRC-25 itself (ref. 3.4-1). It may be used for relay purposes by cross-connecting two equipments with a radio relay cable assembly and operating them back-to-back with a minimum of a three-foot separation between sets. This relay will operate on a single channel only (one-half duplex operation) since the tuned circuits are quite selective. Two complete equipments are necessary for relay operation since the receiver and transmitter units of an individual AN/PRC-25 radio equipment cannot be tuned to different frequencies. Only 30 db of isolation or less is obtained from the use of separate antennas for receive and transmit so that the required additional 60 to 80 db of isolation must be obtained by the use of a frequency separation (F_1-F_2 operation). The weight (less batteries) and volume of the complete relay equipment must be

Table 3.4-1. VHF Relay with AN/PRC-25 Ground Stations

RELAY EQUIPMENT TYPE (Quantity)	Availability	Cost	Weight, Lbs. (less batteries)	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[3] Loss, db	Downlink Allowable[3] Loss, db	Ref. Source 3.4- [ ]	REMARKS
AN/PRC-25 (2)	Prod.	1400	27.2	0.56	15.7	1	1.5-1.0	0.5	30-76	144.7-143.0	144.7-143.0	[1]	
AN/PRC-25 (2) with AM-4306 (2)	Prod.		33.7	0.84	68.5	1	25	0.5	30-76	144.7-143.0	157-157	[2]	
AN/PRC-77 (2)	Dev.	2450	26.5	0.56	9.7	1	2.0-1.5	0.5	30-76	144.7-143.0	146.0-144.7	[3]	
AN/ARC-54 (2)	Prod. Std. A		53	1	261.5	1	10	1.2	30-70	137.2-135.5	153.0-153.0	[4]	
AT-430 (2)	Prod.		40	0.56	132	1	40	0.4	2-76	146.7-145.0	159-159	[5]	
AN/PRC-70 (2)	Prod.		28	0.69	132	1	40	0.4	2-76	146.7-145.0	159-159	[6]	
Broadband Translator			3	0.1	12	12[2]	1	3db[7]	30-50 56-76	131.5-132	140-141.7	[7]	See Paragraph 3.4.2.7
AN/PRC-9 (2)	Std. B		50[1]			1	1.0	0.5[4]	27-38.9	144.7	143.0	[8]	

FOOTNOTES:

1. Incl. Batteries
2. 12 Channels in simultaneous use out of a possible 400
3. For isotropic transmitting and receiving antennas, see paragraph 3.4.2
4. Assumed
7. Noise Figure

Table 3.4-2. VHF Relay with AN/PRC-25 Ground Stations

RELAY EQUIPMENT TYPE (Quantity)	Availability	Cost	Weight, Lbs. (less batteries)	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[3] Loss, db	Downlink Allowable[3] Loss, db	Ref. Source 3.4- [ ]	REMARKS
AN/PRC-10 (2)	Std. B		50[1]			1	0.9	0.5[4]	38-54.9	144.0	142.5	[8]	
AN/PRR-9 (1 Rec.)	Dev.		0.5	35.3 cu in	0.034 (max)	1	--	0.5	47-57	144.0	--	[8, 25]	
AN/PRT-4 (1 Trans.)	Dev.		1.0	28.1 cu in	1.44	1	0.45	--	47-57	--	139.5	[8, 26]	
AN/ARC-114 (2)	Dev.	4200[5]	16	.15	60	1	10	0.6	30-70	143.1-141.4	153	[8]	
R-1297( )-/ARC (Rec. only)	Dev.	1000[5]	2	.025	10	1	--	0.6	48-50	142.4	--	[8]	
AN/PRC-72 (2)	Dev.		50	0.87		1	6	0.5[4]	38-50	144.0	150.8	[16]	
AN/ARC-44 (2)	Std. B		78		495	1	8	0.5[4]	24-51.9	144.0-144.7	152.0	[8]	
AN/ARR-49 (Rec. only)	Dev.	1500	16.8	.22	82.5	1	--	0.5[4]	30-70	143.0-144.7	--	[8]	

FOOTNOTES:
1. Incl. batteries
3. For isotropic transmitting and receiving antennas, see paragraph 3.4.2
4. Assumed
5. Cost for development model

Table 3.4-3. VHF Relay with AN/PRC-25 Ground Stations

RELAY EQUIPMENT TYPE (Quantity)	Availability	Cost	Weight, Lbs. (less batteries)	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[3] Loss, db	Downlink Allowable[3] Loss, db	Ref. Source 3.4- [ ]	REMARKS
Entron, Model CU	Prod.	725	12.5	.35	18	12	3.5[6] mw	7 db[7]	54-216 470-890		107.7	[23]	
AN/PRC-25 (12)	Prod.	8400	163	3.4	94	6	1.5-1.0[6]	0.5	30-76	144.7-143.0	144.7-143.0	[1]	
AN/PRC-77 (12)	Dev.	14700[5]	159	3.4	58.2	6	2.0-1.5[6]	0.5	30-76	144.7-143.0	146.0-144.7	[3]	
AN/ARC-114 (12)	Dev.	25200[5]	96	0.9	360	6	10[6]	0.6	30-70	143.1-141.4	153	[8]	
AN/ARC-114(6) and R-1297( )-/ARC(6)	Dev.	18600[5]	60	0.6	360	6	10[6]	0.6	30-70	143.4	153	[8]	
Broadband Translator (with AM-4306)			6.25	0.24	64.8	12[2]	2.1[6]	3db[7]	Rec. 30-50; Trans. 56-76	145.7-145.0 --	-- 146.2	[24]	See Paragraph 3.4.2.20

FOOTNOTES:

2. 12 channels in simultaneous use out of a possible 400
3. For isotropic transmitting and receiving antennas, see paragraph 3.4.2
5. Cost for development model
6. Power per channel
7. Noise figure

doubled, but the primary power requirements are only the sum of the transmit power of one AN/PRC-25 and the receive power of the AN/PRC-25. Since AN/PRC-25 equipments are in use on both the high altitude and ground terminals of this communications path, the allowable path loss is the same on the uplink as on the downlink.

3.4.2.2 AN/PRC-25 with AM-4306. If a greater amount of transmitter power is thought desirable, to increase the downlink allowable path loss, a single AM-4306 amplifier (ref. 3.4-2) may be used after the AN/PRC-25 transmitter. This increase in power output from 1.5 watts to 25 watts increases the allowable path loss (downlink) by 12.2 db.

3.4.2.3 AN/PRC-77. The next equipment listed is the AN/PRC-77 (ref. 3.4-3). This equipment is a modernized version of the AN/PRC-25, having an output power transistor in the transmitter to replace the single tube of the AN/PRC-25, which gives better reliability and battery life. This equipment is also single channel and may be used back-to-back with a separation of four feet or more between the two equipments (and antennas).

3.4.2.4 AN/ARC-54. The AN/ARC-54 (ref. 3.4-4) may also be used as an unattended relay station by connecting two equipments back-to-back. The ten watt output of this transmitter provides about 10 db more allowable path loss attenuation in the downlink but provides about 7 db less allowable path loss in the uplink than the AN/PRC-25, due to the poor sensitivity of its receiver. It is not fully transistorized, thus it is quite heavy and requires much more primary power than the AN/PRC-25.

3.4.2.5 AT-430. The next equipment listed is the AT-430 (ref. 3.4-5), which is a development of the Avco Corp., intended for airborne applications. It has a high-power transmitter (40 watts output), so that it can provide an allowable downlink path loss of about 16 db above that of the AN/PRC-25. It also has a slightly more sensitive receiver than the AN/PRC-25 and thus provides about 2 db better allowable path loss for the uplink. It also covers a much wider frequency range (from 2 to 76 MHz) and has an optional single sideband mode of modulation, as well as FM. The power drain on transmit is much more than that for the AN/PRC-25, but it is substantially less than that of the AN/ARC-54 (despite its lower output power).

3.4.2.6 AN/PRC-70. The next type that is listed is the AN/PRC-70 (ref. 3.4-6). This equipment has the same performance specification as the AT-430, but it is lighter in weight, smaller, and has a military designation. It is in production in limited quantities. It also uses a 6- to 15-foot whip antenna instead of the 3-foot whip normally used with the AN/PRC-25, which should be more efficient at the 30 MHz end of the usual VHF range.

3.4.2.7 Broadband Translator. All of the equipments that have been listed and discussed up to now are strictly for single-channel operation. The next equipment that is listed is not a production equipment or even a developmental equipment (ref. 3.4-7), but is only listed to suggest the possibilities for an equipment that is specifically designed for this application. It is a combination of off-the-shelf sub-assemblies (or components) that could be assembled and integrated with a minimum of development work. While this equipment has a theoretical capability of handling a total of 400 channels (20 MHz bandwidth), the practical number of channels would be limited to a smaller number. This limitation is due to the division of transmitter power among the active simultaneous users. Figure 3.4-3 shows the block diagram for a broadband translator to operate from 30 to 50 MHz. A similar translator could be designed for the 56 to 76 MHz upper half of this VHF tactical radio band. This broadband translator would require separate receiving and transmitting antennas, which could be mounted colinearly to provide about 30 db of isolation from each other. Bandpass filters, such as the Applied Research, Inc., BPF-35 and BPF-59, could then provide additional isolation of input and output because of the frequency offset built into the equipment. The overall gain of the equipment is about 116 db, and it should be operated in the linear mode with an automatic gain control.

This automatic gain control circuit should have a relatively long time constant to minimize the reduction of gain caused by strong pulsed or impulsive signals, and to reduce the amount of noise during gaps in the incoming signals. Linear operation of the amplifiers is desirable, even with FM signals to prevent capture of the equipment by strong signal (3 db or more above the weaker signals), with a subsequent sharp reduction in the output power of weaker signals. While this effect will still occur with the use of automatic gain control, it is felt that it will be less severe than the capture effect that occurs with the use of "hard" limiters,

While the automatic gain control circuitry, the mixer, and oscillator are not represented by a standard manufacturer's type number, the circuitry involved is quite conventional and should require a minimum of development work. This equipment, while it is quite low power, does have almost as much power as the AN/PRC-25 (for one channel), and offers almost an order of magnitude reduction in weight. This weight does not include packaging, shock mounts, insulation or other modifications that may be necessary for installation in various platform vehicles.

This proposed broadband translator equipment has a bandwidth sufficient for 400 channels (assuming 50 KHz separation between channels) but the number of channels that can be active simultaneously is limited by the power division that occurs between channels. If we assume that 12 channels are in use at the same time at the maximum power level, then the power would only be one-twelfth watt per channel. This power would be insufficient for the maximum range and would limit the usable range considerably. The

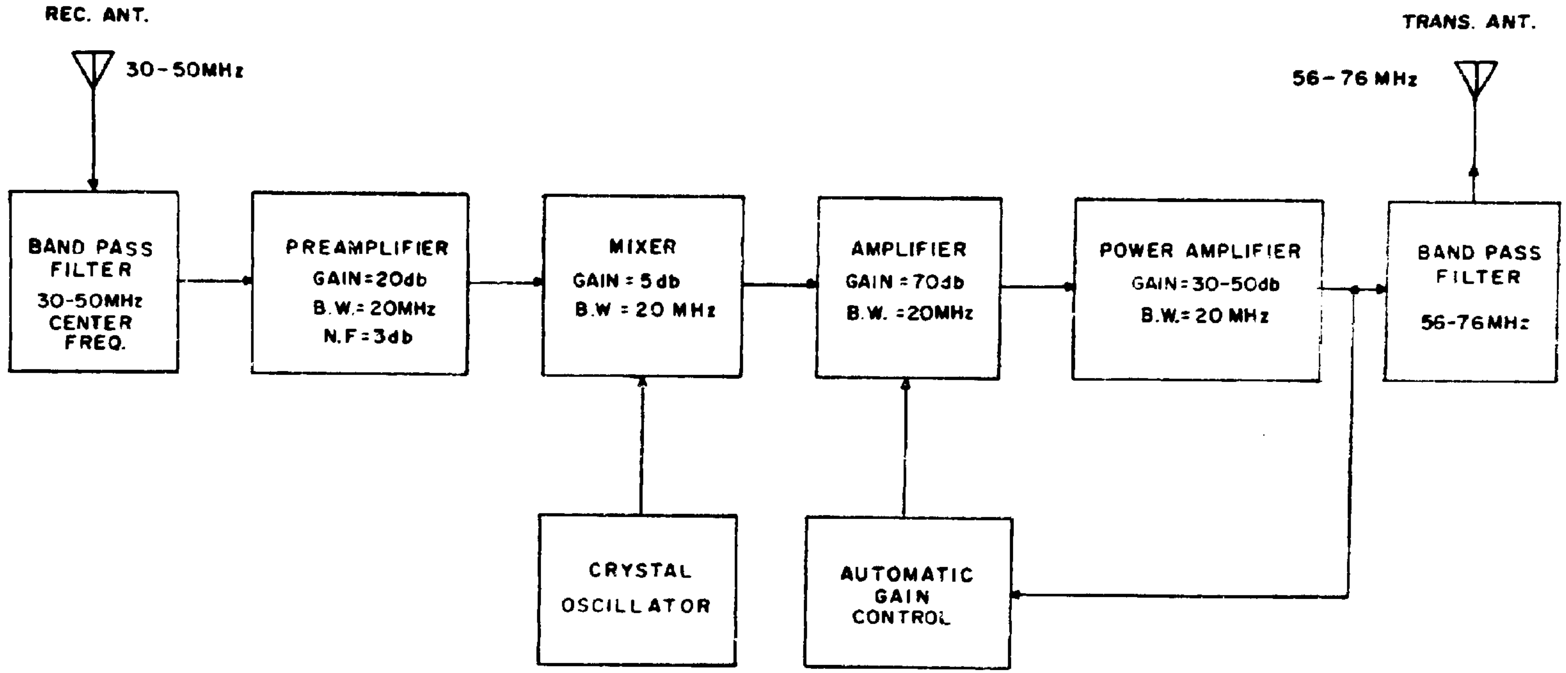


Figure 3.4-3. Broadband Frequency Translating Repeater

range would be about the same as the AN/PRC-25 if only one channel is active at one time. The addition of a power amplifier, such as the AM-4306, is considered later in this list.

3.4.2.8 AN/PRC-8, 9, and 10. The AN/PRC-8, AN/PRC-9, and AN/PRC-10 radio equipments (ref. 3.4-8) may be discussed at the same time, since they are essentially all versions of the same equipment, designed to replace the SCR-300, AN/VRC-3, SCR-509, SCR-510, SCR-609, SCR-610, and SCR-619 radio sets. They may be used for vehicular operation if their dry cells are replaced by the PP-545/U power supply. This equipment series is classified as Standard B and is being replaced by the AN/PRC-25 as soon as sufficient AN/PRC-25 radio sets are available in the field. They are much heavier than the newer AN/PRC-25 radio sets and have a greater battery drain, since they are not transistorized. They also are unsatisfactory in frequency stability and are too hard to retune to other channels, since they require that their master oscillator be retuned and then readjusted to agree with an internal crystal calibrator. Since three different equipment types are necessary to cover the total frequency range, logistic problems have been compounded. They are also almost twice as heavy as the AN/PRC-25 radio sets that are replacing them. The frequency range of the AN/PRC-8 (20-27.8 MHz) is not compatible with the usual AN/PRC-25 ground equipment and is also subject to considerable skywave interference, especially during periods of sunspot maxima. The upper frequency limit of the AN/PRC-10 (54.9 MHz) does not take advantage of the full frequency range of the AN/PRC-25, and thus is limited to a smaller number of frequency channels.

3.4.2.9 Squad Radio Set (AN/PRR-9 and AN/PRT-4). The AN/PRR-9 (ref. 3.4-8, 3.4-25, and 3.4-26) is an ultra-minature helmet-mounted receiver in the later stages of development. The AN/PRT-4 is a hand-held, lightweight transmitter with low power requirements which is also in the later stages of development. Both types of equipment are intended for intrasquad and platoon communications. The transmitter, AN/PRT-4, provides two operating channels which must be separated by less than one MHz. There are two power levels; the low power position (100 mw) is intended for communications from squad leader to individual soldier, and the high power position (450 mw) for the second channel is for intra-squad coordination. The receiver has a single preset channel, tunable with the 47-57 MHz range. The AN/PRR-9 receiver uses five integrated circuits for increased reliability and large reductions in size and weight. The RF amplifier, which has a 5 db noise figure and a sensitivity of .002 picowatts at 51 MHz, is one of these integrated circuits. Others are: the mixer/oscillator module, the IF amplifier, the limiter-squelch, and the audio amplifier. The total power drain is 16.2 milliwatts on standby and 33.9 milliwatts at the full audio power of 5 milliwatts (the audio output stage is biased class B). The transmitter requires 1.44 watts of battery power at full output and does not require any standby power. The receiver only requires a volume of 35.3 cubic inches and the transmitter volume is 28.1 cubic inches.

3.4.2.10 AN/ARC-114. The AN/ARC-114 (ref. 3.4-8) is one of a series of avionics equipments being designed for future use in the light observation helicopter, UH-6B. This unit is completely solid state throughout and may replace the much larger and heavier AN/ARC-54 in the LOH or other U.S. Army aircraft. It has a receiver sensitivity of 0.6 microvolts and the transmitter power output is ten watts. It operates directly from the 27.5 volt dc aircraft primary power supply and requires a maximum of about 60 watts. It is capable of receiving and transmitting frequency modulated voice signals on any one of the 800 frequency channels, spaced each 50 KHz in the range from 30 to 69.95 MHz. Retransmission and housing functions are to be included. The transceiver unit weighs only eight pounds and has a volume of 130 cubic inches (.15 cubic ft.). This equipment has been operated successfully to an altitude of 50,000 feet, even though the original specification was for only 15,000 feet. It has also been tested in the environmental temperature from -25°F to +145°F with no degradation in performance and has given a performance for the preliminary tests within 70 to 80 percent of the specification over the termperature ranges from -55°F to -25°F and from +145° to +165°F, while the specification allowed a 50 percent degradation in performance (unofficial information). This equipment appears to be a prime candidate for the interim time period, when it should be available in production quantities.

3.4.2.11 R-1297 ()-/ARC. This receiver, R-1297( )-/ARC (ref. 3.4-8), is also one of the series of avionics equipments being developed for future use in the light observation helicopter, UH-6B. This receiver is very light in weight (2 pounds) and compact (43 cubic inches), but it may be tuned over only a very limited frequency range (48 to 50 MHz). It is intended to be used to monitor specially designated frequencies within this frequency range for high-priority traffic in tactical aircraft. It may also be used as an auxiliary receiver for FM signals in conjunction with the radio sets AN/ARC-54, AN/ARC-44 or AN/ARC-114. The receiver has an audio output power of 150 milliwatts and requires about 10 watts of 27.5 volt dc aircraft primary power.

3.4.2.12 AN/PRC-72. The AN/PRC-72 (ref. 3.4-16) is a light-weight portable radio set in the final stages of development at the Bendix Corp., Radio Division. The specifications for this equipment were drawn up by the U.S. Air Force Rome Air Development Center but the set is intended for use by all the services. It is a 25-pound package of every tactical radio used by the military services today and is modular construction. It covers the high, very-high and ultra-high frequency ranges in the AM, FM and single sideband modes of modulation. Four separate transceiver modules are used for each frequency range and are mounted on a rack that requires 0.87 cubic feet of volume. The VHF-FM unit covers the restricted frequency range of 38-50 MHz and the transmitter will produce an output power of six watts on any one of six crystal-controlled channels within this frequency range. These transceivers use snap-on, self-contained, steel-tape antennas. Operational aids and safeguards designed into the individual radio sets include low-battery indicators, field change of preset channels without test equipment, interchangeable antennas, and provisions for repeater operations. A headset microphone containing two audio connectors and two push-to-talk switches adds flexibility to the system, allowing the operator to use one transceiver while monitoring another, or to monitor two while talking one one, and so on.

3.4.2.13 AN/ARC-44. The AN/ARC-44 (ref. 3.4-8) is an older design of aircraft communications equipment that is being replaced by the more modern AN/ARC-54. It is thus classified as "Standard B." The AN/ARC-44 consists of only one transceiver unit, the RT-294/ARC-44. It is an FM equipment and is thus compatible with the standardized equipment used in the field, such as the AN/PRC-25 but covers only part of the AN/PRC-25 frequency range. The frequency range of 24 to 51.9 MHz includes 6 MHz from 24 to 30 MHz that may soon be subject to serious skywave interference as the number of sunspots increases. It does not cover the 51.9 to 76 MHz portion of the AN/PRC-25 frequency range, so it cannot provide as many channels as that ground equipment. It is quite heavy (it weighs 39 pounds) and requires a much greater amount of primary power (495 watts for 2 units) than more modern transistorized equipments, such as the AN/ARC-114. This equipment cannot provide channels with closer than 100 KHz spacing between channels so that a total of only 280 channels are available. It is designed for aircraft use so that it will be compatible with the altitude and environmental requirements of airborne operation.

3.4.2.14. AN/ARR-49. The AN/ARR-49 (ref. 3.4-8) is a developmental equipment for receiving only. It was designed to be operated as an auxiliary receiver with the AN/ARC-54 to provide guard channel capabilities to the pilot while in flight status. It is unusual for a guard channel receiver to cover the entire frequency range of 30-69.95 MHz of the accompanying transceiver. This factor probably accounts more for the much greater weight (16.8 lbs. instead of 2 lbs.) than that of the R-1297( )/ARC and the higher cost ($1,500 instead of $1,000). It also requires much more power than the R-1297( )/ARC (82.5 watts instead of 10 watts). In other words, it would be a poor choice for an auxiliary receiver unless the full frequency range is necessary.

3.4.2.15 Entron, Model CU. This production type of CATV equipment is listed only to show some of the possibilities obtained by using broadband translator equipment. The power output is not sufficient for the HARR purpose but amplifiers could be added. The receiving frequency range is also not suitable for this purpose, since it is above the normal military UHF band of 225 to 400 MHz. It could be modified to cover this military VHF band on receive and the lower limit of the transmitting frequency range could be extended downward from 54 to 30 MHz. The resulting equipment could then be used to translate and relay from the UHF band to VHF for liaison between the U.S. Air Force and the U.S. Army. Since it is primarily designed for ground operation, it could not meet the altitude, temperature, and other environmental requirements of airborne operation. It is of value primarily to demonstrate the operation of a broadband multichannel equipment, although the multiple access and dynamic range problems of television are very much simpler than they would be for an equipment intended for military tactical use.

3.4.2.16 Six Channels of the AN/PRC-25. To provide for half duplex operation with six voice channels, 12 transceivers are necessary. They may be operated in six pairs of transceivers, as with the AN/PRC-25. Each pair of transceivers is connected with a radio relay cable kit and set up with a separation of three feet or more to form a radio relay station. Two separate transceivers are necessary for a relay station for one channel because the transmitter must be operated on a different frequency from the receiving frequency or the transmitter of each transceiver will block its own receiver. A second transceiver is necessary for different frequency operation (F_1-F_2) because the same frequency synthesizer is used to establish both the transmitter and the receiver frequency; and the receiver and transmitter cannot be tuned to different frequencies.

The AN/PRC-25 equipment does not have automatic gain control, but does have a squelch circuit. When two AN/PRC-25's are used back-to-back, as F_1-F_2 repeaters, the squelch from one receiver (say F_1) is used to turn on the F_2 transmitter and to short the receiver input to the F_2 receiver. At the same time, the F_1 transmitter is disabled. The attack time of the squelch system is of the order of several milliseconds while the release time is a fraction of a second.

The weight for six pairs (12) of these AN/PRC-25's connected as F_1-F_2 repeaters for six half duplex channels is given as 163 pounds. This weight is for the basic transceivers, without the batteries or the battery cases. It also does not include the power supplies (primary power should be provided by the airborne platform), the output combining networks, the input dividing networks, and possible also a preamplifier or the diplexing filter which isolates the receiver and transmitter from each other but still connects both to the antennas. The weight of optional supervisory equipment is also not included in this weight figure. An additional 20 percent of this weight figure should also be added for equipment mountings. Since the preamplifier is broadband, a single unit may be used for all six channels and only about five to ten pounds need to be added for this equipment. The diplexing filter should cover both preamplifier, diplexer, and input and output combining and dividing networks.

This AN/PRC-25 equipment is made up of equipment now in production and already deployed in the field. It thus represents an excellent candidate for the high altitude radio relay repeater equipment for the initial period.

3.4.2.17 Six Channels of AN/PRC-77. The AN/PRC-77 tactical radio equipment is an all solid-state version of the AN/PRC-25. This equipment, which has a much greater reliability than the AN/PRC-25 and requires less battery drain, is in an advanced state of development. Since it is designed as a transceiver with both transmitter and receiver operating on the same frequency, it will also have to be used in pairs of transceivers, connected back-to-back with a cable. This way the receiver of one transceiver may operate the transmitter of another transciever on a frequency several megahertz away. For six channels it is thus necessary to use twelve transceivers and twelve frequencies. This equipment is almost the same weight as the AN/PRC-25 and has exactly the same volume. It thus may not represent the best that can be done in a development equipment and is not the best candidate for the interim time period.

3.4.2.17 Six Channels of AN/PRC-77. The AN/PRC-77 tactical radio equipment is an all solid-state version of the AN/PRC-25. This equipment, which has a much greater reliability than the AN/PRC-25 and requires less battery drain, is in an advanced state of development and is designed for use in the U.S. Army light observation helicopter, the UH-6B. It is also designed as a transceiver, with both receiver and transmitter operating on the same frequency. In order to use this equipment for a repeater, two transceivers on separate frequencies are joined with a cable to connect the audio circuits and the squelch or other control circuits, as with the AN/PRC-25 and the AN/PRC-77.

This equipment requires only about one-fourth the volume of the AN/PRC-25 and AN/PRC-77 types and is designed for aircraft use. This equipment has been tested successfully at altitudes up to 50,000 feet and over a full temperature range so that no modifications should be necessary to operate the AN/ARC-114 for this airborne application. A substantial savings in weight may be made by using this equipment instead of the AN/PRC-25. Full use of the 10 watt power output of the AN/ARC-114 cannot be made because the system is limited by the low uplink power output (1.5 watts) of the AN/PRC-25 at the ground station. The overall reliability of the entire relay system will be improved, however, because of the improved performance of the downlink. While the primary power requirements of this equipment are greater than the AN/PRC-25 and the AN/PRC-77, the total power for six channels is well within the capabilities of a platform primary power supply.

3.4.2.19 Six Channels of AN/ARC-114 and R-1297 ( )-/ARC. The R-1297 ( )-/ARC, which is an auxiliary receiver being developed for the light observation helicopter may be used with the AN/ARC-114 to provide a simplex type of channel operation. Six channels of F_1-F_2 type may be provided by the use of six of the R-1297 ( )-/ARC receivers with six AN/ARC-114 transceivers. The transmitter portion of the AN/ARC-114 only is in use and the receiver portion cannot be used at all. The worst disadvantage of this system is the requirement for separate receivers or a second transceiver at each ground station, since the repeater signal must be received on F_2 and the ground transmitter must be on F_1 to communicate through the repeater.

Although there is a weight saving of 60 percent for the airborne repeater equipment over the use of two AN/ARC-114 transceivers per channel, the requirement for an additional receiver on the ground is quite serious and tends to make the entire system impractical. Even if the R-1297 ( )-/ARC could be replaced by the helmet receiver, AN/PRR-9, a separate AN/PRR-9 would have to be used on the ground. The normal AN/PRR-9 would be set up on the channel used for squad communications, and channel changes cannot be made easily in the field. This would require the second helmet receiver set up on the repeater transmit frequency.

3.4.2.20 Broadband Translator and AM-4306 Amplifier. A system using a broadband translator would be more suitable for system use if the power per channel of the transmitter were increased to about the same level as that of the AN/PRC-25. The AM-4306 amplifier, designed for use with the AN/PRC-25, has a power output of about 25 watts which would provide over two watts per channel for a 12-channel system. Since the weight of the AM-4306 is only about three and one-fourth pounds and the weight of the broadband translator is only about three pounds, the total weight of six and one-fourth pounds is very much less than any other multichannel equipment. The power requirements are also quite low and are comparable to those of twelve AN/PRC-77's. The volume requirements are for a half-duplex system, since all ground stations must transmit on one frequency to be able to receive on another single frequency (the translator equipment has a fixed frequency offset).

This equipment has the same major disadvantages as the system using combined AN/ARC-114 transceivers and R-1297 ( )-/ARC receivers. This is the requirement for separate receivers or a second transceiver for each ground station, because each ground station must transmit to the repeater on one channel or group of channels and receive on the repeater's second channel or group of channels. A system using a squelch circuit to operate a duplicate repeater system with a frequency offset of the same magnitude but of opposite direction would not work with a broadband system. It could be done only with single channels as with the system using AN/PRC-25's in pairs. Thus, ground stations with single transceivers could not use a broadband F_1-F_2 translater system. This would represent a major disadvantage and would mean that this system is not a prime candidate, even for the interim or long-range time frame, when such a system could be developed.

3.4.3 UHF Repeater Types. The next portion of this list of candidate relay equipment shows a number of equipment types that are compatible with the existing UHF aircraft radio equipment and ground-air radio equipment that is in use or in development for the U.S. Army or the U.S. Air Force. Important technical, logistic, economic and availability factors are listed in Tables 3.4-4 and 3.4-5. Power budgets have also been calculated for these equipments using isotropic antennas and using half-wave vertical dipole antennas at both the ground station and at the repeaters.

Table 3.4-4. UHF Relay with AN/ARC-45 Ground Stations

RELAY EQUIPMENT TYPE (Quantity)	Availability	Cost	Weight, Lbs. (less batteries)	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[2] Loss, db	Downlink Allowable[2] Loss, db	Ref. Source 3.4 - [ ]	REMARKS
AN/ARC-45 (2)	Prod. Std. B	6400	35.4	0.8	187	1	2	3[1]	225-400	130.5	130.5	[8]	
AN/ARC-55 (2)	Prod. Std. B	3100	126	4.0	1100	1	9	3[1]	225-400	130.5	137.0	[8]	
AN/ARC-97 (1)	Prod.		23	0.44	280	1	4	5	225-400	126.0	133.5	[9]	
AN/ARC-51X (2)	Prod. Std. A	3780	62	1.4	600	1	20	2	225-400	134.0	140.5	[10]	
AN/GRC-134 (2)	Prod.		190	5.5	1280	1	50	3	225-400	130.5	144.5	[11]	
AN/PRC-71 (2) (Modified)	Dev.		22	0.4	100	1	3.5	5	230-360 300-400	126.0	132.9	[12]	Uplink Downlink
AN/ARC-89 (2) (Improved)	Prop. Dev.		180	3.2	1880	1	50	3	225-400	130.5	144.5	[13]	
AN/VRC-24 (2)	Prod. Std. A		164			1	15	3[1]	225-400	130.5	139.2	[8]	

FOOTNOTES:

1. Assumed
2. See paragraph 3.4.2

Table 3.4-5. UHF Relay with AN/ARC-45 Ground Stations

RELAY EQUIPMENT TYPE (Quantity)	Availability	Cost	Weight, Lbs. (less batteries)	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[2] Loss, db	Downlink Allowable[2] Loss, db	Ref. Source 3.4-[ ]	REMARKS
AN/ARC-116 (2)	Dev.	4400	20	.18	72	1	40 pep	4	225-400	128.0	143.5	[8]	
AN/TRC-68 (1)	Std. A	7968	254	11.2	360	1	16	6	225-400	124.3	139.5	[17]	
AN/ARC-85 (2)	Prod.		232	7.2		1	50	3[1]	225-400	130.5	144.5	[18]	
AN/ART-46 (Trans. only)	Prod.		65	1.15	843	1	50	--	225-400	--	144.5	[20]	
AN/ARR-71 (Rec. only)	Prod.		18	0.35		1		3	225-400	130.5	--	[21]	
AN/ARC-109 (2)	Prod.		64.6		600	1	30	3	225-400	130.5	142.3	[22]	

FOOTNOTES:
1. Assumed
2. See paragraph 3.4.2

3.4.3.1 AN/ARC-45. The AN/ARC-45 (ref. 3.4-8) is a production type (Standard B) of UHF equipment that is in use by the U.S. Army for communication between aircraft in flight and aircraft and ground stations. It is a low power equipment (only two watts) but is lighter in weight and requires less power than many other equipments of this general type. It is an amplitude modulated (AM) equipment that tunes from 225 to 400 MHz on any one of 1750 channels. Twelve channels can be preset in advance. It is thus not compatible with the present FM ground tactical equipment and may be considered only as a candidate for the interim or the long range time frame.

3.4.3.2 AN/ARC-55. The AN/ARC-55 (ref. 3.4-8) is also a production type (Standard B) of UHF equipment that is in use by the U.S. Army for communication between aircraft in flight and aircraft and ground stations. Since it is designed for aircraft use, it should meet all the necessary altitude and other environmental requirements for use on an airborne platform. The AN/ARC-55 is a heavy and bulky piece of communications equipment that is being replaced by the AN/ARC-51. It is normally used only in larger Army aircraft. Since it is also an AM equipment that operates only in the 225 to 400 MHz UHF band, it is incompatible with the present FM ground tactical equipment and may be considered as a poor candidate for even the interim or the long-range time frame.

3.4.3.3 AN/ARC-97. The AN/ARC-97 (ref. 3.4-9) is an RCA designed radio repeater set that is presently the only available self-contained two-way automatic radio relay system. The complete system includes a remote control panel, a receiver-transmitter unit and a shock mount. The receiver-transmitter unit itself contains two receivers, two transmitters, a power converter, and an axial blower to provide its own cooling. It provides a capability for automatic switching, as required by the signal being received, and thus is suitable for use in completely unattended drone applications or for applications in external pod mounting in many aircraft. An optional coupler is also available that will permit the operation of up to six receivers from a single antenna with no loss in system sensitivity. The availability of two separate receivers and transmitters provides an alternate command set on two frequencies which, if desired by the operator, can override the relay function. The equipment is shock mounted with polyurethane foam, which provides excellent isolation for the receiver-transmitter unit from the airframe, and is capable of continuous transmitter operation up to 10,000 feet. It is thus quite suitable for airborne applications.

The weight is quite low (only 23 pounds), the volume is only 0.442 cubic feet, which is also quite low, and the power requirement is lower than for many of the comparable aircraft communications equipment types.

Since it is also an AM equipment that operates only in the 225 to 400 MHz UHF band, it is incompatible with the present FM ground tactical equipment and may be considered only as a candidate for the interim or for the long-range time frame although it is a good candidate in its general class.

3.4.3.4 AN/ARC-51X. The AN/ARC-51X (refs. 3.4-8 and 3.4-10) is the preferred present production type (Standard A) of UHF radio communication equipment for army aircraft use. This equipment is quite heavy and bulky (31 pounds apiece and 0.7 cubic feet apiece) and requires a large amount of primary power (300 watts apiece), but it does have a higher power output (20 watts) that most of the UHF radio equipment types. It does not represent an advanced design nor it is greatly transistorized. It is also not compatible with the normal FM ground tactical communications equipment since it is an AM equipment operating in the UHF frequency range and not the VHF FM band. It may be considered a poor candidate for even the interim or the long-range frame.

3.4.3.5 AN/GRC-134. The AN/GRC-134 (ref. 3.4-11) is a production type of UHF AM radio communications equipment intended for use with the Marine Tactical Data System. This unit was originally built for use in fixed or mobile ground installations but it operates from a 400 Hz ac power supply and is thus readily adaptable to airborne applications. The frequency synthesizer supplies both the receiver and the transmitter portions of this transceiver so that it cannot receive and transmit on different frequencies. The 50-watt power output is substantially above most of the other UHF radio communications equipment types, which is a partial explanation for its high power requirements (680 watts apiece). It is also quite large (2.75 cubic feet) and quite heavy (95 pounds apiece), and two transceivers would be necessary for a repeater system. Although it will meet environmental specifications for military use, there is no indication of its high altitude capability. This type is also incompatible with the present VHF FM tactical ground radio equipment since it is AM and covers the 225 to 400 MHz UHF range. It is a poor candidate for the HARR system unless large aircraft are used at high altitudes for the airborne platform in the interim or the long-range time period.

3.4.3.6 AN/PRC-71. The AN/PRC-71 is an all-solid-state UHF airborne equipment. A diplexer is used to permit the use of a common antenna for the receiver and transmitter portion of the repeater equipment. A pressurized container is also used to permit operation up to 60,000 feet altitude. The repeater itself does not demodulate the repeated signal so that FM and PM signals, as well as AM signals, can be handled. This equipment has been tested on drone vehicles and on balloons as a repeater. Two complete repeater equipments were in use to permit full duplex operation. An AT-256A antenna was used on the drone, having a gain of -3 db while an AS-1097/GR UHF antenna was used on the balloon tests, having a gain of 6 db maximum (4 db average was used in system calculations).

This equipment is only in the development stages and thus is not available for the initial time period. Since the AN/PRC-71 is a UHF equipment and would be suitable only for the interim or long-range time period. It is a good candidate for the interim time period since it is all solid state thus is light in weight, requires little space, and has reasonably low power requirements.

3.4.3.7 AN/ARC-89. The AN/ARC-89 itself is not actually described in this discussion and on the accompanying data sheet, but a low-power version using more modern component equipments is described. This AN/ARC-89 is made up of the ART-48, or the AN/ART-46, AN/FM transmitter, which is the 50 watt exciter portion of the AN/ART-47 one kilowatt UHF AM/FM transmitter and the AN/ARR-71 receiver. These components have a total weight (for two complete equipments) of 180 pounds and require 3.2 cubic feet of space. They also require a total of 1,880 watts of primary power. These component equipments were originally designed for airborne applications and will meet military environmental requirements. Since this equipment is large, heavy, and requires a very large amount of primary power, it is a poor candidate for the HARR system unless large aircraft are used for the airborne platform in the interim or long-range time period.

3.4.3.8 AN/VRC-24. The AN/VRC-24 is a production AM UHF radio communications equipment specifically designed for use of air control teams in forward combat areas. This equipment is designated Standard A and is also designated RT-323/VRC-24. The transceiver will tune to any one of 20 present channels out of a total of 1,750 channels in the frequency range from 225 to 399.9 MHz. The weight of 82 pounds is fairly high for each transceiver and the power output of 15 watts is about average. This equipment is not compatible with the existing tactical ground FM equipment and thus is not a prime candidate for the HARR system for the initial time periods and is not a good candidate for the interim or the long-range time periods.

3.4.3.9 AN/ARC-116. The AN/ARC-116 radio communications equipment is being developed for use in the new light observation helicopter, UH-6B. It is designed using all-solid-state throughout and is intended as a lightweight replacement for the AN/ARC-51X. This equipment is of modern design, quite lightweight (10 pounds apiece) and small in size (0.9 cubic feet apiece), has a higher power output (10 watts) than many airborne radio communications equipments, and has fairly low primary power requirements (36 watts apiece). Since this AM VHF equipment is not compatible with the existing VHF tactical FM radio equipment, it is not suitable for the initial time period, but it may be a good candidate for the interim time period.

3.4.3.10 AN/TRC-68. The AN/TRC-68 is the same as the AN/VRC-24 except for 50/60 Hz ac power input. It provides a fixed station version of the AN/VRC-24 for airport control. It is not intended for airborne use, is quite heavy and bulky and requires a substantial amount of primary power. Other characteristics are the same as the AN/VRC-24. Since this equipment operates on AM in the UHF frequency range (225 to 400 MHz), it is not compatible with the present VHF FM ground tactical equipment. It is thus not suitable as a HARR equipment for the initial time period, and its other characteristics make it a poor candidate for the interim and the long-range time period.

3.4.3.11 AN/ARC-85. The AN/ARC-85 is a simplex UHF AM radio communications set in service with the AN/ASQ-59 system. It thus requires two transceivers for half duplex communications circuit. The transmitter has a power output of 50 watts, which is more than most of the radio sets in this group. It is a production type of equipment but is quite heavy (116 pounds apiece) and quite bulky (3.6 feet apiece).

Since this equipment operates in AM in the UHF frequency range (225 to 400 MHz), it is not compatible with the present VHF FM ground tactical radio equipment. It is thus not suitable for the initial time period. Its weight and bulk also make it a poor candidate for the interim and the long-range time period.

3.4.3.12 AN/ART-46. The AN/ART-46 is an AM/FM transmitter for the UHF frequency range (225 to 400 MHz) only. This transmitter was designed for airborne use as a medium power communication equipment aboard reconnaissance aircraft to provide UHF AM voice or FM data. The video bandwidth of 100 KHz is suitable for transmitting wideband IR data from a U.S. Army Mohawk aircraft. It has been designed to meet MIL-E-5400 and MIL-E-16400 specifications so that it will meet all required environmental conditions for airborne operation. The power requirement of 843 watts is quite high and the weight of 65 pounds is also fairly high. Since its VHF frequency range is not compatible with the present VHF FM ground tactical equipment, it is not suitable for the HARR system for the initial time period, and its high weight and high power requirements make it a poor choice for the interim or long-range time period.

3.4.3.13 AN/ARR-71. The AN/ARR-71 is an AM/FM receiver that will tune automatically by servo control to any one of 3,500 available channels in the UHF band from 225 to 399.95 MHz. This receiver is all-solid-state, is designed for airborne use (to 70,000 feet), and is compatible with the AN/ARC-89(V) SAC Airborne Communications System. This receiver may be used with the AN/ARC-46 to make a simple voice communication system, or may be doubled with two receivers and two transmitters, to make a half-duplex voice communication system. A half-duplex system, using two AN/ARR-71 receivers and two AN/ARC-46 transmitters would weigh about 166 pounds and require about 3 cubic feet of space. This receiver is designed to meet military environmental specifications, including MIL-E-5400 and MIL-E-16400.

This receiver has been designed for use in communication networks that require extreme linearity and low intermodulation products, such as FM multiplex systems, so that it may be much more useful for the multichannel systems described in the following section of this report.

Since it operates in the UHF range, it is not compatible with the present VHF FM ground tactical equipment and would not be a good candidate for the HARR system for the initial period. It is too heavy and bulky to be a good candidate for the interim or the long-range time period.

3.4.3.14 AN/ARC-109. The AN/ARC-109 UHF transceiver will provide air-to-air or air-to-ground communication on any one of 20 preset channels out of a total of 3,500 channels in the UHF range from 225 to 400 MHz. The transceiver is all-solid-state except for the power amplifier tube. The primary power requirements are rather high (600 watts for a half-duplex set of two transceivers) but the transmitter power of 30 watts is also fairly high. This transceiver is designed to meet military environmental specifications, including MIL-I-6181D and MIL-M-26512C.

Since this transceiver operates in the UHF range, it is not compatibile with the preset VHF FM ground tactical equipment and would not be suitable for use in the initial time period. It is also too heavy and bulky to be a good candidate for the interim or the long-range time period.

3.4.4 Preliminary Selection of VHF Relay. A preliminary selection of several of the most suitable VHF FM relay equipment types has been made, which are listed on Table 3.4-6. Estimated requirements of the number of necessary channels show a need for around a dozen channels in a given area of operations. Cost estimates by the platform study group indicate a cost for the platform that is an order of magnitude greater than the cost for repeater equipment capable of handling several channels. As a result, Table 3.4-6 lists groups of several of the most suitable VHF FM relay equipments that are capable of handling six and twelve-voice channels.

The AN/PRC-25 is an existing equipment that is immediately available, so that it is an excellent candidate for the initial time period. The AN/PRC-77 is an improved, all-solid-state version of the AN/PRC-25 that is in an advanced stage of development. It would probably be available in small production quantities in time for the initial time frame and would be an excellent candidate. The AN/ARC-114 is also an all-solid-state equipment in small production quantities in time to be considered for the initial time frame. It would be a better candidate than the AN/PRC-77 from the standpoint of weight and volume requirements but would not be as good if there are limitations on the primary power supply.

3.4.5 Relay Mode Constraints

3.4.5.1 Introduction. This section deals with the constraints imposed upon relay operation by the choice of relaying modes, i.e., either frequency translating (F_1-F_2) or common frequency (F_1-F_1) modes. The typical configurations of repeaters of each type are described in paragraph 3.4.1 above. The basis for the operational comparison assumes a high altitude relay with a capability of augmenting several FM networks, each consisting of perhaps five "subscribers" equipped with pack-set transeivers of the PRC-25 genre.

Table 3.4-6. Type of FM Relay Equipment

TYPE OF FM RELAY EQUIPMENT	Number of Voice Channels	Number of Trans-ceivers	Weight in Pounds (incl mtg.)	Primary Power watts	Volume in Cubic Ft. (incl mtg.)	Power from Trans. (watts/chan)	Freq. Range MHz
AN/PRC-25	6	12	195	94	6.25	1-1.5	30-76
AN/PRC-77	6	12	1[illegible]	58	6.25	1.5-2	30-76
AN/ARC-114	6	12	[illegible]	360	1.8	10	30-76
AN/PRC-25	12	24	3[illegible]0	188	12.5	1-1.5	30-76
AN/PRC-77	12	24	318	116	12.5	1.5-2	30-76
AN/ARC-114	12	24	230	720	3.6	10	30-70

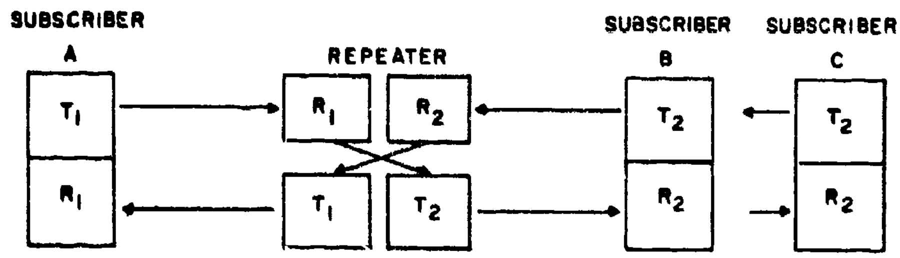
3.4.5.2 Frequency Translating Repeater

3.4.5.2.1 Channel Requirements. The use of frequency translating as a means of establishing a relay point in a communications circuit as a conventional practice for line-of-sight or tropospheric scatter communications systems. The AN/PRC-25 transceiver itself is designed to function in an F_1-F_2 repeater configuration. Since the PRC-25, in application as a repeater is severely limited in channel selection by receiver image and spurious response characteristics (ref. 3.4-26), includes 6 pages of charts showing permissable frequency combinations), the problem of operating several sets in near proximity is formidable. Granted that permissable frequency combinations can be found, at least with the aid of a digital computer, field or in-flight modifications of channel frequency plans is almost impossible. It is therefore imperative that a measure of outboard RF filtering be applied to maintain some flexibility in channel selection. By assigning all transmit frequencies in one spectrum region and all receiver frequencies in another region defined by a diplexing filter, a substantial degree of improvement may be obtained. Further improvement may be obtainedwith tunable preselector filters for each receiver, at the expense of weight and increase of channel-switching time. The extent to which diplexing filters of adequate performance may be made tunable remains to be determined. Operation in a particular location will undoubtedly imply a particular set of constraints on channel assignments, as is the case in Viet Nam, where only a limited fraction of the nominal 920-channel PRC-25 capability may be used.

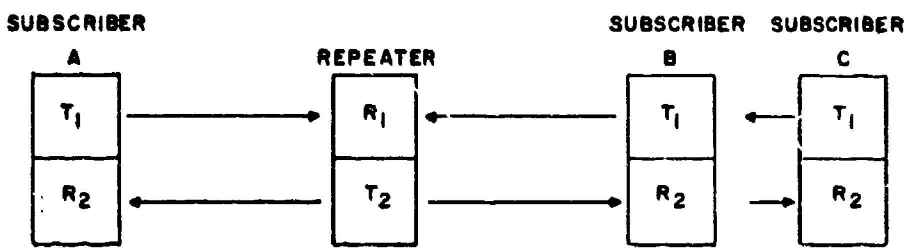
3.4.5.2.2 Operational Considerations. In a conventional FM net, any subscriber may initiate a message to any other. All activity on the net is audible to each subscriber Break-in is possible only by a subscriber whose carrier level is higher at the desired receiver, although the breaking-in subscriber may not be audible to other subscribers, depending on the path losses.

In a conventional PRC-25 repeater configuration, subscriber A and subscriber B may operate on frequencies F_1 and F_2, respectively, using conventional PRC-25 transceivers. This assumes that A and B know, a priori, that the repeater will be in operation.

There are two configurations of frequency translating repeaters with different network constraints. The first configuration is compatible with single frequency transceivers, while the second configuration requires separate receive and transmit frequencies at the transceiver. The first configuration is shown in Figure 3.4-4 (a). Note that while A can talk to B and C via the repeater, he cannot talk directly to B and C. Subscriber B can talk to C, but does not have the advantage of the repeater unless he switches to A's frequency. Traffic can be relayed verbally by A, but at some expense in operating convenience and contrary to standard procedure.



(a) SINGLE-FREQUENCY TRANSCEIVERS



(b) TWO-FREQUENCY TRANSCEIVERS

Figure 3.4-4. F_1 - F_2 Network Configurations

It should also be noted that if B is talking to A, C may not be able to tell that the channel is active, and may interrupt B's message. While A can tell C to stand by until B has finished, this does slow down net operation and does not protect priority traffic.

A further consequence of the above repeater configuration is that if the repeater is inoperative, either A or B, C, etc., must switch to a common frequency. It would presumably be designated in the SOI which subscriber would be responsible for changing.

The second frequency translating repeater configuration is shown in Figure 3.4-4 (b). This configuration requires a simpler repeater and is symmetrical with respect to the subscribers. Since all traffic is now passed through the repeater, each subscriber can listen to all net traffic and has substantially the same break-in capability as with the conventional FM net. If the repeater is inoperative, each subscriber must change to a common receive-transmit frequency.

Both of the above configurations assume that the repeater is dedicated to a particular net. In order to keep interference from the repeater to a minimum, it would be advantageous to use the repeater only when necessary. The subscriber who finds himself out of contact with one or more other subscribers in the net must switch from the normal net frequency, F_1, to the repeater channel, F_2. The repeater translates his signal to F_1 where it is audible to all subscribers in the net. The called party must also switch to F_2-transmit in order to be heard by the calling party. Other net subscribers may talk among themselves and may hear the other conversation, but can only enter the conversation by switching to F_2-transmit. Since the receive frequency is fixed, all net subscribers may be informed of the use of the repeater. This mode requires assignment of an exclusive second frequency for repeater operation. Since the repeater channel will be used only intermittently, interference will be minimal. An AN/PRR-9 receiver added to the PRC-25 would provide the needed second channel.

If the repeater is supervised by an operator (either at the platform or connected by a subsidiary data link), the operator may route traffic to a small number of repeater channels, which may be used more efficiently, although the increased activity on the repeater channels will increase the interference generated on these channels. In order to obtain repeater service, a subscriber calls the repeater operator on a SOI-designated orderwire channel and identifies his net. The operator then directs him to a repeater channel (which may or may not be a prearranged channel for the particular net) with a new up-link frequency and the previous down-link frequency. The calling subscriber is heard by all other net subscribers. The called party then is requested to switch to F_2-transmit for the temporary repeater connection. All transmissions on F_2 are audible to all subscribers, but the subscribers not requiring the repeater may remain in the F_1 FM net mode. Again, use of the PRR-9 as an auxiliary receiver will provide the two-frequency capability required.

Since various FM net subscribers desiring use of the repeater call on a common orderwire channel and may not be able to hear one another, they may interrupt each other's requests for repeater service. This is the same problem which faces taxi dispatchers, whose receivers are often captured by nearby taxi signals in the middle of a transmission by another taxi. Their response is to tell the interfering taxi to wait until the dispatcher calls him back, which should be equally acceptable in the repeater request procedure.

There remains a problem of how to get the repeater channel back into the pool when it is no longer required. A particular subscriber might need the repeater for only a few seconds, or he might need the repeater for twenty minutes or more for directing artillery fire. Perhaps the best answer is for the use of the repeater for more than say, one minute on an exclusive channel basis to require authorization from an appropriate level of command. That is, the operater would accept individual calls from anyone for a 1-minute maximum and would provide "hot-line" service on proper authorization.

3.4.5.2.3 Repeater Electronics. Several problems relating to the repeater electronics result from F_1-F_2 operation. If separate transceivers (or special purpose single-channel repeater equipments) are used for each channel, as there is no synchronism between the push-to-talk activation on the various channels, the receivers must be protected against blocking, overload, or spurious response. This is accomplished partially by choice of operating frequencies and the use of diplexing filters, as described in paragraph 3.4.5.2.1 above. Since the receiver squelch may be used to activate the corresponding transmitter channel, it is important that the squelch not be operated by other transmitters in the repeater assembly.

Where amplifiers common to several channels are used, as in receiver preamplifiers or transmitter power amplifiers, or transmitter power amplifiers, the distortion generated by amplifier overload must be considered in relation to the weaker signal levels. This topic is discussed further in paragraph 3.5.3.3.

3.4.5.3 Common Frequency Repeater

3.4.5.3.1 Channel Requirements. The attractiveness of common frequency, F_1-F_1, repeater operation is largely based on the apparent requirement for a single RF channel for each network using a repeater. However, the operational use of a repeater may require more than one channel, and out-of-band interference generation and vulnerability may also require more than one channel per net.

3.4.5.3.2 Repeater Configuration. The repeater configuration of Figure 3.4-2 is basic to the F_1-F_1 repeaters which have been demonstrated thus far, consisting of a receive memory device, and a transmitter. The memory device, which may consi magnetic tape memory for a Courier-type repeater, or a holding capacitor in a rapid sampling repeater, is loaded while the antenna is connected to the receiver and unloaded with the antenna connected to the transmitter. A multichannel repeater may thus switch all channels synchronously, so as to avoid the channel selection problems which face the non-synchronous F_1-F_2 repeater.

3.4.5.3.3 Operational Considerations. There are several features of the F_1-F_1 repeater which lead to problems in repeater applications. If the repeater operates on the original FM net frequency (as assumed in claiming single frequency operation), some subscribers will receive signals both from the repeater and directly from another subscriber, leading to potential system degradation for some subscribers as the price for improving performance for other subscribers. Since all of the FM net subscribers must use the repeater, it will generate high duty-cycle interference, possible over several adjacent channels.

These problems may be alleviated somewhat by using the repeater on an as-required basis. One means would be to use a second channel for repeater operation, negating the channel requirement advantage. Each subscriber would require an auxiliary receiver tuned to the repeater frequency.

If the repeater is supervised by an operator, a subscriber needing augmentation of his range may call the operator on an orderwire channel to request service, then return to his original net frequency, where the operator will provide temporary repeater service. There is still the possibility that subscribers in the net who did not need the extended range may find their circuit degraded by multipath.

Use of a switching F_1-F_1 repeater may pose problems of compatibility with digital modulation modes, the use of which will become increasingly important in the next few years.

3.4.5.3.4 Switching Rate Considerations. The switching rate of an F_1-F_1 repeater is important in determining the performance of the repeater itself as well as the interference generation and vulnerability interfaces with other systems.

The following factors have been considered in attempting to estimate F_1-F_1 repeater performance potential:

a. Receiver IF pulse response
b. Receiver squelch rate
c. Intelligibility of chopped speech
d. Repeater output spectrum
e. Ground echo return.

In response to a series of carrier pulses, the receiver IF will provide a response similar to a low-pass filter of half the IF bandwidth. For the 36 KHz PRC-25 bandwidth, the response shape is that similar to an

18 KHz low-pass filter. Figure 3.4-5 (ref. 3.4-27) shows the response corresponding to a fixed repetition rate and various values of equivalent low-pass bandwidth. If the repetition rate is less than 0.25 of the IF bandwidth, the carrier will decay to zero during the pulse interval. As the receiver will be provided with enough gain to limit on background noise, the output noise level may rise to a level comparable to the signal level in the inter-pulse interval. The receiver squelch time constant is typically a few hundred milliseconds, so the squelch will not be able to suppress the noise burst. and a severe degradation of the signal-to-noise ratio will result. For lower carrier-to-noise ratios, the degradation will extend to higher switching rates than for high carrier-to-noise ratios, since the carrier may more easily drop below threshold.

Miller and Licklider (ref. 3.4-28) have investigated the effects of switching speech on and off at various rates, and the effects of alternating speech and noise. Figures 3.4-6 and 3.4-7 show some of the results of this investigation. It is particularly noteworthy that the articulation reaches a peak at switching rates of the order of 20-50 Hz, and reaches a minimum at frequencies of several hundred Hertz. For switching speeds of the order of 10-15 Hz, the presence of noise in the gaps makes speech more acceptable, although it does not improve the intelligibility.

For rapid switching rates, an appreciable fraction of the signal spectrum falls outside the IF passband, resulting in an increasing loss of carrier-to-noise ratio up to the point where the first switching sidebands are located beyond the IF passband. The power lost in this manner is of the order of 10 db for cosine-squared keying waveforms with 33% transmit duty cycle, as used in Motorola's experimental F_1-F_1 repeater (ref. 3.5-59).

This power loss may be overcome on the down-link, although there is a loss due to the reduced repeater receiving period on the up-link which cannot be compensated. Since the components of the switching spectrum are each modulated by the original audio waveform, there will be a range of switching speeds where the FM spectra around the carrier and around the first switching sideband are both within the IF-discriminator passband, producing distortion. This suggests that switching rates of the order of half the IF bandwidth plus the peak deviation are needed to minimize distortion.

Echo of the repeater output signal from the ground may degrade the repeater-receiving signal-to-noise ratio, and may confuse the squelch activation of the transmitter. Further investigation of the expected echo amplitude is planned.

The various factors described above have been combined to give a postulated relationship of switching rate and articulation in Figure 3.4-8. Apart from the low-frequency asymptote at 50% articulation, the values are all uncertain and are intended only to indicate trends. The relative magnitude of the low and high frequency articulation peaks is likewise uncertain. A

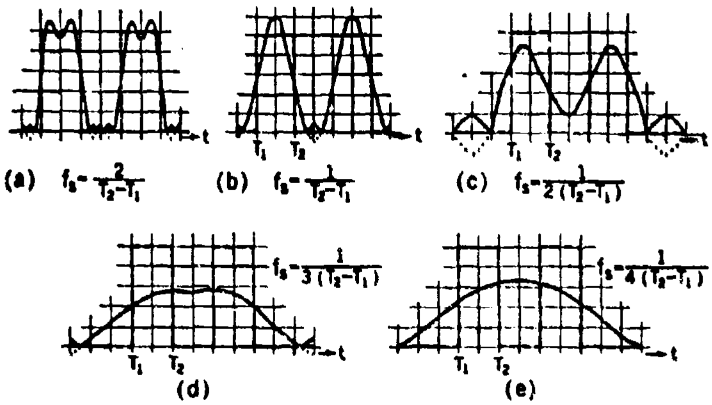


Figure 3.4-5. Effect of Bandwidth on the Transmission of Detail (After Goldman)

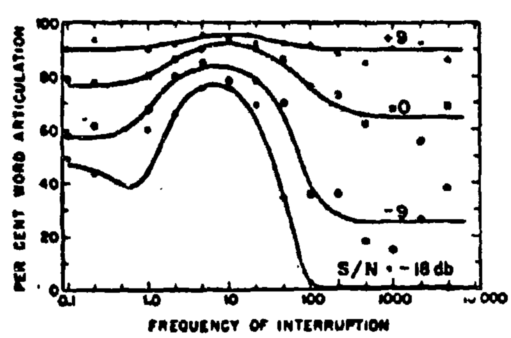


Figure 3.4-6. Effect of Masking of Continuous Speech by Interrupted Noise, 50% Duty Cycle (After Miller and Licklider)

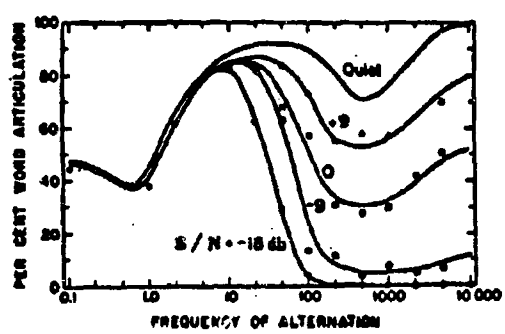


Figure 3.4-7. Effect of Alternation of Speech and Noise Intervals, 50% Duty Cycle (After Miller and Licklider)

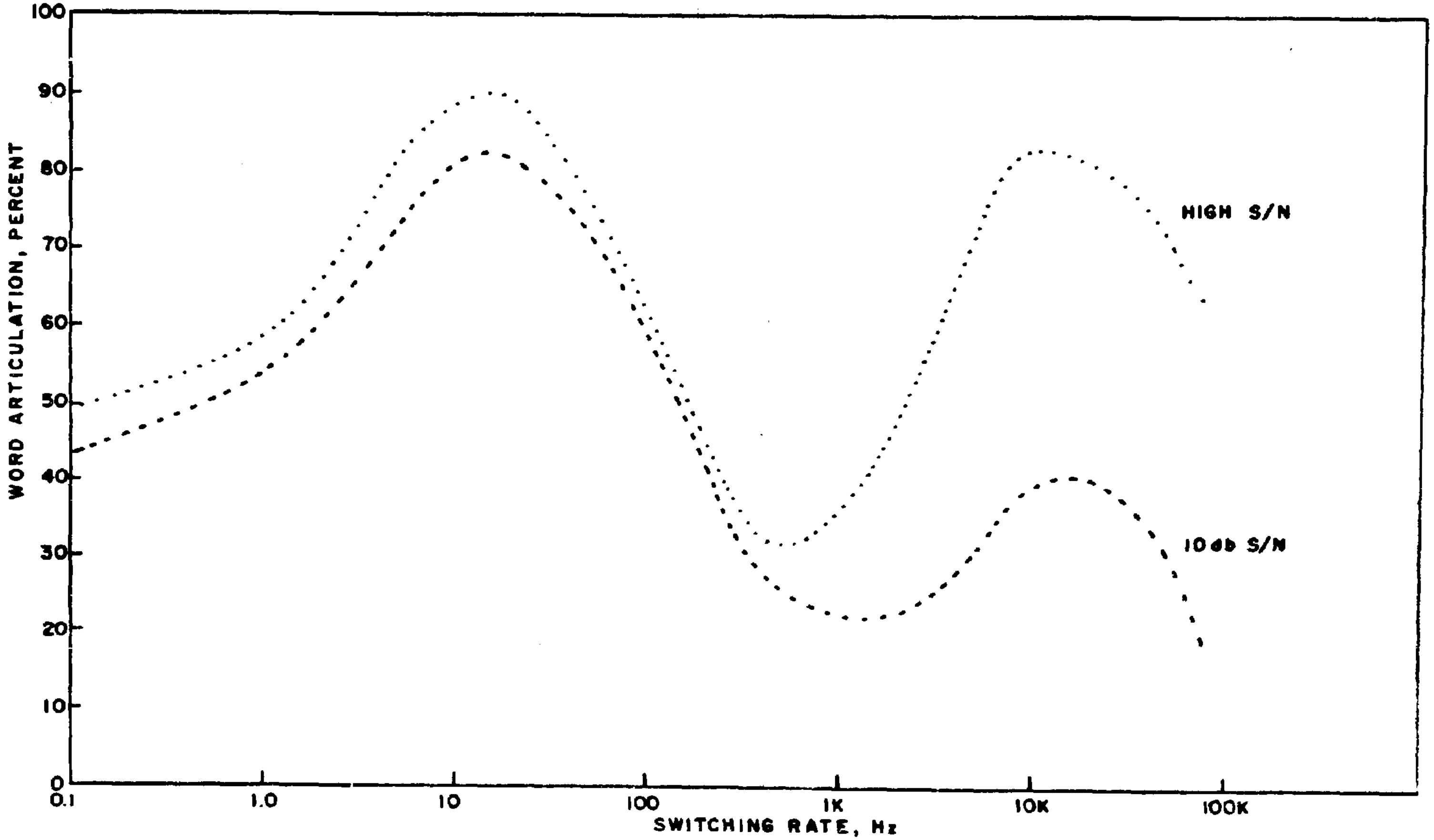


Figure 3. 4-8. Postulated Relative Articulation for F_1 - F_1 Repeater

comprehensive experimental program would be expected to be more productive than further theoretical investigation.

As previously noted, once switching speeds are below the Nyquist rate, they will not be generally compatible with digital modulation formats. Above the Nyquist rate, there may be other factors which tend to degrade digital error rate. Again, measurements of experimental F_1-F_2 repeaters may be more productive than analysis.

3.4.5.4 Summary. A number of considerations have been discussed above bearing on the selection of F_1-F_1 or F_1-F_2 repeater modes in terms of operational restrictions, repeater-tranceiving interfaces, and repeater realization. Preliminary conclusions are that:

a. For the initial time frame, F_1-F_2 repeaters are more likely to provide useful service.

b. Compatibility with PRC-25 equipment requires issuing AN/PRR-9 or similar receivers for second-frequency operation.

c. Frequency allocation problems and varying military estimates of the demand for repeater service suggest that supervised repeaters with limited numbers of channels may best serve the initial requirement.

d. Further pursuit of F_1-F_1 repeaters is justified in view of the increased flexibility in repeater channel switching. In particular, low frequency switching repeaters should be evaluated because of the interference generation and vulnerability of high-speed switching repeaters.

3.4.6 Optimum Repeater Design

3.4.6.1 Objectives. It is evident that the use of existing equipment for the repeater application is intended as a stop-gap measure to shorten the cycle of development, trial, and operational deployment. For the longer range objective, we are more at liberty to apply techniques and components which are not now in military usage, inventory, or development. Among the long-range objectives for future systems are the following:

a. Multiple access power control
b. Protection against interference and jamming
c. Compatibility with RADA techniques.

It may well prove that incorporation of any one of these techniques to the FM network augmentation problem will be incompatible with other systems requirements, such that it is not worth further exploration. On the other hand, those features with useful potential and a reasonable chance of practical realization should be identified in the course of this study.

The following paragraphs review the objectives above, point out the relevant results at this point in the study program, and indicate the direction of future work.

3.4.6.2 Multiple Access Power Control. As will be established in paragraph 3.5.3.3, there is a wide divergence in signal levels received at the repeater from various transceivers within the service area. This range of signal levels imposes a severe limitation on the design of multichannel broadband repeaters, since distortion products from the stronger signals may degrade or obscure weaker signals. If providing adequate dynamic range proves impractical, then the use of power control or of separate channel gain control will be necessary. One means of power control, applied in the ATS-B satellite, employs pilot-tone feedback from the relay for comparison with a standard level tone. The transceivers with lower path-loss to the repeater would then decrease their power output to reduce the variance of the received power distribution at the repeater.

Since there is a substantial time-varying component in the signal level factors, there is a question of the time constant of the amplitude control loop. Whether the loop may provide useful degeneration of amplitude excursions of fading signals depends on the fading rate, time constants, and the nature of the return path modulation.

We have considered the separate channel repeater both in its F_1-F_2 and F_1-F_1 versions primarily because of equipment availability but also because there are several useful features for advanced repeater design. Separate gain control allows the power control function to be performed at the repeater for compatibility with existing transceivers. Modifications of the transceivers could, however, permit control of the repeater output power as well, minimizing interference from the repeater at the price of setting a maximum channel quality. If repeater-receiver automatic gain control is used as an indication of instantaneous path loss for repeater transmitter output control, it should be noted that there will be a loss of correlation of the path losses to and from the repeater with increasing frequency separation.

Separate receiving channels at the repeater provide a further means of reducing the variance of the received power, through the use of diversity reception. The extent to which frequency diversity, polarization diversity, or space diversity can be applied to improving VHF air-to-ground performance remains to be determined. While we plan some general work in evaluating this area, we do not feel that the existing experimental data is adequate for a detailed prediction of diversity improvement in the jungle environment.

3.4.6.3 Protection Against Interference and Jamming. No specific attention has been given to the problems of interference and jamming at the present time, although some general consideration has been given to the interference between channels using the repeater and between direct and repeated F_1-F_1 signals.

The vulnerability to jamming and interference of high-altitude, wide bandwidth repeaters using conventional modulation techniques is evident. Altitude should be minimal, subject to tradeoff with range and platform requirements. The bandwidth should preferably be divided into rapidly tunable minimum bandwidth channels, with both filtering and dynamic range of the separate receiver channels designed for minimum intermodulation from out-of-channel signals.

Whether spread-spectrum techniques can offer any significant advantage within the constraints of man-pack tactical equipment, push-to-talk operation, and party-line network operation has not yet been investigated.

3.4.6.4 Compatibility with RADA. A discussion with Mr. Charles Tepper of the ECOM RADA project office was directed at determining the extent to which RADA techniques could be applied to the tactical communications problems, and at determining the extent to which the RADA program had already explored this area. It was determined that the present RADA effort is directed at division-level communications, and that it is not intended to be compatible with or to replace FM network communications. An extensive list of references was provided (see paragraph 3.7) including ref 3.4-30 which deals with an airborne repeater for use in extending RADA coverage areas by ground-air-ground or ground-air-air-ground relaying.

No further study of the RADA problem has been undertaken pending our review of the project reports referenced above. In the following months we hope to determine whether the RADA repeater may be compatible with the platform or with the multichannel relay equipment such that some useful payload combinations or dual-purpose equipment may be evolved.

3.5 PATH LOSS ANALYSIS

3.5.1 Analysis and Computation. The phenomenon of radio propagation loss introduced by jungle foliage has been observed for many years and has received particular attention under the pressure of military operations in Southeast Asia. In an effort to improve tactical radio communications in this and similar areas by the use of high altitude airborne repeaters, it is necessary to develop models for air-to-ground propagation over terrain characterized by mountains, jungle, foliage, and tropical climate conditions.

In other areas where counterinsurgency operations might be required, quite different propagation conditions may exist. It would appear, however, that the propagation to be expected in deserts, tropical grasslands, or temperate climates would be more accurately predicted by contemporary theory than is tropical jungle propagation. For this reason, and for the immediate time-frame application of repeater techniques, the study has concentrated on the jungle communications problem as observed in Viet Nam and Thailand.

Extensive measurement programs have been conducted in Thailand to determine the radio characteristics of jungle foliage and to evolve techniques for the prediction of the range of communications equipments. A selected bibliography of references to jungle propagation and related topics is presented in paragraph 3.8.

The approach taken to the prediction of path loss for a ground transceiver to airborne repeater is to divide the loss into two components. The first component is a systematic loss computed on the basis of an idealized slab model of the jungle foliage. The second component is a statistically described loss representing the inhomogeneity of the real jungle, the effect of the foliage on the transceiver antenna pattern, and the angular fluctuation of the antenna gain at the repeater platform. It may be possible and useful to separate the latter term. Experimentally determined electrical parameters of the jungle are used in computing the systematic component and measured distributions of the difference between actual loss and systematic loss serves to provide estimates of loss variability.

The following paragraphs describe the propagation analysis and computational procedure, the results of the computations, and the implications for the design of repeater systems.

3.5.1.2 Propagation Model. For a number of years a growth of vegetation has been regarded as a lossy dielectric for purposes of radio wave propagation. Gerber and Werthmueller (ref. 3.5-1) measured quite directly the intensity of electric polarization of the trees of a forest as a function of temperature and type of tree. From these measurements, they then predicted and subsequently verified by measurement the path loss for medium frequencies for propagation through forest. Quite recently Sachs and Wyatt (refs. 3.5-2 and 3.5-3), assuming antennas located in a slab of lossy dielectric between earth and air, have performed an incisively analytical integration of the traditional Bessel transforms (ref. 3.5-4) generally descriptive of propagation in and near lossy media. In reference 3.5-3, Sachs correlates the measurements of Jansky and Bailey (ref. 3.5-5) with predictions based on his analytical representation and finds a very substantial agreement (compare pages 46 and 55 of ref. 3.5-3) -- to within 1.5 db for the 6 - 100 MHz range and to within 4 db for the 250 - 400 MHz range.

Although the Bessel transform is an elegant and properly general representation of propagation, it is recognized that it corresponds in the general case to a superposition of plane waves (compare ref. 3.5-4, page 577) and in suitable circumstances may be replaced by a plane wave or ray representation. In the instance of propagation between a jungle-based antenna and an aircraft-based antenna, it is sufficient to consider a direct and a ground-reflected ray because any additional rays are too attenuated to contribute significantly to the net result.

A computer sub-routine of a larger propagational program has been established to compute the pattern of interference between the direct and ground-reflected rays in the air space above a jungle-sited antenna. More specifically, referring to Figure 3.5-1, inputs to the computer are permeability, permittivity and conductivity for earth and for jungle and--as the program stands--values of permeability and permittivity different from unity may be specified for the air-space, should one wish to do so. Additionally, depth of jungle and height of antenna as well as frequency and polarization are inputs. An isotropic source is assumed in the expectation that the phased gain of an actual source is to be super-imposed on the interference pattern. For this reason, the phase ($<\phi$ in Figure 3.5-1) of the down-going ray relative to that of the up-going ray is a required input. The output of the sub-routine is the amplitude of the interfering pair of rays versus whatever schedule has been specified for the independent variable, θ_o.

3.5.1.3 <u>Propagation Analysis</u>. For a conducting medium, Snell's law requires that θ_1 of Figure 3.5-1 be complex. This corresponds to a real angle of propagation determined by

$$\cos \Psi = \frac{\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}}{\left(\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}\right)^2 + k_a^2 \sin^2 \theta_o}$$

where Ψ = angle of propagation

k_a = complex propagation constant in air

k_j = complex propagation constant in jungle

θ_o = zenith angle of repeater platform

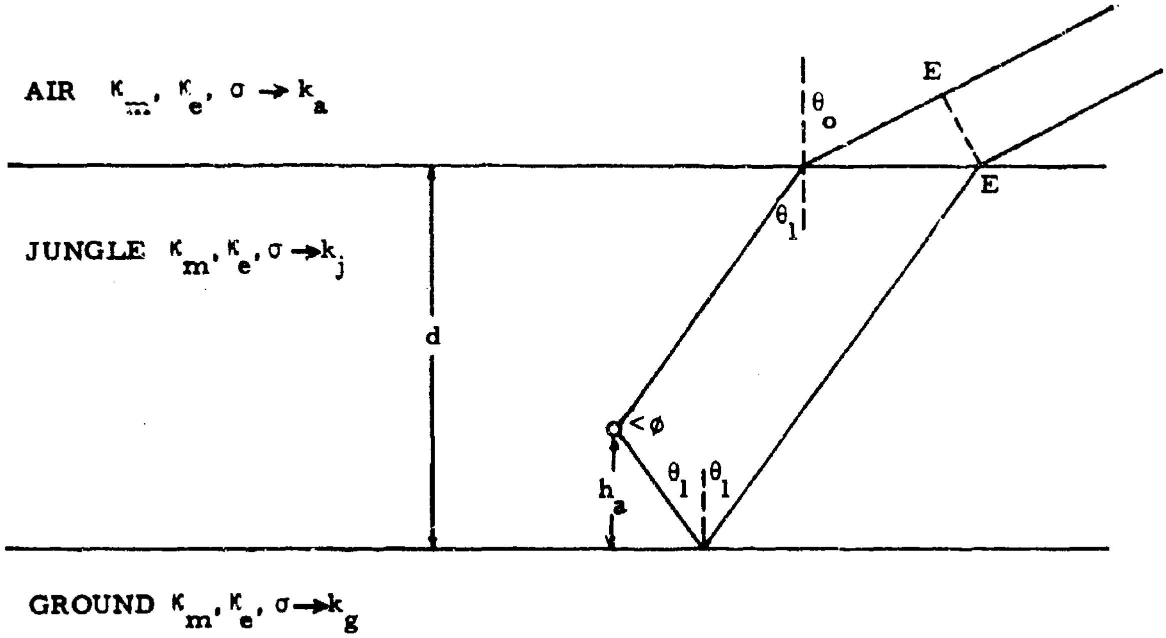


Figure 3.5-1. Geometry of Slab Model

This angle is used together with the antenna height h_a and the jungle height d to compute the direct and indirect ray lengths within the jungle and the distance between rays at the air-jungle surface. The ray lengths are used with θ_1 (Figure 3.5-1) to compute attenuation and phase lengths of the two rays within the jungle. The phase length of the direct ray is augmented by the projection of the distance between rays at the jungle-air surface. The reflection coefficient at the jungle-ground surface is computed as in Stratton (ref. 3.5-4, pp. 493, 494).

The properly phased and attenuated rays are combined at the plane E-E of Figure 3.5-1. The absolute value is multiplied by transmission coefficients, following generally Stratton's development (ref. 3.5-4, pp. 495, 496). For vertical polarization the square of the transmission coefficient is

$$T_v^2 = \frac{4\left|k_a/k_j\right|\cos\theta_o}{\left|1+\dfrac{\mu_a k_j}{\mu_j k_a}\dfrac{\cos\theta_o}{\sqrt{k_j^2-k_a^2\sin^2\theta_o}}\right|^2} \times \frac{\sqrt{\left(\mathrm{Re}\sqrt{k_j^2-k_a^2\sin^2\theta_o}\right)^2+k_a^2\sin^2\theta_o}}{\mathrm{Re}\sqrt{k_j^2-k_a^2\sin^2\theta_o}}$$

where T_v = transmission coefficient for vertical polarization

μ_a = permeability of air

μ_j = permeability of jungle

and for horizontal polarization is

$$T_h^2 = \frac{4\left|k_a/k_j\right|\cos\theta_o}{\left|1+\dfrac{\mu_j k_a}{\mu_a}\dfrac{\cos\theta_o}{\sqrt{k_j^2-k_a^2\sin^2\theta_o}}\right|^2} \times \frac{\sqrt{\left(\mathrm{Re}\sqrt{k_j^2-k_a^2\sin^2\theta_o}\right)^2+k_a^2\sin^2\theta_o}}{\mathrm{Re}\sqrt{k_j^2-k_a^2\sin^2\theta_o}}$$

These coefficients account for the increasing divergence of rays emerging from the jungle at θ_o for real incident angles Ψ_c at which total reflection occurs (T=o). For small conductivity the critical angle to good approximation is

$$\Psi_c = \arc\sin\sqrt{\frac{1}{K_j}}$$

where K is the dielectric constant of the jungle.

3.5.1.4 Path Loss Computation. The preceding analysis has been converted into a Fortran-IV program for use on a CDC-3600 digital computer. The overall program is divided into a main program and a sub-routine.

The main program "Propray" is concerned with the housekeeping chores of I/O formats, free space and atmosphere absorption computation, and the setup of the parameters needed to compute the jungle attenuation. The subroutine "Jungle" computes the path attenuation through the vegatation as mathematically outlined in paragraph 3.5.1.1. It shares some parameters (slab model constants, frequency, polarization and phase term) with the main program through common storage. The direct inputs to the subroutine include the jungle antenna height, canopy height and the elevation angle of the repeater. The values returned to the main program are the propagation loss through the jungle in db and the internal elevation angle.

3.5.1.4.1 Input/Output Parameters. The following input data is required by the main program:

Slab model constants
Antenna polarization
Antenna height (within jungle)
Canopy height
Relative phase of downgoing ray from the jungle-based antenna, φ
Frequency
Reference atmosphere, N_s
Height of repeater
Earth distance from repeater to jungle antenna

From this, the program computes and prints the following outputs:

a. Total path loss, including jungle propagation, free space, ground reflection within the jungle and atmospheric absorption.

b. The elevation angle outside the canopy computed from the distances, reference atmosphere and heights given.

c. The elevation angle inside the canopy computed from boundary conditions determined by the slab constants.

3.5.1.4.2 Input Format. Three separate cards are used for the input to the program.

Card 1 - Assumed three-layer constants.

Card 2 - Antenna polarization, jungle-based antenna and canopy heights and the phase term, φ.

Card 3 - N_s, frequency, height of the repeater, and distance.

Figures 3.5-2 through 3.5-4 illustrate the format of these three cards. The input parameters may vary as shown in Tables 3.5-1 through 3.5-4. All inputs designated "real" must have the decimal point punched with the data. A decimal point must not be punched for "integer" data.

A flow graph illustrating the computational procedure is shown in Figure 3.5-5.

3.5.1.4.3 Output Format. The output format is shown in Figure 3.5-6 for a typical set of input conditions. The four columns of output following the statement of the parameters gives the incremental steps of distance from the transceiver to the sub-repeater point, in kilometers, the path loss in decibels, the elevation angle outside of the jungle canopy in degrees, and the elevation angle inside the canopy, also in degrees.

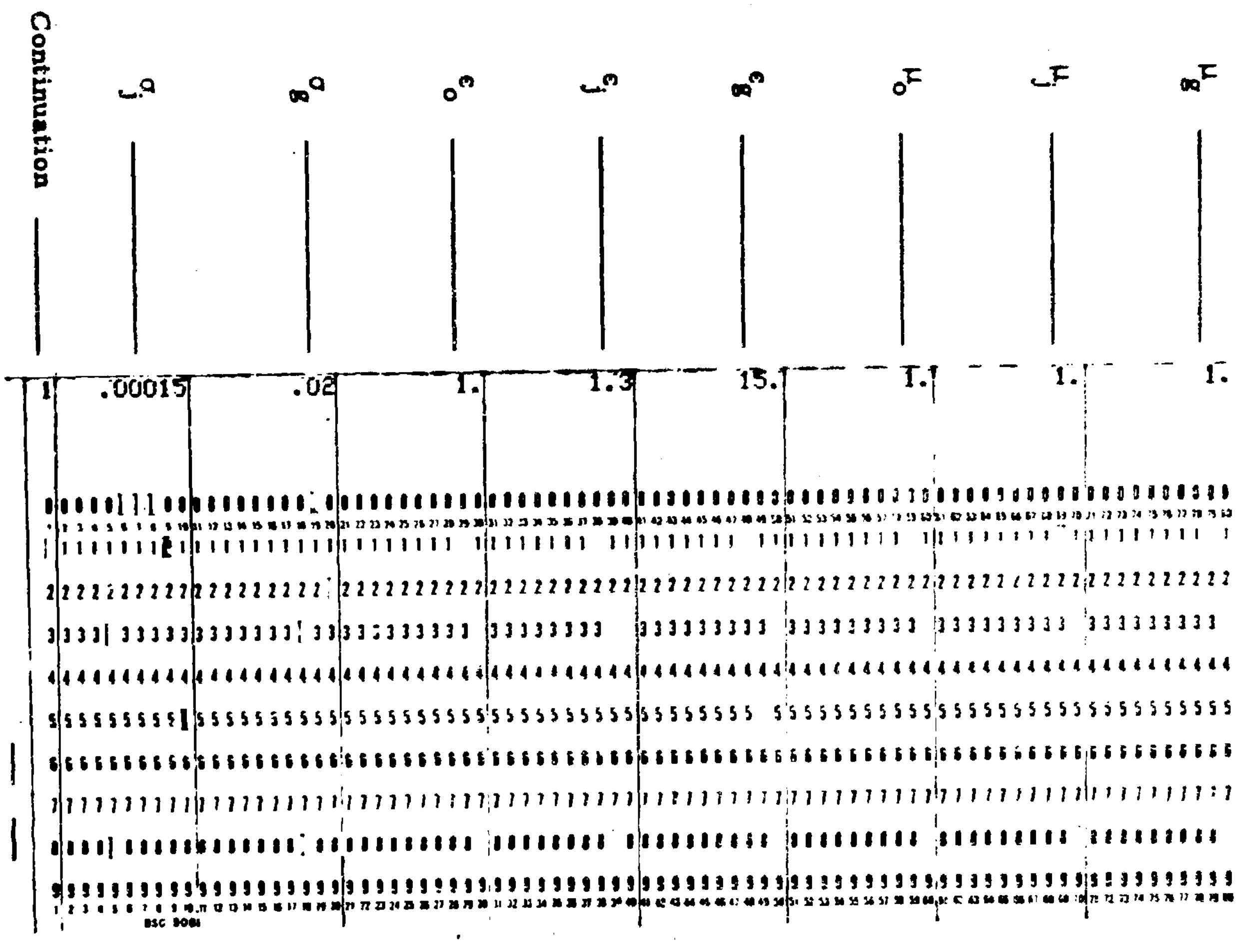


Figure 3.5-2. Card 1

Table 3.5-1. Contents of Card 1

Column	Type	Purpose	Units	Alternatives
1	Integer	Continuation	-	No punch or "1". A "1" indicates other card 1's to follow.
2-10	Real	σ_j	mhos	Any value, decimal must be punched.
11-20	Real	σ_j	mhos	As above.
21-30	Real	ϵ_o	normalized	1.0 = free space
31-40	Real	ϵ_g	normalized	Relative to free space
41-50	Real	ϵ_g	normalized	Relative to free space
51-60	Real	m_o	normalized	1.0 = free space
61-70	Real	m_j	normalized	As above
71-80	Real	m_g	normalized	As above

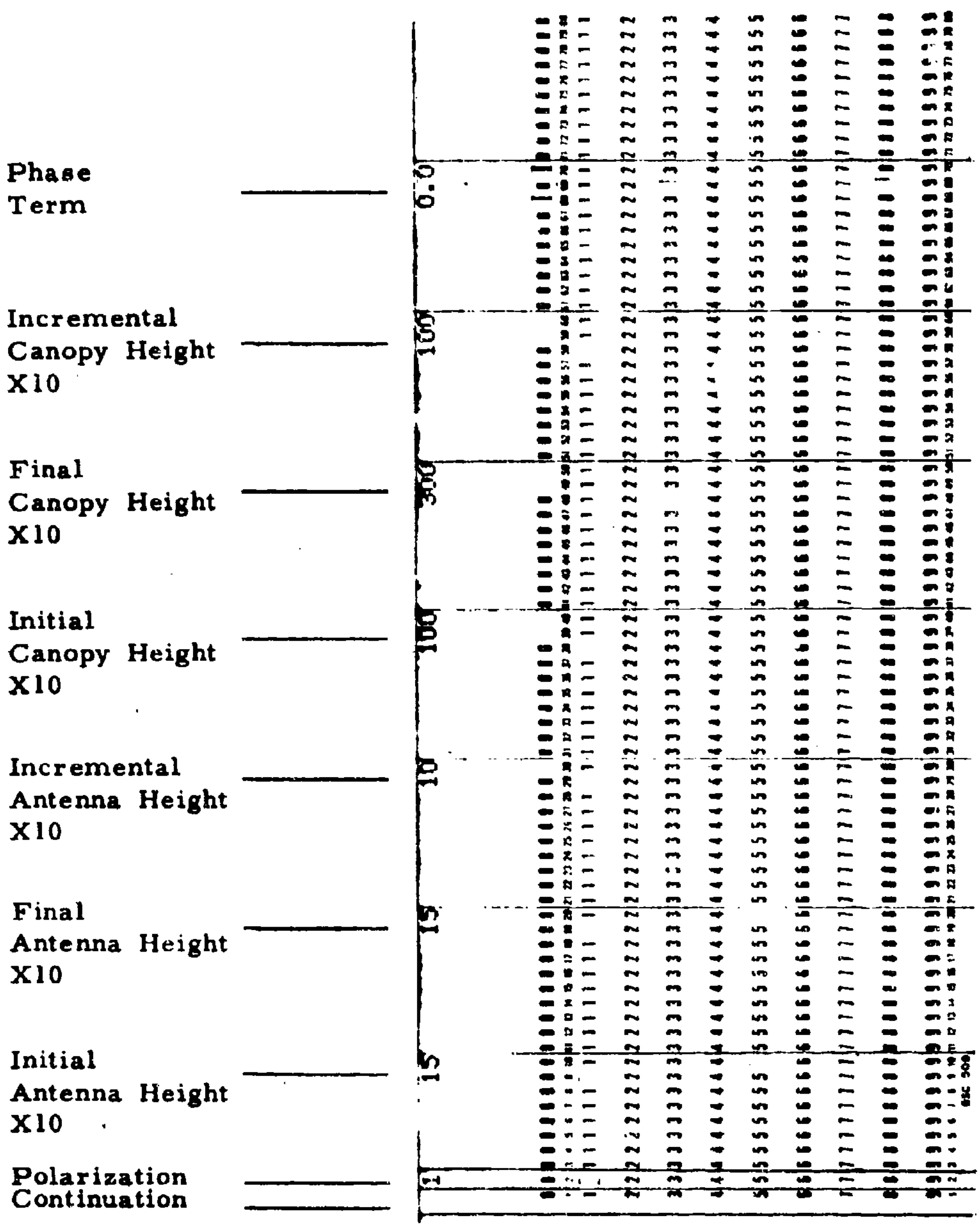


Figure 3.5-3. Card 2

Table 3.5-2. Contents of Card 2

Column	Type	Purpose	Units	Alternatives
1	Integer	Continuation	-	No punch or "1" A punch of "1" indicates that additional card 2's will follow before encountering another card 1.
2	Integer	Antenna Polarization	-	1 = vertical Other = horizontal
3-10	Integer	Initial Antenna Height	Meters X10	The initial or lowest antenna height
11-20	Integer	Final Antenna Height	Meters X10	The final or highest antenna height
21-30	Integer	Incremental Antenna Height	Meters X10	The increase in antenna height for each computation
31-40	Integer	Initial Canopy Height	Meters X10	Must be higher than antenna heights 120 = 12.0 meters
41-50	Integer	Final Canopy Height	Meters X10	As above
51-60	Integer	Incremental Canopy Height	Meters	As above
61-70	Real	Phase Term	-	Difference in phase if desired, between upgoing and downgoing rays from jungle-based antenna Normally 0.0

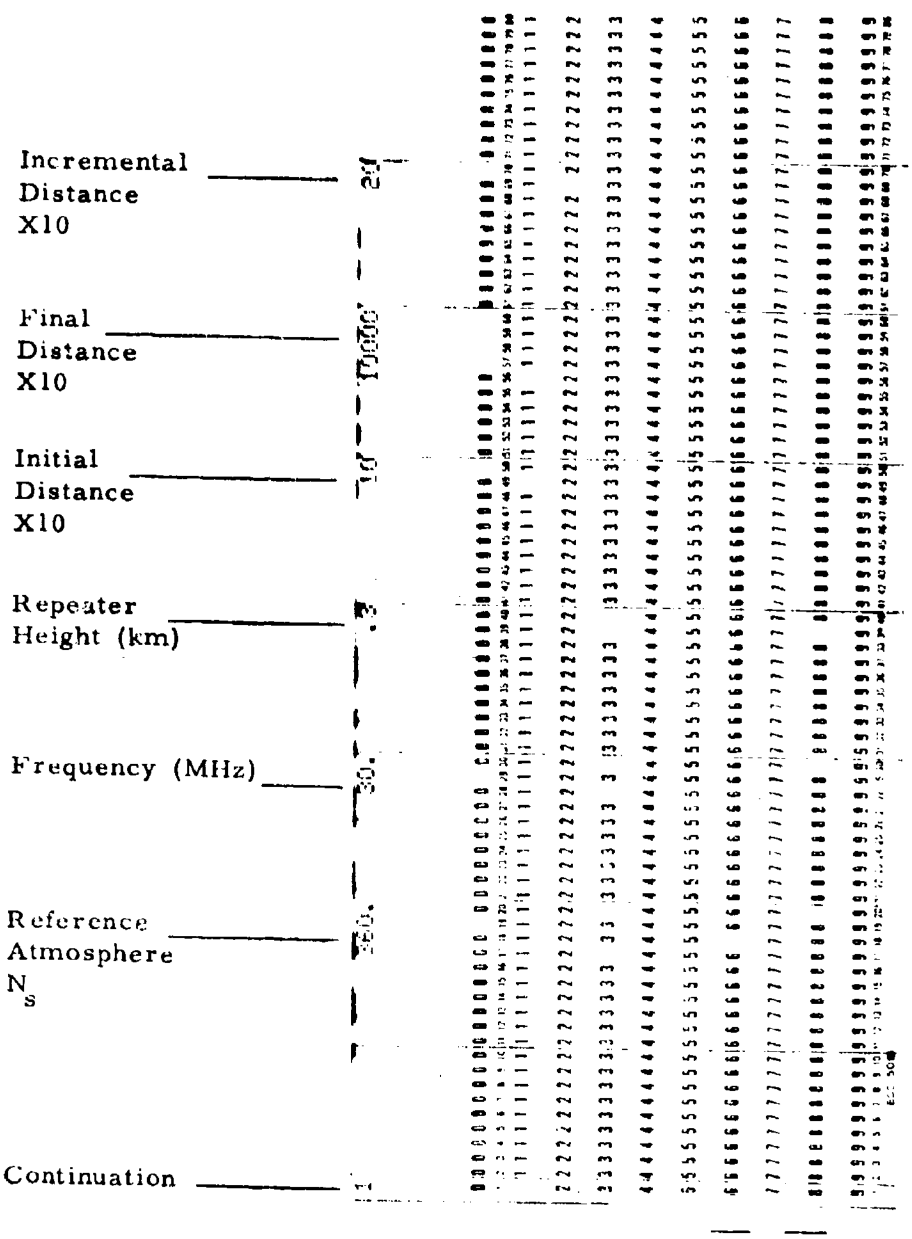


Figure 3.5-4. Card 3

Table 3.5-3. Contents of Card 3

Column	Type	Purpose	Units	Alternatives
1	Integer	Continuation	-	A punch of "1" indicates that additional card 3's will follow before encountering another card 2 or card 1.
11-20	Real	N_s	-	Reference atmosphere to determine effective earth's radius.
21-30	Real	Frequency	MHz	Frequency of transmission.
31-40	Real	Height of Repeater	km	Must be above horizon or diagnostic occurs.
41-50	Integer	Initial Distance	km X10	Smallest or first distance 10 = 1.0 km.
51-60	Integer	Final Distance	km X10	Final or longest distance of computation. If horizon occurs before this distance is reached, the computation terminates automatically.
61-70	Integer	Incremental Distance	km X10	Distance increase for each computation.

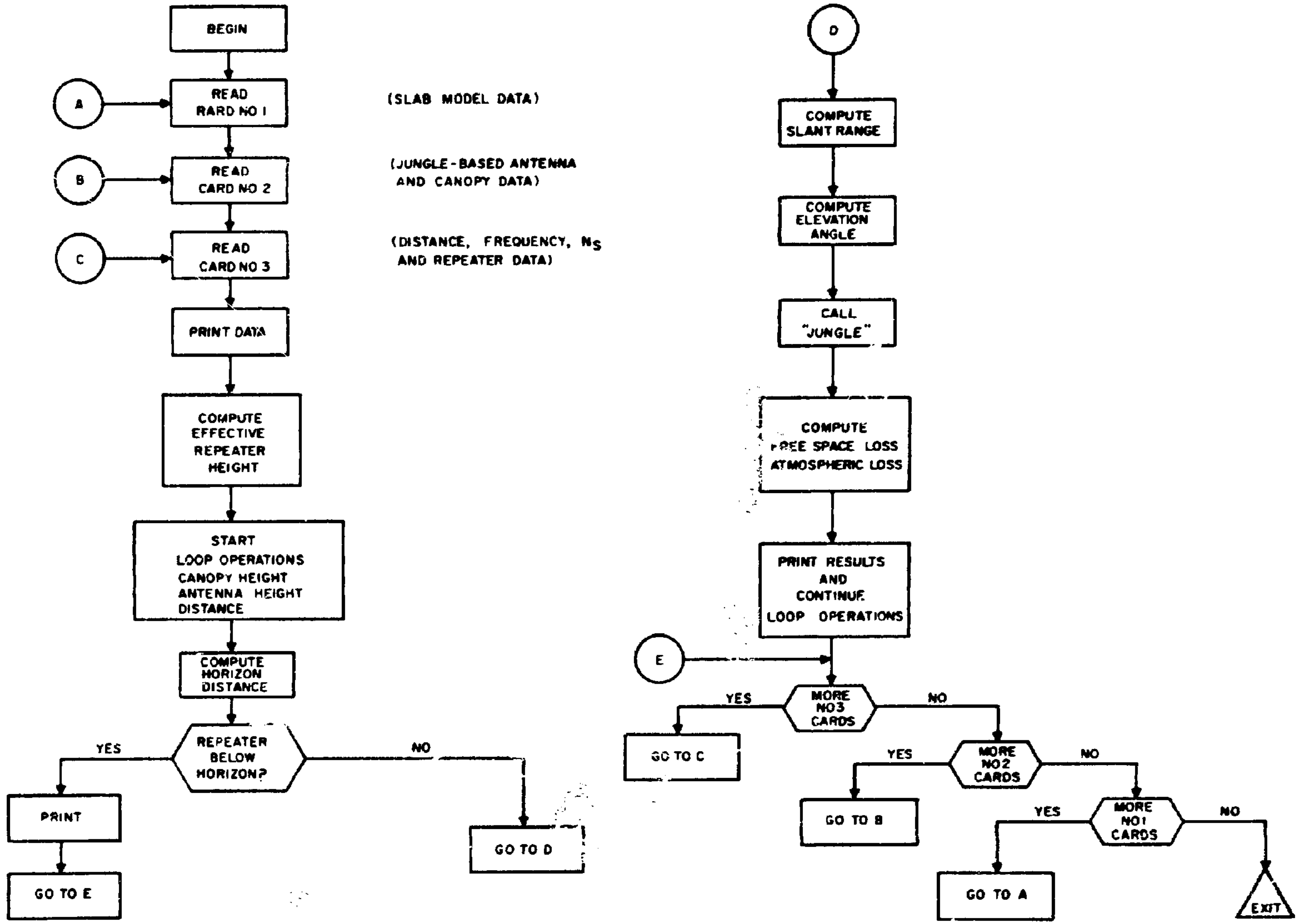


Figure 3.5-5. PATH

```
PROPAGATION THROUGH VEGETATION

ASSUMED THREE LAYER MODEL CONSTANTS ARE
          FREE SPACE      JUNGLE        EARTH
MU           1.00          1.00          1.0
EPSILON      1.00          1.23          15.0
SIGMA        0.0000        0.00015       .2000

THIS COMPUTATION IS FOR THE FOLLOWING INPUTS
REF ATMOSPHERE   340.0        FREQUENCY(MHZ)    30.0

ANTENNA IS VERTICALLY POLARIZED

CANOPY HEIGHT   10.00     ANTENNA HEIGHT   1.50     REPEATER HEIGHT   3.00 (KM)

DIST(KM)=    1.000    PATH LOSS =   76.96     ANGLE (0) =  71.12407    ANGLE (T) =  72.91865
DIST(KM)=   11.000    PATH LOSS =   87.543    ANGLE (0) =  14.82987    ANGLE (T) =  28.38744
DIST(KM)=   21.000    PATH LOSS =   94.137    ANGLE (0) =   7.8314-    ANGLE (T) =  25.73639
DIST(KM)=   31.000    PATH LOSS =   99.759    ANGLE (0) =   5.25254    ANGLE (T) =  25.10330
DIST(KM)=   41.000    PATH LOSS =  102.88     ANGLE (0) =   3.90046    ANGLE (T) =  24.87949
DIST(KM)=   51.000    PATH LOSS =  104.788    ANGLE (0) =   3.08062    ANGLE (T) =  24.77257
DIST(KM)=   61.000    PATH LOSS =  107.102    ANGLE (0) =   2.46105    ANGLE (T) =  24.71387
DIST(KM)=   71.000    PATH LOSS =  109.449    ANGLE (0) =   2.05234    ANGLE (T) =  24.67827
DIST(KM)=   81.000    PATH LOSS =  111.054    ANGLE (0) =   1.71970    ANGLE (T) =  24.65524
DIST(KM)=   91.000    PATH LOSS =  112.441    ANGLE (0) =   1.44957    ANGLE (T) =  24.63957
DIST(KM)=  101.000    PATH LOSS =  114.232    ANGLE (0) =   1.22414    ANGLE (T) =  24.62854
DIST(KM)=  111.000    PATH LOSS =  115.758    ANGLE (0) =   1.03205    ANGLE (T) =  24.62059
DIST(KM)=  121.000    PATH LOSS =  117.256    ANGLE (0) =   0.86466    ANGLE (T) =  24.61475
DIST(KM)=  131.000    PATH LOSS =  118.737    ANGLE (0) =   0.71615    ANGLE (T) =  24.61045
DIST(KM)=  141.000    PATH LOSS =  120.257    ANGLE (0) =   0.58267    ANGLE (T) =  24.60726
DIST(KM)=  151.000    PATH LOSS =  121.857    ANGLE (0) =   0.46119    ANGLE (T) =  24.60493
DIST(KM)=  161.000    PATH LOSS =  123.411    ANGLE (0) =   0.34946    ANGLE (T) =  24.60327
DIST(KM)=  171.000    PATH LOSS =  125.459    ANGLE (0) =   0.24579    ANGLE (T) =  24.60214
DIST(KM)=  181.000    PATH LOSS =  128.329    ANGLE (0) =   0.14883    ANGLE (T) =  24.60143
DIST(KM)=  191.000    PATH LOSS =  132.924    ANGLE (0) =   0.05754    ANGLE (T) =  24.60109

REPEATER BEYOND HORIZON
```

Figure 3.5-6. Path Loss Program Output Format

3.5.2 Propagation Predictions

3.5.2.1 Introduction. From the results of the computer program described in the previous section, parametric curves of the systematic component of path loss have been prepared. The computer program, in effect, translates the radiation pattern of an isotropic radiator immersed in the jungle into an effective free-space pattern in the half-space above the jungle. It includes the effects of the amplitude and phase of the ground-reflected ray, attenuation and retardation of the direct and reflected rays through the jungle, transmission loss (partial reflection and dispersion) through the jungle-air interface, and coherent combination of the resultant two rays in a plane normal to the direction of free-space propagation.

The variability was estimated from the only available source of ground-to-air data (ref. 3.5-6). It is anticipated that considerably more extensive and more appropriate data from SRI's airborne XELEDOP measurements in Thailand will soon be available.

3.5.2.2 Loss Dependence on Repeater Height. For the transceiver-to-repeater path geometry indicated in Figures 3.5-1 and 3.5-7, the systematic portion of the path loss has been computed. Figures 3.5-8 through 3.5-13 plot path loss in db (consisting of free-space loss plus loss in penetrating the jungle, as above) versus lateral distance between the ground transmitter and the sub-repeater point. Curves have been computed for incremental variation of the free-space ray elevation angle θ, and plotted against ground distance $d = a\psi$. Each figure contains six curves parametric in repeater height h_r according to the schedule h_r = 0.3, 1.0, 3.0, 10.0, 30.0, 100.0 km. Other parameters are as follows:

Figure	Frequency (MHz)	Canopy Height h_c (meters)
3.5-8	76	10.0
3.5-9	76	20.0
3.5-10	76	30.0
3.5-11	30	10.0
3.5-12	30	20.0
3.5-13	30	30.0

Electrical constants are:

	Air	Jungle	Ground
Conductivity σ (mho/m)	0	.00015	.02
Permittivity ϵ_r	1.0	1.2	15.0

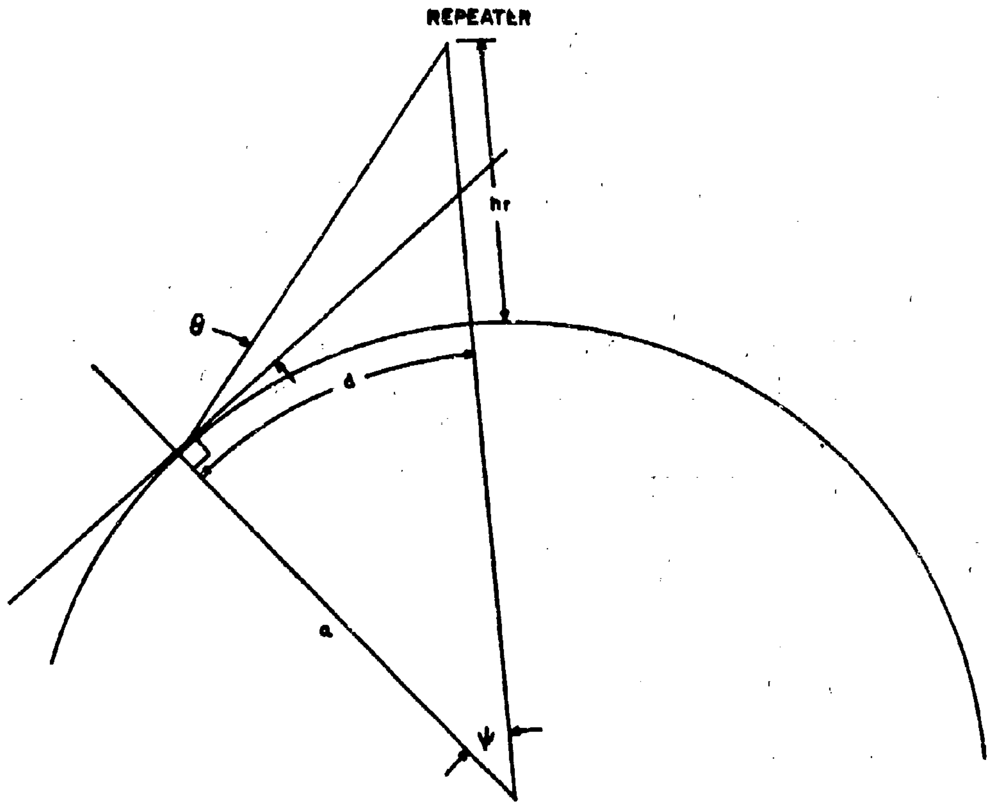


Figure 3.5-7. Repeater Geometry

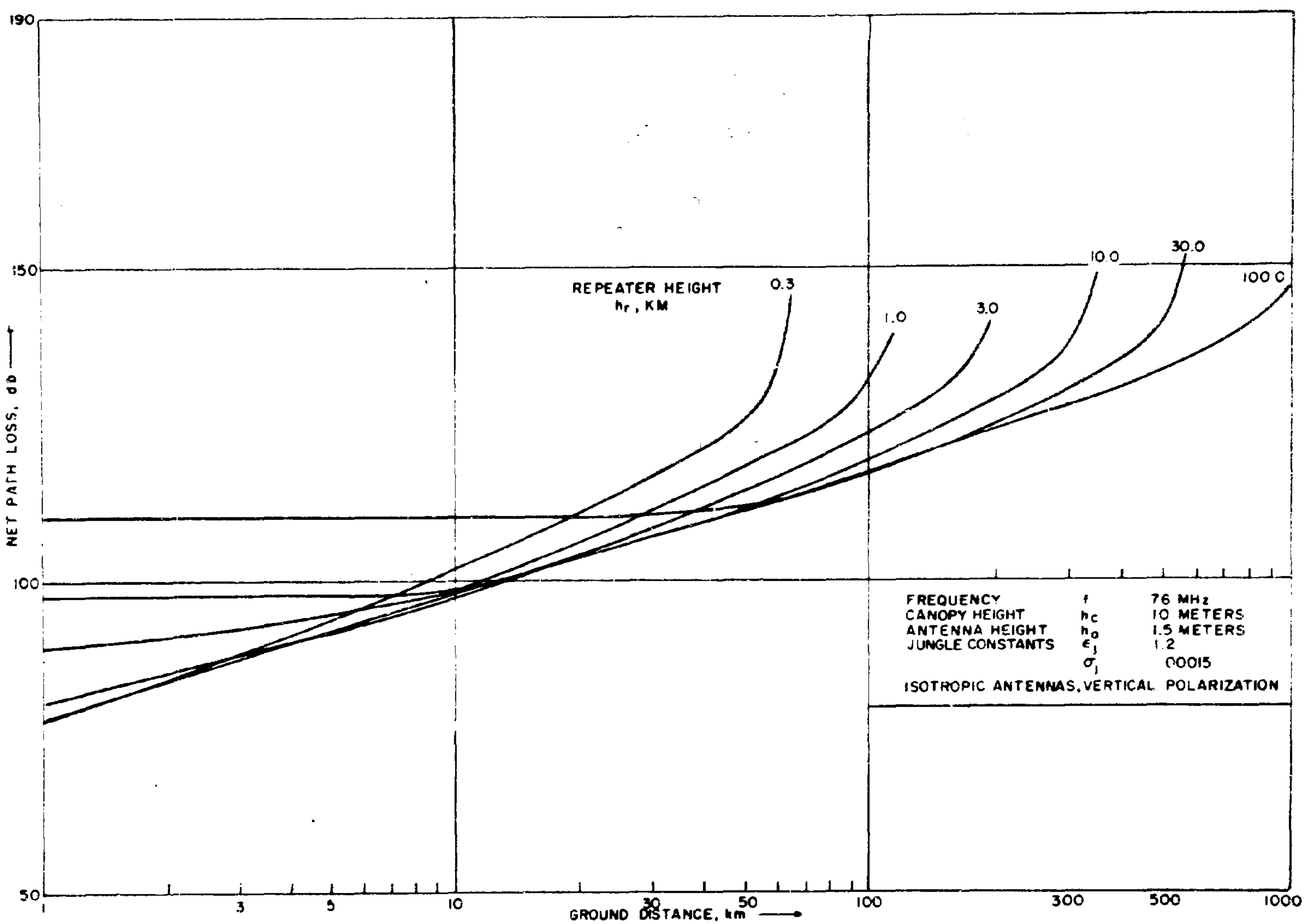


Figure 3.5-8. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

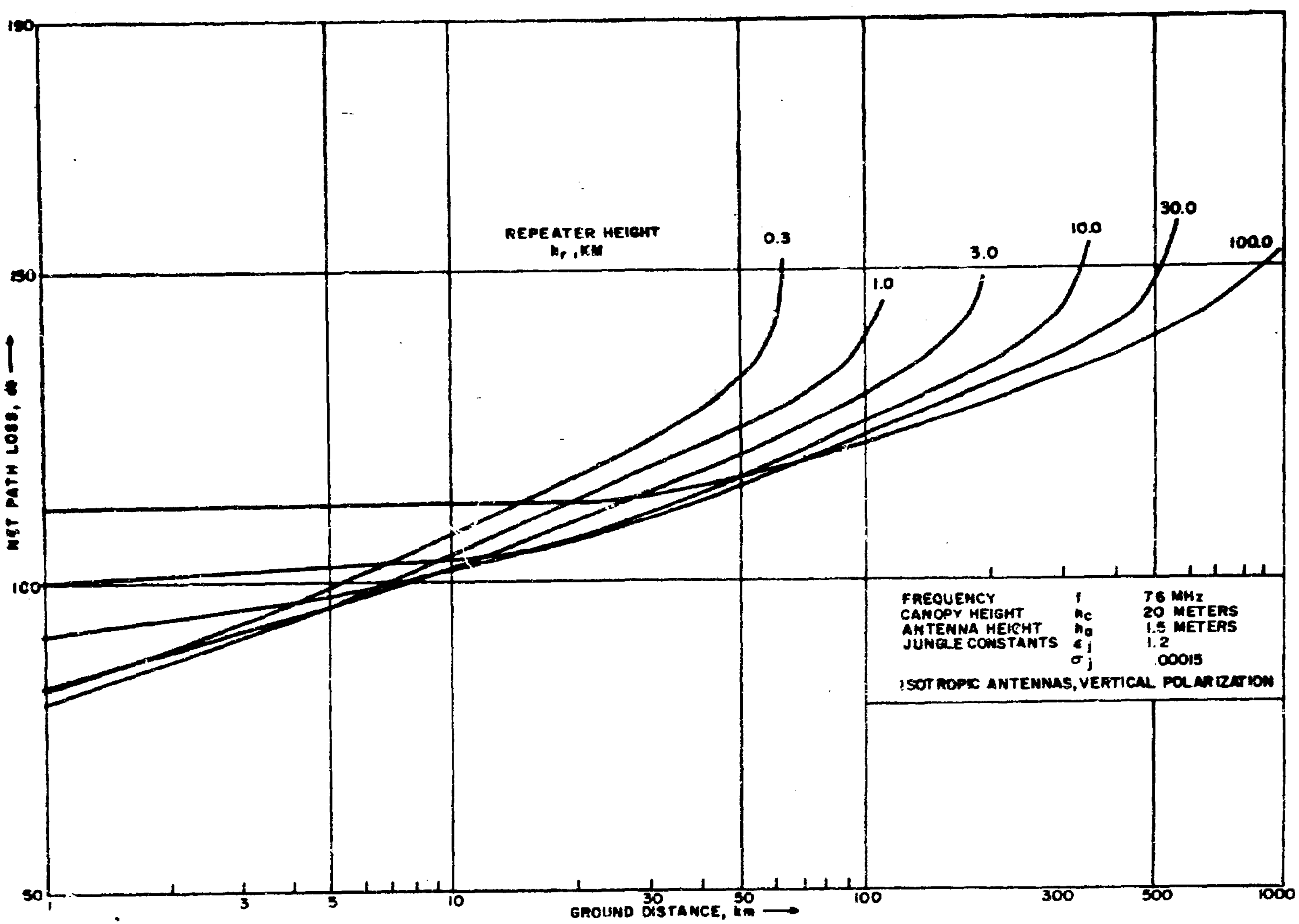


Figure 3.5-9. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

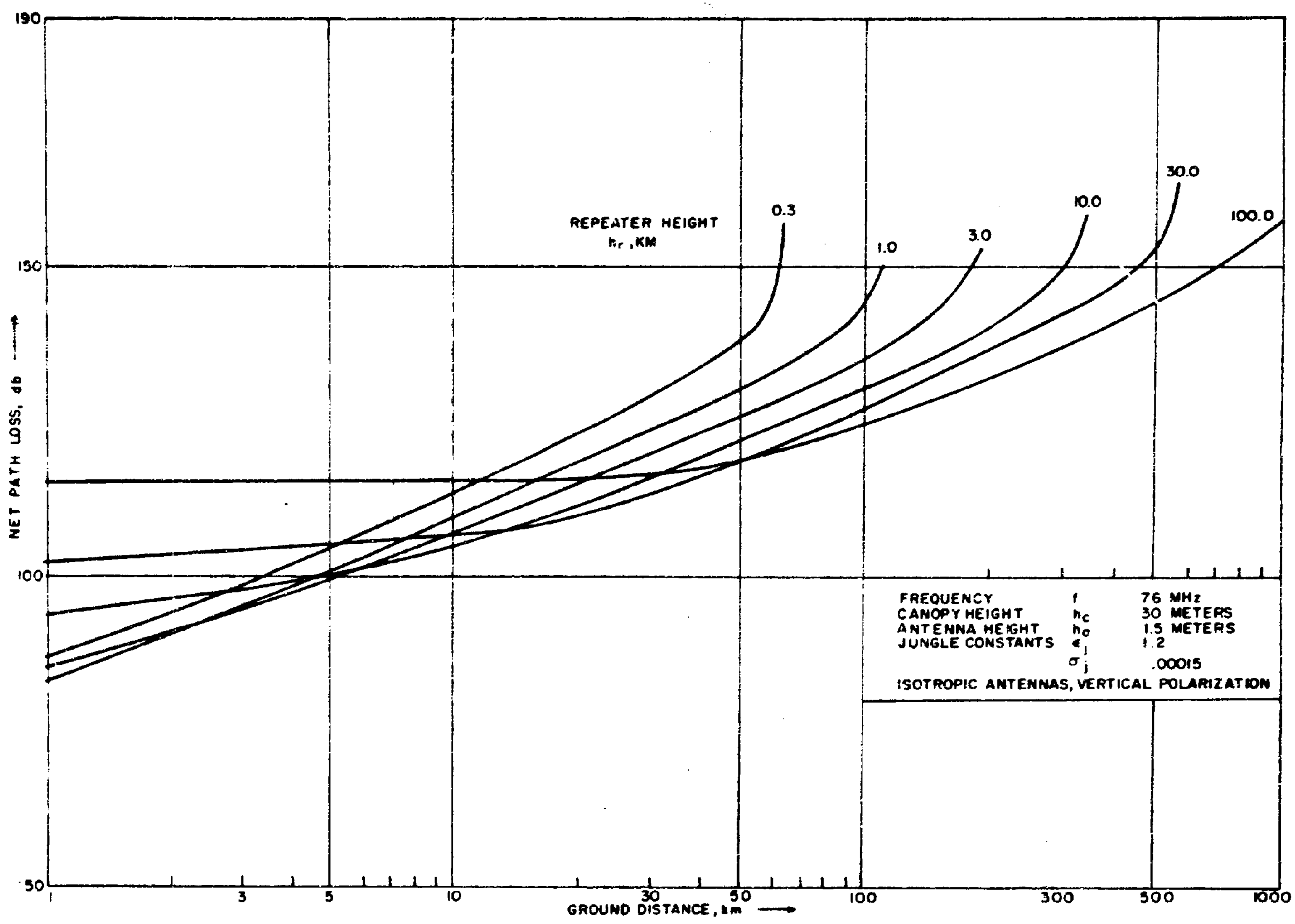


Figure 3.5-10. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

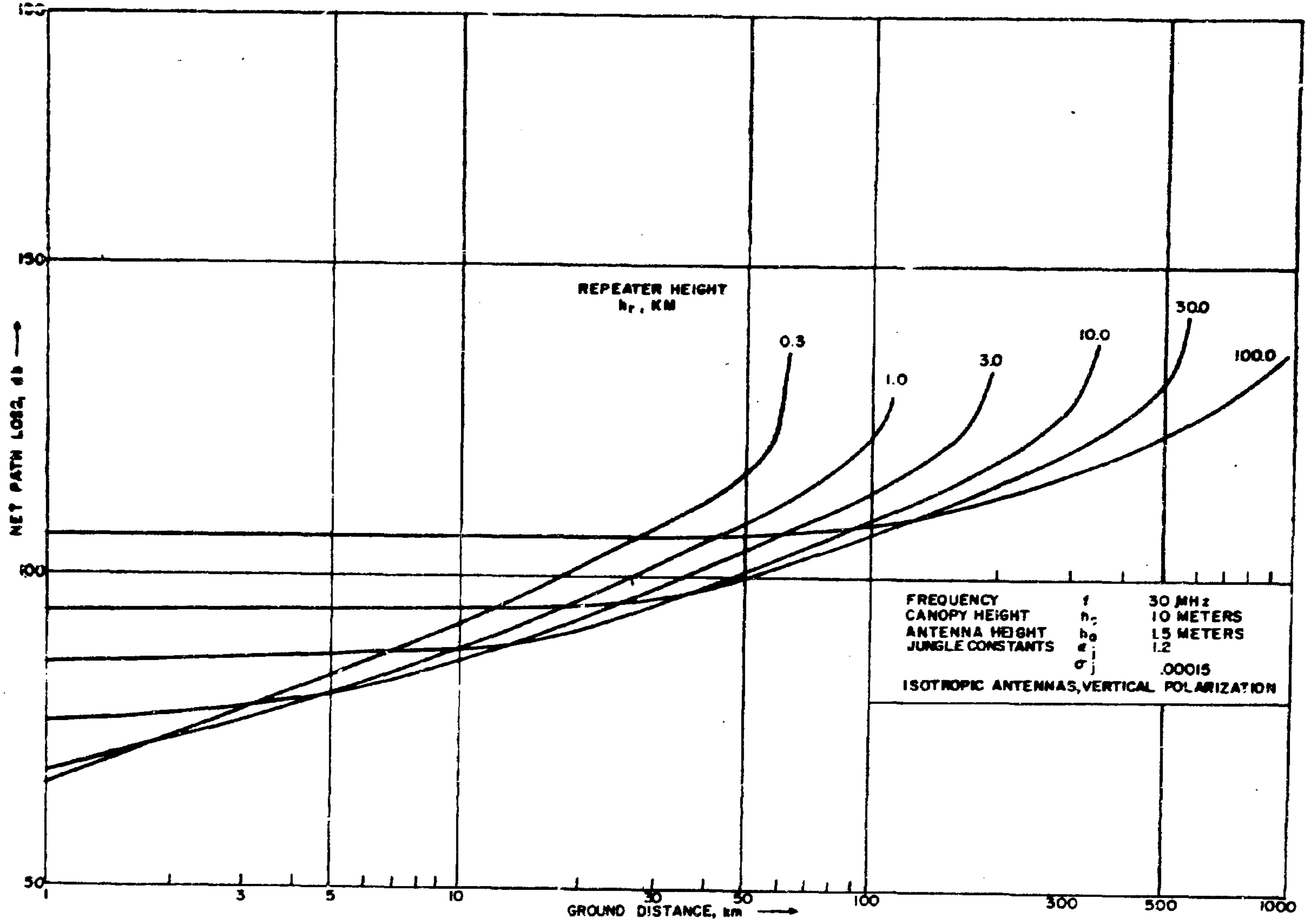


Figure 3.5-1i. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

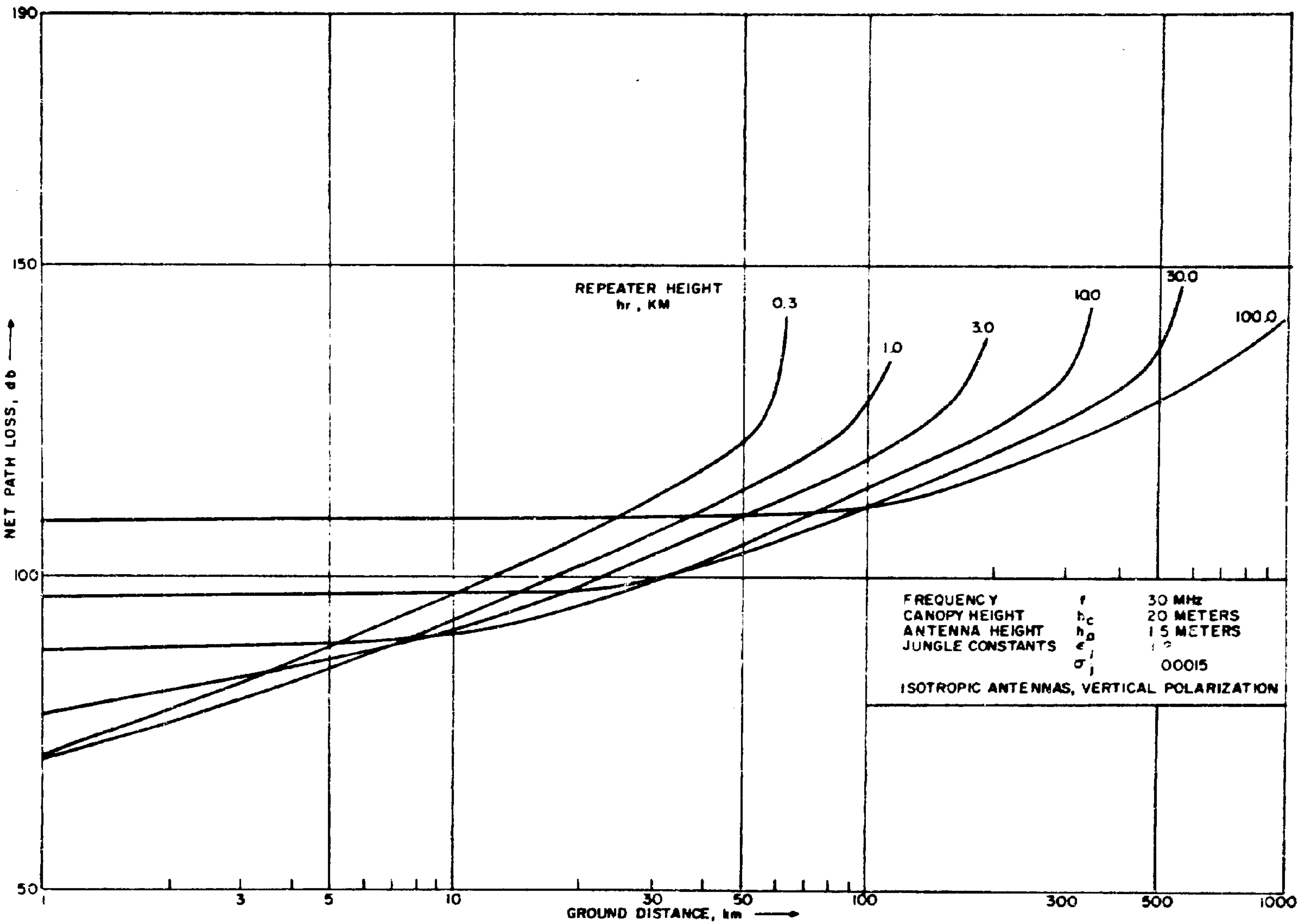


Figure 3.5-12. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

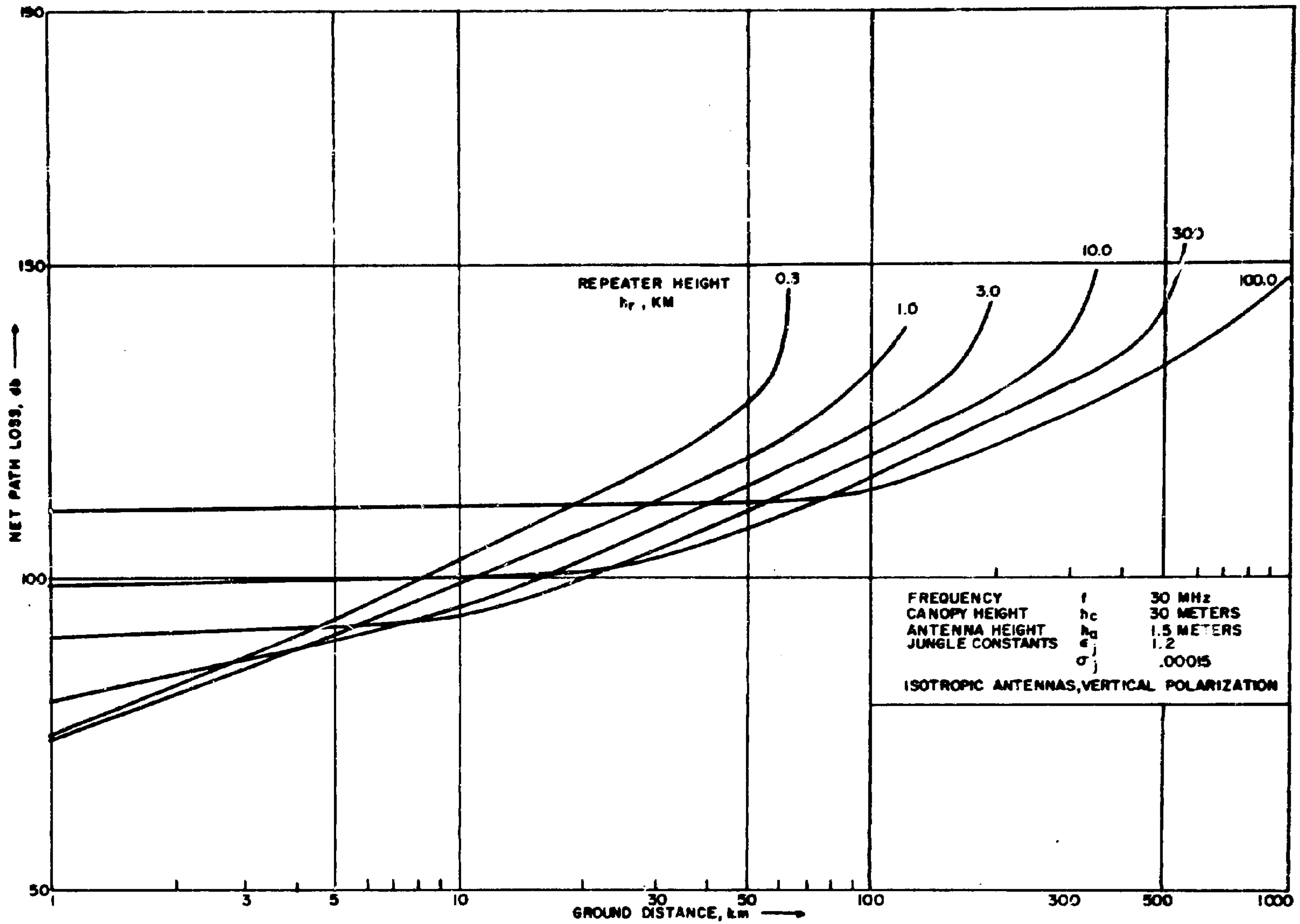


Figure 3.5-13. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

The jungle constants above are based upon Parker and Hagn's measurements of specific permittivity (ref. 3.5-7) and Sachs' best-fit value of conductivity (refs. 3.5-2 and 3.5-3). Subsequent measurements by Parker and Hagn have indicated values of permittivity of the order or 1.02 or 1.05.

3.5.2.3 Sensitivity to Jungle Parameters. Since the analyses of Parker and Sachs agree for representative values of jungle conductivity, no specific analysis of sensitivity to this parameter has been performed. However, Sachs has computed curves between two antennas immersed in the jungle for $\sigma_j = .0001$ and $\sigma_j = .0002$ (refs. 4.5-2 and 4.5-3), and these can be used to obtain some idea of the sensitivity to σ_j.

Sachs uses a value for permittivity $\epsilon_j = 1.02$ in his analyses. Parker's early transmission line measurements indicated a value of $\epsilon_j = 1.2$ which value has been used here. Figures 3.5-14 through 3.5-19 have been plotted to illustrate the sensitivity of path loss ϵ_j. The parameters used are:

Permittivity ϵ_j 1.0, 1.1, 1.2, 1.3

Canopy height h_c 30 meters

Figure	Frequency (MHz)	Repeater Height h_r (km)
3.5-14	76	1.0
3.5-15	76	10.0
3.5-16	76	100.0
3.5-17	76	1.0
3.5-18	30	10.0
3.5-19	30	100.0

It may be seen that little sensitivity to ϵ_j occurs at high ray angles; however, as the ran angle approaches the horizon, varying amounts of path loss reduction with increasing ϵ_j are evident from the curves.

3.5.2.4 Effect of Dipole Antennas. Figures 3.5-20 to 3.5-25 plot net path loss versus ground range for the same parameters and repeater heights as in Figures 3.5-8 to 3.5-13. However, Figures 3.5-20 to 3.5-25 include the pattern effects of vertical $\lambda/2$ dipole antennas at the ground terminal and repeater. The principal effects are some reduction in path loss at longer ground distances and a rise in loss at extremely short ranges corresponding to the nulls of the dipole pattern. Portions of the curves corresponding to more than 30 db total null depth have been dashed to indicate uncertainties as to antenna orientation stability and fill-in resulting from jungle-scattered energy at other angles.

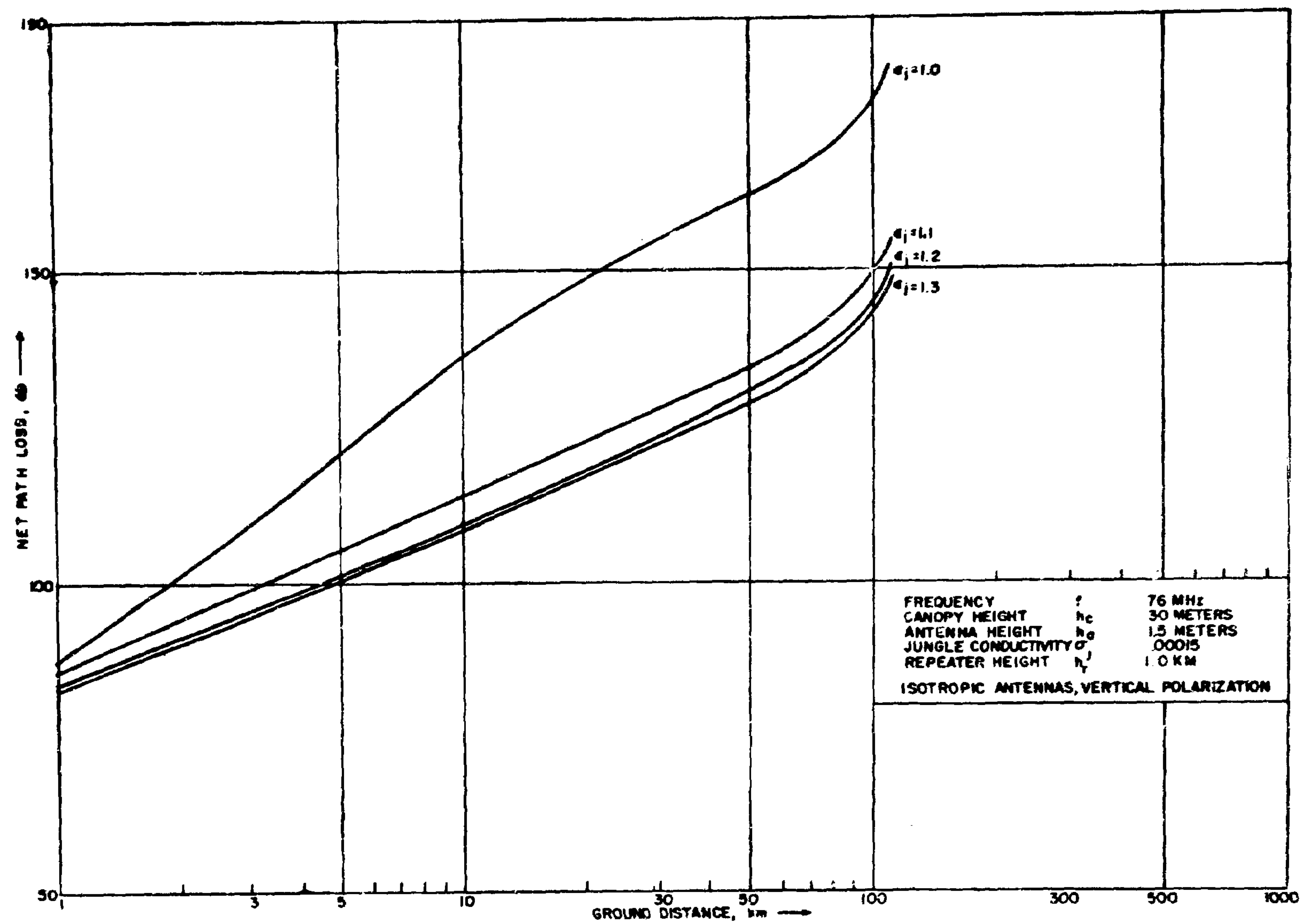


Figure 3.5-14. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

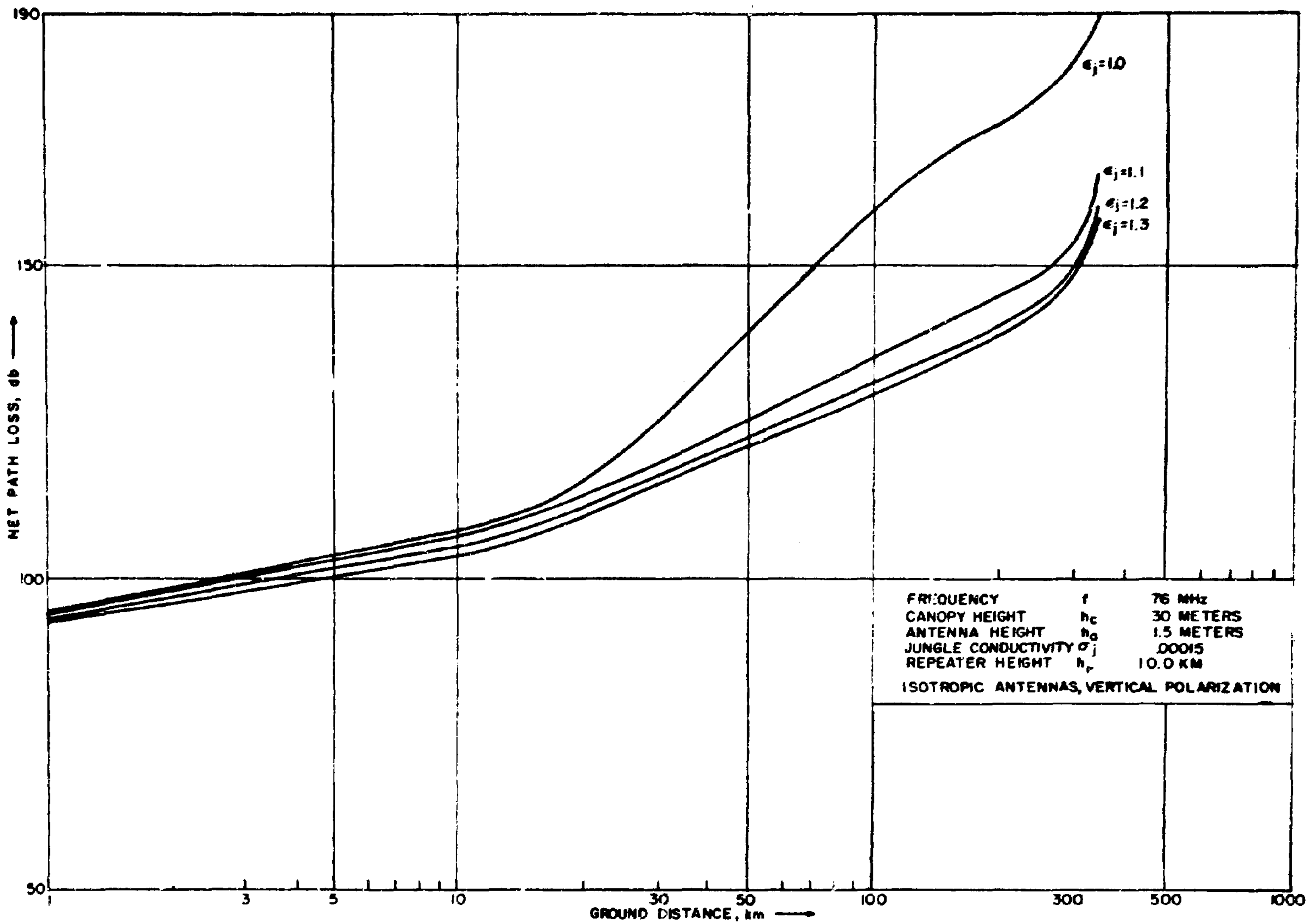


Figure 3.5-15. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

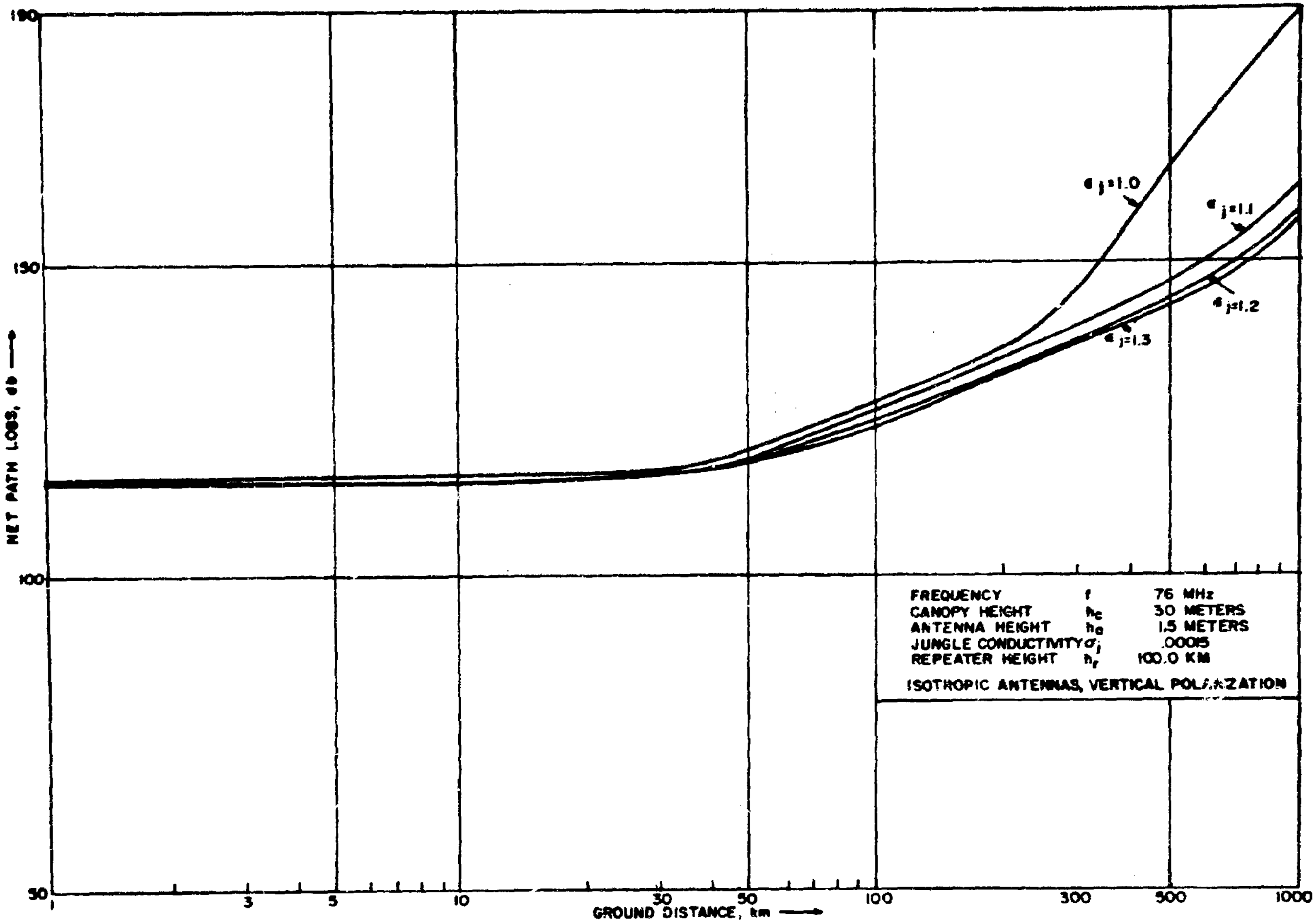


Figure 3.5-16. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

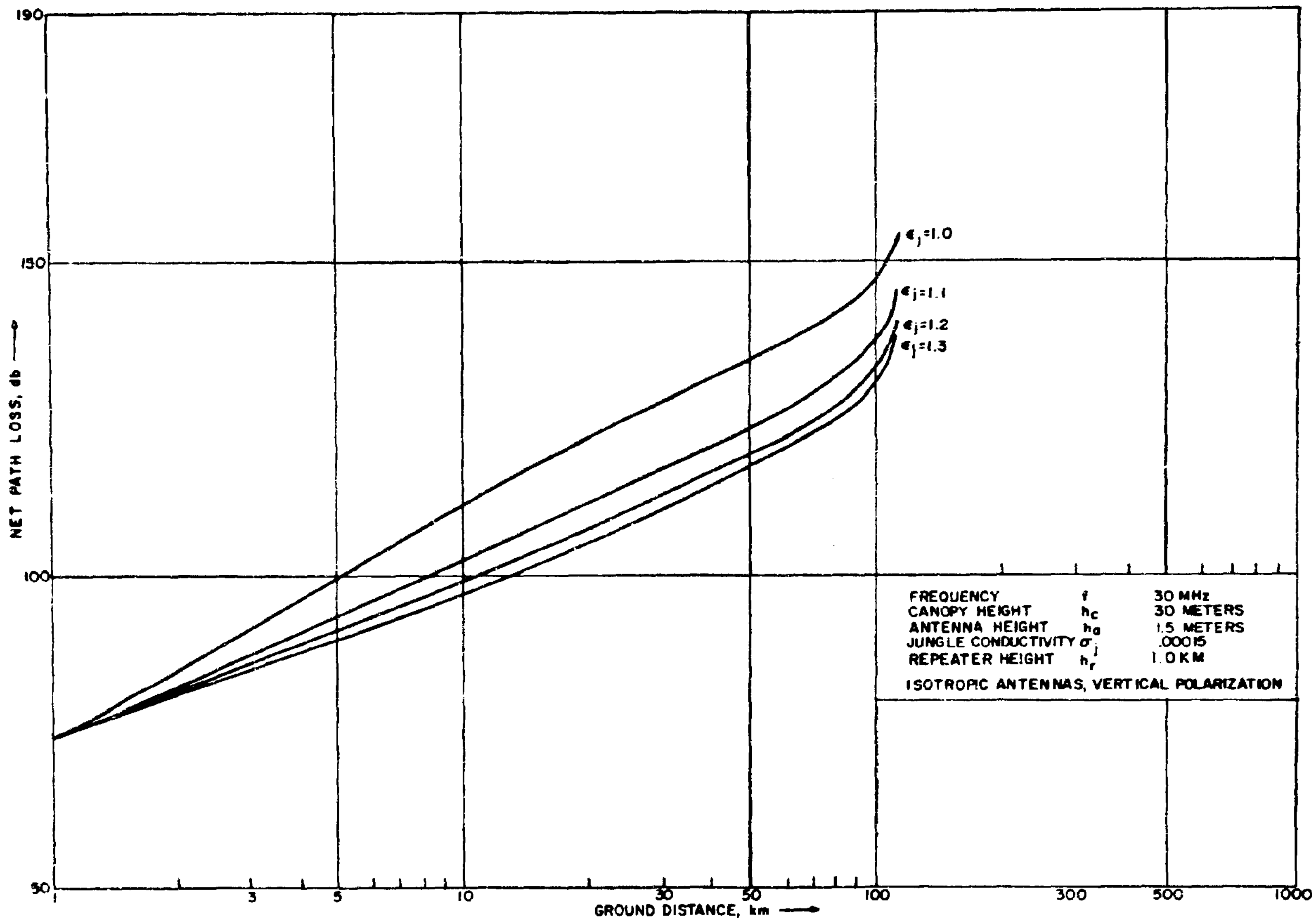


Figure 3.5-17. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

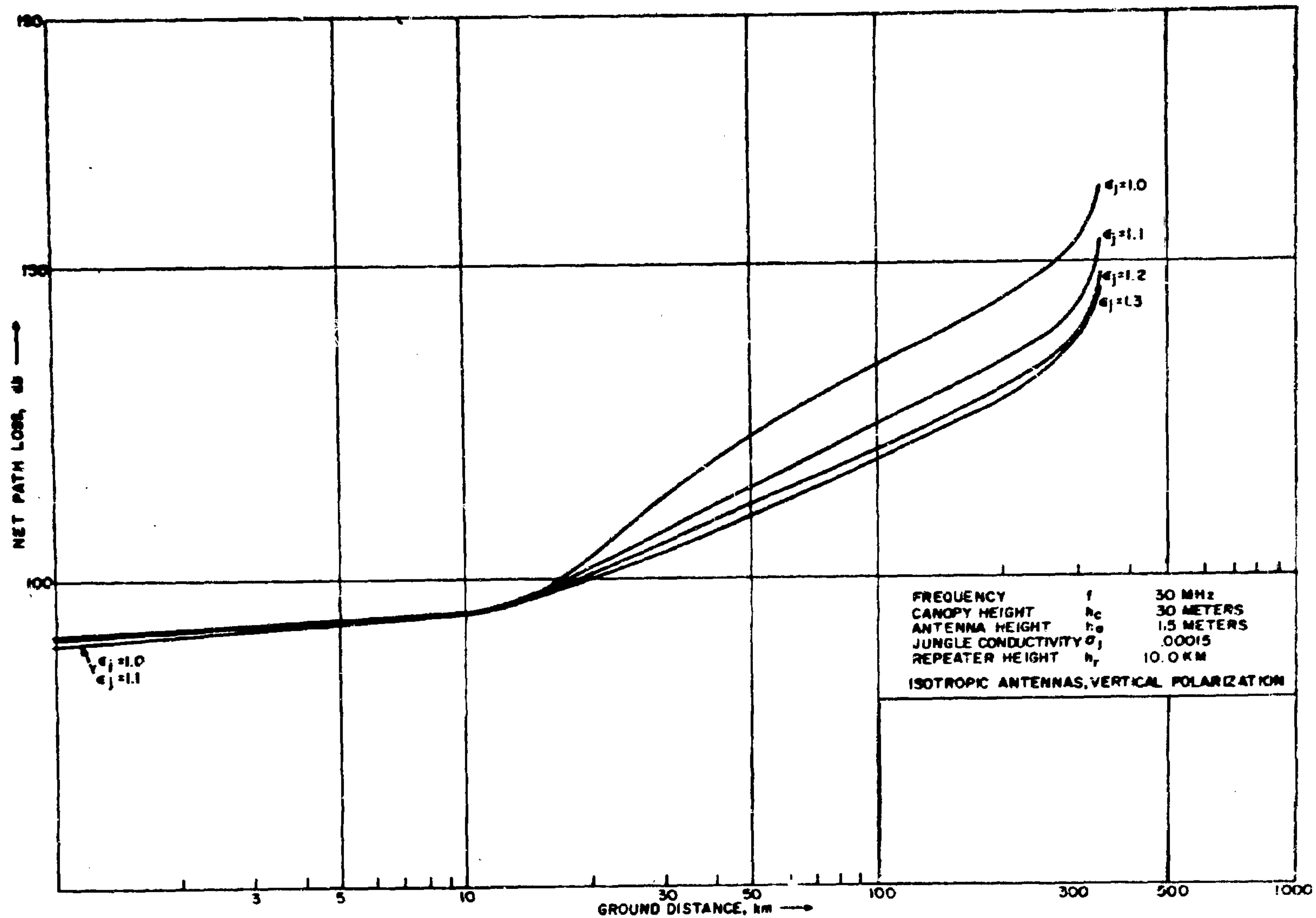


Figure 3.5-18. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

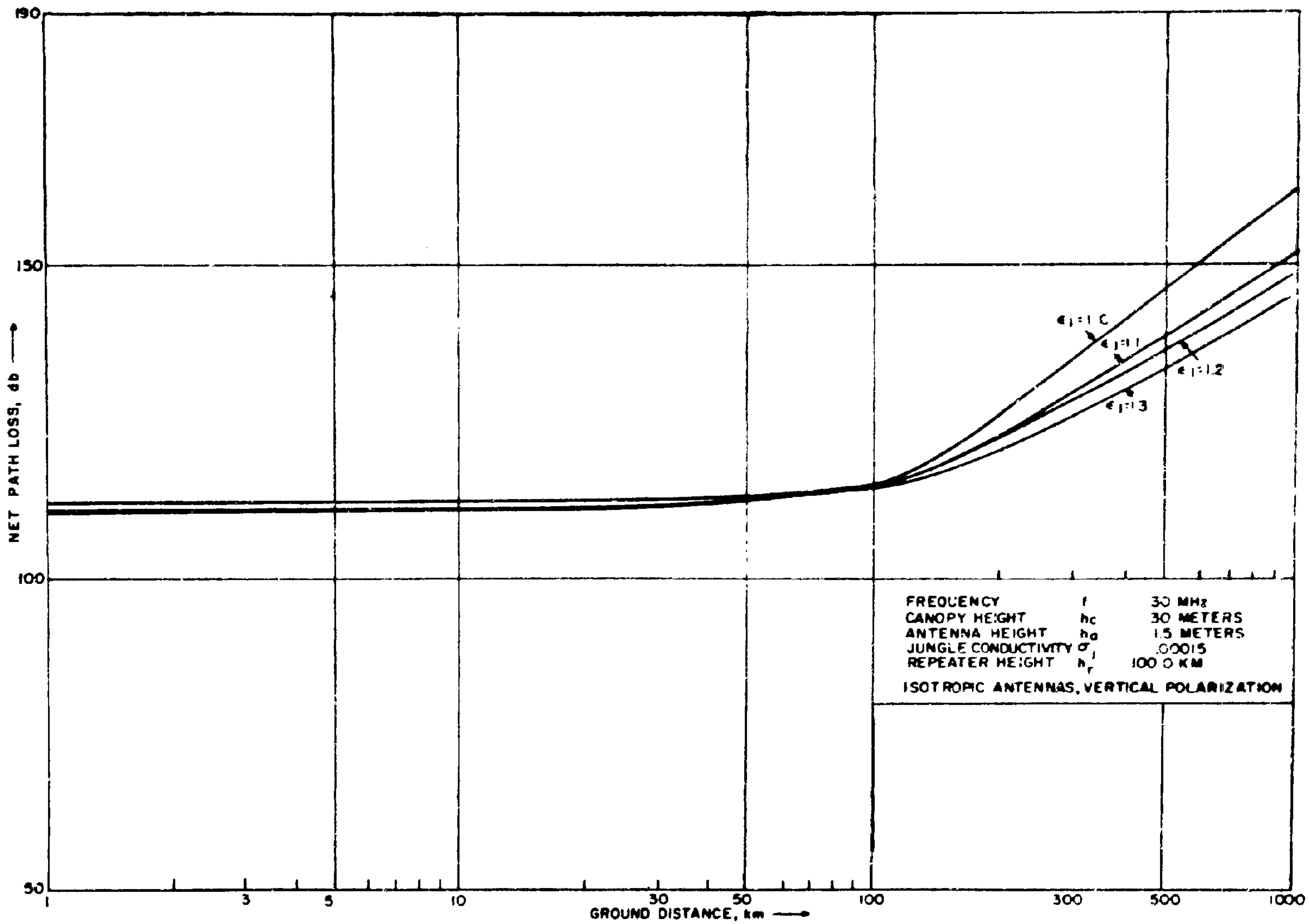


Figure 3.5-19. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

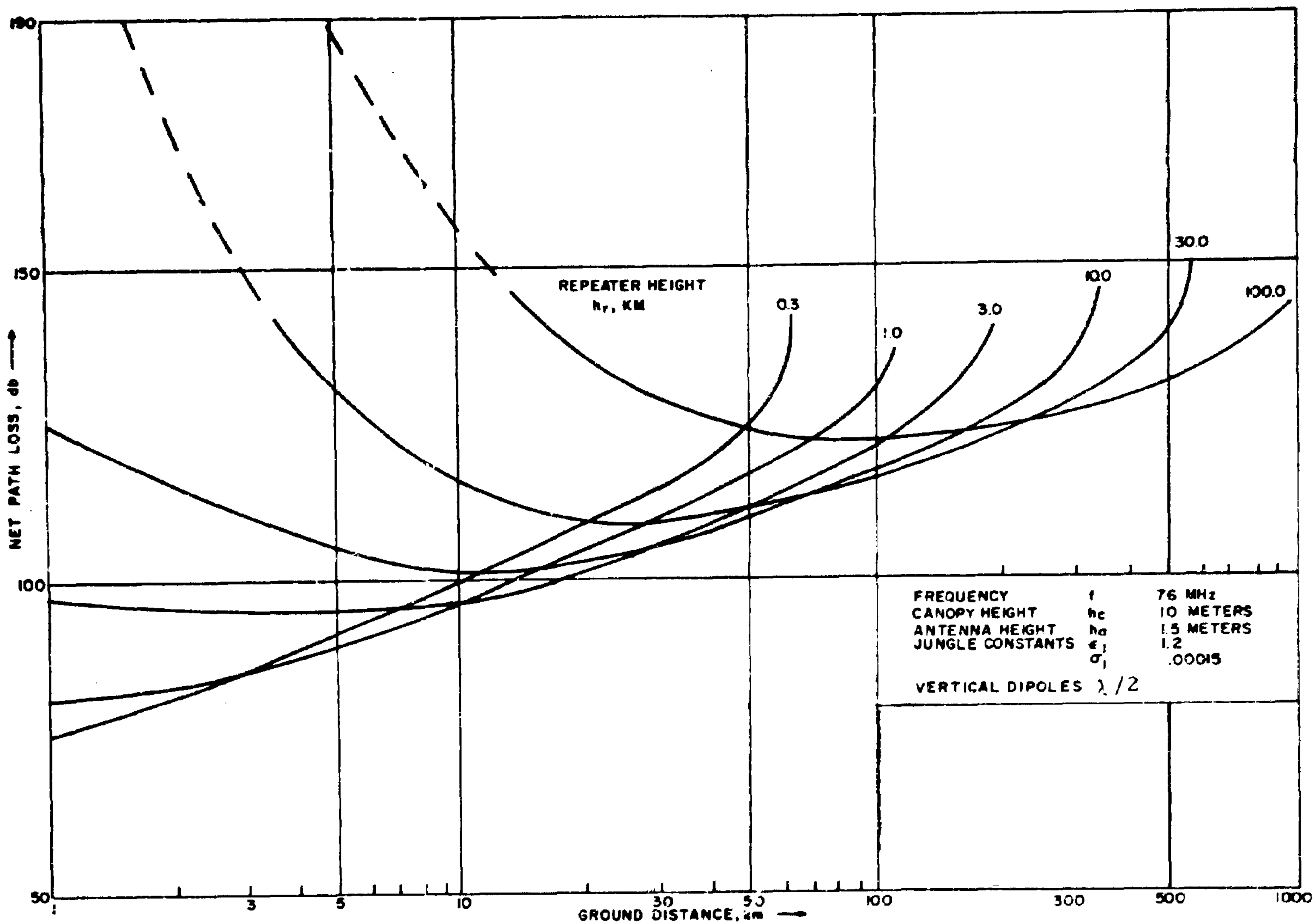


Figure 3.5-20. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

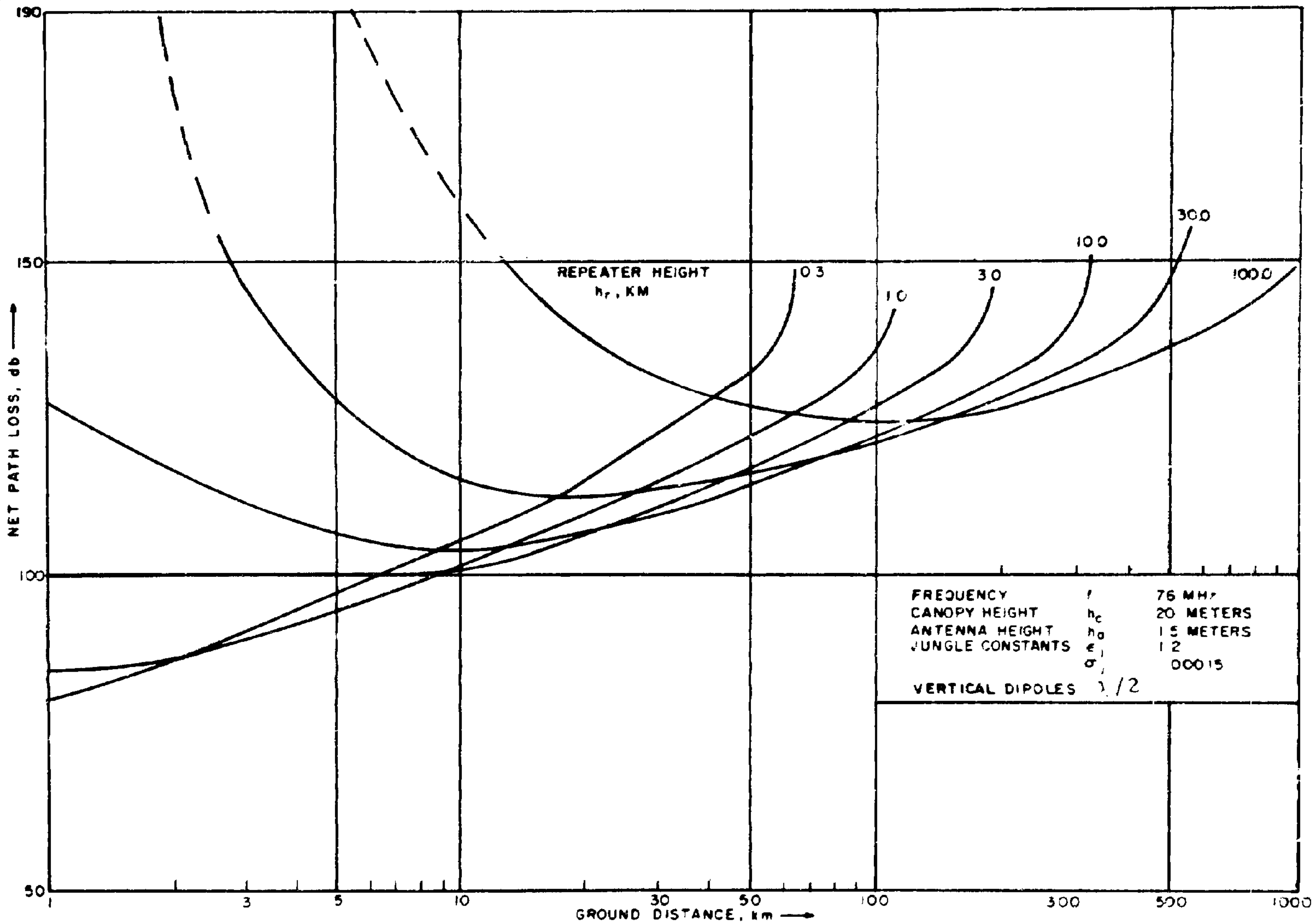


Figure 3.5-21 Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

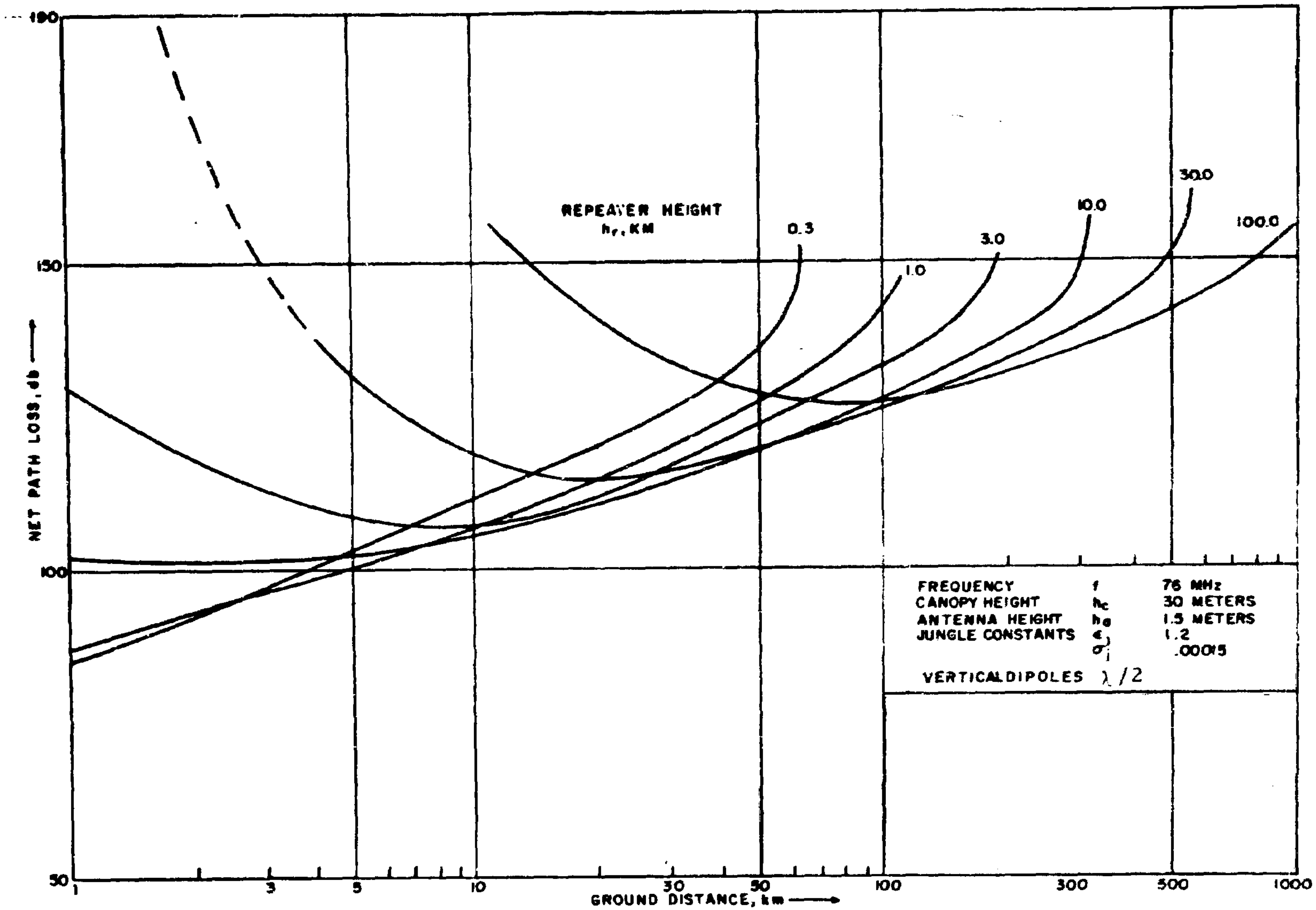


Figure 3.5-22. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

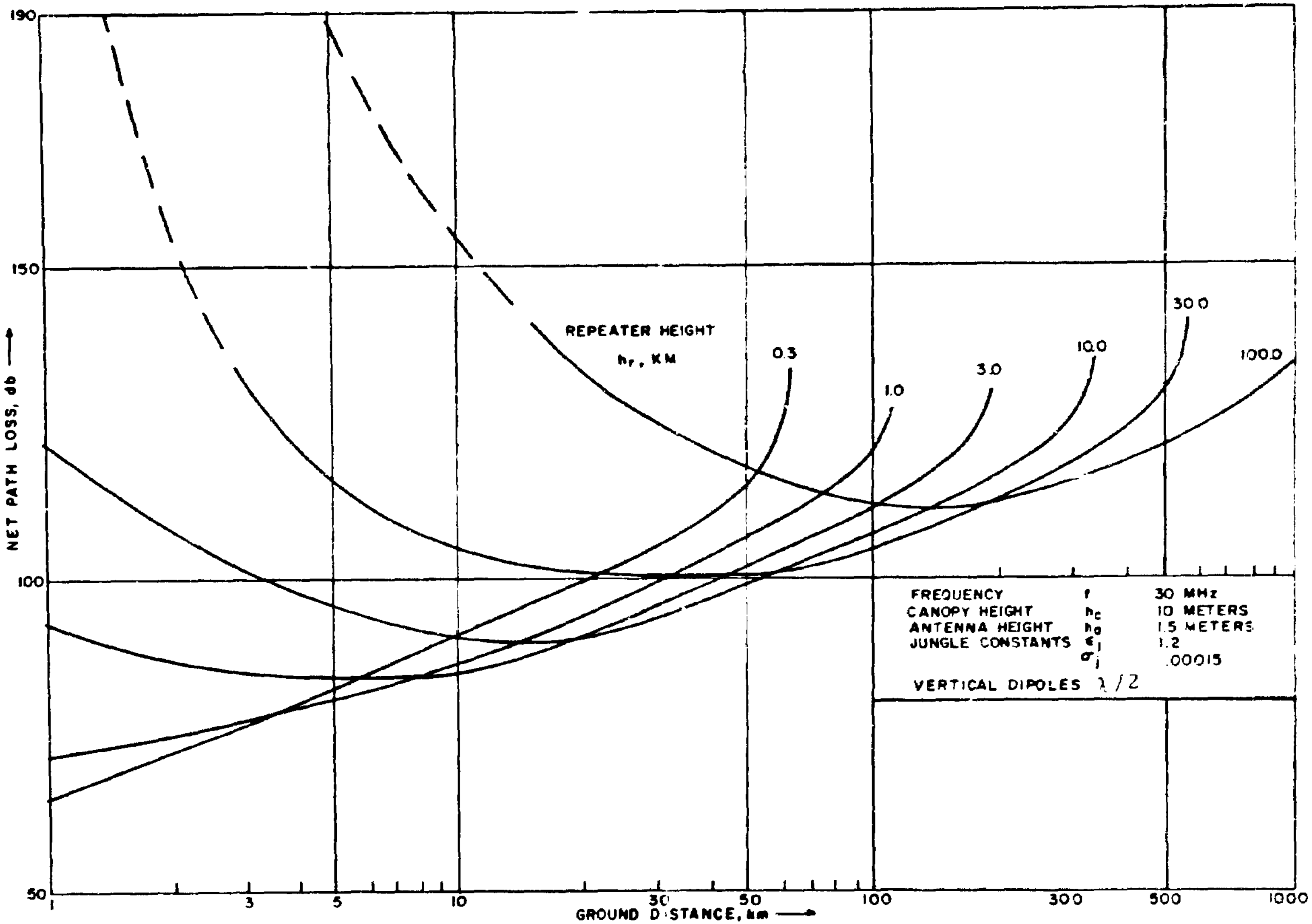


Figure 3.5-23. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

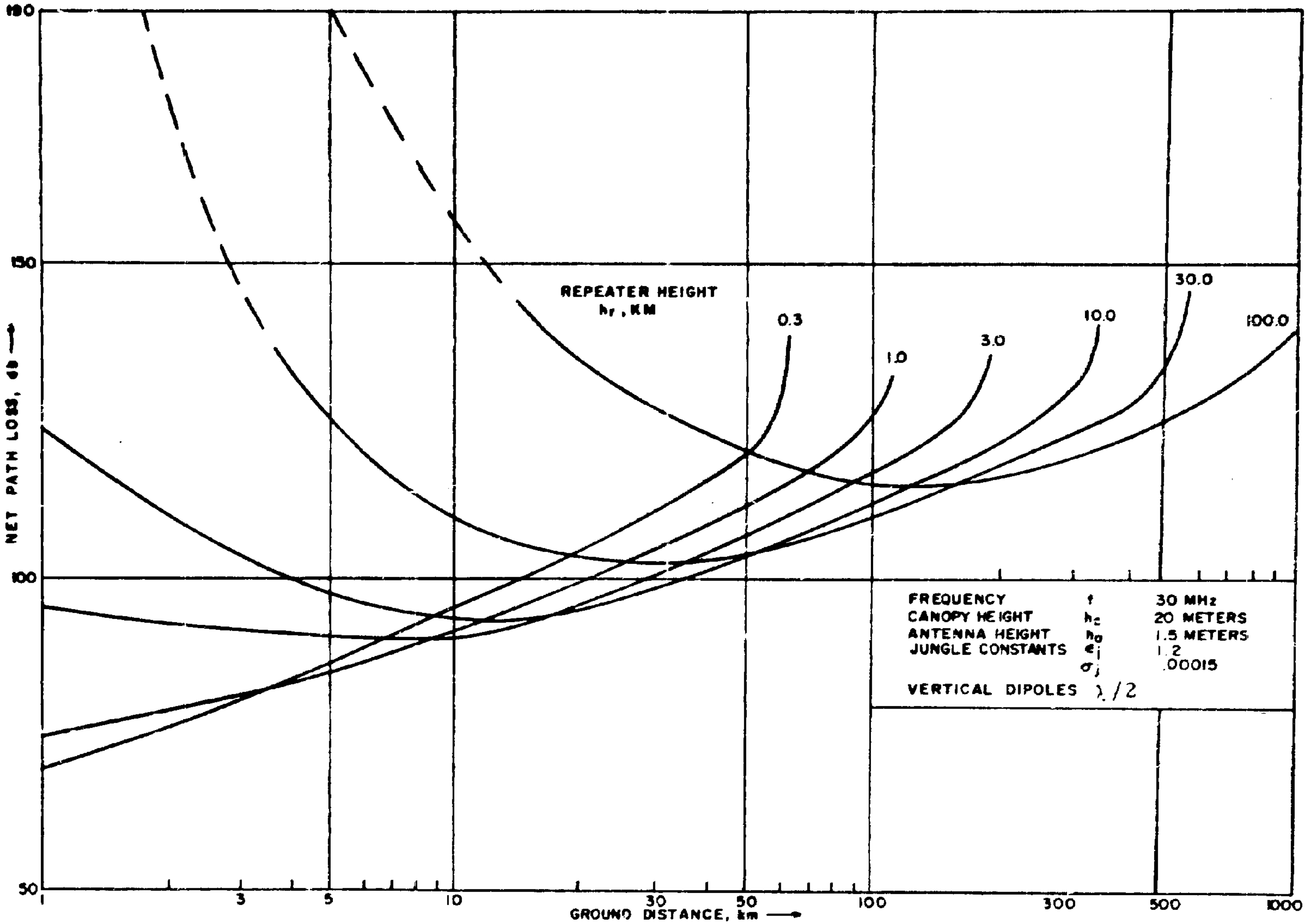


Figure 3.5-24. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

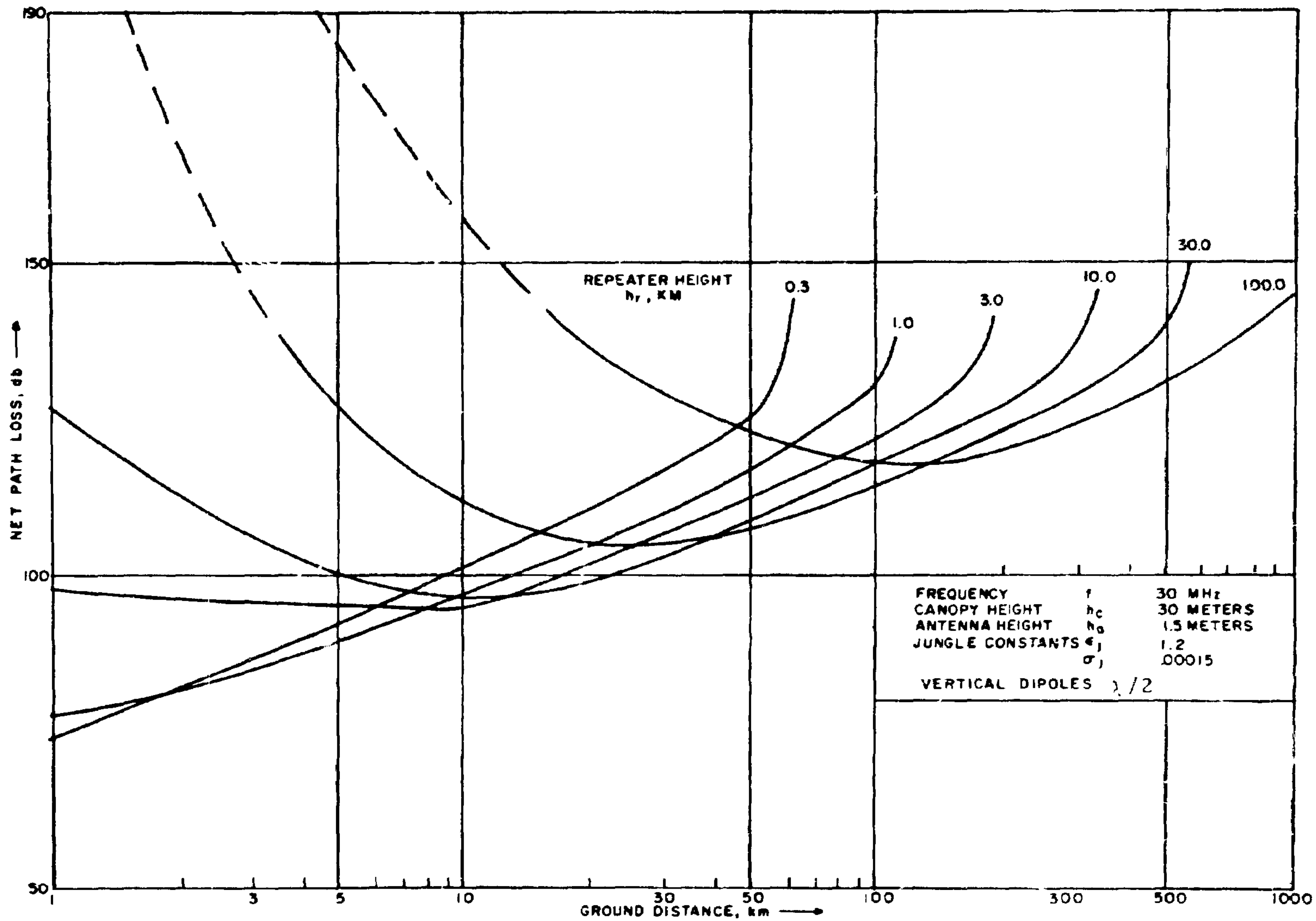


Figure 3.5-25. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

Only uniform pattern effects have been computed in Figures 3.5-20 to 3.5-25. Random space variations of path loss due to inhomgeneities in the jungle, and dissipative losses in the near field will be discussed separately.

Figure 3.5-26 corresponds to the conditions of Figure 3.5-21, but uses the revised value of 1.02 for permittivity. It will be noted that the path loss is somewhat lower, since there is less refraction at the canopy-air boundary and since the loss corresponding to the ground dipole pattern is lower. Revision of other representative curves in the series is planned for the next few weeks.

3.5.2.5 Results Without Jungle. Similar parametric curves without jungle have been plotted in Figures 3.5-27 through 3.5-30. These correspond to path loss between the repeater and a ground terminal in open terrain over good ground (σ_g = .02 mho/meter, ϵ_g = 15) and are plotted versus ground distance parametrically in repeater height, as in the previous cases. The other parameters are:

Figure	Frequency (MHz)	Antenna
3.5-27	76	Isotropic
3.5-28	30	Isotropic
3.5-29	76	Vertical dipoles
3.5-30	30	Vertical dipoles

3.5.2.6 Allowable Path Loss. An alternative presentation of the data may be useful in visualizing platform height-system gain tradeoffs. Here, required repeater altitude is plotted against ground distance parametrically in allowable path loss. Curves of this type are presented in Figures 3.5-31 through 3.5-35. The curves are plotted for a canopy height h_c = 20 meters and for σ_j = .00015. Other parameters are:

Figure	Frequency (MHz)	Permittivity	Antenna Type
3.5-31	76	1.2	Isotropic
3.5-32	30	1.2	Isotropic
3.5-33	76	1.2	Vertical dipoles
3.5-34	30	1.2	Vertical dipoles
3.5-35	76	1.02	Vertical dipoles

It should be noted that these curves do not include the variational component, which defines the additional path loss for a particular fraction of the time.

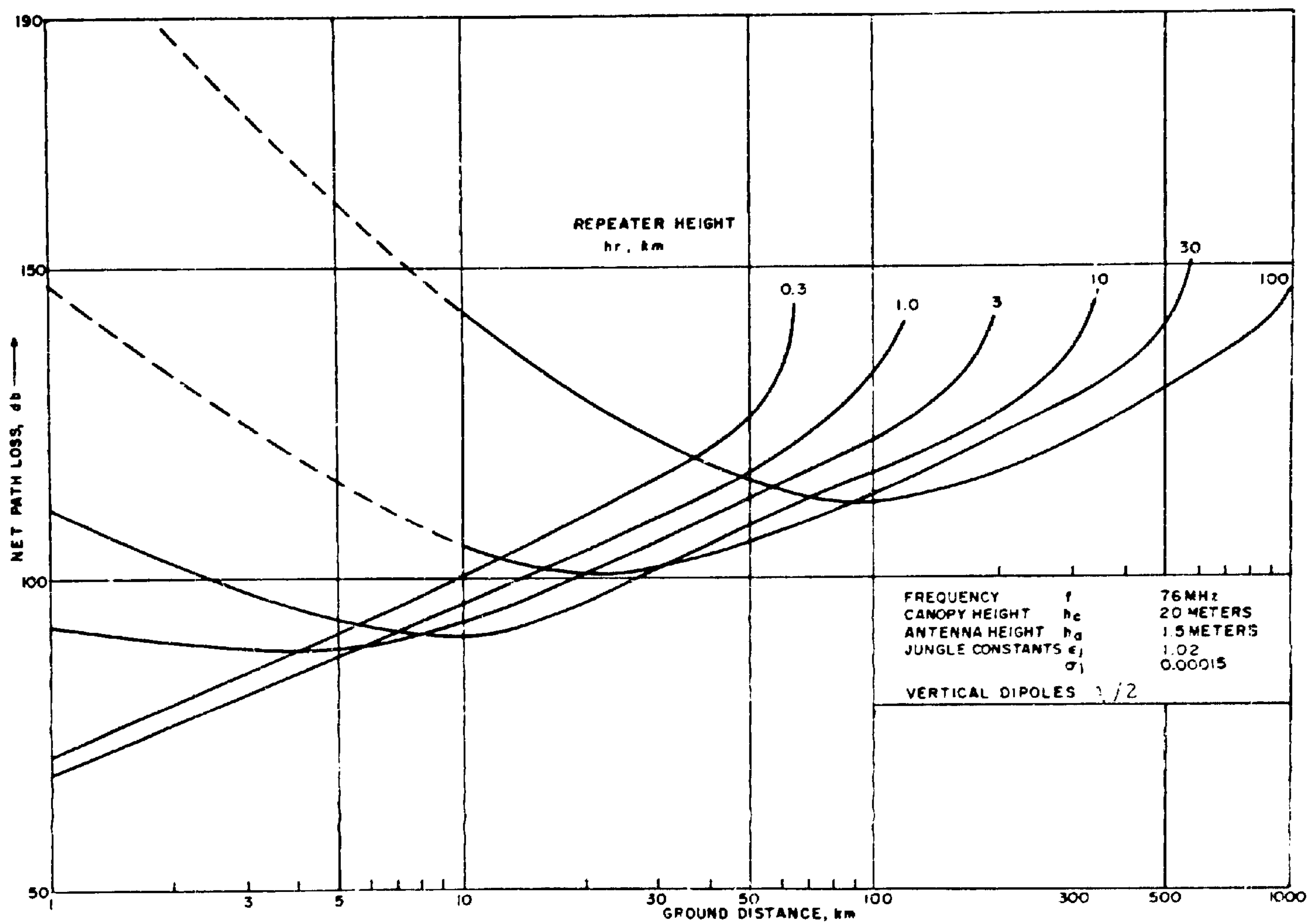


Figure 3.5-26. Path Loss for Transmission from Set in Jungle to Repeater at Height h_r Versus Ground Distance

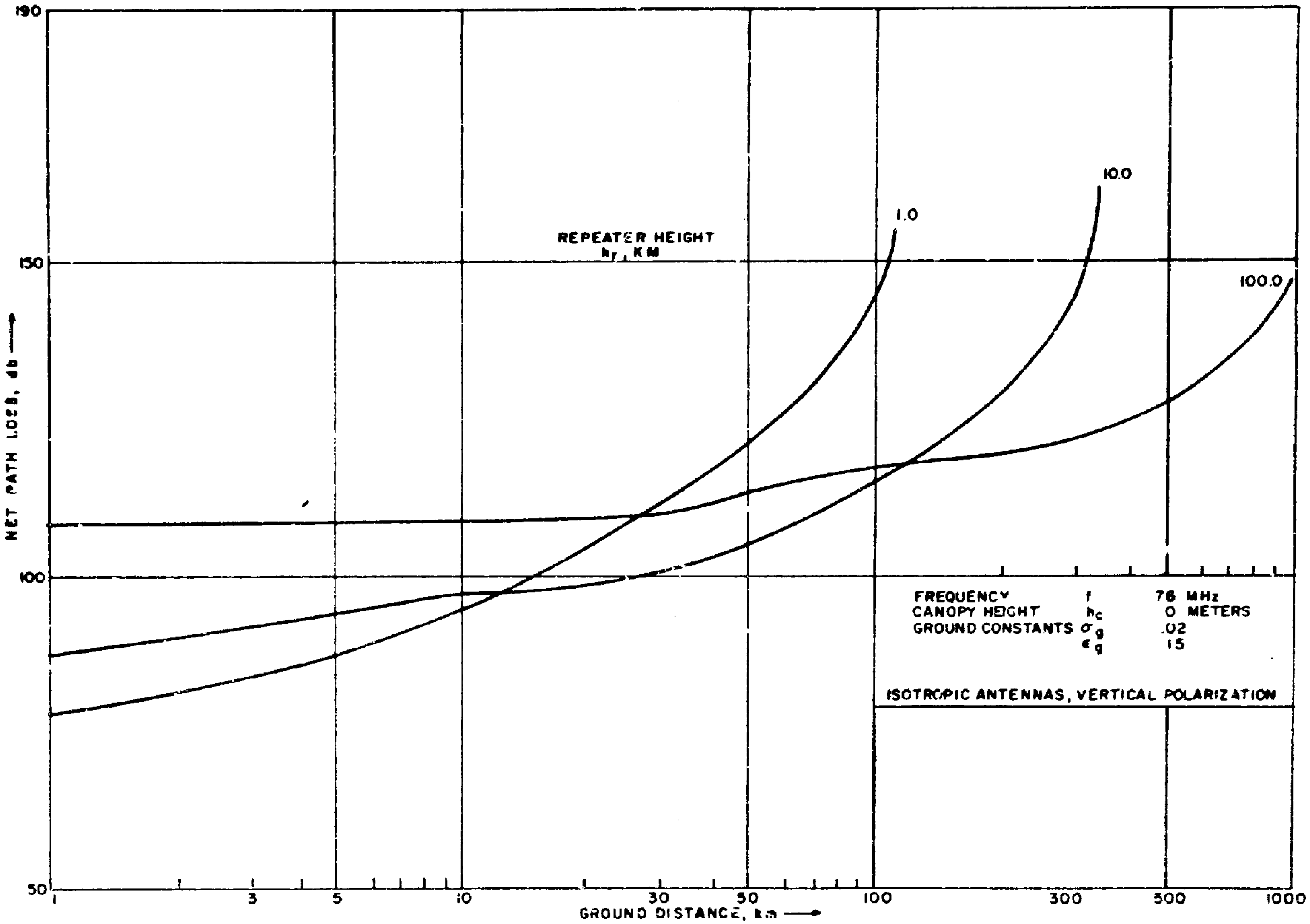


Figure 3.5-27. Path Loss Between Repeater and Ground Terminal Over Open Terrain Versus Ground Distance

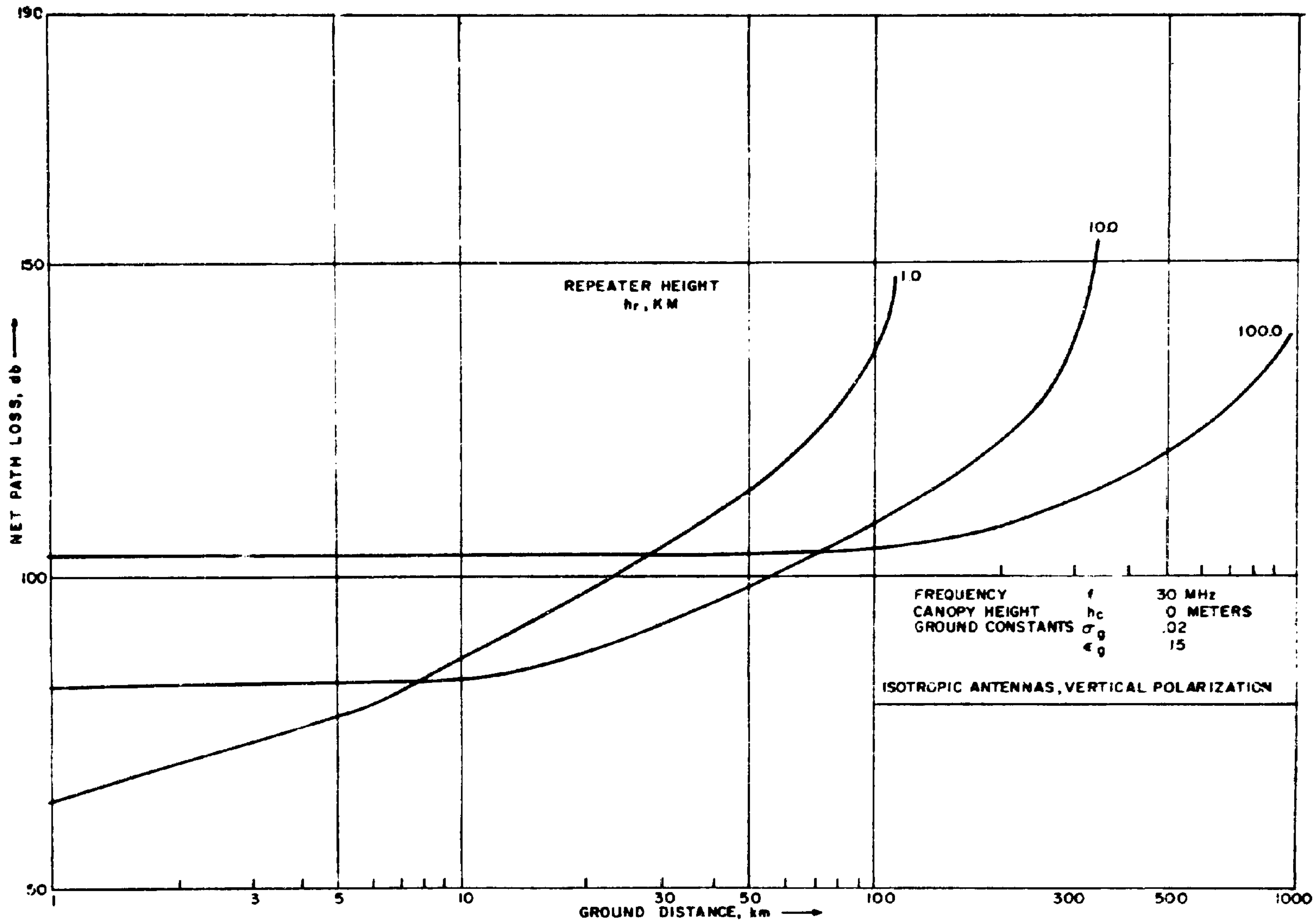


Figure 3.5-28. Path Loss Between Repeater and Ground Terminal Over Open Terrain Versus Ground Distance

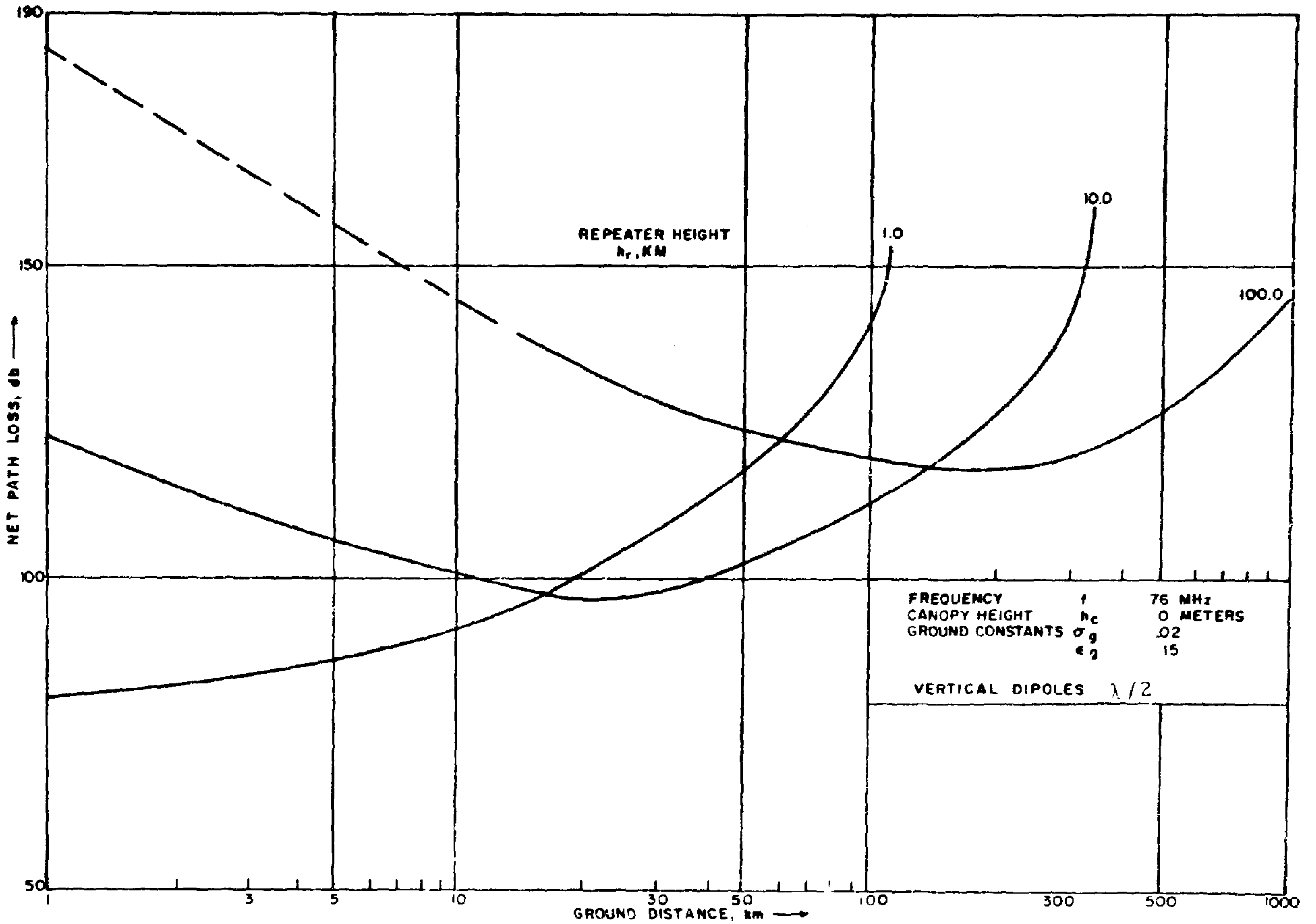


Figure 3.5-29. Path Loss Between Repeater and Ground Terminal Over Open Terrain Versus Ground Distance

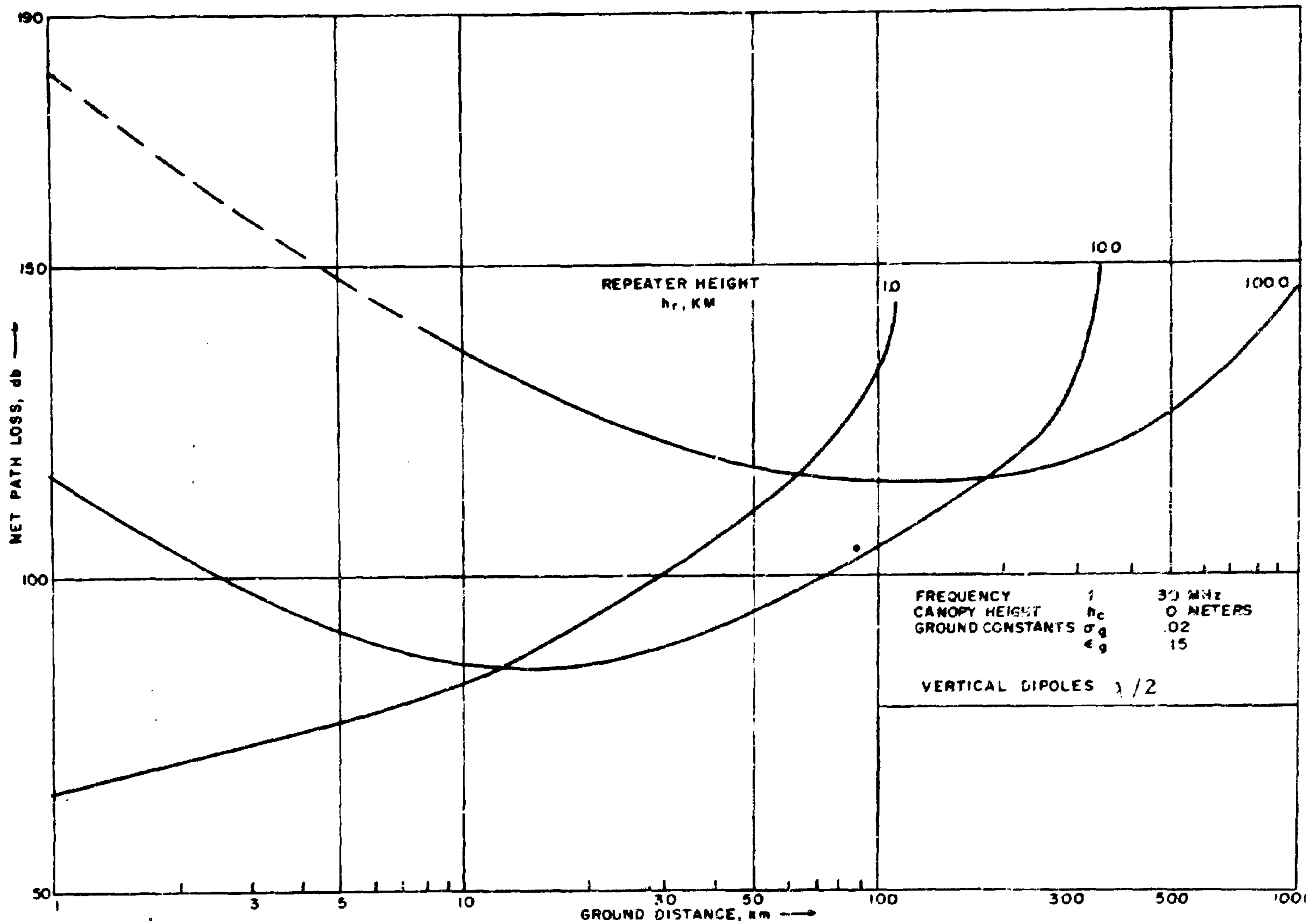


Figure 3.5-30. Path Loss Between Repeater and Ground Terminal Over Open Terrain Versus Ground Distance

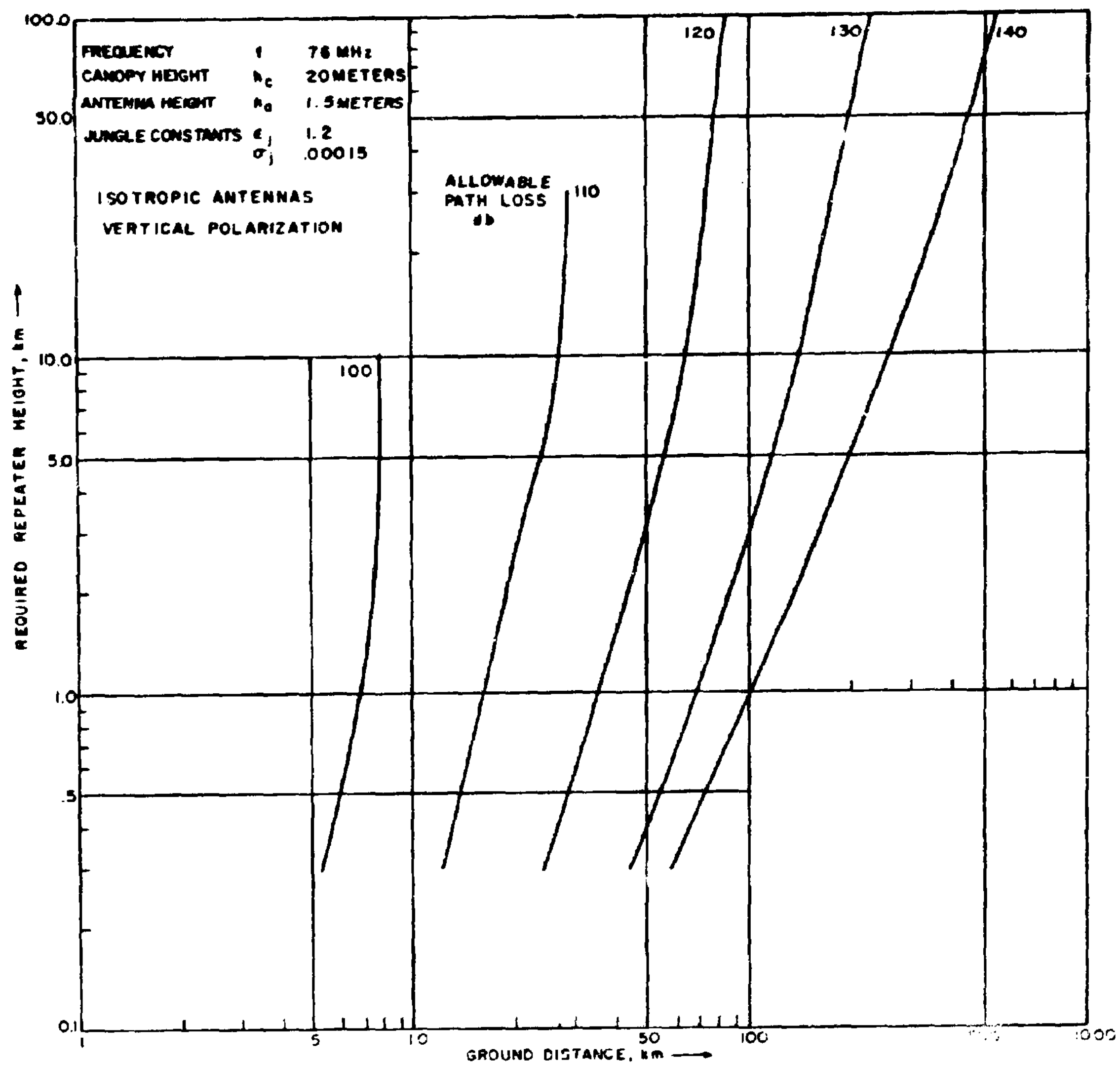


Figure 3.5-31. Required Repeater Height to Communicate with a Specified Allowable System Loss Versus Ground Distance

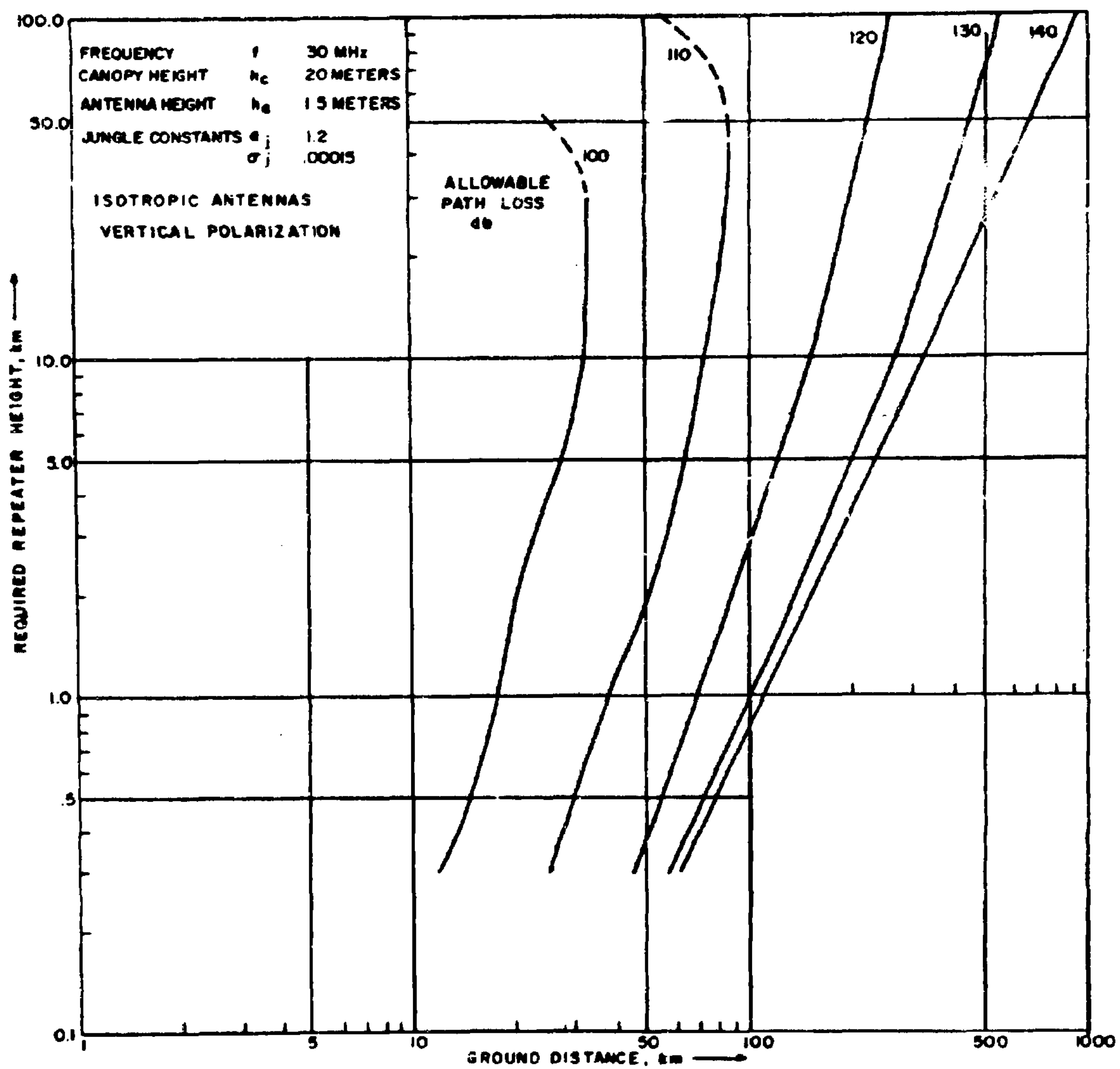


Figure 3.5-32. Required Repeater Height to Communicate with a Specified Allowable System Loss Versus Ground Distance

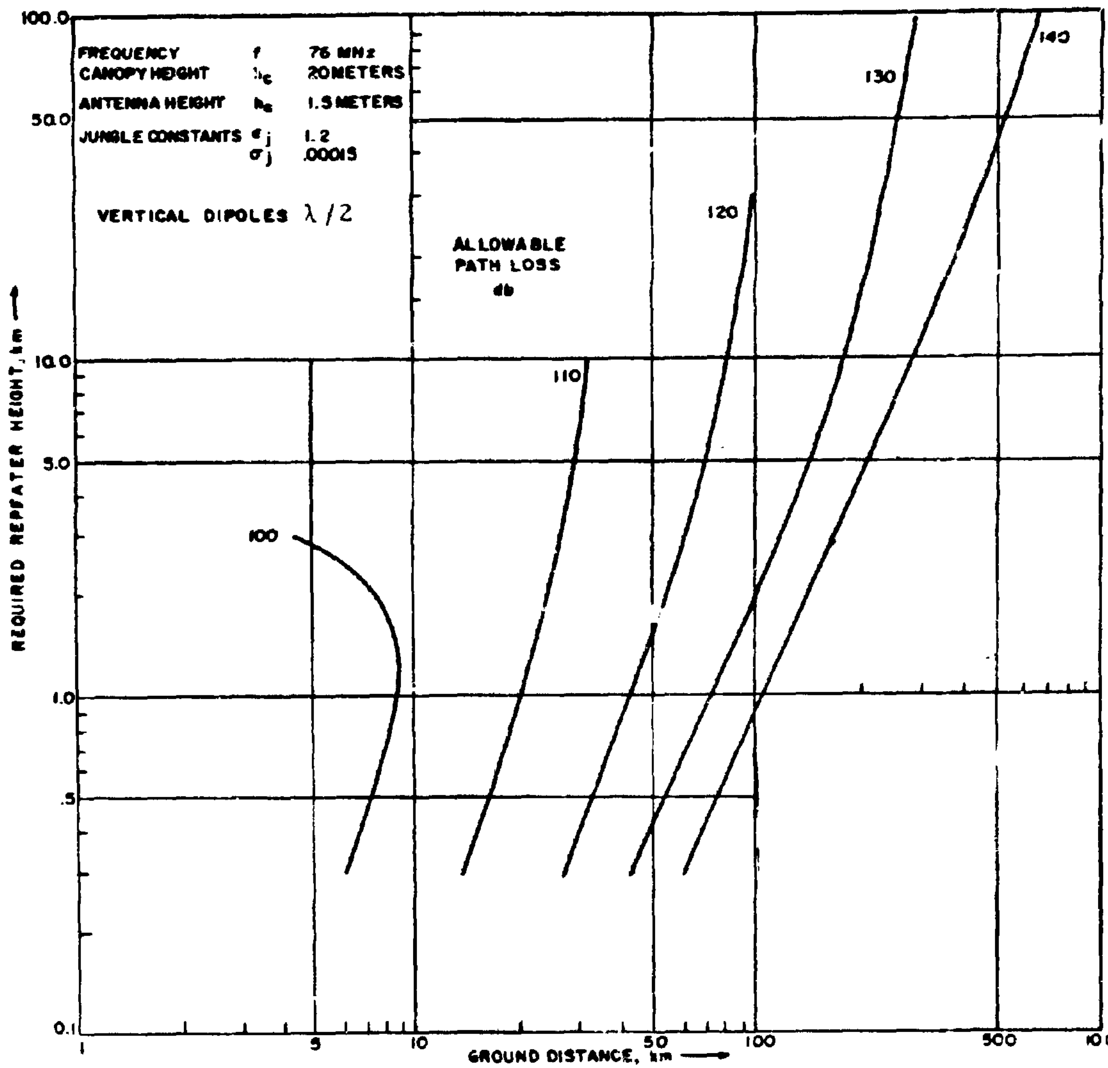


Figure 3.5-33. Required Repeater Height to Communicate with a Specified Allowable System Loss Versus Ground Distance

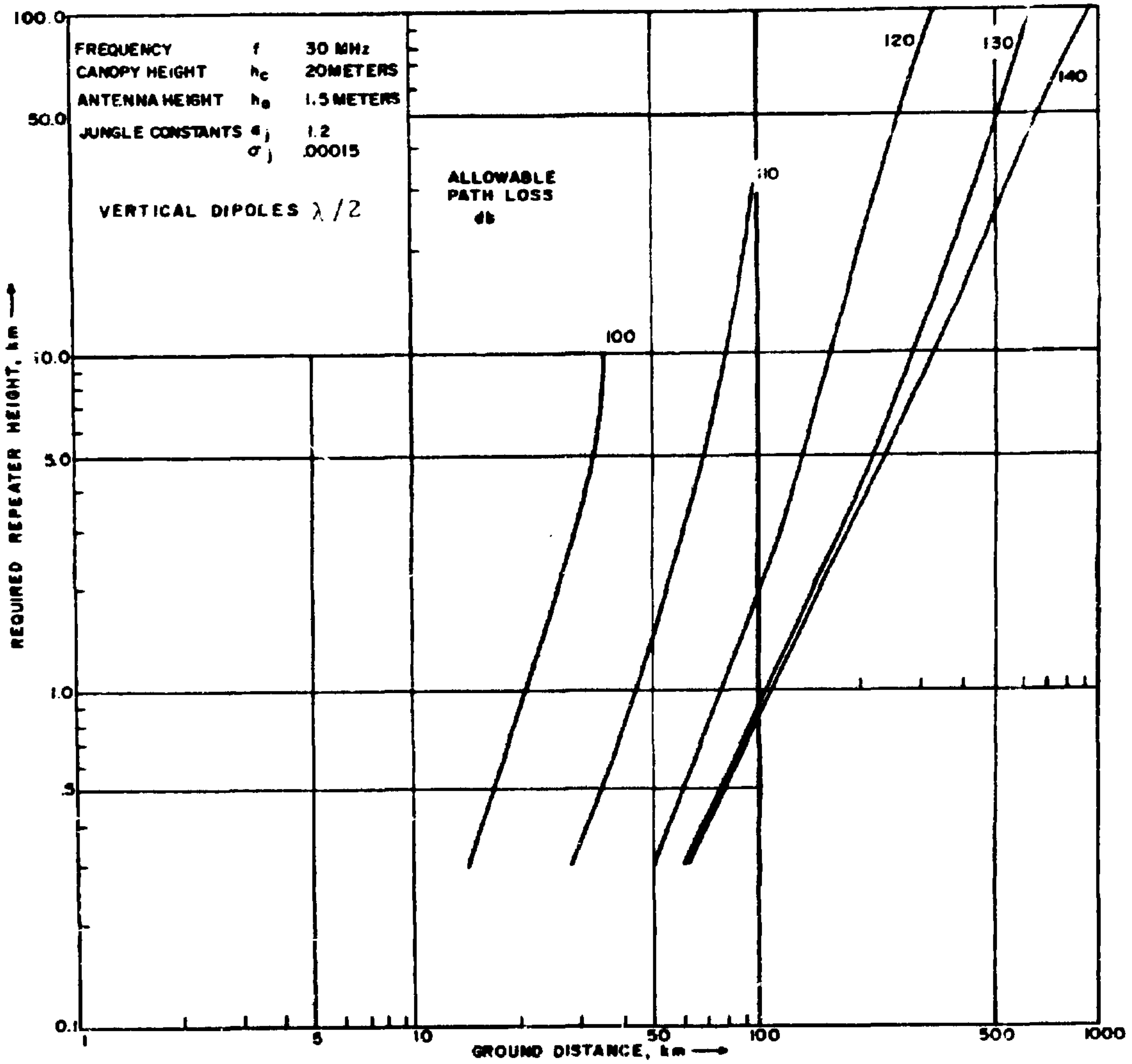


Figure 3.5-34. Required Repeater Height to Communicate with a Specified Allowable System Loss Versus Ground Distance

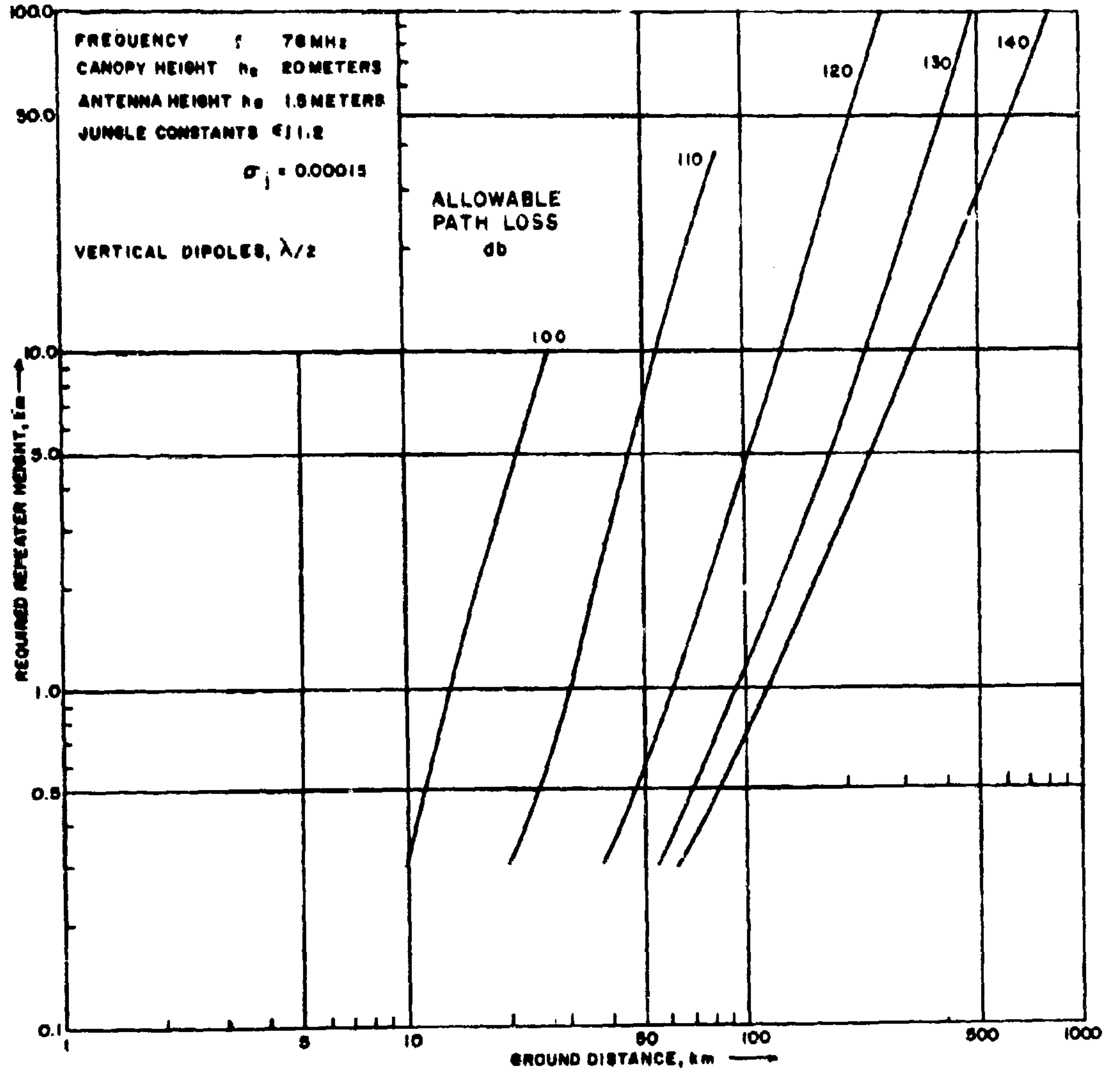


Figure 3.5-35. Required Repeater Height to Communicate with a Specified Allowable System Loss Versus Ground Distance

3.5.2.7 Propagation Variability. Path losses computed for propagation through the jungle are median values based upon average electrical parameters of the jungle. In actual fact, there are discontinuities (such as tree trunks and branches) and voids (large compared with a wavelength) which result in substantial spatial variation in received signal with small displacements about any location. Further, the assumption of a smooth (compared to a wavelength) interface, between the jungle and air, breaks down with increasing frequency. Sachs (ref. 3.5-3, Figures 19, 20) presents distributions of differences between predicted and measured path losses between two antennas immersed in the jungle. These curves are Gaussian in shape and display the following characteristics:

Frequency Range (MHz)	Median Error (db)	Standard Deviation (db)
6 - 100	-1.5	6.0
250 - 400	-4.0	10.5

Somewhat more directly applicable data are available, however, for the VHF ground-to-air case. An SRI report on measurements between an aircraft and a ground transmitter through dense Eucalyptus foliage provides some directly-scaled loss statistics (ref. 3.5-6). Figure 3.5-36, which is replotted from Figure 26(c) of reference 3.5-6, shows the distribution of measurements of path loss exceeding the median.

As previously noted, SRI has performed a series of measurements of air-to-ground propagation in Thailand using a helicopter-towed XELEDOP transmitter, and is currently engaged in analysis of the resulting data. These data are expected to provide a more justifiable distribution of path loss variations.

In the absence of these measurements, the distribution of Figure 3.5-36 can be used to determine margins necessary to assure a specified probability of service. For a 90 percent probability (probably adequate in view of the possibility of avoiding deep nulls by small movements of the antenna), it can be seen from Figure 3.5-36 that a 15 db margin is required; for 99 percent, 20 db becomes necessary.

In a link containing a repeater, if the repeater involves a limiting process, the signal power will remain constant at the demodulator inputs while the noise power for the up-link and for the down-link add. By convolving the single-link loss distribution of Figure 3.5-36 with itself (using a numerical process employing a Stieltjes diagram*), the distribution of the signal variations for two tandem links with equal mediam power may be

*Stieltjes diagram: for random variables x and y, a planar plot on x-y coordinates of equal Stieltjes probability measures $dP_1(x)dP_2(y)$. This unit measure is usually taken as 1% but may, of course, be taken larger or smaller to suit circumstances and convenience.

Figure 3.5-36. Probability that Air-Ground Path Loss to a Site in Jungle will Exceed Calculated Median

obtained. Since the signal level is held constant, this distribution (Figure 3.5-37) may be used to determine the margin required on each of two tandem links for a particular probability of the link being satisfactory. For example, if the desired reliability is 90%, then a per-link margin of 9.5 db must be provided.

Both of these curves (Figures 3.5-36 and 3.5-37) should be compared with the SRI airborne XELEDOP data when they become available.

3.5.2.8 Variability in the Time Domain. As previously described, the variability factor represents momentary, static conditions of the jungle, atmosphere, and platform. In fact, the foliage may be disturbed by wind, the variable refractivity of the atmosphere results in signal variability, and the platform is in motion, os that the signal observed at the ground from a platform will vary with the same amplitude distribution as applied to the static case. The fading rate will be a function of this homogeneity of the jungle, the velocity of the platform, and rotor blade modulation of the repeater antenna pattern. Since the intelligibility of voice communications is the system objective, it is necessary to consider the effects of fading rate as well as fading depth on intelligibility in evaluating system performance.

3.5.2.9 Dissipative Losses in the Near Field. Galejs (ref. 3.5-9) has shown that for short antennas immersed in a lossy dielectric medium, the majority of dissipative loss in the vicinity of the antenna results from the quasi-static electric field. In comparing electric and magnetic dipoles, the ratio of near-field loss is of the order of $[\lambda/2\pi a]^2$, where a is an effective antenna radius. In comparing efficiencies of short electric and magnetic antennas surrounded by a small shell of lossy dielectric, Row (ref. 3.5-10) obtains the similar result that

$$\frac{\eta\ (\text{magnetic})}{\eta\ (\text{electric})} \approx (k_o b)^{-2}$$

where b is the outer diameter of the shell.

These results tend to indicate that radiation efficiency of loaded whip antennas (as for example the AN/PRC-25 at the low end of the tuning range) may be degraded when immersed in the jungle. An evaluation of the severity of this effect is planned.

3.5.2.10 Summary of Propagation Prediction. Propagation curves have been computed and presented accounting for loss between airborne and ground stations, where the ground station is immersed in the jungle. These curves are believed to be of sufficient accuracy for engineering purposes in determining the median loss at VHF to and from the high altitude radio relay. In addition, predicted systematic loss values must be added to a margin term of the order of 15 db to cover random spatial and temporal variations of path loss due to the inhomogeneity of the jungle.

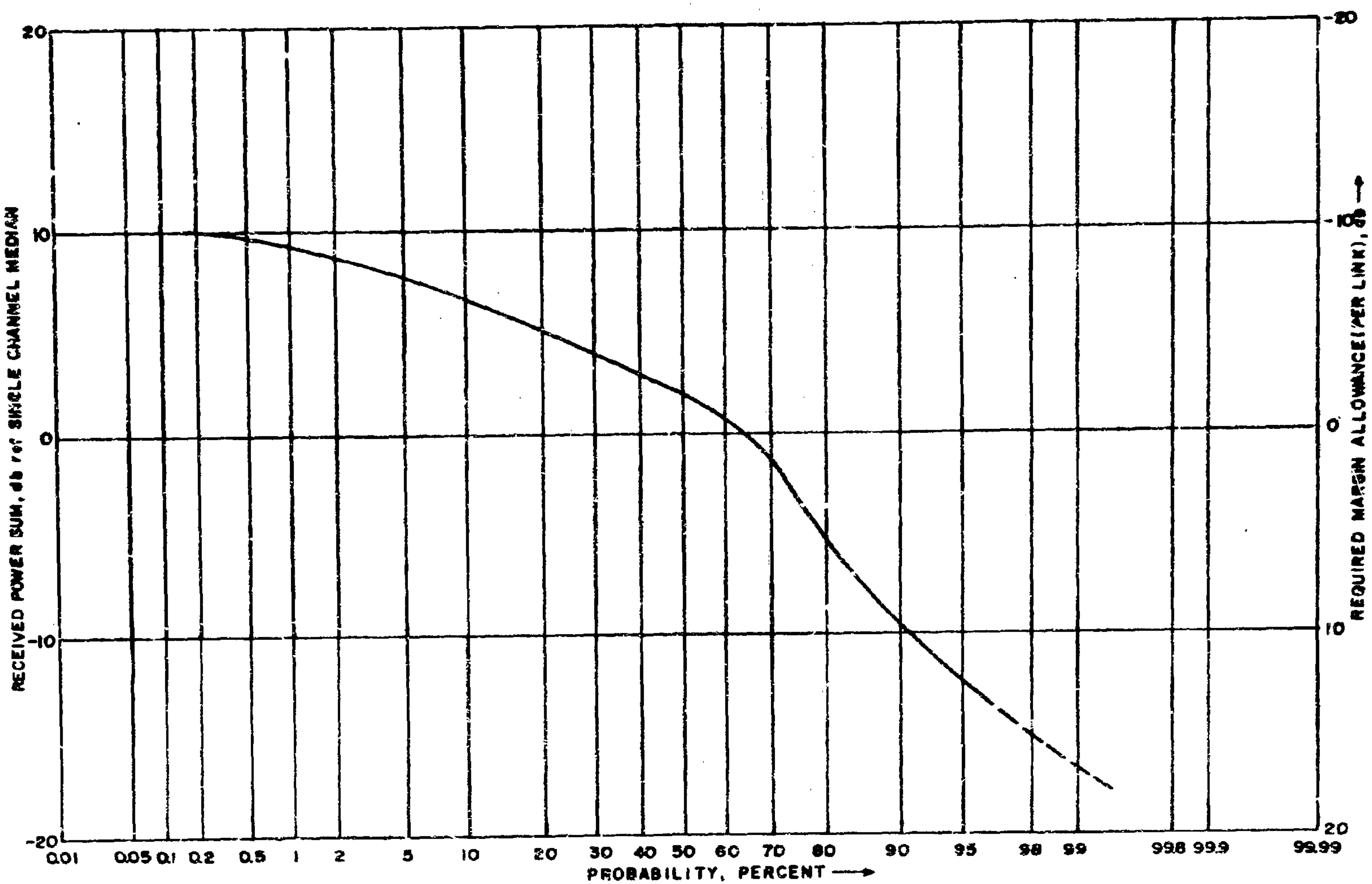


Figure 3.5-37. Probability that Power Sum Exceeds Ordinate, or Power Margin for Specified Probability of Satisfactory Tandem Links

It is planned to revise the variability distribution, if necessary, on the basis of the SRI airborne XELEDOP data when they become available.

3.5.3 Path Loss Implications for Repeater Design

3.5.3.1 Introduction. The primary reason for examing the air-to ground path loss is, of course, to define the necessary repeater power output, receiver sensitivity, and antenna gain for a given communications requirement based analysis of the tactical problems. Conversely, for bounded repeater parameters, the range for a given probability of satisfactory service may be determined.

Those repeater configurations in which broadband receivers (covering more than one RF channel) are used will be exposed to signals of different levels, depending on the range and jungle absorption or reradiation of particular emitters. It is necessary to evaluate the distribution of amplitude differences as a means of determining repeater dynamic range requirements.

In increasing the range of tactical radio sets, the repeater will extend the area over which co-channel interference will be experienced. This is an inevitable price to be paid for increasing the range, but it must be evaluated to determine the extent to which frequency allocations must be changed. The interference analysis is also applicable to the evaluation of jamming susceptibility.

Finally, the use of synchronous satellites as repeaters has been considered briefly and the up-link signals have been found to be marginal for compatibility with vertical whip antennas. Interference is felt to be the primary limiting factor on the use of VHF satellite relaying.

3.5.3.2 Service Range. While the repeater transmitter power output is much more readily increased than the transceiver power output, it is still subject to limitations due to interference and platform power supply restrictions. The uplink from a transceiver to the repeater is the limitation on overall system performance, since the repeater-receiver noise temperature is determined by external noise at the 30 - 70 MHz frequency band. Directive antennas at either the ground or the repeater do not appear to be practical from a physical size standpoint, and transceiver power output is limited by battery weight and life.

In estimating the total path loss and the resulting range for a given equipment configuration, the following factors must be considered:

a. systematic loss component (slab model)
b. jungle loss variability

c. platform antenna pattern variability
d. atmospheric variability
e. loss due to electrically short antennas

Of these factors, (a) has been analyzed in the previous section of the report, (b) and (d) are combined in the experimental variability factor in the previous section, and (c) has been neglected for the time being. The PRC-25 3-foot whip antenna is less than a quarter wavelength at all operating frequencies, and the 10-foot whip is a quarter wavelength at 24.6 MHz. The possible variety of antenna patterns available at various frequencies, heights above the ground, etc., make the antenna gain indeterminate, so the half-wave dipole pattern has been assumed in the computation of path loss contours; and the antenna's lobe structure has been absorbed into the variability terms.

If the repeater-receiver sensitivity is equal to that of the PRC-25, a signal level of -113 dbm provides a 10 db audio signal-to-noise ratio. We will assume the uplink and downlink to have identical parameters. With an output power of 1 watt (+30 dbm) at 76 MHz, and a -113 dbm minimum received signal, the path loss must be less than 143 db. This budget assumes equal median signal-to-noise ratios for the uplink and downlink, with a median signal-to-noise ratio of 10 db at the receiver. The variability factor indicates that a margin of 9.5 db must be provided on each link to give a net 90% probability of a 10 db or greater signal-to-noise ratio. Subtracting the margin requirement from the 143 db "threshold" path loss leaves 133.5 db as a per-link allowable path loss. If the uplink and downlink path loss medians are not equal, the margin should be re-evaluated.

From Figure 3.5-35, it may be seen that the ground range (between a transceiver and the sub-repeater point) for a 3 km repeater height and a jungle canopy height of 20 m is approximately 160 km, compared with the 80 km requirement established in Section 2 of this report. An increase in canopy height or in permittivity will reduce the range.

3.5.3.3 Distribution of Signal Levels. In those repeater configurations requiring the use of multichannel amplifiers, the distribution of signal levels will determine the dynamic range requirements of the repeater. With equal channel spacing in the frequency spectrum, intermodulation products will fall at the same intervals. Channel occupancy is variable, so whether a particular intermodulation product is produced or whether it falls in an occupied channel is probabilistic.

The distribution of repeater users within the service area must be modified by the previously derived path loss relations to obtain a distribution of received power levels. A further correction required is to convolve this distribution with the distribution of path loss variability. The resulting distribution will give estimates of the percentage of signals occuring within specified power ranges for a given repeater altitude and set of jungle parameters.

Looking at the problem in a different way, the maximum signal power at the repeater will be from transceivers operating in clear areas more or less below the repeater. Since vertical dipoles are assumed in the path loss computation, excessively high loss values are associated with this region. In practice, neither the transceiver whip nor the repeater antenna will be quite vertical, and there will be some depolarization by reradiation from the foliage, so there will be relatively little attenuation due to the antenna patterns. Free space attenuation for a repeater altitude of 3 km, at 76 MHz, will be approximately 80 db, compared with the path loss of 130.5 db allowed for minimum signal quality in paragraph 3.5.3.2 above. A range of signal power of the order of 47 db is thus indicated.

Detailed examination of the consequences of this range in terms of amplifier peak power and distortion requirements will be undertaken in the next few months.

3.5.3.4 Interference. Most of the consideration given to interference at this point in the program has been qualitative. It may be useful to compare the ground-to-air path loss computation with the free space loss between two repeaters at 3 km altitude. Suppose that the two repeater platforms were separated by 100 miles (161 km) at 76 MHz, the free-space attenuation be tween them would be approximately 114 db, while the loss (exceeded 10% of the time) to a ground station at 50 miles (80.5 km) range would be 119 db (from Figure 3.5-26) with a 50% probability of exceeding this loss. Use of the same channel at the two repeaters is obviously impossible. Use of adjacent channels would depend on the selectivity and overload characteristics of the repeater-receiver, and may serve to define requirements for these characteristics.

Again, jamming has been considered only from a qualitative view. The increased range at high altitudes may invite the use of jamming from enemy-held areas, or from areas friendly to the enemy outside the combat area. A jammer requires only 1 watt power output and a non-directional antenna to compete with signals on an equal basis. The price of increased power and antenna gain for a single jammer is relatively small.

3.5.3.5 Satellite Relay. It may be useful to indicate the relative attenuation of ground to synchronous satellite paths for comparison with the ground-to-airborne repeater results. The power budget of the following table applies to the ground-to-satellite uplink.

Table 3.5-4. Ground-to-Satellite Power Budget

Power output	+ 30	dbm
Antenna gain	- 3	db
Path loss (76 MHz)	-161	db
Polarization loss	- 3	db
Satellite antenna gain	+ 10	db
Carrier received	-121	dbm
Receiver bandwidth (36 KHz)	45.6	db/1 Hz
Receiver NF (3 db)	24.6	db/1 °K
Boltzmann's constant	-198.6	dbm/Hz/°K
Receiver noise level	-128.4	dbm
Carrier-to-noise ratio	1.4	db

It should be noted that this budget assumes a net antenna gain and foliage loss of -3 db, and assumes use of a 76 MHz version of the ATS-B phased array antenna. The resulting carrier to noise ratio would produce an audio signal-to-noise ratio (ref. 3.5-12) of 16 db.

The above discussion neglects a significant factor in the design of a satellite relay. While the gain assumed is higher than achieved on contemporary satellites, it is not adequate to prevent high-power services in other areas visible to the satellite from obscuring the PRC-25 signal. The example of 76 MHz, for example, would place the PRC-25 signal in competition with television signals on channel 4 with effective radiated power of the order of hundreds of kilowatts. Since the entire 30 - 76 MHz band is shared with other services, the allocation problems involved in establishing exclusive PRC-25 repeater channels are prohibitive.

3.6 MULTI-CHANNEL RELAY SYSTEMS

3.6.1 Relay Application. One of the functions for which the airborne platform relay appears to offer a significant advantage is that of point-to-point multichannel relaying. This is an alternative to the use of tactical tropospheric scatter or future satellite relay equipment. In comparison with the tropospheric scatter point-to-point links, the ground-air-ground relay offers following advantages:

a. Rapidly deployable.
b. Minimal in transport weight and POL requirements.
c. Capable of operation over difficult terrain.
d. Use of standard troposcatter equipment.
e. Less exposure to jamming than synchronous satellite relay.

The relay system would then be applied to temporary use, as in the transitional stages of moving a division headquarters, replacing damaged point-to-point links, augmenting channel capacity, or establishing multichannel links over difficult or enemy-held terrain where conventional relay equipment cannot be installed.

3.6.2 Objective Configuration. As an objective, the ground terminals should be transportable by helicopter. The ground terminal package would include multiplex terminal equipment, power generator, and antenna system. It would be anticipated that because of the need for interfacing with telephone terminal equipment or fixed relay links, the ground terminals would be sufficiently fixed in location to permit installation of elevated antenna support structures or clearing sufficient foreground vegetation to provide a line-of-sight path to the platform.

The airborne platform should not be required to be larger than a UH-1D helicopter, although other platforms may offer advantages in various respects. Because the platform is continually in motion, the use of antennas with limited directivity is essential, unless mechanical or electrical tracking antennas are used. Similarly, the use of limited directivity antennas on the ground would simplify siting and tracking. Both antenna configurations must be considered in terms of the cost and reliability of the antenna and of the associated electronics equipment. Power requirements should be met by the platform's accessory power system.

3.6.3 Objective Performance. There appears to be only one area in which the performance of the airborne relay needs to deviate from standards for point-to-point relay links. This relates to interruption of the circuit while performing handover from one platform to another. Necessary provisions for compatibility with digital modulation systems will be considered in the remaining months of the program.

Practical margins for fading protection may require the use of diversity, perhaps through frequency separations or ground antenna spacing. Frequency diversity may provide a useful means of overcoming antenna pattern fluctuations on the platform.

Interfacing with other systems at the ground terminals is assumed to take place at a baseband level, most probably in baseband assignment compatibility with groups as used in the TRC-24, TRC-90, MRC-107, or MRC-85 multiplex plans for maximum flexibility of application. No monitoring or channel dropping is envisioned at the relay platform, although a UHF orderwire channel accessible to the radio operator or pilot will be necessary for handover coordination.

3.6.4 Relay Equipment. Several useful equipments are available for use in the multichannel airborne relay configuration. Some of the equipment types that have already been discussed for single-channel use are also suitable for this multichannel application. The following paragraphs describe relay candidate systems listed in Table 3.6-1.

Another approach to be given consideration is that of using standard military line-of-sight or troposcatter equipment, omitting the power amplifiers. In this case, the ground terminals would require minimal interface design, and equipment may be available out of military inventory; but the equipment is not specifically qualified for high-altitude and vibration problems to be encountered in flight, and extensive physical interface design for the airborne relay package will be required.

It may be as productive to design a special relay package for aircraft use compatible with line-of-sight or tropospheric scatter interfaces. Such a relay could combine "east" and "west" paths of a duplex link in a single receiver and transmitter.

3.6.4.1 AN/ARC-89(V). First, there is an operational set of UHF equipment designed specifically for airborne operation, the AN/ARC-89(V). This is a 12 voice-channel system with a 60 KHz FM baseband. The system operates from 225 MHz to 399.95 MHz in 3500 synthesized steps. While the normal transmitter complement (AN/ART-47) provides 1 kw output power, it should be possible to use only the exciter and 50-watt intermediate power amplifier. Since there is no provision for diversity reception, a separate diversity combiner would be needed. For a duplex repeater with diversity reception capability, two transmitters, four receivers, and two diversity combiners would be needed. Duplexing filters and antennas are also included in the AN/ARC-89(V). Similar equipment would be used at the ground terminals with one transmitter, two receivers, and a diversity combiner at each terminal.

At the price of introducing non-standard ground terminals with limited channel capacity, the ARC-89 equipment would provide rapid availability, minimal interface design requirements, and flight-tested antennas.

3.6.4.2 MA-2T Wideband Microwave Relay System. The MA-2T, "Wideband Microwave Relay System," is a commercial equipment made by Microwave Associates, Inc., of Burlington, Massachusetts (ref. 3.4-14). The prime application for this equipment is for a relay for live coverage of news and special events in the vicinity of a television station. Since the modulation (baseband) bandwidth of the equipment is 12 MHz, the system may be used for many applications. These may include high-resolution reconnaissance systems, interconnection of high-speed digital computer and data handling systems, as well as the transmission of multichannel FDM or TDM voice and data signals.

The MA-2T system, which operates in the 2200-2300 MHz telemetry band, requires a receiver, the MA-8577, and exciter unit, the MA-8576, and an amplifier, the MA-8575. The transmitter is composed of the latter two units, the MA-8576 exciter and the MA-8576 amplifier. The power output of the transmitter is 15 watts and requires a maximum primary power of 250 watts at 28 volts dc. The receiver, which has a 6 db noise figure, requires only 35 watts of primary power, at 12, 24, or 28 volts dc or 115 or 230 volts ac. These power requirements are quite high for both the receiver and the transmitter but especially for the transmitter which uses a traveling wave tube. The weight of 22 pounds (total) for the transmitter is fairly low, but 40 pounds is rather high for the receiver. The operating temperature range that is given is adequate for most applications, both for storage and for operating conditions. Another receiver type is also available, the MA-8508, for the 1990 to 2110 MHz frequency range. This receiver weighs only 23 pounds instead of 40 pounds but has a poorer noise figure (10 db nominal).

This relay system could be used for the initial time frame since it is a commercial catalog item and should be available in a fairly short time in moderate quantities. Although it is shown in the relay equipment type table with four channels in use out of a possible 240, up to 48 channels could be handled easily if sufficient antenna gain is available to make up for the lower power per channel. It would thus be a good candidate for the initial time period for this multichannel application.

3.6.4.3 AN/TRC-107. The AN/TRC-107 is a radio relay equipment in current production (ref. 3.4-8, -15, -19). This type number applies to a 3/4 ton vehicular application, using two radio relay sets, AN/GRC-103, as a terminal set. This radio equipment was chosen instead of the type AN/TRC-113 which is listed as a repeater set, because it should not be necessary for a repeater application to use three AN/GRC-103 radio sets. The AN/TRC-107 which has two AN/GRC-103 radio sets should be satisfactory and would also permit a substantial saving in weight and bulk. The two basic sets consisting of two receivers and two transmitters weigh 130 pounds apiece, making a total of 260 pounds. They also require 250 watts apiece, or a total of 500 watts at 115 volts ac at 50 to 400 Hz. This equipment is quite heavy and requires a large amount of power for an airborne equipment. It should be possible to provide the multichannel relay capability with a more portable equipment type. It is compatible with the AN/TRC-24, which is also rated "Standard A," between 220 and 600 MHz.

The AN/TRC-107 does not appear to be small and light enough to be a satisfactory solution for either the interim or the long-range time period.

3.6.4.4 AN/GRC-68. The AN/GRC-68 (ref. 3.4-8) is a radio relay repeater set for 12 to 96 voice channels consisting of two basic AN/GRC-66 radio sets. Although the design of the GRC-66 includes two-band operation (1700 to 2400 MHz and 4400 to 5000 MHz), only the upper band equipment is available. In this duplex repeater configuration, the GRC-68 weighs nearly 800 pounds and requires a primary power input of 1.7 kw for a transmitter output power of 1 watt. In view of the weight and power requirements, the use of this equipment would be constrained to operation in large manned aircraft.

3.6.4.5 AN/TRC-38. The AN/TRC-38 is a rear area radio relay set (ref. 3.4-8) capable of providing 23 channels of voice communication. This AN/TRC-38 consists of two each of the R-418/G receiver and two each of the T-303/G transmitters. Thus it has the same equipment as two of the AN/TRC-29 basic radio relay sets. It is given a nomenclature of "Standard A" and is thus out of the development stage and is available quickly.

Since this equipment weighs over 2000 pounds and requires 2800 watts of primary power, it is obviously suitable for only the largest aircraft under consideration.

3.6.4.6 AN/MRC-69(V). The AN/MRC-69(V) may be used as a radio repeater and is air or vehicular transportable. It consists of two AN/TRC-24 radio sets or two AN/GRC-50(V) radio sets so that full duplex operation is possible. Each AN/TRC-24 consists of a receiver and a transmitter; therefore, it may be expressed as a group of two R-417/TRC receivers or two R-1148(P)/GRC receivers and two T-302/TRC transmitters or two T-893(P)/GRC transmitters. The tuning range consists of seven bands from 50 MHz to 1850 MHz. Thus there is little overlap with the 1700 to 2400 MHz ground terminal radio equipments. It is primarily compatible with other frequency division multiplex systems, such as other AN/TRC-24's or with AN/GRC-10's. The AN/GRC-76 and the AN/TRC-35 also consists of two of the AN/TRC-24 radio sets and thus have identical receiver and transmitter equipment. It is also a complete point-to-point or radio relay set intended for ground and/or portable use. The terminal set (AN/GRC-76) uses telephone terminal, AN/TCC-3, to provide four voice channels and one voice frequency orderwire in the subcarrier frequency range from 300 Hz to 20 KHz. It may also be used with telephone terminal, AN/TCC-7, to provide 12 voice channels and one voice frequency orderwire in the subcarrier frequency range from 300 Hz to 70 KHz. This radio relay equipment also is extremely heavy (3400 pounds) and requires a very large amount of primary power (2200 watts). It thus is a very poor choice for any time frame for an airborne application such as the HARR.

3.6.4.7 AN/GRC-39. The AN/GRC-39 (ref. 3.4-8) is a mobile radio relay set capable of four voice channel transmissions or combinations of voice and telegraph or facsimile channels. It is composed of two complete AN/GRC-10 relay sets so that full duplex operation is possible, plus PE-75 power units. The AN/GRC-10 basic set consists of the R-125/GRC-10 receiver unit and the T-235/GRC-10 transmitter unit. Since power should be supplied by the primary power supply of the aircraft or other vehicle, the weight of the unit is based on two AN/GRC-10 units. This total weight value is thus 340 pounds, and the power required to operate the equipment is 450 watts. The equipment is classified as "Standard A" and thus is quickly available. It has a higher power output than most of the equipments listed so far, 40 watts or 10 watts per channel.

Unfortunately, the only tuning range available is the VHF band of 54.0 to 70.9 MHz. This would mean that there would be mutual interference between this point-to-point multichannel relay set and the normal VHF FM tactical radio equipment. For this reason, the AN/GRC-39 does not appear to be a useful choice for multichannel relaying.

3.6.4.8 Passive Repeaters. A selected bibliography on passive repeaters is included in paragraph 6.3. Some work was done in the analysis of system gains using passive repeaters. The preliminary results of this work indicated that the gain of passive reflectors is insufficient for satisfactory channel performance. Some further work may be done with passive and semi-active repeaters for application to the [illegible]-point multichannel relay case where high-gain ground station ante[illegible] able to compensate partially for the low repeater gain.

Table 3.6-1. Multichannel Relay Equipment

RELAY EQUIPMENT TYPE	Availability	Cost	Weight, Lbs.	Volume, Cu. Ft.	Primary Power Watts	Number of Voice Channels (max)	Trans. Power Output, Watts	Receiver Sens., Microvolt	Frequency Range MHz	Uplink Allowable[3] Loss, db	Downlink Allowable[3] Loss, db	Ref. Source 3.4 - [ ]	REMARKS
AN/ARC-89(V)			180	3.2	1880	12	50	3	225-400			[13]	
MA-2T (2) note 1	Prod		250	2	570	24 note 2	15	6 db	2200-2300	137.3	138.2	[14]	
AN/TRC-107 (2-AN/GRC-103)	Prod		260	4.1	500	12	15		220-1000	138.5 134.5	138.5 134.5	[8, 15]	
AN/GRC-68	Std. A		800		1700	120	1		4400-5000			[8]	
AN/TRC-38	Std. A		2000		2800	48	10		1700-2400			[8]	
AN/MRC-69(V) (2-AN/TRC-24)	Std. A		3400		2200	12	75		50-600				AN/GRC-50 used above 600 MHz
							20 10		600-1000 1350-1850				
AN/GRC-39 (2-AN/GRC-10)	Std. A		340		450	4	40		54-70.9	143-144	153	[8]	Interference with FM nets

FOOTNOTES:
1. Modified for I. F. interconnection.
2. Depends on associated mux equipment.
3. See paragraph 3.4.2.

SECTION 4

PLATFORM SYSTEMS

4.1 OBJECTIVE

The objective of the platform analysis was to select at least three platform candidate finalists to be combined with the recommended repeaters to form the initial HARR system alternatives. It is out of these alternatives that the optimum combinations will be chosen and presented as the HARR configurations which could be implemented with minimal development.

4.2 PLATFORM STUDY REQUIREMENT

The platform analysis as outlined in the HARR Study Technical Guidelines, 14 April 1965, is specified to be based on a cost and operational effectiveness study involving airborne platforms conceived during the course of the study or those categorized as:

a. High-altitude balloons
b. Rocket-launched platforms
c. On-station aircraft
d. Synchronous communication satellites

As the result of recommendations made at joint ECOM/HARR study team meetings, activity undertaken during the first half of the study concentrated on an initial configuration developed from existing inventory platforms and repeaters. In keeping with this recommendation, only those platforms are included in the mid-term report that meet initial system configuration requirements. Any exclusion, however, was not possible until an investigation disclosed that at least a year of research and development was necessary prior to procurement.

4.3 APPROACH

The approach used in selecting the three or more platform finalists was: investigate all likely prospects; eliminate enough of these to make a manageable number on the basis of procurement and operational considerations; and narrow down to the final three or more by entry into a cost-effectiveness trade-off. Since a stipulation of the study was that the feasibility of the use of random military aircraft as repeater-bearing platforms be investigated, this analysis was undertaken in addition to the platform selection.

4.4 RANDOM* AIRCRAFT SORTIE DISTRIBUTION ANALYSIS

An initial task in the platform analysis was to test the feasibility of placing a repeater package on all available South Viet Nam U.S. military aircraft.

A critical problem in the pursuit of the "random military sortie distribution" approach was to find sufficient South Viet Nam aircraft flight operation data to make the analysis reliable. First, effort was expended in seeking out Viet Nam aircraft sortie simulation models that could be adapted to the desired requirement. One of these models was found to exist at Mitre Corporation in Burlington, Massachusetts. A specific investigation of this model disclosed that in its existing form it could only handle U.S. Air Force aircraft and that the introduction of Army and Navy aircraft parameters would require additional coding. Therefore, other methods of obtaining reliable distribution values had to be explored. The most promising of these appeared to be a special probability analysis. Obviously, the credibility of the results is only as good as the data used. Work then concentrated on finding reliable Vietnam sortie information that was in sufficient quantity and distribution to make the conclusions significant. Such a data source was found in the Pacific Air Force Management Summary, which is issued quarterly.

Since the classification of this sortie data is SECRET, the distribution computations and results obtained directly from the classified material are not included herein. The restricted data used gives destinations, origins, sortie rates, operational times, typical mission profiles, and considerable pertinent information on ARVN theater military aircraft operations during the past two years. Only that portion of the analysis and the results that have been authoritatively determined as unclassified are included in the aircraft distribution discussion and outcomes contained in the following paragraphs of this subsection of the report. All data used were for daylight operations only.

4.4.1 Results. Figure 4-1 is the probability map for random aircraft to provide a platform where needed during an assumed 12-hour daylight operating period. The values adjacent to the contour lines are the probabilities that a ground unit will be within range of any airborne platform at a randomly selected time. It appears that random aircraft will not serve the purpose of HARR except in the delta where the C-123 alone ensures availability of a platform. This is due to altitude and flat terrain and assumed high-altitude special operations. The relatively "high coverage" ridge from Pleiku to Phu Bai results from the assumption that strikes were channeled via that route.

*"Random" means randomly distributed as to place on time.

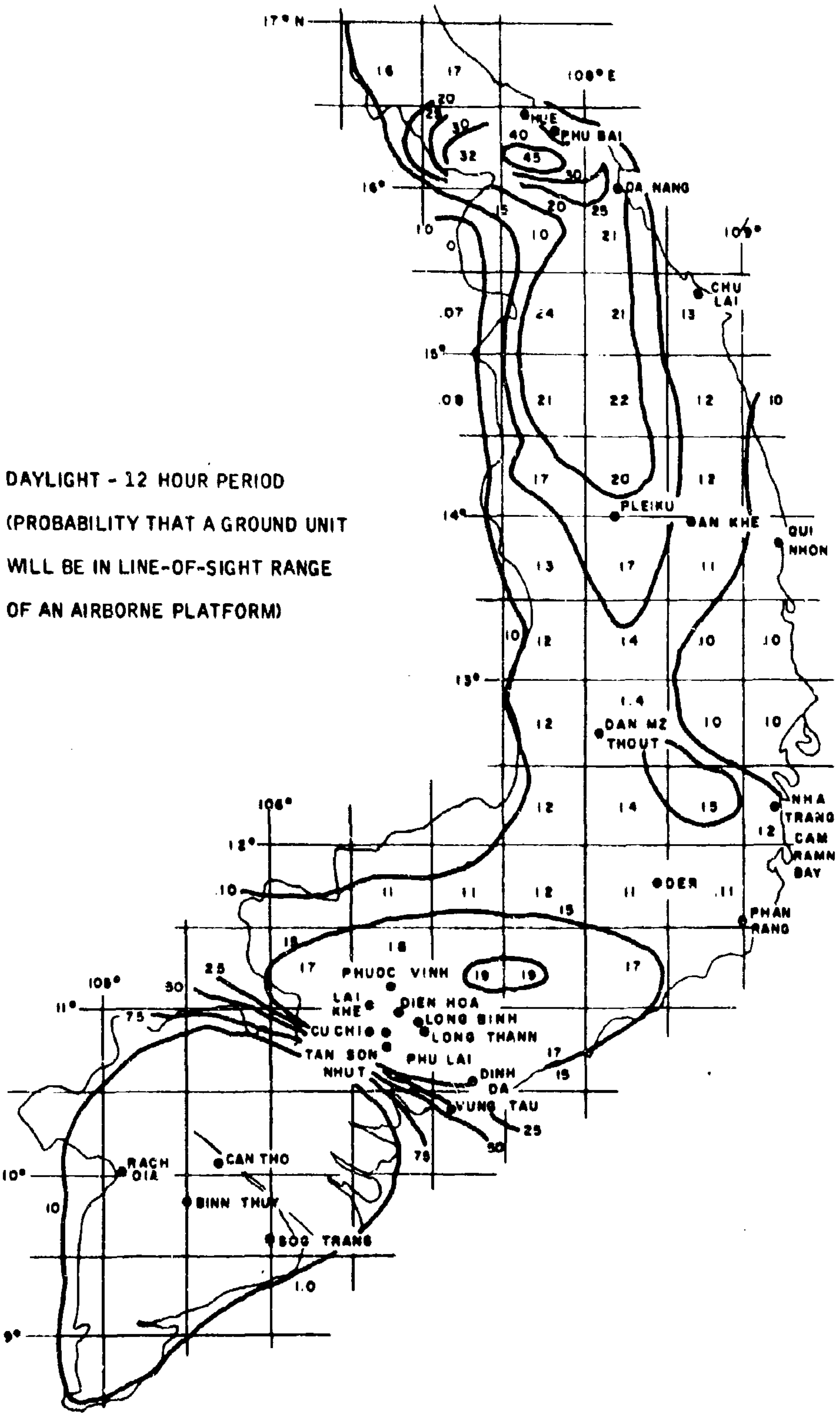


Figure 4-1. Airborne Relay Coverage of Viet Nam

4.4.2 Methodology. The effectiveness measure is expressed as follows:

$$C_i = 1 - \Sigma_j (1 - P_{ij})$$

$$P_{ij} = K_{ij} F_{ij}$$

where

F_{ij} = the fraction of total time during which a platform of type j is in zone i. When n platforms of type j may be in zone i simultaneously:

$$1 - F_{ij} = (1 - f_{ij})^n$$

where f_{ij} is the fraction of total time spent in zone i by each of the n platforms.

K_{ij} = that fraction of the area of zone i which is covered by a platform of type j when it is in zone i.

P_{ij} = the probability that, at a randomly selected instant, a platform of type j is available to a ground station in zone i.

C_i = the probability that, at a given instant, any platform is within range of a ground station in zone i.

NOTE

The assumption of independence implicit in the foregoing is not strictly true in all cases. In those cases where the assumption is not valid, it is sometimes possible to treat the situation as made up of properly mutually exclusive events. For example, in the case of a few aircraft transiting South Viet Nam enroute to Laos or North Viet Nam for long periods on station, the times of transiting a given zone are probably not independent since one aircraft relieves the other. Accordingly, in the calculations the periods spent in a zone are added. As another example, in the case of numerous small aircraft such as FAC operating from a single base, flight paths and distinations are almost certainly not independent on a short-term basis. However, over a long period of time the distribution of aircraft locations may be nearly uniform over an appropriately selected area. The approximation introduced by making the assumption of independence is appropriate to a relatively long period of time.

4.4.2.1 Computations. This analysis makes use of data from operational bases and the aircraft which makes use of the bases. After applying the probability factors shown in paragraph 4.4.2 for C_i. the computational results were plotted on a map of South Viet Nam similar to that shown by Figure 4.1. Contour lines were drawn as isobars connecting the equal probability points. A significant part of the computations was "the cone of coverage" determined for each sortie considered. This cone of coverage was drawn from the position of the aircraft to the ground. A terrain analysis made of each portion of South Viet Nam plus the height of the aircraft determined the amount of area covered by the cone. A "line of sight" value taken from the ground to the aircraft and the range capability of the PRC-25 determined the dimensions of the cone. The percent of time aircraft would be in the vicinity gave the F_{ij} values. When there was a probability of more than one aircraft, F_{ij} became a compound value.

4.5 PLATFORM SELECTION ANALYSIS

4.5.1 Problem. A dual problem governed the treatment of platform capabilities. This was the ability to:

a. Penetrate tropical foliage
b. Avoid terrain masking

It was found that, although it would be most desirable to have a platform responsive to both problem considerations, certain candidates did not lend themselves to more than foliage penetration. As a consequence the analysis was divided into two portions: that dealing with special platforms which could primarily handle the foliage penetration problem, and that dealing with platforms which could take care of the terrain masking avoidance as well as the foliage penetration.

4.5.2 Foliage Penetration Candidates. Although the guidelines of the study prescribed a minimum altitude limit of 1,000 feet, certain platforms were examined that customarily would be put at altitudes below this height.

4.5.2.1 Tethered Balloons. Tethered balloons have been used with some success by the Army of the Republic in Viet Nam (ARVN) forces in South Viet Nam. The ARVN commanders have liked them for fairly fixed locations and are unconcerned about the disclosure of location due to the tether line, since their positions are already known to the Viet Cong.

The antennas used for the ARVN balloons were normally HF, and, although conventionally-shaped balloons were used, the buffeting of the platform did not present a problem until the winds became quite high. In fact, it was found that the tilt angle of the antenna had little effect on propagation up to an angle of 30 degrees.

G. T. Schjeldahl Company currently is developing a tethered balloon-borne antenna system for NATO to extend 15,000 feet above sea level. The balloon is a 70,000 cubic foot natural shape envelope (55-foot diameter) using the tether line for VLF quarter-wave antenna cable. The cable weight is 125 pounds per thousand feet of length. The high-altitude winds have restricted the on-station time of this balloon system from 40 to 80 percent.

Instead of the Schjeldahl antenna supporting device, a tethered balloon system more suited to the HARR mission would be an aero-dynamically-shaped envelope such as that shown in Figure 4-2. The shape of the balloon will enable it to maintain greater airborne stability than if it were given the more conventional pear or spherical shape. The payload package carried by the balloon indicates that it could be used as a repeater. A similar balloon system is described in DDC document AD 445 943, "Tactical Jungle Communication Study."

A disadvantage often associated with the tethered balloon is its hazard to flying aircraft. For the HARR application, balloons would probably be flown at altitudes between 2000 to 5000 feet rather than the much higher altitudes planned for the NASA balloons. However, even at these lower altitudes a series of tethered balloons carrying hard-material payload packages would provide considerable flight crew concern.

4.5.2.1.1 Tethered Balloon Employment. Forward area employment of tethered balloons designed for the HARR mission could be at three recommended echelons. A light-weight two-channel balloon configuration could be designed to carry a payload of 48 pounds. It is estimated to cost $3,000 for platform and tether line only. This configuration would be tethered near a company command post and would be used to service patrol and squad units. The proposed altitude would be from 2000 to 3000 feet.

A second configuration might be designed to carry a six-channel, 282-pound payload. It is recommended that it be used at company or battalion headquarters and be flown at an altitude of 3000-5000 feet. Its estimated platform and tether line cost is $7,100.

The third configuration might be a 14-channel, 628-pound carrying tethered system. Its recommended tethered position would be at battalion headquarters. It also would fly at between 3000 and 5000 feet. Its estimated cost would be around $12,000. Unless a means was found for ground-based channel control, a 14-channel balloon-borne relay could very easily introduce mutual interference problems.

Balloon costs versus the payload weight that can be carried is given by the curve shown in Figure 4-3.

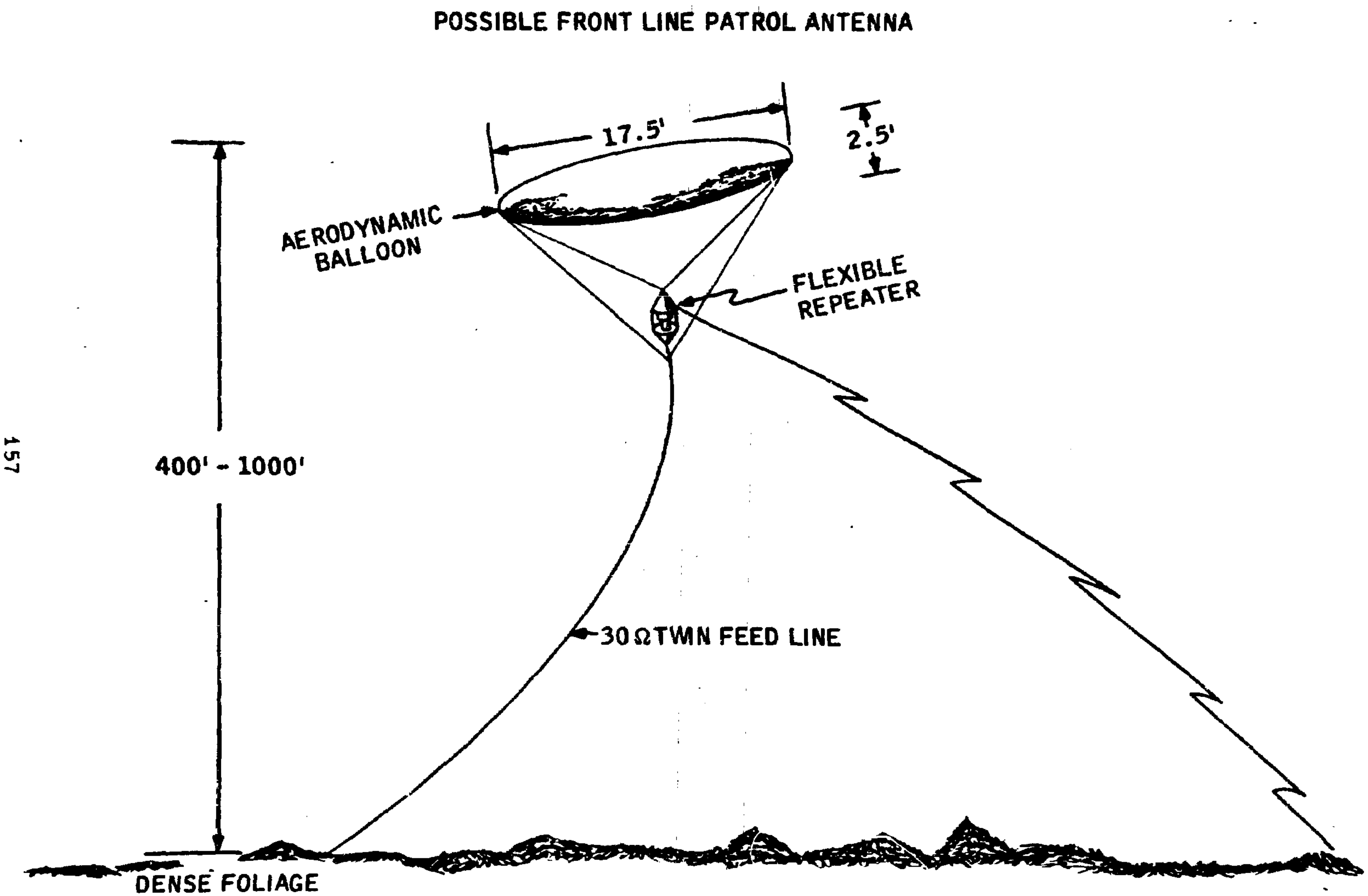
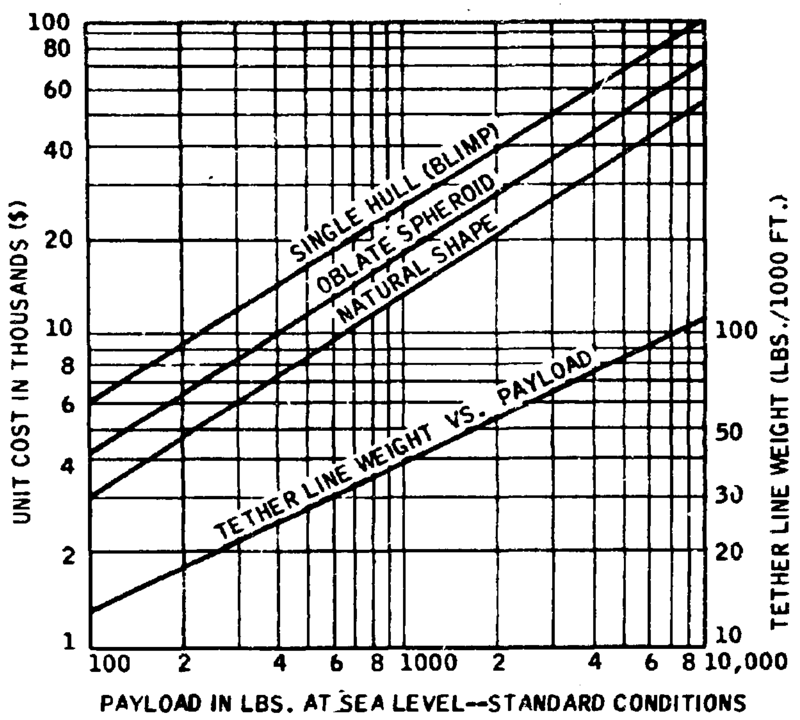


Figure 4-2. Tethered Balloon System



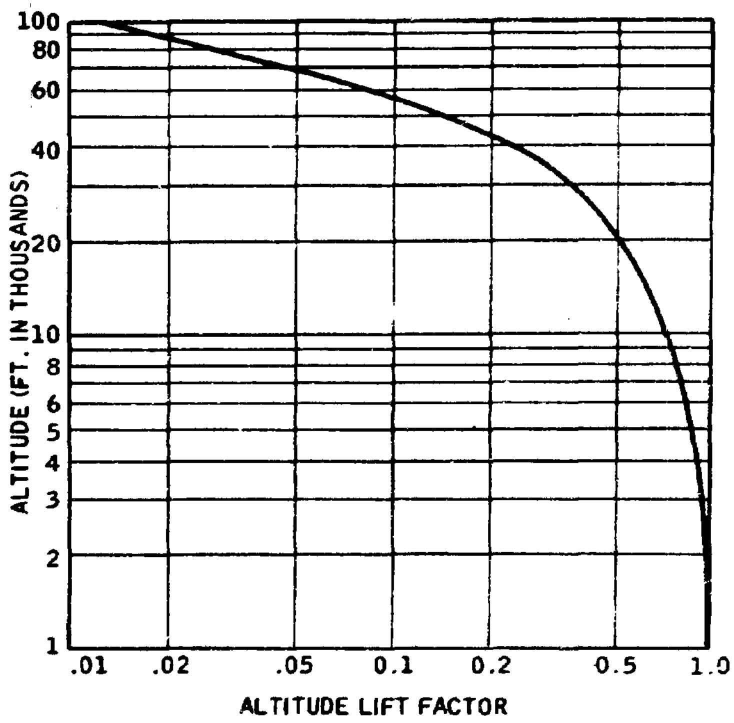


Figure 4-3. Payload vs. Estimated Cost for Various Tethered Balloon Configuration

4.5.2.1.2 Tethered Balloon Support. A 70-hour life is estimated for the batteries each recommended balloon system would carry. In each case it is felt advisable that a two-balloon arrangement be used with the relief balloon launch occurring in order that the on-station balloon can be brought down without a break in the relay service. In this case a timing device would have to be used to make sure both repeaters were not active at the same time. A one-hour turn-around time is estimated on the assumption that at least at the company level the batteries would be circulated by airlift. A critical problem encountered during the ARVN tethered balloon experience was the loss of balloons and their payload due to breaking or snagging of the tether line in high winds. This would mean that a fairly large replenishment of balloons, repeaters, and line should be kept on hand.

A reference used to determine the balloon configuration and tethering characteristics is the paper, "Capability of Captive Balloon Systems," given by J.A. Menke at the 1963 AFCRL Scientific Balloon Symposium.

The greatest problem in forward area support of a balloon would in all probability be in the providing for the necessary hydrogen or helium. A balloon capable of supporting a 100-pound ayload at the higher altitudes required about six cylinders of helium which weigh about 1100 pounds. The use of the hydrogen generator AN/TMQ-3 would considerably lessen the logistics problem, but its use is both time consuming and dangerous.

Aside from the gas supply equipment, the ground support required to operate the balloon platform would be the tether cable, winch, ground plates, and ground handling and protection cloths needed for the inflation gas. If hydrogen is used, the ground equipment might be provided to manufacture it from chemicals that have been brought in, but the advantage of this method of supply will have to be weighed against the use of a highly combustible gas.

4.5.2.2 Treetop Relay Platform. The treetop relay platform is a new item, presented as a candidate which may be developed within six months and employed in Vietnam by early 1968. It consists of a gas-inflated structure designed to bear on the generally dense and continuous typical upper surface of tropical vegetation and support a 50-pound relay payload at its center. The relay is assumed to consist principally of two AN/PRC-6 or AN/PRC-25 radio sets with a common pyrotechnically extendable whip antenna.

4.5.2.2.1 Description. The platform structure (see Figure 4-4) is circular in shape, twelve feet in diameter. The tubular structure has an 8.5-inch diameter outer rim and a 12-inch tube inner hub in the form of a torus which encircles the payload at the center. Eight tubular (spoke) beams between the rim and hub provide stiffness to the platform for bridging bearing voids within the 12-foot span. The top of the platform is a flat sheet covering the full circle and bonded to the tubular structure. Two cylinders containing 2 pounds

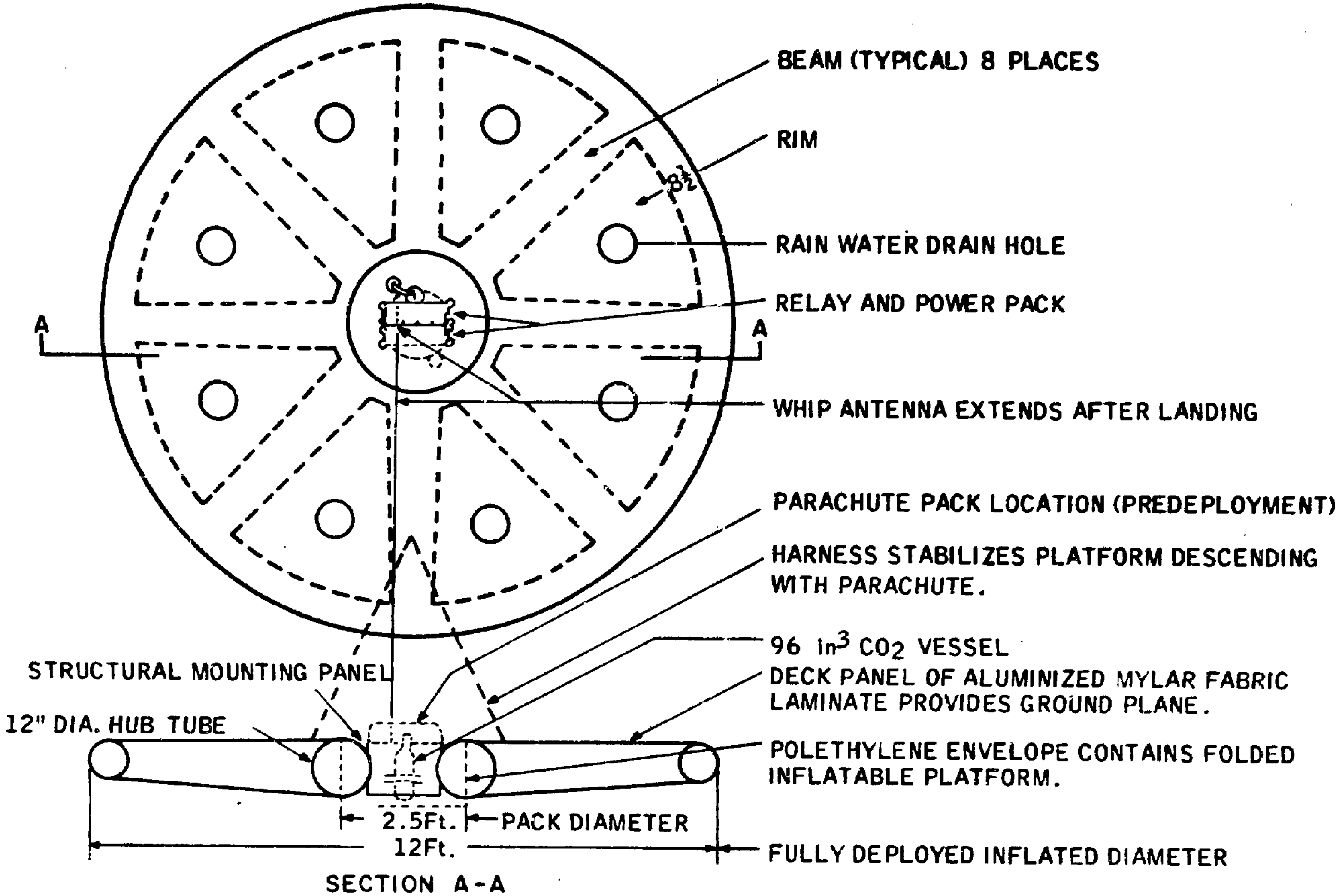


Figure 4-4. Treetop Platform Configuration

each of CO_2 gas (at approximately 1800 psi) mount adjacent to the relay assembly. Valves, triggered by the pull of a lanyard, exhaust the stored gas into the 43-cubic-foot volume of the platform for inflation.

The radio sets and CO_2 vessels mount directly to a 30-inch diameter hard panel which bears on the inner torus. This panel also serves as the top of the undeployed packed system during storage and delivery. The flexible portion of the platform folds and is packed into the annular space between the 30-inch outer diameter and the relay and inflation hardware at the center, to a 15-inch depth. A thin, frangible plastic case contains and protects the folded flexible portion of the platform assembly during storage and delivery until inflation pressure is applied for deployment. If a parachute is used, it is contained in a deployment bag atop the relay mounting panel.

Modern strong imporous balloon materials are used in the inflatable structure. A nylon fabric, mylar film laminate, is recommended. The top sheet is of similar material, but with an aluminized surface to provide a ground plan for the relay system. Based on use of the above materials, a flexible structure of 7 pounds is estimated. A total weight for the system is itemized below:

Inflatable structure	7.1 pounds
CO_2 gas (2.05 per cyl.)	4.1 pounds
Two 96-inch^3 cyl. and valves	12.9 pounds
Mounting panel and brackets	4.0 pounds
Relay, antenna and batteries	50.0 pounds
Parachute and pack	2.2 pounds
	80.3 pounds

The stowed system ready for deployment is 30-inches in diameter and 15-inches high occupying 6.2 cubic feet.

4.5.2.2.2 Deployment. Two methods of deployment are considered: aerial delivery and helicopter deployment. If the tree canopy is consistent and compatible with the bearing area of the platform, the air-drop delivery will provide rapid and efficient deployment. Stations can be at selected points (identified on a map) to be traversed by the cargo aircraft. A series of treetop relay stations then would be static-line deployed in a timed sequence. Airdrop may be performed at any suitable altitude (1500 to 5000 feet or higher), under good or poor visibility conditions.

The deployment sequence (Figure 4-5) starts with the release of the 80-pound package from the aircraft, followed by static line deployment of an 11-foot diameter ringslot parachute. As the parachute starts to inflate, the opening and deceleration force pulls the lanyards between parachute riser

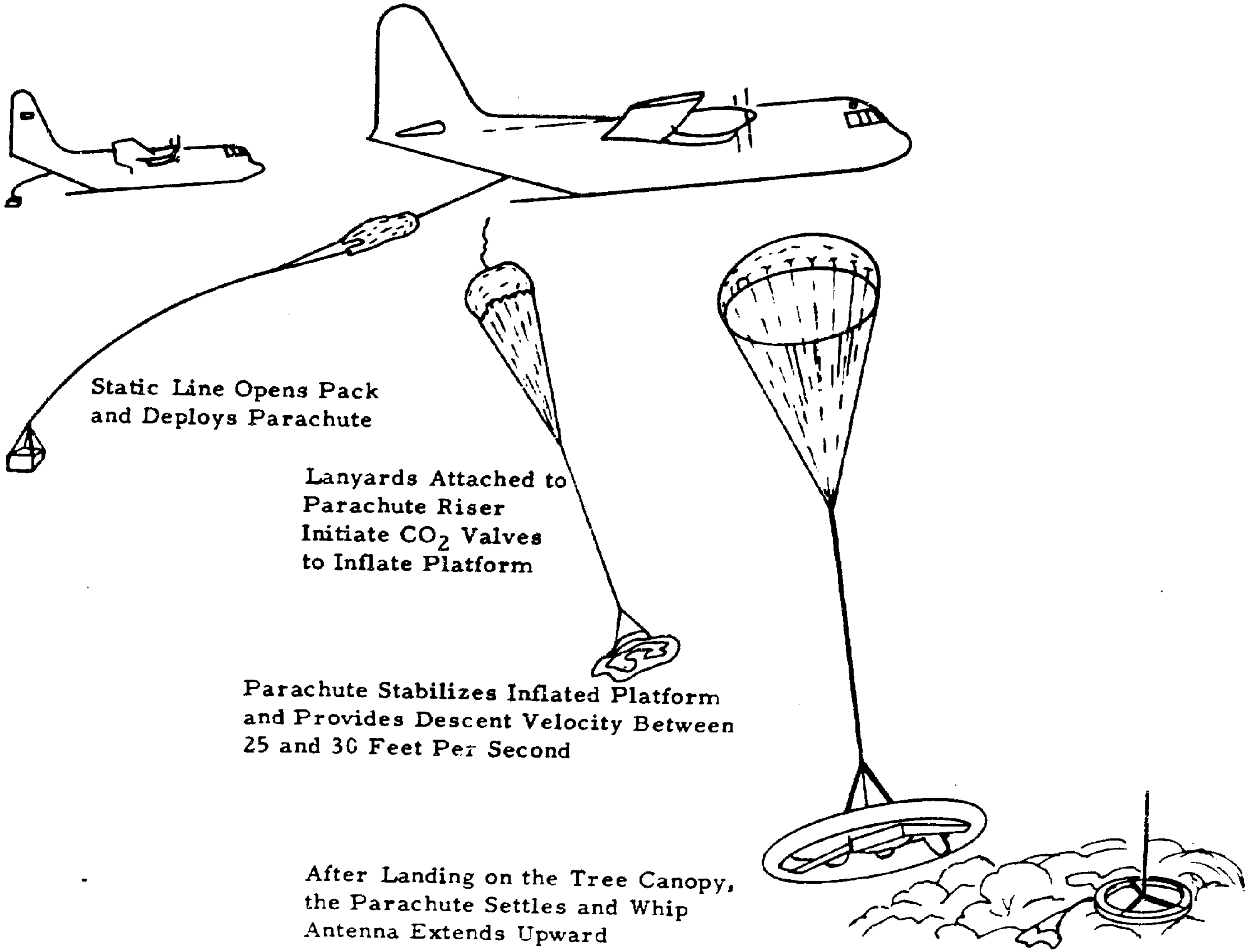


Figure 4-5. Treetop Relay Placement Using Airdrop Technique

and CO_2 valves at the package. The flexible platform then bursts its thin encasement shell and rapidly inflates to full size. The platform, stabilized by the parachute, descends to the jungle canopy to hold a position for operation. After the parachute settles, a timed switch operates to extend the whip antenna and energize the relay.

For an inconsistent free canopy, a deployment by helicopter (Figure 4-6) is recommended. The 78-pound package (without parachute) would be lowered on a cable below the hovering craft to the jungle canopy. Inflation of the platform should be initiated well below the helicopter to avoid instability from down-wash air currents. The platform would not be released until it had assumed a satisfactory bearing on the trees. Following release, the antenna would extend by pyrotechnic actuation; then relay operation would commence.

4.5.2.2.3 Retrieval. A battery life of 70-hours may be feasible with intermittent power to the transmitter. The relay station's usefulness is over when the power fails. Therefore, retrieval and replacement may be feasible. A retrieved relay station can be refurbished simply by recharging batteries, recharging CO_2 cylinders, resetting timers, replacing pyrotechnics and repacking the assembly in storage and deployment status.

4.5.2.2.4 Cost. Based on life raft production cost data, the platform system without relay and batteries should be about $420 each.

4.5.2.2.5 Forward Area Employment. Employment of the treetop relay platform is felt to be most effective at the company level. Improvement in transmission range made possible by the treetop elevation of the platform is not known. D. . David Sachs of DRC has stated that because a system of this type could take advantage of the favorable propagation path that exists above the treetop canopy, a definite improvement in range transmissions from the ground can be expected.

Depending upon the extent of the anticipated ground-to-platform transmission range, a treetop platform would be placed at a favorably-located position within the vicinity of a planned ground activity. Another platform would be placed near company headquarters, and signals picked up by either repeater would be amplified and relayed to the companion platform; here it would be amplified again and transmitted to the ground.

4.5.2.2.6 Forward Area Support. A necessary support item for the treetop platform system that would be in addition to that required by the tethered balloon is the deployment vehicle. The cost of operating this aircraft would have to be added to the costs of the platforms.

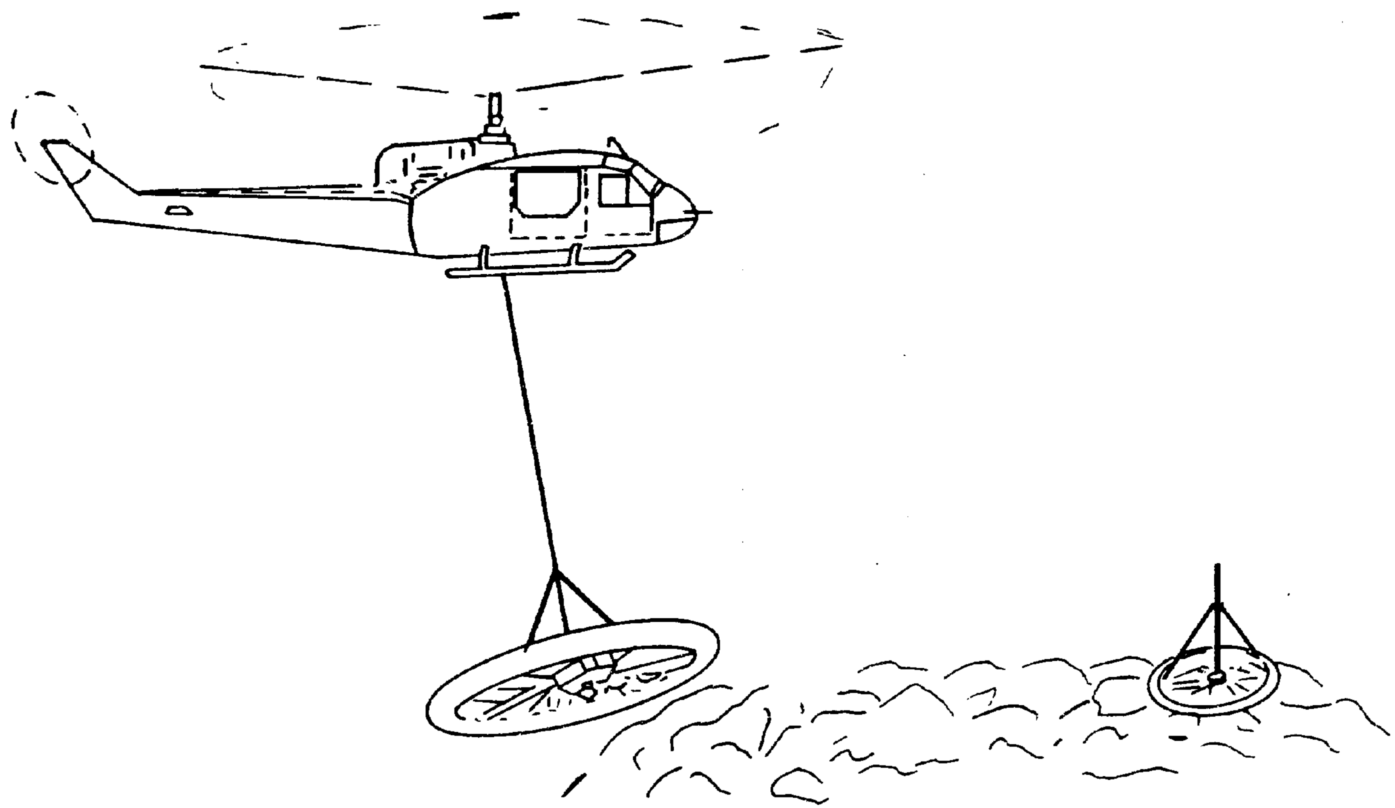


Figure 4-6. Treetop Relay Placement Using Helicopter

4.5.3 Candidates for Avoiding Terrain and Foliage. Platforms that could overcome both the terrain and foliage problems were, of course, characterized by their high-altitude airborne capabilities. An initial platform list was compiled which included quite a number of entries; this list will not be included as part of this report. The aircraft portion of the list itemized 84 manned fixed-wing military vehicle types, 24 manned rotary-wing military vehicle types, 7 fixed-wing military drones, 3 rotaty-wing drones, and one rigid-wing craft. In some instances, non-military aircraft were investigated; but because of the problems known to be associated with their introduction into any military service inventory, it was decided that they be excluded. More than thirty missiles, rockets and satellites also were listed. For each of these (as well as for the aircraft), the name of the vehicle, the DOD or NASA designation, the popular name, the service, primary mission, typical performance or loading, availability, and other vital statistics were included.

4.5.3.1 Aircraft Platforms. Starting with the extensive list of possible aircraft platforms discussed in paragraph 4.5.3, the study analysts went through two elimination exercises.

4.5.3.1.1 HARR Aircraft First Iteration Selection Rejection. The elimination process initially conducted was based on a broad application of what were believed to be pertinent HARR mission and operational requirements. A tentative requirements list is given as follows:

Platform payload	50 - 300 pounds
Relay channels	Single to 6
Relay type	PRC-25 or replacement
Time to deploy	3 hours
Time on station	24 hour potential
Initial HARR configuration	Helicopter, light or medium aircraft, quick look at balloons and drones
Platform deployment facility	Helicopter pad or forward area air strip
Platform flexibility	Capable of variable time and location
Deployment altitude	Deployed sufficiently low to avoid radio channel interference between Army Corps (250-mile line-of-sight separation); deployed sufficiently high to avoid ground fire
Platform support	Minimum required. No new school for training personnel
Destruct capability	Optional
Air traffic control	A consideration, but not deciding at this time

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Figure 4-7.

Pertinent requirements of the above list were applied, as well as operational and procurement considerations which were known to have a definite bearing on remote area employment.

The first elimination iteration was performed on aircraft in the initial platform list, Table 4-1. This work reduced the number of platforms considered for the initial HARR configuration to a more manageable preliminary list, Table 4-2. For candidates which are not suitable (or marginal), summary reasons are given by codes A through G in Table 4-2. They are as follows:

A. On-Station. The aircraft is not suitable because of speed or inability to loiter. For a few aircraft, inflexibility for high (15,000 feet) and low (1,000 feet) altitudes is the criterion.

B. Availability. For initial (i.e., initial configuration, Viet Nam, operational in 1967), this factor includes the inventory in Viet Nam, the allocable inventory elsewhere, the feasibility of reactivating retired aircraft, and manning potential. For interim and long-range, production schedules and probabilities also pertain.

C. Cost. The aircraft is too costly to operate for the HARR mission. (For some aircraft, larger than necessary for HARR, but otherwise very suitable, high costs might be offset by multi-mission potential.) Flying-hour costs are considered more important than procurement costs, particularly for excess aircraft no longer produced.

D. Mission Suitability. The aircraft is not acceptable because of payload limitations, short endurance low level of proven/ related military experience, etc.

E. Divertibility. The aircraft is in short supply for primary missions probably out-ranking HARR; hence, a less effective or more costly substitute platform is preferred for 1967 and even later.

F. Theater Suitability. The aircraft is not acceptable for Viet Nam because of logistics burdens, limitations on combat mobility, vulnerability to combat hardships, inability to operate all hours in all weather, etc.

G. Command. The aircraft is not readily operable by the Army, or by the other services for direct and complete support of Army operations.

Table 4-1. Initial Platform List

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Douglas	A-1J	Skyraider	Navy	Attack	350 mph		Already in Viet Nam
Douglas	A-3B	Skywarrier	Navy	Attack	600 mph		
Douglas	A-4E	Skyhawk	Navy	Attack	8,200 lbs		Delivered to Navy, 1962, still in production.
Grumman	A-6A	Intruder	Navy	Attack	18,000 lbs		Delivered to Navy, 1963, subsequent orders.
Ling-Temco-Vought	A-7A	Corsair 2	Navy	Attack	20,000 lbs	Light attack. USAF order planned	In quantity production.
Cessna	AT-37D	---	USAF	Attack	3,000 lbs	Two evaluated for COIN missions	In production.
Douglas	YB-26K	Counter Invader	USAF	Bomber	750 lb bombs	Modified B-26 for counter-insurgency	Already in Viet Nam
Boeing	B-47E	Stratojet	USAF	Bomber	20,000 lbs	Being phased out	Could be made available.
Boeing	B-52F/G/H	Stratofortress	USAF	Bomber	75,000 lbs	Strategic	Already in Viet Nam.
GD/Ft. Worth	B-58A	Hustler	USAF	Bomber	Subsonic	Strategic	SAC only.
Douglas	B-66D	Destroyer	USAF	Bomber	600 mph		
NAA/LA	F-100D	Supersabre	USAF	Fighter	Mach-1.2	Modernized	Already in Viet Nam.
McDonnell	F-101B	Voodoo	USAF	Fighter	Mach-1.7	U.S. Air Defense	Might eventually be available.
GD/Convair	F-102A	Delta Dagger	USAF	Fighter	Mach-1.2	Being phased out, going to National Guard	Could be made available.

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Lockheed	F-104C/G	Starfighter	USAF	Fighter	Mach-2	Fighter-bomber	Could be made available.
Fairchild Hiller	F-105D	Thunderchief	USAF	Fighter	13,000 lbs	All weather fighter-bomber	Already in Viet Nam.
GD/Convair	F-106A	Delta Dart	USAF	Fighter	Mach-2	U.S. Air Defense	Might eventually be available.
GD/Ft. Worth/ Grumman	F-111A/B	---	USAF Navy	Fighter Fighter	Mach-2.5	STOL capability	Tactical aircraft could be used.
McDonald	F-4B/C	Phantom	USAF	Fighter	15,000 lbs		Already in Viet Nam.
Northrop	F-5A	Phantom	USAF	Fighter	6,200 lbs	For MAP nations	Already in Viet Nam.
Douglas	F-6A	Skyray	Navy	Fighter	Mach-0.9	Prototype flew January 1951	Could be used.
Ling-Temco-Vought	F-8E	Crusader	Navy	Fighter	Mach-1.8		Could be used.
Grumman	F-11A	Tiger	Navy	Fighter	Mach-1.2		Could be used.
Lockheed	YF-12A	---	USAF	Fighter	90,000 ft	Long range interceptor	Not in production as yet.
Lockheed	WU/U-2A	---	USAF	Reconnaissance	90,000 ft		Classified - Special Mission.
Lockheed	SR-71	---	USAF	Reconnaissance	100,000 ft		No further production pending.
McDonnell	RF-4C	Phantom 2	USAF	Reconnaissance	Mach-2		In production, used in Viet Nam.
NAA/Columbus	RA-5C	Vigilante	Navy	Reconnaissance	Mach-2	All weather tactical reconnaissance	Delivered to Navy, 1965-1966.
Martin/GD Ft. Worth	RB-57F	Canberra	USAF	Reconnaissance	100,000 ft		Delivered to Air Force 1964

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
McDonnell	RF-101C	Voodoo	USAF	Reconnaissance	Mach-1.5	Strengthened for low altitude work	Used in Viet Nam.
Cessna	O-1E	Bird Dog	Army	Observation	115 mph	Also USAF Forward Air Controller Aircraft	Used in Viet Nam.
Grumman	OV-1C	Mohawk	Army	Observation	325 mph	STOL performance	Used in Viet Nam.
NAA/Columbus	OV-10A	---	Navy	Observation	4,600 lb bombs	COIN aircraft	7 prototypes, order pending.
Lockheed	P-2H	Neptune	Navy	Patrol	345 mph		
Lockheed	P-3B	Orion	Navy	Patrol	450 mph		In production.
Martin	P-5B	Marlin	Navy	Patrol	8,000 lbs	Flying boat	
Grumman	S-2D	Tracker	Navy	Anti-sub	275 mph		48 ordered in 1963.
Grumman	E-1B	Tracer	Navy	Early-warning	265 mph	Fighter direction	
Grumman	E-2A	Hawkeye	Navy	Early-warning	400 mph	NTDC C&C	Used in Viet Nam.
NAA/Columbus	T-2B	Buckeye	Navy	Training	20,000 ft		In production.
NAA/Columbus	T-28D	Trojan	USAF	Training	350 mph	For Viet Nam, Laos, Congo	In Viet Nam.
GD/Convair	T-29D	---	USAF	Training	230 mph		
Lockheed	T-33A	Shooting Star	USAF	Training	580 mph	Also DT drone director	
Beech	T-34B	Mentor	Navy	Training	190 mph		
Cessna	T-37B	---	USAF	Training	408 mph	For MAP countries	4 A/C per month through 1965
Northrop	T-38A	Talon	USAF	Training	Mach-1.2		Still in production.
NAA	T-39A	Sabreliner	USAF	Training	340 mph		Used in Viet Nam
Cessna	T-41A	---	USAF	Training	138 mph		170 Model 172's used by USAF

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Beech	T-42A	---	Army	Training	236 mph		52 in use by Army
Douglas	TA-4E	---	Navy	Training			Delivered to Navy 1966
Douglas	C-47E	Skytrain	USAF	Cargo/Transports	7,500 lbs		
Douglas	C-54	Skymaster	USAF	Cargo/Transports	32,000 lbs		
Boeing	C-97D	Stratofreighter	USAF	Cargo/Transports	64,000 lbs		
Douglas	C-117D	---	Navy	Cargo/Transports	15,000 ft		
Douglas	C-118A	Liftmaster	USAF	Cargo/Transports	25,000 lbs		
Fairchild Hiller	C-119J	Flying Boxcar	USAF	Cargo/Transports	30,000 lbs		
Lockheed	C-121G	Super Constellation	USAF	Cargo/Transports	40,000 lbs		Used in Viet Nam
Fairchild	C-123B	Provider	USAF	Cargo/Transports	24,000 lbs	STOL modification	Used in Viet Nam
Douglas	C-124C	Globemaster 2	USAF	Cargo/Transports	74,000 lbs		Used in Viet Nam
Lockheed/Georgia	C-130 B/E	Hercules	USAF	Cargo/Transports	45,000 lbs	Drone launch and control	Still in production
G/D Convair	C-131E	Samaritan	USAF	Cargo/Transports	12,000 lbs		
Douglas	C-133B	Cargomaster	USAF	Cargo/Transports	79,000 lbs		Used in Viet Nam
Boeing	C-135B	Stratolifter	USAF	Cargo/Transports	82,000 lbs		Still in production
Boeing	VC-137C	---	USAF	Cargo/Transports	35,000 ft	Presidential transport	USAF version of 707
Lockheed/Georgia	C-140A	Jetstar	USAF	Cargo/Transports	525 mph		Not in production
Lockheed/Georgia	C-141A	Starlifter	USAF	Cargo/Transports	68,000 lbs		Used in Viet Nam
Ling-Tempo-Vought	XC-142A	---	USAF	Cargo/Transports	8,800 lbs		Still undergoing test
Grumman	C-1A	Trader	Navy	Cargo/Transports	250 mph		
Grumman	C-2A	---	Navy	Cargo/Transports	15,000 lbs		USAF delivery 1966

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
DH/Canada	CV-2B	Caribou 1	Army	Cargo/Transports	8,000 lbs	STOL performance	
DH/Canada	CV-7A	Buffalo	Army	Cargo/Transports	10,000 lbs	Army funding not approved by DOD	Deliveries started in 1966
Lockheed/Georgia	C-5A	---	USAF	Cargo/Transports	220,000 lbs		Still under development.
Beech	VC-6A	---	USAF	Cargo/Transports	16,500 ft		
DH/Canada	U-1A	Otter	Army	Utility	153 mph		Used in Viet Nam
Cessna	U-3B	---	USAF	Utility	233 mph		Used in Viet Nam
Aero Commander	U-4B	Aero Commander	USAF	Utility	10,000 ft		
Helio	U-5A	H-500 Twin	USAF	Utility	185 mph	STOL performance	Undergoing USAF evaluation
DH/Canada	U-6A	Beaver	Army	Utility	156 mph		Used in Viet Nam
Piper	U-7A	---	USAF	Utility	130 mph		
Beech	U-8F	Seminole	Army	Utility	239 mph		Still in production
Helio	U-10A	Courier	USAF	Utility	167 mph	STOL performance	Used in Viet Nam
Piper	U-11A	Aztec	Navy	Utility	225 mph		Available in several models
Grumman	HU-16E	Albatross	Navy	Utility	215 mph		Used in Viet Nam
Cessna	U-17A	---	USAF	Utility	185 mph		Still in production

Table 4-1. Initial Platform List (Continued)

U.S. ROTARY-WING AIRCRAFT

Manufacturers	Number	Popular Name	Ceiling (ft.)	Range (mi.)	Remarks
Bell	(47G-4A)	Trooper	13,700	324	
Bell	(47J-2A)	Ranger	15,100	268	
Bell	(206)	Jet Ranger	- -	400	1966 certification
Bell	UH-1D	Iroquois	18,000	315	Armed escort
Bell	(209)	Huey Cobra	- -	- -	Interim AAFSS
Bell	OH-135	Sioux	18,000	324	
Gyrodyne	XRON-1	Rotorcycle	7,300	56	
Gyrodyne	9H-50D	Dash	20,000	35	ASW drone
Hiller	OH-23F/G	Raven	9,500	226	
Hughes	TH-55A	- -	6,500	195	Army primary trainer
Hughes	OH-6A	- -	15,400	394	Army LOH
Hughes	XV-9A	- -	6,000	- -	Research vehicle
Kaman	HH-43B/F	Huskie	25,000	277	In Viet Nam
	UH-2A	SeaSprite	14,500	550	In Viet Nam
Lockheed	XH-51A	- -	10,100	[illegible]41	Rigid-rotor research
Sikorsky	CH-34	Choctaw	4,900	280	In Viet Nam
Sikorsky	SH-3D	Sea King	10,600	62[illegible]	
Sikorsky	CH-3B/C	Jolly Green Giant	7,100	500	In Viet Nam
Sikorsky	HH-52A	- -	14,100	[illegible]	
Sikorsky	CH-54A	Skycrane	11,900	[illegible]3	In Viet Nam
Sikorsky	CH-53A	- -	10,400	282	
Sikorsky	CH-37	Mojave	- -	-	In Viet Nam
Boeing	UH-25B	Retriever	5,200	355	
Boeing	CH-21A	Shawnee	6,100	400	
Boeing	CH-46A	SeaKnight	9,000	246	In Viet Nam USMC
Boeing	CH-47A	Chinook	12,400	234	Army transport in Viet Nam
Boeing	CH-113	Voyageur	10,050	690	RCAF
Boeing	HKP-4	- -	9,100	760	Swedish

Table 4-1. Initial Platform List (Continued)

U.S. VTOL AIRCRAFT

Manufacturer	Designation	Performance	Remarks
Hawker Siddeley	XV-6A Kestrel	50,000 ft	Evaluation as strike/recon. fighter
Lockheed-Georgia	XV-4A (VZ-10) Hummingbird	40,000 ft	Army evaluation
Ryan Aeronautical	XV-5A (VZ-11)	50,000 ft	Army evaluation

U.S. DRONES AND TARGET MISSILES

Manufacturer	Designation	Mission	Service	Endurance	Remarks
Beech Aircraft Corp.	MQM-61A	Target	Army	85 min.	Recoverable
Maxson Electronics	AQM-37A	Target	Navy	15 min.	Rocket power
Northrop Ventura	AQM-38A	Target	Army	30 min.	Rocket power
Northrup Ventura	MQM-57A	Surveillance	Army	40 min.	(SD-1)
Ryan Aeronautical Co.	MQM-34A	Target	Navy/	114 min.	Turbojet

Table 4-1. Initial Platform List (Continued)

U.S. RESEARCH ROCKETS

Manufacturer	Name	Designation	Payload	Ceiling	Remarks
Atlantic Research Corp.	ARCAS	ARC 29KS-336	12 lbs	40 mi	Single stage
Atlantic Research Corp.	ARCHER	ARC 35KS-1375	40 lbs	90 mi	Single stage
Atlantic Research Corp.	METROC	ARC 16KS-140	2 lbs	20 mi	Single stage
Rocket Power Inc.	HOPI	RPI 3.0KS-4000	11-1/2 lbs	50 mi	Chaff Dart
Rocket Power Inc.	JUDI	RPI 1.9KS-2100	10 lbs	33 mi	Balloon Dart
Rocket Power Inc.	RAVEN	RPI 8.5KS-1800	- -	- -	- -
Thiokol Chemical Corp.	TOMAHAWK	- -	45 lbs	100 mi	- -
Rocketdyne (NAA)	AEOLUS	315 lbs thrust	6 lbs	15 mi	(Gun launch)

Table 4-2. Reduced HARR Candidate List

Item Number	Rank (Initial) (1967)	Platform Designation	Limiting Factors (Ref. p. 231)
		Fixed-Wing Manned Aircraft	
1	1	O-1E	
2	1	F-2H	
3	1	S-2D	
4	1	CV-2B	
5	1	U1-A	
6	1	U-6A	
7	2	OV-1C	
8	2	E-1B	
9	2	T-37B	A, C
10	2	T-39A	A, C
11	2	C-47E	C
12	2	C-121G	C
13	2	C-123B	
14	2	U-3B	
15	2	U-7A	
16	2	U-8F	
17	2	U-10A	B
18	3	A-1J	
19	3	YB-26	
20	3	B-66D	
21	3	F-5A	
22	3	RB-57F	
23	3	P-3B	C, E
24	3	T-2B	
25	3	T-28D	
26	3	T-29D	
27	3	T-34B	
28	3	T-38A	A, C
29	3	T-41A	
30	3	T-42A	
31	3	C-54	C
32	3	C-117D	
33	3	C-118A	C
34	3	C-119J	C
35	3	C-131E	B
36	3	VC-6A	C
37	3	U-4B	A, B, C
38	3	U-5A	A, B, C

Table 4-2. Reduced HARR Candidate List (Continued)

Item Number	Rank (Initial) (1967)	Platform Designation	Limiting Factors
39	3	U-11A	
40	3	HU-16E	B
41	3	U-17A	

(42 models eliminated from initial 83 models)

Rotary-Wing Manned Aircraft

42	1	UH-1D	
43	1	OH-6A	
44	2	OH-13S	
45	2	OH-23F/G	
46	2	CH-34	
47	3	UH-2A	C, E
48	3	SH-3D	C
49	3	CH-37	C
50	3	CH-21A	D

(18 models eliminated from initial 27 models)

Fixed-Winged Drone Aircraft

51	1	MQM-36	

(initial 5 models eliminated; 1 or 2 may be reinstated for analysis after this platform category is evaluated versus other categories)

Rotary-Winged Drone Aircraft

52	1	OH-50D	
53	2	DH-2C	

(Only OH-50D was on the initial list)

Payload capability for initial configuration (50 to 300 pounds) has not been a factor in rejecting candidates. For interim and long-range systems, greater payload requirements may be a factor. Antenna mounting requirements have not been considered critical.

4.5.3.1.2 HARR Aircraft Second Iteration Selection/Rejection. The reduction to the 53 remaining candidates still left too large a number for entry into a detailed cost/effectiveness. The candidate reduction process implemented during a second iteration is summarized in Tables 4-2 and 4-3.

Table 4-3 recommends that the 53 candidates be "reduced" initially to 17, and to 8 later in the study. The proposed reduction is on the premise that types of aircraft have common technical and operational characteristics affording gross measures of suitability, as follows:

A. Attack. The A-1 was retained, while other aircraft of this type were rejected because of limited on-station capability, high cost, lack of divertibility from other missions, etc. The A-1 is a marginal candidate, because of the same factors.

B. Bomber. Three models were retained as marginal candidates. Others were rejected because of high cost and on-station limitations, (e.g., ability to loiter at low altitudes in difficult terrain and weather).

F. Fighter. The F-5A was retained, while all others were rejected because of on-station limitations, high cost, etc. While the F-5A is considered to be a marginal candidate, analysis based on F-5A data can be made inexpensively (through access to Norair experience) with respect to the RFP's concern for HARR objectives being served by random sorties - close air support, reconnaissance, etc. Suitability of the A-1 (and, to an extent, of bombers) can be extrapolated from F-5A analyses.

O. Observation. These aircraft are suitable because of Army ownership/experience, ability to launch in an austere environment, on-station loitering capability, low cost, etc. Limiting factors may be all-weather capability, night-flying, and payload capacity.

P. Patrol. This is a unique case. P-2's are being moved from storage to special Viet Nam operations, the storage inventory is being depleted, and active ASW squadrons may or may not be releasing the obsolete P-2's. The P-3 successor (Lockheed's Electra) is not likely to be readily available. Both aircraft have

Table 4-3. HARR Candidate Selection Goals

Aircraft Designators

Code	Type	User	Reduced HARR List	Number of Candidates		
				Final	Interim	Now
A	Attack	N	A-1	0	0	1
B, YB	Bomber	AF	B-66D, RB-57F, YB-26	0	0	3
F	Fighter	AF, N	F-5A	0	1	1
O	Observation	A, AF	O-1E, OV-1C	0	1	2
P	Patrol	N (ASW)	P-2H, P-3B	1	1	2
S	Search	N (ASW	S-2D	0	1	1
E	Early Warning	N	E-1B	0	1	1
T	Trainer	All	T-37B, T-39A, T-2B, T-28D, T-29D, T-34B T-38A, T-41, T-42A	1	2	9
C	Cargo/ Transport	AF, N	C-47E, C-121B, C-123B, C-54, C-117D, C-118A, C-119J, C-131E, VC-6A	1	2	9
U	Utility	All	U-1A, U-6A, U-3B, U-7A, U-8F, U-10A, U-4B, U-5A, U-11A, HU-16E, U-17	1	2	12
CV	Cargo/ Transport	A	CV-2B	1	1	1
Rotary Wing (Helicopter)						
UH	Utility	A	UH-1D, UH-2A	1	1	2
OH	Observation	A	OH-6A, OH-13S, OH-23 F/G	0	1	3
CH	Cargo/ Transport	A	CH-34, CH-37, CH-21A	1	1	3
			Subtotal	7	15	50
			Drones	1	2	3
			Total	8	17	53

Note: Candidates within a type are listed in approximate order of suitability.

good on-station characteristics, particularly around 15,000-feet altitudes, and night/all-weather capability. Capacity and costs are high for HARR. However, should the HARR relay payload be payload be expanded significantly, these aircraft qualify when smaller aircraft candidates for Quick Fix drop out. Present indications are that the P-2 should be analyzed in depth, and the P-3 considered as an alternative.

S. Search. This is also a unique case. USAF is using these Navy ASW aircraft for special Viet Nam missions. Like the P-2, the S-2 is obsolete, but the S-2 does not have a successor in inventory or production. Available S-2 inventories have not been investigated. Compared to the P-2, the S-2 has smaller payload, less endurance, lower costs and better low-altitude performance. Nevertheless, the P-2 is now considered to outweigh the S-2 as a candidate. More evidence is required.

E. Early Warning. The E-1B has much the same characteristics, in terms of HARR, as the P-2 and S-2. The E-1B also has avionics which may abet the HARR mission and facilitate multi-mission operations in Viet Nam. Short-comings may be in the areas of availability, theater logistics, command channels, etc.

T. Trainer. While a number of candidates were rejected because of on-station characteristics and costs, nine remained. The T-37B and T-30A appear to be primary candidates for Viet Nam and Quick Fix. This type aircraft must be subjected further to the same sort of selection/rejection criteria already applied. One possibility is to select a large, slow, inexpensive model and subject both models to cost/effectiveness analyses.

C. Cargo. Larger models were rejected because of excessive capacity and cost, and some of the remaining 9 candidates are marginal for this reason. The C-123B is in substantial use in Viet Nam, and the C-47E and C-121G appear likely candidates.

CV Cargo. The CV-2B is a special candidate because of its availability, logistics support, experience in Viet Nam, etc. This aircraft is one transferred from Army to Air Force, per the April 1966 agreement. Investigation of the impact of this transfer on the CV-2B's HARR candidacy is desirable.

U Utility. A few aircraft of this type appear marginal because of on-station limitations, cost and limited availability, but none were rejected. The U-1A and U-6A are favored because of their present use in Viet Nam. More specific criteria are needed for subsequent selection/rejection. Because of the apparently good candidacy of this aircraft type, a preferability ranking may be needed, rather than suitability exclusions. Relative ranking versus observation aircraft also seems desirable.

UH Utility Helicopter. The UH-1's prevalence in Viet Nam makes it a primary candidate. All versions (including the earlier UH-1B and the new 2-engine model) must be investigated. The UH-2A is less available, probably relatively costly, and possibly not divertible from other missions. The UH-1 is, in terms of HARR, in competition with Utility Fixed Wing aircraft. Analysis may show that the UH-1 compares unfavorably in cost, all-weather operation, etc.

OH Observation Helicopter. There are three good candidates to be reduced to one by some criteria not yet derived or applied. Payload and environmental limitations are expected to rule this type out in favor of Fixed Wing Observation aircraft or Utility Helicopters.

CH Cargo Helicopter. The CH-34 (also designated UH-34) is a primary candidate used extensively over Viet Nam from land and carrier basing by both Navy and Marine Corps. The CH-37 and CH-21A appear to be poorer cost/effectiveness candidates. Unless the HARR payload increases and platform maneuverability becomes a premium factor, the CH-34 may be rejected through subsequent analysis.

4.5.4 Cost-Effective Analysis. As is customary in a cost-effectiveness analysis, the effort was divided into two major areas--that pertaining to HARR operational effectiveness and remote area suitability, and that pertaining to cost. Not in all cases were these areas kept separate. This was because logistic and base support costs were to a large degree dependent on a platform's present status in the U.S. inventory in South Viet Nam and the experience or lack of experience with the candidate in the Pacific theater.

4.5.4.1 Effectiveness Model. By considering the communications requirements discussed in Section 2, and by material found in the Remote Area Conflict Information Center (RACIC) Library, platform mission requirements were specified. These requirements were as follows:

a. Overcome Foliage and Terrain. The platform height was required to meet minimum altitude limits that would overcome both the foliage and terrain problems. If platform altitudes, such as the tethered balloon or treetop net, did not meet this minimum altitude requirement, either their height had to be increased or else the altitude deficiency would have to be made up by the height of the ground at which the platform was tethered or supported. Also, when terrain masking avoidance because a problem, either the extra penalty in payload, special equipment, and on-station endurance costs had to be accepted or the burden had to be shared by special ground-to-air-to-air-to-ground provisions.

b. Avoid Mutual Frequency Interference. As expressed elsewhere in this document, a critical platform requirement was that it carry the additional payload or incorporate within its ground system the sophistication necessary to avoid mutual frequency interference. The AN/PRC-25 repeater range improvement figures shown in Section 3 (a flat earth range of 150 miles for an altitude of 19,650 feet for an allowable path loss of 140 db, or a ground distance of 50 miles for an equal path loss at a 1,775-foot altitude) showed that an altitude improvement payed off handsomely in range; however, mutual frequency interference was now inevitable.

c. Meet Tactical and Environmental Conditions. Among the critical parameters considered in the analysis were force deployment and environmental conditions. The required employment tactics are discussed in Section 2 of this document. The environmental conditions were found by various personal-contact and literature-search references. As much as possible, these were the tactical deployment practice and environmental conditions as they now exist in South Viet Nam.

d. Remain Compatible with Operational Doctrine. Through conferences held with U.S. Army aircraft project managers at AVCOM in St. Louis, Missouri, it was learned that flight crew, ground support, and logistic supply were critical factors to be considered in the evaluation of military aircraft. Often, aircraft manuals present endurance curves that are true for the vehicle, but not for the flight crew, particularly when day-in, day-out, on-station missions are to be flown, such as are required by HARR. Also it was learned that particular care should be taken that the logistic and ground support requirements of a system should not exceed supply and maintenance adjustment limitations. As a consequency, if a platform already exists in the U.S./Viet Nam inventory, it would have a favorable advantage over one that was not; and when it was found that a candidate required unusually demanding repair, logistic or operational support (such as fuel), it should be dropped from consideration.

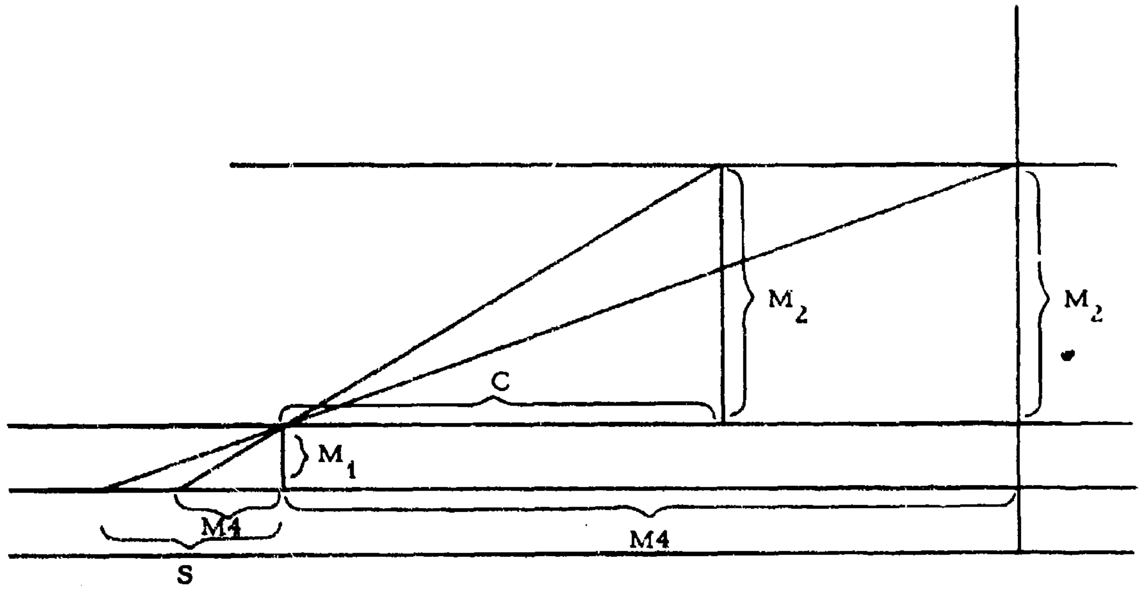
4.5.4.1.1 Environmental Considerations

a. Weather Analysis. For the application of both balloon and aircraft platforms, an understanding had to be established as to the influence of upper winds and surface weather on total operational availability. Upper air winds and surface weather information was obtained from the Environmental Technical Applications Center, Washington, D. C. Specific Viet Nam operational flying condition information was obtained from the AVCOM Army Aircraft Project Offices and specific surface weather percentages, according to South Viet Nam area distribution, from the AVCOM Foreign Intelligence Office. The environmental influences are treated later in the discussion of the cost-effectiveness curves.

b. Terrain Analysis. An important part of the effectiveness model was the amount of transmission coverage that could be counted on from an on-station platform. It was known that this varied with the altitude of the platform and the terrain of the area being covered. Since the South Viet Nam topography varied from the rough mountainous terrain in the north to the lowlands of the south, it was imperative that a terrain analysis be made. Such an analysis was not found to exist that would meet specific HARR requirements, and a means had to be obtained that would give terrain slope results that fell within HARR platform positional limits. These limits were rather broad, and accordingly the terrain analysis was not done in precise detail.

The methodology employed was to obtain a large topographic chart of South Viet Nam. The scale used was 1:1,000,000; the chart was divided up into sections representing ARVN Corps I and II over the northern half and the ARVN Corps III and IV over the southern half. Cross sections were taken over each postion of an area that indicated topographic change. The spacing of the contour lines gave the degree of slope.

1. Shadow Zones. Shadow Zones were computed according to the geometry and equations shown in Figure 4-8. A section of the II Corps area which represents a typical terrain analysis is shown in Figure 4-9. Location of the shadow zones was determined by examining every location that appeared likely. The only exception was the case of the gullies whose banks might have been considerably steeper than the immediately surrounding terrain. As an example, it is probable that a considerable portion of the area around Plei Girao Kup in the southeastern part (in Figure 4-9) is in shadows.



M_1 = Altitude difference in terrain

M_2 = Height of platform above highest terrain feature

M_3 = Contour spacing

M_4 = Distance, platform to highest terrain feature

K = Intermediate factor; $K = \frac{M_2}{M_1}$

C = Intermediate factor; $C = (M_3)K$; If C M_4 there is no shadow

S = Length of shadow; $S = {(M_4)}/{(K)}$; Measured from highest terrain feature at level of M_3.

$$K = \frac{M_2}{M_1}$$

$$C = (M_3)(K)$$

$$S = {(M_4)}/{(K)}$$

Figure 4-8. Shadow Geometry

Figure 4-9. Typical Terrain Analysis - Vietnam

The extent of the platform station was determined graphically as the intersection of a plane at 20,000 feet, with extensions of the slope of the terrain. The general location was first selected by inspection. For the purpose of calculating station extent, ambient terrain slope was doubled. Thus the station envelope, represented by the hatched, pear-shaped area near the "KLON GLUIH" letters, is appropriate for a 10,000-foot platform, if ambient slopes are considered adequate, and for a 20,000-foot platform, if twice the ambient slopes is felt to be more realistic. The approximate center of the station area was used for locating and determining the extent of the shadow. For this rather mountainous section of the II Corps area the shadow zones were estimated to take up less than 5 percent of the total territory of Figure 4-9.

When the HARR system becomes a reality, its utilization will be enhanced if accurate shadow zone charts were available to the forward area commander. These would be prepared for the altitudes which are compatible with the available HARR platforms. Once the commander decided where his forces were to be employed, the platform station would be positioned to optimize the radio relay coverage.

c. Area of Coverage Cones. The two considerations of terrain masking avoidance and foliage penetration were applied to obtain needed platform "cones of coverage." Considering the propagation take-off angle requirements discussed in Section 3, a limiting horizontal angle of 10^{o} was obtained. Figure 4-10 illustrates this foliage penetration angle. When terrain was not the limiting cone of coverage factor, the 10^{o} angle was used.

Figure 4-10 also illustrates the manner in which the terrain-limited cone of coverage was estimated. The maximum slope of the terrain was used which was greater than the 10^{o} foliage limiting angle and which sustained a "line-of-sight" angle that reached to the platform's position at the apex of the coverage cone. The useful area was determined by the intersection of the cone of coverage with the topography, or else by the horizon which made up the 10^{o} foliage-limiting angle.

As might be expected, the area covered by an on-station platform, particularly in rugged terrain, would be quite irregular. This irregularity is illustrated in Figure 4-11. This terrain/relay coverage interface is discussed in the paragraph that follows.

Interface Between Relay and Terrain. With respect to a relay-carrying airborne platform, three major physical factors determine its effectiveness. These are:

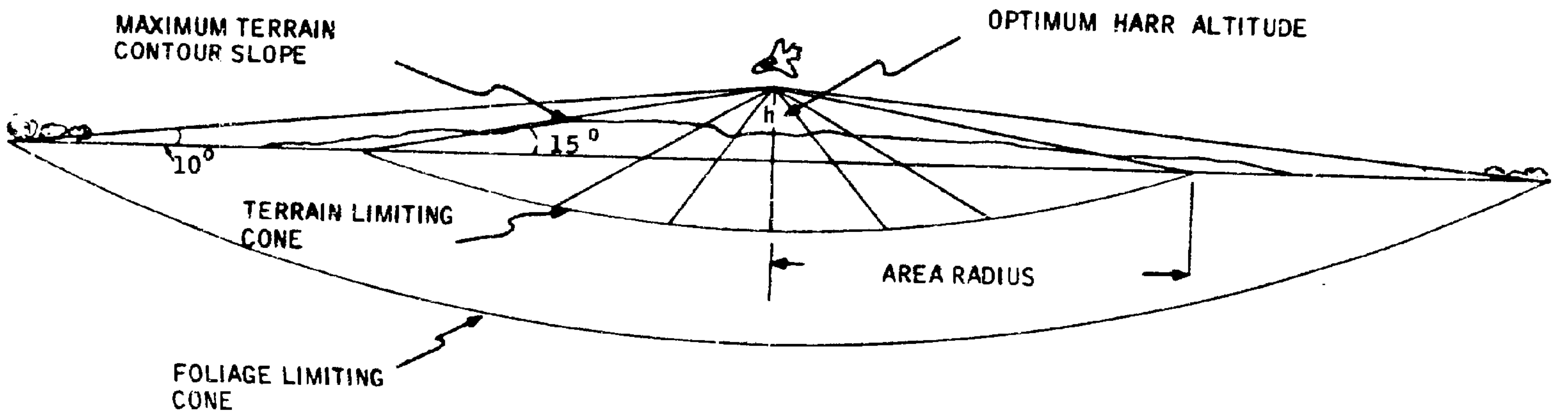


Figure 4-10. Platform Terrain and Foliage Limiting Cones

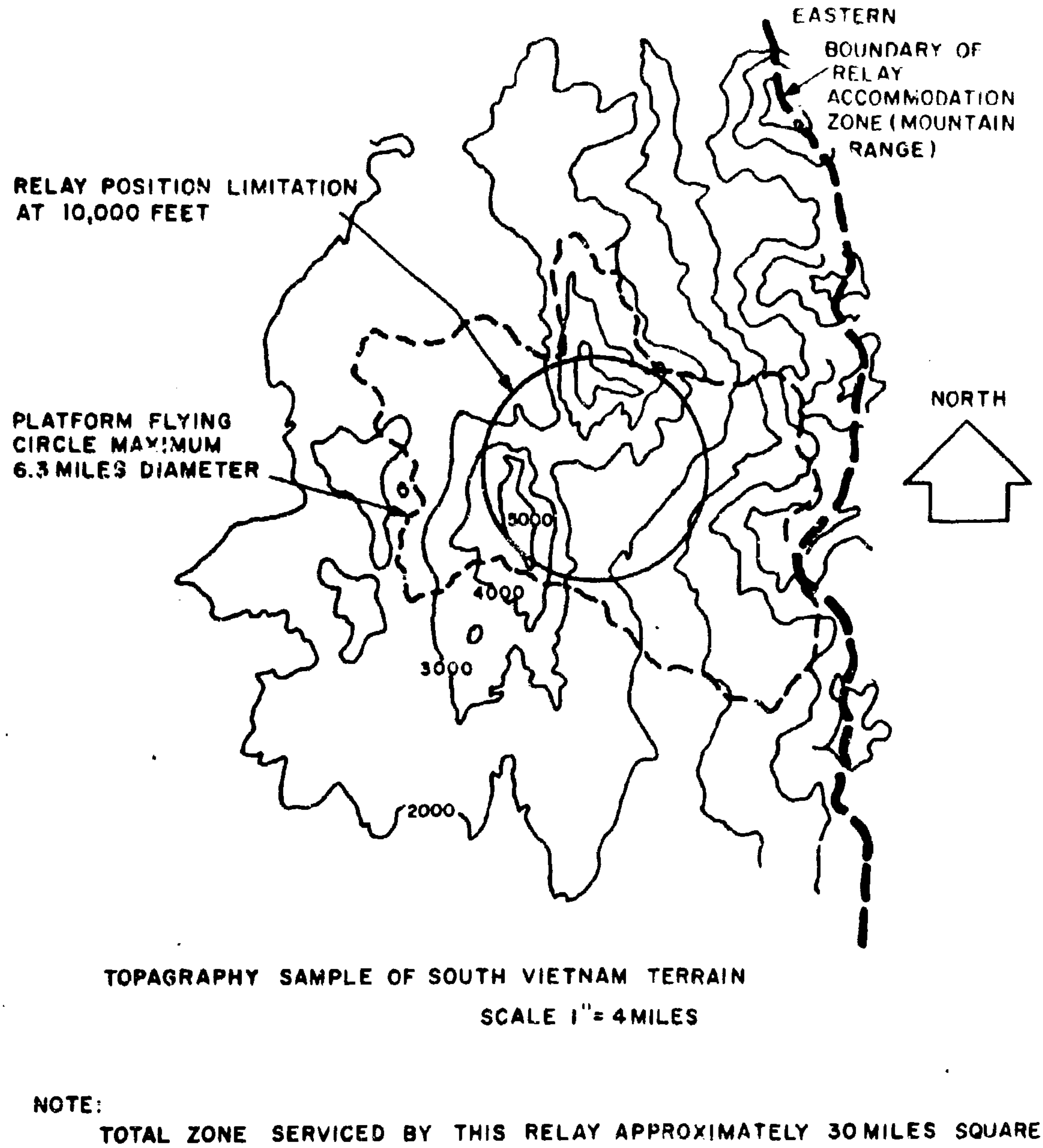


Figure 4-11. Irregular Area of Coverage Due to Rough Terrain

Position	The ability to hold the relay within defined space limits, plus getting it there and back to base.
Environment	With its normal variations; weather sometimes becomes untenable for certain platforms to achieve or hold position.
Configuration	Effect of platform on relay and antenna design.

This discussion deals only with the relay position factor, and advances the idea for terrain definition in terms of platform position on-station.

For purposes of analysis, platform position may be defined as an area over terrain at an arbitrarily selected constant altitude. The limits of this area may be defined by a value of computed signal strength representing an acceptable threshold between receiver sensitivity and voice transmission from a standard man-pack radio at any point on the ground. The transmitted signal will be influenced by indigenous vegetation and roughness of terrain plus normal attenuation for distance. A signal strength contour may then be determined at the selected altitude which describes an irregular envelop within which the input voltage at the relay receiving antenna will exceed the threshold signal strength. For simplicity, the irregular contour should have inscribed within it a circle which defines the relay position limits to be maintained by the platform. An example is given in Figure 4-11.

For a moving platform whose optimum performance altitude differs from the altitude selected to define the terrain, a suitable value for relay position factor may be computed based on free space attenuation and threshold signal strength patterns for higher (and possibly lower) altitudes. Higher altitudes should produce larger circular "on-station" areas over mountainous terrain as line-of-sight angles are relieved.

As shown in Figure 4-11, the dashed-line enclosed area is the guaranteed coverage an aircraft, flying in the 6.3-mile-diameter circular pattern, can obtain when holding a 10,000-foot altitude. The coverage is maintained despite the aircraft's position on the circumference.

d. Coverage Requirements. The area chosen for the first coverage investigation was that of the ARVN II Corps. This, as has been mentioned before, was a fairly rugged terrain characterized by considerable tropical foliage. An O-1E Bird Dog aircraft was chosen as the platform in this analysis. To obtain adequate coverage of this area where some peaks reached nearly to 9,000 feet, it was estimated that the Bird Dog should fly at a constant altitude of 13,000 feet. Figure 4-12 shows the areas of coverage which would have to be provided in order for complete II Corps blanketing by the required 24 simultaneous station-keeping Bird Dog aircraft.

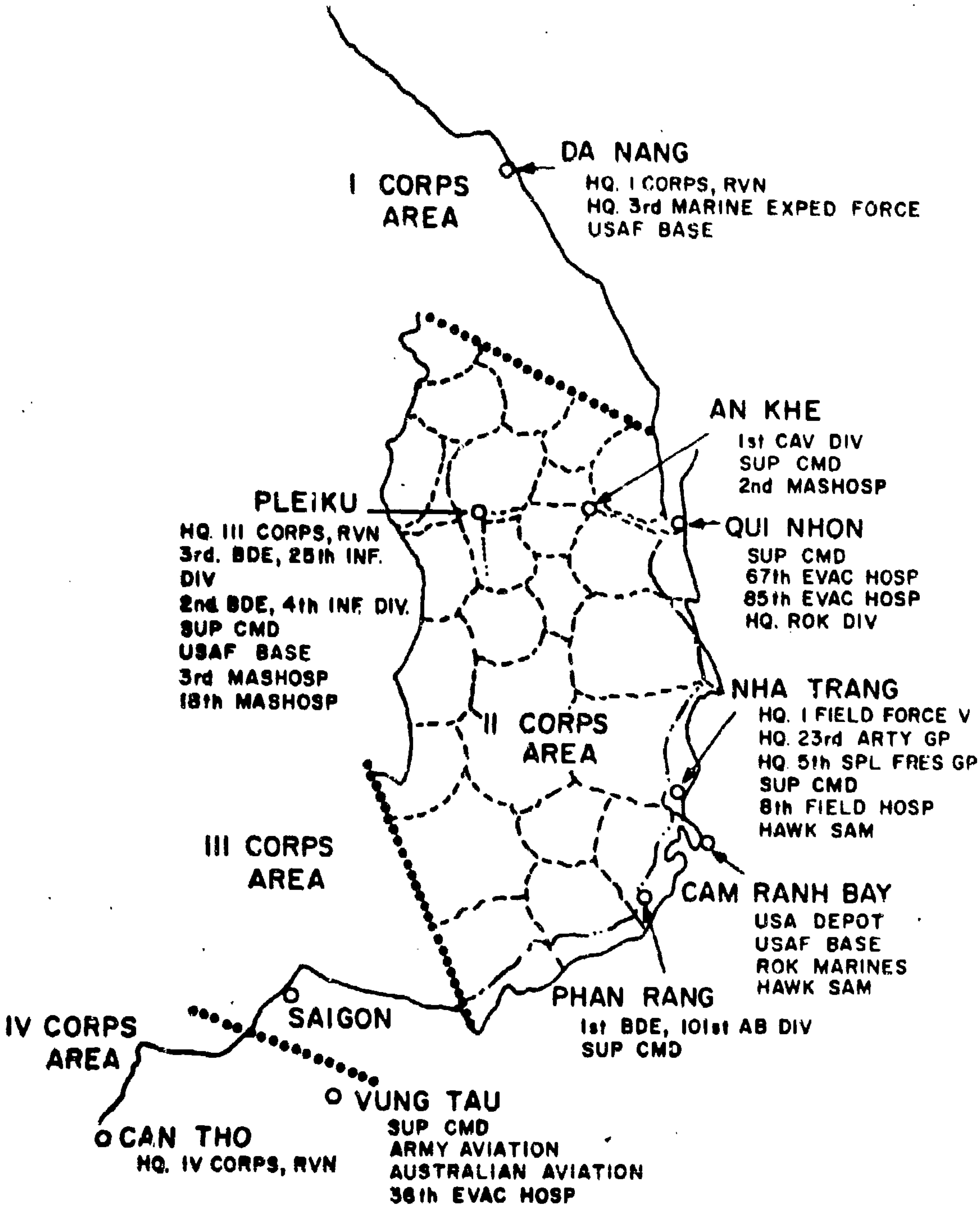


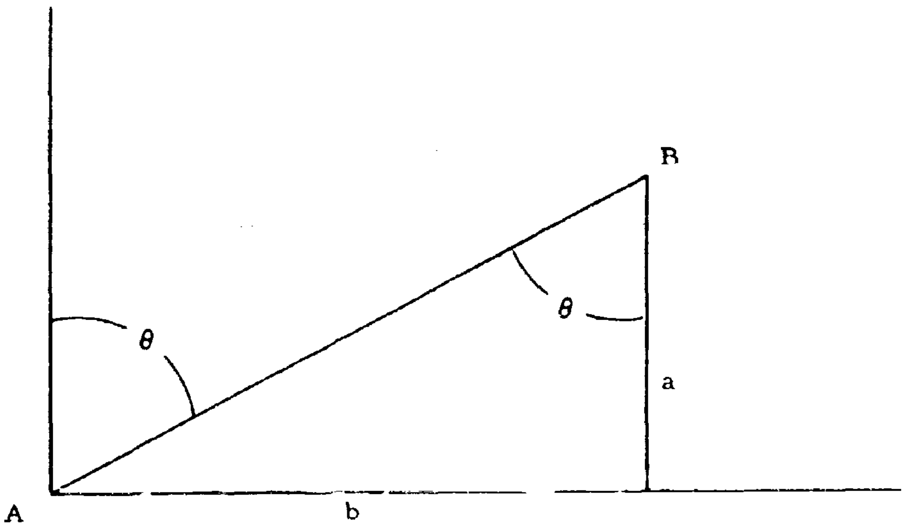
Figure 4-12. Area of Coverage for II Corps by Required 24 On-Station O1-E Aircraft

4.5.4.1.2 Tactical Analysis. The tactical doctrine applied in the HARK platform effectiveness modeling is described in some length in Section 2. This doctrine, as presented in Section 2, was used as the basis for determining platform and communication channel allotment and in building platform tactical employment models.

a. Platform Placement and Communication Channel Allocation

1. Under the simplifying assumptions that for (a) the propagation is a straight line, then (b), the portion of the earth of interest, can, with acceptable accuracy, be treated as a plane.

In this Section, platform altitudes are considered only on the basis of communications requirements and ignore minimum altitude problems of ground fire, etc. The essential elements of the platform placement problem can be represented in the following sketch.



The line AB represents an element of the cone within which communications are confined by terrain, foliage or other mechanism, about a station on the ground at A. That cone can be completely defined by the angle θ where:

$$\theta = \tan^{-1} \frac{b}{a} = \tan^{-1} \frac{1}{\text{terrain slope}}$$

A platform at B is theoretically within the line-of-sight (LOS) of any ground station along b.

In order for a platform at B to cover an area of radius R on the ground, the platform altitude of h must be determined by:

$$h = R \tan \theta = \frac{Rb}{a}$$

2. Figure 4-13 depicts (at distorted scale) the constraints on line-of-sight thus far considered as they apply to discussions which follow.

The line labeled "35%" represents the constraint which will be assumed to apply in rough terrain. It corresponds to an angle of about 70° from the vertical and is at a slope approximately double (when expressed in %) of the slopes which could be measured on the 1:1,000,000 scale charts available. Although the 35% slope may adequately describe the general terrain, there are undoubtedly local conditions which result in much more severe constraints. Those conditions exist at the bottoms of steep-sided gullies and even behind peaks where the slope may be nearly vertical.

The line labeled "80°" represents the constraint which will be assumed for flat terrain and reflects the best currently available estimate of the effects of foliage.

The line labeled "Flat Earth" represents the horizon constraint applicable over water. As long as airborne platforms are above intervening terrain, line-of-sight contact between platforms are governed by flat earth geometry.

The dotted line from 1 to 2 in Figure 4-13 depicts two airborne stations at 5,000 feet altitude and 25 nautical miles apart. The dotted line from 1 to 3 depicts two airborne stations separated by 25 miles horizontally and 5000 feet vertically with the lower station at 5,000 feet. Stations 1 and 3 are within line-of-sight of each other unless intervening terrain interferes, such as, for example, a mountain of altitude greater than 7,5000 feet at the point midway between the stations.

The tolerable intervening terrain altitude is expressed by:

$$h = h_1 + \frac{d}{S}(h_2 - h_1)$$

where:

- h is the height of terrain which will just intercept LOS
- h_1 is the altitude of the lower platform
- h_2 is the altitude of the higher platform
- S is the horizontal platform spacing

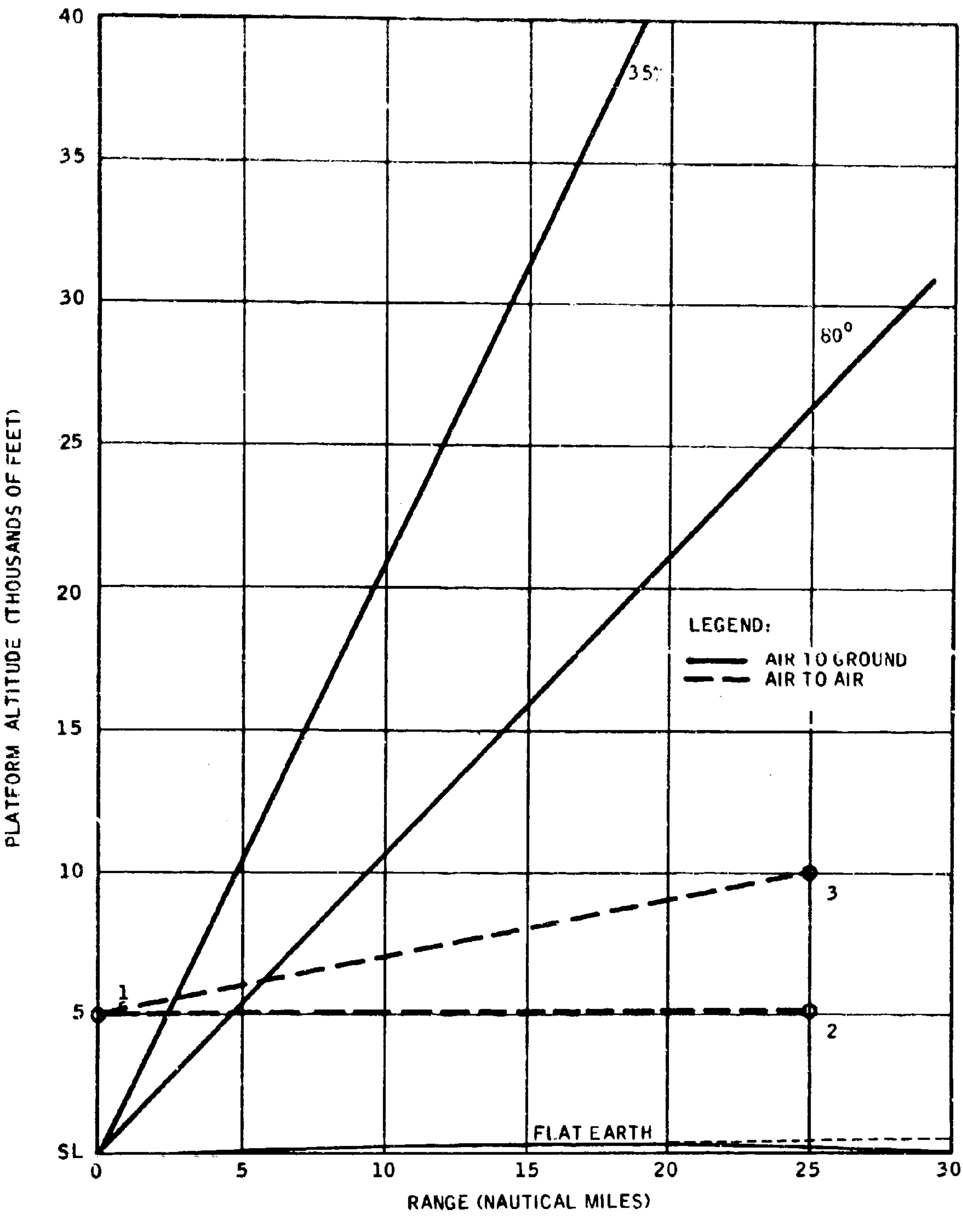


Figure 4-13. Communication Envelopes

d is the horizontal distance from the lower platform to the terrain feature being considered.

If both platforms are at an altitude which exceeds by 200 feet the height of any intervening terrain, they will be in LOS of each other.

The error in assuming a plane geometry treatment is on the order of 60 feet over the 25-mile interval. That error is ignored as insignificant in comparison to other uncertainties such as, for example, the accuracy with which the platforms will maintain altitude.

It must be noted at this point that to ensure the desired coverage under any constraint, the platform altitude must be measured from the highest terrain located in the area to be covered.

3. Figure 4-14 depicts the deployment and the elements of a battalion which are assumed in the discussions which follow. This deployment may be considered as something of a "worst case" in that an infantry battalion will rarely present a disposition of forces more widely separated.

4. Figures 4-15 and 4-16 illustrate application of the previously described concepts of coverage to the battalion deployment shown in Figure 4-14. Figures 4-15 and 4-16 depict the inverted cones of coverage in vertical cross section from various platform altitudes and locations when line-of-sight is defined by 80° and 35% constraints, respectively.

Figures 4-15 and 4-16 illustrate two factors which are generally appropriate:

(a) The minimum acceptable platform altitude is a function of:

(1) the dimensions of the area to be covered

(2) the envelope within which propagation is constrained.

There is also a maximum altitude above which it may be profitable to consider a different deployment of platforms. This is illustrated by points 1 and 2 in Figure 4-15 for example. A platform at 1 can theoretically bridge the communications gap between the platoon leader and company commander. If platform altitude is increased to the level of 2, the capability exists of covering all platoons of a company as well as the company commander. If the platform can carry a sufficient number of relays, it is feasible that it service the entire company.

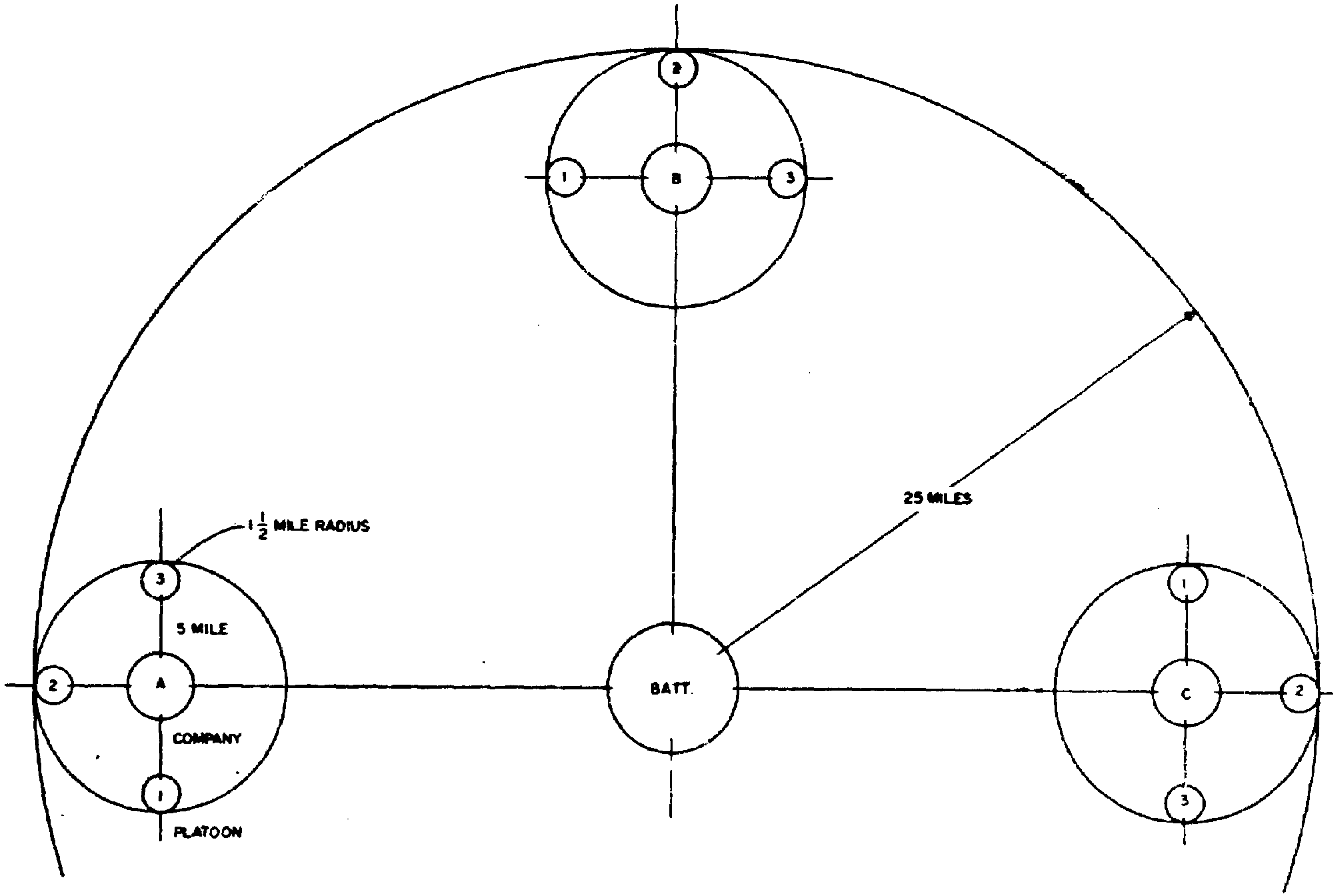


Figure 4-14. Assumed Battalion Tactical Deployment

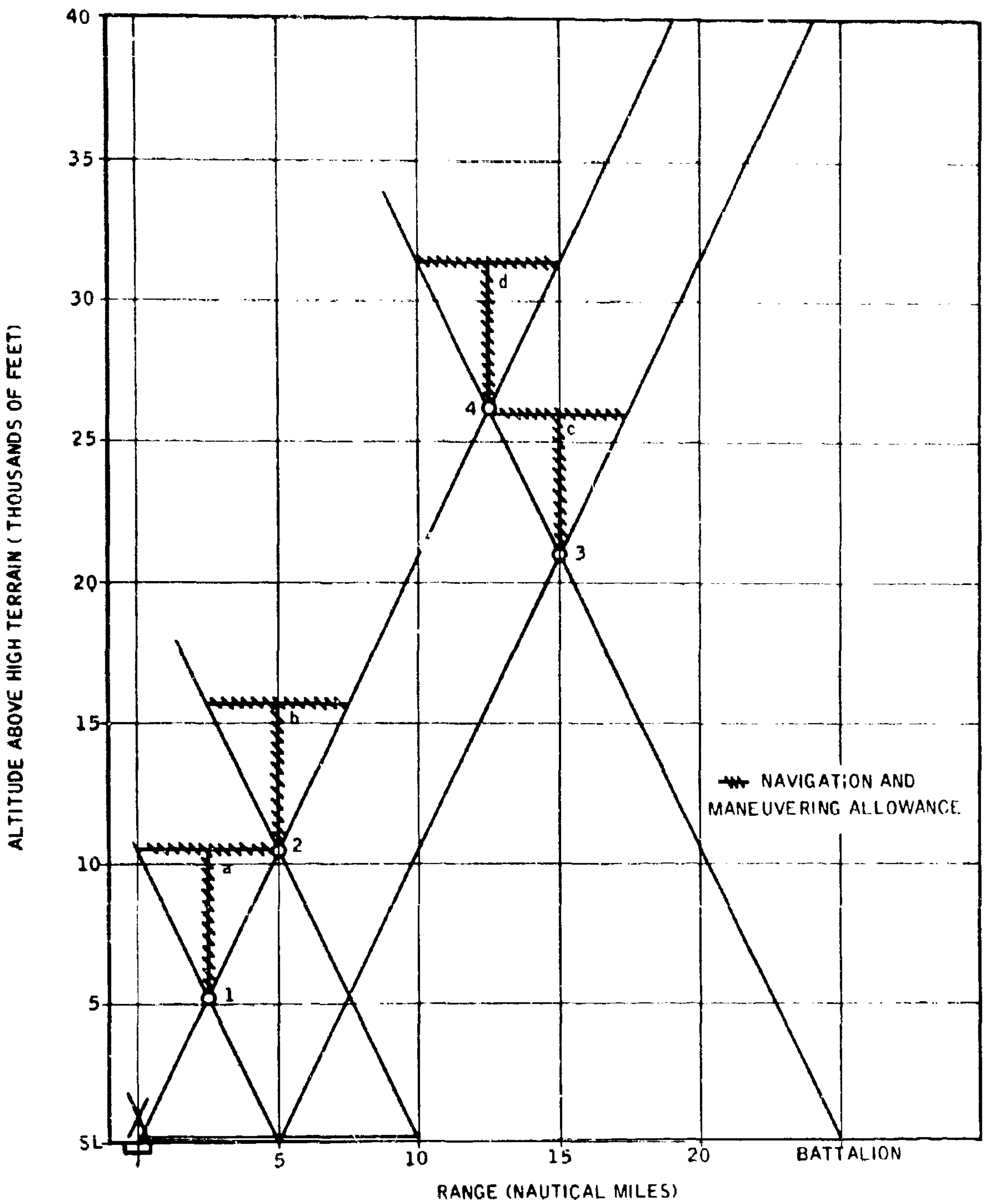


Figure 4-15. Platform Placement in 80° Constraint

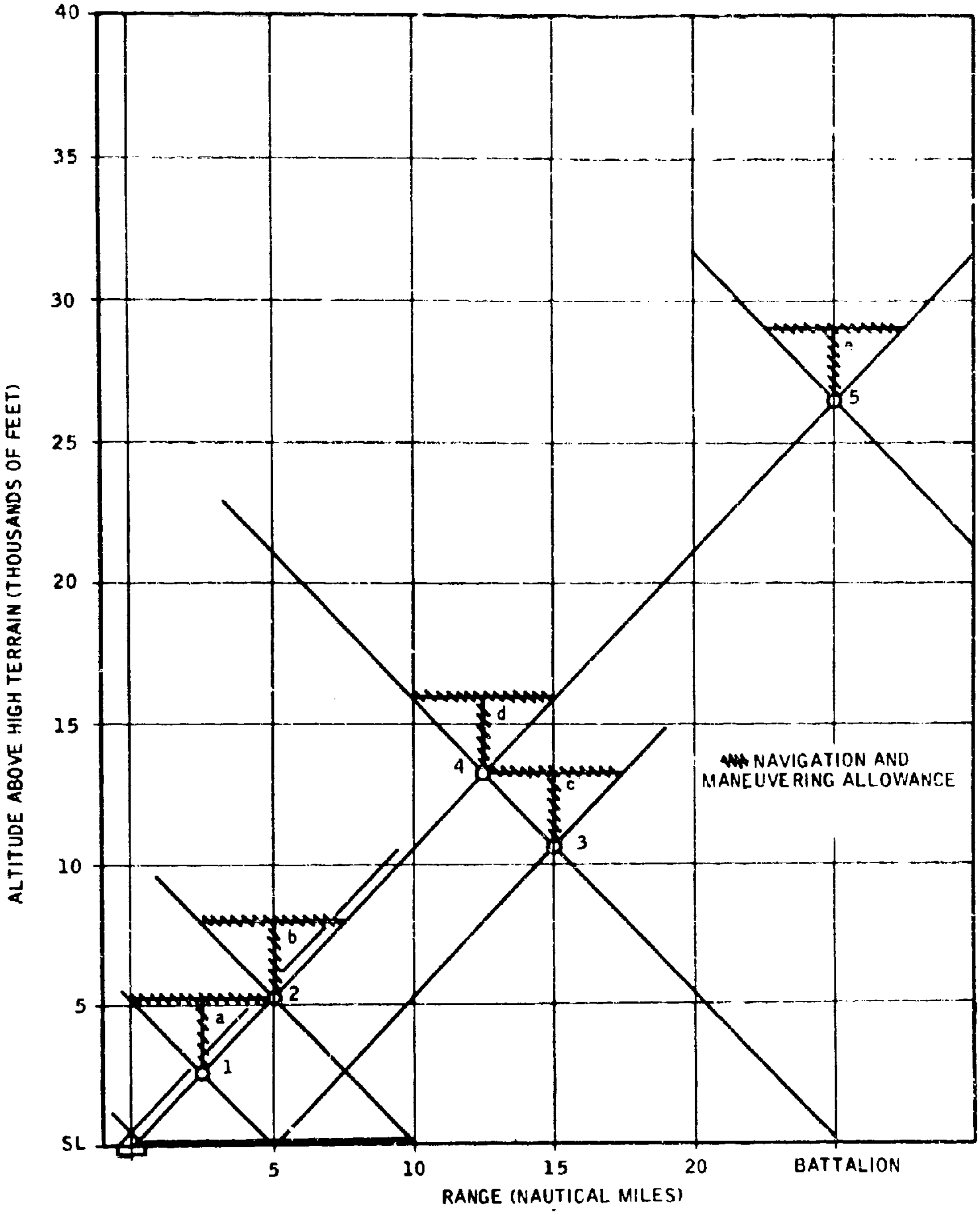


Figure 4-16. Platform Placement in 35% Terrain

(b) The precise positions, such as 1 and 2 in Figure 4-15, cannot be maintained even by tethered balloons. Fixed-wing aircraft must maneuver to stay airborne, and the "brute force" hover of rotary-wing craft reduces endurance. Furthermore, navigational inaccuracies are unavoidable. Thus some allowance must be made for maneuvering and navigational uncertainty. Stations shown in Figures 4-15 and 4-16 labeled a, b, etc., corresponding to and above stations 1, 2, etc., represent the increase in station altitude required to allow for a cumulative 2-1/2-mile error, or to allow a 5-mile diameter maneuvering space. As a maneuvering space, such a circle corresponds roughly to the room required to fly a race track holding pattern with 2-minute legs. Eight hours of that maneuver may be more than a pilot can endure.

It is assumed for the purpose of this report that "over coverage" is not desired. For example, the space between battalion and company headquarters may be occupied by transient traffic but the requirement for relay of vital communications does not concern that traffic. Thus, a platform at such an altitude as to provide coverage not only for the vital areas but for some space outside is providing "over coverage." Some "over coverage" is unavoidable, indeed necessary, but not necessarily desirable. "Over coverage" may also be considered to exist when a ground station has direct access to more than one platform, since relay between platforms is generally unimpeded by the mechanisms which hamper surface communications.

b. Tactical Employment Models. The tactical models described in the following paragraphs produce estimates of the number of platforms required as a function of platform altitude and assumed situation. Table 4-4 lists the results for the following tactical situations, each of which is described in more detail later:

Situation 1: Situation 1 is that in which the objective is to "cover" South Viet Nam completely. Numbers of platforms required are generally untenable in terms of manned aircraft.

Situation 2: Situation 2 is that in which the infantry company with a radius of five miles is the smallest tactical unit considered. Platform altitude must be great enough to ensure coverage of the five-mile radius circle. Tabulated numbers represent the number of platforms required per infantry battalion.

Situation 3: Situation 3 is that in which it is necessary to ensure continuity of communications from platoon through battalion headquarters. Numbers listed in Table 4-4 are the number of platforms required on station per battalion as a function of platform altitude.

Table 4-4. Platforms Required for Given Altitudes/Situations

Platform Altitude (in thousands of feet)	No. of Platforms Required					
	Situation 1		Situation 2		Situation 3	
	ARVN CORPS		ARVN CORPS		ARVN CORPS	
	I II	III IV	I II	III IV	I II	III IV
0.1		23			16	16
0.5		6			16	16
1.0		4			16	16
2.0		3			16	16
3.0	5,470	2			16	10
4.0	3,170	2			16	7
5.0	1,890	2			16	7
6.0	1,310	2		4	10	4
7.0	1,000	1		4	7	4
8.0	755	1		4	7	4
9.0	585	1		4	7	4
10.0	471	1		4	7	4
12.0	333	1	4	4	4	4
14.0	241	1	4	3	4	3
16.0	188	1	4	3	4	3
18.0	146	1	4	3	4	3
20.0	120	1	4	2	4	2
25.0	75	1	4	2	4	2
30.0	55	1	3	1	3	1
35.0	39	1	3	1	3	1
40.0	30	1	2	1	2	1
45.0	24	1	2	1	2	1
50.0	19	1	2	1	2	1
60.0	14	1	1	1	1	1

1. Application. This model produces as a result, the number of platforms required on station at a given time to meet various communications requirements of an infantry battalion. Numbers listed in Table 4-11 may be multiplied by the on-station flight hours to obtain operating costs.

2. Assumptions. The results of the investigation at this stage reflect the assumptions listed below:

(a) Effects of Terrain and Foliage. South Viet Nam was divided into two regions described generally as "mountainous" and "flat." These regions correspond fairly closely to ARVN Corps Zones I and II for mountainous terrain, and Zones III and IV for flat terrain. It was assumed that terrain masking was the principal impediment in the mountainous region. Communications were restricted to a zone above terrain with a "worst average" slope of 35%. In flat terrain, two conditions were assumed. In Situations 1, line-of-sight capability with no interference was assumed. In Situations 2 and 3, communications were assumed restricted by the terrain at a slope of 35% in Zones I and II and by foliage to within a 160° cone in Zones III and IV.

(b) Relay Capability and Interference. These two factors were ignored as problems in this phase.

(c) Effective Radio Range. Extremely high altitude platforms provide line-of-sight coverage to ranges that may exceed the capability of the transceivers under consideration. The effect of incorporating the restrictions imposed by free-space attenuation will be to reduce the radius of coverage. For the purposes of this study effort, the effect has been ignored.

4.5.4.1.3 Data Acquisition. The objective of the data acquisition effort was to obtain as much up-to-date and pertinent cost, performance, and operational data as possible on the platform candidates which had survived the two platforms elimination iterations.

Initially the files at Northrop-Ventura were searched. These produced rather comprehensive data on fixed-wing drones and some balloons but not satisfactory amounts on fixed- and rotary-wing manned aircraft, rotary-wing manned and unmanned aircraft, and the latest developments on balloons and other special platforms.

Considerable assistance, particularly on Air Force and Navy manned aircraft, was obtained from the special data files at Norair in Hawthorne, California; this was supplemented by contacts made at the Rand Corporation, Santa Monica, California. Valuable information on rotary-wing aircraft now undergoing development was obtained from Lockheed Aircraft Corporation, Burbank, California. However, it was not until the necessary need-to-know was established at the U.S. Army Aviation Material Command at St. Louis, Missouri, that the much-needed Army aviation performance and cost data was obtained.

A total of three visits were made to AVCOM. The AVCOM personnel contacted were:

H. M. Sigman	Systems Engineering Division
Frank Barhorst	O-1 Aircraft Project Office
George Johnson	U-8 and U-10 Aircraft Project Offices
Charles A. Doher	U-6 Aircraft Project Office
Mr. Ceaser	CV-2 Aircraft Project Office
Thomas Bell	UH-1 Aircraft Project Office
Cedric L. Davis	Maintenance Directorate Office
Mr. Bartel	Deputy Director, Research and Development and Engineering Directorate
Robert Andrews	Foreign Intelligence Office

In pursuit of information on the Navy DASH helicopter drone, the following key personnel were contacted

CDR. O'Brien	DASH Project Office
LCDR. Savage	Performance Analyst, DASH Project
Dr. Hauser	Avionics, DASH Project
Mr. Robert Bowers	Logistics Support
Admiral (Ret.) Leiper	Gyrodyne Regional Representative, Washington, D.C.
Mr. Allen Yates	Vice President, Gyrodyne Company of America

Besides an extensive search of the literature and correspondence with balloon manufacturers, visits were made to the Cambridge Research Center, Lexington, Massachusetts, and the Aereon Corporation, Trenton, New Jersey.

The latest experimental results on the use of balloons for meteorological instrument carrying and data transmission purposes were obtained from Cambridge Research Center personnel and special evaluation material on the use of small dirigibles as relay platforms from the Aereon engineers.

Considerable use was made of the Remote Area Conflict Information Center (RACIC) library to obtain information on firsthand experience with Army aircraft utilization in South Viet Nam and indications of what the logistic and base support problems might be.

a. Data Treatment. In addition to the individual contacts, the U.S. Army -10 aircraft operational manual series and the U.S. Army Aviation Planning Manual, FM-101-20, were used extensively as data sources. Though there was extensive performance data in these manuals, it was found that considerable special treatment was necessary before the data could be used to give HARR mission values. Considerable effort, therefore, went into the replotting of profile charts and in the development of HARR compatible performance curves.

A caution given by Army Aircraft Project Office members at AVCOM was that for a mission as monotonous and long as would be characteristic of HARR, the human endurance often would become a more limiting factor than the on-station endurance time of the aircraft. Figure 4-17 is a chart which gives an example of the special consideration that was given to a pilot's ability to spend long hours confined within the narrow limits of an O-1E cockpit. Flight hours, i.e., on-station hours plus station taking and base return hours, are divided to obtain the abscissa values. Because the human endurance is appreciably less than O-1E aircraft endurance at each indicated HARR station altitude, the human endurance curve falls consistently farther to the right. The other important critical values used to make up the curves are also presented on the chart.

4.5.4.2 HARR Platform Costing. The costing that was done was divided according to whether the candidate was an aircraft or a special platform. In turn, the aircraft costs were divided according to whether the vehicle was manned or unmanned.

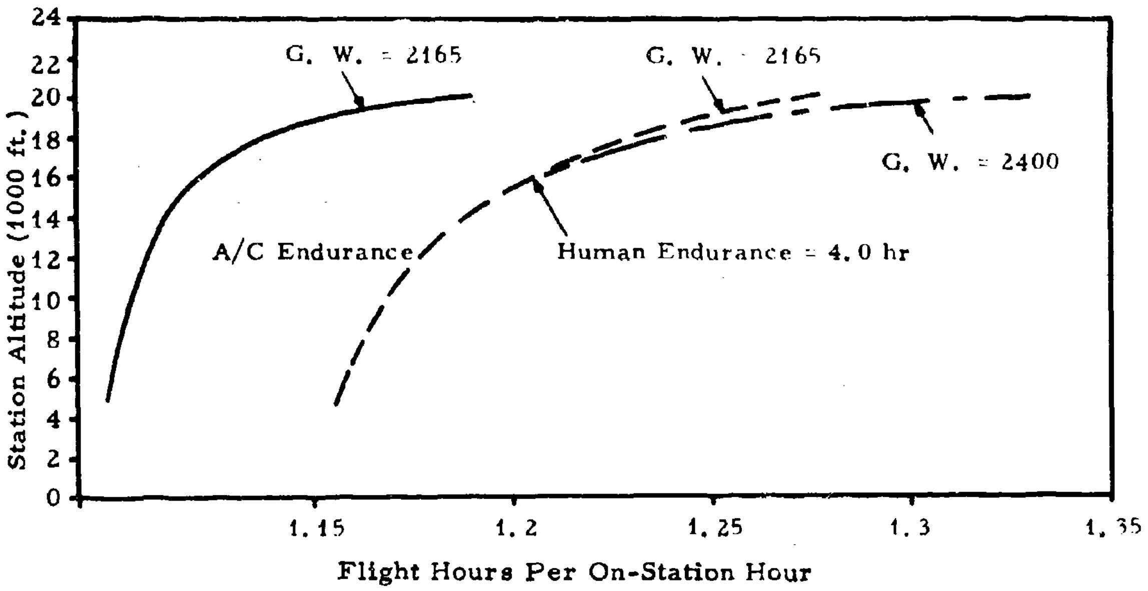
Fuel to Return:

Assume - TAS = 120 mph

Fuel Flow = 5.5 gph

Fuel - $\frac{30}{120}$ 5.5 = 1.4 gal.

Time - $\frac{30}{120}$ = 0.25 hr = 15 min.



Operating Costs:

Assume -

1. Direct Operating Cost = $24 / Hour
2. 720 On-Station Hours / Month
3. No. Vehicles Required / Situation and Area as per R. West Report
4. Flight Endurance / Human Limited to 4.0 Hours
5. 30 Mile Cruise Distance to Station

Figure 4-17. O-1E Endurance Curves

4.5.4.2.1 Costs for Manned Military Aircraft

a. Cost Factors. Several factors contribute to the cost of providing a manned military aircraft such as a HARR platform. These factors are:

1. Cost of the aircraft.
2. Cost to replace aircraft lost through attrition.
3. Cost of fuel and oil for flying.
4. Cost of replacement parts consumed in the maintenance process.
5. Cost of manpower required for maintenance.
6. Cost of a flight crew for the HARR mission.
7. Cost of personnel (not part of the HARR program) providing support for HARR operations.
8. Cost for the HARR "fair share" of base operating support.

Information on these costs is presented in Tables 4-5 and 4-7. Table 4-6 provides data on the requirements for military personnel to conduct and support HARR operations. Table 4-5 gives purchase and operating costs for the candidate aircraft. It lists each candidate and its cost, then gives the attrition rate (losses per flight hour), the attrition cost ($/FH), the cost for fuel oil ($/FH), the cost for replacement parts ($/FH), and the total direct operating cost ($/FH). The total is the sum of the costs for attrition, fuel and oil, and replacements parts.

Table 4-6 gives a breakdown of the military personnel requirements. It lists each candidate, its use rate (flight hours per month), and a particular crew requirement case. Case 1 of Table 4-6 requires the basic HARR flight crew. For this case, the relay repeater equipment will be operated by one of the basic crew. Case 2 requires the basic flight crew, plus a relay repeater operator. For this case, it is assumed that the relay repeater equipment consist of many channels which must be monitored and operated by an additional crew member. Case 3 requires the basic flight crew, plus a relay repeater operator, plus relief personnel. For this case, it is assumed that the flight mission will have a long duration (approximately twenty hours), and extra flight personnel are needed to provide relief during the mission. Following the listing of the particular case, the required number of personnel are provided. The requirement is broken down into the officers and enlisted men needed for the flight crew, maintenance operation, and support.

Table 4-7 gives military personnel and base operating support costs for the candidates. The military personnel costs ($ per month) are listed as calculated from multiplying the personnel requirement by the personnel rate. Thus, for the O-1E which has a requirement for 4.6 officers and 7 enlisted men (for a rate of $1.000 per month per officer and $150 per month per enlisted man), the military personnel costs are $4,600 and $1,050, per month, respectively, for officers and enlisted men. These costs are added and divided by

Table 4-5. Purchase and Operating Costs

AIRCRAFT	COST	DIRECT OPERATING COST				
		Attrition		Fuel & Oil	Replacement Parts	Total
		Losses/FH	$/FH	$/FH	$/FH	$/FH
O-1E	$19,000	15×10^{-5}	$2.85	$2.00	$ 5.18	$ 10.03
U-1A	122,000	13×10^{-5}	15.87	4.09	4.53	24.49
U-6A	98,000	13×10^{-5}	12.75	3.20	8.49	24.44
U-8D	114,000	13×10^{-5}	14.82	5.06	7.52	27.40
CV-2	725,000	13×10^{-5}	94.25	21.41	69.37	185.03
C-47	300,000	13×10^{-5}	39.00	17.00	21.00	77.00
C-123	673,000	13×10^{-5}	86.81	38.00	36.00	160.81
OH-13	55,000	44×10^{-5}	24.20	2.83	11.64	38.67
UH-1D	247,000	31×10^{-5}	76.50	7.90	34.52	118.92

NOTE: Fuel and Oil Cost is for Normal Cruise.

Table 4-6. Personnel Requirements

Aircraft	Use FH/MO	Case	Personnel Flight		Requirements Maintenance		Breakdown Support	
			Off.	Enl.	Off.	Enl.	Off.	Enl.
O-1E	100	1	4	0	0	5	.6	2
U-1A	100	1	4	0	0	7	.6	3
		2	4	2	0	7	.6	4
U-6A	100	1	4	0	0	9	.6	4
		2	4	2	0	9	.6	5
U-8	100	1	4	0	0	9	.6	4
		2	4	2	0	9	.6	5
CV-2	100	2	4	2	0	20	.6	10
C-47	100	2	4	4	0	9	.5	4
		3	6	6	0	9	.6	5
C-123	100	2	6	6	0	17	.6	7
OH-13	50	1	2	0	0	5	.5	3
UH-1	50	1	2	0	0	7	.5	4
		2	2	1	0	7	.5	4

CASE 1 A special relay repeater operator not required.
CASE 2 A special relay repeater operator is required.
CASE 3 A special relay repeater operator is required, and relief personnel are needed do to long duration flights.

Table 4-7. Cost of Military Personnel & Base Operations Support

Aircraft	Use	Case	Mil. Pers. Cost $/Mo.		Mil. Pers. Cost $/FH	B.O.S. Cost $/FH
			Off.	Enl.		
O-1E	100	1	$4,600	$1,050	$56.50	$56.50
V-1A	100	1	$4,600	$1,500	$61.00	$61.00
		2	$4,600	$1,950	$65.50	$65.50
V-6A	100	1	$4,600	$1,950	$65.50	$65.50
		2	$4,600	$2,400	$70.00	$70.00
V-8	100	1	$4,600	$1,950	$65.50	$65.50
		2	$4,600	$2,400	$70.00	$70.00
CV-2	100	2	$4,600	$4,800	$94.00	$63.00
C-47	100	2	$4,500	$2,550	$70.50	$47.00
		3	$6,600	$3,000	$96.00	$64.00
C-123	100	2	$6,600	$4,500	$111.00	$74.00
OH-13	50	1	$2,500	$1,200	$74.00	$74.00
					$83.00	$83.00
UH-1	50	1	$2,500	$1,650	$86.00	$86.00
		2	$2,500	$1,800		

Case 1, 2, & 3 are the same as for Table 4-6

Personnel rates are: $1000.00 per Officer per month
$150.00 per Enlisted per month

the flight hours per month (100 for O-1E) to give the military personnel costs per flight hour ($56.50 for the O-1E). The base operating cost is determined from a general relationship between the cost of military personnel and base operating support. This relationship is that for the cargo transport candidates (C-47, C-123 and CV-2) the base operating support is equal to 67% of the military personnel cost, and for the other candidates the base operating support cost is the same as the military personnel cost.

b. Basis for Cost Information (Table 4-5)

1. Aircraft Cost. The cost of the OH-13, UH-1D, U-6A, U-8D, CV-2B, U-1A, and O-1E are the values listed for flyaway cost in Section II of Chapter 4 of FM 101-20, rounded off to the nearest $1,000. The cost of the C-123 was obtained from personnel at Northrop Norair, and the cost of the C-47 is an estimate.

2. Aircraft Loss Rate (Losses per Flight Hour). The numbers of losses per flight hour for the CV-2, U-1A, U-8, UH-1, U-6, OH-13 and O-1E are the values listed for wartime MOB inactive or non-combat in Section III of Chapter 1 of FM 101-20, rounded off to two significant figures. The values for the C-47 and C-123 are assumed to be the same as for the CV-2.

3. Fuel and Oil (Dollars per Flight Hour). The costs for fuel and oil used per flight hour are taken from Section I of Chapter 4 of FM 101-20 for the U-1A, U-6A, U-8D, CV-2, OH-13 and UH-1; and for the O-1E, C-47 and C-123, they are taken from Table 4 of AFM 172-3.

4. Replacement Parts (Dollars per Flight Hour). The costs for replacement parts consumed in the maintenance process per flight hour are taken from Section I of Chapter 4, FM 101-20, for the O-1E, U-1A, U-6A, U-8D, CV-2, OH-13 and UH-1; and from Table 4 of AFM 172-3 for the C-47 and C-123.

c. Procedure for Determining Personnel Requirements (Table 4-6)

1. Determine Aircraft Use (Flight Hours per Month). The numbers for OH-13 and UH-1 are based on information contained in the April 1966 issue of United States Army Aviation Digest, which stated that the UH-1 helicopters are averaging over 50 flying hours per month. The numbers for the other aircraft are based on information in AFM 26-3H, 12 October 1966.

2. Determine Flight Personnel Requirements (Officers/Enlisted Men). The crews for the candidate aircraft are as follows: (These values arbitrarily selected)

O-1E	Case 1	2 officers	
U-1A	Case 1	2 officers	
U-1A	Case 2	2 officers	1 enlisted

From this information, th following table is established:

Aircraft	Use	MH/FH	Maintenance Men
O-1E	100	4.29	5
U-1A	100	5.77	7
U-6A	100	7.79	9
U-8D/F	100	7.70/7.10	9
CV-2	100	18.19	20
UH-1B/D	50	9.67	7
OH-13H/S	50	6.75	5
C-47	100	8	9
C-123	100	15	17

4. Determine Support Personnel Requirements (Officers/ Enlisted Men). Requirements for support personnel are estimated based on published requirements on other aircraft. The following table is prepared from information presented in Table 1 of AFM 172-3, 31 March 1966.

Aircraft	Program Personnel		Support Personnel	
	Officers	Airmen	Officers	Airmen
F-100	3	21	.7	9.5
F-105	2.6	26	.6	11.5
B-57	3	15.6	.7	7
RB-66	8.4	30	1.8	13
F-4	4.3	30	.8	11.5
C-124	10	49	.6	9.5
C-130	6	32	.6	10

Values for the fighters and bombers are for General Purpose Forces and squadrons of 18 aircraft. Values for the cargo transports are for Airlift and Sealift Forces Industrial Fund and squadrons of 16 aircraft.

NOTE

Requirements listed are per aircraft.

U-6A	Same as U-1A		
U-8	Same as U-1A		
CV-2	Case 2	2 officers	2 enlisted
C-47	Case 2	2 officers	2 enlisted
C-47	Case 3	3 officers	3 enlisted
C-123	Case 2	3 officers	3 enlisted
OH-13	Case 1	2 officers	
UH-1	Case 1	2 officers	
UH-1	Case 2	2 officers	1 enlisted

Next, it is assumed that each flight personnel will fly 50 hours per month. Then one crew is required for the helicopters which fly 50 hours each month and two crews are required for the other aircraft which fly 100 hours per month.

3. Determine Maintenance Manpower (Enlisted Men). The number of maintenance men required is determined from the required MH/FH (maintenance man hours per aircraft flight hour). From FM 101-20, 25 March 1966, Section VIII, titled, "(FOUO) Maintenance Man-Hours," the direct productive maintenance man-hour requirements per flight hour (MH/FH) are:

U-1	5.77	MH/FH
U-6	7.79	MH/FH
U-8D	7.70	MH/FH
U-8F	7.01	MH/FH
O-1	4.29	MH/FH
CV-2	18.19	MH/FH
UH-1B	9.67	MH/FH
UH-1D	9.67	MH/FH
OH-13G	8.63	MH/FH
OH-13H	6.75	MH/FH
OH-13S	6.75	MH/FH

From AFM 26-3H, 12 October 1966, Table II, the maintenance manpower requirements are:

C-47	8 MH/FH	9 Men per aircraft for 100 FH per month
C-123	15 MH/FH	17 Men per aircraft for 100 FH per month
U-4	7 MH/FH	8 Men per aircraft for 100 FH per month
U-6	7 MH/FH	8 Men per aircraft for 100 FH per month
U-4	7 MH/FH	5 Men per aircraft for 50 FH per month
U-6	7 MH/FH	5 Men per aircraft for 50 FH per month

Based on the previous table, the following table is prepared to give estimates of the support personnel requirements:

Aircraft	Program Personnel Officers	Program Personnel Enlisted	Support Personnel Officers	Support Personnel Enlisted
O-1E	4	5	.6	2
U-1A	4	7	.6	3
	4	9	.6	4
U-6A	4	9	.6	4
	4	11	.6	5
U-8	4	9	.6	4
	4	11	.6	5
CV-2	4	24	.6	10
UH-1	2	7	.5	4
	2	8	.5	4
OH-13	2	5	.5	3
C-47	4	13	.5	4
	6	15	.6	5
C-123	6	23	.6	7

Requirements listed are per aircraft.

d. Cost Relationship for Share of Base Operating Support (Table 4-7). Costs for Base Operation Support are estimated, based on published requirements on other aircraft. The following table is prepared from information presented in Table 1 of AFM '72-3.

Aircraft	Military Personnel Cost $/aircraft/month	Share of B.C.S. $/aircraft/month
F-100	$11,400	$13,400
F-105	12,800	15,000
B-57	9,100	10,200
RB-66	20,200	21,200
F-4	16,200	18,900
C-124	27,900	18,500
C-130	18,600	12,600

For the cargo transports, the share of B.O.S. is approximately 67% of the Military Personnel cost. For the others, the share of B.O.S. is about 15% more than the Military Personnel cost. It is assumed that for the C-47, C-123 and CV-2, share of B.O.S. is 67%, as much as Military Personnel, and for the other aircraft, share of B.O.S. and Military Personnel costs are equal.

NOTE

> Share of B.O.S. for the other aircraft is assumed equal to Military Personnel rather than 15% more since B.O.S. of support aircraft would not be as costly as B.O.S. for tactical fighters and bombers.

4.5.4.2.2 Costs for Unmanned Military Aircraft HARR Platforms. The only drone candidate that survived to the cost-effectiveness "run-off" was the DASH helicopter.

The total flight hour on-station costs for the DASH helicopter when modified and equipped for the HARR mission are expected to be slightly above those given in Table 4-5 for the U-8D manned aircraft.

4.5.4.2.3 Costs for Special Platform Types

a. Tethered Balloon. The platform and tether line costs for a blimp-shaped tethered balloon platform are presented as follows:

Channels	Height	Airborne Weight	Ground Payload Weight	Platform Cost
2	2,000 ft.	48 pounds	150 pounds	$ 7,800
6	3,000 ft.	282 pounds	510 pounds	16,800
14	5,000 ft.	628 pounds	1,000 pounds	26,000
14	15,000 ft.	628 pounds	2,400 pounds	45,000

Under the assumption that a thethered balloon HARR platform would not be used during high winds, an attrition rate of .004 per flight hour has been estimated. It is also estimated that two-man teams working in eight-hour shifts will be required to fly and support a two-channel balloon system. This is increased to a three-man team for the six-channel system, a four-man team for the 14-channel system at 5,000 feet, and a five-man team for the 14-channel system at 15,000 feet. Ground support costs are based mostly on the 183-pound standard helium cylinders which must be supplied. Some estimates indicate that the balloons could remain aloft for only 48 hours; but with the improved material now available, an estimate equal to the life of the batteries is used.

Total single station and channel per flight hour costs are given below for the various suggested blimp configurations:

Channels	Attrition/ FH	Personnel/ FH	General Support/FH	Total System/FH	Total Channel/FH
2	$ 31.20	$ 5.05	$ 10.00	$ 45.25	$22.62
6	67.20	7.56	34.00	108.76	22.46
14 at 5,000 ft.	104.00	9.08	67.00	180.08	12.90
14 at 15,000 ft.	180.00	12.60	160.00	352.60	25.20

These costs do not include those for the repeater and its support.

b. Treetop Platform. The most expensive part of the treetop system will be the cost of the aircraft used to plant and recover the platform. The cost figures given are based on the use of a UH-1 helicopter which is estimated to be able to plant and recover 50 treetop platforms during its 50-hour monthly utilization. Some of the ground support will involve the handling and supply of the CO_2 bottles, but these costs are not considered to be high. The attrition rate, however, is estimated to be 10 times that of the tethered balloon. For a two-channel system not including repeater costs, the following estimates are given;

Channels	Attrition	Personnel	Deployment/ Recover	Total System	Total per Channel
2	$20/FH	$5.05/FH	$41.00/FH	$71.05/FH	$35.32

4.5.4.3 Cost-Effectiveness Modeling. Before the cost-effectiveness modeling was begun, it was decided that the major platform cost-effectiveness was to attain the greatest on-station time at minimum cost that was possible within HARR altitude, position keeping, and crew endurance constraints.

When the cost-effectiveness modeling was initially attempted, considerable care went into time and distance to home base considerations, turn around time, relief scheduling, number of backup aircraft needed, and many other operational factors. However, when all the flight hours required of a single aircraft for one month of HARR activity were totalled, almost invariably this total exceeded AVCOM established monthly flight hour limits specified for that aircraft. This brought the realization that the aircraft operational flight hour limit was the overriding factor, and that the modeling development had to be reinitiated with this consideration in view.

This second modeling development is described in the following paragraphs.

4.5.4.3.1 Cost-Effectiveness Model Design

a. Approach. The basic approach taken in designing the HARR cost-effectiveness model was to attack first those items of the total cost for which input data would most likely be obtainable. These appeared to be the costs associated with procurement and operation of the platform. It was assumed that platform suitability from an operational point of view would be evaluated in accordance with a tactical model, the development of which is proceeding separately. The cost-effectiveness model was intended to be applied in making a selection of a platform or a platform mix, from a set of operationally suitable platforms, on the basis of the cost of mounting and sustaining the effort during the greatest practical on-station time.

The model was designed to accept as inputs those cost items commonly available in terms of the parameters in which costs are commonly expressed. As an example, ground support costs are often stated in terms of the flight hours per aircraft-month. Accordingly, flight hours per aircraft-month was taken as a basic parameter.

Consideration of costs, such as training, was deferred until a more firm estimate of the required effort was established.

b. Inputs

1. Flight hours per aircraft month: This is the basic parameter by which operating costs are computed.

2. Operating costs per flight hour: This is a function of the flight hours per aircraft month.

3. Support costs per flight hour: This is a function of flight hours per aircraft month.

4. Endurance and other platform performance characteristics: These characteristics are necessary in determining the number of platforms required, both at the operating base and in the system.

5. Failure and loss rates: These factors are necessary in determining the number of platforms required, both at the operating base and in the system.

6. An assumed tactical situation which defines the distances to be transited, on station times, and number of sites to be supported.

c. Unaccounted Items

1. Aborted Flights. If an abort rate is available or can be estimated, it may be applied to the number of aircraft required on the flight line. An aborted flight will most likely be replaced, with the result that additional flight line aircraft are required.

2. Inclement Weather. It is possible that energetic ground actions will be conducted when it is impossible to put an airborne platform on station. This is particularly so in the case of conventionally powered (reciprocating engine, propellor driven) aircraft. Since altering the number of similar platforms will not alter the situation, it is suggested that the appropriate point of application of this factor is in determination of the operational acceptability of the platform or of a platform mix.

d. Methodology

Step I. Calculate platform endurance and its components. This will generally be an iterative process with the objective of maximizing on-station time for a given tactical situation. Inputs for the process are the platform performance characteristics commonly expressed by means of graphs for a specified platform model, configuration and loading.

E: Platform endurance.

RT: Reserve flight time required over base on return.

FT: Usable platform time.

$$FT = E - RT$$

TT: Transit time from operating base to operating area.

CT: Climbing time, time required to reach operating altitude.

ERT: Enroute time, time required to reach operating position. Reaching operating position will generally involve a horizontal and/or vertical displacement of the platform. The platform is not on station until both are completed.

$$ERT = \text{Maximum} \begin{cases} TT \\ CT \end{cases}$$

RBT: Time required to return to operating base from operating area. This is not a factor when expendable platforms are being considered.

OST: On-station time, that period of time during which platform position satisfies both altitude and geographic requirements.

The relationships of the components of FT are expressed by the following equation:

$$FT = ERT + OST + RBT$$

TAT: Turn around time, that period of time required to ready an item for use.

OP: Operating period, the period of time required for a platform to complete one operating cycle of flight and turn around time.

$$OP = FT + TAT$$

<u>Step II.</u> Calculate a value for the number of aircraft required to support a specific tactical situation in accordance with the steps listed below:

1. Compute the number of individual sorties per month required:

$$SPM\ (req.) = \frac{(30)(TOS)}{(OST)}$$

2. Compute the number of sorties which one aircraft can fly in one month:

$$SAM = \frac{(EFF)}{(FT)}$$

3. Compute the estimated number of aircraft required on the flight line:

$$FLA\ (est.) = \frac{(SPM\ [req.])}{(SAM)}$$

The accuracy of this estimate may be judged qualitatively and roughly for a given situation and platform FLA (est.) is fairly stable unless OST can vary over a wide range. This will be done in slightly more detail in succeeding steps.

FLA (est.) can be factored as the product of two quotients:

$$\frac{(FT)}{(OST)} \text{ and } \frac{(TOS)(30)}{(EFF)}$$

The first factor will be used later as "the number of aircraft required to be airborne simultaneously." The second is the number of aircraft per month required to provide the coverage required if each aircraft realizes maximum utilization. FLA (est.) results in a value, therefore, which is somewhere between the number of aircraft required on the flight line and the number of aircraft required in the system and may therefore be useful as an estimate of neither. It appears that refinement of the estimate is appropriate.

Step III. Depending on the value of TOS, branch at this point in the computation.

1. TOS = 24, go to step IV
2. TOS < 24, go to step V

NOTE

In the common situation where n stations are supported from the same flight line or launch point, the value OST should be replaced by OST/n wherever it appears. For purposes of scheduling, OST/n is the effective OST. It appears that significant savings may be realized in some cases by supporting as many stations as possible from one launch point due essentially to the shorter effective OST which is the launch interval in a regular launch schedule.

Step IV (TOS = 24). Calculate the number of aircraft required on the flight line.

1. Compute the number of aircraft required to be airborne simultaneously.

$$D = \text{next integer larger than } \frac{(FT)}{(OST)}$$

2. Compute the service time available between landing and the next launch.

$$ST = (D)(OST) - (FT)$$

3. Compute the ratio.

$$R = \frac{TAT}{ST}$$

4. Compute the number of flight line aircraft required to next larger integer.

$$FLA\ (req.) = \begin{cases} D + \dfrac{TAT - ST}{OST} & : R > 1 \\ \text{or} & \\ D & : R \leq 1 \end{cases}$$

<u>Step V (TOS < 24).</u> Calculate the number of aircraft required on the flight line.

1. Compute the sorties per day required.

$$SPD\ (req.) = \frac{(TOS)}{(OST)}$$

Rounded to the next larger integer

$$SPM\ (req.) = (30)\ (SPD)$$

2. Adjust the sortie (OST).

$$OST\ (adj.) = \frac{TOS}{SPD\ (req.)}$$

3. Adjust the flight time per sortie.

$$FT\ (adj.) = FT - OST + OST\ (adj.)$$

NOTE

From this point all computed values will be assumed based on adjusted values to obviate the need to write (adj.).

4. Begin a recursive computation to determine the minimum number of flight line aircraft as follows:

$$ST = (K)\ (x) - FT + (OST)\ (y)$$

where

x = 1, 2, ----, N, ----
y = 0, 1, ----, SPD-1
K = the interval between starting each cycle. In the case of one on-station period per day, K equals 24 hours.

Start with x = 1, Y = 0.
Compute the ratio RF

$$RF = \frac{TAT}{ST}$$

If RF ≤ 1, go to step VI to determine if FLA can be less than SPD.

NOTE

> A departure from generality is made at this point in that several on-station periods may be scheduled in one day. In that case (K) (x) would be replaced by a sum. However, it is expected that a sufficiently close estimate will be obtained if regular intervals are assumed.

If RF > 1, compute the ratio N

$$N = \frac{FT + TAT}{24}$$

Round N to the next integer less than the ratio.

Set X = N and solve for the value of y which makes R ≤ 1

If y ≤ (SPD - 1), then

$$FLA = (N)(SPD) + (y - 1)$$

If y > (SPD - 1), then

$$FLA = (N)(SPD)$$

Step VI. To determine relief cycle/short TAT relationships proceed in accordance with the following steps.

1. Compute the number of aircraft required to be airborne simultaneously.

$$ASA = \text{next integer larger than } \frac{FT}{OST}, \quad D \leq SPD$$

NOTE

ASA will only be greater than SPD when FT is greater than TOS. It would be a ridiculously extreme situation, however, in which more than SPD platforms would be airborne simultaneously. It would require an unrealistic combination of

TOS, very large, approaching 24
FT, very large
OST, very small

so that flights for the next period are launched while current flights are still airborne.

2. Compute the short service time available.

$$SST = (ASA)(OST) - FT$$

3. Compute the ratio RH.

$$RH = \frac{TAT}{SST}$$

If RH > 1, round to the next larger integer and go to Step VI-4 below.

4. Compute the sum S.

$$S = D + RH$$

If $S \leq SPD$, $FLA = (D + RH)$
If $S > SPD$, $FLA = SPD$

Step VII. Calculate the expected flight hours per aircraft per month and adjust FLA if appropriate.

1. Compute the ratio RE.

$$RE = \frac{(30)(TOS)}{FLA + C}$$

where C = 0, 1, 2, ----, M, ----
with C = O
If $RE \leq EFF$, use RE as EFF and do not adjust FLA.

NOTE

> This is to the platform's advantage. FLA assumes a maximum schedule. If the schedule can be met with less effort than EFF, any attempt to raise RE is inefficient except for increasing TOS which may be pointless.

If RE > EFF increase C by 1 integer at a time and select that value M which makes RE nearest EFF.

Use FLA (adj.) = FLA + M

<u>Step VIII.</u> Calculate the costs of operating and supporting the platform.

1. Compute the operating costs per month per station maintained.

CPM = (SPM) (FT) (OCH)

where

SPM and FT are computed in either Step IV or Step V.
OCH is obtained by table look-up based on EFF (or RE as in Step VI) as the operating costs per flight hour.

2. Compute the cost of operational support at the appropriate level of flight effort (EFF or RE).

OSC = (FLA) (OSC/Aircraft month)

where

FLA results from the computations of Step VII.
OSC/Aircraft Month is tabulated with respect to EFF.

NOTE

> Some tabulations may combine items CPM and OSC, generally in the form used above for CPM.

3. Compute the cost with respect to ground support personnel.

GSP = (FLA) (Pers. /Aircraft) (Cost/ Pers)

where

FLA results from the computations of Step VII.
Pers. /Aircraft is commonly tabulated with respect to EFF.
Cost/Pers. may not be available. It may be estimated or "number of persons" may be used as a separate cost measure.

Step IX. Calculation of the number of flight crews required on the flight line can be made to directly parallel the calculation of the number of flight line aircraft required in most cases. The scheme is to treat a flight crew as if it were an aircraft with different performance characteristics. The following substitutions are appropriate:

Instead of	Use this
OST	FT: This is the time during which the crew is performing usefully.
FT	ET: The total time devoted by the flight crew to a sortie. Includes brief, debrief, etc.
TAT	CRT: A relaxation period between flights. In extremes this can be deleted since nothing in computations precludes TAT = O.

Computations to account for diurnal and periodic extended rest and recreation periods more closely parallel those of overhaul periods in the case of aircraft. With respect to diurnal periodicity a reasonable approximation may be obtained if TOS is taken as 8 hours and the result multiplied by 3.

The number resulting from the computations will represent flight crews required on the flight line (FCR) instead of aircraft required on the flight line (FLA).

Step X. Calculate the number of aircraft (or flight crews) required in the overhaul/operating base cycle.

1. Compute the expected time between overhauls (TBO) for each aircraft.

$$TBO = \frac{HBO}{EFF} \text{ in months}$$

where

HBO is the time in hours between overhauls.
EFF is taken as EFF or RE from

2. Compute the ratio RO.

$$RO = \frac{OHT}{TBO}$$

where

OHT is the time in months required per overhaul.
RO is the ratio of the number of aircraft in overhaul to that number on the flight line.

3. Compute the total number of aircraft required (TAR) per tactical situation and expected overhaul costs.

$$TAR = (FLA)(1 + RO)$$

NOTE

Step X starting with 1 above may be used to estimate the number of flight crews required when periods of R and R are scheduled at regular intervals. Such intervals are probably scheduled by calendar time but it is possible that other criteria, such as number of missions flown, will also apply. In the latter case, the rotation schedule computations more closely parallel those for aircraft where the comparable criterion is flight hours.

4. Compute the expected costs of overhauls per month for FLA.

$$COH = \frac{(FLA)(CPO)}{TBO + OHT}$$

where

CPO is the cost per overhaul.

Step XI. Determine the cost of personnel training. This cost will be some function, as yet undetermined, of the number of personnel, both flight and ground, and of the type platform.

CPT = C (flight crews, ground support pers., platform type)

Step XII. Calculate expected procurement costs.

1. Compute expected losses per month.

$$LPM = (FT/mo.)(LPH)$$

where

FT/mo. is the total flight time per month.
LPH is the estimated losses per flight hour.

2. Compute expected procurement costs per month.

$$COP = \frac{TAR}{L} + LPM\ CPU$$

where

L is the expected life of the platform in months.
CPU is the cost per unit platform.

Step XIII. Calculate the cost of non-expendable ground support items per month.

$$CGA = \frac{\text{Cost of items}}{L}$$

where L is the expected life of each item in months.

Step XIV. Calculate the cost of supporting a remote launch point (CRS) when required. Determination of this cost item requires information not yet available. Consideration of the overall cost should include it, however. There will be a cost trade-off between the savings realized by shortening the distance from launch point to operating area, and the cost of supporting the remote station. The cost will be some function of the flight effort supported from that station and its remoteness from a resupply point.

CRS = C (FLA, FT, distance to resupply point)

Step XV. Calculate the total costs per month.

Item	Step	Factors	Cost: $/mo.
CPM	VII-1	N (SPM)(FT)(OCH)	
OSC	VIII-2	N (FLA)(OSC/ACMo.)	
GSP	VIII-3	N (FLA)(Pers.)(Cost)	
FCP	IX	N (FCR)(Pers.)(Cost)	
COH	X-4	N (COH)	
CPT	XI		
COP	XII-2		
CGS	XIII		
		Total	

4.5.4.3.2 Cost Tabulation Example Used in Cost-Effectiveness Model. Costs of supporting the II Corps Area on a 24-hour-a-day basis with complete coverage of the area are presented as an example of cost-effectiveness model cost tabulations.

Table 4-8 lists costs for four manned aircraft in three cost categories. The aircraft are UH-1, O-1E, YAT-37D, and C-130. Cost categories are direct operating costs in dollars, number of flight crews required, and number of aircraft on the flight line. Direct dollar operating costs include flight expendables.

In making the computations for spares consumed and maintenance manpower, two basic operational situations are applied. For the UH-1 and O-1E, 24 stations are continuously manned from 9 airfields, each of which is within 25 miles of the operating area. For the YAT-37D and C-130, 3 stations are continuously supported from 2 airfields within 100 miles of the operating area. It was necessary to short circuit the cost effectiveness due to insufficient time and lack of firm data. For example, Turn Around Time (TAT) had to be estimated. Consequently, a number of items could not be realistically estimated, the more significant of which are listed below.

a. Flight Crews. The number of personnel per flight crew may vary substantially. The training requirement is not known but from an operating standpoint it would seem that very little additional training would be required since the flight operations are basic. With respect to the relay however, in the case of large aircraft with long endurance, in-flight maintenance may be feasible indicating possible technical training. Such training might be most economically performed at a service school.

b. Aircraft Procured. Computations did not include a number for aircraft in overhaul. Nor does it allow for mission aborts due either to aircraft or relay malfunctions. Aircraft price is not presently available for all platforms.

c. Remote Support Operations. Additional costs of supporting operations at the outlying (or remote) stations is not considered. This may well be a significant item.

d. Housekeeping Costs. Housekeeping costs generally are not included and input data is not currently available.

Table 4-8. Typical Cost Figure for Supporting the 2nd Corps Area Continuously with Types of Manned Aircraft Platforms.

Cost Item	PLATFORM			
	UHI	O1E	YAT-37D	C-130
Consumables	156,000	43,600	40,500	190,640
Spares Consumed	333,000	1 30,800	34,700	200,000
Manpower (Maint.)	605,000	3 93,000	72,200	377,000
Total (Dollar)	1,094,800	567,400	147,400	767,640
Flight Crews Required	108	108	15	18
Flight Line Aircraft Required	144	108	18	12

4.5.4.3.3 Typical Cost Tabulations

a. UH-1 Utility Helicopter. Three operations supported from each of 9 remote stations gives:

E = 3 hours (180 minutes)

ERT = $\left(\frac{25}{130}\right) 60 = 12$ minutes

ERT + RBT = 24 minutes

OST 156 minutes

OST (eff.) = 52 minutes

*FLA = 4

SPM = $\frac{(30)(24)(60)}{(52)} = 830$/station

*FTM = (830)(3) = 2490 flight hours/mo. per aircraft = 620.

Therefore, FLA will be multiplied by 3 or 4 to make time per aircraft month reasonable, on the order of 150-200 FLA ≈ 16

FLA ≈ 16

FLP = 12 crews for 8-on/16-off cycle.

GSP

2nd Corps FTM = (9) (2490) = 22,400

FCP = 108 crews

FLA = 144 aircraft

CPM	= (22,400) (7)	=	$ 156,800
Spares Cons.	= (22,400) (14)	=	333,000
Manpower (Maint.)	= (22,400) (27)	=	605,000
			$1,094,800

Flight Crews required	108
Procured A/C	144

b. O-1E Observation Aircraft. Three operations supported from each of 9 remote stations gives:

E	=	5 hours (300 minutes)
ERT	=	$\frac{25}{104}$ (60) = 16 minutes
ERT + RBT	=	32 minutes
OST	=	268 minutes
OST (eff.)	=	89 minutes
*FLA	=	3
SPM	=	$\frac{(30)(24)(60)}{(89)}$ = 486/station
FTM	=	(486) (5) = 2430 per A/C = 810
*FLA	=	12
FCP	=	12 crews
2nd Corps FTM	=	(9) (2430) = 21,800

CPM	=	(21,800) (2)	=	$ 43,600
Spares Cons.	=	(21,800) (6)	=	130,800
Manpower (Maint.)	=	(21,800) (14)	=	393,000
				$567,400

Flight crews required (9) (12)	108
Procured A/C	108

c. YAT-37D Fixed-Wing Aircraft. Two operations are supported from one major airfield.

E	=	2.5 hours (150 minutes)
ERT	=	$\frac{100}{320}$ (60) = 19 minutes
ERT+RBT	=	38 minutes
OST	=	112 minutes

OST (eff.) = 56 minutes

D = 2.7 (3)

FLA = 4

$$SPM = \frac{(30)(24)(60)}{(56)} = 772$$

FTM = (772) (2.5) = 1930 per aircraft = 482

FLA ≈ 12

FCP ≈ 9

One operation supported from one major airfield.

E = 2.5 hours (150 minutes)

ERT + RBT = 38 minutes

OST = OST (eff.) = 112 minutes

D = 2

FLA = 4

$$SPM = \frac{(30)(24)(60)}{(112)} = 385$$

FTM = (385) (2.5) = 960 per A/C = 480

FLA = 6

FCP = 6

2nd Corps FTM = (960) + (1930) = 2890

FCP ≈ 15

FLA ≈ 18

CPM	=	(2890) (14)	=	$ 40,500
Spares Cons.	=	(2890) (12)	=	34,700
Manpower (Maint.)	=	(2890) (25)	=	72,200
				$147,400

Flight crews required	15
Procured A/C	18

d. <u>C-130 Transport Aircraft.</u> Two operations supported from one major airfield.

E	=	9 hours (540 minutes)
ERT	=	$\frac{100}{280}$ (60) = 22 minutes
ERT + RBT	=	44 minutes
OST	=	496 minutes
OST (eff.)	=	248 minutes (Assume TAT 2 hours)
D	=	3
FLA	=	4
SPM	=	$\frac{(30)(24)(60)}{(248)}$ = 175
FTM	=	(175) (9) = 1575 per aircraft = 394

FLA ≈ 8

FCP ≈ 12

One operation supported from one major airfield

E	=	9 hours (540 minutes)
ERT + RBT	=	44 minutes
OST	=	OST (eff.) = 496 minutes
D	=	2
FLA	=	2
SPM	=	$\frac{(30)(24)(60)}{(496)}$ = 87
FTM	=	(87) (9) = 783 per aircraft = 392
FLA	=	4
FCP	=	6

2nd Corps FTM	=	(783) + (1575)	=	2358
FCP	=	18		
FLA	=	12		

CPM	=	(2358) (80)	=	$190.640
Spares Cons.	=	(2358) (85)	=	200,000
Manpower (Maint.)	=	(2358) (160)	=	377,000
				$767,640

Flight crews required	18
Procured A/C	12

4.5.4.3.4 Quantity of HARR Platforms Required. The quantity of HARR platforms required depends on several factors. These factors are related to both the mission requirements and the platform capability. Mission requirements are not well established, and will vary from month to month as the operational situations change. Furthermore, platform capabilities vary for the different candidates, and the HARR system may very likely make use of a platform "mix" (a combination of different candidates). Thus, a specific quantity of platforms needed for HARR cannot be determined at this time.

4.5.4.3.4.1 The following paragraphs describe the factors that determine the number of platforms needed. The discussion pertains specifically to manned military aircraft candidates, but is intended to be general enough to apply to other possible platforms. By referring to the discussion, platform quantity requirements can be determined, once mission requirements and platform capabilities have been specified.

The factors considered are:

a. The number and location (altitude and over ground position) of the platform stations.

b. The length of time (period of duration for each assignment and total hours each month) stations are required.

c. The scheduling capability of each candidate (how often it can be assigned to a station and what portion of the scheduled flight is effective time on station).

d. The reliability of each candidate (i.e., the degree of probability that the platform will be able to continue satisfactory operation).

It should be noted that neither the navigational nor the inclement weather limitations are considered. It is assumed that each platform capable of operating can navigate to the station location; and if the weather prevents operation of a particular candidate, increasing the numbers of that candidate serves no purpose.

4.5.4.3.4.1.1 Concerning the number and location of the platform stations, the requirements for relay repeaters generated by a particular military operation can be met by any one of several possible configurations of station positions and altitudes. Station configurations are most likely to have a significant influence on the quantity of platforms required when the number of stations simultaneously provided is a maximum. An upper limit on the stations needed can be determined by considering the more extensive military operations and the particular station configuration, of all the probable configurations, which requires the most stations. This type of station configuration analysis should consider the possibility of using different platforms at different altitudes, and, thus, should determine an upper limit on the stations required in the different altitude ranges. For instance, an analysis may show that six stations between 5,000 feet and 10,000 feet, and two stations between 20,000 feet and 25,000 feet would meet the requirements of a particular operation. It may also show that four stations between 20,000 feet and 25,000 feet is a second probable way of meeting the requirements. Then, the upper limit on stations needed simultaneously between 5,000 feet and 10,000 feet is six, and the upper limit on stations needed simultaneously between 20,000 feet and 25,000 feet is four. Suppose the UH-1D's have been chosen as platforms to operate between 5,000 feet and 10,000 feet, and the U-8F's have been chosen as platforms to operate between 20,000 feet and 25,000 feet. Then, platform requirements based on the number and location of platform stations would be six UH-1D's and four U-8F's. This provides one platform for each station for the situation of maximum simultaneous station requirements.

4.5.4.3.4.1.2 As to the length of time stations are required, each aircraft is limited to the time it can stay on station by its endurance. When mission requirements call for continuous use of a station for a longer period than can be provided by a single flight, flights have to be scheduled to provide continuing coverage. In addition to influencing scheduling, endurance determines the percentage of the aircraft flight time that is effective time on station. Effective time on station equals the total flight time minus the transit time to and from the station. For a given transit time, the percentage of effective time on station increases as the endurance increases. In addition to its endurance limit, each aircraft has a maximum monthly flying hour utilization. The combination of monthly flying hours and effectime time on station gives a maximum number of hours on station each aircraft can provide. As the station altitude increases, the time to station increases and the time on station decreases; thus, the hours on station per month decreases. Enough platforms must be provided to provide the required hours on station.

4.5.4.3.4.1.3 As to the scheduling capability of each candidate, when a single flight does not have the endurance to provide a station as long as it is required, a second platform must relieve the first. Continuous coverage is provided by scheduling. The number of platforms needed depends on the scheduling technique and the capability of each platform to cycle through time on station, return to base, preparation for flight, and flight to the station. The scheduling technique which requires the minimum aircraft is shown in Table 4-9. It consists of staggering the arrival and departure of aircraft at the base, so that each aircraft is reassigned to a station as soon as possible after its turnaround preparation is complete. This type of staggered scheduling would not be needed if the total on station hours per month, divided by the maximum simultaneous stations was considerably more than the aircraft monthly hours on station. The following equation can be used to determine the number of aircraft required for scheduling needs.

$$N_p = NS\left[\frac{T_1 + T_2 + T_3}{T_1}\right]$$

where: N_p is the number of platform needed

NS is the maximum of simultaneous stations

T_1 is the time on station

T_2 is the time in transit to and from the station

T_3 is the time on the ground for aircraft turnaround

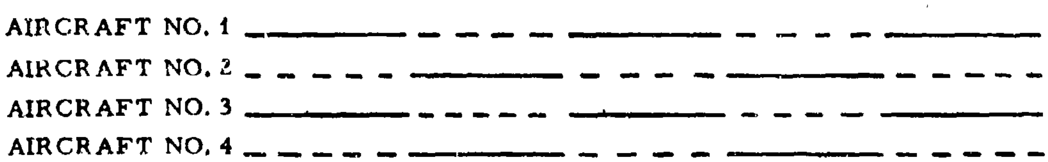
Scheduling tends to become a critical factor as the ratio of $T_1 + T_2 + T_3$ to T_1 becomes large, and the ratio of total on-station hours to maximum simultaneous stations approaches the monthly hours on station per aircraft.

4.5.4.3.4.1.4 Concerning the reliability of each candidate, it is known that, since some aircraft will be lost through attrition and others will fail to operate when needed, backup aircraft are needed. The number required for backup is determined by considering the number of aircraft committed to the HARR mission and the reliability of each aircraft. If ten aircraft are committed (either in flight or in the flight line for turnaround) and the reliability of each aircraft is 90%, then normally one aircraft will be inoperable. However, the possibility is not too remote that two aircraft will be inoperable. But if one hundred are committed, there will nearly always be ten inoperable, and almost never will there be twenty inoperable at the same time. A mathematical expression for backup requirements can be provided; but for the actual operation, it probably does not have much meaning. Enough aircraft will be needed to cover the peak activity periods. If some of the aircraft are inoperable, the lower priority stations will not be provided. If activity decreases and aircraft become available, the lower priority stations will be provided. Where platform reliability is 80% or greater, backup requirements are probably overshadowed by the range between what a commander would like to

Table 4-9. Staggered Platform Scheduling

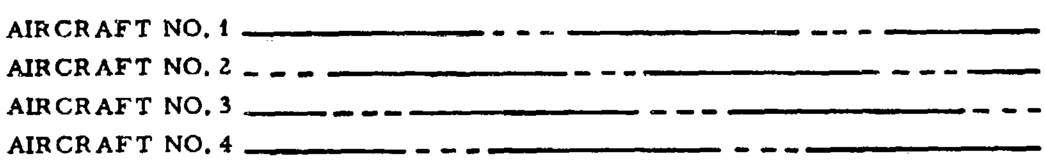
STAGGERED PLATFORM SCHEDULING

CASE 1 $\dfrac{T_1 \quad T_2 \quad T_3}{T_1} = 2$



TWO STATIONS COVERED SIMULTANEOUSLY BY FOUR AIRCRAFT

CASE 2 $\dfrac{T_1 \quad T_2 \quad T_3}{T_1} = \dfrac{4}{3}$



THREE STATIONS COVERED SIMULTANEOUSLY BY FOUR AIRCRAFT

T_1 IS TIME ON STATION

T_2 IS TIME IN TRANSIT TO AND FROM THE STATION

T_3 IS TIME ON THE GROUND FOR AIRCRAFT TURN AROUND

LEGEND

———— TIME SPENT ON STATION (T_1)

- - - - - - TIME SPENT OFF STATION $(T_2 \pm T_3)$

provide and what he must provide to conduct an operation. Where platform reliability is below 80%, backup platforms may be required before an operation would be started.

4.5.4.3.4.2 The number of platforms needed will be determined either by the requirement to provide the specified total hours on station, or to provide the specified maximum number of stations. The number needed to provide the hours on station is determined from the total hours required, the hours provided per aircraft, and the requirement for backup aircraft. The number needed to provide the stations is a function of the number of stations, scheduling, and backup requirements. Equations for the number of stations needed are as follows:

To provide needed hours on station:

$$N_1 = \frac{H_T}{H_p} \times \frac{1}{R} \quad \text{rounded to next higher whole number}$$

where: H_T is the total hours on station in a month

H_p is the hours on station per month per platform

R is the reliability of the platform

To provide needed stations:

$$N_2 = NS\left[\frac{T_1 + T_2 + T_3}{T_1}\right] \times \frac{1}{R} \quad \text{rounded to next higher whole number}$$

where: NS, T_1, T_2 and T_3 are the same as in paragraph 4.5.4.3.4.1.3

R is the reliability of the platform.

The larger of N_1 or N_2 will determine the number of platforms needed. The conditions that tend to make N_1 larger than N_2 are: When there are about the same number of stations required throughout a month and these stations are required more hours than a single platform can provide; or when turnaround time and transit time are small compared to endurance. The conditions that tend to make N_2 larger than N_1 are: When there are large numbers of stations needed for periods longer than can be provided by a single flight, but for less hours per month than a single platform can provide; or when turnaround time and transit time are large compared to endurance, this would require several aircraft per station. Table 4-10 lists the number of aircraft needed for from 1 to 14 stations, and thirteen different ratios of $T_1 + T_2 + T_3$ to T_1 (ranging from 4 to 8/7). When the number is not a whole number, the next higher whole number is the quantity of aircraft needed to schedule continuous station coverage.

Table 4-10. Aircraft Requirements

$\frac{T_1+(T_2+T_3)}{T_1}$	NS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(1+3)/1 = 4	4	8	12	16	20	24	28	32	36	40	44	48	52	56
(1+2)/1 = 3	3	6	9	12	15	18	21	24	27	30	33	36	39	42
(1+1.6)/1 = 2.6	2.6	5.2	7.8	10.4	13	15.6	18.2	20.8	23.4	26	28.6	31.2	33.8	36.4
(1+1.4)/1 = 2.4	2.4	4.8	7.2	9.6	12	14.4	16.8	19.2	21.6	24	26.4	28.8	31.2	33.6
(1+1.2)/1 = 2.2	2.2	4.4	6.6	8.8	11	13.2	15.4	17.6	19.8	22	24.2	26.4	28.6	30.8
(1+1)/1 = 2	2	4	6	8	10	12	14	16	18	20	22	24	26	28
(1.5+1)/1.5 = 1+2/3	1+2/3	3+1/3	5	6+2/3	8+1/3	10	11+2/3	13+1/3	15	16+2/3	18+1/3	20	21+2/3	23+1/3
(2+1)/2 = 1+1/2	1+1/2	3	4+1/2	6	7+1/2	9	10+1/2	12	13+1/2	15	16+1/2	18	19+1/2	21
(3+1)/3 = 1+1/3	1+1/3	2+2/3	4	5+1/3	6+2/3	8	9+1/3	10+2/3	12	13+1/3	14+2/3	16	17+1/3	18+2/3
(4+1)/4 = 1+1/4	1+1/4	2+1/2	3+3/4	5	6+1/4	7+1/2	8+3/4	10	11+1/4	12+1/2	13+3/4	15	16+1/4	16+1/2
(5+1)/5 = 1+1/5	1+1/5	2+2/5	3+3/5	4+4/5	6	7+1/5	8+2/5	9+3/5	10+4/5	12	13+1/5	14+2/5	15+3/5	16+4/5
(6+1)/6 = 1+1/6	1+1/6	2+1/3	3+1/2	4+2/3	5+5/6	7	8+1/6	9+1/3	10+1/2	11+2/3	12+5/6	14	15+1/6	16+1/3
(7+1)/7 = 1+1/7	1+1/7	2+2/7	3+3/7	4+4/7	5+5/7	6+6/7	8	9+1/7	10+2/7	11+3/7	12+4/7	13+5/7	14+6/7	16

4.5.5 Cost and Effectiveness of HARR. All of the previous subsection plus tables contained in this subsection constitute the basis for this discussion. The object of this discussion is to combine the meaningful elements of Subsection 4.5.4 into a form which will enable a comparison of the HARR initial platform candidates on a cost/effectiveness basis.

4.5.5.1 Cost. Paragraph 4.5.4.2 deals extensively with HARR platform costs. Of the many possible ways of representing those costs, the following is appropriate to the form in which the most recent data is tabulated and is consistent with previous cost presentations.

Cost = Direct Operating Cost (DOC) + Procurement (PROC) + Base Operating Support (BOS)

The dimensions of each component are dollars per unit time when possible. An example of the difficulty of assigning dimensions is that of initial procurement. It would be necessary to ascribe a useful life to each platform procured in order to express its costs in dollars per unit time. Procurement costs due to attrition, however, may be so expressed since expenditures for replacement platforms are assumed to occur at the same rate with respect to time as losses.

4.5.5.1.1 Direct Operating Cost (DOC). The DOC's used in this discussion are listed in Table 4-11 which was obtained from AVCOM. Available data, as presented in paragraph 4.5.4.2, indicate that operating costs are not strictly linear functions of flight hours. They will be treated as if they were here. Operating costs will be determined from the following expression

(OST) (FF) (Cost/FH) (N)

where:

OST is the number of on-station hours required per month. Maximum is taken as 720.

FF is the flight factor or ratio of number of hours flight time required in providing one hour on station. Flight factors are taken from previous subsections when available.

$$FF = \frac{FH}{OST}$$

Cost/FH is the dollar value of maintenance and operating costs per flight hour taken from Table 4-11.

N is the number of stations maintained for the case within the platform capability.

Table 4-11. Army Aircraft Maintenance and Operating Cost per Flight Hour

Aircraft Systems	(Maintenance Costs) Labor Costs: Orgn Maint	Labor Costs: Direct Support	Labor Costs: General Support	Parts Costs (1): Orgn Maint	Parts Costs (1): Direct Support	Parts Costs (1): General Support	Depot Parts and Labor	Total Maint	Operating Cost: Fuel Oil	Operating Cost: Flight crew (3)	Total Maintenance & Operating Costs	Bos. Est
0-1	2.84	1.39	1.46	1.10	.30	.55	3.74	11.38	1.93	4.47	17.78	56.50
U-6	3.02	1.99	2.04	1.55	.40	.75	9.81	19.56	4.91	4.47	28.94	65.50
U-8	4.35	2.39	1.46	2.50	1.00	1.00	10.95	23.65	7.50	10.05	41.20	65.50
U-1	3.97	2.59	2.63	1.75	.75	1.15	19.64	32.48	6.74	11.04	50.26	61.00
CV-2B	9.64	4.58	4.09	2.00	4.00	5.00	86.43	115.74	28.83	9.35	153.91	*63.00
OH-13	3.59	1.99	2.34	.70	.80	2.00	13.93	25.35	3.40	4.47	33.22	74.00
OH-23	3.59	2.19	2.34	1.40	1.90	2.00	11.76	25.18	3.62	4.47	33.27	
UH-1	5.48	2.99	3.21	1.93	2.53	1.21	40.38	57.73	8.28	10.71	76.72	60.00
UH-19	6.99	6.57	5.26	2.00	3.00	1.50	39.50	64.82	12.22	4.47	81.51	
CH-21	10.96	7.76	5.84	3.40	4.30	2.90	58.53	93.69	18.14	11.04	122.87	
CH-34	10.77	6.77	6.72	3.30	4.20	2.70	48.08	82.54	20.97	11.04	114.55	
CH-37	17.01	10.75	10.51	4.00	6.00	5.00	132.28	185.55	37.60	12.71	235.86	
CH-47	17.96	11.54	10.80	25.00	15.00	10.00	306.30	396.60	43.41	11.80	451.81	
CH-54	13.23	5.95	5.81	76.00	38.00	13.00	523.00 (2)	674.99	70.92	11.80	757.71	
OH-6	2.33	1.71	1.64	2.00	1.00	1.00	17.20	26.88	2.63	4.47	3[illegible].98	

(1) Expendables
(2) Excludes End Item Depot Maintenance
(3) Source AR 35-247- Superceded by AR 37-29

* For CV-2 in reference (b). Note that correlation is not direct between BOS and Maintenance Operation costs.

4.5.5.1.2 Procurement. Procurement is considered as a two-stage process. First is initial procurement which is stated as a lump sum since the useful life of each platform is not known. Initial procurement is determined from the following expression:

$$\frac{(FH)}{(U)(A)}$$

where

FH is the number of flight hours per month to be flown by the platform. FH = (OST)(FF).

U is the utilization of the platform in hours per month.

A is the platform availability taken from Table 4-12. This table was also obtained from AVCOM.

Procurement to replace attrition losses is expressed as a monthly dollar expenditure as follows:

$$(FH)(AH/FH)$$

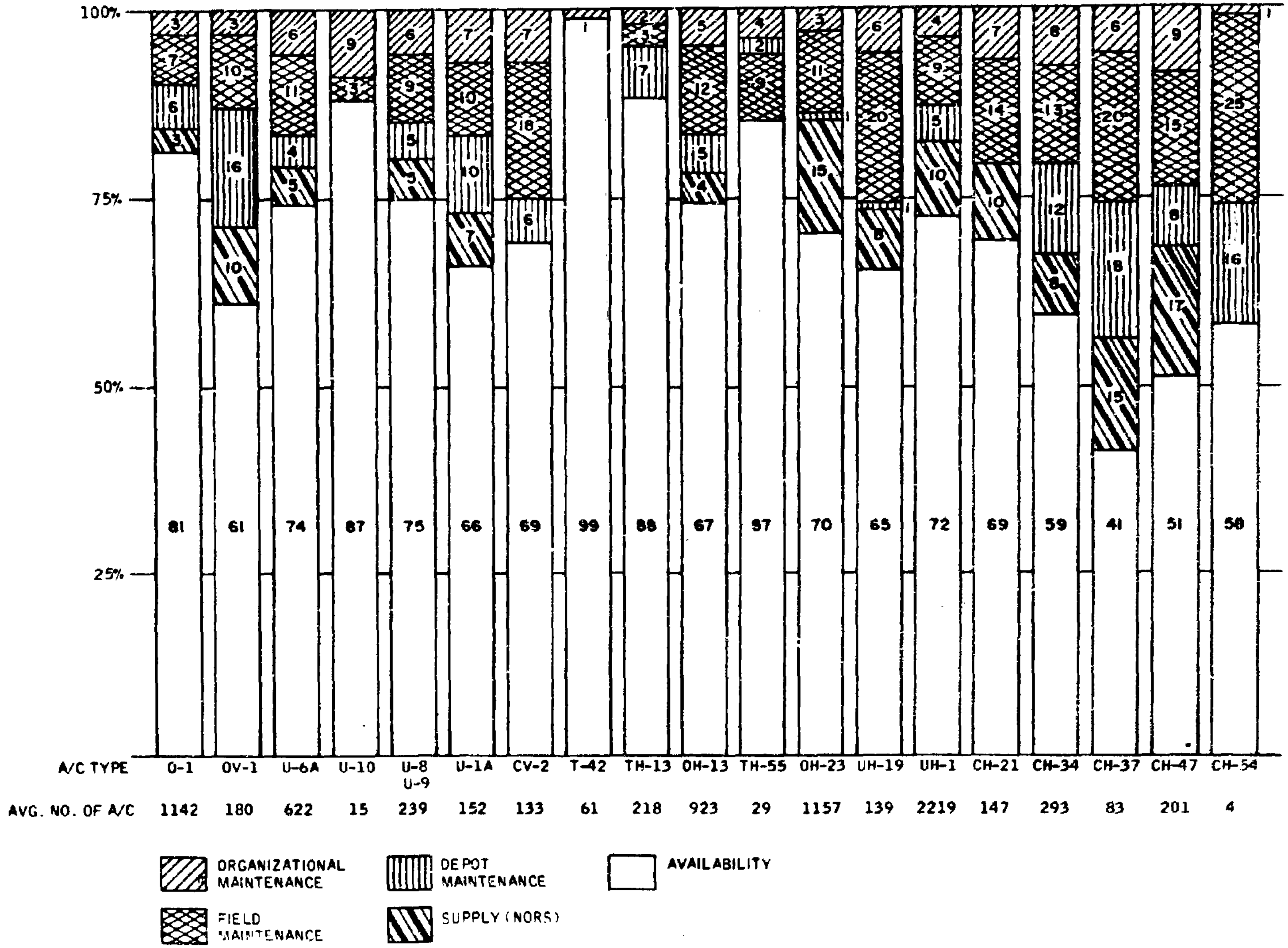
where:

FH is the number of flight hours flown by the platform per month.

AH/FH is the dollar rate of attrition replacement from subsection 4.5.4.2.

4.5.5.1.3 Base Operating Support. Base Operating Support (BOS) is not included in the calculations made in this subsection. This is regrettable since BOS may be more significant than DOC, particularly in view of the difficulties which may be encountered in establishing and supporting remote bases. Available data do not reflect such factors and are most likely determined as a "fair share" portion of the operation of an established base of operations. The basis for "fair share" allocations is not known but may well be number of personnel supported. BOS figures presented in paragraph 4.5.4.2.1 required estimation in some cases but are based on the best data obtained. It should be noted that the variability in BOS dollars per flight hour listed in paragraph 4.5.4.2.1 is not nearly so great as the variability in maintenance and operating costs per flight hour listed Table 4-11. Thus the contribution to "spread" of BOS is less. Therefore, BOS is ignored in this presentation on the grounds that, when known, its contribution to variability is small compared to that of maintenance and operating costs. It is of interest that correlation of BOS with Maint/Op costs is not

Table 4-12. US Army Aircraft Availability and Downtime



direct. The objection to use of BOS as generally known is that operation of an aircraft such as the O-1E from remote fields may exceed that of the U-8, which, due to its all-weather capability, may best be operated from a major airfield.

4.5.5.2 Effectiveness. Definition of a suitable measure of effectiveness for HARR has been troublesome due to the "apples vs oranges" nature of the choice to be made. For example, the O-1E aircraft is very inexpensive to operate. Even though equipped with DF (Direction Finding) radio equipment, it is a single pilot craft and precision navigation is out of the question. HARR station keeping is by visual reference to the ground. Therefore, if 24-hour operations are anticipated, the O-1E simply cannot meet the requirement for night operations by itself. Furthermore, some manned aircraft (e.g., the O-1E) are more sensitive to inclement weather than others (e.g., the U-8). An instrument qualified aircraft can climb to and maintain HARR station with only nominal reference to the ground during takeoff and landing. For purposes of this discussion it is assumed that aircraft such as the O-1E require a ceiling of no less than 5,000 feet. (The 5,000 feet is the minimum altitude to avoid groundfire, and the aircraft must be able to maintain visual reference to the ground.) Weather factors are taken as the most severe of those presented in Table 4-13.

Effectiveness is expressed by:

$$(FH)(W)(R)$$

where:

FH is the number of flight hours per month which the aircraft is capable of providing. The maximum for an aircraft which is restricted to daylight operations is assumed to be 360.

W is the weather factor (Table 4-13) or the percentage of the total time capability during which weather does not preclude flight operations. It is assumed that this factor is independent of the time of day, that is, daylight vs darkness.

R is the relay reliability factor which is not considered here.

4.5.5.3 Cost vs Effectiveness. In this discussion, cost plotted versus effectiveness is a straight line due to the assumed nature of the cost function. The cost/effectiveness ratio is the slope of that line which is simply cost per flight hour. This measure is appropriate only for the number of flight hours per month which the platform can provide. For a requirement in excess of that number the measure is not defined for that platform.

Table 4-13. Weather Distribution of Southeast Asia

Country and Region	Percentage Frequency of Specified Ceiling (Annual)				Percentage Frequency of Specified Visibility Ranges (Annual)				Percent of time Ceiling ≥ 1000ft. Visibility ≥ 2 1/2 mi. (Ann.)	Mean No. of Days with Thunderstorms
	<650'	<1000	<2000'	<5000'	≤1/2mi	≤1 mi.	<2mi.	<5mi.	•	
South Vietnam Mekong Lowlands (Saigon)	2	4	9	16	1	3	6	15	92	48
East Coast (Nha Trang)	<0.5	1	6	18	<0.5	<0.5	[illegible]	5	99	9
East Coast (Tourne)	3	7	12	24	2	4	8	18	89	18
Cambodia West Lowlands (Phom Penh)	1	2	8	22	<0.5	1	2	4	83	51
Siem Reap	1	2	8	36	<0.5	0.5	1	2	97	22
Loas Luang Prabung	Data	Not	Avai	lable	<0.5	2	5	20	Data Not Available	27
Seno	2	5	11	20	1	2	5	27	93	Data Not Available
Vientiane	2	4	7	12	6	9	14	31	85	80

4.5.5.4 Calculations. The results of calculations made must be considered with respect to the assumptions made and the input data. These results must not be considered as final. Further investigation is required in order to arrive at a realistic cost factor. Some examples of missing data have been cited and there are others, the end result of which may completely obscure the factor of maintenance operating costs.

4.5.5.5 Factors. The more significant factors affecting maintenance and operating costs and costs related to purchase of manned aircraft platforms are listed in Table 4-14. These are generally extracted from previous cost tables. One exception is the flight factor for the O-1E aircraft which is very sensitive to payload. It was found to be less expensive to use the 300-lb relay in Case 4 (subsection 4.5.4.1.2) even at the higher flight factor of 1.4 than to use the 100-lb relay at flight factor 1.2 due to the higher number of stations required with a smaller number of channels per platform.

Case 4 is considered appropriate for Army aircraft. The altitudes are within the capabilities of the aircraft and the aircraft cannot operate effectively at the altitudes required for Cases 5 and 6 in mountainous terrain.

Table 4-15 lists the results of calculations to determine maintenance and operating costs for maintaining a single station and 4 stations (as in Case 4) with the aircraft listed in Table 4-15. (Under the assumptions made, one is simply 4 times the other.)

Table 4-16 lists the results of calculations to determine the number of platforms to be procured initially, the cost of initial procurement, and the cost of replacements due to expected losses. Calculations were based on a 4-station battalion situation and were carried out only for those aircraft for which a procurement price was reasonably known. The latter could be included in operating costs but was not due to the low confidence of attrition data. The results are sensitive to the assumed values of utilization (75 hours per month) and number of stations (4). Doubling the utilization, which is not unreasonable for some fixed wing aircraft, and halving the number of stations will reduce to a quarter the number of required platforms as listed in Table 4-6.

4.5.5.6 Cost-Effectiveness Curves. Figures 4-18 and 4-19 show the results listed in Table 4-15. Monthly maintenance and operating costs are plotted against hours coverage provided per month. When the latter is used as a measure of effectiveness, the cost/effectiveness ratio is simply the slope of the line. As mentioned earlier, however, the measure is not defined where the platform capabilities are exceeded. For example, the O-1E is the platform with the lowest cost/effectiveness ratio but it cannot satisfy the requirement if night coverage is required. The next best cost/effectiveness ratio appears to be for the U-6 which can operate at night, from grass fields, etc.

Table 4-14. Manned Aircraft Computation Factors

Type of Aircraft	Diurnal Capability %	Weather Capability %	Flight Factor FH/OST	Utilization Rate Hours/Mo.	Attrition Rate A/C/FH	Availability %	Maintenance & Operation Cost $/FH
O-1 *	50	82	1.4	75	15×10^{-5}	81	17.78
U-6 *	100	99	(1.1)	75	13×10^{-5}	74	28.94
U-8 *	100	99	1.1	75	13×10^{-5}	75	41.20
U-1 *	100	99	(1.1)	75	13×10^{-5}	66	50.26
CV-1 *†	100	99	(1.1)	(75)	13×10^{-5}	61	153.91
OH-13 *	50	82	(1.3)	50	44×10^{-5}	67	33.22
OH-23	(50)	82	(1.3)	(50)	31×10^{-5}	70	33.27
UH-1 *	100	82	1.3	50	(30×10^{-5})	72	76.72
UH-19	(100)	82	(1.3)	(50)	(30×10^{-5})	65	81.51
CH-21 ‡	(100)	82	(1.3)	(50)	(30×10^{-5})	69	122.87
CH-34	(100)	82	(1.3)	(50)	(30×10^{-5})	59	114.55
CH-37	(100)	82	(1.3)	(50)	(30×10^{-5})	41	235.86
CH-47	(100)	82	(1.3)	(50)	(30×10^{-5})	51	451.81
CH-54	(100)	82	(1.3)	(50)	(30×10^{-5})	58	757.71
OH-6	(100)	82	(1.3)	50	(30×10^{-5})	(55)	33.98

*"Prime" candidate.
†Assumed to be comparable to the CV-2.
‡Phased-out aircraft; may be attractive from a procurement point of view.

NOTE: Numbers in parentheses are strictly estimates.

Table 4-15. Platform Maintenance and Operating Costs

Type of Aircraft	Duty Capability %	Duty Hours per Month	Flight Factor	Flight Hours per Month	$/Month per Station	No. of Stations (Case 4)	Cost per Month $ (per Battalion)
O-1 *	41	295	1.4	413	7,340	4	29,300
U-6 *	99	713	1.1	784	22,700	4	90,800
U-8 *	99	713	1.1	784	32,300	4	129,000
U-1 *	99	713	1.1	784	39,400	4	157,500
CV-1 *	99	713	1.1	784	120,500	4	482,000
OH-13 *	41	295	1.3	383	12,700	4	50,900
OH-23	41	295	1.3	383	12,700	4	50,900
UH-1 *	82	590	1.3	766	58,900	4	235,000
UH-19	82	590	1.3	766	62,500	4	250,000
CH-21	82	590	1.3	766	94,100	4	376,000
CH-34	82	590	1.3	766	87,800	4	351,000
CH-37	82	590	1.3	766	180,500	4	722,000
CH-47	82	590	1.3	766	346,000	4	1,382,000
CH-54	82	590	1.3	766	580,000	4	2,320,000
OH-6	82	590	1.3	766	26,000	4	104,000

*"Prime" candidate.

Table 4-16. Procurement Related Costs (Platform Only)

Type of Aircraft	Unit Price ($1,000)	Flight Hrs/Mo.	Utilization Hrs/Mo.	Availability %	Initial Proc. No. A/C per Battalion	Initial Proc. ($1,000)	Attrition Rate A/C per FH	Proc./Mo. A/C	Proc./Mo. $
O-1 *	19	413	75	81	28	532	15×10^{-5}	0.248	4,800
U-6 *	98	784	75	74	57	5,580	13×10^{-5}	0.407	39,900
U-8 *	114	784	75	75	57	6,500	13×10^{-5}	0.407	46,200
U-1 *	122	784	75	66	64	7,810	13×10^{-5}	0.407	49,700
CV-1 *	725	784	75	61	69	50,000	13×10^{-5}	0.407	294,500
OH-13 *	55	383	50	67	46	2,530	44×10^{-5}	0.674	38,720
OH-23		383	50	70	44				
UH-1 *	247	766	50	72	86	21,250	30×10^{-5}	0.919	227,000
UH-19		766	50	65	95				
CH-21		766	50	69	89				
CH-34		766	50	59	104				
CH-37		766	50	41	150				
CH-47		766	50	51	120				
CH-54		766	50	58	106				
OH-6		766	50	55	112				

*"Prime" candidate.

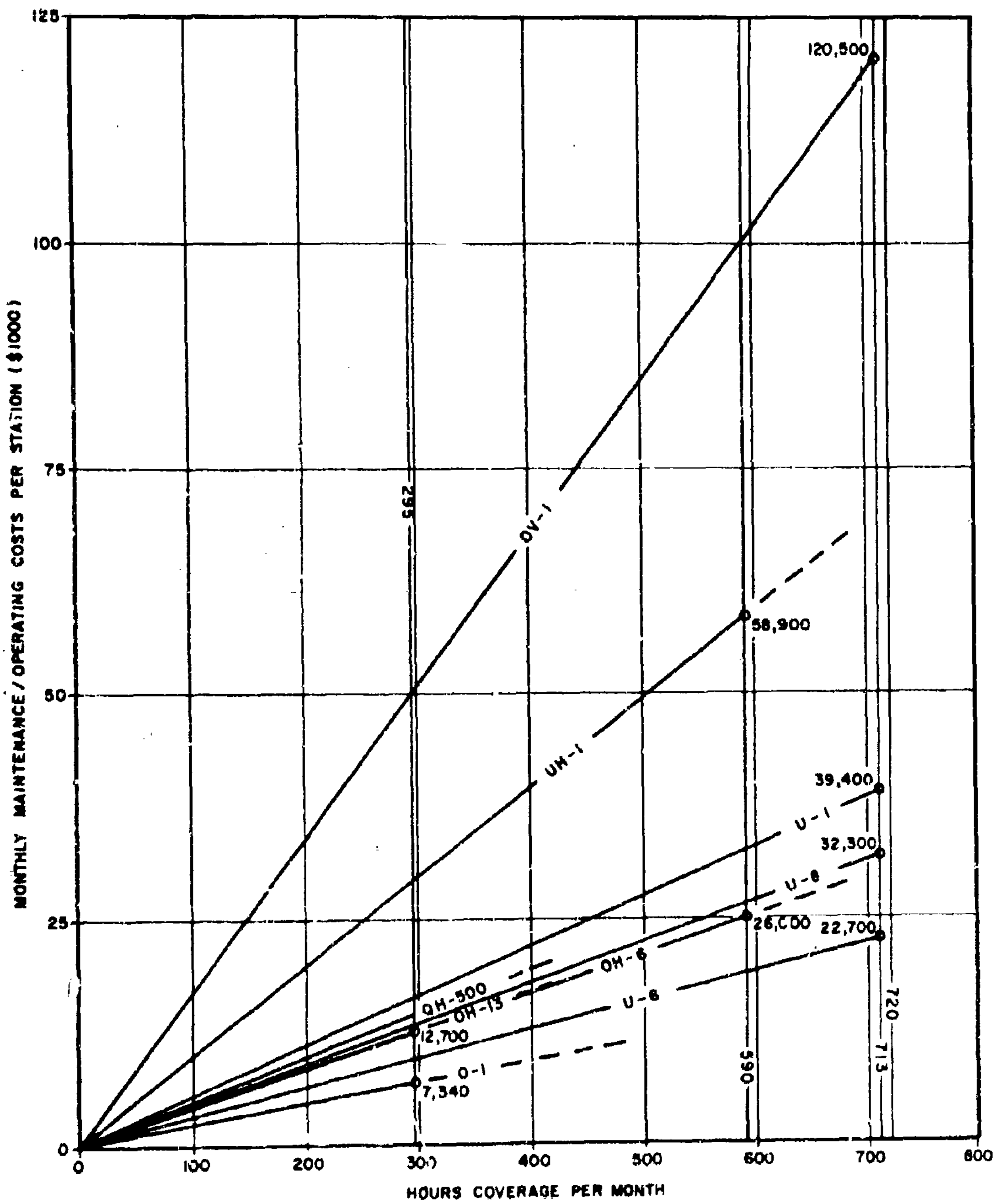


Figure 4-18. Maintenance and Operating Costs for One Station

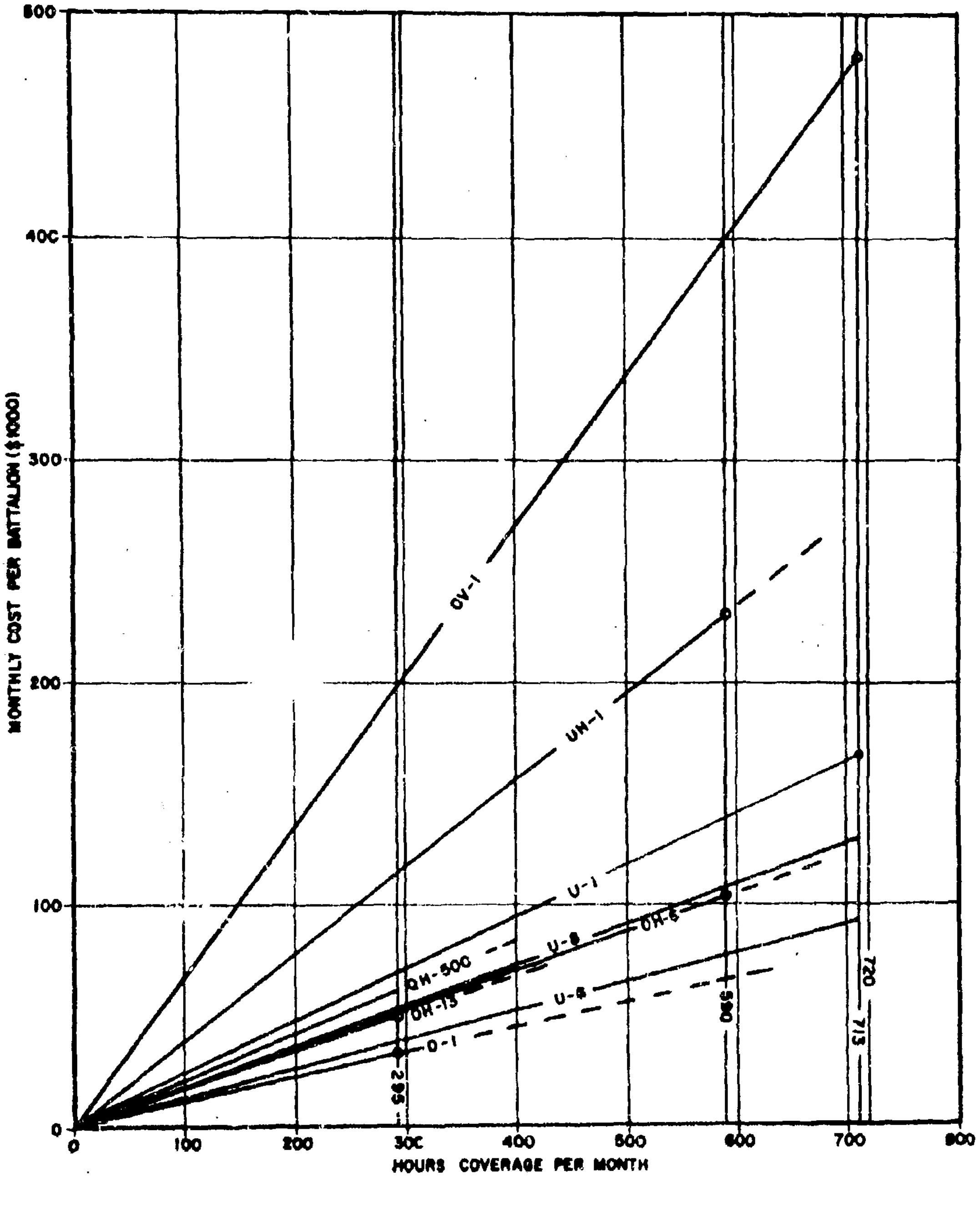


Figure 4-!9. Maintenance and Operating Costs Per Battalion (Case 4 - 4 Stations)

Figure 4-18 lists the results for one station while Figure 4-19 lists the results for the four-station Case 4 battalion. Again, under the linear assumptions, the relationship between the two figures is such that the scales are changed.

4.5.6 Measure of Effectiveness. An equitable measure of effectiveness is difficult to find when dealing with such dissimilar platform candidates as balloons and manned and unmanned aircraft. It was decided to present representative candidates on a cost-per-channel-hour basis with each candidate used in optimum HARR fashion. Once a cost comparison could be made on this basis, qualifying statements would then be possible.

Figure 4-20 presents cost-per-channel-hour measure of effectiveness results for certain chosen representative candidates. Because of its sensitivity to payload, the tethered balloon shows up as a rather flat curve. Though the tethered balloon would have limited range in rugged terrain (i.e., unless tethered from a high peak), it looks very attractive for use for a small number of channels at the company level or for use at the company-to-battalion level when mutual frequency interference is not a problem.

The O-1E is also attractive on a cost basis for a small number of channels. However, it has limited "around-the-clock" utilization particularly in mountainous topography. The O-1E Bird Dog would appear to be an excellent HARR platform choice when a command needs radio coverage of a few channels over a mobile area during daylight hours.

An aircraft that would be used in a fashion similar to the O-1E is the U-6A. It can carry a better payload than the O-1E and can be used at night over rough terrain. Since it is only more expensive to operate than the O-1E, it should be seriously considered as one of the candidate finalists.

The QH-50D DASH Helicopter has proven to be more disappointing as a HARR platform than was initially expected. Its relatively high attrition rate and ground support and control requirements added to the need of a special remote control channel switching system tend to put it in a less favorable light than its manned competitors. The two torpedoes now carried for its present mission would be removed for the HARR application, and additional fuel and the repeater package would be carried instead.

Probably the most promising candidate from the standpoint of channel flexibility and payload is the UH-1D. The advantages of this vehicle as a HARR platform are covered in the next subsection.

An indication of the applicability of a transport aircraft type to the HARR mission is given by the C-2V. It, of course, is the most expensive of the platforms to operate; but when used to carry a number of channels and control console, its cost per channel hour becomes quite reasonable.

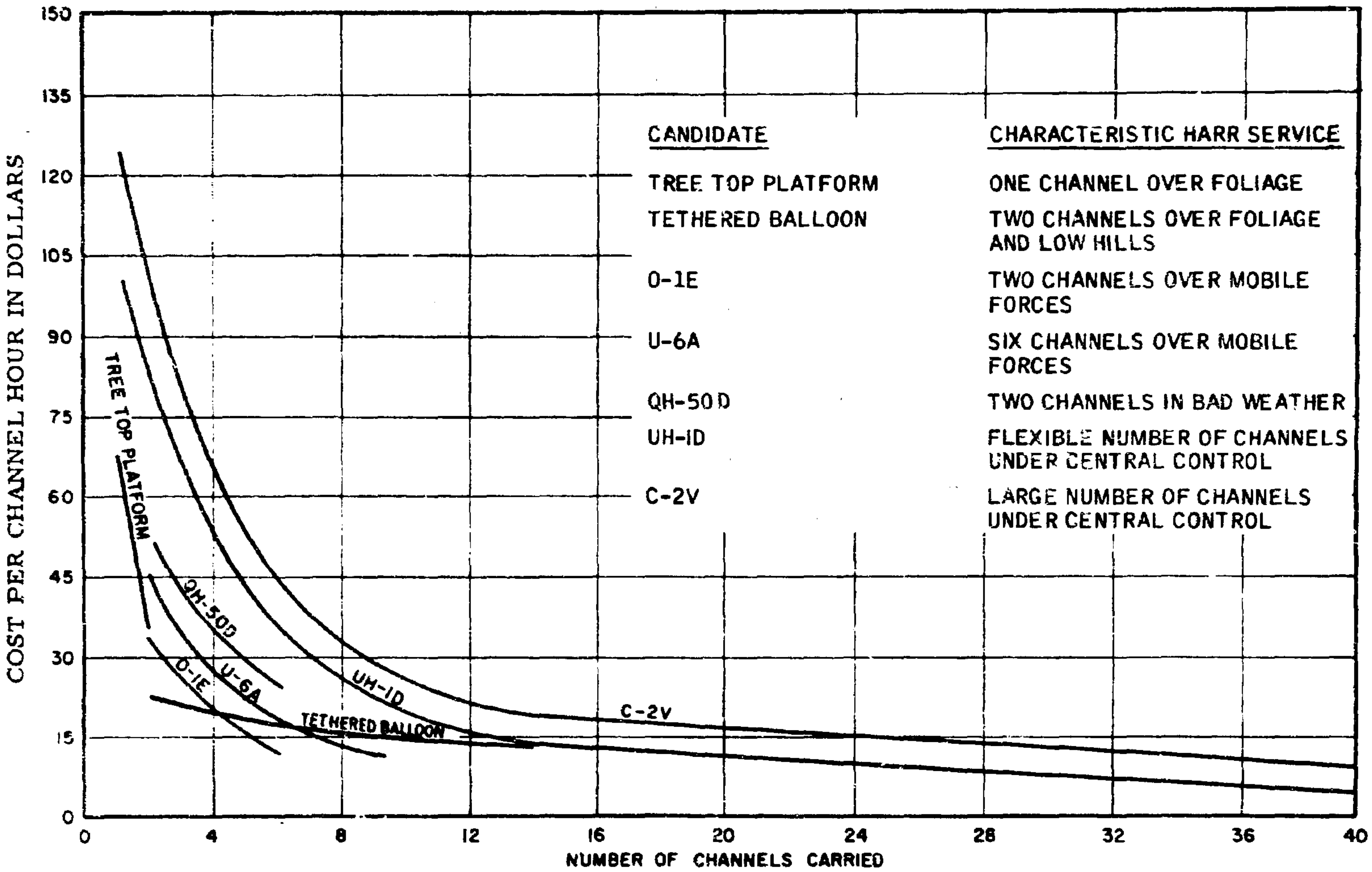


Figure 4-20. Platform Costs per Channel Hour for Representative Candidate Types

4.6 ANALYSIS OF PRIMARY CANDIDATES

4.6.1 Introduction. The preceding discussion has dealt with all categories of platforms applicable to the relay packages defined in Section 3 of this report. As has been indicated, manned aircraft are preferred from the viewpoints of technical feasibility and operational suitability. It is also evident that manned aircraft are costly in terms of normal acquisition and use, battlefield (remote area conflict) operations, and battlefield penalties. Therefore, the HARR study has been concerned with parametric analysis of potential system approaches to the reduction of aircraft costs and the increase of operational effectiveness of aircraft for the HARR mission. Ensuing paragraphs deal with the following:

Time phasing

Costs

Initial aircraft candidates

Airborne functions

The UH-1D candidate

4.6.2 Time Phasing. The HARR applied research study is concerned with "implementable" alternatives. The government has not specified deadline dates by which time a HARR operational capability must be in the hands of tactical commanders engaged in remote area conflict. Conversely, there is no indication that the HARR program should be continuingly concerned with striving toward an idealized system capability which is increasingly defined but not achieved at an appropriate time, after appropriate investment. Figure 4-21 represents a first iteration of the time phasing which may best match operational requirements, technological constraints, system costs and risk-taking.

The initial solution is defined as one applying current state-of-the-art to current combat requirements in Southeast Asia. Analysis to date indicates that the solution discussed in this report is also applicable, environmentally and command-wise, to other specific locales which have remote area conflict potentials defined in classified documents. As illustrated, a two-year service life for the initial solution is suggested to be a reasonable period for trade-off of battlefield penalties attributable to a less-than-perfect system, of amortization of developmental costs, and of learning curve experience applicable to follow-on system capabilities. This two-year period of system operation might be extended or reduced, depending on the intensity of combat requirements and the evaluated necessity for and achievability of follow-on solutions.

The interim solution is defined as modification of off-the-shelf equipment to meet existing or potential combat requirements. For this time-frame, operational planning and developmental activities may provide system flexibility to the degree that tactical commanders will employ a mix of aircraft and non-aircraft platforms for HARR missions, depending on requirements of the moment.

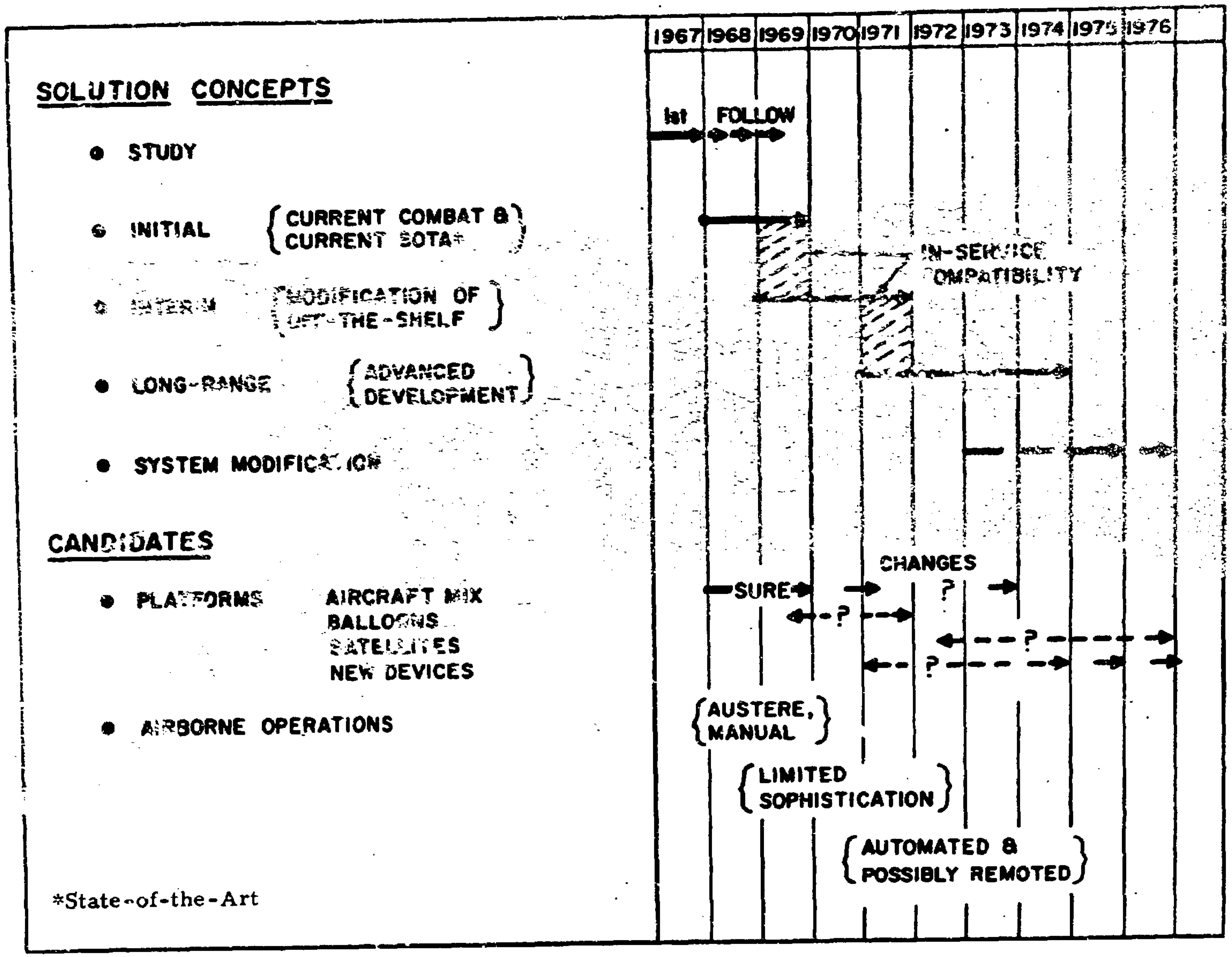


Figure 4-21. HARR Time - Phasing

A three-year operational life cycle is suggested. In this period, the locale of remote area conflict might be significantly different from the tropical environment specified for the present HARR study. Platforms conceivably would be required above windy deserts of large expanse, over a terrain consistently well above sea level, and in an envelope of persistently cold weather with large humidity variations.

The long-range solution is suggested to be one requiring a substantial investment in advanced development. Depending on progress made in the interim solution with relay packages, this development may be largely for new platforms representing radical departure from and/or significant improvement over those used previously for the HARR mission. A four-year life cycle also is shown. Also illustrated is the likelihood that no system will be ideal, hence a system modification during use of the long-range solution is shown. Figure 4-21 also suggests that the evolving of HARR systems must provide for "in-service compatibility" so that technological advantages afforded tactical commanders are not out-weighed by the burdens of complex, duplicative and dissimilar systems. For the initial solution applied to current combat requirements, the tactical ground subscribers and commanders should operate as at present; system changes should be platform/relay oriented, not impositions on ground operations.

Figure 4-21 also shows time phasing considered appropriate for major HARR platform categories for which parametric analyses are required contractually. Various experiments and combat expediencies have shown that aircraft can be used (and are being used) for radio relay. For an initial solution, the preferability of manned aircraft is attributable primarily to the algorithm that "range extension generates mutual interference." Because of this interference, manned control of channel switching and network operations is imperative. This circumstance has been discussed in Section 2 and also is reflected in paragraph 4.6.4 of this Section.

The basic question is, "Can airborne operations required for the HARR mission be automatic and/or ground-controlled, without airborne human intervention and judgment?" If the answer is yes, the parametric values are based on the following: how soon; at how much development cost; with what risk taking; with what battlefield costs and penalties; and for what gain in operational effectiveness. The present conclusion is that costs outweigh operational effectiveness for an "initial solution" predicated solely on an unmanned platform. Consequently, the role of unmanned platforms should be for emergency launching of limited relay frequencies and during limited operational periods, if at all.

As illustrated in Figure 4-21, it is suggested that the initial HARR airborne operation be comprised of austere, manual functions; the interim solution be comprised of limited sophistication of the functions found necessary/desirable during operation of the initial system; and the long-range solution may possibly be automated. In this way, the transition to unmanned alternatives can be at reasonable cost, with acceptable risk-taking, and for the operational effectiveness dictated by operational experience.

4.6.3 Costs. Components of the platform cost model are discussed in paragraph 4.5.4.2.1. It is self-evident that additional system costs are not measurable in dollars but are a function of tactical situations and decisions. Examples of such costs are:

a. reduced force mobility
b. increase logistics burdens
c. additional combat skill requirements

Figure 4-22 postulates system costs generally applicable to the Vietnamese conflict. The intent of this figure is to illustrate cost relationships which are pertinent to selection of HARR candidate systems and to evaluation of system parameters.

A basic design goal is to improve the quality of service afforded by a HARR system and to reduce HARR costs over a long-term program. The proposed measure is "cost per message relayed" which might be $4.00 initially, and $1.00 in a long-range solution. As illustrated, total operating costs may be quite high; and relatively large developmental investments may be justified by the combined need to reduce operating costs and improve service. The illustrated approximations indicate that HARR system costs are influenced more by the selection and tactical use of the platforms than by the selection and tactical use of relay packages.

Some bases for certain of the approximations used in Figure 4-22 are as follows:

a. "Cost per message relayed" is predicated upon tables of organization and equipment for standard forces and upon estimates of the number of transceivers in daily use by American, allied and indigenous forces. The need for range extension is a function of interplay between the environment and tactical situation. Assume that there are 5,000 transceivers assigned to forces which may require HARR support, that at any one time 50% of these transceivers do require HARR support, and that each of these transceivers averages six imperative messages daily. Then, the number of messages annually relayed approximates 5,000,000; the cost approximates $4.00. The value of the message relayed can only be conjectured.

b. Annual platform operating costs are predicated on the example stated in paragraph 4.5.4.3.2 concerning complete and continuous coverage over the Vietnamese Corps III area, where terrain line-of-sight is a severe path problem. The tactical situation may not require "25 stations for 24 hours daily and 365 days yearly." Similarly, it may be a tactical decision to use a $300-per-hour platform rather than a $100-per-hour platform. The total costs illustrated are considered a realistic product of tactical requirements and actual costs. Obviously, the HARR study seeks a minimum number of

INITIAL OPERATIONS

	UNIT COST	ANNUAL COST
• PLATFORM	$100 PER HR. ON STA	$15,000,000 TO $25,000,000
• RELAY	$25,000 PER PLATFORM	500,000 1,500,000

LONG-RANGE DEVELOPMENT

		TOTAL	ANNUAL AMORTIZATION
• PLATFORM	(MODIFY, TEST)	$2,000,000 TO $4,000,000	$ 500,000 TO $ 1,000,000
• RELAY	(RESEARCH, DESIGN)	$3,000,000 5,000,000	500,000 TO 1,000,000

OPERATIONS

	CHANGE FROM INITIAL	ANNUAL COST
• PLATFORM	FEWER; CHEAPER	$ 3,000,000 TO $ 5,000,000
• RELAY	IMPROVED SERVICE	1,000,000 TO 2,000,000
• TOTAL, INCL. DEVELOPMENT		6,000,000 TO 8,000,000

COST PER MESSAGE RELAYED

INITIALLY: $ 4.00

GOAL: $ 1.00

Figure 4-22. Postulated HARR Costs

platforms and minimum cost per platform commensurate with effectiveness required. It is not within the scope of the present HARR study to estimate how and to what degree tactical commanders will decide to employ HARR alternatives at their disposal.

4.6.4 Initial Aircraft Candidates. The ensuing discussion in the following paragraphs concerns the specific aircraft which presently are recommended as initial solutions to the HARR platform problem. Emphasis is placed on cost-effectiveness related to operational suitability as well as technical feasibility. The discussion is outlined as follows:

Basic considerations
Payload considerations
Performance values
Environmental values
Cost values
Platoon repeater platforms
Battalion repeater platforms
Division repeater platforms
Rotary-wing platforms
Drone platforms
Fixed-wing platforms

4.6.4.1 Basic Considerations. The HARR mission is similar in several significant respects to other airborne missions sponsored by Project Agile and presently used or programmed for the remote area conflict in Viet Nam. These missions include defoliation, reconnaissance and surveillance, specialized target acquisition, psychological warfare, specialized logistics support, and so on. It is predictable that similar missions would be required in the event of other remote conflict in the CINCPAC responsibility area, as well as CINCSOUTH, CINCSTRIKE, and other Unified Command areas. Airborne system commonalities include the following.

a. Aircraft require good loitering capability, i.e., the ability to stay over a confined ground area for a prolonged period, and a good ratio of "on-station time" to "to/from-station time."

b. Aircraft must be able to provide maximum "flying hours per month" in spite of environmental, logistics and personnel limitations.

c. Aircraft must be able to adjust well to unavoidable changes in mission profile while in flight.

d. Aircraft should have a good ratio of payload to operating costs, largely because of logistics austerity in remote area conflict.

e. Aircraft payload should not include costly self-protection features (e.g., high-speed performance, armor and armament, countermeasures, etc.), since air superiority is considered to be assured, and ground fire is the major threat.

In these and similar considerations, the prerogatives of the tactical commander to make battlefield selection of valid alternatives are of paramount importance. For HARR, there is no argument in favor of one aircraft to the exclusion of all others. Therefore, a command option to use one aircraft or another (from an inventory of several types/models/series) is recommended. This recommendation leads to the further recommendation that aircraft may be readily configured to and from the HARR mission, and therefore be available for other missions.

It also is basic that the aircraft selected for HARR either be in common usage for remote area conflict, or can be adapted easily in terms of operability, logistics support, command relationships, skill requirements, etc. In this respect, it is desirable to develop military technology which may be used increasingly by indigenous forces, with decreasing dependence upon American operation.

Another basic consideration is the need for platform maneuverability. This need is in two respects. First, it is important that the HARR platform, when airborne, can be quickly and reliably relocated to avoid terrain and weather, to avoid other airborne vehicles which may be hazardous, to remove itself as a hazard to other air operations, to avoid unusual hazards from the ground, etc. Secondly, it is important that the HARR platform be located to optimize the performance of its relay payload. Since battlefield tactical radio traffic rates, location of transceivers, environmental conditions, and communication ranges required or achievable cannot be predetermined or accurately predicted, it is desirable that the controlled, variable location of the HARR platform compensate adequately for the uncontrollability of the variables mentioned. In fact, it is also desirable to provide some degree of flexibility in HARR mission while the platform is airborne.

4.6.4.2 Payload Considerations. The HARR platform is required to accommodate the communications requirements and mission models discussed in Section 2. Likewise, the platform is required to carry the relay payload discussed in Section 3. Neither of these considerations is expected to be definitized to the point that a platform can be selected, tailored, or designed to meet a precise requirement. Rather, the total nature of remote area conflict is considered to be so volatile that the HARR mission must be served by a flexible, modular and modifiable system configuration. For convenience of expression, three basic "models" are discussed with respect to the HARR payload and platform. They are:

2-channel platoon repeater

8-channel battalion repeater

64-channel division repeater

In addition to the basic relay packages represented by these three payload models, there is variability in payload achievable by alternatives in aircraft manning, modification of basic aircraft configuration (e.g., fuel, armor, avionics), and selection of non-relay equipment for the HARR platform (e.g., auxiliary power unit, terrain avoidance radar).

Section 3 gives estimates of the physical characteristics of various relay packages which might be used for the HARR mission. In the selection of appropriate platforms, weight is the limiting physical characteristic. The platoon, battalion and division repeaters are expected to weigh 75, 215, and 1,500 pounds, respectively.

4.6.4.3 <u>Performance Values</u>. For any HARR platform, the primary value is on-station performance, that is, the ability to acquire and maintain the airborne position which optimizes the performance of the HARR system.

For flat jungle, a relay altitude of less than 2,000 feet above terrain will provide relay coverage 50 miles in diameter. On the other hand, a similar coverage in the mountainous terrain by a ground-air-ground link (as compared to a ground-air-air-ground link) would require platform altitudes of approximately 20,000 feet above the terrain, depending on the terrain. For lighter and less costly aircraft carrying heavier relay payloads, this high altitude reduces on-station endurance times sharply, due to high fuel consumption in attaining and maintaining altitude. Depending on topography and flight conditions, more than a half hour might be required to reach a 20,000-foot station from a take-off site ideally located.

There appears to be no way to position a platform at an altitude which will provide with any precision the relay coverage desired. Too low an altitude might provide significant gaps in the relay of communications between netted transceivers irregularly dispersed over irregular terrain. Too high an altitude might amplify the mutual interference which accompanies range extension when frequency assignments are shared between nets. At any altitude, both gaps and interferences might exist, with either predominating. The most desired performance value, then, is ability to change altitude quickly to achieve by performance monitoring, the altitude which best fits the relay mission in process. Environmental conditions and channel interference are likely to limit the achievability of this fit.

Since desired maximum and minimum platform altitudes are not readily defined in terms of relay performance, a generally applicable operational altitude is recommended as follows. The normal minimum altitude for a platform will be 3,000 feet above the terrain. At lower altitudes, the HARR platform is vulnerable to ground fire. Lower altitudes than 3,000 feet may be flown when the weather inhibits both hostile ground fire and attainment of higher altitudes, or when reduction in mutual interference for relay of messages which have urgent priority is mandatory. The normal maximum altitude for a platform will be 10,000 feet above the terrain. At higher altitudes, the HARR platform experiences higher cost, reduced endurance and potential conflict with other military traffic or (at still higher altitudes) commercial traffic. Higher altitudes than 10,000 feet may be flown to escape poor weather or to provide essential radio relay for operations in the highest mountains. Air-to-air relay should be employed to avoid sustained altitudes in excess of 10,000 feet. The HARR mission should be flown at as low an altitude as the requirements permit. Requirement to increase altitude to overcome terrain masking should be determined by relay test messages.

Path analyses referenced in Section 3 indicate that horizontal deviations from an ideal platform position have limited effect on path loss. A circular or lazy-8 mission profile of several miles width at 3,000-foot altitudes will not degrade or eliminate radio relay coverage significantly. In effect, a cone of coverage shifts with the platform's horizontal motion, and transmission loss is only at the perimeter of coverage. A random change in ground coverage will occur in horizontal platform shifting in mountainous terrain. Figure 4-16 illustrates this effect. In such terrain, relay test messages may be used to derive, while in flight, the flight pattern which minimizes terrain masking and maximizes radio relay service to ground transceivers most in need of the service.

4.6.4.4 Environmental Values. Values which bear most on selection of HARR platforms are weather and terrain. Effect of jungle foliage is largely with respect to difficulties in visual position-fixing. This effect does not vary particularly for the different loitering aircraft which are suitable HARR platforms.

Effect of weather on aircraft missions of the HARR sort in remote area conflict is extremely important. The HARR study team has not been able to acquire quantitative data on Vietnamese operations. News reports and government data on strike missions indicate that a surprisingly large percentage of strike missions are either aborted or diverted to secondary objectives because of weather. These sorties, of course, represent a traverse over greater distances and through more variable weather than anticipated on HARR missions. In the absence of conclusive evidence on weather pertinent to the HARR mission, the following experienced observations are paraphased:

a. "In the areas of conflict I was assigned to, there were very few days when the helicopters weren't flying at any hour of the day, regardless of the weather." (Told to the HARR study team by a senior Army officer.)

b. "Weather in Viet Nam is always bad. Throughout the seasons, a rule of thumb is that each day sees good weather in the eastern portion while it's bad in the western portion and vice versa." (Told by a retired Air Force officer who consulted on the HARR project and was previously in charge of Forward Air Controller functions throughout Viet Nam.

c. "The flyability of aircraft in bad weather is at the discretion of commanders at air strips. Under identical circumstances, one commander might ground all rotary-wing aircraft and allow most fixed-wing aircraft to fly, while another commander might decide exactly the opposite." (Same source as b.)

For the HARR mission, take-off, flight, and landing generally will be confined to a small geographical area under localized control It is suggested that the commander should have available locally a variety of platforms for the HARR mission, hence there would be a variable solution to weather problems. It is further suggested that a remotely based platform which can fly "over the weather and terrain" may be useful for HARR missions under unfavorable conditions, even though responsiveness to emergency relay requirements will be slower. For a classified airborne mission in Viet Nam--one similar in profile to the HARR mission--it has been decided through combat experience that weather avoidance radar must be installed. This decision for HARR would put the payload and pilot burden near maximum for the lighter HARR aircraft selected at this mid-point of the study.

A correspondingly complex factor is terrain. Much of the limiting of missions resulting from unfavorable weather (as just discussed) also results from terrain. The two factors are obviously interrelated and have compound effects. The necessity for night flights for the HARR missions adds to these effects. One Army aviation specialist who was consulted by the HARR study team recommended against single-engine fixed-wing aircraft, and suggested twin-engine aircraft for higher altitudes, more difficult terrain, longer endurance and adverse weather conditions. He also suggested a mixed inventory of rotary and fixed-wing aircraft for the HARR mission.

A special environmental situation is the need for HARR missions within valleys so confined by high mountains that aircraft are operationally limited to the valley environment, with only occasional entrance and egress beyond mountain boundaries, and this during favorable weather. In this environment, single-engine aircraft have been able to operate within narrow corridors which are unavailable to twin-engine aircraft. Also, the few air strips available in such terrain very often can accommodate only the lightest aircraft. It is understood that a number of aircraft projects for remote area missions similar to HARR (i.e., all-weather, all-terrain, all-hours, varying altitudes, loitering, etc.) will carry terrain avoidance radar. These projects involve heavier aircraft than those suggested for HARR. Nevertheless, it now seems desirable to include this radar in HARR aircraft which carry the larger relay payloads and may be diverted in flight to difficult terrain, even if the relay payload must be reduced by a number of channels.

4.6.4.5 Cost Values. Figure 4-23 shows the aircraft which have been selected for initial HARR solution. Preceding discussion has dealt with some aspects of the columnar values shown for each aircraft, and more analysis is

	PLATFORM	FLIGHT HOURS	COST PER HR	MAX ALT. *	WORST TERRAIN	WORST WEATHER	PROBABLE BASE
2-CHANNEL PLATOON REPEATER	1 UH-1D HUEY	6	$120	15K'	MTN	FAIR	NEAR
	2 U-6 BEAVER	5	90	10	HILL	FAIR	CAMP
	3 O-1 BIRD-DOG	4	80	10	HILL	FAIR	CAMP
	4 DASH	8	150	15	MTN	BAD	CAMP
8-CHANNEL BATTALION REPEATER	1 LOH-6	3	120	10	HILL	FAIR	NEAR
	2 U-6	4	100	10	HILL	FAIR	CAMP
	3 UH-1D	5	140	15	MTN	FAIR	NEAR
	4 CV-2	6	210	20	MTN	BAD	CAMP
	5 C-123	7	230	25	MTN	BAD	REMOTE
64-CHANNEL DIVISION REPEATER	1 UH-1D	4	160	15	MTN	FAIR	NEAR
	2 CV-2	6	220	20	MTN	BAD	CAMP
	3 C-123	7	240	25	MTN	BAD	REMOTE

* 3K' MINIMUM OVER TERRAIN

Figure 4-23. Initial HARR Candidates

to follow for these values and for cost values applicable to the aircraft selected. Some general observations are in order.

a. The most significant cost variation is expressable in "dollars per channel hour available" which varies between a maximum of $75 for the DASH carrying 2 channels to less than $3 for the UH-1D carrying 64 channels. It appears most desirable to use the fully loaded UH-1D whenever possible, and to avoid using the DASH when alternatives exist. As discussed elsewhere, the cost savings reflected in the largest configuration must be accompanied by a satisfactory solution to large-scale interference problems.

b. As best illustrated by the UH-1D, cost per flying hour increases in proportion to payload for any one aircraft. The altitude and endurance attainable decrease as payload increases. The cost per flying hour increases with altitude. A consistent reduction in flight hours attained increases the proportional fixed costs (e.g., base facilities) and therefore the cost per flying hour. Remote basing of aircraft reduces the on-station flight portion and the productiveness of flight hours.

c. Fine-grained analyses of these detailed cost inter-relationships are not in order for the HARR project at this time, since major cost/operational effectiveness trade-offs outweigh such considerations. For example, during a shortage of aviation gas for all missions, the tactical commander is likely to keep HARR missions at a minimum, and also likely to select the aircraft which consumes least gas per hour, even though resulting deficiences in endurance, altitude and coverage may result. His preference might be the O-1 Bird Dog, which can fly at 8 gallons per hour.

4.6.4.6 Platoon Repeater Platforms. As illustrated by Figure 4-23, the UH-1D "Huey" helicopter, U-6 "Beaver" single-engine utility aircraft, O-1 "Bird Dog" single-engine observation aircraft, and QM-50D DASH drone helicopter (designed for antisubmarine warfare) are recommended in that order.

The platoon configuration--so named for convenience only--is to satisfy several of the radio relay and range extension requirements discussed in Section 2. One requirement is to support platoons with limited dispersion throughout dense jungle and/or mountainous terrain, engaged in operations which may involve high-priority and high-density communications traffic. For this requirement, the tactical commander is expected to exercise the option of launching a HARR platform to cover reliably a specified (and relatively small) ground area for mission durations which may vary from one hour to six or more hours. Adverse weather and diurnal operations may be expected. In the event that coverage proves to be available from so-called battalion and division repeaters, the commander may call back the platoon repeater after very brief on-station time. For this mission, desired platform characteristics include low flying-hour costs, austere takeoff and landing capabilities, limited logistics support requirements, and quick responsiveness to tactical situations. Platforms with payload should be airborne within 15 minutes of the commander's decision and be on-station in less than a half hour under extreme emergency. For planned relay coverage, system costs are reduced by allowing two to three hours to achieve on-station coverage. The selected aircraft meet the foregoing specifications.

A second requirement to be satisfied by the platoon repeater is support of various units on nets which may be so widely dispersed that the commander responsible for these forces cannot determine in advance whether or not relay support will be needed. Therefore, HARR platform launchings must be planned well in advance, so that proper on-station positioning can be achieved initially. Maximum mission durations are desired, as are minimum costs. The communication path difficulties for this HARR mission are expected to be more associated with terrain than with foliage; therefore, aircraft probably will have to fly at higher altitudes and will have to maneuver to find optimum positioning for line-of-sight relay paths. The U-6 and O-1 aircraft, operated from base camp air strips, may be preferable to the UH-1D operated from helicopter clearings. The DASH is least preferred, under normal conditions, for this wide-dispersion mission as well as for the limited-dispersion platoon mission, because of the logistics and control burdens imposed on mobile forces. Its value is for emergency requirements to be met in spite of adverse environments, thus justifying higher attrition rates and more complex battlefield burdens.

4.6.4.7 Battalion Repeater Platforms. As illustrated by Figure 4-23, the preferred platform is the LOH-6 light observation helicopter which now is entering the Army aviation inventory. Its candidacy is strengthened by the fact that it is planned to replace, in large quantity, many of the light fixed-wing and rotary wing aircraft presently used in remote area conflict. In addition to the advantages accruing from prevalence (e.g., logistics support, inventory of skilled personnel, knowledge of flight parameters, full complement of support avionics), the LOH-6 has the advantage of being flyable from clearings closest to the desired area of radio relay coverage. Disadvantages of the LOH-6 may be in limited payload, endurance and altitude inter-relationships. These factors cannot be assessed with much validity at this time, since flight data and experience is limited.

Other candidates for the battalion repeater mission are the U-6, the UH-1D, and CV-2 Caribou twin-engine aircraft, and the C-123 Provider (USAF) twin-engine aircraft, in that order.

The battalion repeater HARR mission is to satisfy radio relay and range extension requirements not too dissimilar from those specified above for the platoon repeater. Operationally, the battalion repeater supports more tactical organizations dispersed over a larger area for more continuous time periods. The HARR payload difference is only a matter of several hundred more pounds of relay packaging. The HARR platform selection and performance for the battalion mission involves more weight-carrying ability, more all-weather flying capability, and more maneuverability over difficult terrain.

These criteria rule out the O-1 and DASH, which were selected for the platoon mission. The LOH-6 and U-6 are acceptable only for the minimum battalion mission. The UH-1D is ideally suited for all battalion missions. The CV-2 and C-123 are expensive platforms, with slower response times, for the minimum battalion mission. They are more suited to a HARR mission supporting multiple battalions and additional special subscribers.

4.6.4.8 Division Repeater Platforms. In conventional ground warfare, the division is the maeuver element which exercises complete control over a continuous area, within which the classical function is to "move, shoot and communicate." In guerrilla and counter-insurgency operations within the limited warfare conducted in remote areas, any large ground area is likely to contain a heterogeneous population of hostile and friendly forces. The latter may be indigenous, American and allied, with variable organization and command relationships. Even so, it is the division command which, in remote area conflict, is likely to have the composite knowledge of all or most operations potentially requiring tactical radio relay, the generalized knowledge of existing and planned transceiver locations, the authority for assigning radio frequencies to specified organizations, and the control over use of HARR to extend range. It is therefore desirable to have a single HARR platform, dispatched from division headquarters, which can carry enough channels in its relay package to satisfy most (if not all) radio relay requirements throughout the division area of responsibility.

The scope and nature of division radio traffic have been discussed in Section 2.

The needs of a division for radio range extension are for highly mobile VHF transceivers in the forward area, and for semi-fixed transceivers (VHF frequencies and higher) in the rear areas.

As shown in Figure 4-23, the UH-1D is the preferred division repeater platform. It accommodates the minimum relay payload nicely, but it has only limited flight capability for the maximum relay payload. The CV-2 and C-123 have capacity in excess of the maximum relay payload now estimated. They also have better ability for overcoming environmental constraints than does the UH-1D. Contrarily, the CV-2 and C-123, because of basing limitations, cannot reach the division's on-station relay status as quickly as the UH-1D.

It is suggested that the command decision might generally be to use the UH-1D when relay payload requirements are minimum, time allowable for reaching on-station is minimum, and the mission profile is for shorter duration and restricted positioning. Conversely, the CV-2 and C-123 might be used when payload requirements are maximum, several hours are allowable for reaching on-station, maximum HARR mission duration is desired, and the platform may be flown in a larger envelope (because of transceiver deployment, terrain and weather conditions, etc).

Additional platforms have been considered for the division repeater mission, and might in fact be used advantageously if they are available in the remote area and can be outfitted there for the HARR mission in addition to or instead of their primary missions. The Navy's S-2 and P-2 antisubmarine warfare aircraft are being recommissioned for remote area conflict use. As announced publicly, these aircraft have been selected for reconnaissance missions because of excellent loitering capability, good speed to the point of use, low acquisition costs, extensive operational experience and logistics support, favorable payload factors, etc. For the HARR mission, these characteristics have similar merit. Further evaluation involves military considerations, such as preempting of limited inventories, establishment of feasible command channels, and disposition of equipments and procedures not compatible with the HARR mission.

4.6.4.9 Rotary-Wing Platforms. As a group of aircraft, helicopters are advantageous for the HARR mission because of their ability to operate from nearby clearings rather than remote air strips. This advantage is partly offset by a higher fuel consumption rate which requires that a refueling complex be operated in very remote areas which are also accessible to other aircraft. Air strips in the rear echelons tend to accommodate most CCIN-type aircraft, but forward airstrips often must be closed to most aircraft because of weather and correlated runway conditions.

Another advantage of helicopters for HARR is the ability to hold a very tight position over rugged terrain in bad weather. Hovering, per se, is not desired because of the very high fuel consumption involved. Very tight flight patterns are not required for effectiveness of HARR radio relay, except for extreme line-of-sight problems. The advantage lies in greater ability to avoid dangerous terrain at night and in bad weather at lower altitudes, thus reducing chances for non-combat loss of personnel, platform and payload.

Helicopters, more so than fixed-wing aircraft, degrade in performance characteristics and increase in operating costs as payload weights increase. This disadvantage can be compensated for somewhat by avoiding overloading and maximum altitudes for HARR mission. Analysis recommends against extensive use of helicopters larger than the UH-1D because of more unfavorable costs, as compared to fixed-wing aircraft. Lighter helicopters (possibly including the LOH-6) are less desirable because of poor performance/payload ratios and limited endurance of platform and pilot.

Operational experience also indicates that a number of the helicopters presently in use have not performed to specification, have presented excessive reliability and maintainability problems, and should be replaced by newer aircraft. The LOH-6 is planned to replace light helicopters and fixed-wing aircraft, but it is premature to place total confidence in the LOH-6. On the other hand, the UH-1D has surpassed performance expectations and is planned to be the predominant helicopter for many more years. The high level of logistics support and skilled personnel inventory for the UH-1D are additional reasons for the "Huey" being most preferable for the HARR mission.

4.6.4.10 Drone Platforms. For the HARR mission profile as defined by study to date, the QM-50D DASH drone is the only drone platform suggested. As shown in Figure 4-23, the DASH might be used in environmental circumstances which preclude manned aircraft, because of increased probabilities of non-combat loss. DASH costs per flight hour are high, but these costs may be tolerable for urgent radio relay requirements. The relatively high attrition anticipated for DASH on HARR missions also should be justified by urgent requirements. This attrition is not because of the helicopter's unworthiness, but rather because of the uncertainty of ground control at extended distances (e.g., 20 miles) in poor weather and difficult terrain. Because launch and recovery of the DASH is a large part of its battlefield burden, long endurance flights should be planned. The payload of the DASH on a HARR mission can be up to 800 pounds of fuel and relay equipment. With two relay channels, an 8-hour flight is achievable.

Fixed-wing drones have been rejected as HARR platform candidates. Operating costs, battlefield burdens and payload limitations for fixed-wing drones are as disadvantageous as for the DASH. Without development and testing, there is no assurance that external fuel stores of sufficient capacity for desired mission endurance can be added. The DASH, with its helicopter flight characteristics, presents no such aerodynamic problem.

Perhaps the most important reason for favoring a rotary-wing drone over a fixed-wing drone is the combined difference of speed/flight pattern. A fixed-wing drone flying a large pattern at relatively high speed might crash into terrain under expert control, while a DASH helicopter flown in a small pattern at low speed has a better chance for terrain avoidance, even if control is less expert. Should propagation and interference tests and "air corridor protection measures" permit drones flying high over rough terrain, fixed-wing drones may be reconsidered as HARR platforms.

As a HARR platform, the drone should be evaluated against other unmanned alternatives. The tethered balloon, with approximately the same payload capacity, is perhaps the best comparison. If cost is the primary concern, the balloon may be preferred to the DASH because of lower platform costs and lower attrition of the platform/relay configuration. However, if precise location and relocation are needed--particularly over rough terrain during high winds--the DASH has definite advantage over balloons. Both are hazardous to other air traffic. The DASH platform and the balloon proper can provide visual and radar illumination. Illumination should also be provided for the balloon tether which constitutes a hazard to low-level helicopter traffic.

Several classified field experiments and CONUS developmental activities have shown the feasibility of using DASH in remote area missions similar to HARR.

4.6.4.11 Fixed-Wing Platforms. In addition to the four shown in Figure 4-23 (O-1, U-6, CV-2 and C-123), the OV-1C and U-3 have proven operationally effective in loitering-type missions in Viet Nam. Both are light twin-engine aircraft which might be preferable to the O-1 and U-6 for missions of longer duration in more unfavorable environments. However, study does not show this to be necessarily the case. No fixed-wing aircraft other than the CV-2 and C-123 are suggested for the payload size called the division repeater. The CV-2 appears preferable to the C-123 because of its ability to use marginal air strips in marginal weather.

The CV-2 and C-123 have capacity in excess of that required for the maximum HARR mission payload suggested by analysis to date. There is a possibility of multi-mission flights (i.e., HARR and other missions requiring loitering over the same area) for these two aircraft, and channels for investigating this possibility might be a desirable step within the remote area conflict program.

The spare cargo space of the CV-2 and C-123 offer an advantage not found in the aircraft selected for the HARR mission. This advantage is the facility for the crew to recuperate from cramped quartering during mission lulls and by rotation. Smaller aircraft sometime have 20% or more endurance beyond that of the pilot. This difference is negligible on a single mission but very important in planning year-round operational capability. Experience in flying four-engine aircraft on barrier missions of 12 or 14 hours duration has shown the importance of human factors under the conditions which would pertain to continuous HARR operations.

4.6.5 Airborne Functions. The cost and operational effectiveness of various HARR platform/relay configuration are influenced significantly by the functions to be performed while airborne. The basic functions are the control of the platform and control of the relay equipment. The HARR project is concerned solely with the airborne relay of radio communications which have, otherwise, insufficient range.

Analysis has not shown any unmanned platform to be dependable or desirable for launching, positioning or carrying the various HARR payloads (at least not in the near future). The DASH drone helicopter is, at best, an emergency measure which involves some risk-taking that should be resolved by a thorough test program before commitment to an operational program or deployment in actual conflict.

Assuming that control of the platform is not to be remoted but is to be in the hands of the pilot, the next major question is, "Can or should the control of the relay equipment be remoted?" If not, it must be determined whether the relay control functions should be performed by the pilot or by another crew member. These determinations depend upon a definition of candidate control functions and upon a realistic appraisal of the cost and operational effectiveness of the functions.

Remoting of DASH control to a ground station is required for both platform and relay. For the platform, only a telemetry and command data link is required (this is already available, including an option to switch to a programmed flight profile). The same data link is usable for limited relay control, such as turning a channel on or off. Remote relay control responsive to evolving requirements of ground subscribers would call for, at a minimum, transmitting relayed radio traffic to the DASH control station where the operational inter-relationships of platform and relay functions would be dealt with in real time.

For a platform already manned, there is no cost/operational effectiveness basis for remoting control of the relay, since there is no need for continuous control on the ground instead of in the air and since all remoting costs would be redundant.

Accepting airborne, manned control of the HARR relay equipment, a trade-off is needed on the level of control required and the interface between airborne platform control and airborne relay control. These considerations vary with the size of the HARR repeater (i.e., platoon, battalion or division) and with the platforms selected for the three payload classes.

In the platform repeater class, the U-6 can be only a one-man aircraft. The O-1 normally carries an observer, but for the HARR mission this "200 pound payload" must be replaced by additional fuel and the relay package in proper balance. The UH-1D has a co-pilot and room for eleven combat-equipped troops. For HARR, only the UH-1D can support a "communicator" to manually control the relay equipment and to interface with "pilot" functions. The O-1 and U-6 pilots must not be given time-consuming additional duties, e.g., HARR relay control. This point is stressed by authorities on aircraft operations over Viet Nam and would apply equally to any other remote area conflict having similarly hostile environment.

In the battalion repeater class, the second man in the LOH-6 may necessarily be displaced by the HARR payload. If not, he should be repositioned so that he can act as "communicator," i.e., as controller of the relay equipment. The UH-1D, CV-2 and C-123 have ample space for manning the battalion class payload and also the division class payload, even if several communicators are required to control relay functions at maximum payload and maximum intensity of communications support.

4.6.6 The UD-1D Candidate. Earlier discussion within paragraph 4.6 has indicated the preferability of the UH-1D "Huey" for the HARR mission. Pertinent information is shown in Figure 4-24, "General Arrangement Diagram;" Table 4-17, "Principal Dimensions;" and Table 4-18, "Communications and Associated Electronic Equipment." Not included in this report, but available in HARR project working papers, are such data and graphs as "Weight limitations and cargo loading chart," "Altitude versus time and fuel to climb," "Fuel flow for best endurance," "HARR mission profiles," "Cost per on-station hour versus altitude and gross weight," and "Total operating cost per on-station hour." These data will be part of the final report. Figure 4-25, "Conceptual UH-1D HARR Layout," is an approximation of how the personnel, equipment and functions discussed throughout paragraph 4.6 might be accommodated within the UH-1D for the "Division repeater" configuration.

Additional basic information about the UH-1D is listed as follows:

a. Model: The D model is larger than the UH-1B and UH-1C which have permanent gun and rocket racks installed externally and are used primarily as attack aircraft. The UH-1D mounts guns in the cargo area, but is used primarily for troop transport and medical evacuation.

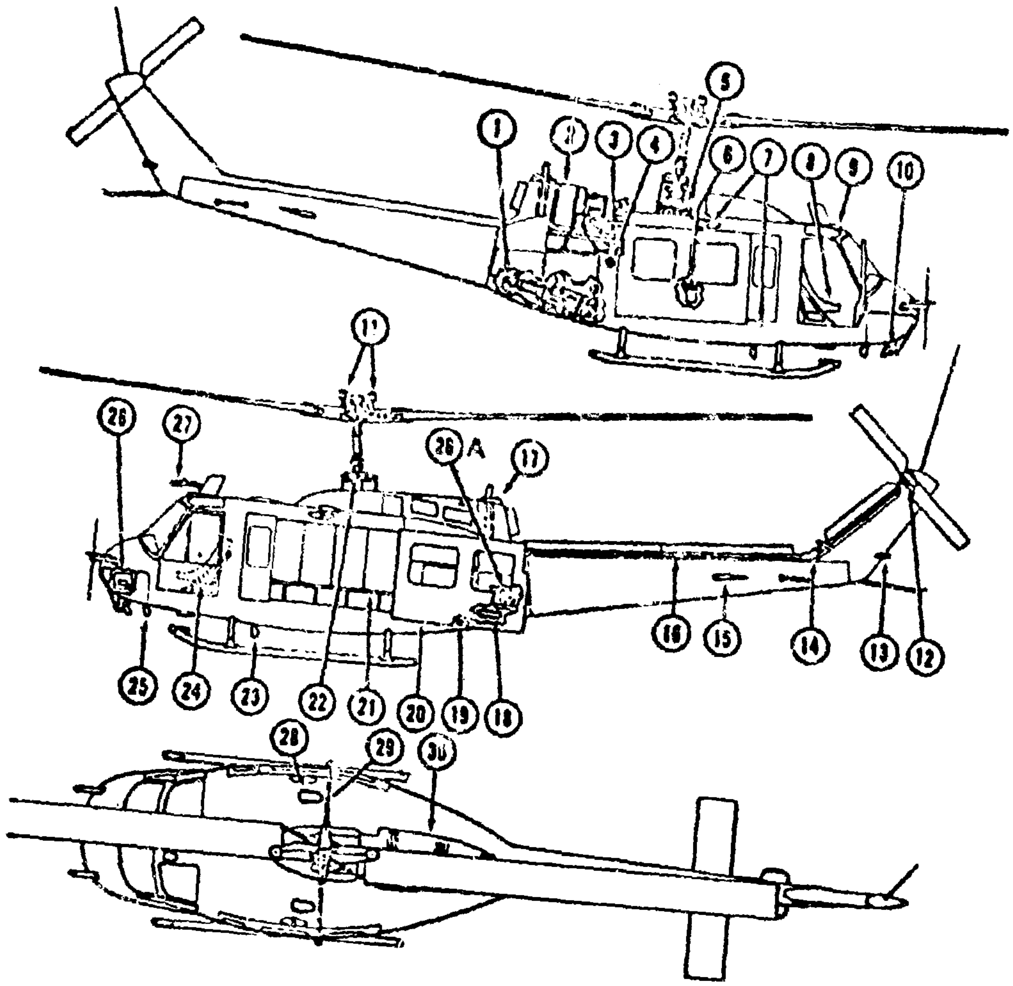
b. Inventories: Approximately 1,000 B's, fewer C's; almost 4,000 D's.

c. Service ceiling: 22,000 feet at intermediate gross weight; fuel flow increases rapidly above 16,000 feet.

d. Weights (pounds): Airframe 4800, fuel 1300, personnel 600, other 100, payload 2700, gross 9500. Auxiliary fuel 110.

e. Cost: $250,000 plus $90,000 avionics; 12-year life.

f. Machine guns: Each 130 pounds plus 80 pounds ammunition. Four are generally carried (delete or reduce for HARR missions).



1. Heating Burner and Blower Unit
2. Engine
3. Oil Tank Filler
4. Fuel Tank Filler
5. Transmission
6. Hydraulic Reservoir
7. Forward Navigation Lights (4)
8. Pilot's Station
9. Forward Cabin Ventilator (2)
10. Cargo Suspension Mirror
11. Collective Counterweights (44 Ft Rotor Only)
12. Tail Rotor (90°) Gear Box
13. Aft Navigation Light
14. Tail Rotor Intermediate (45°) Gear Box
15. Synchronized Elevator
16. Tail Rotor Drive Shaft
17. Anti-Collision Light
18. Oil Cooler
19. External Power Receptacle
20. Cargo-Passenger Door
21. Passenger Seats Installed
22. Swashplate Assembly
23. Landing Light
24. Copilot's Station
25. Search Light
26. Battery

26A. Alternate Battery Location (Armor Protection Kit)

27. Pitot Tube
28. Aft Cabin Ventilators (2)
29. Stabilizer Bar
30. Engine Cowling

Figure 4-24. UH-1D Helicopter General Arrangement Diagram

Table 4-17. UH-ID Principal Dimensions

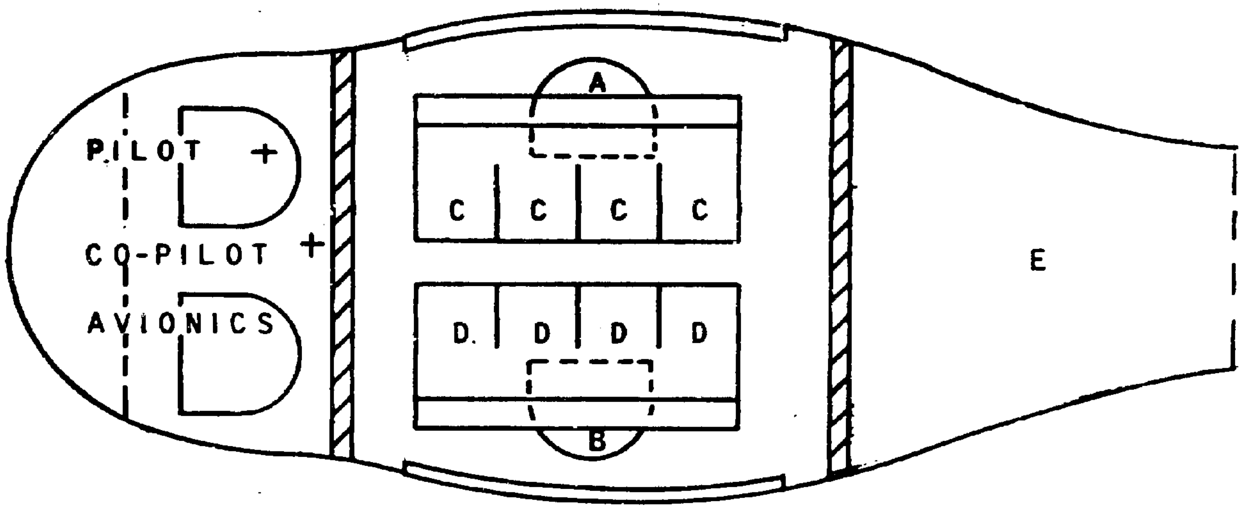
LENGTH:	44 FOOT ROTOR	48 FOOT ROTOR
Overall (main rotor fore and aft and tail rotor horizontal)	53 ft. 1. 1 in.	57 ft. 1. 1 in.
Overall (main rotor fore and aft and tail rotor vertical) to end of tail skid	50 ft. 2. 35 in.	54 ft. 1. 92 in.
Nose of cabin to aft end of vertical fin	39 ft. 5. 09 in.	41 ft. 11. 15 in.
Nose of cabin to aft end of tail rotor (rotor horizontal)	42 ft. 10. 1 in.	44 ft. 10. 1 in.
Nose of cabin to center line of main rotor	11 ft. 8. 66 in.	11 ft. 8. 66 in.
Skid gear	12 ft. 2. 0 in.	12 ft. 2. 0 in.
WIDTH:		
Synchronized elevator	9 ft. 4. 3 in.	9 ft. 4. 3 in.
Skid Gear	8 ft. 6. 6 in.	8 ft. 6. 6 in.
Stabilizer bar	9 ft. 0. 4 in.	9 ft. 0. 4 in.
HEIGHT: (To static ground line.)		
Tip of main rotor forward blade:		
Secured aft	17 ft. 2. 5 in.	17 ft. 1. 49 in.
Pressed down forward	7 ft. 7. 0 in.	7 ft. 0. 69 in.
Top tip of tail rotor vertical position	14 ft. 3. 75 in.	14 ft. 8. 20 in.
Top of stabilizer Chinese weights	13 ft. 4. 0 in.	13 ft. 4. 0 in.
Top of cabin	7 ft. 8. 4 in.	7 ft. 8. 4 in.
Bottom of cabin	1 ft. 3. 0 in.	1 ft. 3. 48 in.
Tail rotor clearance (ground to tip, rotor turning)	5 ft. 9. 75 in.	5 ft. 11. 5 in.
Tail skid to ground	4 ft. 5. 0 in.	4 ft. 9. 0 in.
DIAMETER (Swept circle):	4 ft. 5. 0 in.	4 ft. 9. 0 in.
Main rotor	44 ft. 3. 2 in.	48 ft. 3. 2 in.
Tail rotor	8 ft. 6. 0 in.	8 ft. 6. 0 in.
Stabilizer bar	9 ft. 0. 4 in.	9 ft. 0. 4 in.
Turning Radius		34 ft. 0. 4 in.

Table 4-18. UD-1D Communications and Associated Electronic Equipment

FACILITY	NOMENCLATURE	USE	RANGE	LOCATION OF CONTROLS	REMARKS
UHF command communications	Radio Set AN/ARC-55B AN/ARC-51X or AN/ARC-51BX	Two-way voice communications in the frequency range of 225 to 399.9 mc	Line of sight	Pedestal	
FM liaison communications	Radio Set AN/ARC-44 or AN/ARC-54	Two-way voice communications in the frequency range of 24.0 to 51.9 mc	Line of sight or 50 miles average conditions	Pedestal	AN/ARC-44 dynamotor supplies power for operation of signal distribution panel SB-329-AR
Intercommunication	Radio Set SB-329/AR or C-1611A/AIC	Intercommunication between crew members	Stations within helicopter	Pedestal and cabin overhead	Press-to-talk switches located on cyclic sticks, foot switch on floor in cockpit area, and crew members control panel
VHF command communications	Radio Set AN/ARC-73	Two-way voice communications in the frequency range of 116.00 to 149.95 mc	Line of sight or 50 miles average conditions	Pedestal	The AN/ARC-73 is used as an alternate for the UHF Command Set
HF SSB/AM communications	Radio Set AN/ARC-102	Two-way voice communications in the frequency range of 2.0 to 29.999 mc		Pedestal	Minimum pilot weight is 260 pounds with AN/ARC-102 installed
VHF emergency transmitter	Transmitter T-366/ARC	VHF emergency transmitter	Line of sight		The VHF navigation receiver used in conjunction with T-366/ARC standby transmitter

Table 4-18. UD-1D Communications and Associated Electronic Equipment (Continued)

FACILITY	NOMENCLATURE	USE	RANGE	LOCATION OF CONTROLS	REMARKS
FM homing	Antenna Group AN/ARA-31 used with AN/ARC-44 or AN/ARA-56 used with AN/ARC-54	Homing on FM tranmission within frequency range of 24 to 49 mc	Line of sight or 50 miles average conditions	Pedestal	The FM liaison set must be operated while homing
VHF navigation (VOR, VAR, LOCALIZER)	Radio Receiver AN/ARN-30E or AN/ARN-82	VHF navigational aid and VHF audio reception in the frequency range of 108 to 126 mc	Line of sight	Pedestal	Information is presented aurally in headset, and visually on course indicator and bearing-heading indicators.
Automatic direction finding	Direction Finder Set AN/ARN-59 or AN/ARN-83	Radio range and broadcast reception; automatic direction finding and homing in the frequency range of 190 to 1750 kc	50 to 100 miles range signals 100 to 150 miles broadcast	Pedestal	
Magnetic heading indications	J-2 Gyro Magnetic Compass	Navigational Aid		Instrument Panel	
Marker beacon reception	MB Receiver R-1041/ARN	Navigational Aid	Vertical to 50,000 feet	Pedestal	
Identification	Transponder Set AN/APX-44	Transmits a specially coded reply to a ground-based IFF radar interrogator system	Line of sight		



CARGO COMPARTMENT:

7.7'L X 8.0'W X 4.1'H; 4.0'H X 6.2'W DOOR
LOADING: 300 LBS. PER SQ. FT.

A. COMMUNICATOR (EMERGENCY GUNNER)
B. COMMUNICATOR FOR MAX. MISSION
C. FOUR 8-CHANNEL REPEATER MODULES -- VHF
D. SAME AS C OR UHF AS NEEDED
E. LIMITED HARR EQUIPMENT -- E.G., AUXILIARY POWER UNIT
TERRAIN AVOIDANCE
WEATHER AVOIDANCE

F. STANDARD REPEATER RACKS
G. DISPLAY CONSOLE
H. BACK-WIRING, RECORDER, ETC.

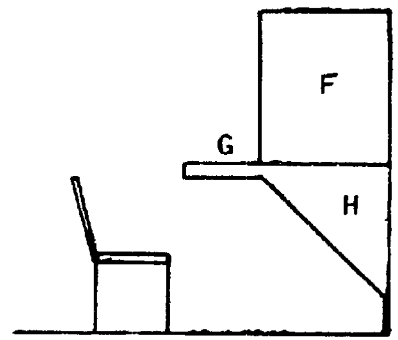


Figure 4-25. Conceptual UH-1D HARR Layout

In summary, the referenced analyses indicate the preferability of the UH-1D as a HARR platform in terms of mission performance at all levels of support--platoon, battalion and division. The cost of the UH-1D is comparatively high for the platoon repeater, but favorable for the division repeater. The division repeater is preferred for the HARR mission. In the initial solution or early time-frame, the frequency interference problems associated with extension of radio range are to be overcome by improvisation techniques and evolutionary equipment modifications for the airborne HARR communicator. Subsequently, solution to interference problems may stem from more extensive development of HARR relay packages, e.g., the use of directive antennas.

In spite of miniaturization potentials for electronic equipments, the maximum HARR payload is expected to continue to require a platform of the UH-1D size, or larger. The HARR mission profile is expected to continue to require relatively precise location over a force area, particularly in difficult line-of-sight terrain. A more pressing requirement might be for maximum flyability and maneuverability under most difficult weather and terrain conditions, with nominal assistance from such ground support facilities as radar, prepared airfields, etc. The emerging "compound helicopter" appears to meet these broad specifications better than other aircraft in development. Prototype compound helicopters have already flown "loops" and other acrobatics, indicating an excellent airworthiness.

Combat evaluation of the AAFSS compound helicopter will not be completed before 1970, and no commitment to extensive procurement of this aircraft is in sight. Furthermore, the AAFSS could not be modified to accommodate the UH-1D's HARR payload quickly or inexpensively. A more promising activity is the proprietary (Lockheed) development of a Universal Tactical Transport (UTT). The UTT compound helicopter is proposed to satisfy a variety of limited warfare mission requirements of all military services. In every respect, it would be a natural and desirable "next generation" platform for accommodating the UH-1D's HARR payload.

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13. ABSTRACT

High Altitude Radio Relay Systems

This is the first semi-annual report on the work being performed under the High Altitude Radio Relay (HARR) study contract. The HARR program is an applied research study effort in support of the Advanced Research Projects Agency requirements for Remote Area Conflict communications (Project AGILE). The theoretical and analytical investigations are aimed at determining the key characteristics and parameters of a system to enable the use of military communications equipment over difficult paths. The technique being investigated is the use of a radio relay installed in a high altitude platform, for the purpose of extending the range of remote area radio communications. (U)

HARR Parameters. The operational parameters being considered are: traffic, transmission range, terrain, foliage, frequency range, modulation, and types of relay capabilities. The equipment parameters being considered are: relay control, transmission modes, size and weight, radio frequency power levels, receiver sensitivities, power requirements, operational life, interference, jamming, platform performance, platform payloads, compatibility, basing, availability, and costs. (U) CONTINUED

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