Chapter 10

COMMAND, CONTROL, AND COMMUNICATIONS (C^3)

Chapter 10.– COMMAND, CONTROL, AND COMMUNICATIONS

TABLE

FIGURES

Chapter 10

COMMAND, CONTROL, AND COMMUNICATIONS (C’)

OVERVIEW

A missile force that physically survives an attack is of no use if the means to command the force do not survive as well. Reliable command, control, and communications (C^3, pronounced “C-cubed”), impervious to Soviet attempts at disruption, are needed if commanders are to assess the status of an MX force, retarget the missiles if desired, and transmit launch commands. There is a wide variety of technical possibilities for wartime communications and just as wide a range of means to disrupt and impede them. The nature of the disruption suffered by the U.S. C^3 system in wartime would depend on the amount of damage done to communications installations themselves and on the extent of disturbance of the atmosphere due to nuclear explosions. Though some disruption would inevitably result regardless of the nature of the Soviet attack, the most stressing circumstance would result from a deliberate Soviet attempt to deny U.S. commanders the means to control and execute their forces.

It will be apparent that no single communications link can be made absolutely survivable, but disruption can be made difficult, time-consuming, provocative, and costly of Soviet resources. Multiple links can also be provided, subject to different failure modes, and provision can be made for reconstituting some links if the primary system is destroyed.

The actual functions that a C^3 system supporting an MX force must fulfill depend to some extent on doctrine for the force’s use. At a minimum, the communications system must be consistent with the operations of the force (e.g., must not compromise missile location in multiple protective shelter (MPS) basing or submarine location in submarine basing) and must permit one-way communication of short launch commands (Emergency Action Messages— EAMs) from commanders to the missiles to order execution of preplanned options of the Single Integrated operational Plan (SIOP). In addition, it could be desirable for the C^3 system to support prompt response to launch commands (“responsiveness”), flexible or ad-hoc retargeting outside of the SIOP, and two-way communications so that the forces could report their status to commanders and confirm execution of orders. Last, if the force expected attrition in an attack, it could be desirable for the surviving missiles to be able to redistribute targets among themselves so that the highest priority targets were always covered by surviving missiles. For a given basing mode, the hardware to carry out these functions, and the functions themselves, can differ substantially from the preattack or peacetime period to the transattack and postattack periods.

OTA has sought to prescribe a technically feasible C^3 system that satisfies these criteria for each of the principal basing modes. In many cases the system described differs substantially from those that are available to U.S forces today. Obviously, providing these systems would involve some cost, but with the exception of launch under attack, in no case is C^3 a cost driver for the basing mode as a whole. Some elements of these C^3 systems would furthermore support other strategic and conventional forces, so their costs should perhaps not be assigned entirely to the MX basing mission.

There are distinct and important differences from basing mode to basing mode regarding both the technical means to support effective C^3 and potential vulnerabilities. In each case it appears that with adequate funding and effort, acceptable technical solutions are available, though it would be extremely difficult to provide a C^3 system survivable against any and all contingencies. Direct comparisons are difficult, but on balance OTA can see no clear reason for preference among the basing modes on the basis of C^3.

The next section discusses the technical aspects of strategic C' in general terms, including available means of communication and their vulnerabilities. The following section lays out in concrete terms the functions desired from a C^3 system supporting MX basing. The next section describes the C^3 systems for the basing modes and describes how they might function before and after attack. The last section contains a technical overview of radio communications.

TECHNICAL ASPECTS OF STRATEGIC C^3

Communications Links

The communication of information between two points requires an intervening communications link. For instance, a telephone microphone converts acoustic signals (i.e., a human voice) into electrical signals, and the earphone converts the electrical signal back into sound. The lines over which the signal travels between the phones is referred to as the communications link. By bouncing radio waves off the ionosphere, it is possible to communicate over very great distances. in the case of this type of communications, the path over which the radio wave travels is the communications link. At very high radio frequencies, radio waves are not reflected by the ionosphere. In order to achieve long-range communications in this case, it is necessary to transmit the signal to a satellite that then retransmits it back to Earth. The channel established through the satellite is called the communications link. This seemingly expensive and complex method of radio communications is valuable for two reasons:

1. Satellite communications links can achieve high data rates relative to radio communications that require reflection from the upper atmosphere.
2. Satellite links, if they are not destroyed, are extremely reliable, since communications capabilities do not change with the fluctuating conditions in the upper atmosphere.

The time it takes to transmit a message of a given length over a communications link is determined by the data rate of the link. Any message, whether transmitted by voice, teletype, or picture, can be expressed as a sequence of "on or off" signals called bits. The data rate is the number of bits per second that can be transmitted over a particular link. Teletype rates are typically a few hundred bits per second. Since each sequence of five to seven bits would be enough to represent a letter of the alphabet, and since on the average there are five letters per word of the English language, a 300 bit-per-second teletype link could carry 8 to 12 words per second. Voice communications require data rates of several thousand bits per second. High-frequency satellite links can transmit data at hundreds of millions of bits per second. These data rates could support tens of thousands of separate voice channels. A particularly important type of message in the case of strategic C' is the EAM. These messages, ordering a strike by U.S. strategic forces, could be preformatted and might consist of a small number of bits, since even a format with a small number of bits would lead to a large number of possible messages that could have the same format. For instance, if EAMs consisted of 20 bits, then more than a million different messages with the same format could be created. EAMs can therefore be very short messages and can be transmitted in a short time even by links with relatively low data rates. Much more information would have to be transmitted to order a strike that was not among the preplanned options. A high data-rate link would be required to transmit such long messages in a short time.

Land lines

Landlines consist either of wires that conduct electricity or of glass fibers (i.e,. fiberoptic) through which light can be guided.

Both types of landlines can be used for extremely high data-rate communications and are therefore very useful for communicating with land-based strategic weapons systems, The communications links and nodes associated with landlines, however, are vulnerable to physical destruction in war and are subject to disruption or destruction by electromagnetic pulse (EMP) generated by high-altitude nuclear bursts. Landlines might therefore only be of use before an attack on a land-based strategic weapons system.

Radio Links

Radio communication bands are, by convention, referred to by acronyms. Since these acronyms are commonly used in discussions of communications systems, they are summarized in table 34.

VLF/LF

Very low frequency (VLF) and low frequency (LF) radio signals are useful for reliable communication over very large distances. A powerful VLF/LF station can be received over distances of many thousands of miles, even if there are nuclear detonations in the upper atmosphere. VLF/LF signals penetrate seawater well enough to make communications possible with submarines and, at a cost in data rate, can be made resistant to jamming. VLF/LF radio has two important drawbacks: the antennas required for transmission and reception must be very large and are therefore susceptible to physical destruction, and the data rates that are possible with VLF/LF are low. However, airplanes are able to trail large antennas in flight and transmit sufficiently powerful VLF/LF radio waves to permit long-range communications. Airplanes can communicate with ground stations, other aircraft, and submerged submarines in this way.

MF

Medium frequency (MF) radio links are higher frequency than VLF/LF radio links and can be used to transmit information at higher rates than is possible with VLF/LF. (The reason for this and other features of radio propagation is discussed in the Overview of Radio Communi*cations* section.) MF radio is in the same band of frequencies as AM radio broadcasting. Like AM radio, MF signals do not, under normal conditions, propagate much further than the length of a metropolitan area, though at night skywave propagation can lead to longer range. MF is a reliable means for moderate data-rate transmissions over short distances. Since the radio signals at these frequencies do not travel very far, they are generally (but not always) difficult to jam from great distances. Distances over which communications at these frequencies can generally be affected are 40 to 50 miles between ground stations and **100** to 150 miles between an airplane and a ground station.

HF

High frequency (HF) ("short wave") radio signals are extremely useful for long-range

Table 34.—Radio Communications Bands

Name of Range		Frequency Range*	Wavelength Range
Extremely low frequency	ELF	.3-3 KHz	1,000-100 km
Very low frequency	VLF	3-30 KHz	100-10 km
Low frequency	LF	30-300 Kfiz	10-1 km
Medium frequency	MF	300-3,000 KHz	1,000-100 m
High frequency	HF	3-30 MHz	100-10 m
Very high frequency	VHF	30-300 MHz	10-1 m
Ultra high frequency	UHF	300-3,000 MHz	100-10 cm
Super high frequency	SHF	3-30 GHz	10- 1 cm
Extremely high frequency	EHF	30-300 GHz	1 -.1 cm

"Hertz = cycle per second, KHz= KiloHertz = 1,000 cycles per second, MHz= MegaHertz = 1,000 KHz, GHz = GigaHertz = 1,000 MHz.

tm = meter= 328 feet, km= kilometer= 1,000 meters= .6212 miles, cm = 01 meters= 394 inches.

moderately high data-rate communications. In contrast to VLF/LF radio systems, HF equipment and antenna systems are compact and do not require large amounts of power. A serious problem with HF band communications is that they are easily disrupted by nuclear detonations in the upper atmosphere, and can be "blacked out" over very large distances for periods of hours. Another problem with HF communications is the possibility of using direction finders to determine the location of the transmitter well enough to attack it. A possible further problem with HF is that the number of usable frequency bands is limited. Many users trying simultaneously to use HF could jam one another.

In spite of these drawbacks, the upper atmosphere would recover electrically several tens of hours after nuclear detonations occurred and would then be able to support the long-range transmission of HF. For this reason, HF would be useful for an indefinite period after a nuclear attack for high-data-rate communications even if other communications links were destroyed.

Today's fielded HF systems require manual tuning, introducing some unreliability even in day-to-day peacetime communications. Microprocessor-tuned HF systems resulting from technology improvements would make HF highly reliable except in periods of significant blackout.

VHF

Very high frequency (VHF) waves are not strongly reflected from the upper atmosphere and do not travel far over ground. VHF is the band at which FM radio broadcasts occur, and it is familiar to radio listeners that FM stations have shorter range than AM stations. Very high data rates are possible with VHF, and antennas and equipment can be made compact.

Long-range communications are possible using VHF by reflecting radio signals off the ionized trails of meteors. Since it is necessary to have a reflecting meteor trail in the right location of the upper atmosphere to permit communications between two points beyond the radio horizon, delays of a few minutes could occur before it would be possible to transmit a message using VHF. One possible advantage of VHF is that it might be possible to communicate effectively by bouncing radio signals off the bottom of the ionized region formed by a high-altitude burst. Thus, VHF communications might actually be improved if the Soviets blacked out HF or UHF.

UHF

Ultrahigh frequency (UHF) is extremely useful for line-of-sight communications between aircraft. The data rates are high and the equipment is quite compact and low power. UHF can be used to communicate to ground installations from an aircraft at a distance of about 200 miles and can be used to communicate between aircraft at distances between 300 and 450 miles. For this reason, UHF could be used to communicate between airborne command posts and to transmit launch commands to land-based missiles.

It is possible to use direction-finding techniques to locate UHF transmitters and it is also possible to jam receivers This problem is unlikely to be serious for line-of-sight aircraft communications but it could be a problem for UHF links through satellites.

Satellite Communications (SATCOM)

UHF SATCOM

UHF satellite links are useful not only because data rates can be very high, but also because UHF antennas are not extremely directional, so users do not have to have means for pointing antennas at satellites. A drawback of UHF SATCOM links is that it is possible to jam the uplinks to the satellites from small mobile jammers (ship or ground mobile) located anywhere in the satellite's hemisphere of view. A problem associated with the multidirectional nature of UHF signals is that enough signal can be "seen" from other directions that it is in principle possible to locate ground-based UHF transmitters from space. Nuclear detonations in the upper atmosphere can also result in "blacking out" of UHF signals for a few hours over regions of the Earth's surface. These regions of blackout would have radii of tens to hundreds of miles. The United States now uses UHF SATCOM regularly for worldwide mi1itary communications.

UHF satellites could be launched from silos into low orbit in wartime to reconstitute disrupted l inks.

SHF/EHF SATCOM

Super high frequency (SHF) and extremely high frequency (EHF) satellite links are extremely useful for very high data rate, reliable communications. Because of the large bandwidth, such links are, at least for EHF, unjammable. Because the wavelengths are so short (on the order of fractions of a centimeter), it is possible to have very highly collimated radio beams that can be trained on the satellite. In addition, SHF/EHF antennas are sufficiently small (about 5 inches in diameter) that they can be conveniently mounted on ground vehicles, aircraft, surface ships, and submarine masts.

Since the SHF/EHF beam is so tightly collimated, it is nearly impossible for a receiver that is not in the beam to "see" the signal. The only way that the presence and location of an SHF/EHF transmitter could be detected would be if the search receiver was itself in the beam. Thus, SHF/EHF satellite uplinks from forces in the field, surface ships, and submarines would not pose the risk of revealing the location of the transmitters.

A potential problem with SHF/EHF is an atmospheric phenomenon called scintillation. Electron density fluctuations in the ionoshere due to high-altitude nuclear bursts could cause the beam to be bent as it propagated through them. This bending would result in fluctuations in the quality of reception at the receiver. It is believed that with suitable signal modulation scintillation would not be a problem at all. For EHF, scintillation would not last, in any event, for more than a few minutes after a high-altitude burst. Another minor problem is that water absorbs EHF signals. However, a major rainstorm would be required to impede communications. Mist and clouds would not be a problem.

LASER SATCOM

The high frequencies and directional nature of laser communication allow for extremely high-data-rate, low power consumption, unjammable links between satellites and between satellites and aircraft flying above the clouds. Communications between ground stations and satellites would not be feasible because of the possibility of cloud cover. Even in clear weather, such communications would create a visible pencil of light in the sky, revealing the location of the user. For this reason laser SATCOM might endanger the covertness of submarines, surface ships, and mobile ground units.

Vulnerabilities of Communications Systems

Physical Destruction

One obvious way to attempt to deny communications capability to U.S. strategic forces would be to physically destroy as many susceptible elements of the system as possible. This destruction would include landlines, landline switching stations, radio transmitter stations (i.e., VLF/LF/MF, etc.), satellite up-and-down-link stations, and fixed command centers

After an initial attack, it could not be guaranteed that landline communications would exist with land-based forces or that fixed VLF stations would be broadcasting to the submarine forces. Only communications links made possible with aircraft and satellites would necessarily still be intact.

Electromagnetic Pulse (EMP)

An effect of the detonation of nuclear weapons, both inside and outside the atmosphere, that is less appreciated but still very important is EMP. The case of a detonation outside of the atmosphere is, however, the most relevant as a general problem for communications systems.

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As explained in the *Overview of Radio Communications* section, a high-altitude nuclear detonation could generate a sudden electric field over large regions of the United States of up to 50,000 volts/meter. This intense electric field could destroy or disrupt communications and electrical equipment of all types. High quality assurance and testing are required to ensure that components are properly sealed and protected if they are to survive the effects of the EMP from high-altitude detonations.

Ionospheric Disruption

Another effect of high-altitude nuclear detonations is ionospheric disruption. The electron densities in the ionosphere would be changed suddenly by the ionizing effects of prompt gamma rays from the nuclear detonation and/or beta rays from fission decay products. These effects could cause significant degradations at those radio frequencies that are reflected from (HF) or pass through (UHF SATCOM) the ionosphere.

Jamming

Jamming refers to the ability of a hostile transmitter to drown out the signal being received. The susceptibility of a radio link to jamming depends on power, bandwidth, modulation technique, and antenna directivity. In general, jamming becomes more difficult as the frequency of the transmission increases. If the nature of potential wartime jamming can be foreseen, it can be compensated by changes in modulation technique and increases in power.

Ant i satellite (ASAT) Threats

There is considerable concern that the heavy dependence of the U.S military on SATCOM will make satellites the targets of attack. The means of attack could be direct-ascent interception, space mines, land-based lasers, or even space-based lasers.

Several of the basing modes discussed in this report could make effective use of SATCOM. A highly reliable SATCOM system based on deep-space millimeter-wave (E H F) communications has been proposed for military use and would be very useful to support MX basing. The following discussion explains why there is considerable interest in such satellites.

Though geosynchronous orbit would be most convenient for such satellites operating at EHF frequencies, it would perhaps be advisable to deploy them in higher orbits. Geosynchronous orbit is that unique orbit 22,300 miles from the Earth at which the orbital period of satellites is equal to the rotation period of the Earth. Thus, satellites in geosynchronous orbits remain over the same point on the Earth's surface as both they and the Earth go around. Because its position relative to the Earth's surface would remain the same, users would have a fixed point upon which to focus their directional antennas. Because of its convenience, however, geosynchronous orbit is quite crowded. It would therefore be possible for the Soviets to station a "space mine" near a U.S. communications satellite and answer in response to U.S protests that the mine was in fact some other sort of satellite that it was convenient to position in geosynchronous orbit. The United States would then not be in a position to assert that the Soviets had no business there, because it would be quite plausible that they did have legitimate purposes for positioning a satellite in this unique, convenient orbit.

If on the other hand the U.S. satellites were in an orbit chosen more or less randomly from among the infinite number of possible altitudes, the United States would be in a better position to assert that the only possible purpose for a nearby Soviet satellite must be to interfere with that of the United States. The United States might then justify on these grounds measures against such interference.

Satellites could also be threatened by direct attack from a missile launched from the Soviet Union. However, the U.S. satellites could be positioned high enough that it would take many hours (18 or so) for an attacking vehicle to reach them. Furthermore, since the interceptor missiles required to reach high orbits would be quite large, the Soviets would probably only launch them from the Soviet Union. Most of the U.S. satellites would be on the other side of the Earth when the first interceptor was launched, and launch of other interceptors would have to be staggered to intercept the rest of the satellites as they "came around." Direct-ascent antisatellite attacks on high orbits would therefore present a timing problem to the Soviets. The United States would certainly be aware that the satellites were under attack hours before they were destroyed.

Last, land-based lasers could not deliver sufficient power to the orbits of interest (five times geosynchronous or so, or half way to the Moon) to destroy the satellites.

A number of measures could be taken to ensure the survival of these satellites. For instance, they could be provided with sensors to allow them to determine when they were under attack, and they could maneuver to avoid homing interceptors and deploy decoys or chaff to confuse homing sensors. Backup satellites at such distances from the Earth might also be able to be hidden entirely by giving them small optical, infrared, and radar signatures. Dormant backup satellites might be hidden among a swarm of decoys and turned on when the primary satellites encountered interference. Last, backup satellites (probably using UHF instead of higher frequencies) could be deployed on missiles in silos and launched into low orbits to replace the primaries. These reconstituted satellites could also be attacked, but it would take time for the Soviets to acquire data on their orbits, even assuming the United States allowed them unhindered operation of the means to acquire this data. Some of these techniques for satellite security are more effective than others.

Command and Control

This chapter deals for the most part with the communications aspect of C^3. The command and control functions for U.S. strategic forces are outside the scope of this discussion, but it is necessary to specify how the command structure is linked to the communications system and thus to the forces.

Decisions regarding the use of U.S. strategic forces are in the hands of the National Command Authorities (NCA), i.e., the President and Secretary of Defense or their successors. The military provides a National Military Command System to support NCA. This system consists of fixed command centers and survivable mobile command posts. The fixed ground centers include the National Military Command Center in the Pentagon, an Alternate National Military Command Center at a rural site outside Washington, D. C., the underground command center at Strategic Air Command (SAC) headquarters at Of futt Air Force Base in Omaha, Nebr., and North American Aerospace Defense Command headquarters in Cheyenne Mountain, Colo.

Since the fixed ground centers could be destroyed early in a nuclear war, a fleet of survivable Airborne National Command Posts is provided for postattack command and control. The most important aircraft in this fleet is the E-4B (modified Boeing 747) National Emergency Airborne Command Post (NEACP, pronounced "kneecap") available for Presidential use. In addition, there is a fleet of strip-alert aircraft at military bases throughout the country, including command posts of the nuclear commanders and the Post-Attack Command and Control System (PACCS) fleet. This fleet could establish a network of line-of-sight UHF communications from the Eastern to Central United States within a short time after an attack. Finally, SAC maintains an EC-135 (modified Boeing 707) command aircraft, called "Looking Glass," on continuous airborne patrol over the United States.

Ground-mobile command posts–disguised as vans traveling the Nation's highways to avoid being targeted — are also a possibility for survivable command posts.

In the descriptions that follow of possible C^3 systems for each of the basing modes, it will be assumed that all force management functions and launch commands originate with, ***or pass*** through, the airborne or grounded NEACP, and that NEACP is provided with the necessary communications systems to link them with the MX force.

C' FUNCTIONS FOR MX BASING

This section outlines the functions desired of an MX C^3 system to support the various aspects of U.S. Nuclear Weapons Employment Policy. These policy aspects are associated with such terms as Basic Employment Policy, Flexible Response, Quick Reaction Hard-Target Counterforce, Secure Reserve Force, and the like, as derived from the public statements of senior defense officials. This section translates these notions into concrete functions required of a C^3 system for MX. The next section will prescribe hardware capable of performing these functions for each basing mode.

These functions, and most certainly the means to accomplish them, differ among the preattack, transattack, and postattack periods. For the purposes of this chapter, the transattack period is defined as the period of airborne operation of certain C^3 aircraft (N EACP, Airborne Launch Control Center (ALCC), TACAMO, etc.). The distinction between transattack and postattack as used here therefore concerns the hardware available to accomplish the C^3 functions and not the functions themselves. Transattack and postattack functions will therefore be treated together.

Preattack Functions

Peacetime Operations

Peacetime communications are required for commanders to assess continuously the status and readiness of the MX force. Continuous one-way communications from commanders to the forces is an obvious requirement. Two-way communications — including from the missile forces to commanders— is clearly important, though intermittent report-back (relevant for the case of submarine basing) might be adequate.

Since the communications links have suffered no damage, the only impediment to maintaining adequate peacetime communications would be the requirement that the means of communications should be consistent with the operations of the force. Thus, the peacetime communications should not be of such a nature as to compromise missile locations in the case of MPS basing or defense unit locations in the case of the MPS/LoADS (low altitude defense system) combination, nor betray the locations of patrolling subs in small submarine basing.

Responsiveness

In the event that NCA ordered the launch of the MX missiles according to one of the preplanned options of the SIOP before the force had suffered attack, all that would be required of the C^3 system would be the capability to transmit a short, preformatted, encrypted message to the MX force. Since the message would be short, low-data-rate communications would suffice.

There could be a requirement that missile launch be accomplished rapidly after the decision to launch was made. This could be the case if a Soviet attack were believed imminent and it was thought desirable to strike Soviet forces before they could attack the United States or disperse from their home bases. This requirement of responsiveness would seek to make the time interval between dissemination of the EAM ordering launch and actual missile launch as short as possible. A portion, though not necessarily most, of this time interval would be comprised of the time it took for the relevant communications links to transmit the short EAM to the MX force with low probability of error.

in order to strike certain hardened targets such as missile silos, it would also be desirable to be able to control the arrival times of RVS so that detonation of one would not compromise the effectiveness of others ("fratricide"). Such time-on-target control could be accomplished by including in the EAM a reference time, relative to which each missile would determine the *arrival time* required of its RVS in order to coordinate arrival with RVS from other missiles. The precise timing would be achieved by coordinating launch time, maneuvers of the missile, and reentry angle.

In addition to short response time, it could be desirable for the MX force to be able to communicate back to the commanders in a short time to confirm successful launch.

Ad-Hoc Retargeting Before Launch

Ad-hoc retargeting refers to the ability to construct attacks that are not among the preplanned options of the SIOP. Such retargeting flexibility could involve either rearranging targets from the extensive target sets already stored in the MX missile launcher's memory or reprogramming the missile with entirely new target sets. Both situations would require transmission of larger amounts of data than contained in the short EAM. In the latter case, the information would include target latitudes and longitudes (calculated in the proper coordinate system), reentry angle, timing, and fuzing.

Since large attack options would likely be included among the S IOP options, extensive ad-hoc retargeting might be confined to a relatively small portion of the force, in which case only that portion need be in a position to receive such high-data-rate communications.

The portion of the force retargeted would presumably be required to report back receipt of the new targets, confirm them, and report successful launch.

Transattack and Postattack Functions

Prelaunch Damage Assessment and Reoptimization Within the SIOP

In the event that the MX force suffered attrition in the attack, it might be desirable for the surviving missiles to reallocate targets in such a way that the highest priority targets continued to be covered even if the missiles that originally covered these targets were destroyed in the initial attack.

Commanders would presumably also wish to know the extent of attrition and remaining target coverage.

Order for Launch of Preplanned Options

Dissemination of the EAM after an attack would require that the surviving portion of the C^3 system support at least one-way low-data-rate messages. Report-back confirming successful launch would require two-way communications. It is not clear that the need for *rapid* response would always be as great in the postattack period as in the preattack period.

Ad-Hoc Retargeting

Assignment of entirely new targets to the MX missiles and confirmation of receipt would require teletype data-rate two-way communications.

C' SYSTEMS FOR MX BASING MODES

In this section, the problems of providing effective C^3 for each of the principal basing modes are discussed and technically feasible solutions identified. In many instances, the C^3 system described for hypothetical future MX basing modes differs substantially from C^3 systems supporting present strategic forces. These systems would have to be acquired at some cost, though in no case (excluding launch under attack) is the C^3 system a major cost driver for the system as a whole. Moreover, some of the communications systems described would be useful for other military missions in addition to MX basing. OTA has only identified feasible C^3 systems and has not attempted to find a "best" solution. Also, the systems have not been subjected to the cost tradeoffs that could occur if a decision were made to deploy one of them.

The baseline MPS system is in full-scale engineering development and subject to certain budgetary constraints. it is therefore natural that the baseline system could be improved on (e.g., with regard to two-way long-haul communications) with additional funding. Since for the other basing modes similar funding constraints have not been applied to the C^3

systems described here, feasible improvements to the baseline MPS system—available at some additional cost — are identified.

Baseline MPS System

Preattack

Peacetime MPS C^3 operations would be accomplished principally through the fiber-optic network linking each shelter with the Operational Control Center (OCC) and with other shelters. Each fiber cable would contain three lines (one for communications in each direction and one spare) capable of 48 kilobit/second data rates. With such high data rates, launch orders and retargeting information could be transmitted in a very short time. Response time to an EAM would be driven by operational procedures and by the several minutes it would take the missile to emerge from the shelter and erect.

PLU would be maintained by having the missiles and simulators transmit encrypted status messages with identical formats according to uniform message protocols.

Transattack

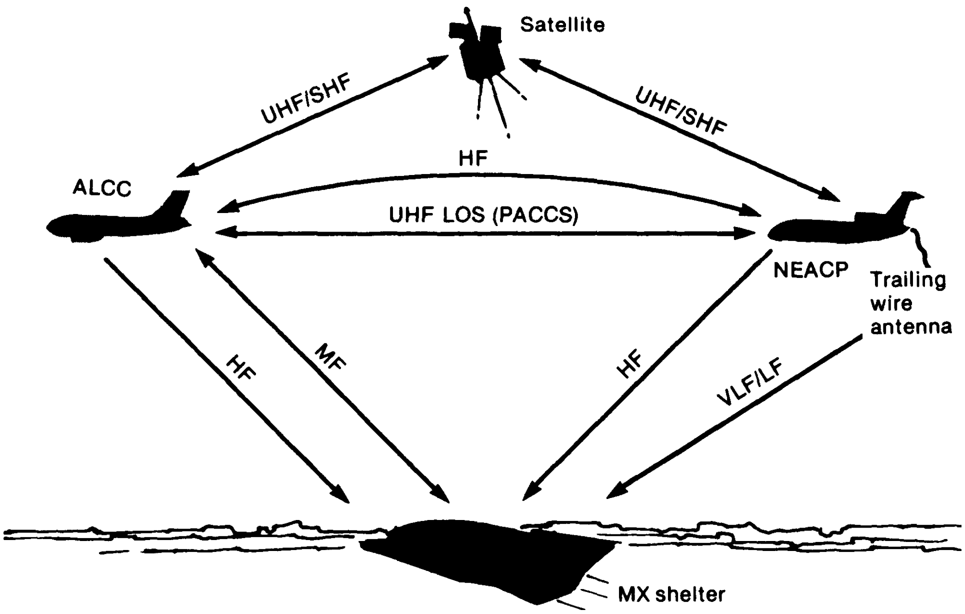
The transattack period is defined in this chapter to comprise the period of airborne operation of the ALCC and NEACP. One ALCC would always be airborne in peacetime, with another *on* strip alert. The in-flight endurance of the ALCC would be about 14 hours, after which communications would have to be accomplished from the grounded aircraft to the MPS shelters.

The transattack C^3 system for the baseline MPS system is shown in figure 124.

Communications between the ALCC and NEACP are relatively secure. Immediately after the attack, however, the HF and UHF SATCOM could be disrupted, and it would take some time to set up the UHF line-of-sight PACCS net.

Of the links from the ALCC to the shelter, HF (line-of-sight) could be disrupted by the nuclear environment, and MF represents a compromise between the better propagation of low frequencies through an ionized at-

Figure 124.–Communications System for Baseline MPS System (transattack)



SOURCE: Office of Technology Assessment.

mosphere and the higher data rates of high frequencies.

MF, which has short range, would be the only means in the present baseline system design by which the shelters could communicate with the ALCC to report their status. Transmission would be through the buried MF dipole antenna at each shelter. Taking into account soil propagation losses, the effective radiated power from each shelter would be only about 2 watts. The low power of the transmitter at each shelter would be multiplied by the "simulcast" technique where each surviving shelter *that contained an MX rnissile* would transmit its status via MF. Other surviving shelters receiving this message would repeat the transmission simultaneously with rebroadcasts by the original shelter. In this way, after many repetitions, all of the surviving shelters would be transmitting, in sequence, the status message of each individual shelter, with a total effective transmitting power of all the shelters taken together.

Since only the shelters containing MX missiles would be transmitting in this period, these emissions might reveal the locations of the surviving missiles if the Soviets could detect them. However, the short range of ground-wave MF would preclude direction-finding by remote ground stations or ships, and ionospheric absorption and refraction would prevent satellites from detecting and locating the emissions. Thus, this hypothetical threat to PLU may be impossible for the Soviets to capitalize on. This security from detection is one of the reasons why MF communication was chosen.

The simulcast would also be used to enable the surviving missiles to redistribute targets among themselves in order to maintain coverage of the highest priority targets. The missiles would be numbered I through 200, and for each SIOP option there would be 200 target sets, numbered 1 through 200 in priority order. Before the attack, missile #l would have target set #l, missile #2 target set #2, and so on. After the attack, missile #200 would listen on the MF simulcast for a status message from missile ##1. If missile #I did not report or reported that it was unable to fire, missile #200 (if it survived) would assume target set M. If missile #2 had not survived, its target set would be assumed by missile #199 (if it survived), and so on.

Transattack *two-way* communications between the ALCC and the missile force would rely exclusively upon the single MF l ink, Since MF is short-range, the ALCC would have to approach within 50 to 100 miles of the missile field in order to receive the MF simulcast and assess the status of the force. There could be concern for the effects upon the ALCC of dust and radiation lofted into the atmosphere by the attack.

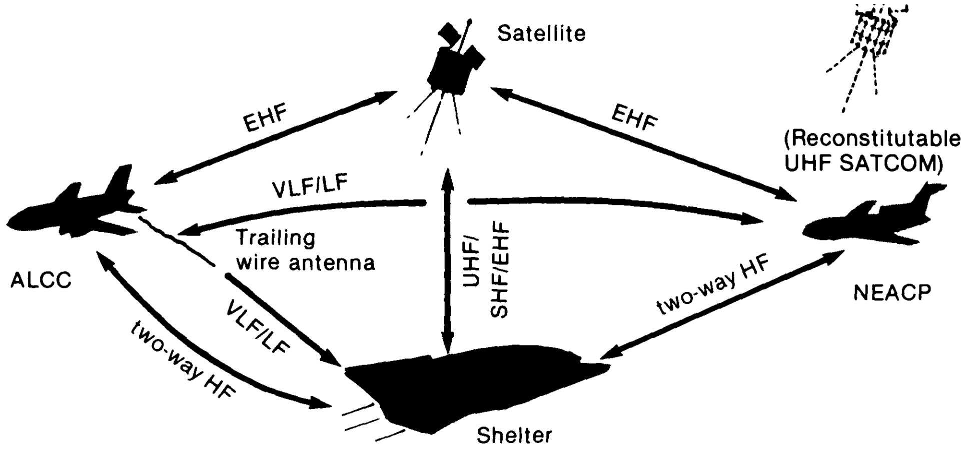
This situation could be improved by provialing HF transmitters (as well as receivers) and/or SATCOM terminals at the shelters, as shown in figure 125. A UHF SATCOM terminal would cost about $100,000, so SATCOM at each shelter would cost about $500 million.

Postattack

The postattack period, as defined for the purpose of this discussion, would begin when the airborne command posts (ALCC and NEACP) were forced to land, either to refuel or for extended grounded operations. The baseline C^3 system for this period is shown in figure 126. HF and MF skywave communications could be disrupted for hours or days after attack. The ground-wave communications would in any case be short range. The ALCC would have to be within 50 to 100 miles of the shelters or it would be out of MF range. The Soviets would not necessarily spare airfields this close to the deployment area. There would therefore be a need for long-haul two-way communications from the grounded aircraft to the shelters in the postattack period. This communication would be needed especially if the ALCC were inoperable, and the grounded NEACP had to communicate with the MX force over thousands of miles.

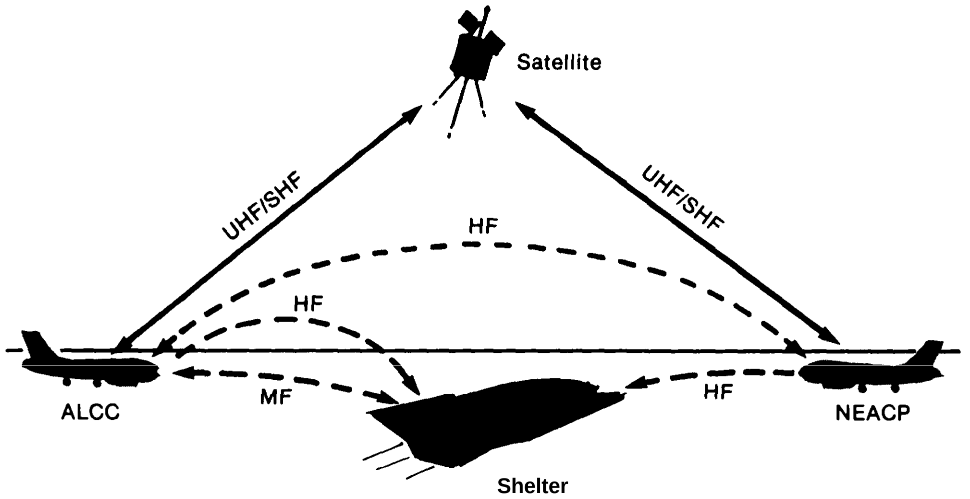
Means to provide these two-way long-haul communications that are *not* part of the present baseline design are shown in figure 127.

Figure 125.—Possible Additions to Baseline MPS Communications System (transattack)



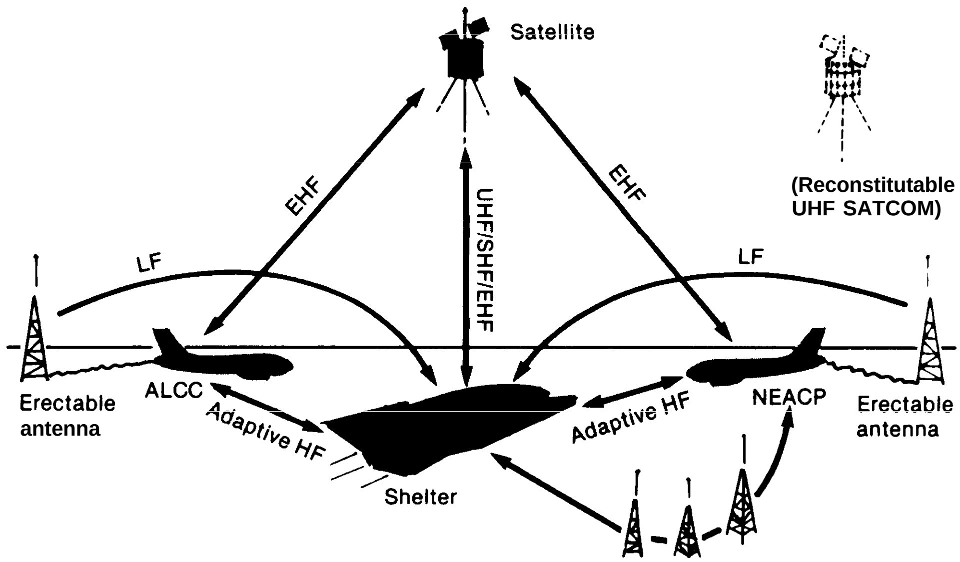
SOURCE: Office of Technology Assessment,

Figure 126.–Communications System for Baseline MPS System (postattack)



SOURCE: Office of Technology Assessment.

Figure 127.—Possible Additions to Baseline MPS Communications System (postattack)



SOURCE. Off Ice of Technology Assessment.

They include adaptive HF, ground-based HF or MF relays proliferated across the United States, satellite communications, and erectable LF antennas.

MPS Basing with LoADS ABM System

The two principal C^3 functions required if LoADS were added to MPS basing would be: 1) tactical warning of Soviet attack so that the LoADS defense units (DUS) could break out of their shelters and prepare to defend; and 2) communications to transmit a breakout order and authorization to activate the nuclear-armed interceptors ("nuclear release").

If the design goal providing for awakening dormant electrical equipment in the DU and breaking the radar and interceptor cannister through the shelter roof within a very short period of time could be achieved, warning of Soviet attack would not be required until late in the flight of the Soviet ICBM reentry vehicles (RVS). Means to provide such late warning (within 15 minutes of impact) could include rocket-launched sensor probes, sensor aircraft, and ground-based radars, in addition to satellites. Such warning sensors are discussed extensively in chapter 4. Radars similar to the LoADS radars themselves could be positioned at the northern edges of the deployment area. The sensors could provide attack assessment if such information were required to attempt to limit degradation of defense effectiveness in the face of a potential Soviet Shoot-Look-Shoot capability (see ch, 3). Without adequate warning for breakout, the LoADS defense would clearly be useless. If breakout occurred in peacetime as a result of error, the shelters containing the LoADS DUS would be destroyed.

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Though it might be feasible physically to activate the defense in a short time, the procedures whereby commanders assessed the warning information and ordered breakout and nuclear release could in practice lengthen the reponse time considerably. In the present LoADS command concept, breakout and nuclear release are effected by two distinct commands. The communications needed to support timely activation of the defense would depend on who was authorized to order nuclear release. Offensive nuclear release must be ordered by NCA. Whether authority for defensive nuclear release could be delegated to military commanders is unclear.

At the time the breakout and release orders were given, detonations of Soviet SLBM RVS could already have occurred in the deployment area and at other centers of the National Military Command System. MF injection from the ALCC might therefore be the only means to transmit the defense commands. If the ALCC operating area were expanded by using longer range communications (H F or VLF/LF) between the ALCC and the shelters, the lower data rates could lengthen the time it would take to transmit commands to the defense.

At present, uncertainties in the LoADS system architecture and unresolved operational procedures do not permit judgment on the feasibility of supporting the defense's warning and breakout needs.

If a LoADS defense were added to a vertical-shelter MPS system, the radar and interceptor cannister would have to be emplaced in separate shelters. In this case it would probably be necessary to deploy a separate communications network to support the rapid transfer of data from the radar to the interceptors in an engagement.

Launch Under Attack

Warning and communications systems to support reliance upon launch under attack are discussed extensively in chapter 4. Since these systems would be the only "basing mode" to speak of, considerable time, effort, and money would presumably be spent assuring their reliability in the face of determined Soviet efforts at disruption. As discussed in chapter 4, it would be technically feasible to deploy a wide variety of warning sensors and communications links to airborne command posts that, taken together, would be exceedingly difficult for the Soviets to disrupt. Such disruption could furthermore be made time-consuming and provocative.

What cannot be determined on the basis of technology alone is whether information provided by remote sensors would be adequate to support a decision of such weight as the launch of U.S. offensive weapons, whether procedures could be devised to guarantee timely decisions by NCA, and whether (given the complex interaction of human beings and machines operating against a short timeline) a bound could be set and enforced upon the probability of error resulting in catastrophe.

Small Submarines

Since seawater absorbs radio waves of all but the lowest frequencies of the radio spectrum, completely submerged submarines are confined to low data-rate receive-only LF, VLF, and ELF communications. Two-way communications and high data rates require putting either a mast antenna or a trailing buoy antenna above the surface. While the buoy or mast antenna itself poses essentially no threat to submarine covertness, broadcasts at moderate frequencies could reveal the locations of the submarines. E H F communications to survivable deep-space satellites such as have been proposed for a wide variety of military communications missions would permit high data-rate communications from submarines to commanders with essentially no risk to submarine covertness. Present U.S. fleet ballistic missile submarines use a variety of classified means for report-back.

This section describes a technically feasible C^3 system to support small submarine basing of MX. The system described differs somewhat from the C' system that supports present submarine forces and intends to provide the small submarine force with some of the attributes of a land-based missile force.

Preattack

SYSTEM DESCRIPTION

The preattack C^3 system is shown in figure 128.

The land-based VLF transmitters exist at present. The network provides worldwide coverage and would be more than adequate for the small submarine deployment area. The transmitters have high power, adequate anti-jam capability, and can transmit an EAM to submerged submarines in an extremely short time. There is also a worldwide LF network.

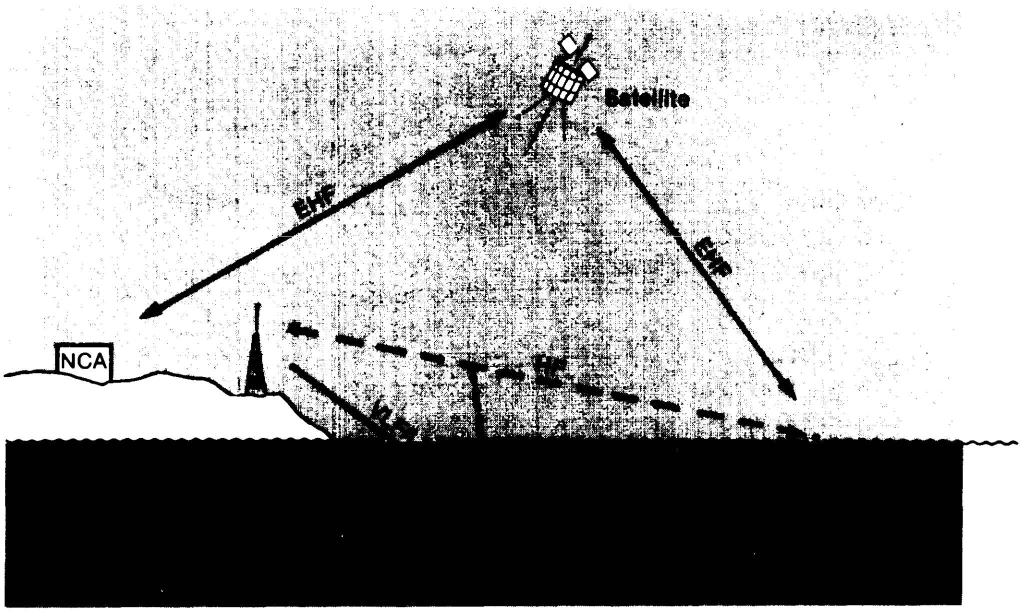
The EHF satellites do not exist at present, but a similar satellite (LES 8/9) has been deployed with great success. EHF frequencies are chosen because jamming them is virtually impossible, submarines can communicate with virtually no chance of betraying their locations, data rates are high, and small (5 inch) mast antennas can be used. Such satellites in deep-space orbits could be made exceedingly difficult for the Soviets to disrupt (see the discussion of ASAT in the Technical Aspects *of Strategic C3* section).

PREATTACK FUNCTIONS

peacetime covert operations could be accomplished in the same way as with the present submarine force copying VLF. The VLF network would also permit transmission of an EAM in an extremely short time. The SIOP would contain a timing plan, keyed to a reference time in the EAM, to allow the missiles to coordinate their time-on-target. Depending on where it was in the deployment area, each missile would calculate a launch time, reentry angles, missile maneuvers, and bus deployment to provide the required time-on-target coordination. Coverage and footprinting could be arranged by advance operational planning.

Ad-hoc targeting instructions for limited nuclear options could be assigned to 10 to 12 percent of the force that would be snorkeling at any given time. These submarines could be copying high data-rate SATCOM via their mast antennas. If a larger portion of the force were required for ad-hoc retargeting, the VLF net-

Figure 128.—Preattack C^3 System for Small Submarines



SOURCE: Office of Technology Assessment

work could direct more submarines to erect their masts or deploy awash buoys to copy other communications.

Report-back could be arranged, at no additional risk to the submarines, by having them transmit status messages via EHF SATCOM whenever they snorkeled. Classified means are used today for submarine report-back.

Transattack

SYSTEM DESCRIPTION

The transattack period is defined for the purposes of this chapter as the period when NEACP and TACAMO are airborne. This period would normally be the first 12 to 14 hours after attack plus additional periods if provision were made for extended operations. The transattack C^3 system is shown in figure 129.

The land-based VLF antennas are assumed destroyed in the attack, though this might not be true of the antennas on the soil of other nations. The EHF satellites are assumed intact.

There are at present several TACAMO aircraft in the Atlantic and a few in the Pacific. More Pacific TACAMOS are expected to support Trident operations. These TACAMO aircraft will be EM P-hardened.

Both TACAMO and the E-4B NEACP would be capable of transmitting an EAM directly to submerged submarines from their VLF trailing antennas.

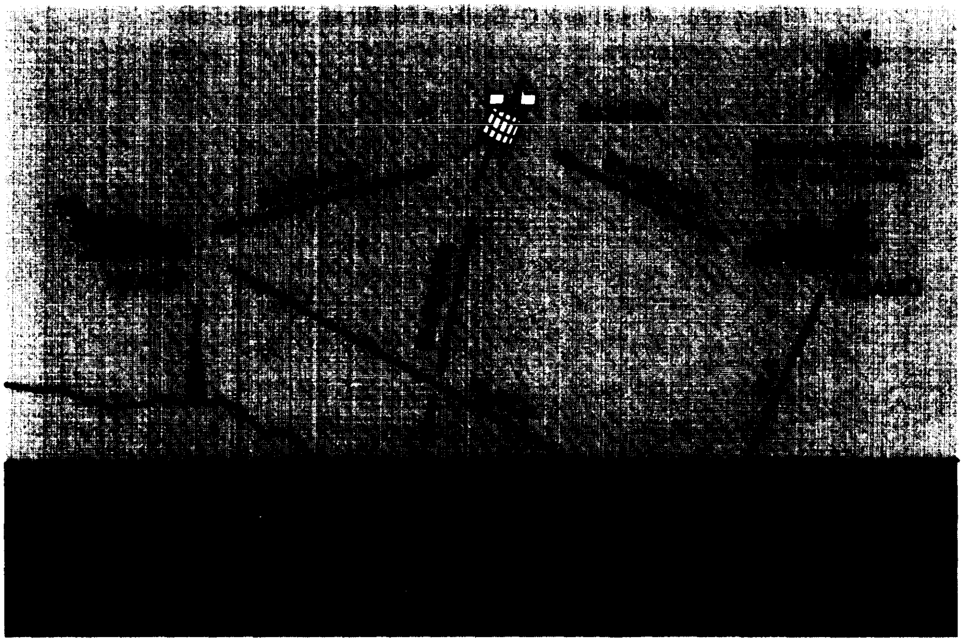
TRANSATTACK FUNCTIONS

Prelaunch damage assessment and targeting reoptimization would be unnecessary for the small submarine force, since it would be expected to be almost completely survivable.

EAM transmission could occur via VLF from TACAMO or NEACP. When the submarines lost communications with the land-based VLF transmitters, they would tune to TACAMO.

Ad-hoc retargeting would require high data rates and two-way communications, so VLF would not be appropriate. A short-coded message via VLF ordering certain submarines to come to depth and copy targeting instructions via E H F SATCOM would be a means to accomplish ad-hoc retargeting the transattack period.

Figure 129.-Transattack C^3 System for Small Submarines



SOURCE Office of Technology Assessment

Postattack

Two-way communications via EHF SATCOM could be available in the postattack period, and HF and UHF SATCOM could be reconstituted in this period as well. The postattack C^3 system is shown in figure 130.

Air Mobile MX

Preattack

The principal preattack C^3 requirements for an air mobile fleet would concern receipt of timely warning messages to support the fleet's high alert posture. A wide variety of reliable warning sensors, available at some cost, is discussed in chapters 4 and 6. The communications l inks from these sensors to commanders authorized to order dispersal of the fleet and from commanders to the alert airbases would presumably be used before the communications system had suffered extensive damage.

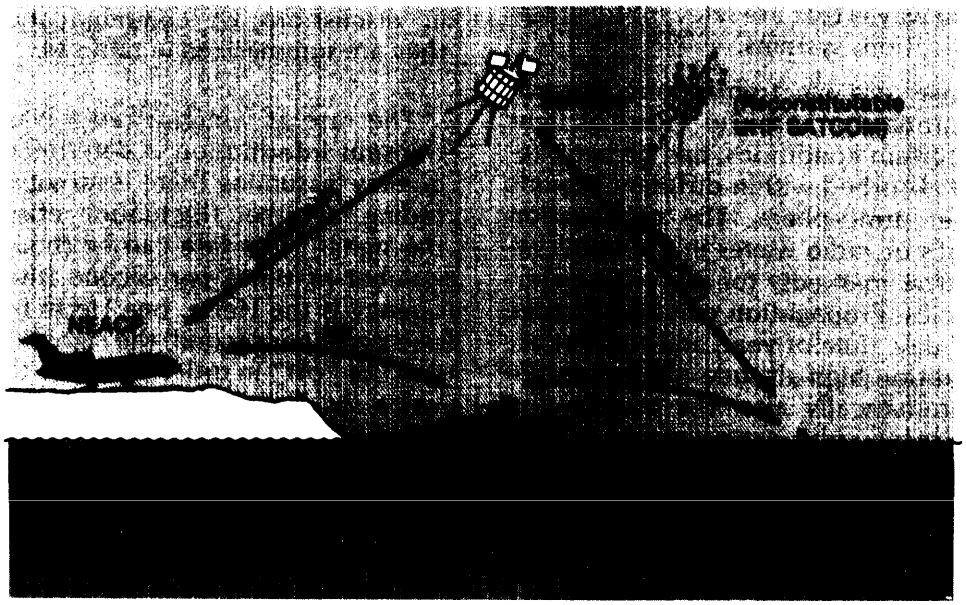
The responsiveness of an air mobile force to a launch order would be limited to the time—perhaps **10** minutes or so– it would take the aircraft to take off and climb to launch altitude.

Transattack and Postattack

The C^3 system to support the complex force management needs of the dispersed MX fleet would require at least teletype data-rate communications between each missile-carrying aircraft and command aircraft. The aircraft would be required to report their status, including remaining fuel supplies, and receive launch instructions. Targeting reoptimization would not be required if a substantial portion of the fleet survived the initial attack. The airborne fleet could make use of a wide variety of communications including UHF line-of-sight (including the PACCS fleet), adaptive HF, VLF/LF, and SATCOM, as shown in figure 131. The communications system itself would be low risk, the principal C^3 problems being associated with the need to manage the dispersed force, assess its status, and ready it for launch.

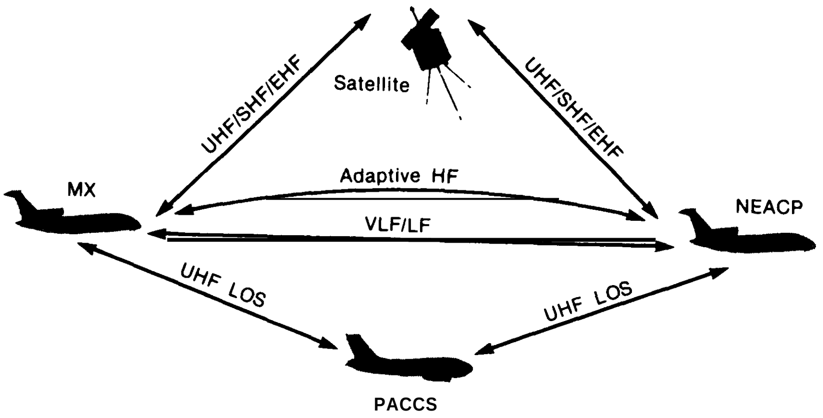
The problems of making provision for endurance beyond the few hours of unrefueled flight time are discussed extensively in chapter 6. If

Figure 130.—Postattack C^3 System for Small Submarines



SOURCE: Off Ice of Technology Assessment

Figure 131 .—Transattack Air Mobile MX Communications System



SOURCE: Office of Technology Assessment.

airfields survived for reconstitution, they would have to be located, their status assessed (including local fallout levels), and landing aids provided in advance.

Last, providing for missile accuracy comparable to land-based MX would require communications from Global Positioning Satellites (GPS) or a Ground Beacon System (GBS).

OVERVIEW OF RADIO COMMUNICATIONS

Radio Wave Propagation

This section discusses some of the characteristics of radio waves that are relevant to strategic communications systems.

Radio waves are electromagnetic disturbances that propagate with the speed of light and, under certain conditions, can be bent, reflected, and absorbed within different regions of the upper atmosphere. The propagation characteristics of radio waves in the upper atmosphere differ markedly for waves of different frequencies. Propagation can also change with time of day, time of year, and sunspot activity. In addition high-altitude nuclear explosions can dramatically alter the propagation characteristics of radio waves within the atmosphere. This circumstance has obvious and important implications for communications systems that may have to function reliably in a nuclear environment.

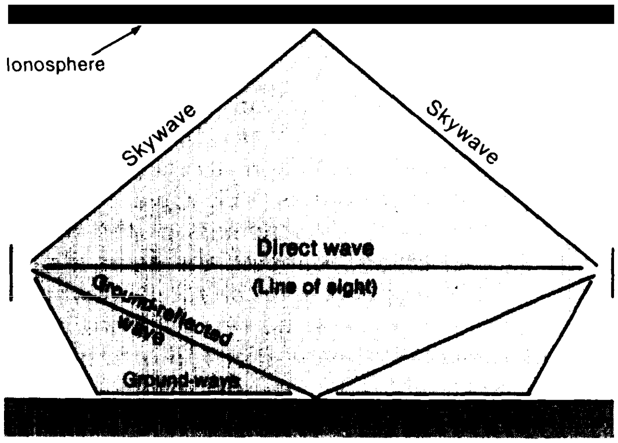
Radio communications bands are, by convention, referred to by different names. Since the names of these bands are commonly used in discussions of communications systems, they are summarized in table 34.

The rate at which a radio wave is able to transmit information is determined by its frequency (assuming there is no significant noise, fading, or other fluctuation effects mixed in the signal). This rate can be thought of as the number of times per second (the unit of frequency is the Hertz; one Hertz is the same as one cycle per second) the signal can be turned "on" or "off" in order to create the sound of a voice or to transmit information in other forms. This "on-off" rate can never be greater than the frequency of the wave since the frequency of the wave is in fact the number of times per second that the wave itself is turned "on and of f." A rough rule of thumb is that a radio signal can carry information at about 10 percent the rate of its frequency. Thus, if low-fidelity voice communication requires the transmission of a voice signal that has primary frequency components in the 1,000 to 2,000 cycle per second range, then the radio wave must have a frequency of at least 10,000 to **20,000** Hertz. This means that the lowest usable frequencies for voice communications lies in the upper end of the LF band. High-quality voice transmission would require the transmission of voice components at frequencies of order 10,000 to 15,000 Hertz, thus requiring frequencies on the order of several hundreds of kiloHertz. These frequencies lie in the lower end of the MF band or broadcast band, where commercial AM radio stations are licensed to operate. For situations that require particularly reliable signal reception and good rejection of noise, much higher frequencies are preferable, as is the case with high fidelity music transmissions that are transmitted in the VHF (FM radio) band. Still higher data rates may be required for transmitting enough information to construct pictures rapidly in time, as is the case in television broadcasting. Television information rate requirements dictate radio frequencies **in the VHF and UHF radio bands.**

Radio waves can be received between ground stations over several different physical paths If the stations are close enough together to have line-of-sight contact, they can receive "direct-wave" transmissions (see fig. 132). It is also possible to use different layers of the upper atmosphere to bend or reflect radio waves back toward the surface of the Earth for over-the-horizon reception (or for over-the-horizon radars). Signals received over such paths are called skywaves. Radio waves can also be reflected from the surface of the Earth, to the ionosphere, and back again toward the Earth. This phenomenon, which occurs mostly at lower radio frequencies, can result in the radio wave being "guided" along the Earth's surface for great distances. The radio waves are, in effect, trapped by the boundaries of the ionosphere and the Earth's surface.

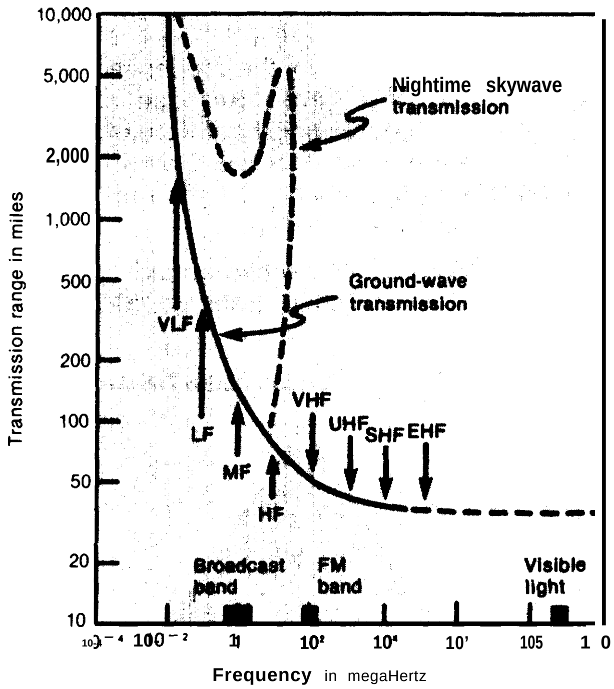
Figure 133 shows a graph of typical distances over which communications can be

Figure 132.—Physical Paths of Radio Waves



SOURCE: Office of Technology Assessment

Figure 133.—Electromagnetic Transmission Ranges at Different Frequencies



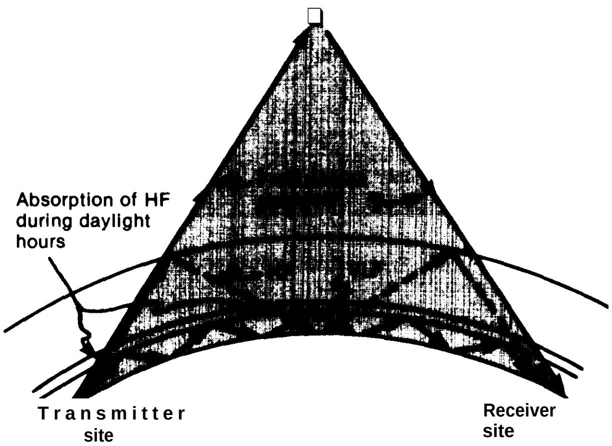
SOURCE. Office of Technology Assessment

achieved between ground stations using commonly available radio equipment. VLF signals (designated by an arrow at 10 KHz on the graph) can be reliably received at distances of many thousands of miles because they are guided along the Earth's surface by the boundaries on the ionosphere and the ground (fig. 134 shows the geometry of VLF over-the-horizon radio propagation). At higher frequencies encountered in the LF band, radio waves begin to suffer attenuation at the greater distances due to absorption. As a result of these effects, LF reception tends to be of shorter range than that of VLF waves. At still higher frequencies, less and less of the radio waves get redirected back to the Earth's surface by the ionosphere and the range at which radio transmissions can be received drops to the line-of-sight distance. (For radio transmissions, line-of-sight distances are approximately 40 miles. This distance is somewhat larger than visual line-of-sight distances.]

Many communications applications require high data rates in addition to long range and high reliability. High data-rate communication mandates the use of high radio frequencies. Since high frequencies are either not reflected or poorly reflected from the ionosphere, it is necessary that the transmitter and receiver have line of sight geometry if reliable communications are to be affected. One way of increasing the range of line-of-sight radio communications is to use airplanes.

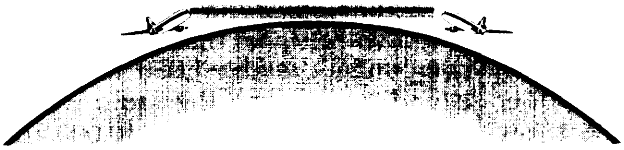
Figure 135 illustrates schematically the geometry for line-of-sight communications be-

Figure 134.— Over-the. Horizon Radio Transmission



SOURCE: Office of Technology Assessment

Figure 135.—Geometry of Aircraft Direct Path Communications



SOURCE: Office of Technology Assessment.

tween aircraft. As an airborne relay, line-of-sight transmission between aircraft can be affected over distances of approximately 400 miles using the HF and UHF bands. The aircraft can also communicate with ground installations over distances of approximately 200 miles at those same frequencies.

Another feature of aircraft communications links is that they are constantly in motion and are therefore difficult to target from great distances. For this reason, aircraft are particularly useful as survivable command posts, launch control centers, and communications relays.

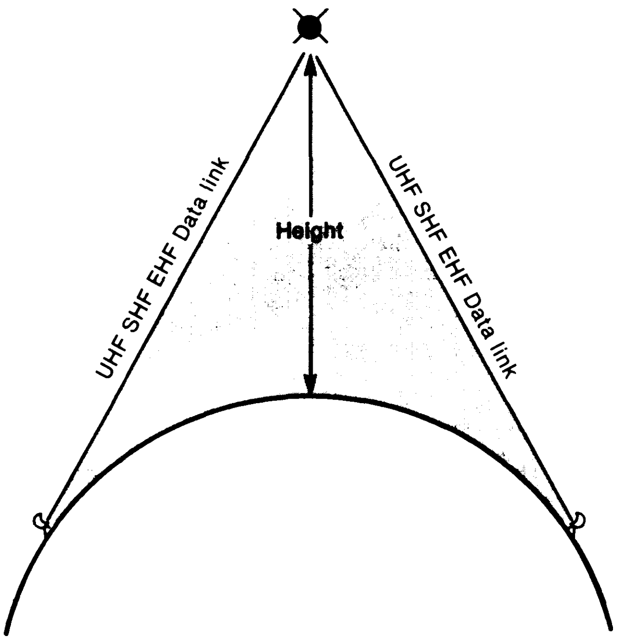
For still greater distances and high data-rate communications, satellites can be used as orbiting relays. The geometry of an orbiting satellite relay is shown in figure 136. A particularly convenient orbit used for long-range, high data-rate satellite communications is at a distance of 22,300 miles from the Earth. Satellites in orbits that lie in the plane of the Equator at that distance will always remain over the same point on the Earth's surface. For this reason, many communications satellites are put in such "geosynchronous" orbits.

Disruption of Radio Communications Due to Nuclear Detonations

Electromagnetic Pulse

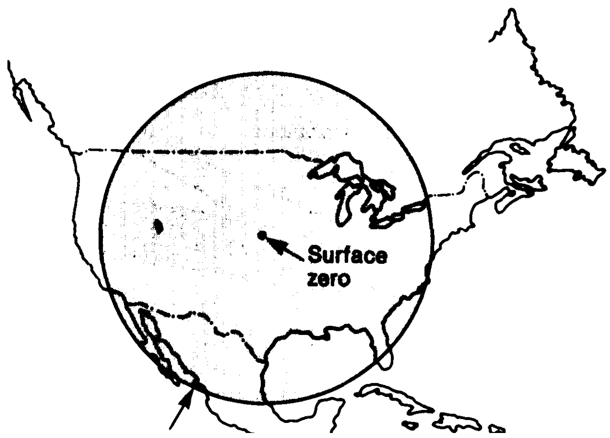
When a nuclear detonation occurs, a large number of gamma rays is emmitted by nuclei in fission and fusion reactions, resulting in an initial "gamma flash" of extremely high intensity. If the nuclear weapon is detonated at an altitude above the sensible atmosphere, the gamma rays from the weapon can induce extremely intense electromagnetic fields in the layer of air between 15 and 25 miles altitude.

Figure 136.—Geometry of Satellite Communications



SOURCE. Off Ice of Technology Assessment

Figure 137.-Electromagnetic Pulse Ground Coverage for High-Altitude-Nuclear Explosion



Height of burst = 190 miles

SOURCE: Off Ice of Technology Assessment

These electromagnetic fields will then propagate towards the surface of the Earth.

Nuclear-explosion-generated electromagnetic phenomena of this type are known as EMP effects. EMP fields are of great interest since they are sufficiently intense to represent a potential threat to the survivability of almost al I electronic equipment.

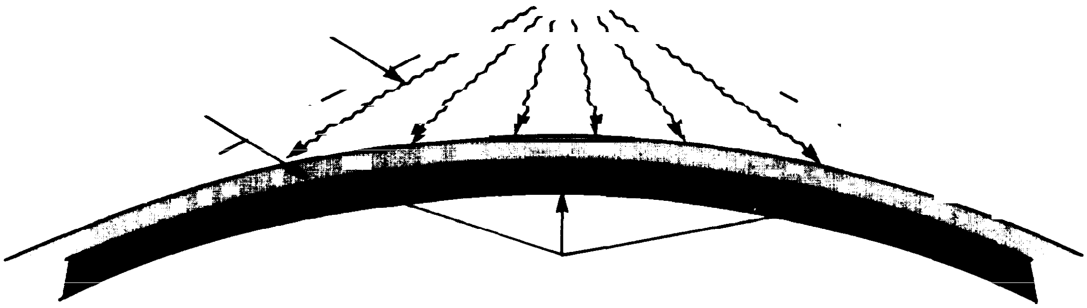
Figure 137 shows the area over which an intense electric field of 25,000 volts per meter or more would be generated by a nuclear explosion of several hundreds of kilotons yield at an altitude of 190 miles. The area affected essentially covers the entire United States and parts of Canada and Mexico.

The size of the area that could be affected by EMP is primarily determined by the height of burst and is only very weakly dependent on the yield. For example, the size of the affected area shown in figure 137 could be increased by 60 percent if the detonation height were increased to an altitude of 300 miles. Thus, severe EMP effects are possible over very large areas without the use of high-yield weapons.

The physical reason for the altitude dependence of EMP phenomena can be seen from figure 138. The tangent to the Earth from the burst point determines the maximum range at which the gamma rays can induce intense electromagnetic fields. The gamma rays initially generated by the exploding weapon deposit their energy in a band of the atmosphere between 15 and 25 miles altitude. The electromagnetic field that reaches the surface of the Earth is generated within this band of atmosphere. If the weapon is detonated at a greater height, the tangent will occur at a greater ground range from the surface zero point, and the extent of the gamma ray-induced band will also be greater.

During the initial period of a nuclear attack, intense electric fields from high-altitude-nuclear detonations could cause severe damage to electronic equipment. Powerlines, radio antennas, metal conduits, and other conducting surfaces would collect EMP energy like antennas and destroy or disrupt the electrical equipment to which they were connected. Even equipment that had been carefully designed to survive the effects of EMP could be temporarily disrupted for a period after a high-

Figure 138.—Origin of Electromagnetic Pulse From High-Altitude-Nuclear Explosion



SOURCE: Office of Technology Assessment

altitude nuclear detonation (for instance EMP-protected computers could be disrupted by loss of sections of memory or computation).

Ionospheric Disruption

Since the gamma rays from a high-altitude nuclear detonation can change the electron densities in very large regions of the ionosphere, the propagation characteristics of radio waves may change dramatically. A result of this change could be a "blackout" of radio communications.

Figure 139 shows the skywave paths of radio waves of different frequencies. The D layer of the ionosphere is responsible for reflecting VLF and LF radio signals. Nuclear explosions in or above the D layer would change ionization levels in the D layer. The effect of this change would be to lower the altitude at which VLF and LF signals would be reflected from the ionosphere. This effect could disrupt communications over long ranges, but it would be unlikely that VLF and LF communications would be blacked out by nuclear detonations.

MF radio propagation is normally limited to groundwaves because the MF radio waves get absorbed in the D layer before they can reach the upper layers and be reflected back to the Earth's surface. At night, when the lack of sunlight results in a drop in the ionization of the D layer, MF radio may propagate to fairly great distances (see the curve marked night-time skywave transmission in fig. 133). For this reason it is sometimes possible at night to pick up AM broadcasts from remote transmitters. Nuclear explosions in or above the D layer could blackout MF skywave communications for hours near the point of detonation.

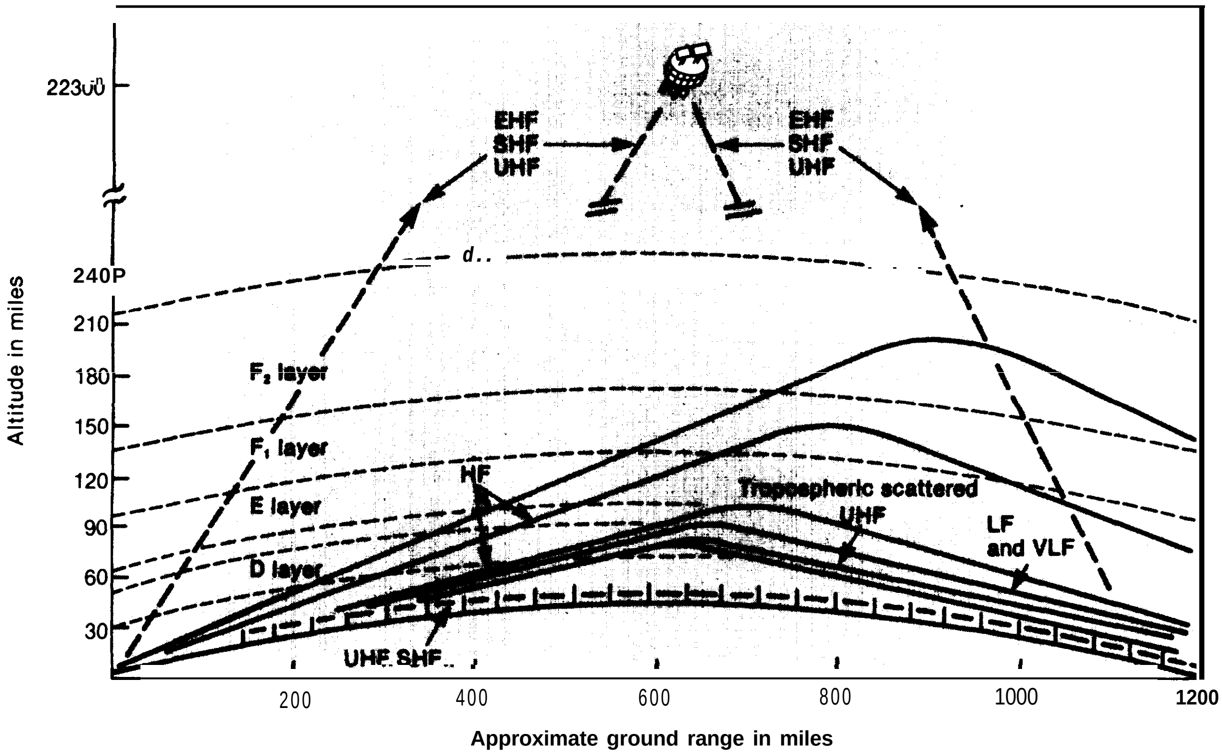
The HF band is used extensively for long-range communications. If conditions in the ionosphere are such that H F waves are not absorbed, HF waves will be bent back to Earth when they reach the E and F layers of the ionosphere (see fig. 139). HF is particularly useful for long-range communications because its frequency is high enough that large amounts of information can be transmitted and yet it is low enough that the ionosphere will bend it back to the surface of the Earth.

Nuclear detonations in or above the D layer could change ionization levels sufficiently to cause absorption of HF waves in the D layer. The changed ionization levels could also lower the altitude at which HF waves were reflected from the ionosphere (see fig. 140). This change could result in severely degraded HF communications for periods of minutes to hours.

A nuclear burst at an altitude of approximately 200 miles would be expected to disrupt HF communications over the same area in which severe EMP would be experienced. The blackout from such a detonation could last for hours.

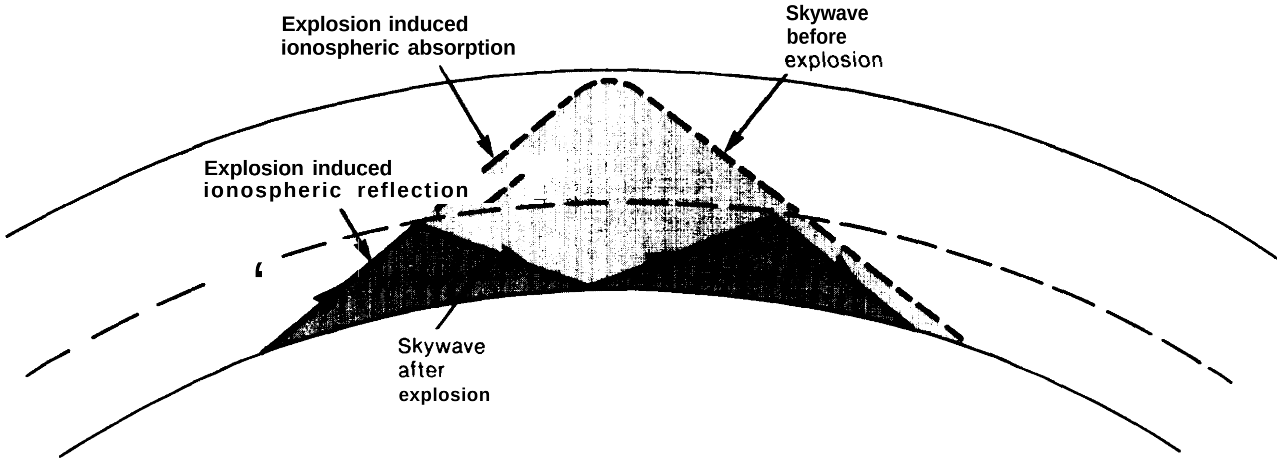
In bands above HF, most radio transmissions would suffer varying degrees of degradation through the ionosphere. However, provided satellites were not attacked, communications at these frequencies would probably not suffer severe degradation.

Figure 139.—Atmospheric Radio Propagation at Different Frequencies



SOURCE Office of Technology Assessment

Figure 140.— Radio Propagation Paths Before and After High-Altitude-Nuclear Explosion



SOURCE Office of Technology Assessment