Chapter 7

SURFACE SHIP BASING OF MX

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OVERVIEW

The object of basing the MX missile on surface ships would be to attain survivability by using both deception and large areas of ocean to exhaust or overwhelm Soviet ability to trail or maintain surveillance over the force. The fleet of MX-carrying ships would attempt to deceive Soviet trailers and sensors by looking like typical merchant ships. By operating within the 6,000- nautical-mile (nmi) range of Soviet targets, they could hide in between 50 million and 60 million square miles (mi^2) of ocean. Since the ships would have to look like merchant ships, they would not be fitted with a launch pad. Instead, the ships would unload missiles directly into the water, and fire them from a floating position.

Surface ships appear attractive as a means for deploying the MX because they are easy to build. Therefore, if a policy decision were made to deploy MX off land, it would be easier to build a fleet of surface ships than a fleet of submarines.

The choice of whether MX should or should not be deployed at sea is a matter of policy. Some of the views that argue for or against sea basing are presented in the discussion of small submarines (ch. 5).

In the discussion that follows, the features of surface-ship basing that are common to the concept are discussed first. Then a point design is presented and its survivability discussed. This section will be followed by a discussion of the accuracy, responsiveness, flexibility, and endurance that could be possible with a system of MX-carrying surface ships. In the final section, the cost and deployment schedule will be presented,

FACTORS COMMON TO ALL DESIGNS

Surface ships are large floating objects. Consequently they can be observed at very great distances, under a wide variety of conditions, by a wide variety of sensors. The long distances at which ships can be observed and the ease of identification of ships create opportunities for very effective trailing operations as well as for very effective wide area search. This circumstance is fundamentally different from that of submarines.

In order to compensate for the fact that ships can be observed at great distances with modern sensors, the ships would be disguised to look like merchant ships and would patrol in very large areas of the ocean. They would sometimes mingle with other merchant ships in busy shipping lanes and at other times they would patrol in areas where Soviet surveillance is believed to be poor. The ships would have a speed sufficient to outrun trailing trawlers and commercial ships, light defensive armaments, and electronic jamming and spoofing equipment.

A large fleet of MX-carrying surface ships would pose a considerable threat to the Soviet homeland and to Soviet strategic weapons systems. It could therefore be expected that the Soviets would be unlikely to ignore such a threat, and in response, might commit substantial resources to trailing and surveillance. Since Soviet ships would have to make long transits to and from home ports before attempting to trail MX-carrying surface ships, this deployment would result in a considerable expenditure of Soviet resources. This tactic could create resource problems for the Soviets and force them to divert resources from other military commitments.

The counter problem, from the American point of view, is that confidence in the survivability of the surface ships would be low.

There would be periods of time when the weather in the Northern Hemisphere would favor surveillance, tracking, and trailing. During these periods there would always be the possibility that large fractions of the fleet would be under surveillance or trail.

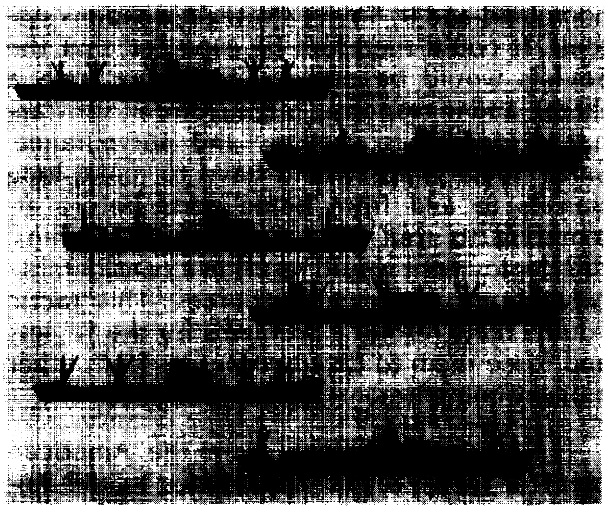
Under certain operational conditions, survivability of the force could depend on maneuvering duals between the trailers and the trailed ships. As adversaries developed familiarity with each other's operational procedures and capabilities, the initiative could constantly shift from one force to the other. The constantly shifting tactical momentum between the different forces would have much of the unpredictability of a classical "war at sea" as forces maneuvered about, attempting to maintain an advantage. This situation could result in serious doubts in the minds of the public and decisionmakers about the survivability of the force in times of crisis.

The result of this constantly shifting circumstance would be that the vulnerability and the survivability of the fleet would constantly fluctuate. If the fleet were vulnerable during a time of crisis, a substantial incentive would exist to preempt before the opportunity was lost.

SYSTEM DESCRIPTION

The fleet of MX-carrying surface ships would be made up of 30 fast merchant-like ships with movable superstructures, false hatches, and movable cranes and booms (see fig. 95). This equipment would allow them to change their appearance and complicate the process of radar satellite tagging of the ships. The ships would, in addition, be rigged with multiple sets of navigation lights so they could be made to change appearance to night observers. The ships would be constructed of lengths varying between 550 and 650 ft and would have a displacement of between 15,000 and 20,000 tons. They would have an unrefueled-at-sea endurance of about 20,000 nmi assuming a patrol speed of about 20 knots. The ships would also have high-speed gas turbines in order to reach the 30 + knot speeds needed to break trail.

Figure 95.—Topside Arrangements



SOURCE: Office of Technology Assessment.

The ships are assumed to have an at-sea rate of about 80 percent (60 days at sea and 15 days in port). Missile reliability, extended refits and overhauls will result in a ship availability of less than 80 percent. (See ch. 5 for and explanation of the effects of overhaul, extended refit, and missile reliability on the availability of ships.) If survivability fell below 50 percent, it would require an increase in the number of ships if the fleet is to be able to maintain the requisite number of survivable missiles on station. As will be demonstrated in the section on survivability, an assessment aimed at optimizing the at-sea rate and overhaul rate is not justified in light of the very large uncertainties associated with survivability.

Each ship would carry 8 to 10 MX missiles so that 200 MX missiles would be at sea at all times. This total would be an adequate number of MX missiles if the ships had a survivability rate of 50 percent. The conditions under which such a survivability rate might be achieved are discussed below in the section on survivability).

The ship would be equipped with Trident-like navigation and communications suites. Antenna masts would be disguised to look like normal merchant equipment or would be recessed so they could not be observed by aircraft, other ships or satellites. Jamming and electronic countermeasure equipment would also be available on the ship to aid in defense and to help confuse potential trailers. In addition to the Trident inertial navigation system, the ship's navigation suite would be equipped with a gravity gradiometer (assuming such gradiometers are successfully deployable on surface ships) and a system for interrogating acoustic transponders.

The ships would also be equipped with a sonar system that could be extended or withdrawn from recesses under the hull. This would give the ship a modest active and passive sonar capability against trailing submarines. It would also be possible to mount a far more capable sonar array on the bottom of the hull but this would be observable to submarines or divers and could be used as a means of "sorting" ships while at sea or in port.

Since the ships would have to be indistinguishable from merchant ships, their acoustic outputs would have to be comparable with those of merchant ships. Since merchant ships are considerably noisier than combat ships, it would be considerably easier for a distant trailing submarine or surface ship to maintain contact with the aid of a passive sonar system once the MX ship has been taken in trail.

The ships would have an onboard security force to protect the missiles and nuclear weapons in the event of an incident at sea. This force would be armed with conventional small arms and would also man the ships' defenses. Defenses might include heavy machine guns, rockets, cruise missiles, and light cannon. Perceived needs for heavier armaments would have to be balanced against the need to maintain deception. Provision would also be made for the destruction of the nuclear weapons as a measure against the possibility of a successful boarding.

A system of 150 acoustic transponder fields would be secretly emplaced in the 50 million to 60 million mi^2 of the surface-ship deployment area. The transponder fields would make it possible for the ships to obtain extremely accurate velocity and position information for the missile guidance system prior to a launch. In the event of a need to use these transponder fields, the ships could proceed at 30+ knots to the nearest field. Fleet deployment to the fields could be affected within 11 to 12 hours.

The MX missile guidance system could be modified in a number of ways in order to achieve high accuracy at sea. A minimal modification would involve the development of software optimized for a purely inertial guided sea-based MX. A more involved modification of the guidance system would involve the use of a star tracker in conjunction with the MX inertial measurement unit. Still another modification of the guidance system would involve the use of radio beacons in conjunction with the MX inertial measurement unit. These methods of guidance, and their capabilities, are discussed in detail in the section on submarine basing of MX.

An additional activity aimed at achieving improved accuracy with the surface-ship-based MX would involve the measurement and use of gravimetric data for the deployment areas in which the ships operate. These data would then be used to correct for gravitationally induced missile guidance errors along flight trajectories.

The ships would deploy from two bases on the east and west coasts of the continental United States. These bases would have special shore facilities for assemblage, storage, and handling of MX missiles. In addition, explosive handling loading docks would be constructed so that damage from an accidental ignition or explosion of rocket propellant would be limited to the loading facility.

OPERATIONAL CONSIDERATIONS

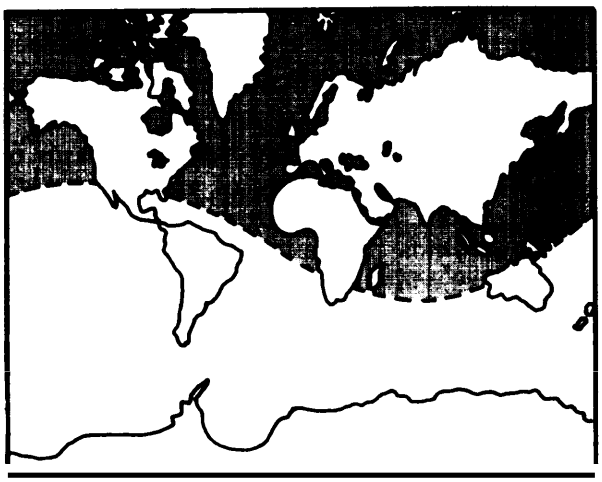
The fleet of surface ships would operate in an area as large as 50 million to 60 million mi^2 (see fig. 96). There would be a goal of operating in as large an area as possible to decrease the likelihood of surveillance. This goal would be constrained by the need to stay within missile range of Soviet targets.

The ships would attempt to remain covert using a variety of techniques. They would fly the flag of the country of registration and display the hull identification markers of a merchant ship.

The pattern of deployment would take advantage of shipping lanes, bad weather, day/night cycles, and intelligence on Soviet patrol activities. The ships would be in constant receipt of shore-to-ship very low frequency (VLF) signals. Since the ships would be on the ocean surface, they could also monitor shore-to-ship high frequency (H F) transmissions and satellite transmissions on a continuous basis.

There would be an operational need to report back to National Command Authorities (NCA) on a regular schedule to prevent the Soviets from attritting a large part of the fleet without U.S. knowledge. In addition, there could be concern about the potential piracy of the nuclear weapons loads.

Figure 96.—Surface Ship Deployment Area



SOURCE: Office of Technology Assessment

Report-back could be accomplished through high-orbit millimeter wave satellites. A 5-inch dish antenna could be used to report back to NCA on a regular basis. Since the beam from the ship-borne antenna would be very narrow, there would be a very low probability of transmissions being intercepted. The antenna would normally be recessed within a section of the ship so it could not be observed from other ships, aircraft or high-resolution satellite photography.

The ships could constantly monitor their position using the Global Positioning System (GPS) anywhere in the deployment area. On a command to launch, the missiles could be slid into the water from ramps deployed to the rear of the ship and fired from a floating capsule container.

Since sliding missiles into the water would be visible to a trailing observer, such a procedure would invite preemptive sinking of the ship. An alternative method of launch would be to carry the encapsulated missiles inside the hull and launch them through the bottom of the hull as the ship moves forward. The encapsulated missile would then rise to the surface behind the advancing ship. Upon broaching the surface of the water, its engines would be ignited and it would fly out of the capsule. In this manner, it would be possible to launch the missiles without providing a trailer with tactical warning of a launch.

Another possible means of obtaining navigational fixes would be to use the acoustic transponder fields that had been placed throughout the deployment area. If the GPS were attacked, these fields could be used when the the Ship's Inertial Navigation System (SINS) has to be reset. Deployment to acoustic transponder fields would take 11 to 12 hours, well within the period of time needed between updates (see ch. 5 for a more complete description of the SINS capabilities).

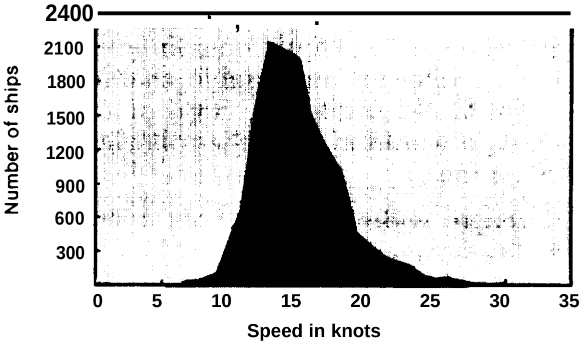
SOVIET DATA COLLECTING ACTIVITIES RELEVANT TO THE VULNERABILITY OF MX-CARRYING SHIPS

The MX-carrying surface ship would carry 8 to 10 cannisterized MX missiles and would displace about 15,000 tons. The need to carry a heavy load of cannisterized missiles, to maintain at-sea endurance, and to have a high-speed capability dictates the size class of the ships.

Table 30 presents Department of Commerce statistics on the number and displacement of ships in the world. There are 5,094 ships with displacements greater than 10,000 tons and 1,561 ships with displacements over 15,000 tons. There are 130 ships with displacements over 15,000 tons that fly American flags.

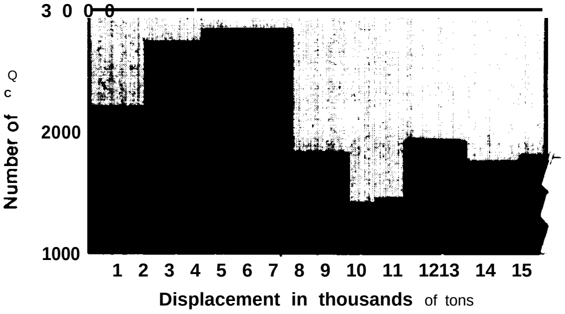
Figure 97 is a plot of the number of merchant freighters in the world **versus** speed. As can be seen from the plot, there are very few merchant ships in the world capable of being used to trail an MX ship with a 30 + knot burst speed. The bar graph in figure 98 shows the number of merchant freighters as a function of displacement. The graph shows that there are 1,400 to 1,500 merchant freighters in the world with displacement greater than 15,000 tons and about 1,400 merchant freighters with displacements between 13,000 and 15,000 tons. Between 1,500 and 3,000 of the world's 24,000 ships would be in a class that could potentially be mistaken for MX-carrying ships.

Figure 97.—Speeds of World's Merchant Ships



SOURCE: Department of Commerce

Figure 98.— Displacements of World's Merchant Ships



SOURCE: Department of Commerce

Table 30.—Number and Displacement of Ships in the World

World ships over 1,000 gross tons				
Total number of ships	Passenger and cargo	Freighters	Bulk carriers	Tankers
24,511	487	14,410	4,651	5,233

Merchant-type freighters *over 1,000 gross tons*				
World total	Foreign flag	U.S. flag total	Private	Government owned
5,094	4,657	437	260	177

Merchant-type freighters over 15,000 *gross tons*				
World total	Foreign flag	U.S. flag total	Private	Government owned
1,561	1,431	130	125	5

SOURCE: Department of Commerce.

Any sensible Soviet reaction to the deployment of MX-carrying surface ships would involve the cataloging of surface ships of the world. Such a catalog would include all free world surface ships of length, width, and displacement similar to that of the MX surface ships. The catalog would contain information about all relevant measurable characteristics that could aid in identification of the ships. Such data would include the following list of information:

- length, width, and draft of the ship;
- displacement;
- propulsion (steam, gas-turbine, diesel);
- side-view profiles;
- radar signatures at different frequencies;
- infrared signatures; and
- acoustic signatures.

Other ship features useful in "tagging" ships would be such identifiable characteristics as hull length-to-width ratios; hull shapes; wake characteristics; and the positions of hatches, booms, and lifeboats. Much of this data could be obtained from standard sources on commercial shipping and the rest could be obtained by making measurements while ships leave and enter commercial ports. Data could also be collected by trawlers, surface combatants, satellites, submarines, and airplanes. These data could be correlated with data collected by shore observers on the characteristics, numbers, departure times, and destinations of merchant ships in deepwater ports around the world.

In the discussion that follows, it should be kept in mind that this background of data collecting would be an ongoing process, constantly being refined and updated, so that radar, infrared, optical, and acoustic data would be available for purposes of "sorting" ships.

THREATS TO MX SURFACE SHIPS

The threats to a surface ship fleet fall into two broad categories:

1. continuous trailing of the MX ships so that a coordinated attack could be executed at will, and
2. wide area trackin$_g$ of the surface fleet so that MX ships could be localized well enough to attack at will.

Continuous trailing would most likely be attempted by picking up the ships as they egress from known operating ports. Ports from which ballistic missile ships operate would have special facilities for loading MX missiles onto the ships. Since the missiles are very large and there are strict explosive handling safety requirements, these facilities would be easily identified by onshore agents or satellite reconnaissance. Ships that are pulled up to these docks could either be photographed by satellite or observed by onshore agents. These data would be added to the Soviet computer catalog of ship characteristics.

Wide area, open ocean search could be attempted with aircraft, satellites, or over-the-horizon radar systems. Since the area in which the ships would operate would be enormous, search by aircraft would be very difficult and expensive. Optimistically, a fleet of 600 to 800 long-range surveillance aircraft and 100 to 200 airborne refueling tankers would be required to localize enough ships in a short enough time to be able to destroy a large fraction of the force. Other wide area search techniques that would be more promising include infrared, optical, and radar search using satellite-borne sensors and over-the-horizon radar search using frequency scanning radars.

Continuous Trailing

A potential Soviet response to the deployment of a fleet of MX-carrying surface ships could be to deploy a fleet of surface ships to maintain and establish trail on MX ships operating at sea. If a high percentage of MX ships could be brought under trail, a preemptive strike could result in the loss of a large part of the MX fleet.

Establishing and maintaining trail at sea is not likely to be a simple matter. The success or failure of such operations will depend on the capabilities of the trailing ships, availability of support forces to aid the MX ships, tactics, and environmental conditions. There are also political and legal factors that could affect the activities and tactical options of both the trailing and trailed ships. Such factors are difficult to analyze in technical terms, since they basically involve violations or reinterpretations of international law of the sea. Operations or tactics that would require routine violations of international law are therefore not considered in detail in the technical assessment to follow.

In order to trail a fleet of MX-carrying surface ships, the Soviets might build a new type of surface ship with the necessary speed and endurance to transit from home ports, trail the MX ship for 60 days, and transit back home for resupply and refit. The surface ships would be equipped with surface search radars, infrared and optical search systems, and facilities for handling remotely piloted vehicles and/or helicopters. They would also be equipped with surface-to-surface cruise missiles, torpedoes, and possibly cannon. Possible ports from which the ships would operate might be Cuba, or Murmansk, Petropavlosk, and Vladivostok. Table 31 shows transit distances to ports that might potentially handle the surface ships.

In order for Soviet ships to continuously trail MX ships, one or more of these ships would have to be available to trail ships as they egressed from port. Figure 99 shows a possible schedule for keeping track of MX-carrying surface ships. The middle horizontal time line shows the total cycle for a Soviet ship-trailing mission against MX-carrying surface ships. The ship first transits to the port from which the MX ship operates, waits outside the port until the MX ship leaves on a sea patrol, trails the MX ship for the sea-patrol period, transits back home, and undergoes refit and resupply in its home port. The top and bottom horizontal time lines in figure 99 show the activities of

Table 31.–Operational Factors Affecting Fleet of Soviet Trailing Vessels

	Transit[a] distance (nmi)	Transit[b] time (days)	Base[c] loss factor	Required[d] number of ships
Murmansk to Norfolk	4,300	17.9	1.51	1.78
Murmansk to Cuba	4,600	19.2	1.53	1.80
Cuba to Norfolk ... , ...	870	3.6	1.23	1.45
Cuba to Charleston	610	2.5	1.20	1.41
Petropavlosk to Seattle	3,600	15.0	1.46	1.72
Petropavlosk to San Diego	2,800	11.7	1.40	1.65

[a] One-way transit distance,
[b] Two-way transit time assuming 20-knot average transit speed.
[c] Assumes ships spend 5 days In ref!t and an average of 7 days on Port watch waiting to pick up MX ships leaving port.
[d] Assumes that 15 percent of the tra!ling ships are In overhaul at all times.

SOURCE: Office of Technology Assessment

other trailing ships that are either transiting from home base to take up position outside of port or transiting to home bases after having completed an at-sea trailing mission. The number of ships needed in order to keep one ship constantly available for trailing at sea would then be given by the expression:

$$B_{lf} = \frac{3\ (\text{total cycle time}) - 2\ (T_{pw} + T_{trail})}{(\text{total cycle time})}$$

where:

B_{lf} = base loss factor

total cycle time = $2\,T_{transit} + T_{pw} + T_{trail} + T_{refit}$

T_{pw} = time spent in port watch

T_{trail} = time spent trailing surface ship

$T_{transit}$ = time spent in transit to or from home port

T_{refit} = time spent in port for refit

The base loss factor Blf is simply the number of ships needed to keep a single ship on station at all times. Additionally, this factor must be adjusted for the percentage of ships that would be unavailable due to major overhaul activities in shipyards. The required number of ships would therefore be given by the expression:

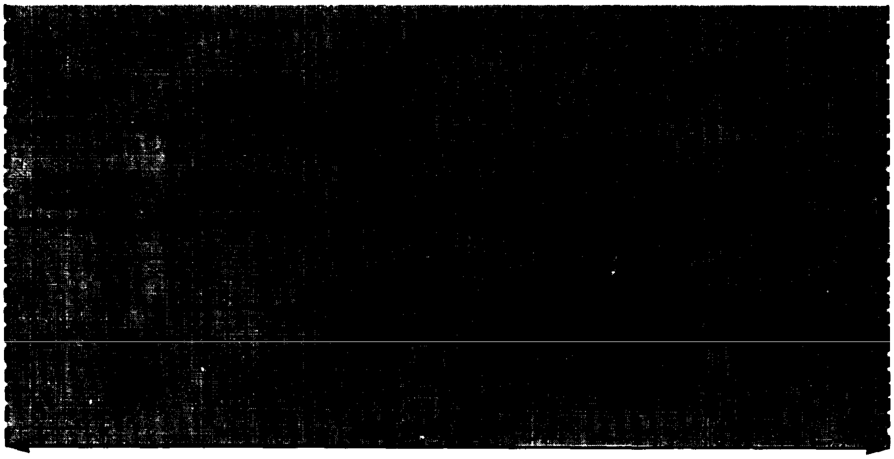
$$\text{Total number of ships required for trailing} = \frac{(\text{number of MX ships})\ (B_{lf})}{(1 - F_o)}$$

where:

F_o = fraction of time ships in overhaul

Table 31 shows typical transit times to and from different Soviet ports to ports from which

F gu e 99 T a ng Cyc e Aga ns MX Ca ry ng Su ace Sh ps



SOURCE: Office of Technology Assessment

MX missile ships might operate. The base loss factors and number of ships necessary to continuously cover different ports are also presented. These factors were calculated assuming Soviet ships spend an average of 5 days in port changing crews and being resupplied and an average of 7 days on port watch waiting to pick up a trailing ship. It would therefore be necessary for the Soviets to build a fleet of 45 to 50 ships in order to have a ship continuously available at sea to pick up and trail surface ships as they leave port.

Initiating trail as the ship leaves port could be a potentially complex operation. A line of reconnaissance ships could be set up outside the port using relatively slow and inexpensive trawlers to patrol sectors of line. Onshore observers could also be used to inform ships on the line of departure of a surface ship. Surface search radars could be used to detect the egressing surface ship and imaging radars could be used as an aid to identification in fog. At night, infrared sensors and TV cameras could also be used. The ships on the reconnaissance line could also be equipped with remotely piloted helicopter vehicles and fixed-wing remotely piloted vehicles. These aircraft could be launched in good or bad weather to help cover large areas of the ocean. They would also be of use if multiple ships egressed from port and it was necessary to obtain a high-resolution look at several ships in order to identify the MX-carrying ship. The number of fast-trailing ships kept on station outside the port would always be greater than or equal to the number of MX ships in port at any one time. Multiple egresses and surging of MX ships would be possible to complicate port-watch operations but this would have to be balanced against a requirement to keep missiles on station. If the missile ships were surged too often, it would result in periods where the United States would have more than the desired number of missiles on station and other times when the United States would have less than the desired number of missiles on station.

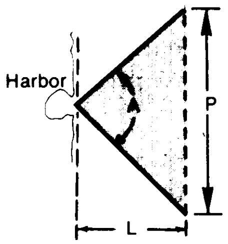
The number of ships required for the reconnaissance barrier can be estimated by considering the geometry of a port egress, number of MX-carrying ships in port, the range at which an MX ship can be detected, the barrier ship's ability to identify a ship as an MX carrier, and the rate at which multiple ships could exit the port. Figure 100 shows the geometry of a port egress for a range of exit tracks. The length of the barrier is:

$$\text{barrier length} = 2L \frac{\sin A}{1 + \cos A}$$

where:

L is the territoriallit-nit

Figure 100.—Geometry of Barrier Outside a Port With Unobstructed Access to the Sea



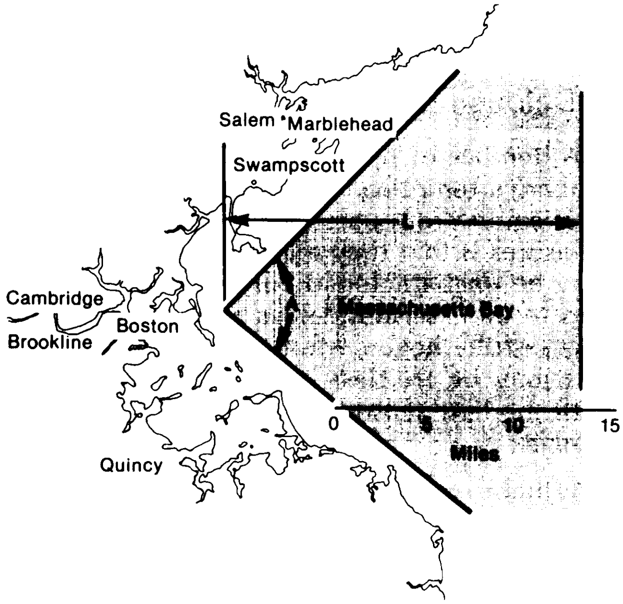
SOURCE: Office of Technology Assessment

Assuming that the territorial limit is 12 miles and the ships can exit within a cone of 150 the barrier length would have to be about 45 miles long. This geometry could apply to ports like San Diego, Charleston, Seattle, and San Francisco. Ports like New York and Boston have considerably more constricted access to the sea and would therefore require shorter barriers (see fig. 101). The average number of merchant ships leaving three major American ports are listed below:

Port	*Average number of exits per day*
Boston	10 to 20
New York	60 to 80
San Francisco	30 to 50

Two extreme cases are of interest: Ships exiting port at a uniform rate over a 24-hour period and ships exiting port at a maximum rate at one time. A maximum rate might be estimated by assuming that the ships would maintain 1,000 yd between them and exit at 10 knots. The maximum rate would therefore be one ship every 3 minutes. If the exits occurred during conditions of poor visibility, the ships might instead maintain a 2,000- to 3,000-yd distance and exit at 5 knots. This exit process would make the maximum rate one ship every 12 to 18 minutes. If the displacements of the exiting ships reflected that of the world's ocean going ships, 15 to 25 percent of the ships would be 15,000 tons or over. Thus, assuming a very busy commercial port could be used for deployment of nuclear armed MX ships, an exit rate as high as three to five ships an hour in the 15,000-ton class could be leaving port during peak periods of shipping. These ships could possibly be MX carriers and might have to be inspected at close range by the barrier patrol ships.

Figure 101.—Geometry of Barrier Outside a Port With Obstructed Access to the Sea



SOURCE Office of Technology Assessment

In actuality, it would probably not be necessary to inspect all these ships closely, since onshore observers could collect information on sailing schedules and send confirmation to the offshore ships on the sailing of the ship. It would therefore be necessary only for the barrier ships to leave their stations if it appeared that more ships of the right size were crossing the barrier than expected.

Assuming that the barrier ships used surface radars with a range of 5 miles, five ships would be required to maintain a constant barrier patrol. This total might be an adequate number for average peak sailing periods. Since the barrier ships would more closely approximate trawlers rather than the more expensive trailing ships, a prudent and determined adversary might commit two or three times as many ships.

If the port was not a major commercial port, then peak exit rates could only occur if several ballistic missile ships exited at the same time. Since scheduling of trailing ships would be responsive to such fluctuations, additional long-range trailing vessels could be on station.

"Delousing" of Trailers at Port Egress

A number of options are available to ships that are attempting to "delouse" themselves as they egress from port. The problem with such measures is that they may involve tactics that may be uncharacteristic of merchant ships or may result in serious delays before the patrol is successfully begun. More serious yet, the tactics may be fruitless against ships equipped with modern sensors. These tactics might in-Clude:

1. make repeated exit attempts until free,
2. use alternate port exits when available,
3. coast run to avoid the port watch barrier,
4. take advantage of dark and bad weather,
5. utilize military escorts to harass barrier ships, and/or
6. jam barrier ship sensors.

Tactics 1 through 4 would be very difficult to use successfully against ships equipped with modern sensors. Tactic 5 could create a large number of incidents that could have international repercussions. Tactic 6 would be very difficult to do if the ships were equipped with high-quality radars with good beam-forming and anti jam signal processing.

The success or failure of trailing operations would depend in a sensitive way on many details of ship operations, on the resolve of the trailing and trailed ships, the quality of the equipment available to each side, and on the resourcefulness of the different ship commanders. If the adversary is determined to commit the resources to establish trail, there appears to be little hope that the MX ship would "delouse" itself during egress from port. Once at sea, there also appears to be little opportunity for delousing. However, it could be argued that bad weather or tactical maneuvering could be used repetitively until trail is broken. This possibility is explored in the next section.

At Sea "Delousing" of Trailers

It is of interest to determine how large a fraction of the force might be free of trail if it is assumed that bad weather or some other opportunity to break trail presents itself to the ships.

Low-visibility conditions at sea could be of use in "delousing" the surface ships. The percentage of maritime reports in which visibility is below 1 mile is about 5 percent.

If a low-visibility condition is assumed to exist for 1 day, then on the average, the probability of encountering such a weather condition during a patrol of length n days would be:

$$P = 1 - (\text{probability of clear weather})$$
$$= 1 - (1 - 0.05)^n$$

or

$$P = 0.95 \text{ for a 60-day patrol (i. e., } n = 60)$$

The probability of encountering low visibility weather on the ith day of the patrol would simply be:

$$P_i = (\text{probability of i-1 days of good weather}) \times (\text{probability of bad weather on the ith day})$$
$$= (\text{probability of one day's good weather})^{i-1} \times (\text{probability of one days bad weather})$$
$$= (1 - 0.05)^{i-1} \times (0.05)$$

If the probability of breaking trail during low visibility is pb, the expected number of days free of trail for a patrol of n days will be:

$$Q = (\text{probability trail will be broken}) \times (\text{average number of days before bad weather is encountered})$$
$$= P_b \times (\text{average number of days before bad weather is encountered})$$
$$= P_b \times \sum_{i=1} (n - i) P_i$$

The fraction of the fleet under trail at any given time would be:

$$F = \frac{[\text{number of days on patrol} - \text{number of days free of trail}]}{[\text{number of days on patrol}]}$$
$$= \frac{n - Q}{N}$$

For 60 days at sea (n = 60 in the above summation), the average number of days free of trail would be about 12 days if the probability of breaking trail during a day of bad weather is 0.5. if the probability of breaking trail during a bad day of weather is 0.25, then the average number of days free of trail would be about 6. Thus, for the case where there is a 0.5 probability of losing the trailer when the weather is bad, the fraction of the fleet under trail will be:

$$F = \frac{60 - 12}{60} = 0.80$$

or 80 percent of the fleet would be under trail.

For the case in which the chance of losing the ship during a bad day of weather was 0.25, the fraction of the fleet under trail would be:

$$F = \frac{60 - 6}{60} = 0.90$$

or 90 percent of the fleet would be under trail.

If the ships could somehow choose weather conditions so that it was five times more likely that they would encounter weather with visibility of less than 1 mile, then the probability of encountering such weather on any given day would go from 0.05 to 0.25. If again it is assumed that the ships would lose their trailer with a probability of 0.5 on any day that such weather is encountered, the mean number of days free of trailers would rise to 28 and the fraction of the force under constant trail would be 50 percent. If the ships lost the trailer every time bad weather was encountered, the fraction of the force under constant trail would be only 7 percent.

Reacquisition of Trailed MX Ships

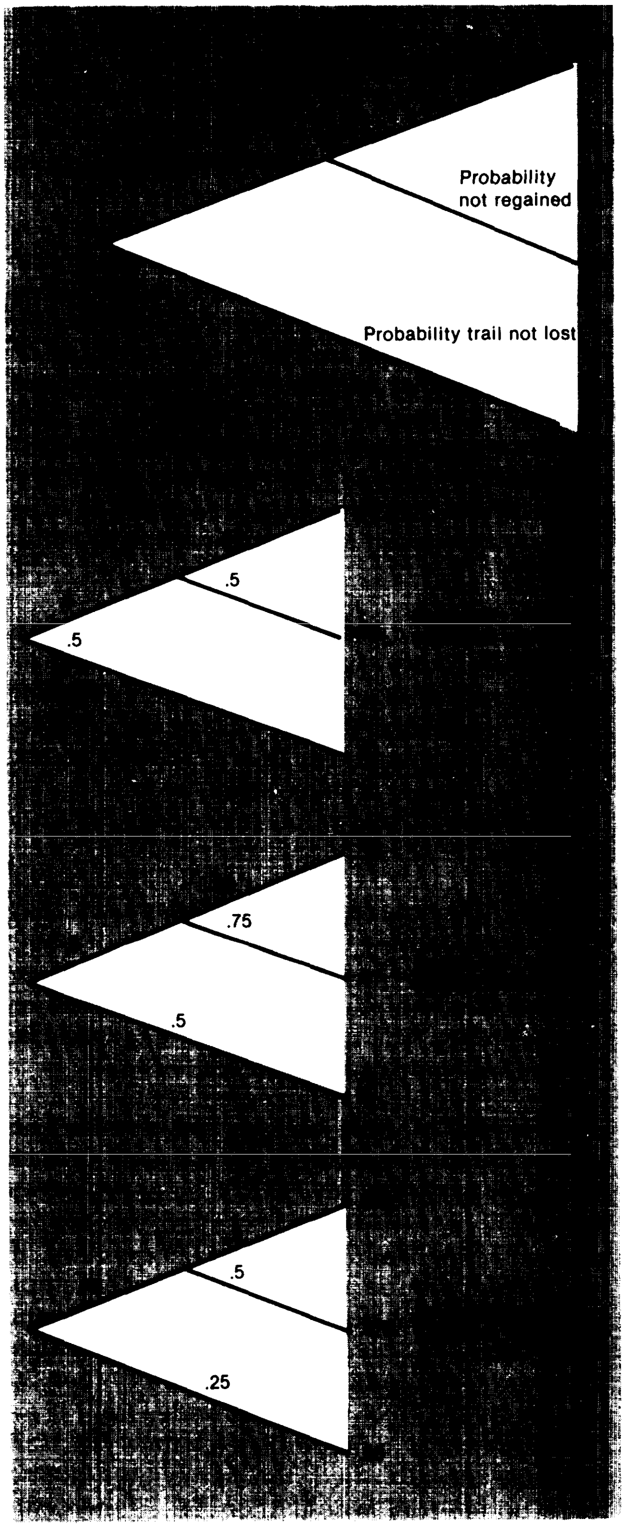
The discussion above assumes that once the MX ship has been lost to the trailing vessel it is not reacquired during the remainder of its patrol period. If a search is immediately initiated once the trailer has lost the MX ship, and remotely piloted helicopters or remotely piloted winged vehicles are used, it is possible that the MX ship could be reacquired. If the remotely piloted vehicle could fly at 100 knots and had a modest radar with a range of 5 nmi, then the vehicle could search about 1,000 mi^2/hr. If the MX ship were to make a 30 + dash upon determining the trailer had lost contact (a questionable action if the visibility were less than 1 mile and other ships were nearby), then it is conceivable that the ship could generate a large enough area of uncertainty to evade the drone vehicles. If the drone vehicle was not launched for half an hour after the trail was lost, the ship could be anywhere in a circle of radius 15 nmi. The trailing ship would be at the center of this circle of area 700 mi^2 when the drone is launched. If the drone flies in widening circles around the trailing ship it will have searched the 700-mi^2 area within about 45 minutes. By that time the surface ship could be within an area of radius of 36 to 37 miles (an area of 4,300 mi^2). The drone might therefore not acquire the surface ship in time if it is not launched quickly from the deck of the ship. If, instead, the drone is launched within 15 minutes after trail is lost, it could be expected to reacquire the ship with a probability of 1.

Since the ability to reacquire the target ship is sensitive to the capability of the drone (i. e., its radar might have a 10-mile range instead of a 5-mile range) and to how quickly the crew responds to the loss of trail, it is of interest to ask what percentage of ships would be kept under trail if the ships had some success reacquiring lost trails.

Figure 102 diagrams the possible events that might occur during a period of bad weather. The lower branch diagrams the situation in which trail is maintained during the period of poor visibility. The upper branch diagrams the events that could occur after loss of trail.

After loss of trail one of two events can follow: the ship reacquires the trail or it fails to reacquire trail. The lowermost diagram shows the result of a situation in which the probability of losing trail is very high (75 percent). If trail could not be reacquired and the ships were able to seek out poor weather 25 percent of the time (i. e., five times more bad weather than would randomly be encountered) then 30 percent of the fleet would be under trail. If instead there was a 50-percent chance the trail could be reestablished, the percentage of the force under trail would then be 37 percent. Therefore, the fraction of ships under trail

Figure 102.—Loss of Trail Probability Event Tree



SOURCE: Office of Technology Assessment

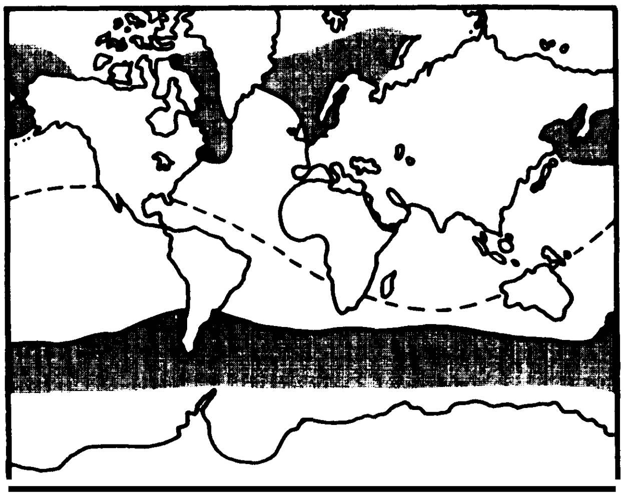
could change significantly if the trailing ships had a modest ability to reacquire trail.

It should also be noted that if a ship is taking advantage of bad weather to intermingle with other ships (so as to make it difficult for a radar operator to keep track of the MX-carrying ship) it is relatively easy to sort ships with the aid of fixed wing or helicopter-like drones. If the MX-carrying ship makes a dash at 30+ knots, its acoustic output would be enormous and it could be heard for many miles by the trailing ship. The ship could then send a drone in the direction of the acoustic signal to determine whether this was in fact the MX ship running for freedom, or just a decoy ship acoustically enhanced to sound like a fast running surface ship. In any case, the use of advanced pilotless drones with advanced sensors would make the reestablishment of a temporarily broken trail quite likely.

Regions of Poor Visibility Weather

The shaded region in figure 103 shows areas of the world that have poor visibility a high percentage of the time. Due to proximity to the Soviet Union, Soviet air and ocean surveillance could be expected to be quite good in the northern regions near the Bering and Norwegian seas. Therefore, the regions of poor

Figure 103.—Regions Where Visibility is Often Poor



SOURCE: Office of Technology Assessment

visibility weather that could be used for attempting to break trail would be only the several hundred thousand square miles of ocean west of Greenland and north of Antarctica. These regions will have weather that varies significantly with changes in season. It could therefore be expected that if these regions were used extensively, the fleet could be seriously unmasked during periods of clear weather. Another problem encountered in these regions is ice. While it would normally not be considered prudent to operate in poor visibility weather without radar, it would be suicidal to do so in waters populated by icebergs. The radar emissions of the trailed ship could therefore be used as an aid for the trailing vessel during periods of poor visibility. The emissions would not exclude the trailer from also observing the trailed ship with its own advanced radars as well.

Final Comments on Trailing

It should be clear from the above discussion that the survivability of a fleet of MX-carrying ships could be sensitive to operational details, capabilities of search radars and possibly weather. Advanced sensors and remotely piloted vehicles would substantially enhance the ability of a fleet of trailing ships to maintain trail. If there is a 5-percent chance per day that trail will be lost (either due to weather, at-sea tactics or equipment failures) as much as 45 to 50 percent of the fleet could be free of trailers. This circumstance, however, would be very unlikely with the variety, diversity and reliability of advanced sensing technologies that can be expected to exist in the late 1980's and early 1 990's.

OTHER SURVEILLANCE TECHNOLOGIES

Although trailing would be the most technologically conservative means of keeping track of the MX-carrying surface ships, there are a number of other important technologies that could either supersede the trail ing threat or be used to aid the trailing vessels. These technologies are over-the-horizon radars and satellite-borne sensors.

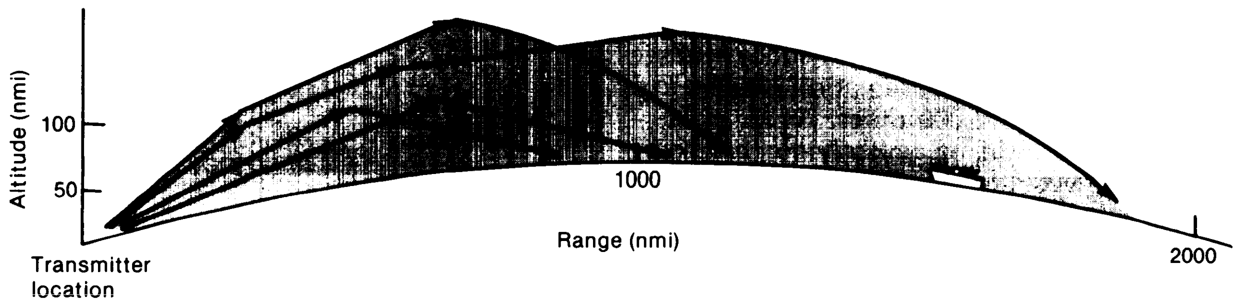
Over-the-Horizon Radars

An over-the-horizon radar illuminates targets over the horizon by bouncing a radar signal off the ionosphere (see fig. 104). The reflected signal from the target also bounces off the ionosphere before it arrives back at the radar receiver.

Over-the-horizon radars are restricted to frequencies no higher than that in the HF band since higher frequencies are not substantially reflected from the ionosphere. A consequence of such a low radar frequency is that the radar has low resolution.

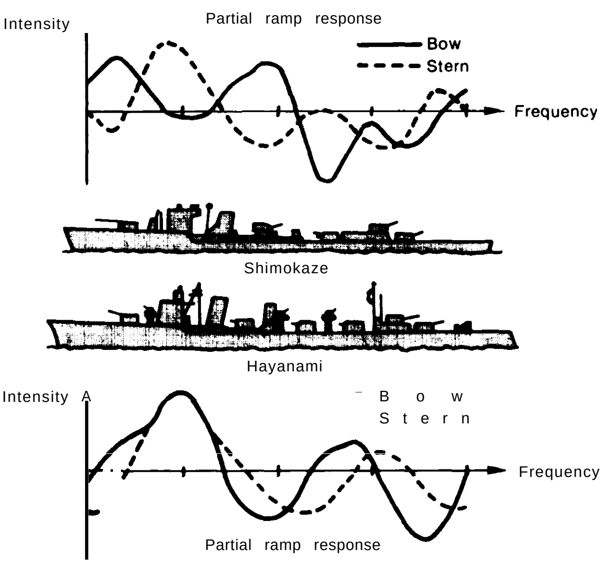
Figure 105 shows the scattered intensity at different frequencies for two similar looking

Figure 104.—Geometry of Over-the-Horizon Radar



SOURCE: Office of Technology Assessment.

Figure 105.— Radar Cross Sections of Two Similar Looking Ships at Different Over"the"Horizon Radar Frequencies



SOURCE: E. K. Young and J. D. Walton, Surface Ship Target Classification Using H. F. Radar, Office of Naval Research, Final Report 712352, May 1980.

ships as they might appear to an over-the-horizon radar reflecting off a perfectly smooth undisturbed ionosphere. Although the ships are not resolved in a visual sense, the frequency dependent radar signal differs for each ship. An actual over-the-horizon radar would have to track ships in the presence of traveling ionospheric disturbances and sea clutter.

It is possible that over-the-horizon radars would be able to track and identify ships on the surface of the ocean almost continuously. This identification could be possible if the intensity of reflected radiation at different frequencies, can be measured accurately in the presence of ionospheric disturbances and sea clutter.

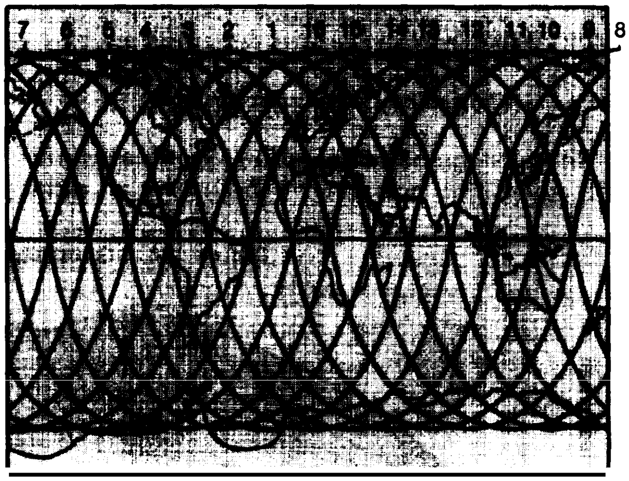
If this promising technology is successfully developed, the *range* of observation is likely to be on the order of 2,000 miles. An over-the-horizon radar would be unlikely to threaten the fleet of MX-carrying ships but could be used to open large areas of ocean to observation from shore-based radars.

Satellite-Borne Sensors

Satellite-borne sensors could include microwave radiometers (to pick up electromagnetic emissions from ships), infrared sensors, optical sensors, and various types of radars. Figure 106 shows the ground tracks of the Cosmos 749 satellite that has an orbital period of about 95 minutes and an orbit inclined at 740 from the Equator. As the Earth rotates to the east, the ground track of the satellite precesses to the west. Because of the chosen orbital period, the satellite ground tracks repeat themselves every 24 hours (or every 16 orbits).

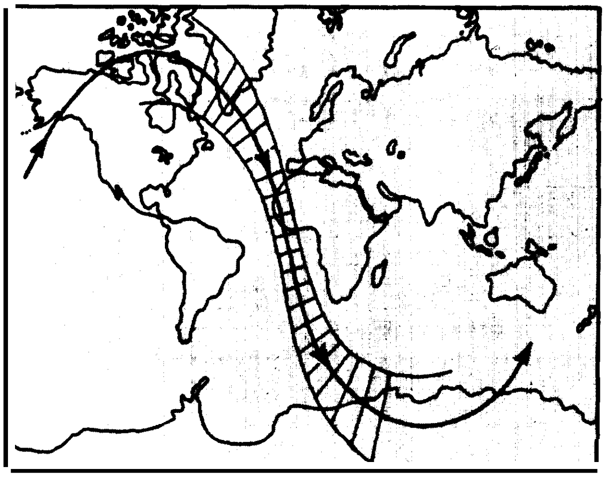
Figure 107 shows the ground swath of the satellite assuming that it has a sensor range of 500 to 600 miles from its ground track. The changing shape of the ground swath is due to the ground swath being drawn on a Mercator project ion, with a changing distance scale. Figure 108 shows the orbits for which it overflies the Atlantic. This overflight occurs twice during a 24-hour period of 16 orbits. Figure 109 shows ground swaths of two successive satellite orbits. If the satellite sensors have a range of 800 to 900 miles the satellite swaths would overlap even at the Equator and al l the over-

Figure 106. —Ground Track of Surveillance Satellite in a 24-Hour Period



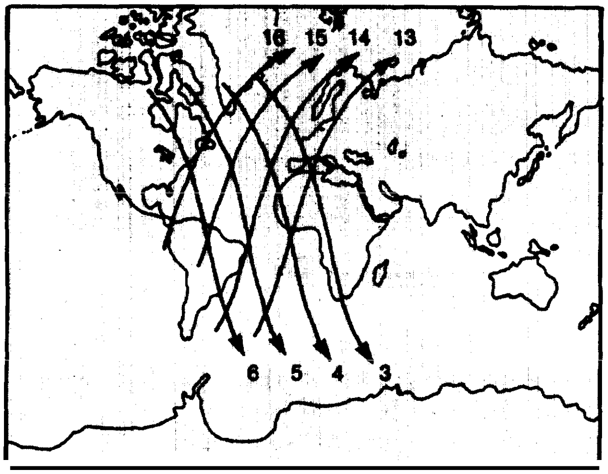
SOURCE: Stockholm International Peace Research Institute Yearbook

Figure 107.—Obsemation Swath of Surveillance Satellite



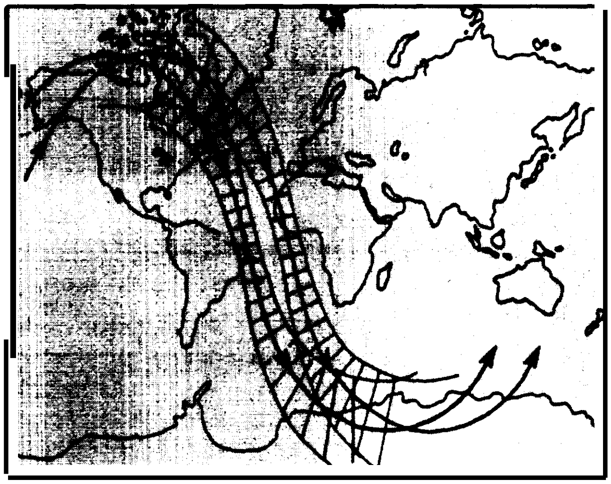
SOURCE: Off Ice of Technology Assessment

Figure 108.—Single Satellite Repeat Coverage of Mid-North Atlantic in a 24-Hour Period



SOURCE Off Ice of Technology Assessment

Figure 109.— Precession of Observation Swath on Two Successive Orbits of a Surveillance Satellite



SOURCE: Office of Technology Assessment

flown regions of the Earth's surface could be covered by a single satellite. If three such satellites were launched in orbits separated by an order of 700 to 800, the surface of the Atlantic would be observed on an average of every 3 to 4 hours (see fig. 110 for details of the satellite overflight schedule). If the range of the sensors did not allow for overlapping observations on successive orbits, more satellites would be needed. A sensor range of 450 nmi would require 6 satellites and a sensor range of 225 miles would require 12 satellites. This range would allow the Soviets to observe all areas of the world's oceans (with the exception of the region near the North and South Pole) every 3 to 4 hours.

If an extensive system of satellites was used to observe (but not identify) large surface ships while at sea, an operational need might arise for the MX ships to make false reports to shore using standard merchant HF channels. Since owners of merchant ships usually want to remain informed about whether or not their ship is on schedule, merchant ships will usually report their positions to shore based H F stations once a day. If Soviet ships on regular patrol routinely recorded HF messages and reported them back to a central facility, there would be a very high probability that HF messages would be intercepted. These data could then be combined with data collected from published merchant ship sailing schedules and satellite reconnaissance data to help identify ships that might be MX carriers.

Satellites could not only be of use in observing ships on the surface of the ocean but signature data could be accumulated and correlated with observations from surface ships and aircraft. If some form of "fingerprinting" could be accomplished using either radar, infrared,

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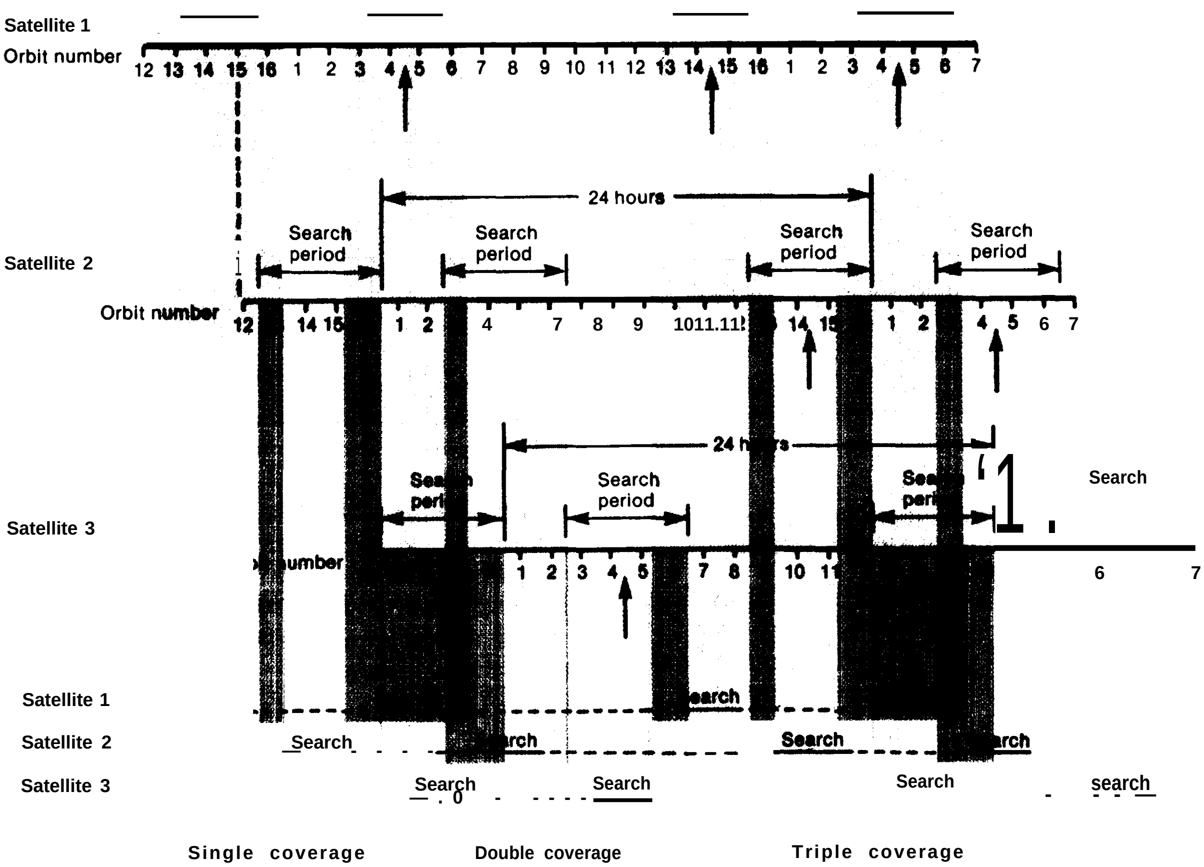
Figure 110.-Search Schedule of Surveillance Satellites at Mid= Northern Latitudes



SOURCE: Office of Technology Assessment

or passive microwave sensors the ships could be continuously tracked from space. "fingerprinting" was not technically possible, the satellites could be used by trailing ships to help reestablish contact with recently lost surface ships. This *use* of the satellites would greatly reduce the need to trail at very close distances and would also be an aid to picking up ships after port egress.

MX REQUIREMENTS AND SURFACE SHIP FLEET

As has been demonstrated in the sections above, major uncertainties would exist with regard to the survivability of a fleet of MX-carrying surface ships. These uncertainties derive from the fact that surface ships are observable at very great distances. As sensing technologies advance, new and novel capabilities for detecting and "fingerprinting" surface ships at great distances can be expected to contribute to surveillance capabilities. Once "fin gerprinted," a surface ship would not have to be resolved in the sense that is usually associated with "seeing" an object, if it is to be successfully tracked. While it can be expected that tracking capabilities would change with the weather, time of day, and ship operations, it cannot be expected that cover of night or bad weather will dramatically enhance the survivability of such a fleet.

Another aspect affecting the survivability of a fleet of MX-carrying surface ships is the operational circumstances of individual ships. These circumstances would be constantly changing with time. The survivability of some ships may be due to circumstances independent of those of other ships (i. e., some ships may have to transit between bad weather while other ships do not) or may be due to circumstances dependent on those of other ships (a trailer confronted with two ships, might, for instance, have to choose which ship to trail). The survivability of such a fleet of surface ships is therefore an unpredictably changing variable.

Since the surface ship fleet would have to be sized to allow for ships destroyed in preemptive action, and the survivability is a constantly changing unpredictable variable, there is no way to size the fleet for such a contingency. It is therefore important to note that it is *unlikely that the requirement for 100 surviving rnissi/es on station after any enemy action can be met on a continuous basis if* MX *were deployed on surface ships.*

ACCURACY OF SURFACE-SHIP-BASED MX

The guidance technology used by surface-ship-based MX would be largely the same as that used for submarines. The accuracy figures discussed below assume the same sets of guidance technologies as those discussed in the chapter on submarines.

Since surface ship survivability requires that the ships operate in as large an area of ocean as possible, many of the ships could be expected to be at a full 6,000-mile range from Soviet targets.

Figure 85 in chapter 5 shows the CEP multiplier v. range for an inertially guided missile and a star-tracker-aided inertially guided missile. The CE P multiplier is a number defined as the CE P of the sea-based missile divided by the CEP design requirements of the land-based MX. Thus, an accuracy multiplier of 1.5 means that the CEP of the missile in question is 1.5 times that of the CEP design requirements of the land-based MX.

As noted in chapter 5, it is expected that the land-based MX will exceed its CEP design requirements, so a CEP multiplier of 1.0 does not necessarily mean accuracy equal to a land-based MX.

Figure 85 is a plot of CEP multiplier at a full 6,000-nmi range for a sea-based MX guided with purely inertial technology and with inertial technology aided by a star tracker. For pure inertial guidance, at a range of 6,000 nmi the accuracy of the missile would be degraded relative to the accuracy design requirements of the land-based MX. If the advanced inertial measuring unit were aided with a star tracker, the CEP multiplier at 6,000 nmi could be expected to be comparable to the design requirements set for the land-based missile.

If the surface ship fleet were forced to deploy at 6,000-nmi ranges from Soviet targets and the sea-based MX has purely inertia l guidance the single-shot kill probability against hard targets would be degraded. However, if the hard targets were to be attacked with two warheads, the double-shot kill probability would still be high.

If a star tracker were added to the inertial guidance system of a sea-based MX, the accuracy would degrade much more slowly with range. I n this case, ships deployed at a 6,000-nmi range from targets could have CEPs comparable to the design requirements set for the land-based MX. For this set of circumstances the single-shot kill probabilities would be very large and, correspondingly, the double-shot kill probability would also be very large.

A third system of guidance technologies that might be used would be to enhance the accuracy of the missile by updating the inertial guidance system of the missile with the aid of a system of radio ground beacons or with the GPS. Using this system of guidance, MX accuracy would be achieved against Soviet targets from any point in the deployment area if the GPS were used.

If the GPS was unavailable due to attacks on the satellites, the ground beacons deployed on the coast of the continental United States and the coast of Alaska could be used instead. In order to use the ground beacons, it would be necessary for the ships to deploy to areas within which the missiles could "see" the beacons after launch. These regions are shown in figures 86 and 87 in chapter 5.

RESPONSIVENESS OF A SURFACE SHIP FORCE

The operational complexity of a surface ship force could make it very difficult for a fleet of MX-carrying surface ships to be responsive to NCA.

A major operational problem that could affect the responsiveness of the force is the low survivability of the ships to preemptive action. It would be necessary for a roll call to be taken in order to be sure that high-priority targets were covered. If ships were still threatened with attack during the process of taking the roll call, high- priority targets would have to be reassigned to still other surviving ships. This reassignment could make the timing of a large coordinated strike extremely difficult to execute.

It is also possible that hostile forces would be unable to attack the remaining ships. This inability could occur if the United States successfully destroyed Soviet surveillance sensors and a significant portion of Soviet Naval forces. Under these conditions, retargetting the ships could be done with a multisynchronous satellite system, that would have the ability to survive Soviet antisatellite attacks. Since the satellites would use extremely high frequency (EHF) channels, the ships could direct transmissions into such a narrow beam that the probability that the ships' transmissions would be intercepted would be very low. The ships could then communicate two ways with NCA at very high data rates and retarget the surviving MX missiles.

A surface ship would have the ability to maintain high accuracy for an indefinite period of time after antisatellite attacks on GPS if the missile guidance system were based on star tracker enhanced inertial guidance and the ships inertial navigation system utilized advanced guidance technologies. Under these conditions the ship could carry out launch orders against very hard targets without serious delays.

If the missile guidance were purely inertial, missile accuracy would rapidly be degraded as a function of time (in a period of time of tens of hours rather than tens of days). This degradation occurs because the star tracker can be used to help correct for navigational errors which accumulate over time in the ships' navigational system. If the missile does not have a star tracker, errors in the ships navigational system cannot be compensated for during the early portion of the missile's flight.

Without a star tracker update, the damage expectancies against very hard targets would be significantly degraded over time unless the ships positioned themselves near acoustic transponder fields so they could update their guidance systems. The ships would then have to operate in a manner that could diminish their survivability.

If the missile guidance were based on radio beacon updates of the missile's guidance system, the ships would have to redeploy to the areas shown in figures 86 and 87 in chapter 5. In this case, redeployment activities could delay execution of the force for days and the responsiveness of the system would be poor.

FLEXIBILITY

If attrition of the force was occurring on a time scale on the order of that required for attacks on targets, flexibility of targeting would be nonexistent.

If the force was not being attritted and there was confidence that ships ordered to carry out attacks would survive long enough to carry out orders, targeting flexibility of the MX-carrying surface ships would be possible. This flexibility would be accomplished using communications channels through the multi synchronous EHF satellites or simply with VLF transmissions from land-based VLF stations or survivable airborne VLF radio relays. Emergency Action Messages could be transmitted over VLF if preplanned options or sub-options within preplanned options are to be executed. Large amounts of data required for ad hoc attacks on targets designated by latitude, longitude, and height of burst would be transmitted over the EHF channels through the multisynchronous satellites.

ENDURANCE

The endurance of a fleet of surface ships could be very great provided the ships were not under constant attack from sea-based Soviet assets. The ships could have an at-sea endurance in excess of 120 days. Assuming that the ships were at sea for an average of 30 days at the beginning of hostilities, no ships would have to return to port for at least s o days. At the end of 90 days, half of the surviving ships would have to return to port and by the end of 120 days surviving ships would either have to be replenished at sea or return to port.

COST AND SCHEDULE

The surface ship considered for the cost analysis is the SL-7 type fast containership . The specifications of the SL-7 are shown in table 32, It should be noted that this ship was chosen for purposes of costing because it is an existing design of a merchant ship with a very high speed (33 knots). It is unlikely that SL-7S would be a good choice of surface ship because the ratio of its hull length to width would be easily distinguishable from space. It should be noted that the SL-7 has insufficient fuel capacity to stay at sea for more than 26 to 27 days at a 20-knot patrol speed. The ship could be operated at a lower average patrol speed but this would make the endurance requirements on Soviet trailers less severe and would therefore diminish the stress on Soviet forces committed to tracking the ships, Therefore, at a minimum, the ships would have to be modified to carry an additional 5,000 to 6,000 tons of fuel or would have to be refueled at sea.

The lifecycle cost estimate for a fleet of SL-7-type surface ships is presented in table 33.

Initial operational capability would be sometime in 1987, assuming the success-oriented missile development effort is not seriously delayed by the need for guidance system modifications or redesign. This date is determined by the long leadtime needed for the MX missile, not by long leadtime required for the construction of ships. The time estimated for construction of the leadship is on the order of 3 years. The time required for follow-on ships would be on the order of 2 years.

If it turned out to be feasible to home base the ships near the Atlantic strategic weapons facility (SWFLANT) and the Pacific strategic weapons facility (SW FPAC), some costs and construction could be avoided,

Table 32.—SL-7 Specifications

Length overall	946' 1-1/2"
Beam	105' 6"
Draft - design	30'
operating	34'
Propulsion	Geared steam turbines
Shafts	2
Boilers	2
Shaft horsepower (total)	120,000
Depth at main deck (fwd of aft deck house)	64'
Depth at main deck (aft deck house to fantail)	68' 6"
Speed (light draft)	33 + kts
Displacement - 30' draft	43,000 tons
34' draft	50,300 tons
Fuel capacity	4,434 tons
Fuel consumption -33 kts	614 tons/day
25 kts	240 tons/day
19 kts	159 tons/day
12 kts	34 tons/day
Electrical capacity	2 installed, 3,000 kW Ships service turbo generator
	1 installed 1,500 kW Ships service diesel generator
	1 installed, 60 kW Emergency diesel generator

SOURCE J W Noah

Table 33.—1 O-Year Lifecycle Cost (billions, fiscal year 1980 constant $)

Cost element	Number	cost
RDT&E		
Surface ship	—	$0.100
Missile	—	6.056
SWS	—	0.400
Capsule	—	0.282
Nav. aids	—	0.190
Total RDT&E		$7.028
Procurement		
Surface ship	30	$9.983
Basing	2	4.830
Missile	485	5.578
SWS		2.190
Capsule	5%	1.705
Nav. aids	1 500/3000	1.400
Total procurement		$25.686
Total acquisition		$32.714
Operating & support		
IOC to FOC		$ 1.165'
FOC + 10		8.879
Total operating & support		$10.044
Total 10-year LCC		$42.758

"Note: Ship availability and basing availability are not compatible, therefore interim support ship basing used.

SOURCE Office of Technology Assessment

It is also possible that ships could operate from other existing naval bases. The feasibility of this approach would be determined by the availability of waterfront area and land near these bases. There would be a need to construct additional waterfront facilities for the ships. These facilities would have to be constructed to satisfy "minimum" safe handling distances for explosive materials. Large amounts of additional real estate would also be required for a missile assembly area and a weapon storage area.

It should be noted that early deployment (i.e., 1987) of a few MX-carrying surface ships would not necessarily result in surviving missiles at sea, as would be the case with submarines. Because surface ships achieve survivability by dispersing in large areas of the ocean in an attempt to exhaust Soviet trailing and monitoring capabilities, the first surface ship that goes to sea may face substantial Soviet trailing assets. The survivability of a fleet of surface ships will depend on the ability to spread trailing forces thin enough that it is difficult for a trailer to reacquire the ship if it is lost. A Soviet decision to commit substantial assets to trailing a fleet of surface ships could result in a substantial Soviet trailing capability by the time the first lead ship is deployed. The survivability of the surface ships would only improve as more ships came on line, taxing the capacity of the Soviet trailing fleet and driving the size of the Soviet trailing commitment to substantial levels.