RADAR, COLLISIONS, AND THE RULES OF THE ROAD.

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The officer of the deck of a vessel equipped with radar is often faced with the necessity of deciding whether or not affirmative action is necessary when an unidentified target is reported. The situation generally arises during periods of limited visibility or when running with darkened ship. The officer has at his disposal the three best tools for preventing collisions at sea : his judgment, the Rules of the Road, and the mechanical radar.

After the initial enthusiastic reception of radar and some twenty collisions later, the maritime world has gained experience which will allow some evaluation of radar as a navigational aid which will tend to place radar in its true perspective.

For the purposes of this article, collisions involving naval vessels have been used extensively as examples because they tend to bring home the problem of the officer of the deck. The mechanical aspects as affecting the use of radar as a navigational aid are treated first. This is followed by a discussion of what effect, if any, radar information should have on the navigator in following the Rules of the Road. Some of the examples are wartime cases ; some of the actual radar in use are obsolete, but the problems which the collisions present are still present in varying degrees.

At first blush it is difficult for the unitiated, and in some cases, the initiated, to comprehend how a vessel equipped with the magic eye of radar could come into collision with another ship. "Certainly the radar-equipped vessel should keep well clear", is the usual reaction. But the reader is reminded that already there have been two collisions in which *both* vessels had radar. In the normal situation the officer of the deck will not know whether the other vessel has radar or not.

"Radar" itself, like "automobile", is a generic word. It covers a multitude of types, each with its own limitations, variations, and designed functions. The Navy has had in use over one hundred marks and modifications of radar which today bear no security classification. The number of classified sets is unknown to the writer. Each of the unclassified models had differences important enough to differentiate it from other types.

Figure 2 shows the two basic types of display presented to the viewer. The first is the old "A" type display, now mostly obsolete ; the second is the more modern "PPI" (Plan Position Indicator) display which eliminated many of the serious limitations of the "A" type. The "PPI" display gives the viewer a contemporaneous picture of the area around his ship. In general, his vessel is in the center of the plan, and targets show on the display in positions relative to his vessel.

Radar is not television. Figure 3 is a picture which was given wide circulation and publicity shortly after the security ban was lifted from radar discussion. The caption writer went overboard in his enthusiasm and has misled laymen into believing that radar can televise. Radar technicians themselves are not agreed as to what the picture itself represents or how it came about. The aircraft is between the viewer and the ground, but is so close that it has intercepted the radar wave either going from the antennae or returning, so that a normal echo is precluded. In any event, the picture is a freak. Figure 4 shows the display which can be expected from a modern set now generally in use.

Further, each individual type and instrument has inherent limitations on its range and bearing accuracy. This factor has played a part in many collisions. The resolution factors are of utmost importance in crowded or restricted waters.

The beam resolution of an average radar in use today is approximately 4 to 5 degrees and 50 to 100 yards. This means that if more than one object is present in the area included within the resolution limitations, the radar will not differentiate between them. They will show up as but one object.

Outside of the pure mechanics of the set is the personnel factor. Trained operators generally become better with experience. The scarcity of highly-trained personnel is unavoidable, but the mariner must bear this in mind : different operators have different acuities and abilities.

Collision cases are inherently complicated. In the following cases most of the discussion of the navigational features unrelated to radar have been omitted, unless they have some interesting or unusual features. The reader must bear this curtailment in mind. Some of the vessels in collision were not carrying the proper lookouts, were sounding improper signals, or were guilty of gross errors in judgment and errors of omission and commission, the recital of which would tend to make the analysis of each collision overly drawn out.

In the first litigated case involving radar, the Army Transport *Barry* was held to be solely at fault for colliding with a wooden hull fishing vessel, the *Medford*. The government stipulated that had the radar on the *Barry* been in use, it would have located the *Medford*. On the basis of this stipulation, the court sounded the keynote of radar liability. The court did not say that if a vessel equipped with radar was in collision it was *ipso facto* at fault, but it did warn that if a vessel had radar available in a fog, she should use it.

The first collision involving a United States naval vessel equipped with radar and a merchant vessel occurred in April of 1942. The U. S. S. *Wilkes*, escorting the U. S. S. *Augusta* in Massachusetts Bay, was struck by the British Motor Vessel *Davila*. The *Wilkes* had an SC-1 radar, with an "A" scope type of screen. The SC radar was designed as an air warning radar, and was very crude according to present day standards. Accuracy was directly sacrificed for range and sensitivity. It was unable to resolve targets within 30 degrees of azimuth and 500 yards in range.

The data material to this discussion are as follows : The *Wilkes* was on course 000 degrees on a leg of a zig-zag. Her speed was 17 1/2 knots. Visibility was good for lighted objects but was only about 1,000 yards for unlighted objects. The course lay towards Jeffrey Ledge, a fishing bank. The officer of the deck sighted steady lights slightly on the port bow at an estimated distance of 14,000 yards. He asked the radar operator to get an echo from these targets. The radar operator complied and verified the distance and the bearing. Though no contemporaneous radar log was kept, the Commanding Officer of the *Wilkes*, who was on the bridge, vividly remenbered that some time after the initial contacts, he received from the radar information that a suspicious object was picked up at 030, distance 3,500 yards. Some time afterwards, the same target was reported at 030, distance 2,300 yards. A plot of these two bearings shows that with time intervals of one, two, and three minutes between the bearings, the target was crossing the bow of the *Wilkes* from starboard to port. The Commanding Officer, due to the presence of the reported object and the fishing vessels ahead, changed course to 070 and, because of the relative position of the *Augusta*, slowed to 15 knots. A few minutes after the course change, the M/V *Davila* loomed out of the fog and struck the *Wilkes* on the port side just aft of the bridge.

In order to demostrate some extrinsic features which might enter into a collision case, the following is a summary of the situation on the *Davila*. The *Davila* was operating in a five-ship convoy on course 193 and speed 9 knots. She had a Chinese lookout on the port wing of the bridge, a Chinese helmsman, a sixteen-year old apprentice officer and the mate on the starboard wing. Her engine room telegraphs and light switches were inside the wheelhouse. The mate first saw the loom of the *Wilkes* about two points on the starboard bow. He told the apprentice to get the night glasses which were in the wheelhouse. Then he lit his pocket flashlight and flashed it at the *Wilkes* over the dodger. He then started for the wheelhouse and collided with the apprentice who was coming out. Extricating himself from the tangle, he noticed the *Wilkes'* port running light. He then entered the charthouse, ***put the engines full ahead***, ***ordered the rudder hard to port***, ran in front of the helmsman and then to the back of the wheelhouse to turn on his lights. They came on as the collision occurred.

In the instant case the dilemma of the *Wilkes* Commanding Officer was acute.

Radar was very new, untried, and unanalyzed from experience. A plot of the possible target positions (using knowledge gained from subsequent experiments) at differing time intervals, shows that the target, assuming it was one ship or a group of ships, could have been on any course from 180 to 000, at a speed from dead slow to any practical speed. The convoy, in fact, was on a course and speed which barely

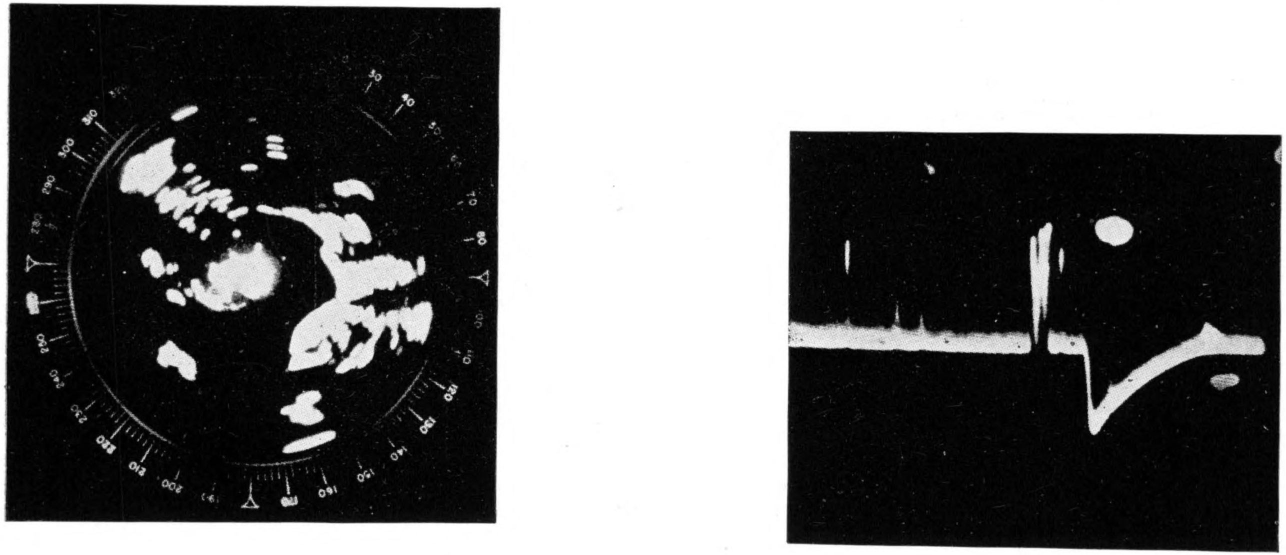

FIG. 2. — The Two Basic Types of Radar Scope.

On the right is the "A" Scope, where the range is determined by moving the depressed "step" until it coincides with the raised pip. On the left is a PPI Scope presentation taken on board a vessel in Tokyo Harbour.

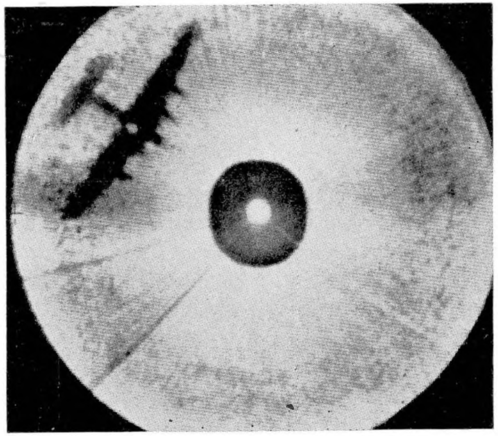

FIG. 3. — RADAR IS NOT LIKE TELEVISION.

This picture represents the unusual event in which the target (a bomber) is so close to the radar antenna that it intercepts the beam and prevents it from echoing. If the proportion were correct relative to the radar scope, this bomber would have a two-mile wing span!

passed through the possible courses from the plot, and far from the most probable course and speed of such a plot.

Other factors of navigation entered into the case, so the question of whether the collision could have been averted is impossible to answer. As far as radar is concerned, its presence in this case could only serve to further alert the *Wilkes* to the fact that there was possible danger to the north.

The practical lessons for the present day navigator shape up as follows : Each radar has inherent errors and resolution limitations which affect the accuracy of the reported range and bearing. Fortunately today, with radar specifically designed for surface navigation and with much more limited resolution errors, the extreme case of the *Wilkes* would not happen. However, the lesson remains, lessened only by the degree of accuracy between the *Wilkes* radar and the present day set.

A further example of inherent physical limitations of radar occurred in a collision off the Long Beach-San Pedro Breakwater at about 0745 on September 3, 1947, between the U.S.S. *Andromeda* and a barge.

The *Andromeda* picked up a pilot at 0736. The pilot stated to the Commanding Officer that on his way out he had seen a tug evidently towing. In fact, the personnel on the *Andromeda* could hear the fog signals of a towing vessel with a tow apparently off their port bow. The helm was put to port, and the radar operator was asked to see if he could locate a tug and a barge. As the *Andromeda* came to port, the fog signals apparently shifted over to the starboard bow. About nine minutes after taking the pilot aboard, the bow lookout reported a low lying barge dead ahead, and collision followed.

The barge was made of wood and had a very low freeboard. These two features combined to accentuate the extreme difficulty of locating a target made of wood as well as the difficulty of locating a target with a small effective reflecting surface. These two elements explain why radar technicians shuddered the day they read of the daring tug which navigated the Hudson River from 79th Street to the Ambrose Channel at 12 knots in a dense fog, using its radar. Once again the enthusiast went overboard for publicity which could well be a cause of future property damage or loss of life. The tug in the story was just lucky.

The collision between the U. S. S. *Corduba* and the S. S. *Joyce Kilmer* off the Virginia Cape in 1948 illustrated some further limitations of radar. The night was foggy. The *Corduba*, inbound for Norfolk on course 300, picked up a target bearing 299, distance 8,800 yards. Eight minutes later (other targets having been picked up in the meantime) the radar showed the original target bearing of 299 and a distance of 4,000 yards. On the strength of these bearings the *Corduba* came to course 320 and reduced speed from 11 to 4 knots. Eight minutes after changing course, the *Kilmer* loomed out of the fog and struck the *Corduba*.

The *Kilmer* had also been inbound for Hampton Roads, but because of the fog had decided to remain off the cape and find an anchorage. About eight minutes before the collision she had changed course to port in order to anchor on a small shoal.

The question naturally arises as to why the *Corduba* did not continue to take bearings on the *Kilmer*. In retrospect it is an easy matter to censure this failure. However, considering the fact that other vessels were in the vicinity and demanding attention after the course change, some navigational excuse can be found. But there were mechanical excuses too which are of great importance : (1) Each time the *Corduba* sounded her fog signal, the steam blast would cause the radar screen to blur and render it useless for an appreciable time ; (2) the minimum effective range of the particular set was somewhere around 1,500 yards, due to sea return and atmospheric conditions.

These factors must always be considered. In some vessels the whistle blast will have no effect. Sea return is always present to some degree. It in turn depends on many factors such as height of antennae and structural design of the set, as well as the state of the sea. Sea return is basically a reflection of the beam off the water. The water echoes like any other object, and it being all around the vessel, the screen near the vessel shows nothing except the solid water. Similarly heavy rain, snow, or sleet may reflect the beam and produce a "clutter" on the screen.

A collision involving elements of pure frustration occurred in the Ambrose Channel on May 27, 1948, between the U.S.S. *Nespelen* and the French M/V *Indochinois*. The *Nespelen* was making an outbound passage. The weather was foggy. Ambrose

Channel is dog-legged and only about 650 yards wide. The officers on the bridge were discussing the distance to a buoy as they passed it to starboard. They asked the radar operator to affirm their estimates and he was able to pick the buoy out through the sea return, and reported it to be 150 yards abeam. This split the two estimates in question. As the operator commenced to sweep again, he immediately picked up a target at 7,600 yards entering the channel. The Commanding Officer changed course 5 degrees to starboard to get closer to the starboard edge of the channel. He did not dare go too close for fear of grounding on Romer Shoal. The radar stayed on the object, and in due time the *Indochinois* loomed out of the fog. The *Nespelen* went hard starboard, and then, seconds before the collision, hard port, in an effort to throw her stern away from the *Indochinois*. The *Nespelen* was *hit* a glancing blow just aft of the well deck. The location of the contact on the *Nespelen* was fortuitous, because aft the vessel was loaded with gasoline and a collision at or nearer the well deck might well have caused an explosion.

The speed of the *Nespelen* was four knots. The speed of the *Indochinois* was about 7 1/2 knots, according to the master and the pilot, because at a lesser speed the *Indochinois*, deeply laden, was sluggish and almost impossible to manoeuvre. Of course, she should have anchored outside the channel, but once committed to the passage of the channel, fate took over on the *Nespelen*. She had three choices : first, she could have tried to reach the safest course as close to the starboard side of the channel as possible ; secondly, she could have attempted to get over on the left hand side of the channel ; or third, as the office wag suggests, she could have backed down at 7 1/2 knots to the East River. She chose the first alternative and nothing can be found amiss with the choice.

The radar aspect appears to indicate that the *Nespelen* was in a position from which she could not extricate herself. It is all well and good to look at a radar screen and see a vessel bearing down upon you, but when it is out of your power to attempt to avoid the collision except by actions *in extremis* it must be very trying on the soul. Actually, the radar was sensitive enough to pick up the buoys. It could also observe the relative position of the pip of the *Indochinois* with respect to the line of buoys, once it had actually started up the marked channel. But, here again, it must be remembered that radar does not give a television picture. All it could show were small blobs in a line, with a larger blob between them. The operator could guess whether the target was on the right or left of the center line, but even in the modern radar, the resolution is not so accurate as to tell the navigator within a one or two degree accuracy exactly where the target is. The center of the blob might appear to be a little to the right or left of the center line of the channel, and yet the target might actually be a little on the opposite side. Consequently it is impossible to tell exactly where the center line of the target is. In a narrow channel like Ambrose Channel, any bearing on the ship ahead will indicate a collision course, merely because the channel is so narrow that ships will have to pass within 500 yards of each other. Thus, the lesson from the *Nespelen* case involves the proposition that in a narrow channel, the best the radar will do is warn of the approach of a vessel, and getting over to the right hand side of a narrow channel is still the safest course, with or without radar.

A narrow channel collision occurred off Casablanca in February, 1944. The facts of the collision might well be set down as recreational reading. Radar played a relatively minor role in the instant case, but an important lesson can be drawn, even though it is a negative one. Basically three convoys and their escorts were involved. One convoy was inbound from sea, the other two outbound. The Casablanca Swept Channel was approximately 30 miles long and only about 1,000 yards wide. The outbound convoys were delayed by materiel casualties, so that by a collocation of circumstances, all three convoys happened to be traversing the channel at the same time. Nature took a hand in the matter by providing an intermittent fog which set in after the vessels had been committed to the passage. This type of fog is best described as "snakelike". That is, it was an extremely long narrow bank which zig-zagged as it moved.

The vessels involved were of many nationalities — American, British, Dutch, French, and a Yugoslav. The escorts were both American and French. Only the escorts had radar.

The channel buoys were spaced at five-mile intervals, and picket boats had been s ationed to guide the vessels in the vicinity of the buoys. The radars appeared to be capable of picking up the land mass and roughly navigating from tangents taken on the land. The radar also was able to pick up some of the ships and distinguish

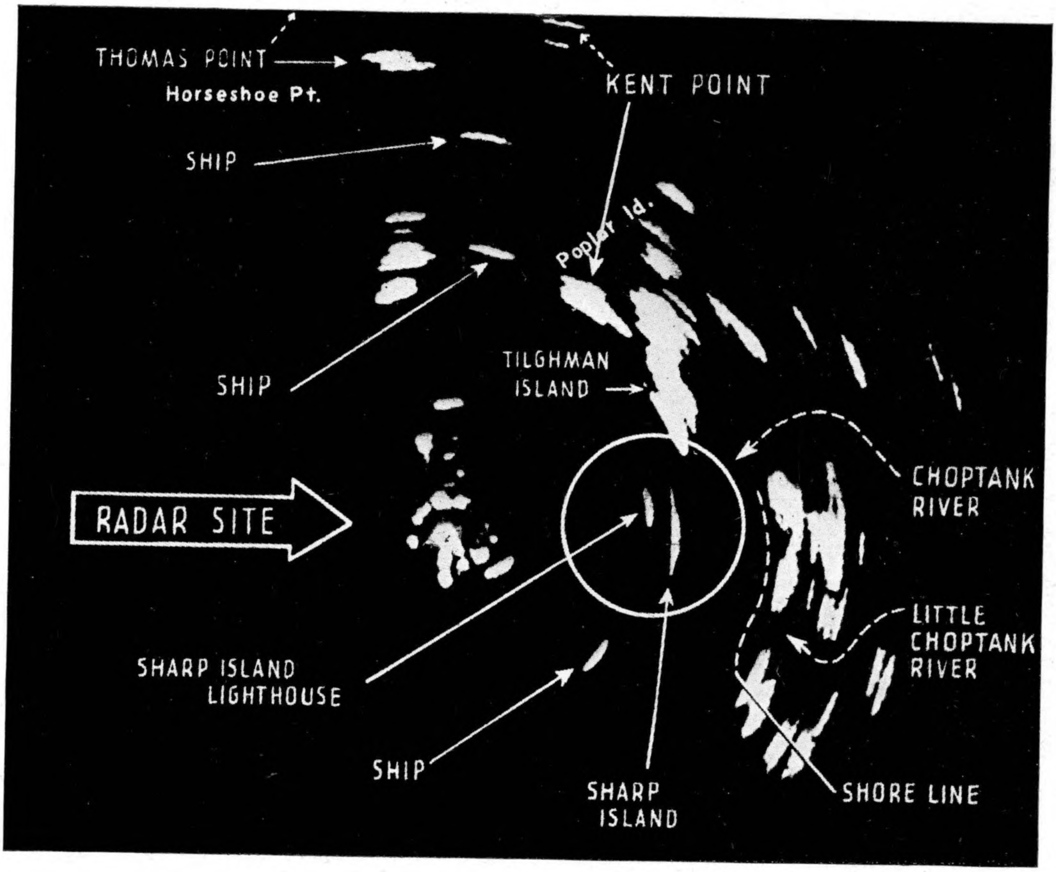

FIG. 4. — IT TAKES EXPERIENCE TO "READ" THE RADAR.

In this PPI presentation of the area around the Naval Research Laboratory, Chesapeake Bay Annex, the lighthouse appears to be similar to a ship. Note the distortion of the pips in general.

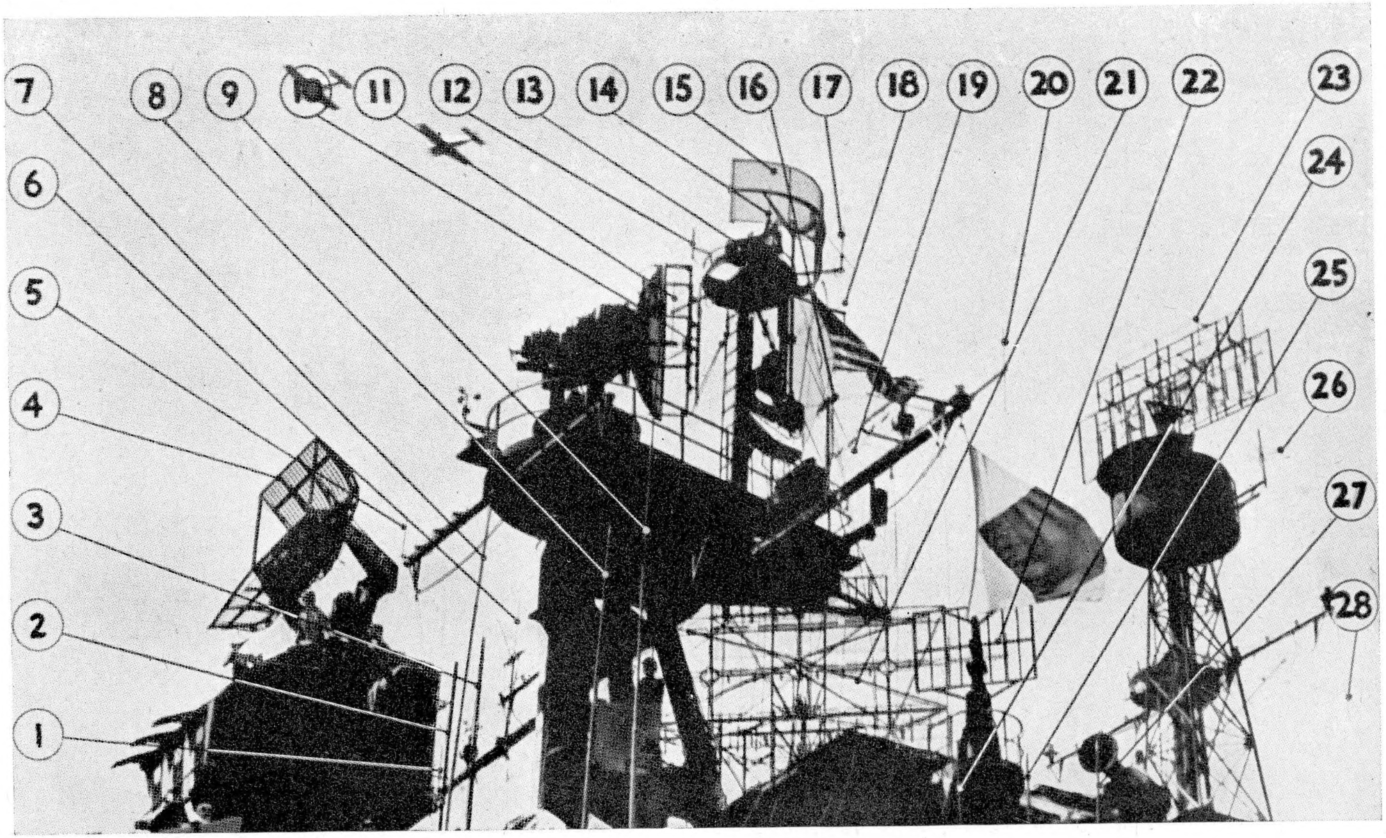

FIG. 5. — A FOREST OF ANTENNAE :

Among the radar antennae on this modern carrier, No. 4 is a fire control radar ; 10, 21, and 23 are air search radars ; 13 is a surface search radar ; and 15 and 22 are homing beacon radars.

them as ships. They were incapable, however, of keeping the convoys in line and ascertaining with any degree of accuracy on which side of the channel the convoys were operating, if, in fact, it could be ascertained whether the individual vessels of each convoy were not themselves so dispersed as to be on both sides of the channel. The vessels were supposed to be following in single file, but it is extremely doubtful that they were so doing, since as the events unfolded, very few of the ships seemed to have passed through the same waters as the ship ahead. All of the vessels and the escorts were sounding fog signals, and none of the vessels was in visual contact. The S. S. *Winsum*, leading ship of the incoming convoy, came to grief first. From ahead of her loomed the S. S. *Empire Tana*, the leading merchant vessel of the outbound convoy, and a collision ensued. The S. S. *Jaarstrom*, following the *Empire Tana* out of Casablanca, somehow got on the starboard quarter of that vessel and passed well clear of the *Winsum-Empire Tana* collision. Ten minutes later, however, she collided with the S. S. *Agen*, the third ship in the incoming convoy. The *Empire Tana*, continuing down the channel, then came into collision with the S. S. *Dunav*, the fourth ship in the incoming convoy, sinking this vessel. Meanwhile, the S. S. *Lookout Mountain*, in the second convoy outbound, was catching up with the others, and she joined the melee by coming into collision with the S. S. *Shirrabank*, the second ship in the *Winsum* convoy. The total personnel casualties were a bruised hand, a cut foot, and a compound fracture of the nose.

From a navigational standpoint, a myriad of reasons enter into fixing the blame, if any. Obviously the initial confusion caused by the fog quickly disintegrated into chaos, once the *Winsum* and the *Empire Tana* collided.

The radar aspects of the case, as indicated, are mostly negative. In the first place, navigating with radar by taking tangents from capes and points ashore is probably more accurate than celestial navigation, but not accurate enough to ascertain positions in narrow, sparsely-marked channels. In the second place, unless a highly developed communication system is available, the information gleaned from radar is almost impossible to communicate to the other vessels. In view of the different nationalities involved, the impossibility of whistle signals for warning (in view of the numerous fog signals), and the impossibility of the radar-equipped vessel from doubling back and warning each vessel by voice (since the leading vessels were presumed to be following the wake of the escort), it can be tabbed impractical in this instance to disseminate the radar information even for what it was worth.

The Casablanca fiasco leads into the highly important escort situation. While there is no duty on the part of an escort to actively control the navigation of the escorted vessels, since such a duty would be impossible to perform, there have been many occasions where one vessel in possession of radar information has been in a position to inform other vessels as to the situation.

A collision occurred in the Caribbean Sea about 150 miles east of the Canal Zone on the evening of September 9, 1944. The S. S. *Hindoo* and three lives were lost.

The S. S. *Australia Star* was proceeding independently from the Canal Zone at full speed pursuant to orders. She picked up two targets on her radar at some eight miles. The targets were dispersed, and though no radar log was kept, it is plain that the range closed, although there was a considerable divergence as to whether the bearings remained steady so as to indicate a collision course with either vessel. When the nearest of the two pips reached about 4,000 yards, the observing vessel turned on her lights.

The two targets were a merchant vessel, the *Hindoo* and a Navy escort, the *PC-616*. The escort was zig-zagging ahead of her charge, which may account for the divergense of opinion as to whether she was on a steady bearing from the *Australia Star*.

The case was tried in the United States District Court for the Southern District of New York. It was held at the trial that the *PC-616* did not have an affirmative duty to warn the *Hindoo* of the oncoming vessel. The Circuit Court of Appeals reversed this holding, stating that since the *Hindoo* was subject to the orders of the naval escort, she could reasonably expect to be warned of any danger known to her escort which would require a departure from such orders. *Failure to so warn the* Hindoo *was held to be a breach of legal duty and a cause of the collision.*

This case stands as the law at present, despite the practical predicament in which it puts the wartime escort. The *PC-616* could not act until the *Australia Star* was identified. When she turned on her running lights, the choice lay with warning a blacked-out vessel that a lighted vessel was heading for her or warning a lighted vessel that she was heading for a blacked-out vessel. It further imposes a duty on the escort to supervise the actual navigation and prudent seamanship of the escortee. If the escort does not know whether the escortee sees the navigation lights of an approaching vessel, although they have been on for twelve minutes prior to collision, he is under a legal duty to warn the vessel and is responsible for any collision resulting therefrom.

So the law, as it stands at present, requires a vessel equipped with radar to warn the other vessels in company with her of approaching danger, even if she has reason to believe the danger is already known. Thus another aspect of radar navigation is written in the books.

On the plus side of the ledger there are innumerable unreported cases in which radar information has been effectively disseminated. Unfortunately the success stories are often unpublicized because "nothing happened", and as a result valuable doctrines are hard to formulate from experience. One case was reported in the New York *Herald Tribune* on December 10, 1945, which is worth passing on.

During a fog on the Great Lakes a merchant vessel equipped with radar obtained two pips on her screen. Observing the relative movements of the two targets, the mate became convinced that the vessels were on collision courses. He was able to contact them by radio in time for both vessels to manoeuvre clear and avert a catastrophe.

On the other hand, the Proceedings of the Merchant Marine Council has reported two cases where both vessels had radar and yet came into collision. Apparently there were no mechanical considerations involved, or in any event they were not reported. Both situations happened to be head-and-head collisions. In both cases one vessel turned to port and the other turned to starboard. These cases naturally lead into the consideration of the question, "How should I manoeuvre, when I do not know what the other vessel will do or whether it has radar ?"

Another case reported by the Council indicated that a radar antenna was offset from the center-line of a vessel so that a mast intercepted the beam. A vessel approached in this "blind" spot, was undetected, and collision resulted. Few naval vessels have these "blind" spots, but there is some analogy to the *Corduba's* whistle limitation.

At the present time it is better always to assume that the other vessel does not have radar. As soon as it becomes apparent that the vessels may be in danger of collision, common prudence dictates that action should be taken to avoid the situation. What action should be taken is dependent on many factors which cannot be listed exhaustively. In restricted or coastal waters a prime consideration is the possibility that the other vessel may change her course and speed ; that land masses may appear like vessels ; it must always be borne in mind that there are other vessels in the same waters which may have radar, etc. These factors indicate that good judgment must be exercised rather than the following of any set doctrine.

However, the Rules of the Road are not superseded. Every vessel is bound to obey them.

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Radar logs or deck logs with radar entries are valuable in ascertaining fault for collisions, but only if written contemporaneously with the occurrence. Navy Regulations do not require that a radar log with target entries be kept, but the officer of the deck may make or break his case on what an entry shows. Similarly, the Navy Department often benefits from radar entries. In the *Corduba* case the radar showed that the speed of the *Kilmer* was over 7 knots, which was immoderate ; in the *Indochinois* case the radar proved that the French vessel was proceeding at an average speed of at least seven knots, which again was immoderate. On the other hand, the "radar log" of the *Wilkes* was written up the day after the collision by an operator who at no time during his watch saw a clock, and who even logged targets appearing after the *Wilkes* had made its turn and there were none visible, due to sea return ! It is easy to explain the log as such, but difficult to overcome its inferences, no matter how erroneous they are.

The conclusions to be reached from an analysis of the described collisions indicate that the definite limitations of radar must be borne in mind.

The mechanical limitations are :

(a) Sea return and clutter, depending on type of radar, antennae height, and the state of the sea and atmosphere.

FIG. 6. — SEA RETURN AND CLUTTER.

Sea return and atmospheric clutter may completely obliterate the display in the vicinity of the vessel. This picture vividly represents one of the major limitations of radar for close-in work.

(*b*) Bearing and range resolution, depending on the type of set.

(*c*) Echoing efficiency of the target, depending on the material of which it is made and the effective echoing surface.

(*d*) Extrinsic physical factors which may affect the radar such as whistle steam, and ship's structure.

The personnel considerations are :

(*a*) The amount of training, personality, acuities, and abilities of the operator.

(*b*) The ability of the officer of the deck to analyze the situation and evaluate the information which he receives.

(*c*) The facilities and personnel available for plotting each contact.

The Rules of the Road must be considered —

(*a*) Until sighting or hearing the other vessel the Rule of Good Seamanship (General Prudential Rule) and the Rule of Special Circumstances apply.

(*b*) After sighting or hearing the vessel, unless collision is imminent, the regular Rules of the Road apply as if the radar were not present.

In general :

(*a*) Early avoiding action should be taken with due regard to the physical circumstances.

(*b*) All things being equal, the starboard turn offers the better of the choices if a turn is to be made.

(*c*) Slowing down to steerageway will seldom cause any trouble, and will often avoid it.

(*d*) Nothing can be lost by plotting each contact.

(*e*) It is sound practice to disseminate information which you obtain from radar to other vessels who may be able to use it.