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MARITIME INFRARED LINESCANNING
Trials against submarines

by

Ø Wenstøp

Approved
Kjeller 30 December 1977

H K Johansen
Superintendent

FORSVARETS FORSKNINGSINSTITUTT
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SUMMARY

Within the scope of project 286, "IR-linescan" the possibilities for detecting surface wakes caused by submarine activity were to be investigated.

It became necessary to develop and build an infrared linescanner with high thermal resolution and provision for real time pictorial representation of thermal patterns on the sea surface.

With this equipment trials have been conducted from a DCH-6 aircraft against our Kobben class submarines.

This report presents the results of the trials and also briefly describes the experimental equipment.

The project has been carried out by the Norwegian Defence Research Establishment and the Royal Norwegian Air Force in cooperation, with assistance from the Royal Norwegian Navy.

1 INTRODUCTION

Thermal mapping of the sea surface is of great interest for general reconnaissance and surveillance purposes. Typical applications in Norwegian coastal waters may include surveillance of pollution and mapping of thermal gradients in estuaries and in the sea.

For military purposes there is an interest in thermal mapping of the sea surface in order to detect surface wakes from a submarine mast breaking the surface or possibly from a submerged submarine. With the intention of assessing detection of surface wakes as a means to increase the power of the maritime patrol service, we have carried through a domestic project. In this report we briefly describe the experimental work that has been done and also present the results we have obtained from trials against Kobben class submarines.

The only useful remote sensing technique is the use of an image-forming infrared sensor carried by an aircraft. The sensor system should utilize the wavelength region 8–13 μm. In this wavelength region the atmosphere is relatively transparent. The 8–13 μm region is also the best choice as to maximizing the radiation contrast from a specific difference in temperature between a surface wake and the surrounding water.

At these wavelengths there exists no highly sensitive detector with two-dimensional structure like the photographic film. To build up an imagery it is therefore necessary to scan the scene by a single detector-element of very small size. The spatial resolution is then defined by the angle subtended by the element. Only photon detectors cooled to cryogenic temperatures can meet the inevitable demands on high information rate and high detectivity.

The surface is scanned transversely to the flight path. The two-dimensional coverage of the scene evolves through the combined motion of the scanner and the aircraft.

An image-forming infrared sensor characterized by the principles which we have briefly reviewed, is usually termed an *infrared linescanner* (IRLS). The conventional IRLS provides an extension of the covert reconnaissance capability into nighttime or under illumination conditions unfavourable to ordinary photography. Used together with photography, it provides additional knowledge on military activities that somehow cause thermal or emissivity disturbances.

The instrument is designed to give a high spatial resolution map of the overflown scene. During flight the detector signal modulates a light source that exposes a photographic film line by line. Thus a map of the overflown surface is built up on the film. This film is processed on the ground and therefore the resulting imagery is never presented or used in real time. The thermal resolution amounts to the order of 0.5°C; this is the minimum scene temperature difference that is discernible as a graylevel difference on the film.

As regards submarine detection and tracking, we are likely to encounter extremely small temperature differences between a surface wake and the surrounding water. The apparent temperature differences may be at the order of some few hundredths of a degree. In a maritime patrol aircraft real time information is needed, for tactical purposes.

Due to insufficient thermal sensitivity and lack of real-time presentation, the conventional IRLS is not suitable for submarine detection and tracking.

The linescanning concept, however, is quite valid to govern the design of an infrared equipment appropriate for submarine detection.

We shall use the term *maritime infrared linescanner* about a linescanner specially designed for mapping of thermal patterns on the sea surface.

The conventional IRLS is commercially available. Today this type of infrared reconnaissance equipment is found in several high performance combat aircraft, either internally installed or carried in an external pod.

Although it is likely that experiments in the field of maritime infrared linescanning are being conducted in some countries, this activity has not produced any commercially available maritime IRLS.

2 MARITIME INFRARED LINESCANNER

In 1973 the Royal Norwegian Air Force (RNoAF) and the Norwegian Defence Research Establishment (NDRE) agreed to undertake a project that should aim at carrying out domestic experiments with a maritime linescanner. The purpose of these experiments was to be at least twofold:

a) To gain experience with respect to the potential of a maritime linescanner as a means to increase the power of a maritime patrol aircraft to detect and track submarines

b) To enhance our general knowledge in the field of maritime linescanning in order to prepare ourselves for international collaboration

To our knowledge no trials with maritime infrared linescanning against submarines have been carried through in this country since 1968. In that year we conducted some trials in the 3–5 μm wavelength band in cooperation with the Royal Radar Establishment (presently the Royal Signal and Radar Establishment) and the Royal Air Force, both of the United Kingdom (1).

Our knowledge is sparse, however, on what results have been achieved from foreign activities in recent years.

2.1 Basic principles

Because of no offer from the commercial market, we have at NDRE built a maritime IRLS. To grasp the main principles on which the design of this instrument is based, it may be worthwhile to consider any linescan system consisting of two subassemblies, the optical receiver and the image synthesising section.

The output from the optical receiver is an electronic signal from the detector preamplifier. The high thermal sensitivity is achieved at the expense of spatial resolution, a trade-off which is justified because an exact geometric representation of the surface phenomena is of less concern. The solid angle through which the detector views the scene defines a *projected area* on the sea surface. Geometric details within this area are not resolved.

This solid angle, the linear dimension of which is commonly termed *the instantaneous field of view*, is proportional to the detector element size. The thermal sensitivity can therefore be increased by increasing the size of the detector element. Our maritime IRLS utilizes an element size of 2 mm squared. The instantaneous field of view amounts to approximately 1.5 degrees. An element size of about 0.1 mm is typical for the conventional IRLS.

The most widely used detector material for the 8–13 μm region is cadmium-mercury-telluride. The making of detector elements of this material as large as 2 mm squared has been hampered by difficulties in obtaining a homogenous structure. These technological difficulties have not been overcome until quite recently.

The detector signal, which is voltage versus time, is converted to a signal characterized by intensity or shade of gray versus position in the image synthesising section of the system. Since the information is collected by the linewise scanning motion and because a two-dimensional image contains numerous lines, some kind of information storage must be provided.

The imagery is needed as close to real time as possible. Since new information arrives as the aircraft is moving, the most effective way to produce real-time imagery is to introduce an operator's display presenting a living scene.

If the traditional long-persistence display were employed, neither the storage function nor the living scene presentation would have been cautiously taken care of. A more advantageous solution is to use a short-persistence display and refresh it at a rate sufficiently high to give a flicker-free presentation. There must then exist an external storage which stores the detector signals in real time. From this storage the same information must be retrieved as required to furnish the display. A storage having this function is usually referred to as a *scan converter*.

The operator will see the received information from the scan just completed on top of the screen. The line from the preceding scan will be placed adjacently. A number of lines representing the immediately previous history are all placed contiguously

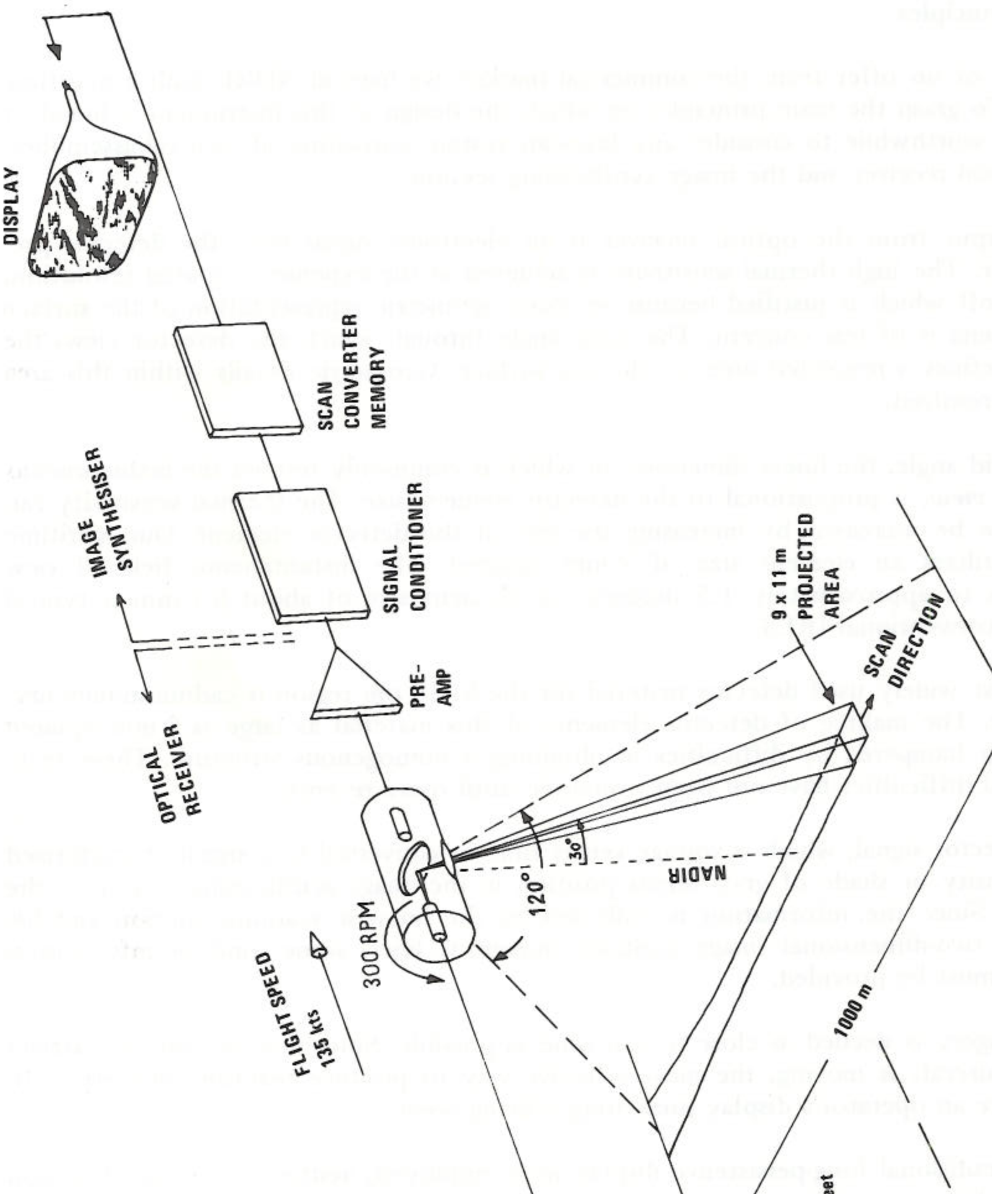


Figure 2.1a Linescanner subassemblies

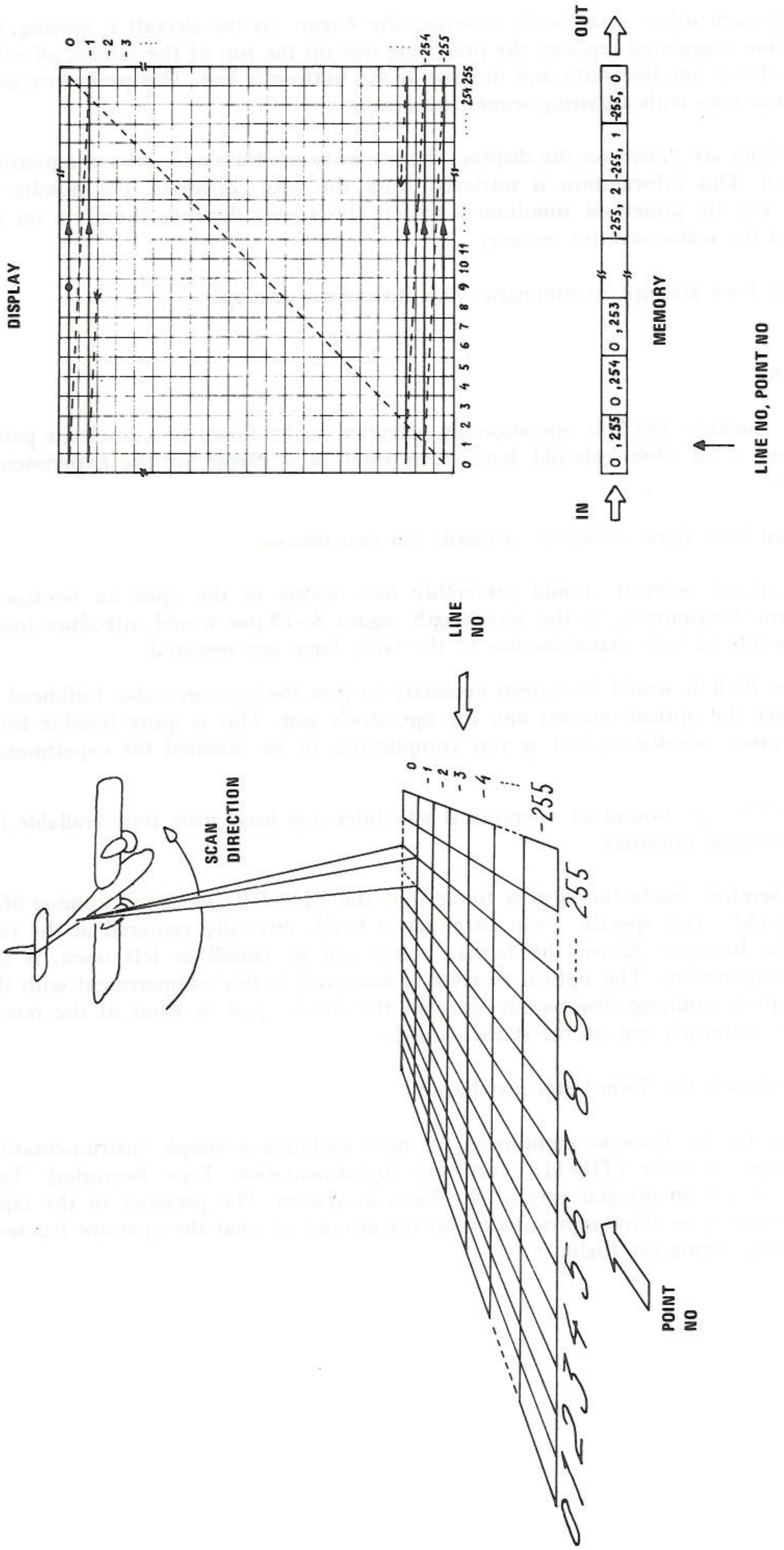


Figure 2.1b Scan-converter function

underneath each other, completely covering the screen. As the aircraft is moving, the last scan line completed replaces the preceding one on the top of the screen; all other lines step down one linewidth and the one at the bottom is lost. This procedure gives a continuous map with a passing scene presentation.

When the lines are drawn on the display, the intensity modulation carries the pictorial information. This information is retrieved from the scan converter. The number of lines that can be presented simultaneously on the screen depends therefore on the capacity of the scan-converter memory.

In Figure 2.1 we attempt to summarize the linescanner principles.

2.2 Installation

Because a maritime IRLS is operationally intended to be flown in a maritime patrol aircraft, our P3-B *Orion* should have been used as a carrier of the experimental linescanner.

This has not been done, however, primarily for two reasons:

a) The optical receiver should preferably have access to the open air because a window transmitting in the wavelength region 8–13 μm would introduce losses and would be very expensive due to the fairly large size required.

   In the P3-B it would have been necessary to pass the pressure cabin bulkhead to connect the optical receiver and the operator's seat. This is quite feasible for a permanent installation but is too complicated to be justified for experimental work.

b) Our P3-B's are bound to operational schedules that leave little time available for experimental purposes.

We have therefore made the system to fit into the DHC-6 *Twin Otter*, number 063, of the RNoAF. This specific Twin Otter has a hatch vertically centered in the rear part of the fuselage. Above the hatch, which can be closed or left open, is the stowage compartment. The optical receiver is mounted in this compartment with the scanning optics pointing downwards through the hatch. Just in front of the rescue door is the operator's seat on the starboard side.

Figure 2.2 depicts the Twin Otter installation.

In addition to the linescan equipment we have included a simple instrumentation magnetic tape recorder (TIR 115 Tandberg Instrumentation Tape Recorder). This instrument is not an integral part of the linescan system. The presence of the tape-recorder is mainly to allow reproduction on the ground of what the operator has seen on the display during the flight.

2.3 Initial flight tests

In the autumn 1973 we began constructing the linescanner and in October 1975 it was flown for the first time.

The initial flight-tests should assess the aircraft environment mainly with respect to electromagnetic interference. These tests led to an acceptable solution regarding cabling, shielding and grounding, apart from one peculiarity:

The use of the IFF-system ("identification friend or foe") caused heavy crosstalk; the reason is probably to be found in the location of the antenna very close to the detector-preamplifier assembly.

Because the Twin Otter should only serve as a carrier for trial purposes, no effort was made to make the linescanner insensitive to the use of the IFF-system.

To extract submarine wakes from the "large signal" thermal picture of the sea surface such that the wakes become visible on the display, some kind of signal processing must be introduced between the preamplifier output and the intensity modulation input of the display. Because little was known about the features of wake signals, we had to do some flight tests to gain insight into the matter. By overflying various surface phenomena showing striplike patterns, like wakes after occasional surface vessels, stream edges and surface currents, we recorded the detector signals on the tape recorder. This information was thereafter used in the laboratory to synthesize a signal processing scheme. Through subsequent flights we verified the usefulness of the principles chosen and also became aware of the need for further modifications. This iterative procedure finally led to an experimental maritime linescanner at the end of the year 1976.

Another source of interference was discovered during the first submarine trial. Communication between the aircraft and the submarine was established in the UHF-band. The use of the aircraft transmitter turned out to disturb the picture on the display. We therefore had to avoid transmitting to the submarine during overflying for the purpose of displaying thermal wake.

2.4 Principal specifications

In Table 2.1 we have tabulated the performance specifications of the linescan system and in Table 2.2 its main design characteristics.

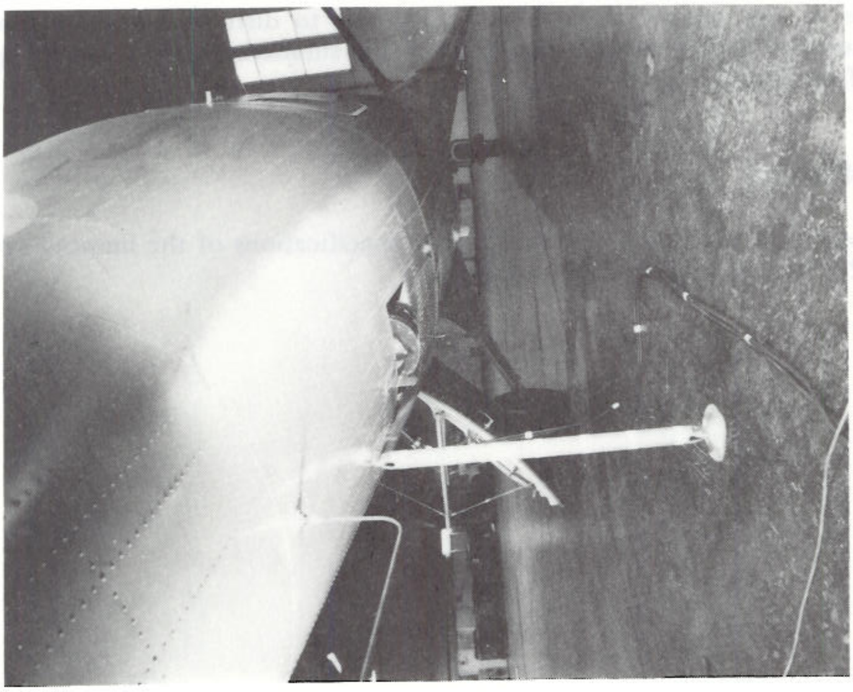


Figure 2.2a Location of the linescanner in the rear part of the DHC–6 No 063 fuselage

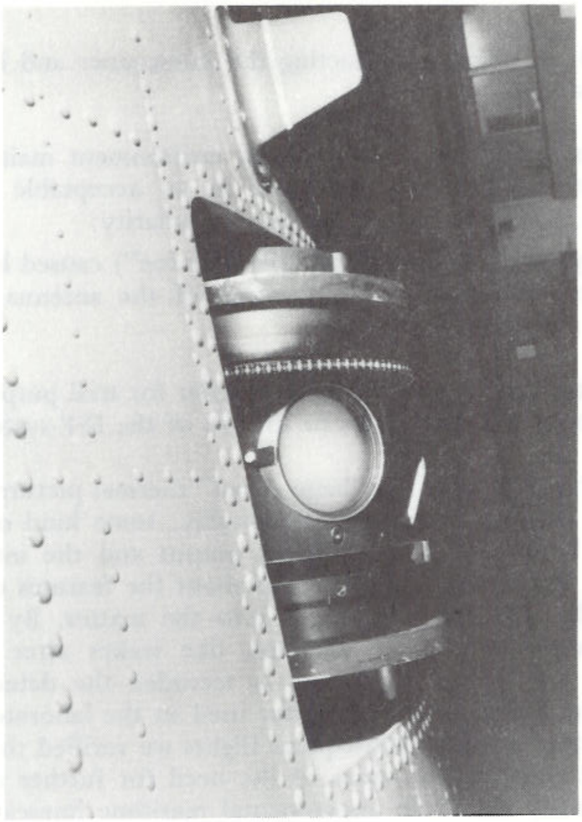


Figure 2.2b Optical receiver, scanning optics

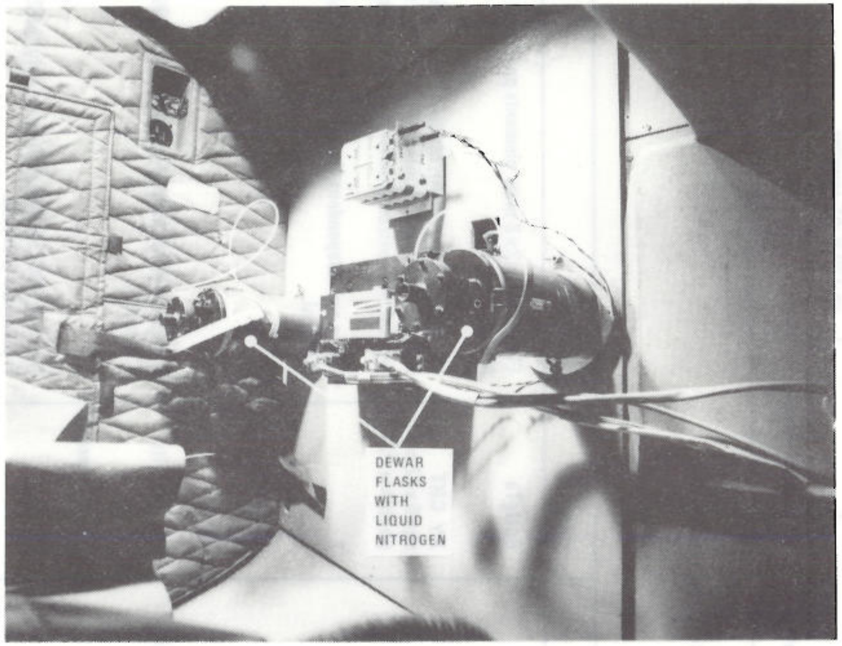


Figure 2.2c *Optical receiver, installation in the stowage compartment*

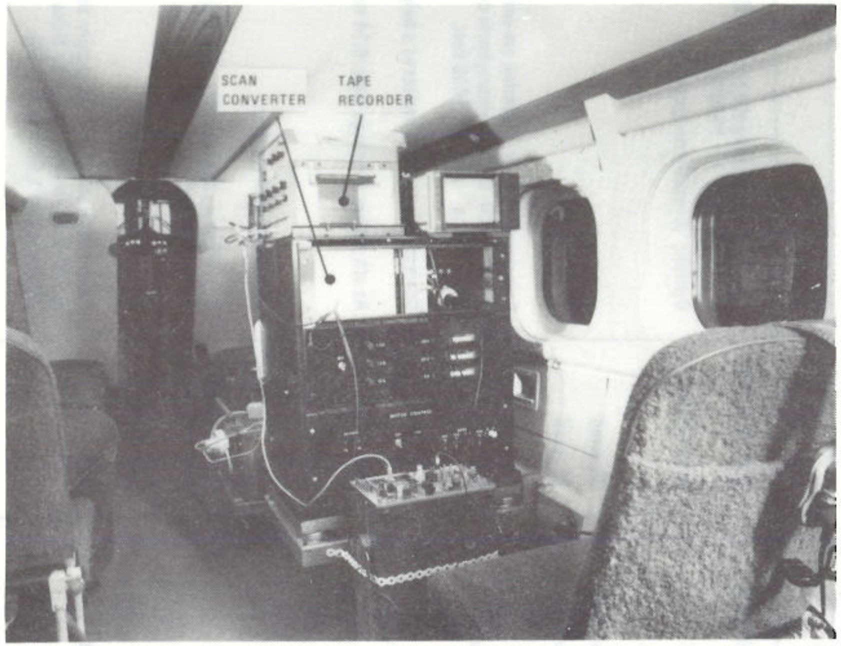


Figure 2.2d *Operator's seat in front of the image synthesising section*

PARAMETER	VALUE	REMARKS
Aircraft velocity to height ratio (v/h)	0.14 to 0.27 s^{-1}	Normally used during the trials: 0.23 s^{-1} (v = 135 knots, h = 1000 feet).
extended v/h range	0.11 to 0.45 s^{-1}	Option; presently not provided.
Spatial resolution		
instantaneous field of view across track	25 mrad	
instantaneous field of view along track	25 mrad	
Thermal resolution		
noise equivalent temperature	0.005 °C	Calculated at nadir, assuming sea-surface temperature at 4 °C, ideal atmospheric conditions, v/h $\leqslant$ 0.27 s^{-1} and h $\approx$ 1000 feet.
Transversal coverage	120°	Corresponds to 1000 metres at a height of 1000 feet.
Display memory time	25 s	At v/h within the range from 0.14 to 0.27 s^{-1}.
Spectral region	8 to 13 μm	
Cooling system		Liquid nitrogen transfer.
Cooling endurance	Consumption $\approx$ 2 litres/hour	Depending on the quantity of liquid nitrogen that may be carried.
Power consumption	500 watts	From 220 V AC, 50 Hz.
Power supplied by the aircraft	900 watts	From the aircraft 28 V DC supply through a 28 V DC to 220 V AC inverter made by Nova Electric Mfg Co (USA), model 1.5K50–24 (230).
System weight	312 pounds	Including various handheld utilities such as an oscilloscope, a multimeter etc, but excluding the 28 V DC to 220 V AC inverter.
System weight including inverter	540 pounds	

Table 2.1 Performance specifications

PARAMETER	VALUE	REMARKS
Detector type	CdHgTe	Element size 2x2 mm; elements purchased from Mullard Ltd, UK.
Display type	XY CRT size 9x12 cm phosphor P31	Hewlett Packard (USA), Model 1332A. This is an electrostatically deflected aluminized cathode-ray tube display with vertical and horizontal amplifier rise time equal to 25 ns.
Optical channels, number of	2	These are independent channels; they are purposely made identical.
Receiving aperture, area of	41 cm^2	
Focal length	7.9 cm	
Scan-converter memory capacity	262 144 bits	N-channel MOS-shiftregister organized as 65 536 words of 4 bits each.
Scan rate	10 scans/second	
Scanner rotational speed	300 rpm	Options: 250, 375 and 500 rpm; only the 250 rpm option is presently provided.

Table 2.2 Design characteristics

3 TRIALS AGAINST SUBMARINES

Through the next four sections we shall give a review of the trials we have conducted and also present the general contents of the results obtained.

3.1 Survey of the accomplished program

During the months from March till June of the year 1977, the instrument has been flown against our own Kobben-class submarines as targets. In order to utilize submarine time that could be released from the operational schedule and also to be able to operate the aircraft from the Bodø Airfield (719 squadron) without excessive transits to the exercise fields, all trials were conducted in the waters of Vestfjorden, Ofotfjorden and Andfjorden. Four submarines were involved, KNM *Kobben*, KNM *Utsira*, KNM *Ula* and KNM *Kunna*, but only one boat was employed at a time. The aircraft, however, was always the Twin Otter number 063 for reasons previously mentioned.

The passes have mainly been flown at a height of 1000 feet and at a speed of 135 knots, while the submarine has advanced at a speed of 5 knots. The submarine has in most cases operated at periscope depth, but also down to a depth of 30 meters. At periscope depth we have tried three different configurations, one with diesels running and all masts ploughing the surface, another with diesels turned off and only periscope and UHF-mast penetrating the surface, and finally a third configuration where all masts were drawn in.

In all these trials we have flown along the path followed by the submarine except when she made turns and detours. In addition we have made passes at about 45° with respect to the course of the submarine.

The average weather conditions we have experienced can be sorted into two groups. The first group represents good conditions characterized by wind ranging from no wind to light breeze and wave heights ranging from calm sea to half a meter. The second group represents modest conditions characterized by wind ranging from gentle to fresh breeze and wave heights between half a meter and one and a half meters. White horses were quite frequent at moderate breeze.

As far as sea and air temperature go, the dependence of the sea temperature on the depth is the most interesting parameter. This is because the larger the temperature difference is between the surface layer and the layer beneath the submarine keel, the larger may be the thermal gradient at the surface due to the motion of the submarine.

We did not succeed in making any realiable recording of the temperature profile. A coarse thermometer installed in the submarine at the coolant water inlet was read at different depths. From these readings we have obtained some indications of the temperature conditions in the waters of Vestfjorden between the Skrova and Tranøy lighthouses. In late April at a depth of 1.5 m the temperature was about 2°C. In the middle of May the temperature was around 4°C at a depth of 8 m and around 8°C in the middle of June. Further, we got the impression that there was no appreciable difference in temperature between the depths of 8 m and 30 m in late April. In the middle of June, however, the temperature at a depth of 30 m seemed to be around 1°C lower than at a depth of 8 m.

A total number of 18 missions has been flown. Of these, 13 missions have been successful in the sense that no malfunctions have hampered the operations. The average exercise time has been one hour per mission.

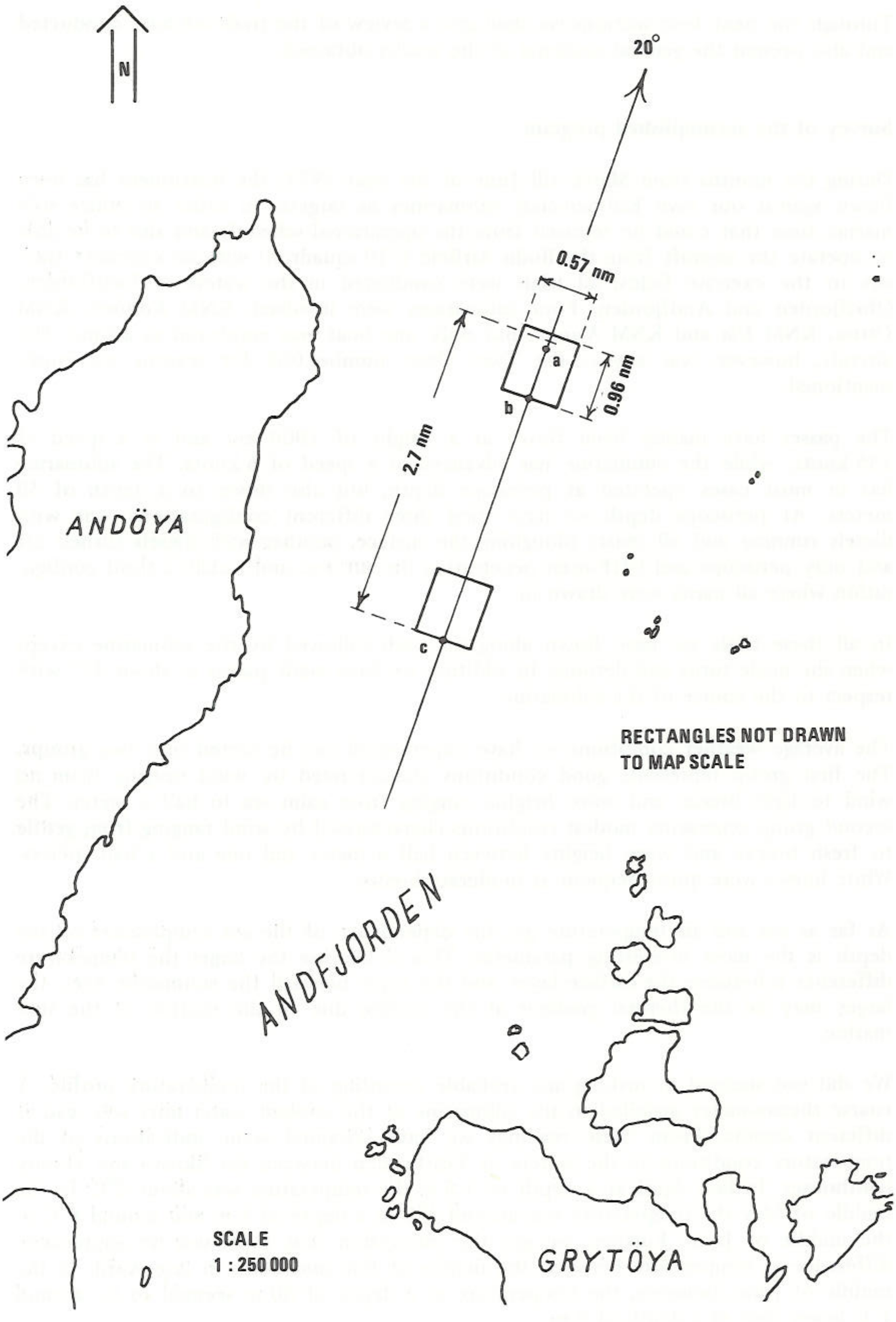


Figure 3.1 Contour of the experimental situation

During the other five missions we have been plagued with various failures mainly related to the operation of the linescanner. These unsuccessful missions were all experienced during the earlier interval of the total period from March till June. The origins of the failures were in most cases found and the equipment repaired. However, degraded imagery still occasionally occurred at the display. This undesirable behaviour was not remedied until we discovered that part of the copper leads of the preamplifier printed circuitry had been contaminated. Some deposits had been formed which caused false conductance. New preamplifiers were built and installed. Thereafter we carried through the last ten missions without any malfunctions.

3.2 Introductory examples on displayed imagery

To begin with, we shall attempt to familiarize the reader with the image the operator will see on the display when a submarine wake is overflown.

The contour of the experimental situation is shown in Figure 3.1. The day is 19 April at 1100 hours. The aircraft is flying on a course opposite to the submarine's when the submarine route is overflown. The aircraft height is 1000 feet and the speed is 135 knots. The submarine is proceeding at periscope depth and is heading north at a speed of 5 knots. All masts (i e snorkel, periscope, and three antennas) are ploughing the sea surface and the diesels are running. The sky is almost clear, occasionally light mist is present. The sea is calm, mainly showing swells of less than one meter. There is no wind.

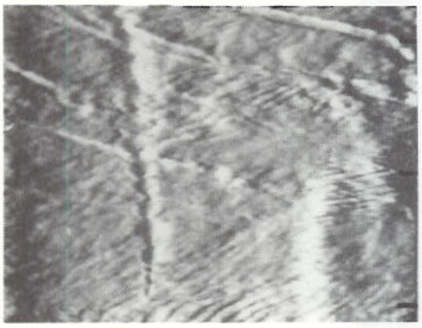


Figure 3.2 Displayed image with aircraft at point b in Figure 3.1

Let us focus our attention on the instant where the aircraft is at point "b", the submarine at point "a". The image on the display appears as shown in Figure 3.2. The image covers a rectangle on the sea, measuring 0.57 nautical miles across-track and 0.96 nautical miles along-track. The location of the projection of the aircraft on the sea surface (nadir) is always at the top of the image and the submarine is in this case near the lower edge. We can see quite clearly the thermal track extending from the location of the submarine and upwards, in the left half of the image. Note the appearance of the surrounding water. Besides a region of peculiar appearance in the lower right-hand corner, the thermal gradients running transversely in the upper half of the picture are the more outstanding phenomena.

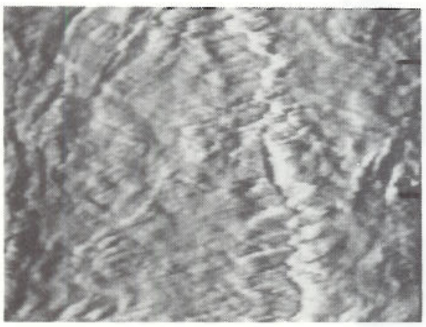


Figure 3.3 Displayed image with the aircraft at point c in Figure 3.1

Seventy seconds later the aircraft is at point "c" in Figure 3.1 and the frame which is instantaneously covered by the display represents another rectangle on the sea surface. The displayed image turns out as shown in Figure 3.3. We see that the thermal wake

Figure 3.4 A complete run from an exercise in Andfjorden
All masts breaking the surface, diesels running.

from the submarine is still quite pronounced. The pilot has been guided by the linescan operator in order to keep the submarine wake mostly along the centre-line of the display. The submarine has now just passed point "a", and is 2.7 nautical miles in front of point "c". The 33 minutes that have elapsed since the submarine was at point "c" is the age of the wake we see at the top of the picture in Figure 3.3.

By flying down the thermal wake in this manner the wake will sooner or later cease, in the sense that it is no longer visible on the display. The time it has taken the submarine to establish this full wake length is called the wake persistency. In this particular case the wake did not disappear until the aircraft arrived at the point of rendezvous where the submarine had commenced the exercise. No persistency can therefore be assigned to the observed wake length.

After having passed the rendezvous, the aircraft returns to somewhere north of the location of the submarine, makes a turn and is prepared for the second run. The submarine is still sailing at periscope depth at a speed of 5 knots at 20° heading. This time we shall present the result as a picture covering the complete run, see Figure 3.4. The reader must keep in mind that to the linescan operator the image on the display appears as if a frame of the size indicated in this figure was travelling upwards at a speed of one frame height per 25 seconds.

Some 11 minutes have passed since the aircraft was on top of the submarine in the previous run, and we realize from the picture in Figure 3.4 that the submarine has moved approximately one nautical mile during that time. As a seamark we can use the thermal gradients which we recognize as being those we saw in Figure 3.2 from the previous run. Throughout the trials we have observed that if the sea surface exhibits very pronounced thermal patterns they tend to persist for a long time, at least one hour, which in most cases has been the duration of one mission excluding time for transit. It is to be expected that these patterns may last even longer than an hour, but we have no evidence to support this statement.

Let us turn our attention to another experiment. The rendezvous is in the waters of Vestfjorden, 5 nautical miles south-east of the Skrova lighthouse. The submarine is proceeding on a course of 60° and is overflown by the aircraft flying in the opposite direction. The day is 10 May at 2200 hours, which is half an hour after sunset.

In Figure 3.5 we present two complete runs; they have been flown consecutively. Again the reader must remember that the presentation in the figure differs from the real-time presentation on board. On board, the operator saw a living scene continuously covering 25 seconds flying time, the uppermost line on the display representing the information presently being received.

We appreciate from Figure 3.5 that the submarine wake emerges distinctly, and we also learn that the surrounding water appears quite differently from the impression we recall from the results we have presented in Figures 3.2, 3.3 and 3.4. In this case the picturesque "background" is absent; we note, however, a grid of fine lines which run crosswise. These lines stem probably from the light wind of 3 knots which was present. The wind direction was 50°, so the lines run at right angles to the wind direction.

The submarine has started the exercise with all masts ploughing the surface and the diesels running. Later the diesels were turned off and all masts were drawn in except the periscope and the UHF-mast. We can clearly see from the picture in Figure 3.5 where this change of configuration has occurred, that is, where the wake is abruptly weakened.

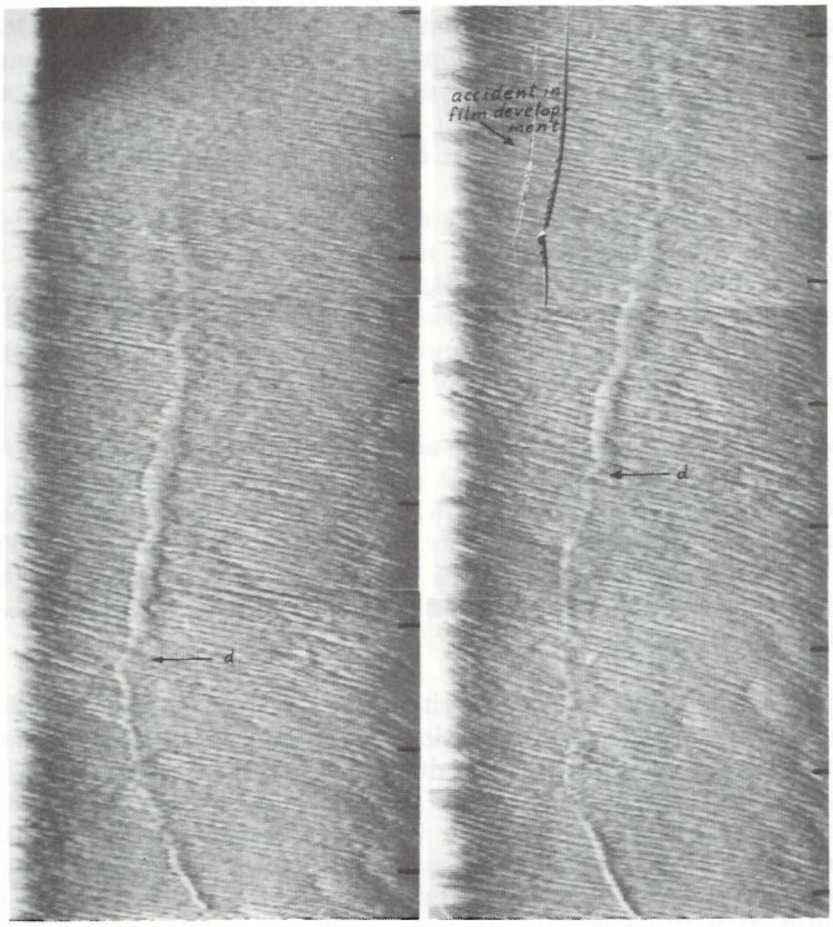


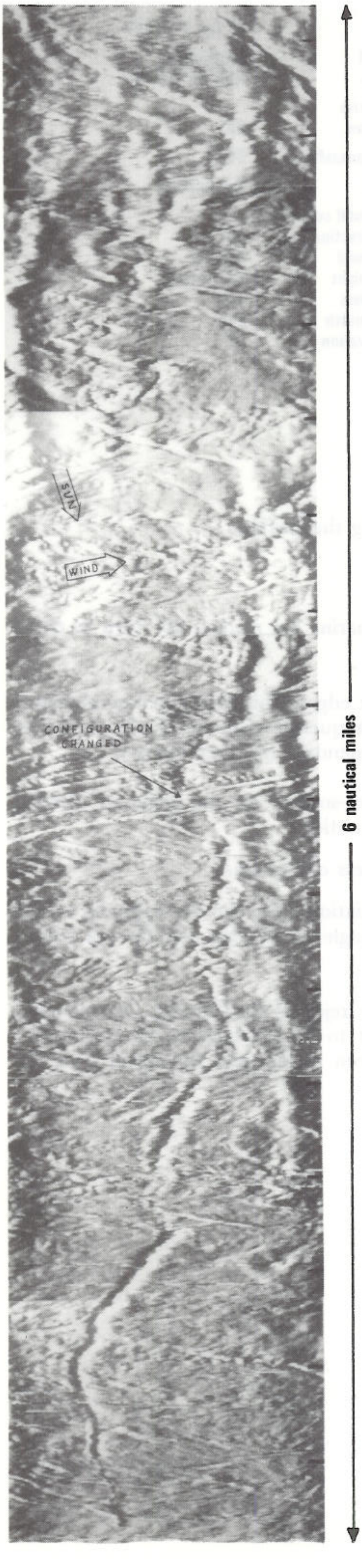
Figure 3.5 Two consecutively flown runs in Vestfjorden
Diesels turned off and masts other than the periscope and the UHF-mast withdrawn at point d.

We can follow the wake on the picture in Figure 3.5 until it is no longer visible. In this case the submarine has travelled a greater distance from the starting point than this wake length. We can therefore assign to the observation the conception of persistency. The persistency turns out to be half an hour.

3.3 Presentation of results from all missions

After the introductory examples of the previous section, we shall in this section present one or a couple of runs from each of the 13 missions that have been carried through. The presentation will be given by means of a photograph of the type we have seen in Figures 3.4 and 3.5; that is, one covering a complete run. Accompanying the photograph is a list giving time and location, courses and environmental conditions. Further, a description of the depth profile followed by the submarine, the mast exposure and the condition of the propelling machinery are given. This state, giving the behaviour of the submarine, we shall refer to as a configuration. Finally there are some remarks on the result.

The reader should keep in mind that the real time intensity modulation of the display has suffered from the various processes necessary to produce the photographs in this report.



– Time	19 Apr 77 : 1200
– Location of rendezvous	Andfjorden N69°06′ E16°14′
– Present course of submarine	20°
– Course of aircraft	200°
– Persistency	70 minutes
– Environmental conditions:	
– Wind direction	110°
– Wind speed	2 knots
– Wave height	0.6 meters
– Cloudiness	4/8
– Precipitation	Light mist
– Sun azimuth	182°
– Sun elevation	32°

Configuration:

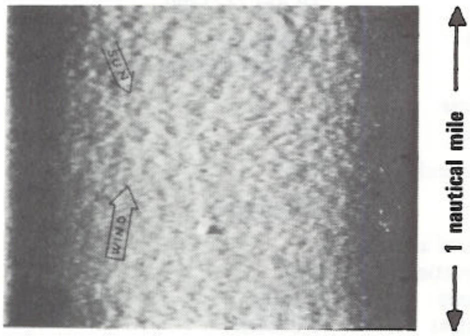
Periscope depth, diesels running, all masts ploughing the surface.

This configuration has lasted from the starting point to a point about 3 nautical miles behind the present location of the submarine (i e where the wake starts at the lower edge). At that location *the configuration was changed to:*

Still periscope depth, diesels off, the periscope and the UHF-mast the only masts breaking the surface.

Remarks:

The winding shape of the wake is probably caused by natural motions in the surface layers.



– Time	26 Apr 77 : 1400
– Location of rendezvous	Vestfjorden N68°05′ E14°50′
– Present course of submarine	60°
– Course of aircraft	240°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	50°
– Wind speed	9 knots
– Wave height	0.6 meters
– Cloudiness	1/8
– Sun aximuth	215°
– Sun elevation	32°

Run a

Configuration:

Periscope depth, diesels running, all masts ploughing the surface.

Remarks:

This is the first run of this mission, and the submarine has made a 90° turn to enter the course set out for the exercise.

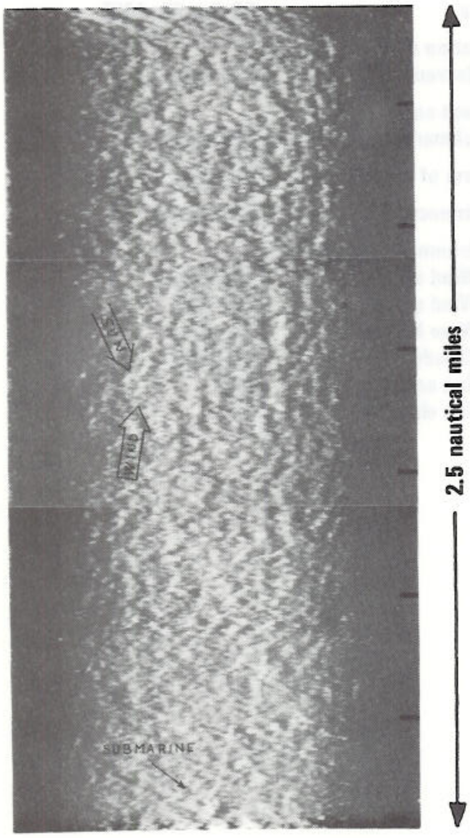
There are no variations in the shade of grey at the edges. This phenomenon emanates from an unusually high modulation of the low-frequency content of the radiation from the sea surface. This modulation is mainly dependent on three factors:

a) The dependence of the emissivity of the sea-surface on the angle of viewing which varies from 0° to 60° due to the scan motion.

b) The emissivity fluctuations due to the roughness of the sea.

c) The reflected radiation from the sky; the radiation from the sky depends on the cloud conditions, the reflected part on the angle of viewing and the sea roughness.

The low-frequency content of the signal is highly rejected by filtering. Occasionally, however, the low-frequency modulation turns out to be too large to be sufficiently depressed. If higher discriminating filtering had been introduced, the signal from the submarine wake would have been degraded.



– Time	26 Apr 77 : 1413
– Location of rendezvous	The same
– Present course of submarine	The same
– Course of aircraft	The same
– Persistency	27 minutes
– Environmental conditions:	
– Wind direction	The same
– Wind speed	The same
– Wave height	The same
– Cloudiness	The same
– Sun azimuth	220°
– Sun elevation	31°

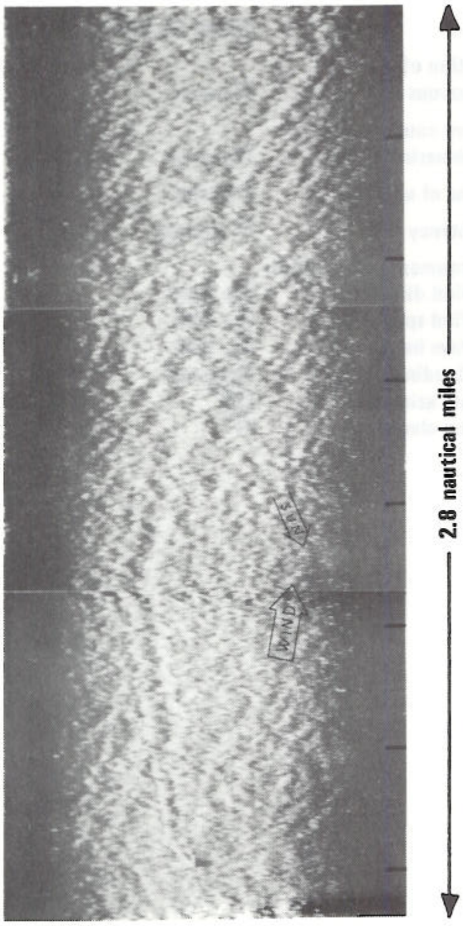
Run b

Configuration:

The same.

Remarks:

The wake is barely visible.



- Time — 26 Apr 77 : 1425
- Location of rendezvous — The same
- Present course of submarine — The same
- Course of aircraft — The same
- Persistency — 32 minutes
- Environmental conditions:
  - Wind direction — The same
  - Wind speed — The same
  - Wave height — The same
  - Cloudiness — The same
  - Sun azimuth — 222°
  - Sun elevation — 31°

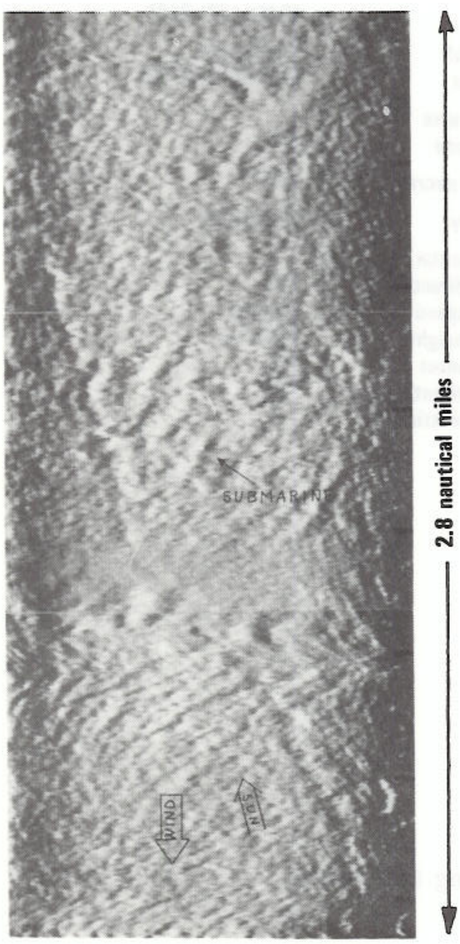
Run c

Configuration:

The same.

Remarks:

The wake is clearly visible.



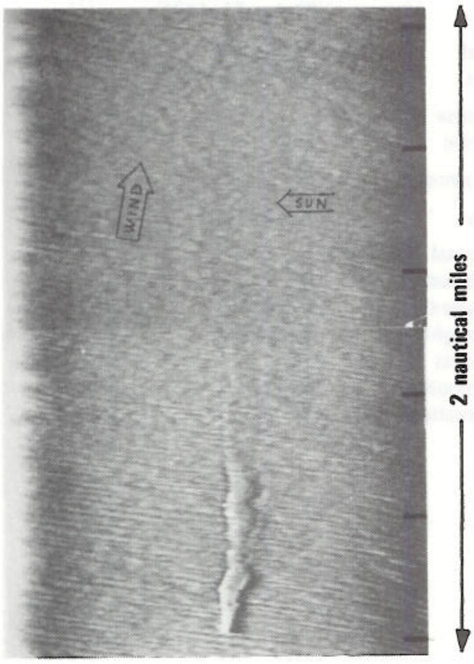
– Time	27 Apr 77 : 1434
– Location of rendezvous	Vestfjorden N68°05' E14°50'
– Present course of submarine	240°
– Course of aircraft	60°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	60°
– Wind speed	6 knots
– Wave height	0.5 meters
– Cloudiness	1/8
– Sun azimuth	225°
– Sun elevation	30°

Configuration:

Periscope depth, diesels running, all masts ploughing the surface.

Remarks:

The present location of the submarine is marked in the picture. The preceding course is easily followed from the right corner at the bottom of the picture and then diagonally towards the top. Thereafter follows a 180° turn. Shortly after the submarine has completed the turn, the wake disappears. We cannot see even a faint track leading to the present location of the submarine. Nothing is reported from the submarine about diving, so the phenomenon is rather inexplicable.



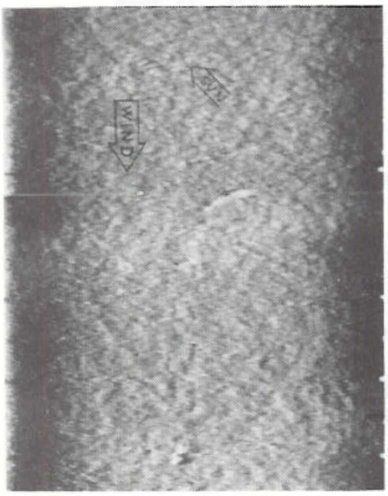
- Time: 10 May 77 : 2141
- Location of rendezvous: Vestfjorden N68°05′ E14°50′
- Present course of submarine: 60°
- Course of aircraft: 240°
- Persistency: 23 minutes
- Environmental conditions:
  - Wind direction: 50°
  - Wind speed: 3 knots
  - Wave height: Calm sea
  - Cloudiness: 3/8
  - Sun azimuth: 330°
  - Sun elevation: −1°

Configuration:

Periscope depth, diesels running, all masts ploughing the surface.

Remarks:

The wake is clearly visible.



1.4 nautical miles

- Time — 11 May 77:1247
- Location of rendezvous — Vestfjorden N68°05′ E14°50′
- Present course of submarine — 240°
- Course of aircraft — 60°
- Persistency — 11 minutes
- Environmental conditions:
  - Wind direction — 60°
  - Wind speed — 13 knots
  - Wave height — 1 meter
  - Cloudiness — 7/8
  - Sun azimuth — 195°
  - Sun elevation — 39°

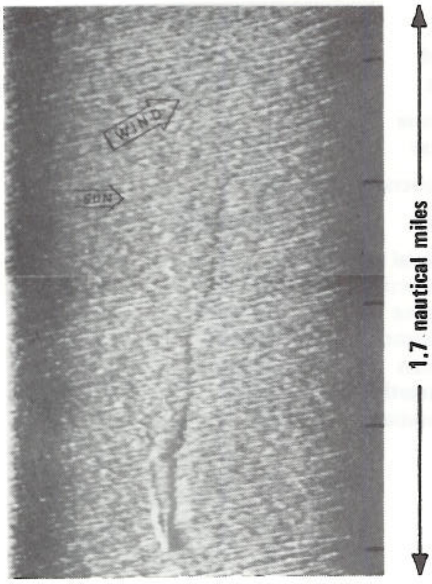
Configuration:

Periscope depth, diesels off, the periscope and the UHF-mast being the only masts breaking the surface. Later the diesels were turned on and all masts were elevated.

Remarks:

Due to interfering gunboats the submarine has temporarily been submerged to a depth of 30 m. She has probably ascended to periscope depth at the beginning of the visible curved track and has turned on the diesels and elevated all masts about half a mile behind the present location.

While the track where the submarine alters course is clearly visible, the wake from the end of the turn to the present location of the submarine is barely visible.



– Time	11 May 77 : 2150
– Location of rendezvous	Vestfjorden N68°o5' E14°50'
– Present course of submarine	240°
– Course of aircraft	60°
– Persistency	14 minutes
– Environmental conditions:	
– Wind direction	300°
– Wind speed	10 knots
– Wave height	0.5 meters
– Cloudiness	6/8
– Sun azimuth	330°
– Sun elevation	– 1°

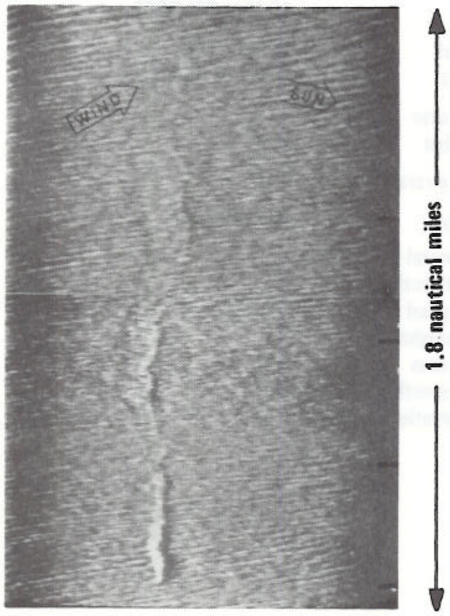
Run a

Configuration:

Periscope depth, diesels running, all masts ploughing the surface.

Remarks:

The wake is clearly visible. Note the peculiar V-shape extending backwards about half a nautical mile from the submarine.



– Time	11 May 77 :2234
– Location of rendezvous	Vestfjorden N68°05′ E14°50′
– Present course of submarine	240°
– Course of aircraft	60°
– Persistency	19 minutes
– Environmental conditions:	
– Wind direction	300°
– Wind speed	10 knots
– Wave height	0.5 meters
– Cloudiness	6/8
– Sun azimuth	340°
– Sun elevation	– 3°

Run b

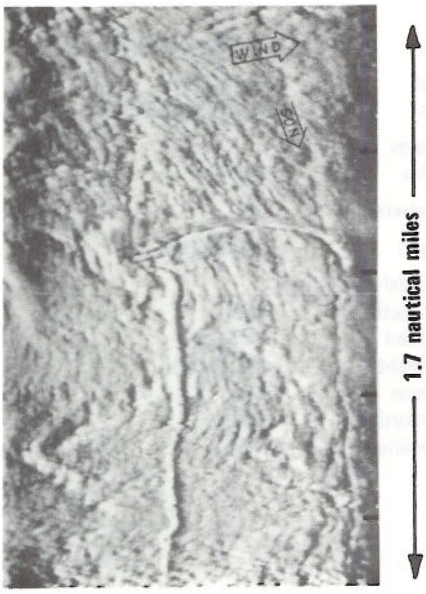
Configuration:

Periscope depth, diesels off, the periscope and the UHF-mast being the only masts ploughing the surface.

Remarks:

The configuration mentioned above was established when the submarine was in the position of the previously reported run. 44 minutes have passed since then. The wake of the present run shows a persistency of 19 minutes; thus this run is completely made up from this less exposed configuration.

The V-shape does not begin at the point where the submarine is instantly located, but seems to appear 0.4 nautical miles behind this point from where it evolves into a double track.



- Time — 13 May 77 : 0527
- Location of rendezvous — Ofotfjorden N68°26′ E16°50′
- Present course of submarine — 280°
- Course of aircraft — 100°
- Persistency — Not relevant
- Environmental conditions:
  - Wind direction — 0°
  - Wind speed — 5 knots
  - Wave height — 0
  - Cloudiness — 5/8
  - Sun azimuth — 79°
  - Sun elevation — 15°

Run a

Configuration:

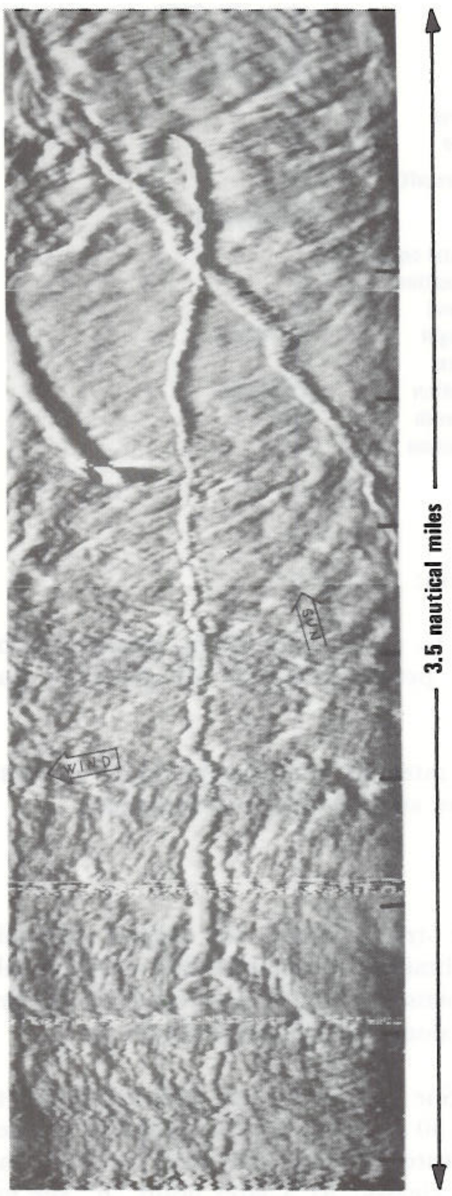
Periscope depth, no masts breaking the surface.

Remarks:

During this mission the submarine has travelled the same route back and forth. Due to the presence of a couple of cargo vessels she had to make some detours. Therefore the total sailing pattern looks somewhat entangled.

We have described the configuration as one with no masts breaking the surface. For safety reasons the periscope has been raised now and then. On the average the periscope has been elevated during one third of the total exercise time. However, no modulation of the wake can be seen that corresponds with the up/down motion of the periscope.

From the picture we can follow the prehistory of the submarine through the opposite directions along the route. Note the 360° turn.



– Time	13 May 77 : 0548
– Location of rendezvous	Ofotfjorden N68°26′ E16°50′
– Present course of submarine	280°
– Course of aircraft	280°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	0°
– Wind speed	5 knots
– Wave height	Calm sea
– Cloudiness	5/8
– Sun azimuth	83°
– Sun elevation	17°

Run b

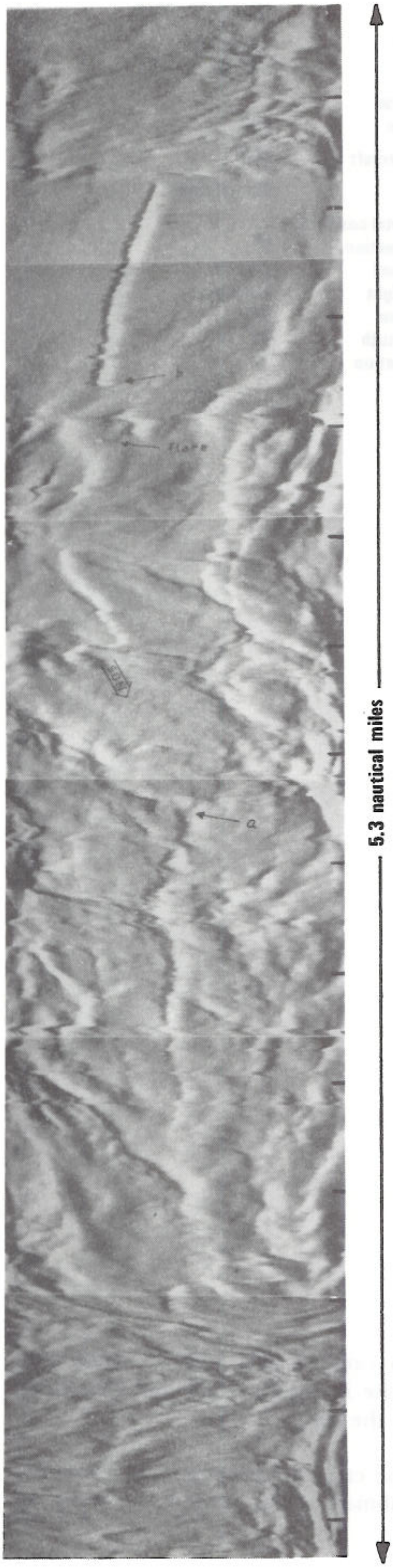
Configuration:

The same.

Remarks:

The two wakes running obliquely stem from two cargo vessels, one of which is at present in the picture. The wake from the submarine is clearly visible and runs along the centre-line of the picture; the submarine is near the top.

The submarine wake and the wake from one of the cargo vessels intersect. From the appearance of the wakes we realize that the submarine has passed the point of intersection at a later instant.



– **Time**	**13 Jun 77 :2103**
– **Location of rendezvous**	**Andfjorden N69°08′ E16°14′**
– **Present course of submarine**	**20°**
– **Course of aircraft**	**20°**
– **Persistency**	**Not relevant**
– **Environmental conditions:**	
– **Wind direction**	**–**
– **Wind speed**	**0**
– **Wave height**	**0.1 meters**
– **Cloudiness**	**8/8**
– **Precipitation**	**Light rain**
– **Sun azimuth**	**321°**
– **Sun elevation**	**7°**

Configuration:

Submerged to a depth of 30 m, interrupted by intervals at periscope depth for guidance purposes.

During the intervals at periscope depth all masts were exposed and the diesels were running.

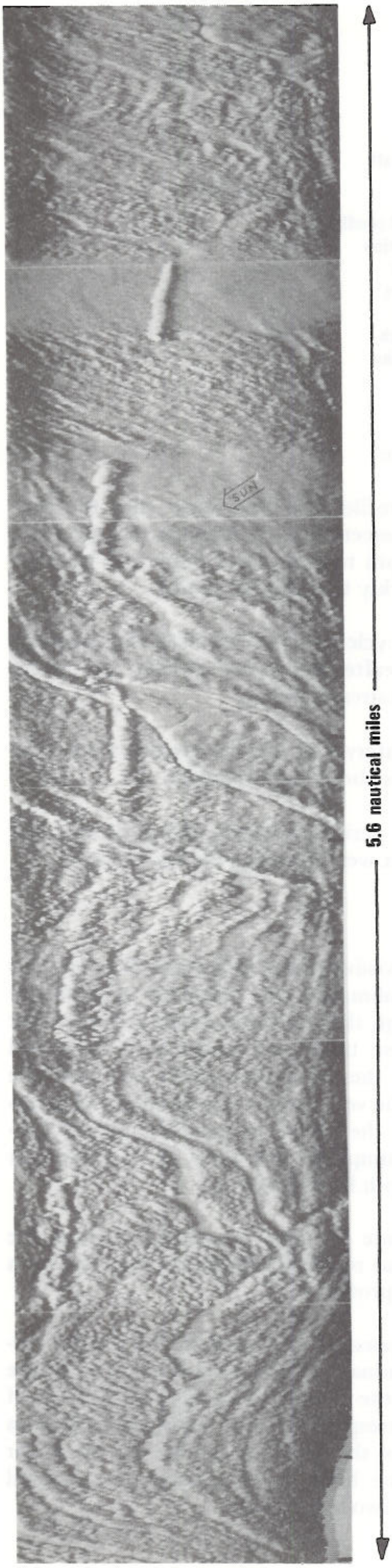
Remarks:

The visible track which we almost certainly expect to obtain from the intervals with the submarine at periscope depth were used for piloting the aircraft along the submarine route.

The submarine has dived from periscope depth to a depth of 30 m at a point "a" which is marked on the picture. We see the wake beneath this point quite clearly. At a later point "b" she has ascended to periscope depth again. The small white spot about two cable lengths behind point "b" is a flare that has been launched from the submarine.

In the vicinity of the location of this flare there is no trace that joins the beginning of the very pronounced wake gained from the succeeding sailing at periscope depth.

We therefore conclude, at least provisionally, that the submarine is not detectable from a depth of 30 m. Going back to the point where the submarine has dived, we see a trace extending in approximately the same direction as the submarine has followed through the subsequent travel at a depth of 30 m. Therefore we are in doubt as to whether the submarine has been observed from a depth of 30 m during this trial.



– Time	14 Jun 77 : 2105
– Location of rendezvous	Tranøy N68°11′ E15°31′
– Present course of submarine	263°
– Course of aircraft	263°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	–
– Wind speed	0
– Wave height	0
– Cloudiness	2/8
– Sun azimuth	321°
– Sun elevation	7°

Configuration:

Submerged to a depth of 30 m, interrupted by intervals at periscope depth for guidance purposes.

The intervals at the depth of 30 m have lasted approximately five minutes, and so have those at periscope depth.

At periscope depth only the periscope and on occasions also the UHF-mast have been breaking the surface.

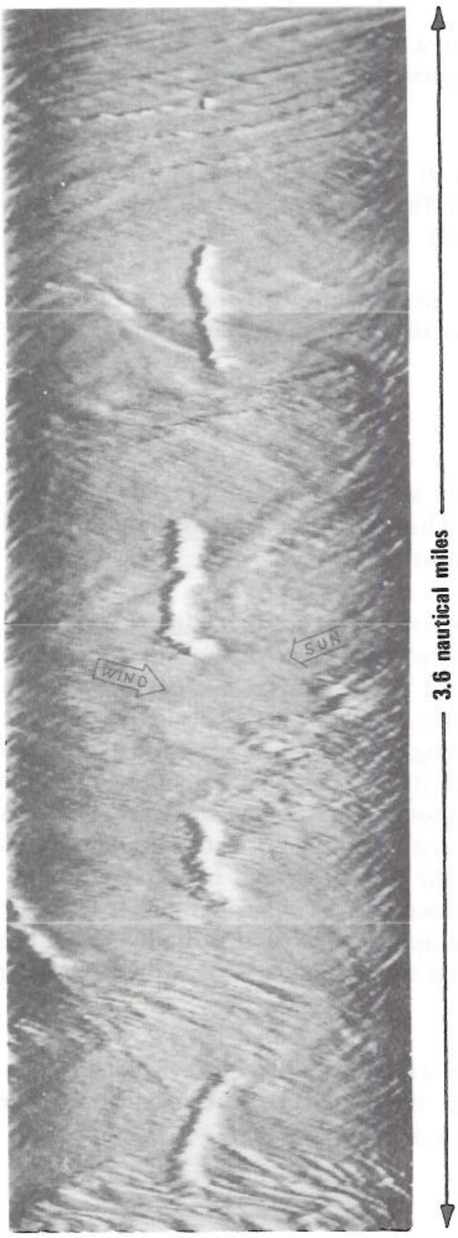
Remarks:

We can clearly see five intervals travelled at periscope depth. The submarine has just ascended and is visible at point "a".

From the periods where the submarine is submerged to a depth of 30 m we have no signs from that activity on the sea surface. Closer inspection of the pictures, however, reveals a shadowlike strip connecting the second uppermost and the third "surface strip". This shadow emerged gradually during about a couple of minutes. When it first became visible it was located somewhat to the right of the line described by the two neighbouring "surface strips". Altogether, the whole nature of the appearance of the shadow gave the impression that upwelling water was the prevailing mechanism.

We are fairly convinced therefore, that the shadowlike strip is related to the motion of the submarine at a depth of 30 m.

- Time — 17 Jun 77 : 1040
- Location of rendezvous — Skrova N68°10′ E14°50′
- Present course of submarine — 85°
- Course of aircraft — 85°
- Persistency — Not relevant
- Environmental conditions:
  - Wind direction — 10°
  - Wind speed — 6 knots
  - Wave height — 0.1 meter
  - Cloudiness — 0/8
  - Sun azimuth — 154°
  - Sun elevation — 44°



Configuration:

"Staircase profile", in the sense that the submarine has descended in a stepwise manner from periscope depth to a depth of 30 m and has then returned quickly to periscope depth.

After three cycles she has reversed the sequence and has thereafter descended quickly and ascended along a staircase profile.

Each time interval at depths greater than periscope depth is about eight minutes.

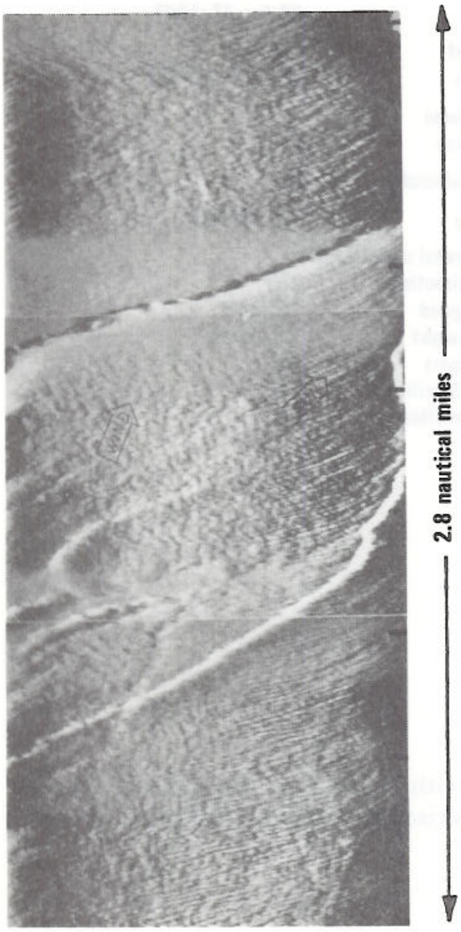
Whenever at periscope depth, the periscope and the UHF-mast were breaking the sea surface.

Remarks:

We have got visible tracks only from those periods where the submarine has advanced at periscope depth. Though there is some doubt as to whether some of these tracks are longer than we would expect from the annotation made on board the submarine, the very abrupt appearances and disappearances of the visible strips in the picture support the assumption that only the activities at periscope depth have shown up.

When we made the first run of this mission, the submarine had reached a depth of about 20 m in the staircase profile.

The wake appeared as shown in the smaller picture. The gradually diminishing track may be the image from the diving submarine with the tip of the wake corresponding to a depth of 20 m. This wake strip is the same as we see in the larger picture at the bottom. 34 minutes have elapsed between the two recordings.



– Time	20 Jun 77 : 2028
– Location of rendezvous	Skrova N68°10′ E14°50′
– Present course of submarine	85°
– Course of aircraft	85°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	290°
– Wind speed	12 knots
– Wave height	0.5 meters
– Cloudiness	6/8
– Sun azimuth	312°
– Sun elevation	9°

Configuration:

Periscope depth, alternately with masts exposed and withdrawn.

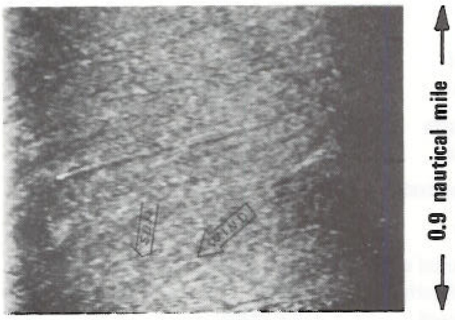
Through a time interval of five minutes the periscope and the UHF-mast have been ploughing the surface, for the next five minutes no masts were breaking the surface, thereafter the two masts were again ploughing for five minutes, and so on and so forth.

Remarks:

The wake is barely visible. Strong natural currents seem to overwhelm the submarine wake.

The submarine is located about half a nautical mile below the top of the picture. The wake extends downward along the middle of the picture and moves smoothly to the left through the last nautical mile.

It is important to note that the strength of the track exhibits no dependence on the change of mast configuration. The submarine is just as barely visible when the periscope and the UHF-mast penetrate the sea surface as when no masts break the surface.



– Time	22 Jun 77 :1447
– Location of rendezvous	Skrova N68°10′ E14°50′
– Present course of submarine	85°
– Course of aircraft	220°
– Persistency	Not relevant
– Environmental conditions:	
– Wind direction	270°
– Wind speed	13 knots
– Wave height	1.2 meters
– Cloudiness	6/8
– Sun azimuth	230°
– Sun elevation	39°

Configuration:

Submarine course purposely at an angle of 45° with respect to the aircraft course. Periscope depth, diesels running, the snorkel, the periscope and the UHF-mast ploughing the surface.

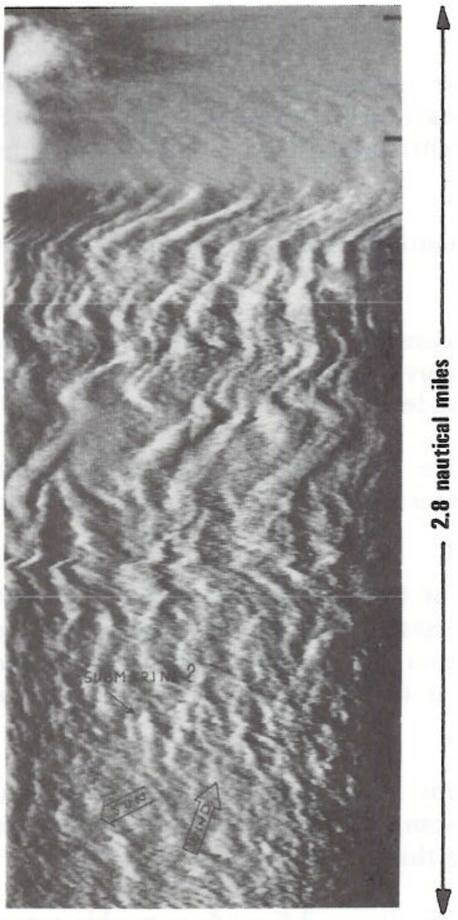
Remarks:

The objective of this exercise was to investigate whether the submarine wake will appear on the display when the wake is overflown at a direction other than parallel.

This situation resembles a real one; the pilot has, however, due to the real time display, the possibility of altering his course to follow the direction of the wake as soon as it is discovered.

At this point we suggest that the reader recalls the examples from wakes where it can be seen that the submarine is doing turns. These turns leave pieces of tracks at right angles with respect to the aircraft course.

From the picture we observe the wake as being clearly visible. Because the scanning mechanism does not provide conformal imagery, the wake appears closer to an angle of 90° than the actual 45° which was flown.



- Time — 23 Jun 77 : 1135
- Location of rendezvous — Ofotfjorden N68°26′ E16°50′
- Present course of submarine — 110°
- Course of aircraft — 110°
- Persistency — 0
- Environmental conditions:
  - Wind direction — 310°
  - Wind speed — 10 knots
  - Wave height — 0.5 meters
  - Cloudiness — 5/8
  - Sun azimuth — 174°
  - Sun elevation — 45°

Configuration:

Periscope depth, diesels off, the periscope and the UHF-mast the only masts breaking the surface.

Remarks:

No wake can be seen from the motion of the submarine. The very pronounced parallel running currents of natural origin seem to completely mask any thermal disturbance caused by the submarine.

There may be some argument as to whether the submarine masts appear as the white spot marked in the picture; in any case it is highly doubtful that this slight disturbance would have caught the operator's attention.

For the sake of comparison, the reader is advised to refer to the mission on 13 May. At that time the same route was followed. We got then a clearly visible track and moreover, no masts were breaking the surface.

The natural currents we encounter this time probably arise from melting snow and ice.

3.4 Review of the achieved results

As long as masts were ploughing the surface, we obtained a thermal track on the display in 77% of the trials, even when the diesels were turned off. The sea state, short sea more pronounced than swells, and currents turned out to heavily affect the distinctness of the track and its visible length.

Although we have observed tracks lengths of 7 nautical miles, the mean length turns out to be 1.7 nautical miles.

With all masts drawn in we have obtained plain scores on the display from operations in smooth sea. In moderate sea we have got barely visible tracks; in most cases, however, such that the operator would have responded.

With the submarine running at a depth of 30 m we have in 1 case of 24 trials observed a very faint score that seemed to appear a couple of minutes after the boat had passed.

From the trials performed by flying at an angle of 45° with respect to the course of the submarine, we have observed clearly visible wakes in most cases. Throughout the exercise period we have also observed wakes from the submarine when she made turns and thereby for a limited interval steered at right angles to the course of the aircraft.

In section 3.3 we have attempted to report our results by presenting a faithful selection of the events experienced by the linescan operator. The operator in this sense is the NDRE personnel permanently running the project.

In order to complete the presentations, we have in Figure 3.6 made a graphic representation covering all the 121 runs from all the 13 missions. We have judged the results from all runs and have formed them into five groups depending on their perspicuity. These five groups have been named:

"clearly visible"
"less clearly visible"
"barely visible"
"doubtful"
"not visible"

In making these judgements we have examined pictures covering a complete run, i e pictures of the kind presented in the previous section. However, we have viewed the pictures through a mask reproducing the display frame, but have moved this mask until it covered that part of the run where the wake showed up most distinctly. This procedure is justified by the fact that it faithfully portrays the actual situation.

As is seen from Figure 3.6, we have assigned to the three best characters a label stating that the operator's attention would have been caught. This is to say that *we* did react, but we were operating under experimental conditions, not tactical. We had an a priori knowledge of the presence of the submarine.

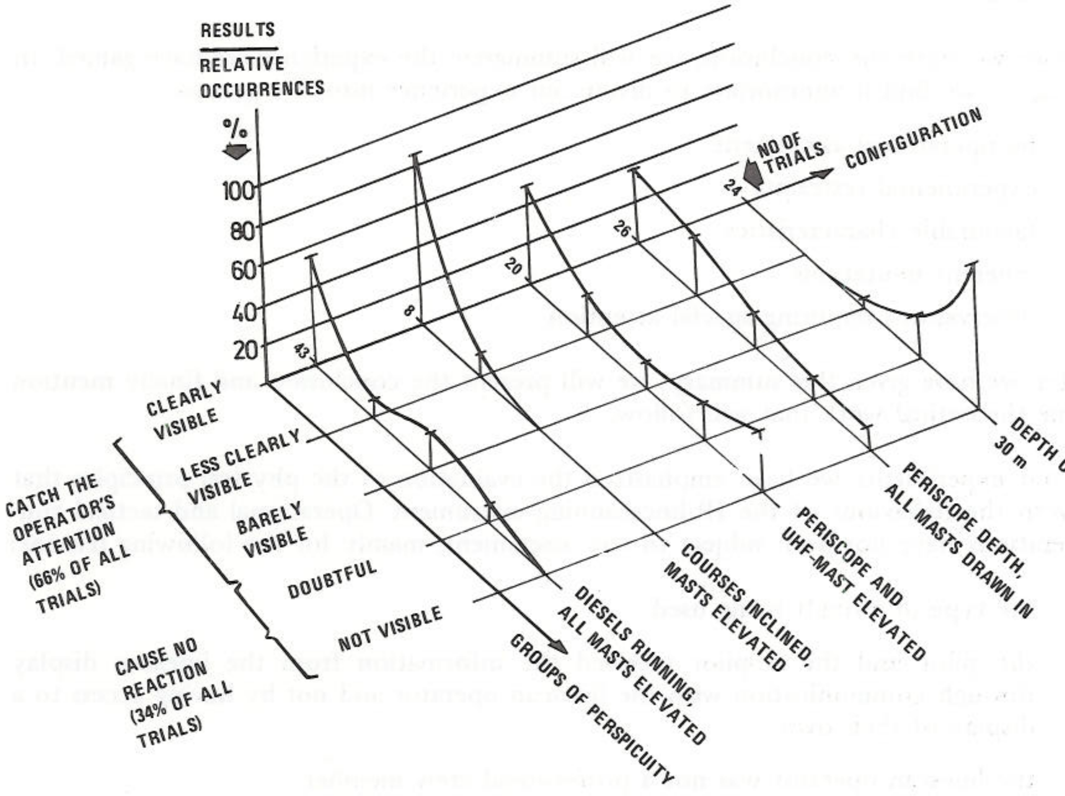


Figure 3.6 Review of the results from all trials against the Kobben-class submarine

Further, we have depicted the five different configurations in which the submarine has operated; they are here listed according to decreasing "power":

"diesels running, all masts elevated"	(all masts ploughing the sea surface)
"courses inclined, masts elevated"	(submarine course purposely at an angle of 45° with respect to the aircraft course)
"periscope and UHF-mast elevated"	(the only masts ploughing the surface)
"periscope depth, all masts drawn in"	(nothing penetrating the surface)
"depth of 30 meters"	

Now, for each configuration we have along the vertical axis quoted the relative number of trials that came out with a result which fell into one of the give groups of perspicuity. Thus, the vertical axis shows relative occurrences, and the sum of the values belonging to the same configuration is always unity (100%).

We have five distributions, one for each configuration. All of these distributions, except the one for the depth of 30 m, indicate that more trials tend to render results to the benefit of the operator than to his dissatisfaction. The shape of the distributions is not strictly monotonically decreasing; the deviation is apparently caused by the small number of trials involved.

4 CONCLUSION

Before we state the conclusion, we will summarize the experience we have gained. In doing so, we find it appropriate to divide our experience into five groups:

a) no operational assessment
b) experimental restraints
c) favourable characteristics
d) inherent limitations
e) observations requiring special attention

After we have given this summary, we will present the conclusion and finally mention some theoretical work that will follow.

In our experiments we have emphasized the evaluation of the physical principles that govern the behaviour of the IR-linescanning instrument. Operational and tactical considerations have not been subject to any assessment, mainly for the following reasons:

- the type of aircraft being used
- the pilot and the co-pilot received the information from the linescan display through communication with the linescan operator and not by having access to a display of their own
- the linescan operator was not a professional crew member
- there was always a previously agreed procedure that the aircraft and the submarine were going to follow
- the targets were limited to one particular class of submarine representing one of the smallest types of manned submarines

Even if we do not ask for operational evaluation, we have to point out that the experiments have been subject to various retraints:

- mainly good weather conditions
- limited exercise area
- trials conducted over a limited period of the year

From the trials we have learned that IR-linescanning technique possesses certain characteristics which may be utilized to the benefit of submarine detection, localization and tracking. As far as we can see, the more *favourable* characteristics are:

a) at any instant the submarine has left uncovered her activities at periscope depth for a period of time lasting from a couple of minutes to about an hour prior to that instant
b) the real-time moving scene display permits the pilot to adjust his flight pattern for the purpose of relocalizing and tracking
c) the use of the technique is independent of whether it is day or night
d) the technique represents a passive method and therefore offers covert operations
e) radiation within the optical wavelength region we utilize, penetrates smoke
f) the primary mechanisms which are responsible for the observable effects on the sea surface cannot be concealed

Let us remember that the primary mechanisms are:

- stirring of a water volume due to the motion of the submarine
- heat dissipation

Further, we have noticed that the use of IR-linescanning is subject to some inherent limitations:

- High sea state
  A rough sea-surface counteracts the submarine's attempt to establish a regular disturbance and either prevents the wake from showing up at all or erases it quickly. Even after the wind has fallen off and the surface is composed of swells, but no crests, the thermal surface effect from a submarine may be small because the stirring of the wind may have smoothed out the variation in temperature from the surface to some depth.

- Coverage transverse of flight path essentially limited to 1000 – 3000 m
  This limitation is related to the altitude and the angular coverage. The wide instantaneous field of view necessary to achieve sufficient thermal resolution demands altitudes less than 3000 feet in order to allow the wake dimensions to be spatially resolved. The maximum angular coverage is 60° at each side of nadir. The angular dependence of the water emissivity prevents operation at more oblique line of sight; even 60° is at the border of what can be justified.

- No all-weather capability
  Relative humidity below saturation causes no significant attenuation. If fog is present, however, absorption and scattering effects prevent any useful signal being received. Likewise, clouds are essentially opaque, and their presence underneath the aircraft will render the IR-linescanner useless. Rain on the other hand, though reducing the performance of the linescanner, may not prevent the intended mission being performed.

Finally, there are two sets of observations that need special attention. This is because we envisage the introduction of some improvements:

- Our experience has been that a submarine of the size of the Kobben-class might be detected at a depth of 30 m. Though we have only once seen a faint sign of the presence of the submarine at this depth, this incident ought to support the argument that an increase of the thermal sensitivity will reveal appropriate use of IR-linescanning technique for detection of submarines at greater depths than periscope depth.

- Various thermal patterns of natural origins, like currents, add confusion to the picture on the display and may prevent the operator from discovering the submarine wake. We recall, however, that these disturbing patterns exhibit static behaviour compared to the wake from the submarine in motion. Therefore, by some elaborate correlation technique it is possible that the confusion arising from thermal patterns of natural origins can be reduced.

Herewith ends the summary of the experience we have gained and we arrive at the *conclusion:*

a) **The use of IR-linescanning technique as a method to detect, localize and track submarines adds a new dimension to the realm of acoustic and magnetic detection means.**

b) Through the trials we have verified the design principles on which the construction of the experimental linescanning system has been based, as being correct principles. Likewise the construction itself has turned out to be a sound construction.

c) We are still not in a position to give an unconditional "yes" or "no" answer to the question we originally put forward, namely: "Does the introduction of the maritime IR-linescanner concept into the maritime services increase the power of the maritime patrol aircraft in anti-submarine warfare?" The reason is that we lack information on the utilization of the IR-linescanning concept in the operative structure.

The principal contents of this report were orally presented to representatives from the Royal Norwegian Navy (RNoN) and the Royal Norwegian Air Force (RNoAF) at a meeting held at the Central Headquarter of Defence (CHOD Norway) on 13 December 1977. Following the presentation the RNoAF Inspector of Flying formed a study group that should work on an assessment of the use of maritime IR-linescanning with respect to the operational concepts of our maritime patrol services. The work of the study group should be finished in 1978 and the result of the work should give an addendum to "point c" in this conclusion, such that the final answer as to the eventual introduction of the maritime IR-linescanner can be given.

APPENDIX

Figure A.1 is a functional diagram of the scanner optics. A rotating drum holds two lenses and a mirror with both surfaces specular. The lenses are mounted diametrically at the rim of the drum, while the mirror is intersected by the axis about which the drum is rotating. The lenses are made of polycrystalline zinc sulphide, a material which is widely used as long-wave infrared transmitting material for various optical

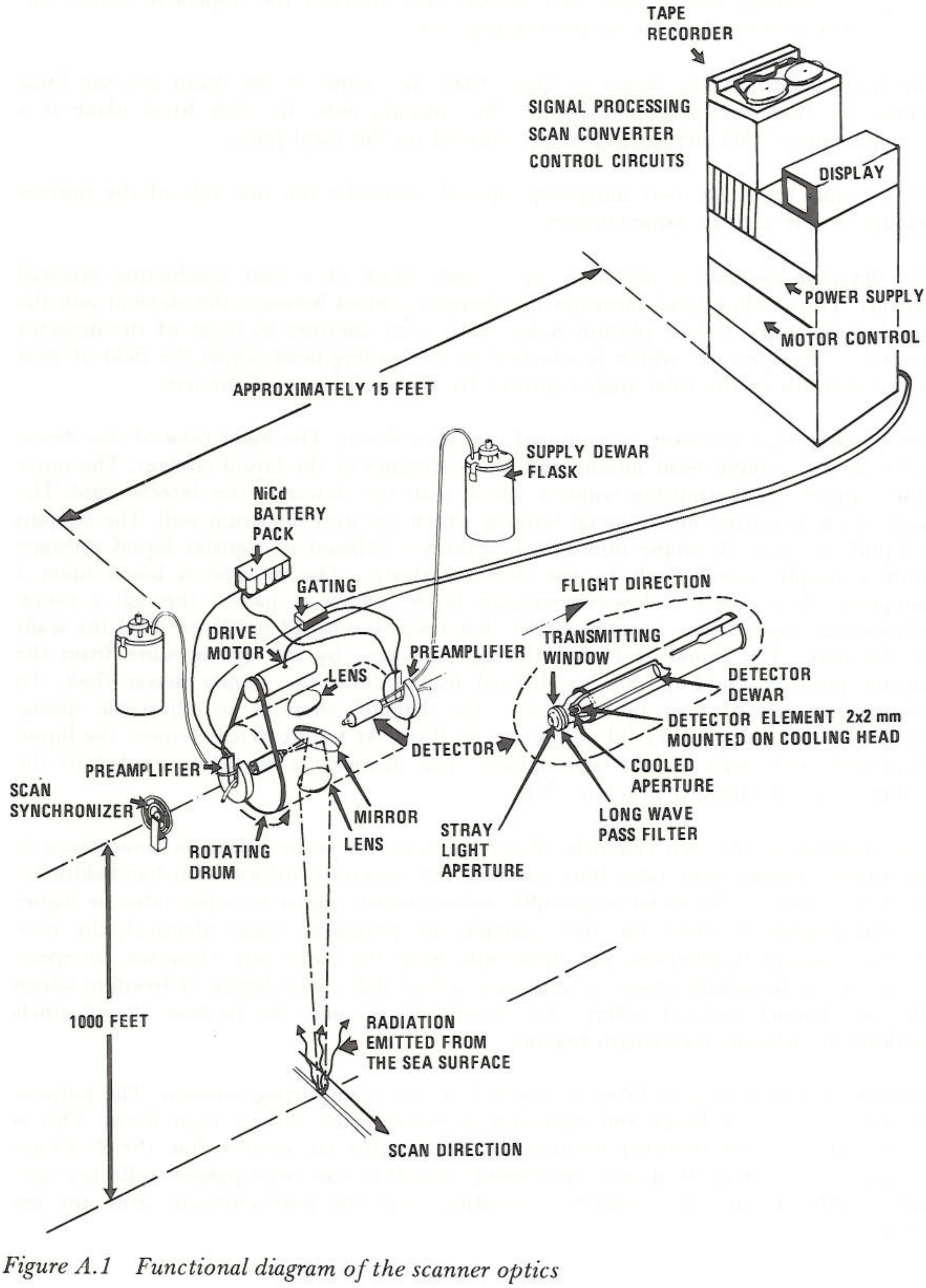


Figure A.1 Functional diagram of the scanner optics components. The shape is meniscus with aspheric curve on the negative side, thus exhibiting very low spherical abberations. On the other hand the chromatic abberation is fairly high. The lenses are given an anti-reflection coating.

The mirror is made of a glass-ceramic material with negligible thermal expansion and high mechanical stability. The reflective layers are gold which has been deposited by evaporation. The optical axes of the lenses are mutually parallel. The mirror is inclined 45° with respect to the optical axes of the lenses. The lenses are displaced along the rotating axis so that their optical axes intersect the respective mirror surfaces at two points which lie on the rotating axis.

The focal length of the lenses is larger than the radius of the drum and the focal planes are therefore perpendicular to the rotating axis. In each focal plane is a 2x2 mm square CMT detector element centered on the focal point.

We see that there are two indepdent optical channels; the one side of the mirrow belongs to one and the same channel.

The detector element is mounted on a small block of a heat conducting material (Kovar). This cooling head furnishes the thermal contact between the element and the liquid coolant. To reduce photon noise there is an aperture in front of the detector element. This aperture, which is attached to the cooling head, limits the field of view of the detector to the solid angle captured by the useful part of the lens.

The cooling head assembly is mounted in a glass dewar. The inner tube of this dewar serves as the cooling head mount and as a container of the liquid coolant. The outer tube supports a transmitting window which seals the dewar at the detector end. The glass dewar is potted into a metal housing which fits into the drum wall. The coolant is liquid nitrogen. A simple liquid-feed method is utilized to transfer liquid nitrogen from a supply dewar flask to the detector dewar. The method is based upon a two-phase flow where a low-temperature liquid which is passed through a room-temperature pipe, forms a gaseous skin that keeps the liquid insulated from the walls of the pipe. The liquid is forced through the pipe by the gas pressure from the natural pressure build-up due to thermal leakage into the supply dewar flask. To control the rate of flow of liquid into the detector there is an adjustable spring-loaded on–off valve in the lid of the supply flask. At the detector element the liquid evaporates and vents to the atmosphere. The element is therefore cooled to the boiling point of nitrogen which is 77 K.

The presence of the two channels allows the scan rate to be halved in comparison to the single channel scan rate, thus reducing the necessary information bandwidth by the same amount. Reduced bandwidth means higher signal to noise ratio or higher thermal resolution. Since the two channels are purposely made identical, the two-channel concept is otherwise not noticeable from the user's side. However, for specific use it can be advantageous to purposely utilize that extra degree of freedom which the two-channel concept offers. An evident feature may be to have the channels working in different wavelength regions.

An optical long-wave-pass filter is attached to the transmitting window. The purpose of this filter is to block out radiation at wavelengths shorter than 8 μm. This is significant since the detector responds to wavelengths far shorter than the 8–13 μm atmospheric window. If shorter wavelength radiation had been passed, reflected daylight might obscure the imagery originating from the pure emission from the sea surface.

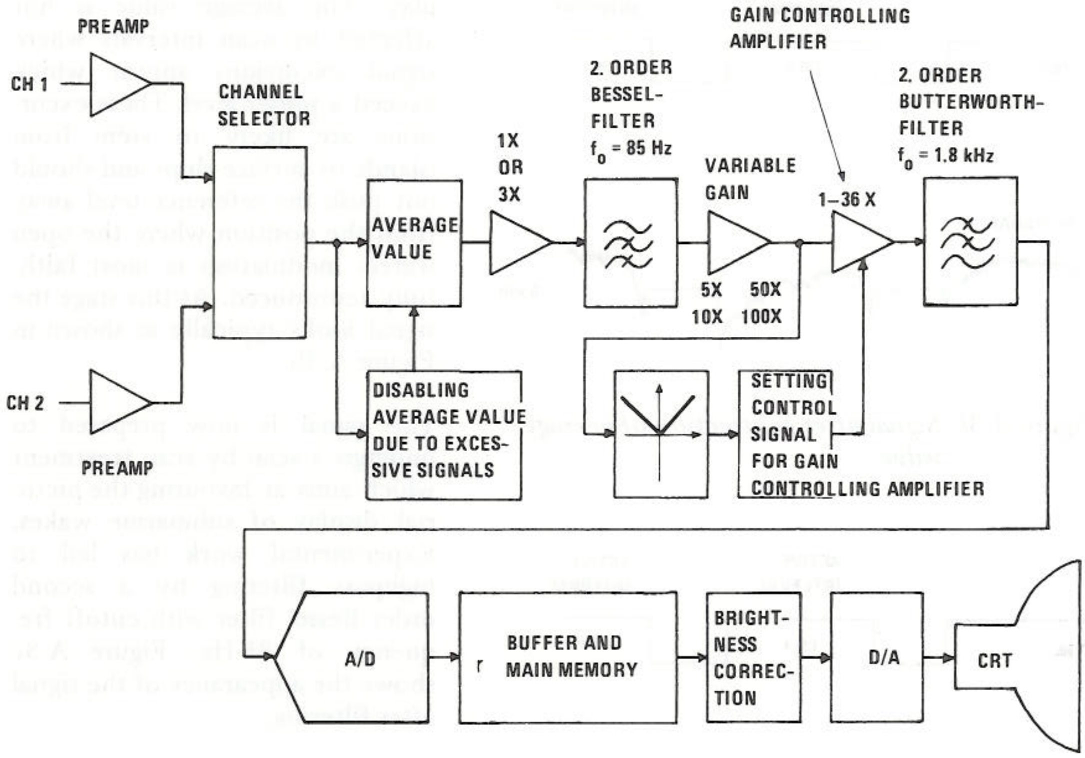


Figure A.2 Signal processing block diagram

Figure A.2 is a block diagram exhibiting the signal processing which the received information undergoes on its way from the detector to the display.

The conductivity of the detector varies in accordance with the variation of the incoming radiation. The low-noise preamplifier brings forth a varying voltage which is the replica of the incremental component of this radiation. The slowly changing absolute level of the radiation is not transferred.

As the drum is rotating, the detectors alternately receive radiation from the sea surface and the interior of the scanner housing. However, the two detectors never receive radiation from the sea surface simultaneously. The preamplifier signals therefore are combined successively and the perceived information is thereafter presented as one signal; see Figure A.3a.

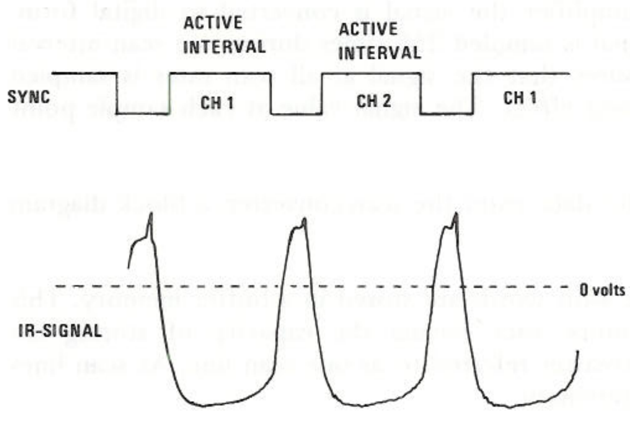


Figure A.3a Output from channel selector; signals successively combined

At each instant the average of this signal over approximately the ten preceding scans is computed and is subtracted from the signal itself. Only the 120° active scan interval is permitted to contribute to the average. The resulting signal is therefore varying around the system quiescent zero voltage level. This level is finally assigned

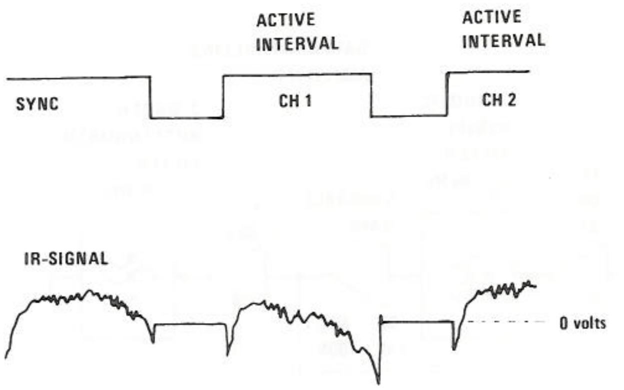


Figure A.3b Signal after subtraction of average value

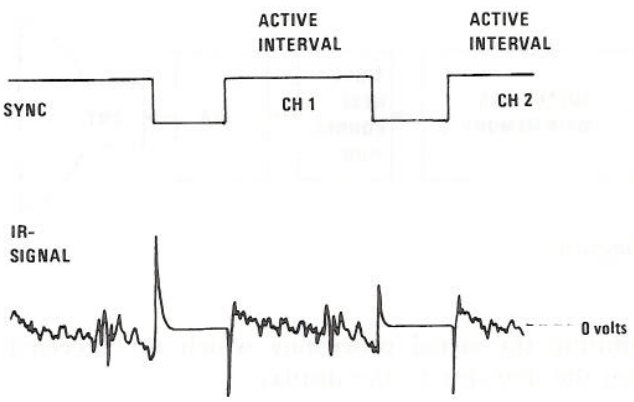


Figure A.3c Signal at the output of the Bessel-filter

to the mean grey level of the display. The average value is not affected by scan intervals where signal excursions appear which exceed a preset level. These excursions are likely to stem from islands or surface ships and should not push the reference level away from the position where the open waters modulation is most faithfully reproduced. At this stage the signal looks typically as shown in Figure A.3b.

The signal is now prepared to undergo a scan by scan treatment which aims at favouring the pictorial display of submarine wakes. Experimental work has led to highpass filtering by a second order Bessel filter with cutoff frequency of 85 Hz. Figure A.3c shows the appearance of the signal after filtering.

Varying sea and atmosphere conditions cause varying signal strength. In order to discover the fine details, it is of utmost importance that the grey scale capability of the display is utilized to its full extent. This is achieved by amplifying the signal through a linear amplifier with controllable gain. The gain is set by the incoming signal such that this signal always drives the amplifier completely through its linear region. If some interval of the signal before it enters the amplifier has driven the preceding circuitry into saturation, this signal interval will not influence the gain setting.

At the output of the controllable amplifier the signal is converted to digital form. Independent of the scan rate, the signal is sampled 256 times during one scan interval of 120°. This sample frequency ensures that the signal at all scan rates is sampled frequently enough to avoid any aliasing effect. The signal value at each sample point is converted to a 4 bit word.

After analog to digital conversion, the data enter the scan-converter, a block diagram of which is shown in Figure A.4.

As the sampling process goes on, the 4-bit words are stored in a buffer memory. This memory consists of two identical units, each having the capacity of storing the 256·4 bits from one scan interval; hereafter referred to as one scan line. As scan lines arrive they fill up each buffer unit alternately.

The buffer memory in turn furnishes the main memory. This memory holds a complete display frame consisting of 256 lines, thus yielding a capacity of 256·256·4 bits.

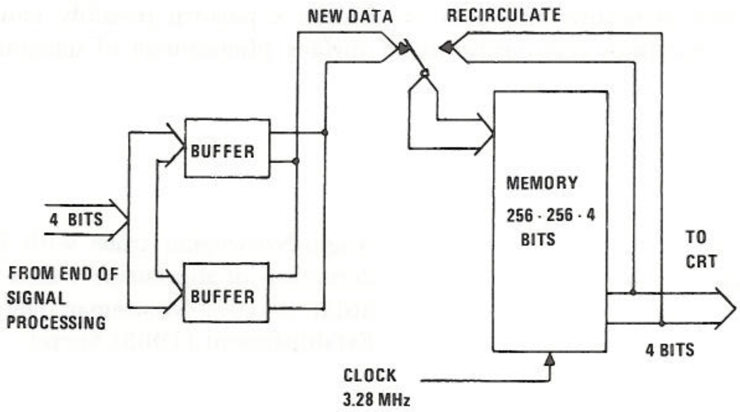


Figure A.4 Scan-converter block diagram

As the electron beam of the cathode ray tube (CRT) traces the picture in a TV-like fashion, each picture element is intensity modulated from the main memory.

The display frame rate is 50 frames per second, which gives a flicker-free presentation. Since the main memory, which is organized as a shift register, must feed 256·256 picture elements in 1/50 second, it must be clocked at a frequency of 3.28 MHz.

The main memory always runs at that clock rate. The time between the instants where the buffer just has been filled with the scan line most recently picked up, is dependent on which of the four available scan rates is being used. The main memory therefore displays the same picture repeatedly until new information is available from the buffer memory.

The scanner motor motion, the write and read sequences of the two memories and the deflection of the CRT beam are all periodic runs which have to be mutually synchronized. The reason for using two buffer units instead of the one strictly required, is to ensure no loss of data should the scanner motor and the clock driving the main memory temporarily lose mutual synchronism.

The luminous output from the phosphor surface is an unlinear function of the modulating voltage. This effect leads to very poor modulation at the lighter end of the luminous output range and thus effectively reduces the useful range of sensible brightness. What we desire is a linear relation between input voltage steps and steps in the sensation of brightness. This is achieved by modifying the output signal from the main memory according to a transfer function which has been found experimentally under realistic ambient light level and viewing distance.

This transfer function has been permanently stored in a "read-only" memory (ROM). Each 4-bit number from the output of the main memory addresses that location in the ROM where the corresponding value of the transfer function is stored. In this way the output signal from the main memory is converted to the corrected signal to be forwarded to the display. After conversion to analog form the output signal from the ROM enters the modulating input terminal of the CRT.

The observer behind the "moving scene" display is the last member of the signal processing chain. His ability to perform a very complicated pattern recognition has great influence on the system over all signal to noise ratios. He must learn to detect a faint scar of line structure and also to discern a pattern possibly caused by a submarine within sometimes very pronounced surface phenomena of natural origin.

References

(1) Bergstad, P
Ø Wenstøp – Anglo-Norwegian trials with IR-linescan for detection of submarine wakes 1968, Teknisk notat S–167, Norwegian Defence Research Establishment (1968) Secret