TITLE

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SUMMARY

This report describes results obtained during a sea trial in which a system for the control of engines and helm directly from the bridge was systematically compared with the conventional voice-ordered system. Both systems were used aboard a modern destroyer by six experienced captains each of whom performed measured manoeuvres about a frigate during a period of five days. The principal observations were that

(a) manoeuvring, generally speaking, was improved by direct control from the bridge;

(b) the improvement was achieved by simultaneous control of both helm and engines by one person, seated;

(c) only two or three hours' practice with the totally unfamiliar direct control system was necessary to acquaint the captains adequately with the performance and characteristics;

(d) errors in the relaying of verbal orders occurred in the conventional control mode;

(e) good all around visibility from the bridge is an essential requirement for good ship control;

(f) all six test captains preferred the direct control system.

It is therefore concluded that

(a) direct control from the bridge is more effective, is less prone to human operator error and is more easily learned than the conventional voice-ordered system, and

(b) considerable long-term savings in personnel would be achieved if the system were adopted throughout the RCN.

DIRECT BRIDGE CONTROL OF ENGINES AND HELM ON A DESTROYER
SEA TRIALS RESULTS

1. INTRODUCTION

Though man is remarkably versatile, he does not relay verbal communications efficiently. Spoken orders passed between one or more intermediaries are always delayed and are sometimes in error(1).

For many routine situations, this is a matter of minor inconvenience. Requests for clarification in telephone and other conversations are common, but in operational situations, communications delay and error can have serious consequences. The conventional ship control system requiring all engine and helm orders to be passed from the bridge by voice is an example of a system that is inherently fallible because it relies on relayed voice communication. In emergency situations (e.g. rescues), during 'alongsides', transfers and anti-submarine operations, delay and error in ship control can be critical.

A recommendation that the Royal Canadian Navy adopt direct bridge control of engines and helm was contained in a report(2) prepared by the Defence Research Medical Laboratories in 1964. Later, a sea trial was arranged in collaboration with the RCN in which the conventional voice-ordered ship control system was compared with a direct bridge control system on board a modern destroyer, HMCS SASKATCHEWAN, in terms of captains' manoeuvring performance. The enthusiastic post-trial opinions of the six experienced captains, each of whom spent a week handling the destroyer using both systems, were reported shortly after the trial was completed(3).

The present report summarizes the performance data gathered during the SASKATCHEWAN trial.

2. METHOD

(i) GENERAL DESCRIPTION OF CONTROL ARRANGEMENTS

HMCS SASKATCHEWAN and HMCS NEW GLASGOW, a World War II frigate, were named as the test and consort vessels, respectively. Both ships were made available for the exclusive purposes of these trials for a six week period.

SASKATCHEWAN was equipped with a temporary small closed bridge atop her normal bridge (Fig. 1). This bridge, though somewhat crude in design, had large windows and, because of its high location, afforded excellent visibility (Fig. 2). Two throttle levers and a small steering wheel were installed at a sit-down console to provide direct control of the engines and rudder. It is important to note that the throttles and wheel were arranged to be operated by the same person. The concept of 'split' direct controls seen elsewhere and requiring two operators, i.e., the wheel positioned on the bridge centre-line well back on the bridge and the throttle console elsewhere on the bridge, was considered to be less desirable (see DISCUSSION).

During all tests for both voice-ordered and direct control systems, the ship was controlled from the same position.

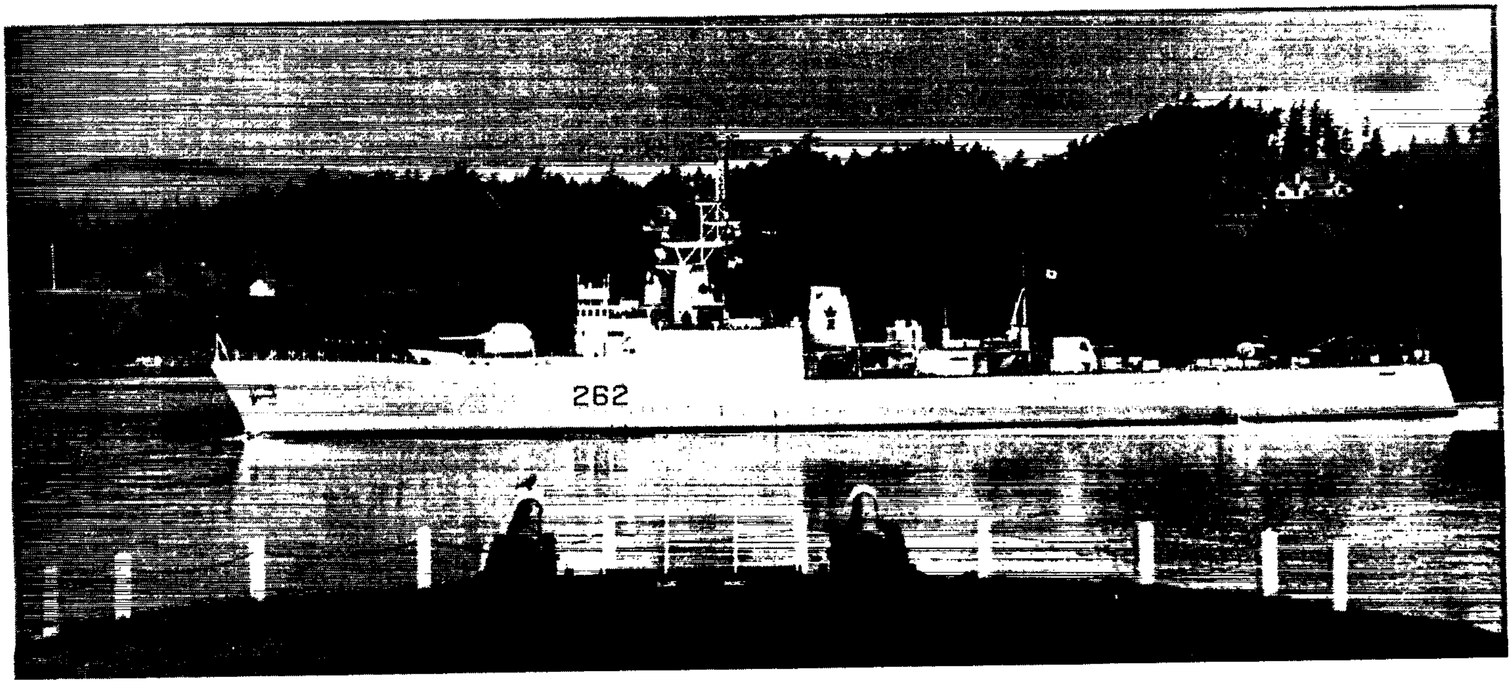


Figure 1. HMCS SASKATCHEWAN showing trials bridge.

(ii) TRIALS MANOEUVRES

Four manoeuvring tests were devised. They ranged from 'alongsides' to the keeping of transfer station whilst circling – a difficult manoeuvre not normally conducted in day-to-day exercising by HMC ships. Each manoeuvre was performed ten times by each test captain, five times in each of the two control modes.

(a) Alongsides – From a stopped position in the Esquimalt harbour entrance SASKATCHEWAN was required to move ahead some 2,000 yards and then turn to port through approximately 70°, to approach and come alongside the Esquimalt refuelling jetty, stopping when about to touch and when the ship's stern was abreast of the seaward end of the jetty. The test captain was asked to complete the manoeuvre in minimum time. At the conclusion of each run SASKATCHEWAN backed off to re-position herself in the harbour entrance.

(b) Transfer Positioning on a Straight Course, Speed Varying – Consort proceeded at 12 knots in open sea. SASKATCHEWAN followed half a cable astern. When signalled by light, SASKATCHEWAN moved up to take transfer station, port side to, bows abreast, 120 feet separation. After further signal, and as quickly as possible, SASKATCHEWAN dropped back moving across consort wake, then moving up to identical position starboard side to. Consort then varied speed according to a programme unknown to the test captain who attempted to maintain a constant transfer position. At the conclusion of each run a signal light directed SASKATCHEWAN to drop back to the position astern of the consort.

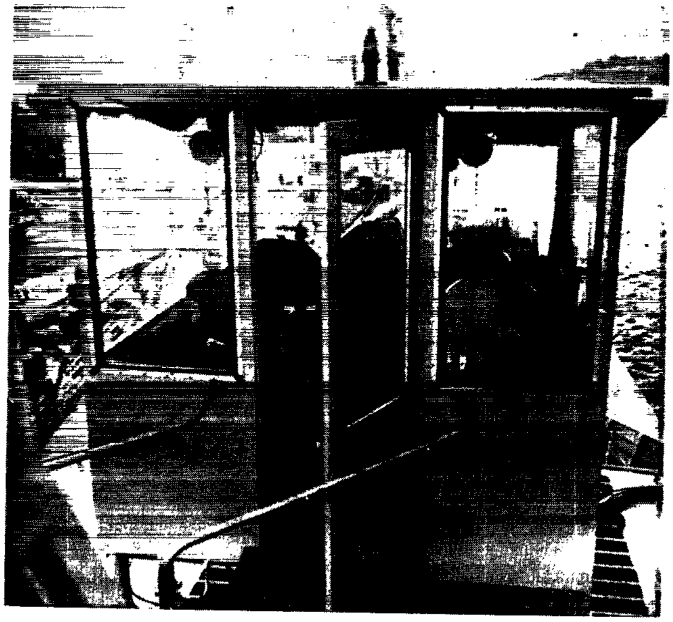
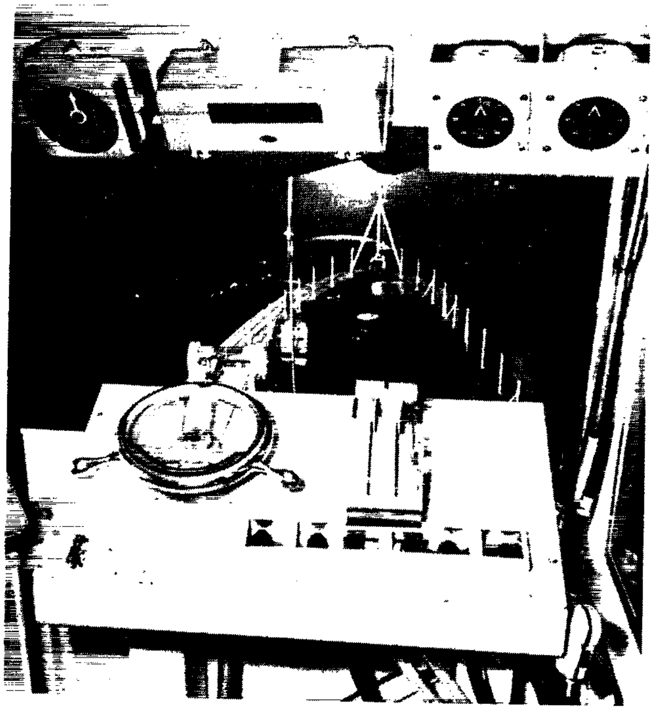


Figure 2. Arrangement of trials bridge showing wheel, throttle levers and instruments-rudder angle, gyro repeat, shaft RPM.



(c) Close Positioning Astern During Zigzags – Consort proceeded at 12 knots in open sea. SASKATCHEWAN was stationed astern at half a cable. After light signal, SASKATCHEWAN closed to 75 yards between her bow and consort's stern, attempting to maintain that separation whilst staying directly astern of the consort. A further light warned that the consort was commencing a series of turns to port and starboard according to a programme unknown to the test captain. Headings were held for varying intervals. At the conclusion of each run, a signal light directed SASKATCHEWAN to drop back to half a cable.

(d) Transfer Positioning Whilst Circling – Consort proceeded at 12 knots in open sea. SASKATCHEWAN was stationed astern in column at half a cable. After light signal SASKATCHEWAN moved up to transfer position starboard side to, bows abreast, 120 feet separation. Consort then signalled her intention to commence a turn through 360° to starboard using 10° rudder. SASKATCHEWAN attempted to maintain constant position. After completing a 360° turn a signal light from the consort required SASKATCHEWAN to resume station astern at half a cable. Consort continued the turn meanwhile through a further 180° with SASKATCHEWAN following.

(iii) TEST CAPTAINS AND PRACTICE

Six experienced test captains controlled SASKATCHEWAN, each for five consecutive days. The first day was allotted to briefing and practice, since the direct control system was new to the captains. After only two or three hours of practice at most, captains without exception expressed their readiness to proceed with the trials manoeuvres. Motivation was keen since each test captain was obviously anxious to perform in such a way that his reputation as a ship handler would be upheld. At the conclusion of his final day, each test captain completed a questionnaire designed to elicit his personal evaluation of the merits of the direct versus the voice-ordered control system(3).

(iv) SASKATCHEWAN'S SHIP CONTROL SYSTEMS

The direct control equipment was manufactured by Canadian Aviation Electronics Ltd., Montreal, to specifications provided by Canadian Forces Headquarters. DRET had very limited input to the design, specifying only that the controls should be operated by one person seated at the control console. CAE provided a trials technical representative within the terms of their contract to assist in equipment modifications and maintenance. The temporary direct control system could be described as an improvised model.

(a) Steering Control – Steering was controlled by a wheel operating on a two to one ratio, i.e., 90° of wheel rotation corresponded to 45° of rudder movement. The wheel, as installed, had no 'feel' or centering – an essential characteristic of a control of this type(4). To provide 'feel' a SASKATCHEWAN technician devised an ingeniously simple remedy – a pneumatic screen door closer corded to the hub of the steering wheel.

The conventional hydraulic wheelhouse/tiller flat control loop was replaced by a compact electrical control system using synchronous transmitters coupled to a small hydraulic activating mechanism in the tiller flat. The activating unit controlled the main steering motor pump output.

(b) Engine Controls – The two main engines were controlled by two throttle levers mounted on a gated quadrant and located to the right of the steering wheel. For small asymmetric settings ahead they could be operated together in one hand. For large asymmetric settings the throttles were operated by the same hand, but singly. Small astern settings could also be made with the levers parallel, but at large astern power settings the throttles were 'split', even though equal power was being obtained at the shafts. This unexpected situation arose because of differences between the outputs of the main engines and could not be overcome. For this reason 'alongsides' data were discarded (see RESULTS).

Movement of a throttle lever ahead or astern created an error voltage which was amplified and acted to cause the engine-room throttle valve to move in a direction reducing the voltage error to zero. When at zero the demanded turbine power was achieved and engine-room throttle movement ceased. To safeguard the engine-boiler systems, the throttle activating system contained a dual clutch providing fast and slow engagement rates which could be selected at the bridge console. This clutch was designed to adjust the 'reaction-time' of the engine response system. Neither clutch setting gave an acceptable response; the fast setting was beyond boiler output capability and the slow setting was too sluggish at most throttle settings. CAE modified the system to give automatic two-speed function of the slow-speed clutch at specific increments of throttle opening. It should be noted that boiler control was not automated as part of the control system loop. Therefore, during the trials, great care was exercised by the boiler-room staff to ensure that sufficient steam was available to meet demands.

(v) PERFORMANCE RECORDS AND MEASUREMENT

(a) Manoeuvring performance was recorded by means of fixed 35 mm. cameras photographing downwards every ten seconds from a Bell light helicopter which flew above the ships at heights varying between 500 and 800 feet, according to ceiling. Single frame analysis of a scaled projection of each frame (equating the height variations), enabled an XY plot to be constructed and variations of SASKATCHEWAN's position relative to the consort or jetty to be measured.

(b) Movements of the direct engine and rudder controls were recorded on an 8-channel magnetic pen recorder.

(c) All voice-control orders were recorded on a 4-channel tape recorder and were synchronized with the record (b) above. Using these records, it was possible to note errors in the voice-ordered mode and to determine where in the voice-ordered system the error occurred.

(vi) PERFORMANCE

Each test captain controlled SASKATCHEWAN for five runs in each of the normal voice-control and direct-control systems in each manoeuvre. The first day of each week was allotted to briefing and practice with the direct system, and the second to the docking or 'alongsides' manoeuvre, during which the normal and direct modes were assigned randomly to morning and afternoon for the six test captains, changeover from the normal mode to the direct mode and vice versa being anticipated as too lengthy to permit modes to be mixed during a morning or afternoon. In fact, changeover times were found to be short. The three sea manoeuvres, (b), (c) and (d), were assigned to the six captains on the remaining three days of the week in two 3 x 3 Latin square arrangements to minimize the effect of learning between manoeuvres. Normal and direct modes were assigned randomly to morning and afternoon runs in such a way that each captain was to have equal numbers of normal and direct mode runs in the morning and afternoon, and also so that each manoeuvre was to be assigned an equal number of times in mornings and afternoons in order to minimize learning within manoeuvres. The resulting trial schedule is shown in Table I.

TABLE I

Trial Schedule

CAPTAIN NO.	DAYS							
	2		3		4		5	
	AM	PM	AM	PM	AM	PM	AM	PM
1	aN	aD	cD	cN	dN	dD	bD	bN
2	aD	aN	bD	bN	cN	cD	dN	dD
3	aD	aN	cN	cD	bN	bD	dD	dN
4	aD	aN	dN	dD	cD	cN	bN	bD
5	aN	aD	dD	dN	bD	bN	cN	cD
6	aN	aD	bN	bD	dD	dN	cD	dN

N — Normal control mode.

D — Direct control mode.

a — alongsides or docking
b — transfer positioning on straight course
c — close astern positioning during zigzag course
d — transfer positioning while circling.

3. RESULTS

(i) PERFORMANCE MEASURES

As described under Methods, para (v), XY plots of SASKATCHEWAN's position relative to the consort during manoeuvres (b), (c) and (d), were constructed in order to determine the degree of success with which the test captains maintained constant transfer or close astern positions during each run. Data from manoeuvre (a), alongside positioning, was discarded because of mechanical difficulties encountered with astern power settings in the direct control mode. Data taken from plots of the straight-course (b) and circling (d) transfer position manoeuvres were distance between SASKATCHEWAN and consort and distance of SASKATCHEWAN's bow ahead or astern of consort's bow. Data from the zigzag manoeuvre (e) included distance between SASKATCHEWAN's bow and consort's stern. Each scaled frame showing SASKATCHEWAN's relative position during each run of each manoeuvre was measured and the resulting data were recorded on punched paper tape for processing by digital computer.

Throughout the trial, emphasis was laid upon the importance of maintaining a constant transfer or close astern position rather than upon maintenance of a specified distance; in other words, deviation from the specified positions was regarded as of less importance than deviation about a mean position, regardless of difference between mean and specified positions. In accordance with this principle, the measure of performance was taken to be the variance about the mean position during each run, in the sense that the smaller the variance, the more nearly the test captain held a constant position, and hence the better the performance.

TABLE II

Summary of Results

Exercise	Measurement	Mode*	df	Variance	F	Significance
b_1	Distance between ships	N D	193 198	529.19 723.56	1.367	$p<.05$
b_2	Ahead/astern	N D	189 195	2714.01 925.56	2.932	$p<.001$
c	C stern to S bow	N D	516 525	4010.19 3414.16	1.174	$p<.01$
d_1	Distance between ships	N D	173 266	2352.46 2095.98	1.122	N.S.
d_2	Ahead/astern	N D	166 263	3844.36 2313.61	1.662	$p<.001$

*N — Normal control mode
D — Direct control mode

Because of the high correlation (about 0.8) between successive frames, it was found necessary to apply a smoothing procedure to the data. Computation of autocorrelation functions of the data indicated that the serial correlation coefficient was effectively reduced to zero for a lag of approximately five frames; accordingly, the observations were averaged in non-overlapping groups of five to yield sets of uncorrelated data and hence, on the assumption of normality, independent measurements from which the means and variances were computed in the usual manner.

In all cases the statistical hypothesis to be tested was that of no difference in performance between the normal and direct control systems, as measured by the variance about mean position. It is apparent that the test captains' performances in the normal and direct control modes are different. Differences in variance in three of the five test comparison measurements (b_2, c, and d_2) indicate a highly significant ($p<.01$) improvement under direct control. In comparison d_1, no difference appears and in b_1, a significant ($p<.05$) degradation in performance is noted with direct control. The negative result*

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*An earlier analysis of the unsmoothed data failed to reveal the degradation in performance noted in item b_1 (Table II), and its results reported elsewhere(4) should be disregarded.

($p<.05$) favouring the conventional system applies only to ship's lateral movement and is probably attributable to the similarity of helm response times for both control modes, i.e., manoeuvring performance could be expected to be the same, slightly better, or slightly worse, and sampling variation. Significantly, no entry for the lateral deviation in zigzag manoeuvre (c) is shown; these measurements were almost uniformly zero in both modes. Missing runs and gaps in the film were responsible for the differences in numbers of observations in exercise (d).

(ii) ANALYSIS OF CONTINUOUS RECORDS OF HELM AND ENGINE CHANGES

(a) Engine Response Delays – Conventional mode engine orders were given by telegraph (coarse setting) and revolution (fine setting) in the proportion of 9% and 91%, respectively. Average times from engine order to shaft response are shown in Table III for both control modes tested.

TABLE III

Average time from engine order to shaft response

	Conventional Mode (Voice order to initial shaft response)	Direct Mode (Throttle movement to initial shaft response)
All manoeuvres pooled	5.80 seconds (1252 orders)	3.65 seconds (1226 orders)

(b) Helm Response Delays – Average delay in helm to initial rudder response for 2,742 orders, was a little more than one second in the conventional mode and zero in the direct mode. Average times to apply the rudder from midships are shown in Table IV.

TABLE IV

Average time to apply Rudder from Midships (all movements sampled)

	Conventional Mode Degree of Rudder	Direct Mode Degree of Rudder
	5°,10°,15°,20°,30°	5°,10°,15°,20°,30°
All manoeuvres pooled		
	Seconds	Seconds
	2.00,2.62,3.60,4.20,4.64	1.00,1.35,2.13,3.83,5.86

62% of helm orders were given in degrees of rudder, 38% as ships headings, e.g., steer 312°.

(iii) ERRORS IN VOICE-ORDERED SHIP CONTROL COMMUNICATIONS

During the trial a tape recording was made of all voice ship control orders. Of 4,981 orders, only eight errors were noted during analysis; they appear below within encapsulated verbatim bridge-wheelhouse voice-order conversations.

Example I –

Captain "Slow ahead both engines"
Quartermaster "Slow ahead both engines"
Quartermaster (to telegraph operator) "Get it on slow ahead, not full ahead"
Quartermaster "Both engines slow ahead Sir"
Captain "Roger".

Example II –

Captain "Steer one-one-two"
Quartermaster "Steer one-one-three"
Captain "One-one-two"
Quartermaster "One-one-two".

Example III –

Captain "One-zero-eight"
Quartermaster "Revolutions one-zero-eight"
Captain "Neg that, steer one-zero-eight"
Quartermaster "Steer one-zero-eight"
Captain "Check revolutions".

Example IV –

Captain "Revolutions one-two-zero"
Quartermaster "Revolutions one-three-zero"
Captain "Revolutions one-two-zero"
Quartermaster "Revolutions one-two-zero"

Example V –

Captain "Slow astern both engines"
Quartermaster "Slow ahead both engines or slow astern both engines?"
Captain "Slow ahead both engines"
Quartermaster "Slow ahead both engines, both engines slow ahead, Sir".

Example VI –

Captain "Steer one-three-one"
Quartermaster "Steer one-two-one"
Captain "one-three-one"
Quartermaster "one-three-one".

Example VII –

Captain "Starboard ten"
Quartermaster "Starboard five"
Captain "Midships"
Quartermaster "Midships, wheel amidships, Sir".

Example VIII

Captain "Starboard ten"
Quartermaster "Starboard fifteen, one-five-two revolutions fast repeated, fifteen of starboard wheel on, Sir"
Engineer Officer to Captain from engine room "Sir, I'd like to request a new telegraphsman on the starboard engine, he's twice gone the wrong way in the last five minutes"
Captain to Wheelhouse "Who's on the starboard telegraph down there?"
Quartermaster "Starboard telegraph! er, Able seaman - - - - - - Sir"
Captain "Very good, see that he pays attention; he's gone the wrong way twice in the last five minutes".

4. DISCUSSION

(i) MANOEUVRING PERFORMANCE

The results obtained during the sea trial indicate that there are advantages to be gained from direct control in manoeuvring performance when both engine and helm controls are used by one operator. In practical terms, the results show that engine control (fore-and-aft movement of the ship) was better with direct control than with the voice-ordered system, whereas helm control (lateral ship's movement) was equally good, generally speaking, with either system. These findings probably reflect directly the longer line of communication between the bridge and engine room, compared to that between the bridge and wheelhouse which was effectively the same for both direct and normal helm systems.

In their use of direct controls the test captains nearly always made visual estimates of the manoeuvring requirement and, by feel, adjusted the wheel or throttles to suit. If they occasionally required specific settings of rudder or engines, they adjusted the controls with reference to the rudder indicator, the scale markings on the throttle quadrant or the rpm indicators.

These were not satisfactory control/display arrangements. The throttle quadrant interval markings were crude-ballpoint pen markings in blue and red ink on masking tape. The rpm indicators had no 'command' pointers corresponding to throttle lever movement. Consequently, the test captains would make an approximate setting by interpolation on barely legible quadrant scales and would then have to wait for the rpm indicators to slowly settle before accurate readings could be made. Had the trials required voice orders to be set by means of the direct controls, the quadrant markings and the rudder indicator would have been used almost exclusively, though this is not a preferred arrangement (see Design and location of the direct controls, para (vii), page 13).

An important consideration, not examined during the trial, but often crucial in ship control, is that of the captain's need on occasion to revise his decision, and consequently his orders, quickly. The specified and rigid pattern of voice orders does not facilitate rapid change. Small corrections, readily made with direct control of steering but not with the conventional voice-ordered system, are shown in the traces of helm operation presented in Figure 3. To change rudder setting from port to starboard, or vice versa, the captain must order "midships" as an intermediate step and receive a verbal response from the quartermaster before ordering the final rudder movement. Similarly, to change engine movements from ahead to astern, the captain should order "stop both engines" before giving the astern order. If he should fail to do this, his quartermaster (monitoring the performance of the telegraph operators and tending the wheel) has no way of knowing whether the captain inadvertently made a wrong statement (this happened during the trial; see RESULTS, para (iii)), and he correctly may query the order and so cause further delay.

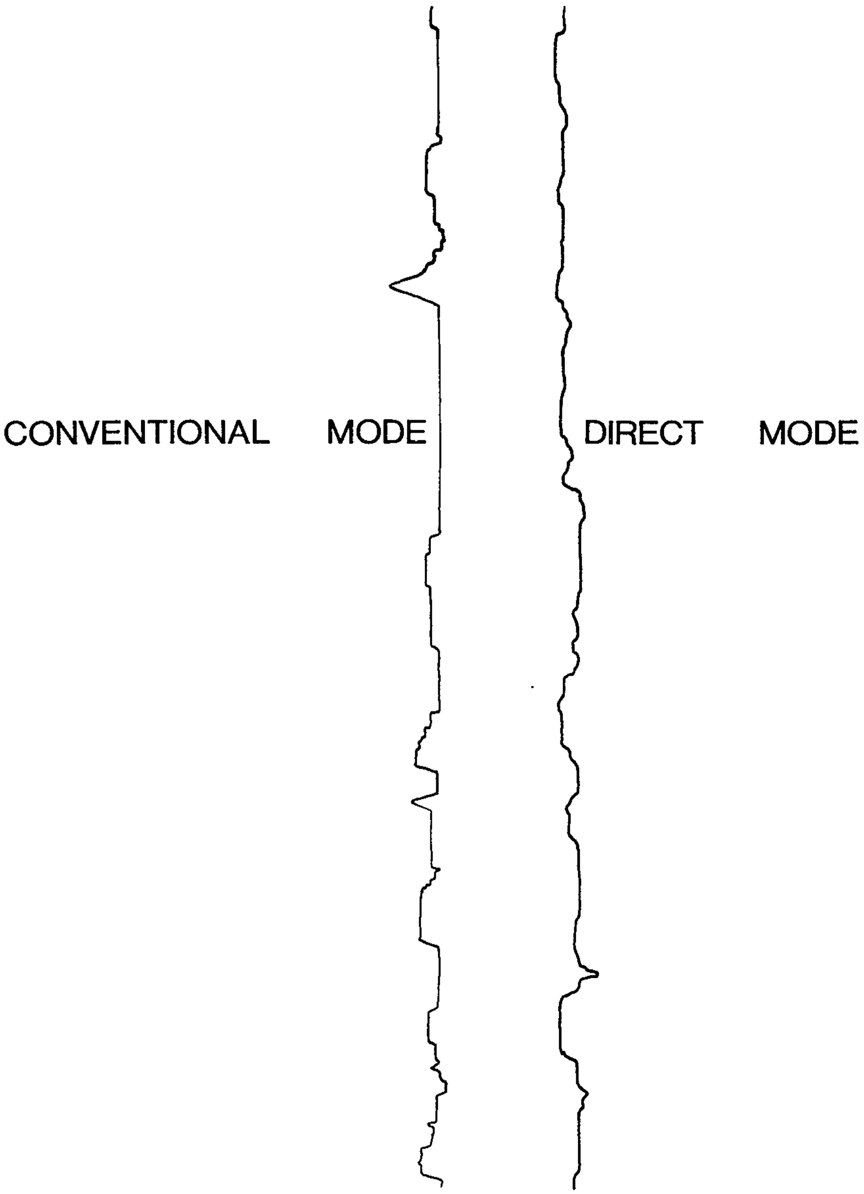

Figure 3. Examples of rudder control movements in direct and conventional control modes.

Many amusing stories are told in fighting ships of captains who not only change their ship control orders radically, but also issue orders so frequently during 'alongsides' that the engine room staff cannot keep up. One such story concerns an enterprising engineer officer who recorded engine voice orders issued from the bridge during a difficult 'alongside' in high wind. He later tried to marry the recorded orders to the actual throttle changes logged and found that they by no means tallied!

(ii) RESPONSIBILITIES IN OPERATING DIRECT BRIDGE CONTROLS

For precise manoeuvring in difficult situations, there is no doubt that direct controls should be in the hands of the officer making decisions on course and speed. In routine situations, control could be delegated to a quartermaster or junior officer trained in ship control. The quartermaster should, however, be authorized to exercise his judgment in emergency situations, e.g., if he sees an obstruction immediately ahead, or realizes that collision is unavoidable if there is delay, he should be able to effect initial changes in course or speed on his own initiative. A review of the responsibilities of administration and ship control, vis-a-vis direct control from the bridge, would be timely.

(iii) MANPOWER ECONOMIES GAINED FROM DIRECT CONTROL INSTALLATIONS

In the earlier post-trial report(3) the considerable economies in engine room, boiler room and quartermaster manpower to be realized from the automated control system required for direct bridge control were discussed. If fitted in new construction ships and retrofitted in older vessels of the RCN, direct control would achieve considerable annual savings. Obviously, men released from each ship could be allocated to other duties.

(iv) CAPTAIN ACCEPTANCE

It is generally recognized that a new system aboard ship must have captain's approval if it is to be accepted. Not only were the six test captains unanimous in their preference for the system(3) but SASKATCHEWAN's captain, who drove the ship on many occasions using the direct system, was particularly enthusiastic. All were impressed by the brevity of the period necessary for familiarization.

(v) TRAINING

Strong training implications are seen in the fact that all of the test captains declared and demonstrated their readiness to manoeuvre SASKATCHEWAN at close quarters after only two or three hours of practice with the totally unfamiliar system. Using direct control, *ab initio* ship handlers need not learn, remember and speak a rather special jargon before manoeuvring the ship themselves. They could simply put into action their control decisions. They would of course have to learn voice-order procedures to handle conventional ships and use a limited version to pass orders to a quartermaster on the bridge handling the system under supervision.

(vi) 'HARD' VERSUS 'SOFT' STEERING SYSTEM RATIOS

Most conventional ship steering arrangements require the helmsman to turn the wheel several times to achieve maximum rudder deflection. This is known as a 'soft' system, involving high wheel-to-rudder ratios, and is a throwback to days when there was no power-assist in the steering system.

Direct control provides opportunity for a 'hard' or low ratio steering system to be employed. A two-to-one ratio was selected for the SASKATCHEWAN 'lash-up' and, used throughout the trials, it enabled large rudder deflections to be made without the effort of excessive steering wheel rotation. A slightly softer steering ratio (i.e., 4 to 1), though not tested in the trial, was suggested by SASKATCHEWAN's captain. Which of these ratios is most suitable for general ship handling is a question that cannot be answered without separate study.

In general statement, the situation is comparable to the 'hard' steering system used in racing cars and the 'soft' system installed in many private cars. The former is preferable if highly responsive control is sought.

(vii) DESIGN AND LOCATION OF THE DIRECT CONTROLS

The trial demonstrated clearly that controls of throttle and helm can be operated simultaneously by one person. The 'split' location (throttles and wheel widely separated and operated by two persons) normally found on ships with direct controls is therefore unnecessary and wasteful of manpower. Moreover, such an arrangement can lead to error of a different kind. We have witnessed a captain in another service, while conning his vessel through a narrow gorge, move to the engine control console saying, "I think I'll bring her up to one ninety" (meaning 190 revolutions). The helmsman positioned aft on the bridge said, "Turning onto one nine zero." The captain quickly cancelled the helmsman's move since the result would have been disastrous – the passage was due West!

A design of direct controls and associated displays appropriate for destroyer operation might include

(1) i. Throttle levers operated together by one hand (other than for widely divergent settings) and adjusted by visual reference to quick-reaction 'command' pointers on the rpm indicators rather than by reference to throttle quadrant markings.

ii. An 'indent' or easily negotiated 'gate' to denote zero revolutions.

iii. Damping, so that the throttle levers can be 'locked' at a given setting for long periods of time and not accidentally moved.

and (2) i. A small steering wheel with 'feel' proportional to deflection, i.e., the greater the wheel displacement from centre, the stronger the tendency to return to centre.

ii. Routine course steering by reference to a gyro-tape repeater or a 'quickened' steering display.

iii. Specific rudder deflection by reference to a rudder angle indicator.

No matter what arrangement of direct controls is adopted by the systems designer, it is important that

i. the direct controls of engine and helm be operated by one person,

and ii. the direct control console be so positioned that the operator, when at the controls, has the vantage point on the bridge with respect to visibility.

(viii) VISIBILITY FROM THE BRIDGE

Good all-round visibility has received insufficient attention in bridge design, but is crucial in some ship control situations. During the trial, exceptionally good visibility was provided by the temporary bridge. This, of course, pertained equally to control in both modes. In general, however, ships have relatively poor viewing arrangements on the bridge(5), especially from the closed portions. Open wings and control platforms atop the closed bridges give better visibility, but in poor weather they are miserable stations from which to exercise control.

Visibility aft is particularly poor from closed bridges. Funnels, superstructure and helicopter hangars are generally so positioned that the stern-rail cannot be seen. During movements astern, e.g., backing off when slipping, the captain needs to see the ship's stern. If he cannot, his estimate of stern position is difficult to make and he may require to position a stern lookout, a procedure involving intermittent voice communication between the lookout and the bridge.

The marine architect should aim to meet one primary criterion in bridge design, i.e., that the closed bridge be so designed and positioned that the entire perimeter of the ship can be seen from the position of a seated operator handling controls of engine and helm. In other words, direct control from the bridge should be coupled with good all-round visibility from the bridge. If not, though voice communication errors in ship control will be eliminated by direct control, manoeuvring performance may be degraded. Better visibility from conventional bridges can be gained by use of closed-circuit television to view 'blind' areas ahead and astern(4,6).

(ix) BRIDGE DESIGN

Much has been written on the subject of bridge design. Recommendations for improvement are many and wide-ranging. There is a discernible trend toward 'cockpit' arrangements, of which examples can be seen in our own early work(2). A stimulating destroyer captain's viewpoint on destroyer bridge design also follows this plan(7). The general nature of the seagoing design community is sufficiently conservative, however, that few such designs are yet to be found aboard large ships. It is possible, for example, to hear the question "Will not the bridge complement fall asleep if they are permitted to sit whilst on watch?" This is a fallacious question, of course, since many combat information centre operators work effectively while sitting at consoles in modern ships.

5. CONCLUSIONS

The sea trials demonstrated that

(1) human operator delay and error in the control system was reduced by the direct control system;

(2) human operator errors and delays occur with the conventional voice-ordered system;

(3) with one exception, manoeuvring with direct control was as good or better than with the conventional voice-ordered system;

(4) engine control rather than helm control appeared to contribute most to improvements in manoeuvring performance with the direct system;

and (5) all test captains preferred the direct system, as did SASKATCHEWAN's captain.

On the basis of this demonstration, it is concluded that

(1) basic training in ship control could be simplified if the system were adopted throughout the fleet;

(2) 'transfer' of personnel from conventional to direct-control ships should create no training problem;

(3) visibility from the direct control conning console on the bridge must be good or supplemented by a device such as television if the full potential of the system is to be realized;

(4) portable ship control arrangements can be envisaged that would permit the operator to carry the controls with him to a vantage point, i.e., to the wing of the bridge when coming alongside at sea. However, orientation of the controls might then be critical if, for example, they were turned to face aft, as the control/vessel response relationship would be reversed.

It would also appear that installation of miniaturized direct controls on a master tactical console in the operations room should result in better tactical manoeuvring performance when ship control is exercised from that space.

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