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From 15 January through 15 April 1982, the U.S. Combat Support Boat (USCSBMK I) was tested on the Connecticut River, in and around Hanover, New Hampshire, to examine its operation on an ice-covered waterway. The objectives were to determine to what extent shoreline ice would affect launch and recovery and if the boat could create an ice-free channel across a river so that a ribbon bridge could be floated. Shoreline ice can inhibit launch and recovery, but several solutions were developed to reduce or eliminate these problems. The boat can, to a limited extent, be used as an expedient icebreaker. It can break competent

20. Abstract (cont'd)

ice sheets 3.5-4 in. thick as well as significantly thicker thaw-weakened ice sheets. Sheets of well degraded "end of season" ice up to 13 in. thick were broken.

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April 1984

US Army Corps
of Engineers
Cold Regions Research &
Engineering Laboratory

Operation of the U.S. Combat Support Boat (USCSBMK I) on an ice-covered waterway

J. Stubstad, J. Rand and L. Jackson

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by John M. Stubstad, former Mechanical Engineer, Applied Research Branch, Experimental Engineering Division; John H. Rand, Mechanical Engineer, Engineering and Measurement Services Branch, Technical Services Division; and Linda Jackson, former Student-Trainee, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided under DA Project 762730AT42, Design, Construction and Operations Technology for Cold Regions; Task A, Cold Regions Combat Operations Support: Tactics, Doctrine, Logistics; Work Unit 008, Cold Weather Bridging.

The authors thank Carl Gardner, David Fisk, David Chase and Marvin Rocke of CRREL for their assistance during the testing program. Thomas Marlar and Robert Demars, also of CRREL, deserve a special note of thanks for their outstanding photo documentary efforts.

The authors also express their appreciation to R. Tofferi of the U.S. Army Engineer School for sponsoring these tests and to K. Harris and M. Lipari of the U.S. Army Mobility Equipment Research and Development Command for arranging the loan of a Combat Support Boat with transporter. Finally, the authors express their gratitude to Sgt. Major Whittington of MERADCOM for his continual help throughout the test program.

The operational practices and procedures described in this report DO NOT represent approved doctrine for employment or operation of the Combat Support Boat. Nor should it be implied or construed that the testing program described herein represented an extensive effort to establish the complete cold weather performance characteristics for this equipment.

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These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
inch	25.4	millimetre
foot	0.3048	metre
mile	1609.347	metre
yard	0.9144	metre
pound (mass)	0.4535924	kilogram
gallon	0.004546092	cubic metre
degrees Fahrenheit	$t°_C = (t°_F - 32)/1.8$	degrees Celsius

OPERATION OF THE U.S. COMBAT SUPPORT BOAT (USCSBMK I)
ON AN ICE-COVERED WATERWAY

J. Stubstad, J. Rand and L. Jackson

INTRODUCTION

The winter battlefield presents the combat engineer with conditions that will help as well as hinder. A fresh snowfall, for example, can be a problem but it also provides natural camouflage for recently constructed defensive positions, and the snow itself can be used to build positions resistant to small caliber weapons fire (Swinzow 1972, Johnson 1977).

For tactical river crossings, however, the effects of winter will probably hinder rather than help, especially if the river has a thin ice cover -- a thin ice cover being one that does not have sufficient bearing capacity to support the heaviest vehicles that need to cross. Table 1 shows that with this definition, a 15-in. ice sheet would not be thin if only 2-ton or lighter trucks had to cross; however, that same ice cover would be thin if any armored vehicles needed to cross.

If the river's ice cover can not be used exclusively as the means for crossing it, an alternate method of crossing would have to be provided for at least some of the vehicles (the limiting case, ice covers less than 7.5 in. thick, requires an alternate means for all vehicles). If the river is narrow enough, an Armored Vehicle Launched Bridge (AVLB) or a Medium Girder Bridge (MGB) can be used. However, when the river is too wide to use an AVLB or MGB, the river ice cover would either have to be thickened or reinforced to provide the necessary load bearing capacity or partially removed so that conventional float bridging equipment could be used.

The use of artificially thickened ice covers, both with and without reinforcement, to make high strength ice bridges is a well accepted practice in colder climate zones. Haspel et al. (1981), for example, describe a 100-ft-wide, 9-mile-long unreinforced ice bridge constructed at Barrow, Alaska, that could support 700,000-lb (320-metric-ton) construction vehicles. Michel et al. (1974) also discuss several log-reinforced ice bridges constructed in 1972 and 1973 near James Bay, Canada. The 172nd Infantry Brigade, Fort

Table 1. Load bearing capacity for freshwater ice (after Department of the Army 1979).

Load	Ice thicknesses for temperatures 0-10°F Risk (cm)	(in.)	Normal (cm)	(in.)	Distance between units (m)	(yd)
Single soldiers on skis	4	1.5	5	2	5	6
File of soldiers - 6.5-ft interval	8	3	10	4		
Vehicles:						
1/4-ton truck	13	5	20	8	15	16.5
1-1/4-ton truck	25	10	32	13	25	27
2-1/2-ton truck	33	13	40	15.5	25	27
5-ton truck	45	17.5	55	21.5	60	65.5
5-ton tractor w/loaded trailer	80	31.5	90	35.5	80	87.5
M60 tank	47	26.5	80	31.5	70	76.5
M88 recovery vehicle	71	28	85	33.5	70	76.5
M100 how., SP, 155 mm	50	20	55	22	50	54.5
M107 gun, SP, 175 mm	45	17.5	50	20	40	43.5
M110 how., SP, 8 in.	50	20	55	22	50	54.5
M113 APC	33	13	45	17.5	25	27
M548 cargo carrier	33	13	45	17.5	25	27
M577 carrier, CP	33	13	45	17.5	25	27
Tractor, D7	45	17.5	50	20	40	43.5
Tractor, D8	50	20	60	23.5	50	54.5
Crane 20-ton	50	20	60	23.5	70	76.5
Grader	35	14	40	15.5	50	54.5

Richardson, Alaska, commonly construct ice bridges in support of their winter maneuvers. The use and construction of such ice bridges for military operations are discussed in appropriate U.S. Army Field Manuals (Department of the Army 1963, 1979).

A critical factor in the construction of ice bridges is, of course, the weather at the site. Air temperature, intensity and duration of solar radiation as well as prevailing wind conditions all influence the rate at which water layers placed on top of an ice sheet can be frozen. Figure 1, for example, illustrates the influence of mean air temperature and initial water

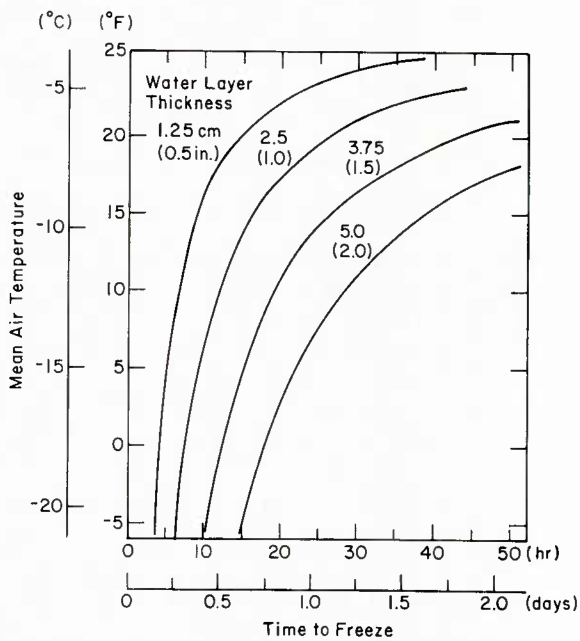

Figure 1. Freezing times for sea water layers on an ice sheet as a function of mean air temperature for 8 mile/hr (3.6 m/s) winds (After Adams et al. 1963).

layer depth on the amount of time required to freeze a layer of sea water on an ice sheet. Although we can anticipate that at any particular temperature the freezing rates for fresh water would be somewhat greater than those indicated in Figure 1, the same general curvilinear trends would prevail. Low air temperatures will produce rapid freezing while near-freezing temperatures result in exceedingly slow freezing.

Comparing the curves of Figure 1 with the data provided in Table 2, we can readily see that the climate of locations such as Barrow and Moosonee (James Bay) are ideally suited to ice bridge construction. Winter at these locations is sufficiently long and cold to provide rapid freezing rates. In contrast, Table 2 also indicates that such ideal ice bridge construction conditions are not commonly found in either the Federal Republic of Germany or the Republic of Korea. Thus, unless these areas were experiencing a sustained period of unseasonably cold weather, the construction of artificially thickened ice bridges to support military operations will, at best, be only marginally feasible.

Therefore, upon encountering a wide river with a thin ice cover in locations such as these the engineers would, in all probability, elect to clear a channel across the river so that a conventional float bridge could be deployed. Standard techniques that might be used to create such a channel across the ice sheet would be explosives to fracture the ice or chain saws to cut the sheet into blocks. Depending upon the size of the resulting fractured or cut pieces of ice, subsequent clearing may or may not be required. (Some armies have developed guidance for deploying floatbridges directly on

Table 2. Mean monthly temperatures (°F) during winter at select locations based on 30-year records (NOAA 1980, 1981).

Location	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Barrow, Alaska, U.S.A.	15.3	-0.6	-12.3	-14.6	-18.6	-15.2	-0.9
Moosonee, Canada	40.5	24.3	4.5	-4.4	-0.6	10.6	27.9
Schleswig, W. Germany	47.8	40.8	35.4	32.0	32.2	36.1	43.7
Hannover, W. Germany	48.4	41.2	35.3	32.3	32.9	38.5	46.6
Nurnberg, W. Germany	47.1	38.7	32.0	29.5	30.9	38.7	46.8
Kangnung, S. Korea	57.9	47.8	36.3	30.2	32.5	40.5	52.7
Inchon, S. Korea	57.6	45.0	31.3	24.8	29.1	38.1	49.5
Pusan, S. Korea	61.9	52.0	41.0	35.3	38.3	45.1	54.5
Mokpo, S. Korea	61.0	50.5	36.1	33.8	35.8	42.6	52.7

top of an ice sheet. After the bridge has been deployed, explosives or chain saws are then used to weaken the ice so that the bridge will then drop into the river. Although this is currently not recognized in U.S. doctrine, work is underway at CRREL to develop similar guidance for U.S. floating bridges.)

A limitation to the explosive and chain saw techniques is that the ice sheet must have sufficient strength to support work parties. According to Table 1 this implies that the ice sheet should be at least 4 in. thick. If the ice sheet does not have sufficient strength to support work parties, then some expedient technique must be improvised to support and protect the personnel as they work. For example, pneumatic reconnaissance or assault boats could be used as movable work platforms. It must be recognized, however, that in using such expedient techniques crew productivity, namely, the rate at which a channel could be cleared, would probably be very low.

A possible alternative to the procedures outlined above would be to employ a readily available boat, such as the new Combat Support Boat (USCSBMK I), as an expedient icebreaker. To investigate the feasibility of such a concept, several questions had to be answered. For example, could the boat break 4- to 6-in.-thick ice sheets without suffering significant hull damage? Also, would the ice particles produced during icebreaking foul the hydrojets or the raw water intakes? And finally, would shoreline ice significantly affect launch and recovery?

To address these questions a series of tests were conducted using a Combat Support Boat loaned to CRREL by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia. The tests were conducted on ice-covered sections of the Connecticut River in and around Hanover, New Hampshire, from 15 January through 15 April 1982.

In all, eight separate launch and recovery tests and more than 1-1/2 hours of ice breaking tests were performed. Documentation of these tests is provided in this report and in a separate video tape.

EQUIPMENT

Description of boat

The Combat Support Boat (Fig. 2) is a 4-ton vessel with an aluminum hull that is powered by twin diesel engines. Each of these turbocharged diesel engines is used to drive hydrojet propulsion units that are mounted on the stern (Fig. 3). Each hydrojet is fitted with a scoop (water deflector) that

Figure 2. Combat Support Boat on transporter.

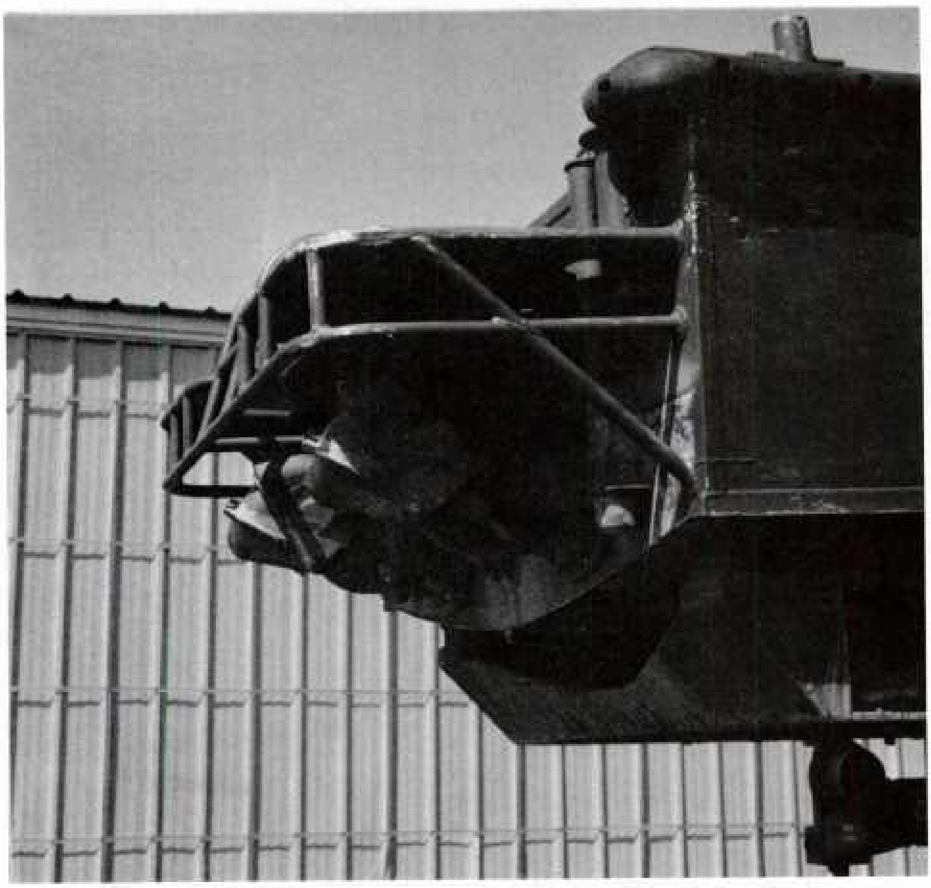

Figure 3. Hydrojet propulsion unit.

can be rotated over the jet outlet. When the scoop is pointed up it directs the flow of water toward the bow, generating a rearward thrust. The boat can be reversed by pointing the scoop down. This way, the boat's direction can be changed without reversing the direction of water flow through the hydro-jet.

The hydrojet arrangement used on the boat also provides two methods for steering control. The steering wheel provides direct control by rotating the water jets to the left or right. An alternate method of steering is to point one scoop down (reverse) while the other is pointed up (forward). The opposing thrust forces produce a turning movement that can be used to maneuver the boat at low speeds. When these two methods are used together at low speed, the boat can make a complete turn within its own length.

The diesel engines, turbocharged for extra power, are arranged side by side, approximately amidships. Cooling water for each engine is drawn from the river through "raw water" intakes located between the engines. The river water is passed through a heat exchanger where waste heat from the engine cooling system is transferred to it. The heated river water is then discharged with the turbocharger exhaust through the engine exhaust ports.

Water for the hydrojets is drawn through intakes located in the bottom of the hull, astern of the engine compartment. Each intake is covered by a grille (Fig. 4) to help keep debris from entering. An inspection port above the waterline over each intake is used to check for any debris jammed in the

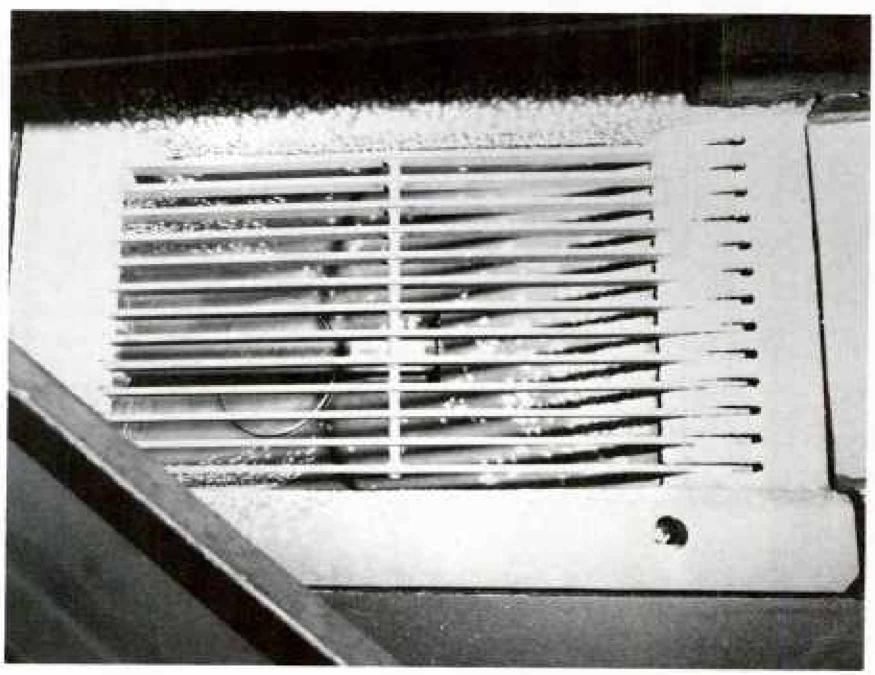

Figure 4. Hydrojet water intake with grille.

grille or intake and, if necessary, to manually clear it. Normally, however, jams are cleared by back-flushing the hydrojets. To do this, a transmission that connects the engine to the hydrojet is put into reverse gear, thereby driving the hydrojet backwards. This reverses the flow of water through the hydrojet creating the desired flushing action.

The Combat Support Boat is mounted on a modified M812 5-ton transporter for overland movement. An aluminum cradle adapts the boat to the transporter and acts as a ramp during launch (Fig. 2).

Launching the boat from a level bank

Launching the Combat Support Boat, when there is direct drive-in access at the river waterline, is a relatively simple procedure. The transporter is first backed into the water until the rear clearance lights of the transporter are approximately 6 in. above the waterline. The A-frame boom on the transporter is then raised slightly (Fig. 5a), using the A-frame hydraulic cylinder. A hydraulically operated locking pin that keeps the boat cradle on the A-frame is then disengaged and the boat and cradle assembly are allowed to roll off the rear of the transporter (Fig. 5b) under the control of a hydraulically operated winch.

As the stern of the boat enters the water (Fig. 5c), the flotation force that results separates the rear of the boat from the cradle. This separation takes place because the shoe that holds the bow of the boat can pivot with respect to the cradle dolly. Once the stern of the boat separates from the cradle, the rear of the cradle sinks to the bottom of the river keeping it from further rearward motion (Fig. 5d). Continued unreeling of the winch cable then allows the dolly to roll down the cradle (Fig. 5e and f), thereby lowering the bow of the boat into the river. At this point the engines are started, the safety cables that hold the bow of the boat to the dolly are removed and the boat is backed out of the shoe and away from the transporter and cradle, thereby completing the launch.

The recovery procedure is virtually the opposite of the launch sequence. After the transporter has been backed into the river and the cradle and dolly assembly deployed as in the launch sequence, the boat is driven forward very slowly until the bow engages the shoe on the dolly. The bow-to-dolly safety cables are then attached, the engines are shut down and the boat is recovered by executing the remainder of the launch procedure in reverse order.

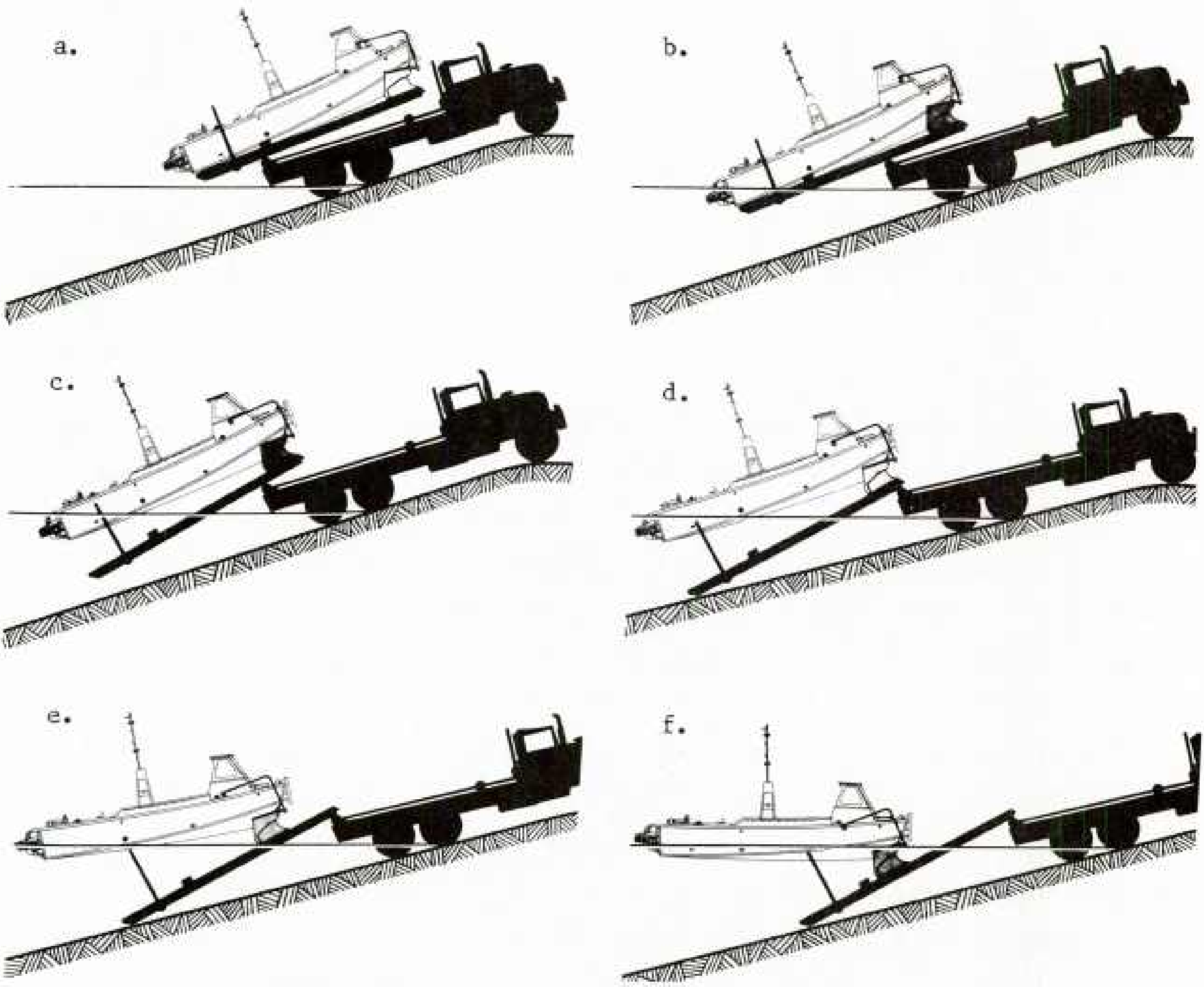

Figure 5. Normal launch sequence for the Combat Support Boat.

<u>Launching the boat from a steep bank</u>

An alternate to the procedure outlined above is a technique known as the steep bank launch (the problems related to launching the boat from a steep bank using the first technique are described in a later section). The first step of this procedure is to position the transporter holding the Combat Support Boat along the edge of the riverbank, parallel to the axis of the river. The boat and cradle assembly are then placed on the ground using the transporter A-frame hoist.

A second, unloaded transporter is then backed up to the boat so that it is perpendicular to the boat's axis and centered approximately on its center of gravity. After removing the cables that tie the boat to its cradle, the A-frame hoist of the second transporter is used to lift it off the cradle. The cradle is then moved out of the way using the first transporter.

At this point the second transporter, with the boat still held in the air, is slowly backed to the edge of the river bank. The A-frame is rotated out towards the river and the winch cable is slowly unwound, placing the boat in the river.

One of the problems with the steep bank launch is that when the boat is suspended from the A-frame of the second transporter, it creates an over-center load behind the transporter, thereby inducing an overturning moment on the vehicle itself. Even when the A-frame is nearly vertical,the center of the load being close to the A-frame pivot, there is a sufficient moment to reduce the front-to-rear weight distribution, thereby making the transporter hard to steer. If the A-frame boom is then rotated toward the rear, i.e., moving the boat further over the river, the potential for overturning will increase. Eventually, the point can be reached where the overturning moment has increased sufficiently to reduce the vehicle's front axle load to zero -- a condition of only marginal stability -- and any disturbance to the system can cause the transporter to rotate about its rear axles and flip over backwards.

To help preclude this possibility the following procedures and practices are suggested by MERADCOM:

1. The dry land portion of the steep bank launch site (i.e., the location of transporter during final launch phase) should have as shallow an angle to the horizontal as possible. The angle of bank inclination adds to the boom angle, thereby decreasing the angle of the boom with respect to a perpendicular from the transporter bed, giving marginal stability.
2. The launch site selected should have deep water as close to the final transporter position as possible. This reduces the amount the boom has to reach out to place the boat in sufficiently deep water.
3. The winch cable from the transporter front winch should be connected to a ground anchor and the cable should be kept taut during launch. This provides some additional restraint and control for the front end of the transporter during launch.
4. The weight of the boat should be kept to a minimum prior to launch. Mission related equipment and personnel should not be loaded until after the boat is launched.

It should be noted that the steep bank launch procedure, even including the recommendations outlined above, does not necessarily provide a solution to the problem of launching the boat when shoreline ice is present. The reasons for this are discussed in detail in the following section.

SHORE ICE LAUNCH PROBLEM

At first glance the problem of launching the Combat Support Boat at a site where shoreline ice is present may appear to be just a special case of the steep bank problem and thus resolvable using the steep bank launch technique. However, as will be shown, the steep bank launch as well as the normal launch techniques are inadequate solutions for this problem.

Normal launch

When using the normal launch procedure the factor that principally determines whether the attempt will or will not be successful (a launch without swamping) is the angle at which the boat enters the water. If the angle of entry is sufficiently shallow (Fig. 5), only the lower watertight portion of the hull enters the water. As such a flotation force equal to the weight of the volume of water is created. As more of the watertight portion of the hull enters the water this flotation force increases until eventually the rear of the boat begins to float free of the cradle. The boat continues to move down the cradle until it is floating.

At steeper launch angles, however, a portion of the rear deck as well as the watertight portion of the hull enters the water (Fig. 6). When this happens at least a portion of the stern hatch covers (Fig. 6d and 7) become submerged. Since these hatch covers are not watertight, water flows into the stern compartment. While this flooding does not physically harm the hydrojet and steering gear located in this compartment it does substantially reduce the flotation force generated. The net reduction in flotation force is, or course, directly proportional to the volume of water that enters the compartment.

The ultimate result of this is that the net flotation force that can be generated is reduced from being proportional to the volume of water displaced by the hull to just being proportional to the volume of water displaced by the polystyrene floats located in this compartment (polystyrene floats are positioned at key locations so that even if the hull completely fills with water the boat will merely swamp rather than sink). Unfortunately, because of the steeper launch angle the component of the flotation force vector that is perpendicular to the cradle does not create a sufficient moment about the

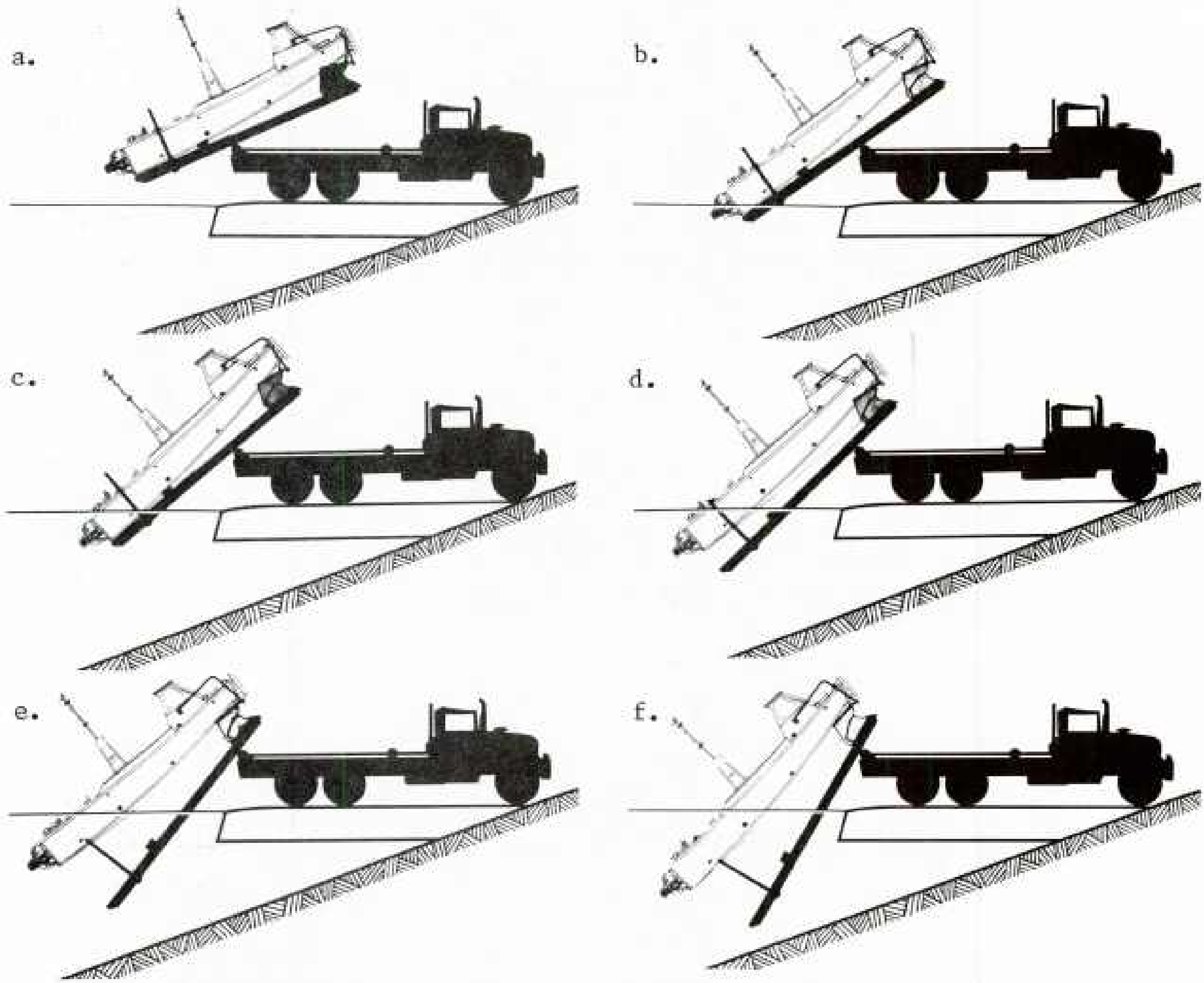

Figure 6. The Combat Support Boat can swamp when it is launched from a steep bank or ice shelf using the normal procedure.

Figure 7. Location of stern hatch covers.

bow shoe pivot pin to overcome the moment generated about this pin by the weight of the boat acting through the center of gravity. Under these conditions the rear portion of the boat will not float free of the cradle but instead will tend to settle with it. Continuing the launch procedure when this happens merely aggravates the situation. Using the normal launch procedure at a steep bank, no matter whether the steep bank results from the normal cross section of the river or is the result of shoreline ice, is not acceptable.

To understand the problems that can be encountered should the steep bank launch procedure be employed at a site with shoreline ice requires a somewhat detailed evaluation of the load transfer phenomenon of the steep bank procedure, as well as some consideration of the structural behavior of shoreline ice deposits. These two items are discussed sequentially in the following section.

Steep bank launch

The loading geometry for the steep bank procedure at the instant just prior to launch is illustrated by Figure 8. The weight of the boat, acting through its center of gravity, is an overcenter load on the transporter A-frame hoist. As such it creates a moment on the transporter that attempts to rotate the truck about its rear axle. The magnitude of this moment is

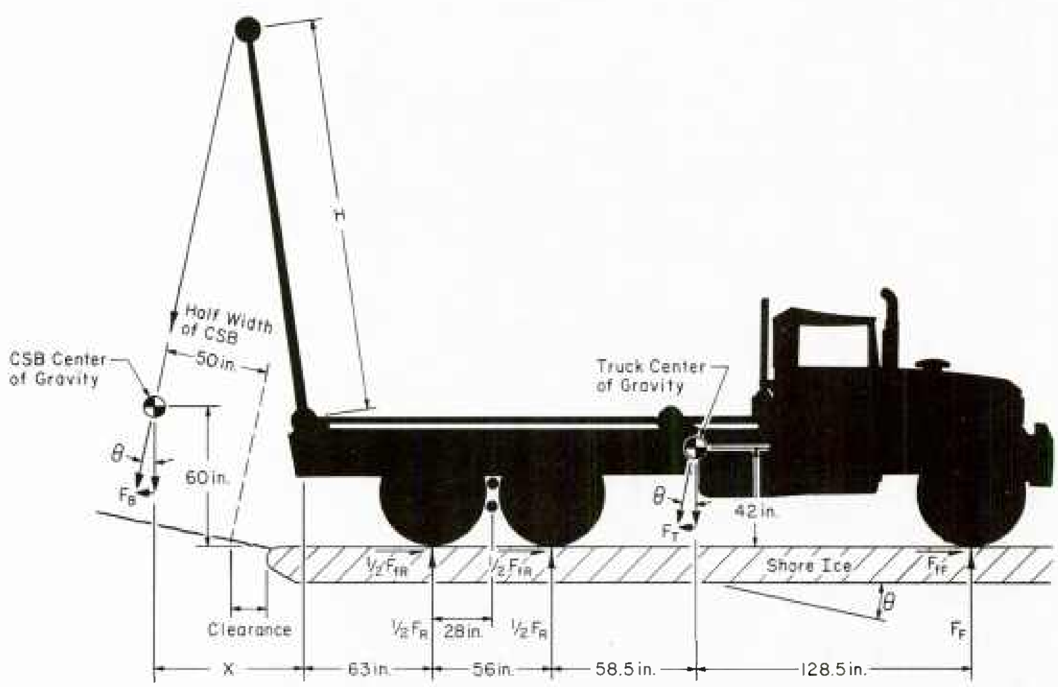

Figure 8. Loading geometry of the steep bank launch procedure for an arbitrary bank angle θ (CSB - Combat Support Boat).

equal to the vector dot product of the weight of the boat and the distance between its center of gravity and the point of rotation.

If we assume that the front winch cable has not anchored the truck, then the only force that generates a moment in opposition to this overturning moment is the weight of the "empty" truck acting through its center of gravity. As such the entire system remains statically stable only as long as this moment exceeds the overturning moment.

If we make the following simplifying assumptions:

1. The location of the empty truck's center of gravity is basically unaffected by the angular positioning of the A-frame boom,
2. The brakes of the truck are locked on so that if there should be rotation the center of rotation will be at the trunnion axle on the bogie suspension assembly rather than at the point of contact for the rear tires,
3. The load distribution between the rear and intermediate axles can be reasonably approximated as generating an equal load on each axle,

then for static equilibrium we require

$$\frac{1}{2} F_R + \frac{1}{2} F_R + F_F = (F_T + F_B)\cos\theta \tag{1}$$

$$\frac{1}{2} F_{fR} + \frac{1}{2} F_{fR} + F_{fF} = (F_T + F_B)\sin\theta \tag{2}$$

$$-215\, F_F + 86.5\, F_T \cos\theta - 22\, F_T \sin\theta - (91 + x)\, F_B \cos\theta$$
$$-40\, F_B \sin\theta = 0 \tag{3}$$

where

F_T = truck weight (28,880 lb)
F_B = boat weight (9600 lb)
F_R = total load on intermediate and rear axle
F_F = load on front axle
F_{fF} = frictional force on front tires
F_{fR} = total frictional force on rear and intermediate axle tires
x = overcenter distance.

Using eq 1 and 3 and substituting the appropriate values for F_T and F_B yields, after simplification,

$$F_F = 7556 \cos\theta - 4741 \sin\theta - (44.65 \cos\theta)\, x \tag{4}$$

and thus, again employing eq 1 and solving for F_R yields

$$F_R = 30{,}924 \cos\theta + 4741 \sin\theta + (44.65 \cos\theta)\, x. \tag{5}$$

Finally, if we assume that the frictional forces F_{fR} and F_{fF} can be approximated using

$$F_{fR} = fF_R \qquad \text{and} \qquad F_{fF} = fF_T \tag{6}$$

where f is the friction factor and, as a first order approximation, we can assume that the friction factor will remain constant, then dividing eq 2 by eq 1 yields

$$f = \tan\theta. \tag{7}$$

Equations 4 and 5 allow the loads on the front and rear axles (note that the load on the rear axle is assumed to equal one-half the value of F_R) to be calculated as a function of the overcenter distance for any given bank angle. Figures 9 and 10 illustrate the variation in front and rear axle loads for selected bank angles. The combinations of bank angle and the overcenter distance that result in a "zero" front axle load represent the marginal stability conditions since with these combinations the transporter will be on the verge of overturning.

We may conclude from this analysis that, for any given bank angle, the marginal stability condition is best avoided by minimizing the overcenter distance (i.e., distance "x" on Fig. 8) during the entire launch process. Unfortunately, this can only be done by moving the transporter as close to the outer edge of the ice shelf as possible. Since an ice shelf is a cantilever structure, moving the transporter to the outer (free) edge of the shelf increases the induced bending moments and thus increases the level of stress in the ice, especially at the junction between the ice shelf and the river bank. In turn, this increases the possibility of fracturing of the ice shelf or

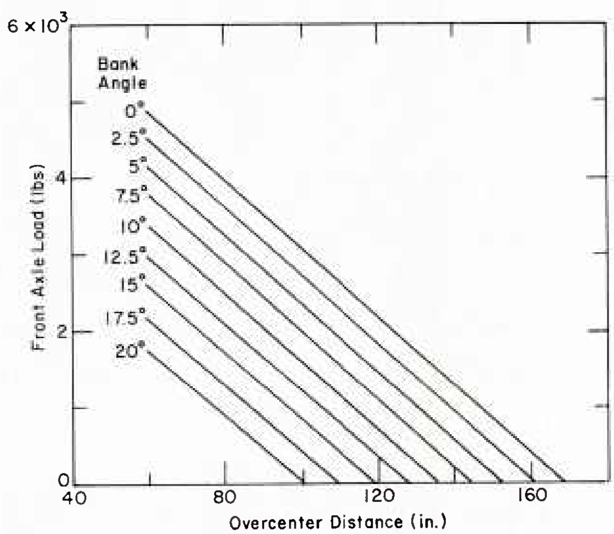

Figure 9. Variation in front axle load for various overcenter distances and bank angles.

separating the ice from the river bank -- a catastrophic failure.

Based on the results from this analysis and the knowledge and insight acquired from attempts to use the standard procedure to launch the boat from an ice shelf, it became obvious that any potential solution to the ice shelf launch problem must satisfy the following criteria:

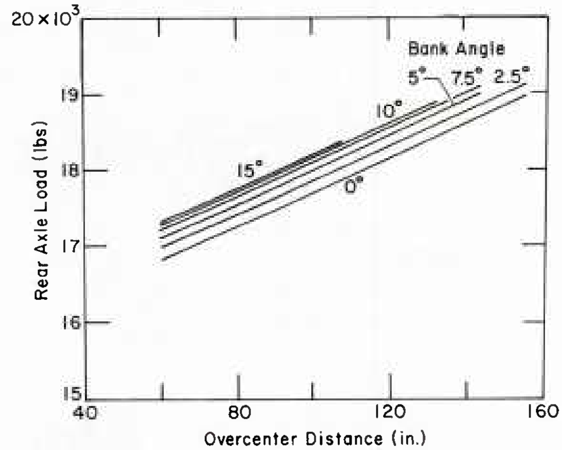

Figure 10. Variation in rear axle load for various overcenter distances and bank angles.

1. The initial angle at which the boat enters the water must be held to a minimum to prevent flooding of the aft compartments.
2. The loaded transporter should be kept as close to the shoreline edge of the ice sheet as possible to minimize any possibility for failure of the ice shelf.
3. The attitude of the boat during launch should, if possible, be such that in case there is a catastrophic failure of the ice there is at least a reasonable possibility that the boat will not be seriously damaged or immediately swamped. This last criterion is based on the assumption that the boat is the item of equipment most essential to the mission. Thus the launch procedure should seek to minimize risk to the boat, even if this increases the risk of loss or damage to the transporter or cradle. The ideal, of course, would be to minimize risk for all three items.

Ice shelf launch

The ice shelf launch procedure ultimately developed at CRREL (Fig. 11) completely satisfies the first two criteria and partially satisfies the third. The procedure begins by locating the transporter (Fig. 11a) so that the centerline of the rearmost axle is slightly less than 15 ft from the edge of the ice sheet. The A-frame boom is than raised slightly and the winch cable is slowly released, allowing the boat and cradle to roll off the transporter (Fig. 11b). Because of the distance of the transporter from the edge of the ice sheet, the lower rear edge of the cradle will not come to rest on

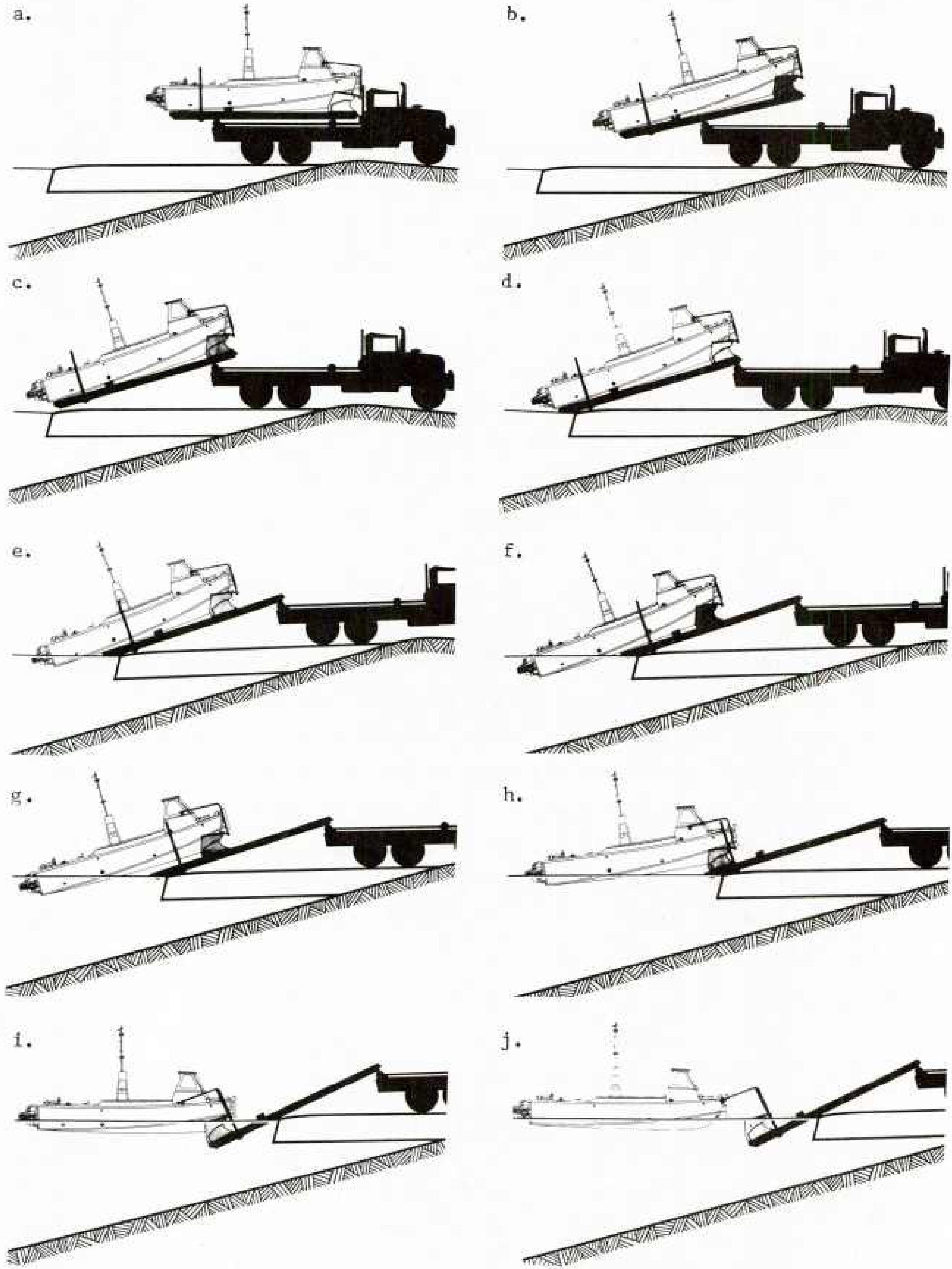

Figure 11. Procedure developed by CRREL for launching the Combat Support Boat from an ice shelf.

the upper surface of the ice. Instead (Fig. 11c and d), it will project over the edge of the ice shelf.

The transporter is then slowly driven forward (Fig. 11d) to engage the forward tie-down pins of the cradle with the rear restraint locks of the transporter (slack must be provided in the winch cable prior to moving the transporter to allow relative motion between the transporter and cradle). Two chains, each approximately 3 ft long, are then looped over the cradle tie-down pins and around the crossmember steel tube of the boom pivot support on the transporter. Fastened with grab hooks, these chains provide a flexible mechanical connection between the transporter and the cradle that will be needed during a later step of the procedure.

The safety latch for the boat dolly is then released and the winch cable is unwound, allowing the boat and dolly to roll down the cradle (Fig. 11e, f and g) under the force of gravity alone. (Sometimes, the boat may initially stick in place as a result of frictional forces created by the aft cradle support pads. Should this occur these forces can be easily overcome by having two individuals [standing on the ice shelf, not the boat] gently rock the boat from side to side.) Once the dolly has reached its limit of travel (Fig. 11h) or as far down the cradle as the force of gravity will drive it, the transporter is slowly backed towards the edge of the ice shelf.

In this step, the one for which the chains are needed, the bow of the boat is inserted into the river (Fig. 11i) so that the bow restraining cables may be released and the launching completed (Fig. 11j).

The suggested recovery procedure for ice shelves is virtually the reverse of the launch procedure. With the assumption that the dolly and cradle are deployed as indicated in Figure 11j, the boat is guided into the dolly saddle and the restraining cables are attached. (One secondary benefit provided by using chains to hold the cradle on the transporter is that they maintain the overall alignment of the system. Thus it becomes very difficult to accidentally knock the cradle off the transporter rollers.) The engines can now be stopped and the winch cable used to bring the boat and dolly up the full length of the cradle (Fig. 11d).

Depending upon the condition of the ice shelf, the recovery process can be completed in place or the transporter can be slowly driven forward until it is completely off the ice. For either case, the next step in the recovery process is to remove the chains. The winch is then again employed, this time to bring the cradle with boat up onto the transporter (Fig. 11a and b). The locking pin and safety cables are then installed,completing recovery.

Although the launch and recovery procedures described above may seem unwieldy and thus time-consuming, they can actually be done rather quickly. For example, after only three practice launches and recoveries, the three-person CRREL crew could consistently launch or recover the boat in less than 5 minutes. After considerable practice the norms for launch and recovery were on the order of 2-1/2 minutes each. At this point the limiting factor on the rate at which the boat could be launched or recovered was the speed of the winch rather than the technique employed.

OPERATION IN ICE

Ice effects on the boat

One of the concerns mentioned earlier in this report was whether or not ice particles in the river would clog the hydrojet and raw water intakes of the Combat Support Boat. If this happened consistently, then the concept of using the boat to break thin ice would be invalid.

We decided to operate the boat in increasingly more rigorous ice conditions, in terms of amount and thickness. Thus, during the first test the boat was driven through areas of intact and fractured skim ice (i.e., ice with thickness on the order of 1 in. or less). Since we encountered no difficulties with skim ice, the boat was driven through areas with progressively thicker ice covers.

This testing revealed that ice clogging of either the hydrojet inlets or the raw water intakes was not a problem. In more than 2 hours of operation in and around fractured ice, there was only one clogging incident with one hydrojet inlet. This clog was, however, quickly and easily cleared using the standard back-flushing procedure.

We did find small quantities of little ice particles trapped in the screens of the raw water intakes. However, because these particles collected at the top of the screen, well above the location where the raw water pumps draw water from the standpipe, they never affected the engine cooling system. Because the boat was never operated for more than a few hours on any particular day during the test program, it is impossible to predict whether 6, 8 or more hours of continuous operation in ice-filled rivers would result in sufficient ice accumulation to obstruct the flow of water to the cooling system.

Thus we recommend that if the boat must be operated in such ice conditions for extended periods, the raw water intake screens should be periodically checked and, if necessary, removed and flushed. We suggest that the inspections should be about once every 2 hours of continuous operation, combat conditions permitting.

These early tests did reveal a different problem. When the boat was maneuvered stern-first into areas of fractured ice, chunks of the fractured ice had a distinct tendency to wedge themselves between the lower tubular frame member of the diving platform and the casing of the hydrojet. When this happened operation of the steering gear and scoop controls was difficult at best and in some cases totally impossible. (It should be remembered that all maneuvering of the boat in fractured or intact areas of river ice, whether bow- or stern-first, was done only at exceptionally low speeds. Engine speed, for example, whenever ice was present, was typically kept below 1500 rpm and many times below 1000 rpm.)

We usually used boat hooks, ice chisels and crowbars to free the wedged chunks of ice. However, there are two reasons why we judge this method for dealing with this problem to be less than fully satisfactory. First, because large pieces of ice may wedge under the diving platform, the crewperson attempting to clear the ice must lean out over the platform and then reach back up and under it just to get at the ice. (Jams created by small pieces of ice can be cleared by opening and working through the inspection hole on one side of the platform while standing on the other side. However, because the crewperson must lean over the diving ladder to do this, it is not effective when large pieces of ice must be pried or broken out.) In addition to substantially increasing the possibility of the crewperson falling overboard (because of the danger of frostbite and hypothermia, getting wet should be avoided), this is hardly the type of posture from which an individual is able to work efficiently. There is, instead, a tendency for the individual to simply thrash about, accomplishing little other than becoming fatigued.

The second concern is that relatively fragile items -- steering linkages, control cables for scoops, the cast aluminum housings for the hydrojets -- are all located in this area. Thus they are vulnerable to damage not only from the ice as it becomes wedged under the diving platform but also from careless efforts to clear the jammed pieces of ice. As such, we feel that the best solution to this particular problem is prevention. For example, an expedient structure, along the lines of the old locomotive "cowcatcher," designed to deflect ice away from this area when the boat is operating in reverse is one potential solution.

Icebreaking ability of the boat

Except for the jamming problem during rearward movement described above, we found that, mechanically, the boat could be successfully operated in areas filled with fractured ice; we then proceeded to test the icebreaking capabilities of the boat. Similar to the clogging tests, we subjected the boat to increasingly more rigorous situations and thereby established its maximum icebreaking ability.

The testing revealed that for very thin ice, i.e., ice with a thickness on the order of 4 in. or less, the boat would "wedge" its way through the ice cover. As the forward edge of the bow first entered the ice sheet it would create a fracture line ahead of it. To within about 10° this fracture line would generally coincide with the overall direction of motion of the bow.

Continued forward motion of the boat, forcing the edges of this fracture line to separate to accommodate the ever expanding waterline profile of the bow, would propagate the fracture line further ahead. Eventually, as the crack approached a free edge of the ice cover, a sudden,complete failure of the ice would be produced thereby separating the ice cover into two distinct pieces.

In contrast to the process described above, we encountered an entirely different ice failure process for ice covers 6 to 10 in. thick. In this case the bow of the boat would ride up out of the water on top of the ice sheet, loading the upper surface of the ice at a point that in turn created a semicircular fracture pattern centered about that point. We feel that in this situation failure of the ice was caused by tensile overstressing resulting from local high bending moments.

After the ice had been fractured, the now broken chunks of ice would rotate down and away from the hull as the bow of the boat settled back into the river. As such the overall process was roughly equivalent to the breaking and clearing process generated by standard ice-breaking ships.

Since the raw water and hydrojet inlets did not clog from ice chunks, this process could be repeated until either a complete channel had been cleared or the boat encountered a section of ice it was incapable of breaking. Such an unbreakable section of ice, at least as far as the boat would be concerned, might be an area where ice thickness exceeded 7 to 10 in. or zones of ice grounded to the river bottom or both.

When the boat encountered ice covers from 4 to 6 in. thick, the failure mechanism was a combination of the two described earlier. At times the bow of the boat would begin to ride up on the ice, but before the complete bending failure pattern could develop a wedging crack would be created. In other cases the boat would begin wedging apart the ice when suddenly it would ride up onto the ice.

In general, our icebreaking did not physically damage the boat. After more than 1-1/2 hours of actual icebreaking, the net effect on the boat was erosion of the paint layer on and around the forward section of the bow.

The testing also revealed, as might be suspected, that the boat could break areas of thin ice much more rapidly and effectively than thicker zones. With the wedging failure process, the boat could break or clear large sections of thin ice at trolling speeds, i.e., 1000 to 1500 rpm. In contrast, the point loading failure process had to be done incrementally.

First, the bow had to be driven up and onto the ice sheet, and then held stationary until the ice failed. Once the ice had failed and the bow had settled back into the river, the boat would have to be backed up slightly to clear ice chunks that may have jammed around the bow before it could be driven forward again up onto the ice. In addition, since the total area of ice broken during any one particular point loading cycle was relatively small, we did not think that the process was highly effective or efficient for clearing large areas of thicker ice.

As a final note and warning, it must be mentioned that it is not difficult to drive the boat almost completely out of the water and up on top of an ice sheet, thereby "beaching" the boat. The problem this can create is that the weight of the boat may cause the section of ice supporting it to break free from the rest of the ice sheet. Should this occur, the separated section of ice can become lodged beneath the boat because the keel will tend to remain locked into the groove it created in the ice sheet when the boat was first driven out of the water.

This means that the added buoyancy provided by the ice trapped beneath the boat upsets its normal trim both from side to side and bow to stern. If a sufficient amount of ice is trapped, the added buoyancy can lift the raw water intakes, hydrojet inlet grilles or the hydrojets themselves out of the water. If any of these things happened, the motors would have to be shut down and the boat allowed to drift until the ice was cleared.

Finally, clearing such a section of trapped ice can be difficult. Because of the buoyancy of the ice there will be a positive contact pressure between the ice and the hull that must be overcome. In addition, because of the groove created by the keel, the only feasible method for separating the boat and ice is to move either the boat or ice directly forward or astern relative to the other. Depending upon the contact pressure between the two, this may be rather difficult to do.

CONCLUSIONS AND RECOMMENDATIONS

The Combat Support Boat (USCSBMK I) can be used to break up river ice covers up to 10 in. thick. For the thinnest ice covers (i.e., ice thickness less than or equal to 4 in.), the procedure is extremely efficient, allowing large sections of ice to be cleared rapidly. The procedure becomes progressively less efficient as ice thickness increases above 4 in. The procedure is judged to have little to no value for ice covers with thickness greater than 8 in. and should be avoided to prevent potential beaching.

Both the standard and steep bank launch procedures are not recommended for launching the boat from an ice shelf. Instead, we recommend the modified standard launch technique described in this report for launch or recovery from an ice shelf.

When the boat is operated in ice-filled waters, the screens in the raw water intakes should be inspected and, if needed, flushed periodically. Conditions permitting, a 2-hour interval is suggested for such inspections.

To the maximum extent possible the boat should not be backed into ice. If this cannot be avoided then we recommend that an expedient-type barrier be mounted aft of the diving platform to deflect ice away from the hydrojets. In addition, even with such a barrier in place extreme care should be exercised during such maneuvering.

Whenever the boat is operated in or near river ice only extremely low speeds should be used. In general, engine speeds should be kept below 1500 rpm and, if possible, below 1000 rpm.

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APPENDIX A: ADDITIONAL OBSERVATIONS

During the test program we made a number of observations about operating the Combat Support Boat during cold weather. Since these observations are, in our opinion, worth noting but are not directly related to the main topic of this report, they have been included in this Appendix. The order in which these various observations are presented is not and should not be construed to represent any type of priority or ranking.

Ice pressure fracturing of the cradle's aft transverse member

Figure A1 illustrates the transverse member that connects the aft ends of the main cradle beams. This transverse member is a welded aluminum box section that provides transverse and torsional rigidity for the cradle.

Figure A2 illustrates the crack that was created in this member by freezing of water trapped inside it. We assume that water entered the member during launch and recovery because the weld joints did not provide a com-

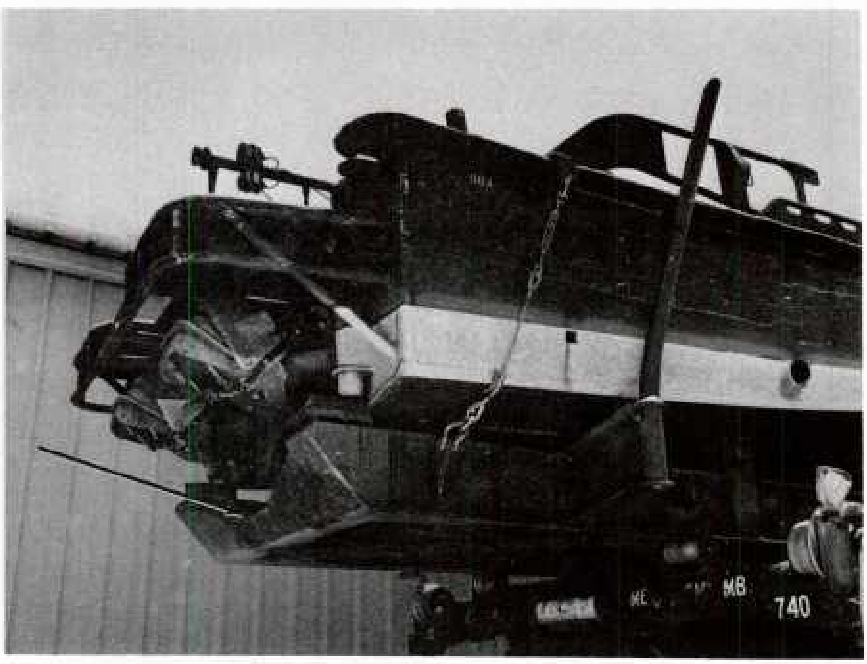

Figure A1. Aft transverse member of Combat Support Boat's cradle.

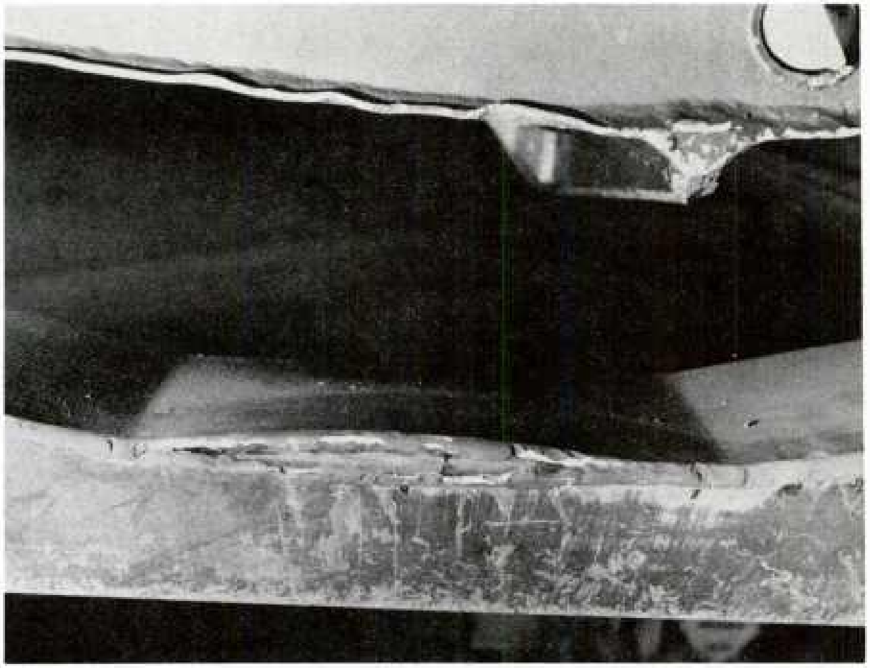

Figure A2. Crack produced by freezing of water trapped in aft transverse member.

pletely watertight seal. Filled with water and exposed to overnight subfreezing air temperatures, the member was unable to vent or otherwise relieve the pressures generated as the water froze and expanded, and therefore it cracked.

The solution to this particular problem is relatively simple. Drain holes should be drilled. To prevent potential clogging of these drains with silt or other sediment, we suggest that the holes be relatively large.

Freezing of aft bilge pump

A drain plug is provided at the rear of the boat to drain the hull once it has been removed from the water. Unfortunately, because of the height of this drain plug it does not completely drain the sump surrounding the aft bilge pump. The result of this is that water remains around the aft bilge pump inlet even after the boat has been "drained." If exposed to subfreezing air temperatures this water will freeze, thereby blocking the bilge pump inlet and rendering the aft bilge system inoperable until the ice is removed.

No corrective modifications are suggested for this particular problem. Boat operators should be told that this problem exists, and that when it does occur the aft bilge sump should be treated with hot water to remove the ice and proper bilge operation restored before the boat is launched.

Charging system switch-over

The boat has an emergency switch that allows all four batteries to be connected together to provide reserve power for difficult cold weather starts. Unfortunately, only the port engine alternator can be used to recharge these batteries. The starboard engine alternator is wired to only support the other electrical systems of the boat.

The problem that we encountered during our test program was that in cold weather the starboard engine was much easier to start than the port one. However, starting the starboard engine first was not a good procedure because its charging system could not be used to recharge the batteries and thus aid in starting the port engine.

As such, to provide greater flexibility, we suggest that the electrical system of the boat should be modified so that either the port or starboard engine charging system could be used to recharge the batteries or support the other electrical systems of the boat.

Out of river engine operation

Without the lubrication provided by the flow of water through the raw water pumps, friction would quickly destroy the raw water pump impellers because of the materials used in their construction. As such the manual for the boat specifically warns boat operators not to run the engines when the boat is not in the river.

Although this procedure will protect the raw water pumps from damage it produces two specific difficulties. In very cold weather the engines must be operated for a rather long period before they warm up to normal running temperatures. Thus in cold weather combat, quite a bit of time may be lost waiting for the engines to warm up.

The second difficulty that this can cause is that it makes it impossible for a maintenance and overhaul shop to do actual running tests of the engines without first launching the boat. If the maintenance shop is not located directly adjacent to a launch site this means that shop time for the maintenance staff would be wasted moving the boat to and from the test site.

This restriction against out-of-river operation of the engines needs not be so all-encompassing. By use of the procedure described below, the engines may be safely operated at any location.

The first step is to temporarily seal the raw water intakes located on the underside of the hull. Standard laboratory rubber stoppers of no. 11

size can be used for this. Next, the inspection covers at the top of the raw water standpipes must be opened and the intake screens removed.

A source of running water, such as a garden hose connected to a water line, is inserted into the raw water standpipe of the engine to be run. This source of water is used to both initially fill the standpipe before starting the engine and to keep it filled once the engine is operating. The amount of water needed to keep the standpipe full with the engine running will be a function of engine speed. The table below provides the water flow rates that were needed to support one engine of the Combat Support Boat loaned to CRREL. Of course, operating both engines at the same time would require the use of two hoses, one for each standpipe, and a water source able to provide twice the flow rates listed in Table A1.

Table A1. Water flow rate required to support one engine of the Combat Support Boat.

Engine speed (rpm)	Flowrate (gal./min.)
700	6.1
1000	8.6
1200	10.8
1300	12.0

With this procedure the engines can be tested safely right at the maintenance shop. Under field conditions, where a piped source of water would probably not be available, one could be improvised using elevated 55-gal. drums filled with water.

When using this procedure it should be kept in mind that the water pumped by the raw water pumps is eventually discharged out of the engine exhaust ports. If the boat is mounted on the transporter this water will splash on the walkways of the transporter frame as well as the surrounding ground. In cold weather this discharge water will form ice on these surfaces making them potentially hazardous to walk on.

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