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## **MOTAN: A NOVEL APPROACH FOR DETERMINING ICE-INDUCED GLOBAL LOADS ON SHIPS**

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### **ABSTRACT**

This paper introduces an inertial measurement system called MOTAN and discusses results from one of its full-scale installations. Recent measurements have shown that the MOTAN system offers a novel approach for determining ice-induced global loads on ships. The system consists of two parts: an instrument for measuring whole-ship motions, and software for processing those motions to obtain global ice impact loads. A background of the MOTAN system is given, along with model-scale and full-scale data to support its feasibility for determining global loads from transient ice impacts. The focus of the paper is full-scale data acquired while the CCGS LOUIS S. ST-LAURENT rammed old ice floes in the high Arctic. MOTAN-derived global loads are presented for three representative events. Data show that ice impact forces can approach 17.3 MN when ships operate in heavy ice conditions.

### **INTRODUCTION**

Traditionally, global ice impact forces on ships have been measured by strain gauging the structure. That approach involves treating the ship as an elastically deformable structure. Its structural deformations are measured by strain gauging strategic hull-girder beams throughout the ship. Measuring structural strains can be an effective method for measuring global loads, however installing the gauges can be a time-consuming (and expensive) process.

Recently, a novel approach for determining global loads on ships was put forward by the Canadian Hydraulics Centre (CHC) of the National Research Council of Canada. The method assumes the ship is a rigid body and uses its whole-ship motions to determine external ice forces. The whole-ship motions in six-degrees of freedom are measured using an instrument called the MOTAN. Specially developed MOTAN software is used to process those motions and calculate global impact loads. To date, the MOTAN has been used on three icebreakers. The first, full-scale installation of the MOTAN was on the USCGC HEALY in April 2000. The *HEALY* trials, which provided a proof-of-concept for the MOTAN, showed that the system was feasible for use in full-scale

installations (Johnston et al., 2001-a). The second MOTAN installation was on the CCGS LOUIS S. ST-LAURENT during its October 2000 ice trials. When the *LOUIS* trials were conducted, the objective of the using the MOTAN was to provide information on ship accelerations in ice (Johnston et al., 2001-b). Most recently, the MOTAN has been used to measure global loads on the CCGS TERRY FOX during controlled impacts with various bergy bits (Gagnon et al., 2002-a). This paper uses data acquired during the *LOUIS* trials to demonstrate the feasibility of the MOTAN for determining ice-induced global loads.

## MOTAN SYSTEM

The MOTAN system is a two-part package that consists of an instrument, and computer software to process output from that instrument (Figure 1). The instrument weighs 1.88 kg and measures 260 mm by 160 mm by 100 mm. It uses three accelerometers and three angular rate sensors, arranged in a strap-down configuration, to measure whole-ship motions in six degrees of freedom. The accelerometers measure the total ship acceleration (including the earth's gravity components) and the rate sensors measure the three-dimensional angular rotational rate of the ship, along a fixed coordinate system. Ship motions measured by the MOTAN are resolved along the instantaneous positions of the X, Y and Z body axes of the ship.

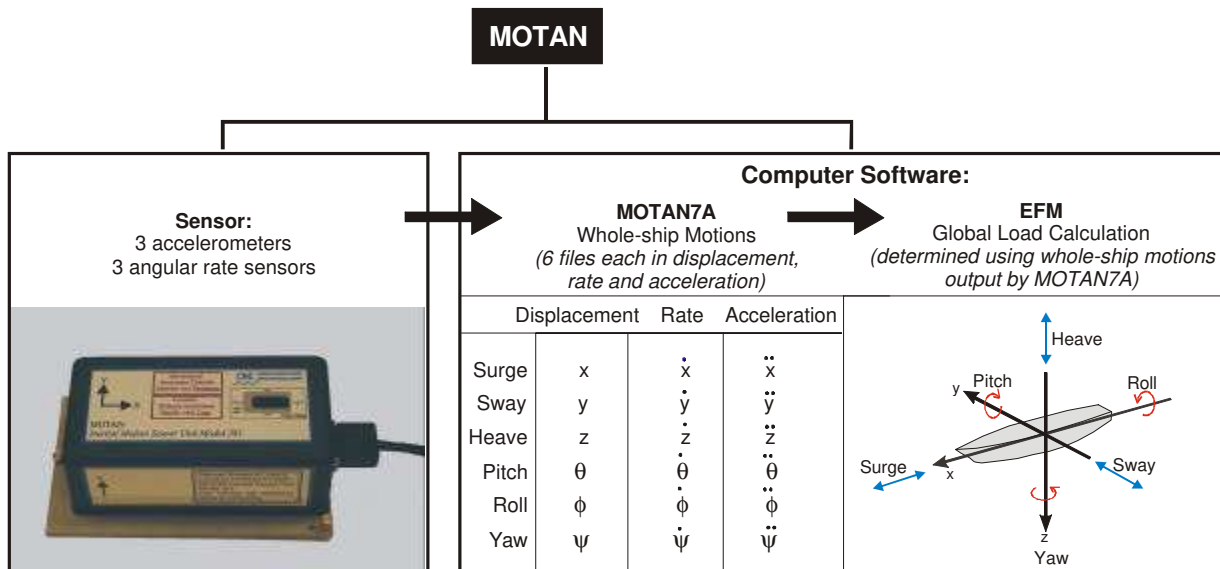


Figure 1 Schematic of MOTAN system

## DETERMINING WHOLE-SHIP MOTIONS USING MOTAN

A standard data acquisition system is used to record six analog voltage signals from the MOTAN. A program called MOTAN7A is used to convert the measured ship accelerations and angular rates to whole-ship motions in six degrees of freedom. The conversion is done using methods originally developed by the CHC for measurements of ship model motion in the laboratory. The program MOTAN7A provides time series of displacement, velocity and acceleration for the surge, sway, heave, roll, pitch and yaw motions, relative to a fixed coordinate system (Figure 1).

The MOTAN computes angular motions using the standard Society of Naval Architect and Marine Engineers (SNAME) convention for defining roll, pitch and yaw (SNAME, 1952). The whole-ship motions are output using a right-handed co-ordinate system, based upon the following sign conventions:

- X-axis: positive towards the bow
- Y-axis: positive to port
- Z-axis: positive upwards
- Positive Surge = forward motion
- Positive Sway = motion to port
- Positive Heave = upward motion
- Positive Roll = starboard side down
- Positive Pitch = bow down
- Positive Yaw = bow turning to port

Whole-ship motions can be computed at any point on the ship, regardless of where the MOTAN instrument has been installed, provided the positional coordinates of the unit are known and the ship can be reasonably assumed to be a rigid body. Since it can be easily installed at any convenient location on the ship, the MOTAN has a great deal of flexibility, which makes it ideal for field operations.

## USING WHOLE-SHIP MOTIONS TO DETERMINE GLOBAL LOADS

Calculating the global load from the six-degree-of-freedom whole-ship motions requires solving six linear differential equations of motions of the (vectorial) form;

$$\{F\} = [M + A] \{\ddot{\eta}\} + [B] \{\dot{\eta}\} + [C] \{\eta\} \quad (1)$$

where

- $F$  = exciting force, vector for three forces and three moments
- $M$  = generalized mass matrix of the ship
- $A$  = hydrodynamic added mass matrix
- $B$  = hydrodynamic damping coefficient matrix
- $C$  = hydrostatic restoring force moment coefficient matrix
- $\eta$  = vectorial translatory and angular displacements

Since the hydrodynamic coefficients used in Equation (1) are case-specific, they must be determined for the particular ship(s) of interest. To date, the hydrodynamic coefficients<sup>1</sup> have been developed for the three icebreakers on which the MOTAN has been installed: the *HEALY*, the *LOUIS* and the *TERRY FOX*. Fleet Technology (2001) discusses the methodology used to determine hydrodynamic coefficients for the three icebreakers.

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<sup>1</sup> The coefficients were developed for operating speeds of 1, 4, 8 and 12 knots and encounter wave frequencies to cover a maximum speed of 12 knots in head seas.

Equation (1) is solved using a second MOTAN program, EFM, to calculate the exciting forces and moments acting on a ship from the surge, sway, heave, roll, pitch and yaw motions computed by the program MOTAN7A. All output from the MOTAN software is referenced to the origin of the ship's co-ordinate system, which is taken as the intersection of a vertical line through the ship's centre of gravity and the plane of the undisturbed free surface of the surrounding water.

### ***Determining Salient Components of the Global Ice Impact Force***

The MOTAN load calculation software, EFM, outputs three forces and three moments, all of which are calculated at the origin of the ship's coordinate system. The force and moment components output by EFM can be used to calculate the longitudinal ( $F_x$ ), lateral ( $F_y$ ) and vertical ( $F_z$ ) force components at the point of impact, provided some assumptions are made about where the external ice force is applied<sup>2</sup>. The following equation can be used to determine the resultant global ice impact force:

$$F = \sqrt{(F_x)^2 + (F_y)^2 + (F_z)^2} \quad (2)$$

where

- $F$  = global ice impact force
- $F_x$  = longitudinal ice impact force component
- $F_y$  = lateral ice impact force component
- $F_z$  = vertical ice impact force component

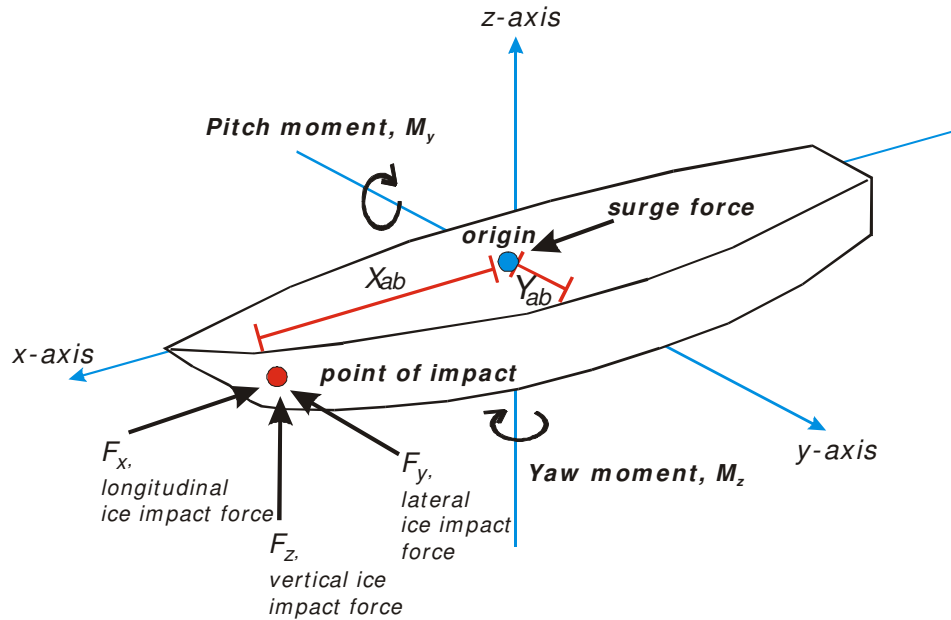
#### **Longitudinal Ice Impact Force Component, $F_x$**

One of the forces output by the EFM program is the surge force, which is calculated at the ship's origin (Figure 2). The surge force can be used in Equation (2) as the longitudinal ice force component,  $F_x$ , because ship motions in the longitudinal direction are the same everywhere along the length of the ship. Translating the surge force from its reference point at the ship's origin to the point of impact is an appropriate step in determining the global ice impact force,  $F$ .

In comparison to the ship's surge motions, the sway and heave motions at the origin of the ship's coordinate system are much smaller than sway and heave motions at the bow. Therefore, it is more accurate to use pitch and yaw moments to calculate respectively the lateral ice impact force component ( $F_y$ ) and vertical ice impact force component ( $F_z$ ), at the point of impact. This is done by dividing the moments by the radial distance from the ship's origin to the point of impact, as discussed below.

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<sup>2</sup> The point of impact can sometimes be (roughly) determined using observations recorded on the bridge. When that information is not available, the impact is assumed to act on the shoulder, at the waterline.



**Figure 2 Three components used to calculate global load at the point of impact:  
Pitch moment, Yaw moment and Surge force**

#### Lateral Ice Impact Force Component, $F_y$

The lateral ice impact force component (in the y-direction,  $F_y$ ) can be determined from the yaw moment ( $M_z$ ) by dividing by the radial distance to the point of load application. In the case of yaw, the radial distance is in the longitudinal direction ( $X_{ab}$ , as shown in Figure 2). The roll moment does not factor into the lateral ice impact force,  $F_y$ , because the impact is assumed to act at the waterline. Hence, there is no roll moment associated with  $F_y$ .

#### Vertical Ice Impact Force Component, $F_z$

The vertical ice impact force at the point of impact ( $F_z$ ) can be determined from the pitch moment,  $M_y$ . That is done by dividing  $M_y$  by the same longitudinal distance ( $X_{ab}$ ) that was used to compute the lateral force,  $F_y$ . Since ice impacts are seldom purely symmetrical, head-on collisions in which forces are applied along the centreline of the ship, roll moments can be significant. Much of the roll moment comes from the vertical force component therefore the roll moment could be used to determine  $F_z$ . That would require dividing the roll moment by some fraction of the breadth of the ship ( $Y_{ab}$ ), depending upon the radial distance to the point of impact. Since the longitudinal distance ( $X_{ab}$ ) is greater than the lateral distance ( $Y_{ab}$ ), it is not as sensitive to errors that may arise when estimating the radial distance to the point of impact<sup>3</sup>. Both methods involve some percentage of error, which is why the pitch moment is preferred for calculating  $F_z$ , rather than the roll moment.

<sup>3</sup> The point of impact is either determined using bridge observations, or by assuming that the impact acts on the shoulder. A sensitivity study is currently being conducted to evaluate the importance of having accurate information about the point of impact and to determine how the calculated loads are affected by assuming a radial distance to the point of impact.

### ***Calculating the Resultant Global Ice Impact Force***

Using the surge force, yaw moment and pitch moment to calculate the global ice impact force, and making some assumptions about where the point of impact occurs, Equation (2) can be rewritten as:

$$F = \sqrt{(F_x)^2 + \left(\frac{M_z}{X_{ab}}\right)^2 + \left(\frac{M_y}{X_{ab}}\right)^2} \quad (3)$$

where

- $F$  = global ice impact force
- $M_z$  = yaw moment, about z-axis
- $M_y$  = pitch moment, about y-axis
- $X_{ab}$  = longitudinal distance to point of impact

### **MOTAN VALIDATION**

A full-scale validation study of the MOTAN was performed using data acquired on the *TERRY FOX* during the 2001 Bergy Bit Trials. The trials were conducted from 18 to 23 June 2001 and involved conducting controlled collisions with small pieces of glacial ice at various speeds (Gagnon et al, 2002-a). Figure 3 shows a typical collision that occurred during the Bergy Bit Trials.



**Figure 3 Ship-ice collision during the Bergy Bit Trials, June 2001**

Three different instrumentation systems were used to measure loads on the *TERRY FOX* during the Bergy Bit Trials. The MOTAN measured the whole-ship motions, from which global loads have been determined for 17 impacts (Johnston et al., 2003-a). The other two measurement systems involved instrumenting localized areas of the hull. The first system consisted of an external impact panel and the second system used the more conventional technique of strain gauging (Gagnon et al., 2002-b). Because the impacts occurred over relatively small areas, loads on the localized areas could be compared to the MOTAN-derived global loads.

The Trials resulted in more than 178 events, 17 of which were examined during the full-scale MOTAN validation study. That investigation involved comparing the MOTAN-derived global loads to the loads measured on either the strain gauged area or the impact panel. Because the two measurement areas of the hull were separate, each MOTAN event could only be compared to one or the other of the instrumented areas.

Data acquired during the Bergy Bit Trials are proprietary until July 2004, therefore the MOTAN-derived global loads for the 17 examined impacts can not be presented here. A controlled report has been issued to document the full-scale validation study (Johnston et al., 2003-a). Although the magnitude of the global loads measured during the Bergy Bit Trials cannot be presented here, the following conclusions were made in the study:

- Comparison of global loads was possible for 8 of the 17 examined impacts. The remaining nine impacts either occurred outside the instrumented area or involved multiple hits in close succession (for which data from the other instrumentation systems are not available).
- There was good agreement between the global loads measured by the three different instrumentation systems.
- Because the MOTAN uses whole-ship motions to determine global loads it is not restricted to localized areas of the hull. Therefore, it provided an upper bound for the loads measured on the *TERRY FOX*. On average, the MOTAN-derived global loads were [somewhat] higher than on the strain-gauged area and [considerably] larger than loads measured on the impact panel.

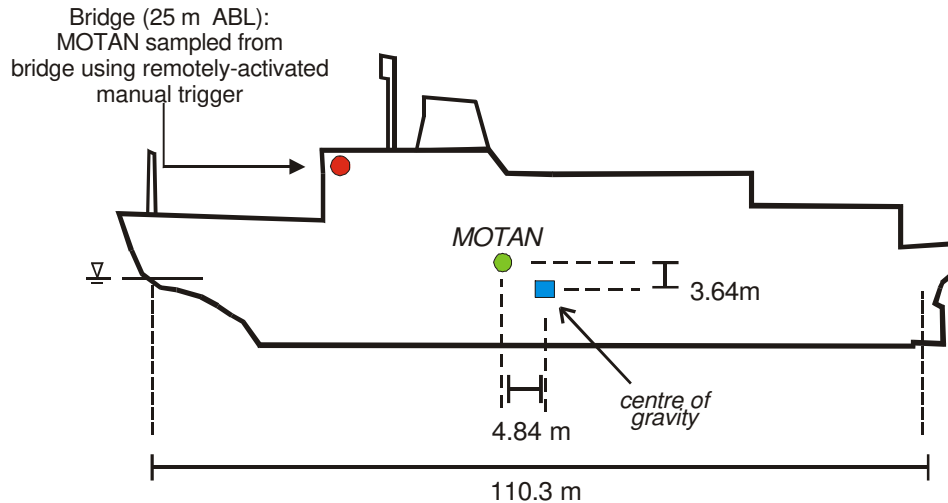
## **FULL-SCALE INSTALLATION OF MOTAN ON CCGS LOUIS S. ST-LAURENT**

The October 2000 Ice Trials of the *LOUIS* took place in the central Canadian Arctic (75°N, 93°W). The trials involved extensive backing and ramming operations in thick first-year ice, second-year ice and multi-year ice. The MOTAN was used to measure whole-ship motions for a total of 42 event records. More than 200 individual impacts have been identified from the time series of the MOTAN-derived global loads (Johnston et al., 2003-b).

### ***MOTAN Installation on LOUIS***

The MOTAN was installed near the centre of gravity of the *LOUIS*, at the rigid intersection of two I-beams, in the engine casing area (Figure 4). Event records were triggered from the bridge using a remotely activated, hand-held device. Typically, MOTAN events were logged for 15 minutes to completely capture several backing and ramming cycles. The MOTAN signal was passed through a signal-processing unit, where it was amplified (by a gain of 5) and a 5 Hz low-pass filter was applied. All of the *LOUIS* event records were sampled at a frequency of 50 Hz.





**Figure 4 Location of MOTAN on *LOUIS***

### ***Selecting Global Loads on LOUIS***

Individual impacts were identified from the 42 event records by comparing the translational (surge, sway, heave) and rotational (pitch, roll and yaw) accelerations to observations made from the bridge. Timing of the observations was made using a stopwatch (synchronized to the MOTAN instrument) to note when individual impacts occurred. Post-processing of the MOTAN data showed that measured changes in ship accelerations directly corresponded to the time at which bridge observations showed the impacts occurred. The surge, sway and heave accelerations were particularly relevant to impact identification, since they related closely to the original raw signal (Johnston et al., 2002-b).

Time series of the surge acceleration were particularly useful for identifying events that were characterized as symmetrical, head-on rams. The surge acceleration usually showed an appreciable change that reflected the deceleration of the ship upon hitting an ice feature. In comparison, oblique impacts caused lateral ship motions predominantly, for which the sway acceleration was appropriate in impact identification. Typically the impacts caused significant changes in the pitch, roll and yaw accelerations that were used to corroborate the time of impact. As a final check, the whole-ship motions were compared to ship speed, since the impact usually produced a noticeable change in ship speed.

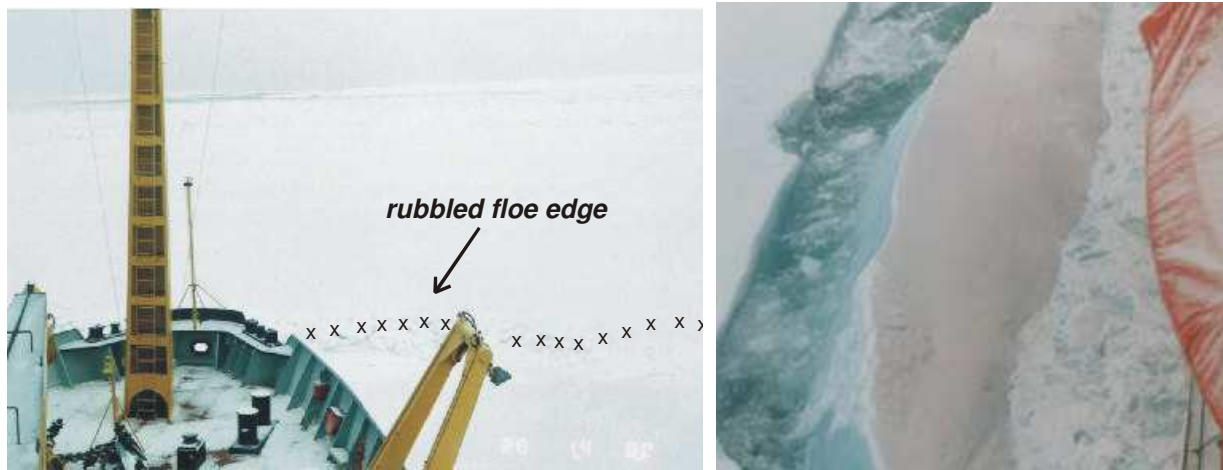
The following sections discuss three event records for which MOTAN-derived global loads on the *LOUIS* were determined. An arbitrary number of impacts were selected from each event record, based upon the pure ship accelerations and observations made from the bridge. The selected impacts resulted in some of the highest global loads measured during the *LOUIS* trials.

### Case I: Event L19

Event L19 was recorded on 20 October, when the *LOUIS* impacted a multi-year floe that had been rammed several times earlier in the day. As it approached the rubbled periphery of the targeted floe (Figure 5-a), the *LOUIS* passed through about 1 m thick ice. As it did, the ship slowed to 10 knots (from 13 knots) and experienced considerable sway. The 1 m thick ice on the edge of the main floe was classified as thick first-year ice (although, technically, it may have been thin second-year ice). Observations from the bridge indicated that, at an elapsed time of 505 s, the *LOUIS* penetrated the rubbled periphery of the main floe. The cusps of ice that the *LOUIS* upturned at its shoulder showed the ice to be in excess of 2 m thick (Figure 5-b).

Figure 6 shows MOTAN-derived global loads corresponding to the 480 to 520 second interval of Event L19. The figure illustrates the period during which the *LOUIS* passed through first-year ice (495 to 505 s) and into the main multi-year floe (505 to 520 s). The ship came to a halt about 15 s after it penetrated the multi-year ice.

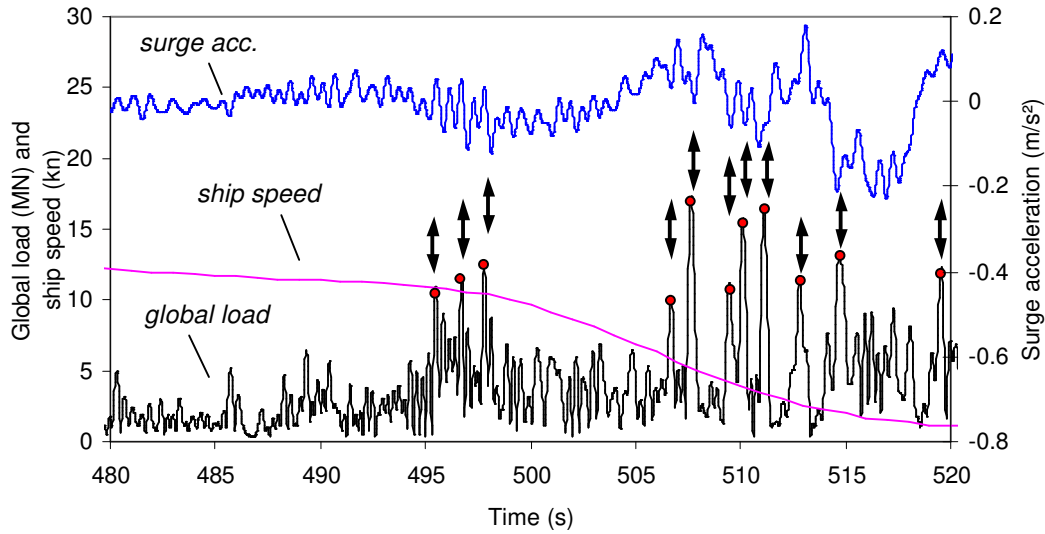
A total of 11 impacts were selected from the global load time series of the ram shown in Figure 6. The first three impacts occurred when the *LOUIS* was in thick first-year ice and the remaining eight impacts resulted from multi-year ice. The figure shows that all of the selected impacts had an associated change in surge acceleration. Global loads from the three impacts in first-year ice were from 10.4 to 12.4 MN, for a ship speed of about 10 knots. The eight multi-year ice impacts caused global loads from 9.5 to 17.3 MN, as the ship slowed to 1.2 knots (from 5.6 knots). The series of impacts that occurred during penetration of the multi-year floe resulted in the three highest global ice impact forces measured during the *LOUIS* ice trials (17.3, 16.7, 15.7 MN).



(a) rubbled periphery of multi-year floe

(b) ice cusp formed during Event L19

**Figure 5 Second-year floe associated with Event L19**

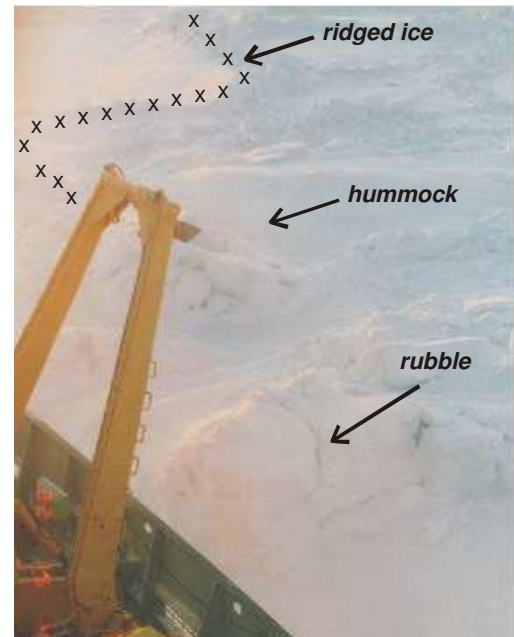


**Figure 6 Global loads and motions of *LOUIS* during ramming Event L19**  
(double arrows used to help align global loads and accelerations)

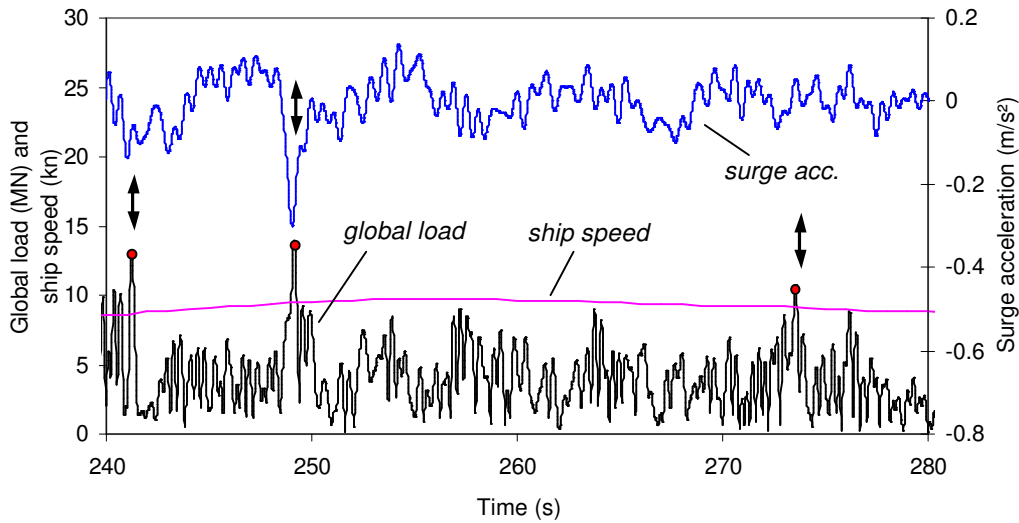
#### Case II: Event L34

Event L34 occurred on October 22, when the *LOUIS* impacted a ridged, second-year ice floe. Figure 7 shows the well-defined ridge that ran through the floe. Note that the ridge was nearly parallel to the point at which the *LOUIS* entered the floe.

Figure 8 shows the MOTAN-derived global loads that were measured during an interval of Event L34 (240 to 280 s). During that period, the ship speed remained relatively constant at 9 knots. Although there was little change in ship speed during that period, the impact that occurred at 249 s caused the fourth highest impact load (14.0 MN) of the *LOUIS* trials. Observations from the bridge confirmed that a very hard impact occurred on the starboard side of the *LOUIS* at 249 s. That impact produced one of the ten highest ice impact forces, in the longitudinal ( $F_x$ ) and vertical ( $F_z$ ) directions, of more than 200 impacts.



**Figure 7 Floe from Event L34**

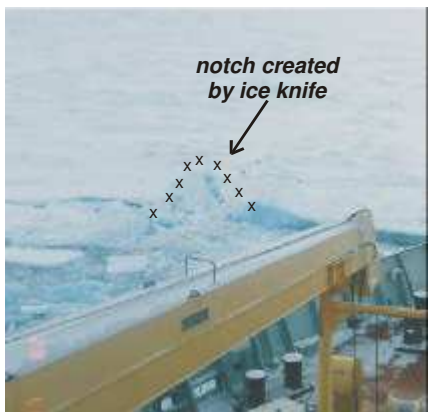


**Figure 8 Global loads and motions of *LOUIS* during Event L34**

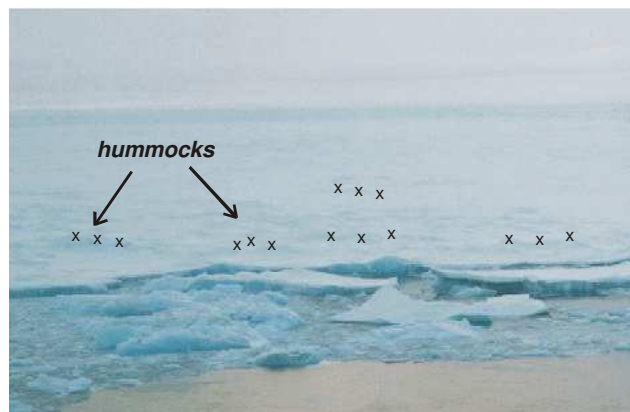
### Case III: Event L42

Event L42 was recorded on 23 October, when the ship impacted the hummocked multi-year floe shown in Figure 9. The event file included two runs at the same floe – the first run occurred about 50 s after the event began and second at an elapsed time of about 408 s. Both rams were made at the same location on the floe. In fact, during the second run, the *LOUIS* aimed for the notch in the floe that was created by the ice knife during the previous ramming cycle, as shown in Figure 9-a.

Figure 10 shows the time series of global loads for the first ramming cycle of Event L42 (elapsed time of 47 s). The first ram was conducted at an impact speed of 8.4 knots. Four impacts were selected from the first ramming cycle, each of which corresponded to a change in one (or more) of the ship accelerations. The surge acceleration is used in Figure 10 to illustrate that point. The global loads associated with the four impacts shown in Figure 10 ranged from 9.5 to 12.6 MN, for ship speeds from 6.1 to 7.8 knots. The 12.6 MN force that occurred at 54 seconds was the tenth highest global ice impact force measured during the *LOUIS* trials.

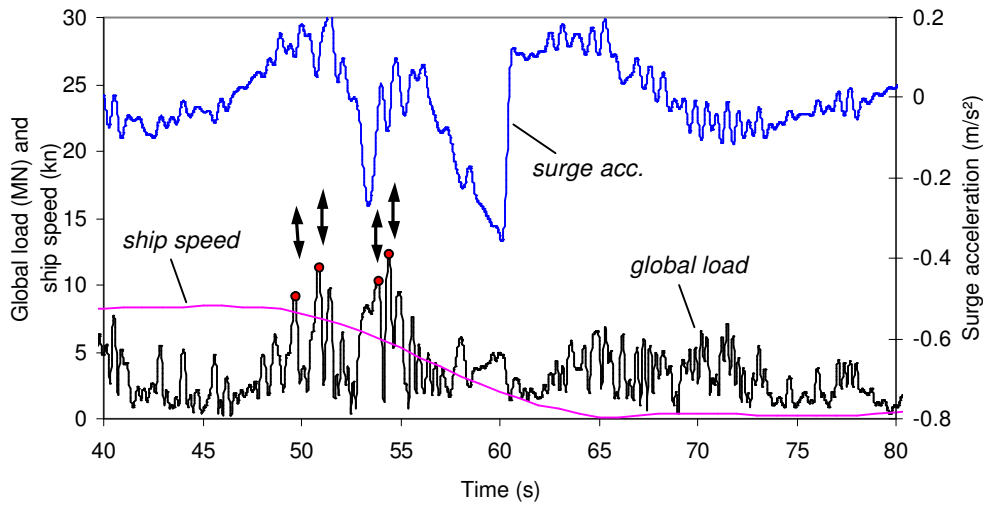


**(a) floe after first run in Event L42**



**(b) floe after second run in Event L42**

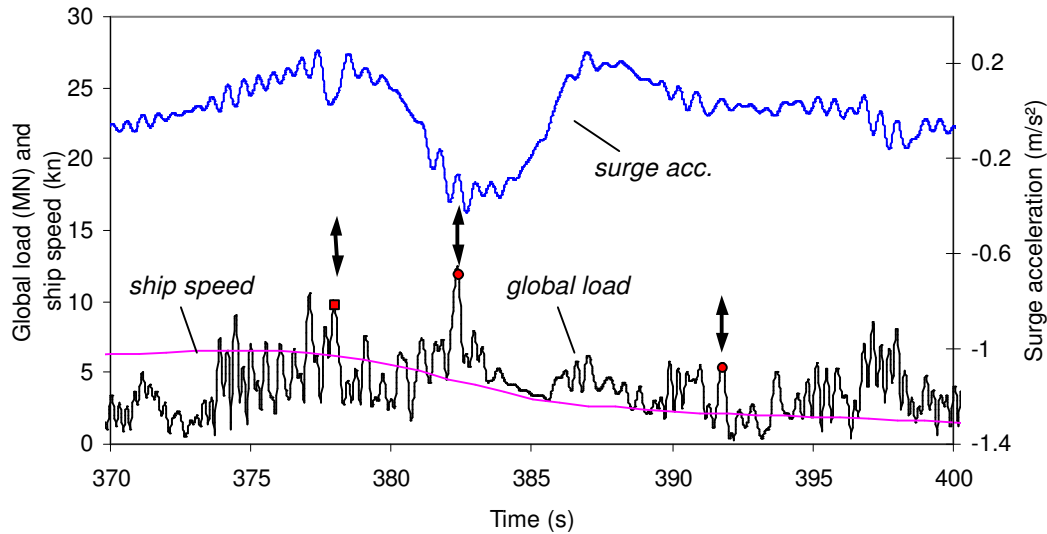
**Figure 9 Ridged multi-year floe associated with Event L42**



**Figure 10 Global loads and motions of *LOUIS* during first ram of Event L42**

The second ramming cycle of Event L42 occurred at about 377 s (Figure 11), when *LOUIS* aimed for the notch in the floe at a speed of 6.5 knots. The second ram of Event L42 was included as an example because it generated the most significant ship motions measured during the *LOUIS* trials, as discussed below.

Observations from the bridge noted that when the *LOUIS* rode-up onto the ice during its second attack on the hummocked floe, the ship rolled to the starboard side by about 4 degrees. Suddenly, the ice under the port side of the ship collapsed, causing the ship to roll sharply back to the port side by about 12 degrees. As can be imagined, the sudden collapse of ice beneath the ship resulted in significant accelerations – persons on the bridge lost their footing and were literally thrown to the port side (as was dinnerware in the dining quarters, much to the cook’s dismay!). Global loads associated with the four impacts selected from the second ramming cycle ranged from 5.7 to 12.5 MN, for ship speeds of 2.3 to 6.5 knots (Figure 11). None of the impacts shown in Figure 11 ranked within the ten highest global loads measured during the *LOUIS* trials. However, the 6.2 MN impact that occurred at 378 s was the eighth highest vertical ice impact force ( $F_z$ ) of the *LOUIS* trials and the 3.6 MN impact that occurred at 382 s was the third highest longitudinal ice impact force ( $F_x$ ) of the trials.



**Figure 11 Global loads and motions of *LOUIS* during second ram of Event L42**

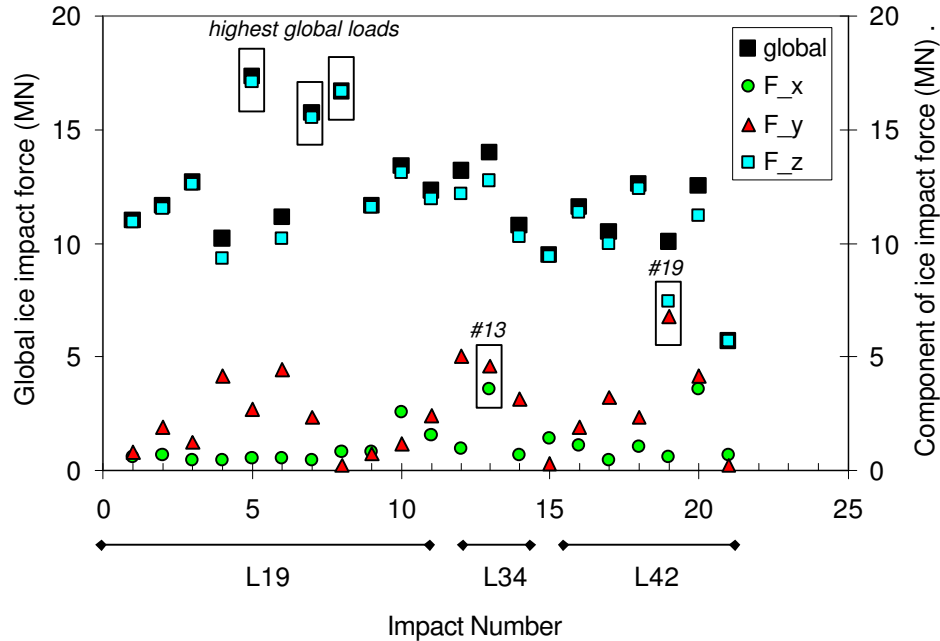
## SUMMARY OF RESULTS

A total of 21 impacts were examined from three event records measured by the MOTAN during the *LOUIS* trials. Two of the examined event files (L19 and L42) involved multi-year ice and the third event file (L34) involved ridged second-year ice. Figure 12 shows the different load components and resultant global load for the individual impacts. As mentioned previously, Event L19 caused the three highest global loads measured during the *LOUIS* trials (15.7, 16.7, and 17.3 MN).

Measurements in the literature show that the global loads measured by the MOTAN are a reasonable approximation for ice impact forces. In 1985 the USCGC POLAR SEA conducted ice impact tests in heavily ridged, thick, first-year ice and multi-year in the Beaufort Sea (Minnick et al., 1990). The bow forces measured during that program ranged from 4 to 25 MN. In 1986, a second series of ice impact tests was conducted with the USCGC POLAR STAR in similar, but less severe, ice conditions in the Beaufort Sea. A maximum bow force of 20 MN was measured during the those trials. Similarly, the MV Arctic measured vertical bow forces of 4 to 23 MN in thick first-year and multi-year floes (German and Milne Inc., 1985).

### ***Largest Component Ice Impact Forces of Resultant Global Load***

Figure 12 clearly shows that the resultant global load (plotted on left axis) depends most heavily upon the vertical ice impact force component ( $F_z$ , plotted on right axis). With the exception of one event,  $F_z$  was considerably larger than lateral ice force ( $F_y$ ) and the longitudinal force ( $F_x$ ). The exception was the impact identified as Event L42, #19 in Figure 12. That was the previously described impact in which ice beneath the ship collapsed and caused the ship to suddenly roll to the port side. The unexpected ship motions resulted in a 6.8 MN lateral impact force ( $F_y$ ) and a 7.4 MN vertical impact force ( $F_z$ ).



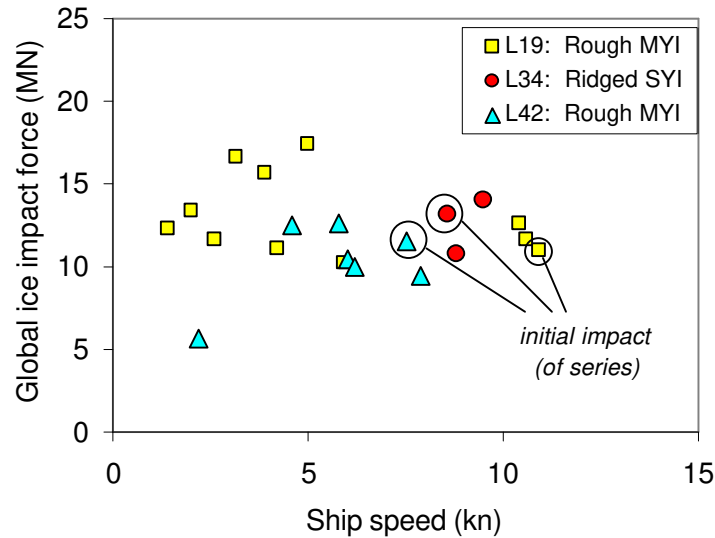
**Figure 12 Components of Ice Impact Force for the Examined Impacts**

The examined impacts showed that, usually, the longitudinal force exceeded the lateral force, although that was not always the case. The highest longitudinal force ( $F_x$ ) resulted from the impact identified as Event L34, #13 in Figure 12. That impact, which occurred when the *LOUIS* impacted a ridged second-year floe, had an  $F_x$  of 3.6 MN and an  $F_y$  of 4.6 MN. Impact #13 was one of the cases in which the longitudinal and lateral ice impact forces were comparable.

#### ***Effect of Ship Speed and Ice Type on Global Load***

Figure 13 presents a cross-plot of the global ice impact force and ship speed for the examined events. The data are categorized based upon the type of ice involved in the impact. Although the data are limited, results show that the global loads generated from the rough multi-year ice were comparable to those measured in ridged second-year ice. In addition, there does not appear to be any clear relation between global load and ship speed. Finally, one might expect that the global loads generated during the initial impact would have exceeded subsequent impacts, but that was not found to be the case. Frequently, the higher loads would be experienced after the ship had penetrated some distance into the floe.





**Figure 13 Global ice impact force versus ship speed**

## CONCLUSIONS

The MOTAN system has been introduced as a novel approach for determining ice-induced global loads on ships. The working concepts of the MOTAN were discussed, along with some details of full-scale validation work on the MOTAN. The validation work involved comparing the MOTAN-derived global loads to the loads measured on a strain gauged area or an impact panel. Although details of the measurements must remain proprietary until 2004, the study showed good agreement between global loads measured by the three independent systems.

Three event records from the *LOUIS* ice trials in October 2000 were used to demonstrate the applicability of the MOTAN in determining global loads. A total of 21 individual ice impacts were selected from the event records. Global load time series from a single ram showed that backing and ramming operations in second-year and multi-year ice produce multiple impacts, with loads up to 17.3 MN. In general, global loads during the 21 impacts ranged from 5.7 to 17.3 MN, for ship speeds from 1.4 to 10.9 knots. The MOTAN-derived global loads were shown comparable to loads measured (independent of the MOTAN) during the *POLAR SEA*, *POLAR STAR* and *MV ARCTIC* ice trials.

Measurements showed that most of that MOTAN-derived global load results from the vertical force component, although on occasion, the lateral force component can have a significant contribution. The global loads for each event were plotted against ship speed at the time of impact. There was no apparent correlation between global load and ship speed, regardless of whether multi-year ice or second-year ice was impacted.



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