Mechanical and Physical Risk Prevention

Studies and Research Projects

REPORT **R-870**

Assessment of Roll-damping Systems in Québec's Mid-shore Fishing Fleet

Francis Coulombe
Marie-Hélène Fournier
Aurem Langevin

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IRSST – Communications and Knowledge Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
Fax: 514 288-7636
publications@irsst.qc.ca
www.irsst.qc.ca

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Francis Coulombe[1], Marie-Hélène Fournier[1,2], Aurem Langevin[3]

[1]Merinov
[2]Halieutec
[3]Consulting engineer

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PEER REVIEW

In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

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SUMMARY

Fishing is one of the most dangerous occupations, as the fatal accident statistics for the fishing industry compared with those for other occupations clearly show. On a fishing boat, the work is performed under difficult conditions, on a slippery, moving surface exposed to the elements. For greater safety and ease of execution of fishing operations, roll-damping systems are used to reduce the impact of the vessel's motion. The main function of such systems is to limit lateral movement without too much impact on the longitudinal pitching motion caused by the sea. The purpose of this project was to inventory roll-damping systems on mid-shore fishing vessels in operation in Québec and to conduct comparative performance tests of the two most popular roll-damping systems used in Québec, hinged fins (an emerging system) and paravanes (most widely used in the province's fleets).

The inventory showed that half of the 292 vessels of more than 15 gross tonnage are equipped with paravane systems, whereas only 11% have hinged fin roll-damping systems. The use of hinged fins is, however, on the rise. An additional survey, conducted at the end of October 2010, of 53% of vessel captains/owners who had equipped their boats with hinged fins, indicated a high rate of satisfaction on all levels: ease of handling, comfort, safety and general performance at sea.

In the summer of 2010, sea trials were conducted aboard twin crabbers, the *Danie Martine*, equipped with paravanes, and the *Rudy L1*, equipped with hinged fins. The purpose of the trials was to see if the *Rudy L1* outperformed the *Danie Martine* in terms of three aspects of concern to fishers and regulatory agencies: vessel stability, crew safety and comfort, and energy costs (fuel). Sea trials were conducted over three days in the Baie-des-Chaleurs off the coast of the Gaspé peninsula. On each of these days, 21 trials lasting 15 minutes each were conducted, during which the three major variables were tested: (1) position of the roll-damping system (vertical, semi-deployed and immersed); (2) vessel speed depending on operations (drifting, half-speed, as while fishing, and full speed, as when steaming between the dock and the fishing grounds); (3) vessel position with respect to wind direction (headed into the wind, running with the wind or in crosswinds). Data were continuously recorded with specialized instruments, including an inertial navigation system (INS), a torque indicator on the drive shaft, a GPS system for determining speed over ground (SOG) and an anemometer for determining wind speed and direction. The weather was quite mild during the three days of testing, so the sea was not rough.

Under these conditions, mean values of roll amplitude recorded during lateral movements of the *Danie Martine* and the *Rudy L1* were within a safe range, between two and six degrees. More specifically, the minimal mean values of roll amplitude were recorded on the *Danie Martine* and the maximal values were observed on the *Rudy L1*—though the differences were small, especially when the roll-damping systems were immersed. Pitch amplitude was lower when the vessels were drifting or running at half-speed and the roll-damping systems were not deployed. The minimal values were around 1.0 degree, while maximal values were about 2.5 degrees. Pitch amplitude of the *Rudy L1* was greater than that of the *Danie Martine* when the vessels were travelling. In terms of energy consumption, the *Rudy L1* proved more economical than the *Danie Martine* at half-speed, but energy consumption of the two vessels was similar at full speed when the roll-damping systems were deployed.

Like paravanes, hinged fins reduce roll and increase the general stability of the vessel and the safety of the crew. Our visual observations also showed that the hinged fins are simpler and easier for the crew to deploy than the paravanes. It is also easier for the captain to determine the span of the hinged fins, which have fixed geometry, whereas the geometry of paravanes depends on the effect of water resistance on the paravane-cable coupling. In addition, with the hinged fins it is easier to avoid obstacles floating on the surface or just below it.

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1. INTRODUCTION

According to the Occupational Safety and Health Branch of the International Labour Organization (ILO), 24,000 fatal accidents occur every year in the fishing industry, worldwide.[1] When the statistics regarding fatalities in the fishing industry are compared to those of other occupational categories, it appears that fishing is one of the most dangerous jobs (Petursdottir et al., 2004). In Canada, the numbers of deaths in the industry are estimated to be one person per month (Bussières, 2010).

Conditions are difficult on a fishing boat, with tasks performed on a slippery, moving surface exposed to the weather, and the crew must often work in uncomfortable positions. The design, construction, maintenance and use of a vessel all have direct impacts on the health and safety of workers. The risks vary according to the type of fishing, fishing grounds, weather conditions, vessel size, gear, and tasks performed by each fisher.

The surface of the sea is in constant movement and ever changing, and fishing activities require frequent changes of course and speed. These conditions will affect the vessel's movements, which are dependent on the inherent stability of each. Stability can be defined as being the ability of a vessel to return to its original position after having undergone (transversely or longitudinally) a disturbance (wind, sea conditions, etc.). While vessel stability is essential to safety, boats must also be seaworthy and comfortable for the crew, in order to prevent injuries (TSB, 1998). Increasingly, fishers are attempting to lessen the impacts of movement of the work platform caused by the sea conditions during fishing operations, for safety, comfort and ease of execution. To this end, systems and equipment have been developed to reduce roll, i.e., the lateral rocking movements, and to a lesser extent, the longitudinal movements of the vessel, caused by sea conditions. Among the most common systems or equipment used are anti-roll tanks (also called flume tanks), bilge keels, paravanes, hinged fins and bulbous bows.

This study will concentrate on the most popular system used in Québec, paravanes, and an emerging system, hinged fins.[2] Both systems have been the subjects of Ship Safety Bulletins issued by Transport Canada.[3]

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[1] According to a December 13, 1999 International Labour Organization press release. Found at http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_071324/lang--en/index.htm. [Last consulted December 5, 2013].

[2] The description of technical terms is presented in Appendix 2.

[3] Bulletin no. 15/2000: *The use of roll damping paravane systems (paravane stabilizers)*, published November 20, 2000, and Bulletin no. 04/2010: *Fishing Vessel Safety: Hinged Fins as Anti-Roll Devices*, published May 17, 2010.

2. RISKS ASSOCIATED WITH FISHING ACTIVITIES IN QUÉBEC AND CANADA

In 2008, slightly more than **2800 fishers** and deckhands were fishing in the marine waters of Québec, on over **1000 boats**. Fishing activities are carried out inshore along the coasts or in mid-shore areas. The inshore fishery employs the highest number of fishers, and harvests a wide variety of fish, molluscs and crustaceans, including the entire lobster catch.

2.1 Frequency of Accidents

The risk of accidents in the fishing industry is high. In Canada, small fishing vessels have the highest rate of marine accidents. With more than 200 incidents reported to the Transportation Safety Board (TSB) every year, the problems associated with these incidents must be formally identified to "improve safety and reverse this tragic trend."[4]

In Canada, in each year from 2005 to 2009, 65 to 86 incidents, which put the lives of 16 to 37 people in danger, were reported to the Canadian Coast Guard (CCG). In 2009, the CCG intervened in 84 officially reported fishing incidents in Canadian waters. Of that number, nine were situations of distress, with 26 lives in danger and two fatalities. The two deaths occurred in Québec's coastal waters on a vessel with paravanes. For the four previous years, the 297 incidents recorded did not result in fatalities (Audet, 2010).

From 1998 to 2007, Transport Canada reported over 2370 accidents involving fishing boats, with 50 capsizings. In the same period, more than 86 people lost their lives, for an annual average of close to 10 Canadians (Pelletier, 2010). This information was provided by the TSB and the CCG.

In comparing the safety register of the fishing industry with registers from other industrial sectors, we can see that fishing continues to be the most dangerous activity by a significant margin. In 1995–1996, according to the Marine Accident Investigation Branch (MAIB) in the United Kingdom, there were 77 fatal injuries per 100,000 fishers, compared to 23.2 in the mining and wood processing (squaring) industries, the two other most dangerous sectors. Furthermore, out of the 1418 accidents and incidents occurring at sea in 1999 and reported overall in the United Kingdom, 641 of the cases were from the fishing sector (MAIB, 1999, cited by Pillay and Wang, 2003).

In Québec, in 2010, the contribution rate to Québec's compensation system for industrial accidents and occupational diseases from the fishing industry was almost four times higher than the average from other industrial sectors, according to statistics from Québec's workers' compensation board, the Commission de la santé et de la sécurité du travail (CSST, 2010). This rate is correlated with the assessment of risk level.

[4] According to a news release from the Transportation Safety Board of Canada, no. M03/2009.

2.2 Causes of Accidents

In most cases of fishing boat accidents, the information reported is incomplete or even absent. It is therefore difficult to assess the problems and the effectiveness of amelioration measures (Loughran et al., 2002, cited by Pillay and Wang, 2003). The data that we have show that human error, inadequate equipment and environmental conditions make the greatest contribution to compromising the safety of boats and crews.

Among the six main causes identified, capsizing is the deadliest. It is related to a lack of vessel stability while fishing or while navigating, specifically in bad weather. In the case of bad weather, the smallest fishing boats (under 12 m) are the most vulnerable.

3. STATE OF KNOWLEDGE

3.1 The Paravane Roll-damping System

In Québec's maritime regions, approximately two thirds of fishing boats equipped with a roll-damping system have adopted paravanes (Figure 1). That system consists of booms that protrude from each side of the vessel and paravanes (metal delta-shaped foils, sometimes weighing hundreds of kilograms) that, when immersed, provide vertical resistance in the water and increase the effectiveness of the roll-damping effect by approximately 45% (Sterling and Klaka, 2007).

Figure 1. Paravane roll-damping system

This system came into use at the beginning of the 1980s, on fiberglass vessels that had certain stability problems when they were light. It was developed and adapted by naval architects, built and installed on boats, then modified by captains on their own initiative. Since then, the booms have been lengthened, the paravanes have become larger and heavier and the support cables have been extended, enabling the paravanes to be sunk down deeper in the water, thus reducing the frequency of broaching.

The use of this system was the subject of a Ship Safety Bulletin (15/2000) issued by Transport Canada, which uses a precautionary approach in the absence of objective data on the inherent risks of this technology with respect to a given fishery.

First and foremost, the paravane system has many disadvantages and its use involves a number of risks:

- It adds topside weight, especially when it is not being deployed, which contributes to raising the centre of gravity of the boat and increasing the rolling motion.
- The safe operation of paravanes depends greatly on the speed of the boat and the

complementarity of their action to port and starboard, so that the righting moment caused by the downward force on one side is synchronized with the upward roll of the boat on the other side. The failure of a boom or the loss of a paravane would eliminate the synchronous and complementary operation of the system (TSB, 1998), meaning it would no longer be effective, and even dangerous.

- This system has many moving parts. As there is no standard that directly governs construction and installation, material fatigue of the components is not taken into account.
- There are other operational constraints related to this system (numerous attachment points, dependence on a hydraulic system, extension past the hull, variable and uncontrollable span and difficulties in estimating the depth of immersion of the paravanes).

In discussions with fishers, most of them express some fears about using this kind of system. However, comfort is important and the booms, with or without immersion of the paravanes, are deployed immediately after leaving port, even when the seas are calm. The consequence of this is wear and tear on the fittings and frequent knocking of the booms, leading to premature "mechanical fatigue."

Paravane roll-damping systems have caused serious injuries to crew members at various moments in their operation. Structural damage caused by paravanes can cause dangerous conditions (smashed wheelhouse windows, damage to the hull and deck), which could result in sinking.

3.2 The Hinged Fin Roll-damping System

Several years ago, a new roll-damping system was adapted from New Zealand: the hinged fin system (Figure 2). The system was introduced in Québec by Marinexpert Plus inc., located in the city of Gaspé, with the first vessels being equipped by Chantier Naval Forillon inc., a shipyard in the same area. Other manufacturing companies have entered the market since then. The number of vessels equipped with these systems shows a growth trend that could almost be qualified as exponential.

Relatively simple to use, the system requires only two hydraulic winches and two steel cables to move the fins and the two sliding arms. The fins are attached to hinges on each side of the hull at bilge level, in a position that enables maximum draught below the waterline of the vessel. They can be pulled up along the sides of the vessel when they are not being used, meaning that there is minimal encumbrance and the vessel returns to its original navigational condition.

Figure 2. Hinged fin roll-damping system

The sliding arm is attached to the end of the fin and holds it in place when it is deployed. Rigidity and stability are assured through the triangle formed by the side of the boat, the fin and the sliding arm.

Human intervention is limited to securing the latches. They are located so as not to disturb the operation of the fishing gear. The fins are always secured in such a way that they remain rigid. Therefore, no movement is possible, as there is for the paravanes, which are attached at the end of cables or chains, enabling them to broach and then to slam against the side of the vessel or to strike its occupants. The sliding arms and the fins always have a defined trajectory when being deployed or folded against the side of the vessel.

All the information gathered leads us to believe that these fins are as, if not more, effective in damping roll than paravanes. Given that, unlike paravanes, the two hinged fins act simultaneously to stabilize the roll, Helmore (2000) has calculated that, for an equivalent immersed surface, the roll reduction effect could theoretically be four times greater for Australian fishing boats. In addition, the fins appear to be safer, easier to use, and, according to Helmore (2000), cause less drag than paravanes. This observation corresponds with the comments gathered from the first fishers who equipped their boats with hinged fins. However, these advantages remain to be proven during manoeuvres at sea.

3.3 Safety Problems

In Québec, according to our own monitoring system, from 2003 to 2010, the period during which hinged fin systems were introduced, there were at least a dozen incidents/accidents involving boats equipped with paravanes, and a single case involving those equipped with hinged fins. The following are some examples gathered from fishers, which have been summerized and reformulated:

- A vessel capsized while underway with the paravanes up, killing two people.

- In bad weather, the starboard arm dipped in the water and the forestay fixture was ripped off the bow. When it entered the water, the arm tore off the gunwale and a paravane was lost. The vessel took on water, putting the crew in danger.
- A part of the system that had been modified and had deteriorated gave way in good weather. One of the paravanes went through a window of the wheelhouse, just missing the captain, who was at the controls.
- While manoeuvring over a string of traps in calm weather, a paravane came out of the water and struck the roof of the wheelhouse before falling back into the water. No major damage was caused, but it left the owner with a lot of questions.
- While unloading equipment, a crane struck one of the booms of a paravane system, cracking a weld. That incident raised questions about the system's design, because it showed that there was no reinforcement in strategic spots.
- A paravane punched a hole through the hull of a vessel, a foot above the waterline, into the engine compartment.
- A trawler had its mast broken off as a result of too much strain being put on it by the paravane system.
- While out fishing, underway with two loads of crab traps, a paravane suddenly emerged from the water, striking the vessel's bulwark, at less than 10 cm from the rail, while a man on deck was in its path.
- A boat was travelling towards the Magdalen Islands, full of crab, south of Anticosti Island, when the main support cable between the masthead and the starboard boom gave way, causing the latter to break. All the rigging was precariously towed back to port.

With respect to the hinged fin system, only one minor accident was reported, while the vessel was not at sea: a newly equipped vessel was docked, the weather was bad, and there was no adequate protection to keep the fin from rubbing against the wharf. This resulted in the welds on the fin supports failing and it appears that the hoisting cable was damaged.

4. RESEARCH OBJECTIVES

4.1 General Objective and Sub-objectives

The general objective of this research is to assess the hinged fin roll-damping system with respect to boat safety, crew comfort and performance (in terms of energy efficiency). The sub-objectives are as follows:

1. Inventory the roll-damping systems on mid-shore fishing vessels in operation in Québec.

2. Carry out a survey to measure the degree of satisfaction of fishers who use hinged fins as roll-damping systems, with regard to operation and safety.

3. Carry out comparative performance tests at sea on two identical crabbers equipped with two different roll-damping systems: one with paravanes and the other with hinged fins. As these two systems are currently the most commonly used on mid-shore fishing boats, this sub-objective could be qualified as major.

5. MATERIAL AND METHODOLOGY

5.1 Inventory of Roll-damping Systems

The first step taken was to inventory existing roll-damping systems in the mid-shore fishing fleets operating in Québec, paying specific attention to paravane and hinged fin systems.

To that end, various information sources were used: Transport Canada, Fisheries and Oceans Canada and the ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (vessel names, registration, type of fishing, etc.). In addition, in 2010, the team toured the main boat yards in the Québec maritime region (Newport, Sandy Beach, Rivière-au-Renard, Tourelle, Matane, Rimouski, Baie-Comeau, Sept-Îles, Havre-Saint-Pierre, Rivière-au-Tonnerre, and those on the Magdalen Islands).

5.2 Survey of Fishers

The second step was to meet with users of hinged fin roll-damping systems to discuss the main issues respecting operations and, above all, safety.

A detailed interview technique guide was developed specifically for boat operators who had gone through at least one fishing season with a hinged fin roll-damping system. All the interviews with the operators were carried out between December 2010 and February 2011. The goal was to describe the technical characteristics of the hinged fin systems installed on each boat. The interview guide also included a section (eight questions) on safety and comfort aboard the vessels, in which fishers were to express their level of satisfaction by responding to the following questions:

1. What is your general level of satisfaction with the hinged fin system compared to the paravane system?
2. Compared to paravanes, what is your assessment of the steps required to deploy hinged fins?
3. Is it easier to handle the boat during fishing operations with hinged fins than with the paravane system?
4. Are manoeuvres in port easier with hinged fins than with the paravane system?
5. Is it easier to handle a vessel underway at full speed with hinged fins than with the paravane system?
6. What is your general level of satisfaction with the hinged fin system compared to the paravane system in terms of fuel consumption?
7. Compared to the paravane system, does the use of the hinged fin system improve working conditions on board?
8. Following our discussion, do you still have the same general level of satisfaction with the hinged fin system compared to the paravane system?

A five-point classification was drawn up to obtain quantifiable data concerning the ease of operation and safety: (1) No effect; (2) Low; (3) Average; (4) Good; (5) Excellent. The technical specialist in the scientific team met with 16 fishers out of a possible 30 during the time alotted for this part of the research.

5.3 The Vessels

Two similar vessels, with the same equipment on deck and doing the same type of fishing, were selected for the sea trials. These vessels are crabbers designed by Mailloux Desgagnés and operating out of the Ste-Thérèse de Gaspé port. They were built by Chantier Naval Forillon inc., situated in the city of Gaspé, in 1994. They were both modified in 2004 by lengthening the hulls. Both have a 500-hp. Cummins motor with an MG 516 transmission. Their tonnage is identical: 73.87 gross tonnage and 55.40 net tonnage. The *Rudy L1* (RL) has had a hinged fin system since 2007, while the *Danie Martine* (DM) has a paravane system (Figure 3).

Figure 3. *Rudy L1* and *Danie Martine*

5.4 Sea Trials

The sea trials took place over two fishing seasons: 2009 and 2010. A preliminary experiment lasting five days at sea was carried out in the spring of the 2009 fishing season. It gave us an understanding of the variables present on commercial fishing boats (which were until then unknown), and enabled us to calibrate the instruments, fine-tune the experimental protocol and familiarize the fishers with the various measurement instruments. The analysis is based on data acquired on May 27, June 1 and June 3, 2010.

On a daily basis, the experimental program consisted of 21 15-minute trials (Table 1). The twin vessels followed similar and parallel courses. They sailed side-by-side at a distance estimated as between 150 to 200 metres, which meant that each could avoid the other's wake, while remaining in the same environmental conditions.

When leaving port at the start of the day, weather conditions were noted (wind velocity, direction and force, and wave height). Throughout the day, any changes were registered in the observation log. During the comparative trials, the data was recorded automatically by the measuring instruments.

One observer was on board each vessel to input data by hand. At the beginning of each trial and in the middle of it (t = 7.50 minutes), various observations were noted: wind direction and force, sea conditions (Beaufort scale), the vessel's course and speed. This manually recorded data helped corroborate whether the instruments were automatically recording valid data.

Throughout the days of sea trials, video footage and photos were taken to document each step in the deployment of the systems. In addition, any out-of-the ordinary event was filmed.

Table 1. Daily sampling plan of comparative sea trials

Trials	**Systems in vertical position (SV)**	**Systems semi-deployed (SSD)**	**Systems Immersed (SI)**
1	Stop		
2		Stop	
3			Stop
4	Headwind Half speed		
5	Crosswind Half speed		
6	Tailwind Half speed		
7	Headwind Full speed		
8	Crosswind Full speed		
9	Tailwind Full speed		
10		Headwind Half speed	
11		Crosswind Half speed	
12		Tailwind Half speed	
13		Headwind Full speed	
14		Crosswind Full speed	
15		Tailwind Full speed	
16			Headwind Half speed
17			Crosswind Half speed
18			Tailwind Half speed
19			Headwind Full speed
20			Crosswind Full speed
21			Tailwind Full speed

5.5 Experimental Conditions

The method consisted of comparing variables in vessel performance according to environmental factors (wind direction and force) and the factors set by the investigator (position of roll-damping systems, vessel speed and direction with respect to wind), on two crabbers with similar hulls and different roll-damping systems. The experimental conditions were as follows:

Weather conditions (wind speed)
- Calm weather, less than 10 knots (X)
- Temperate weather, 10 to 20 knots (Y)
- Stormy weather, 20 knots and over (Z)

Position of roll-damping systems
- Lifted, in vertical position (1)
- Booms only deployed, without immersion of the paravanes, or a single fin deployed and immersed (2)
- Deployed: paravanes in the water and two fins deployed (3)

Vessel speed
- Immobile (A)
- Moderate speed (6 knots) (B)
- High speed (9 to 10 knots) (C)

Boat direction with respect to prevailing wind
- Headwind (HW)
- Crosswind (CW)
- Tailwind (TW)

5.6 Measuring Instruments

Several instruments were used on both vessels to register the weather conditions in real-time, the lateral and longitudinal movements of the vessel, propulsion, vessel course and speed. OpDAQ Systems developed a specialized monitoring system for the project. This system, using OpDAQ Systems' data acquisition platform, simultaneously integrates measurements from the following four instruments:

- Xsens inertial motion sensor (Figure 4A), which records the vessel's movement through a three-dimensional coordinate system (Figure 5).
  Parameters measured: the angular position, the vessel's direction and its speed over ground using a GPS.

- R. M. Young Anemometer (Figure 4B)
  Parameters measured: speed and direction relative to the wind.

- Binsfeld torque meter
  Parameters measured: torque (couple) transmitted to the drive shaft.

- Speed indicator
  Parameter measured: rotation speed of the propeller shaft.

A. Inertial motion sensor, attached to the ceiling of the wheelhouse in each of the two crabbers

B. Anemometer

Figure 4. Instruments used to record data during the sea trials

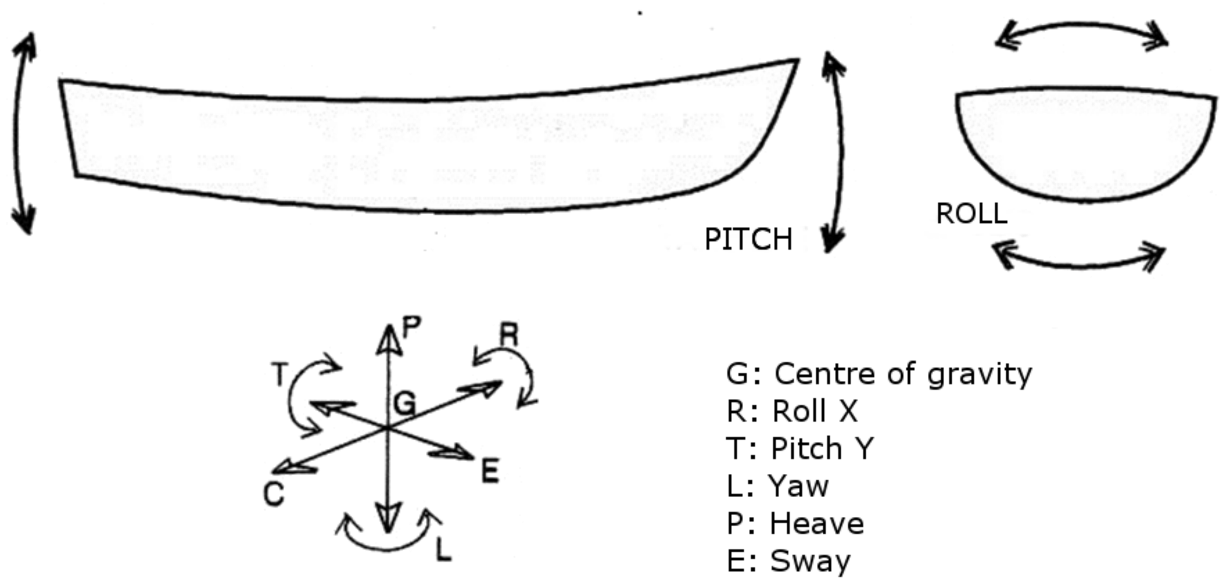

Figure 5. Vessel movement according to sea conditions

The data from these instruments was recorded in daily logs with a sample rate of 4 Hz. The data thus acquired were analyzed to assess the effectiveness and operational impact of the roll-reducing system on fishing vessels. OpDAQ Systems also developed analytical software for this data to produce simplified tables from which descriptive and quantitative analyses were performed.

All the measurement instruments described above were linked to each other to enable synchronic data acquisition. The variables retained for analysis were as follows: Roll (X) and pitch (Y) in terms of angle and acceleration, energy linked to the boat's propulsion (E), and speed over ground (SOG). Wind direction with respect to the vessel's course was noted by the observers and used afterward, because the data gathered from the anemometers was unreliable. Afterward, wind direction was corroborated by weather observations from Environment Canada's Cap d'Espoir station, situated nearby the experimental zone.

5.7 Data Analysis Methods

5.7.1 Signal Processing

The data for **movements** (traveling and angular acceleration while rolling [X] and pitching [Y]), gathered during each sea trial, were post-processed using the following two methods:

- The mean of 20 maximum values (max method)

  This method enabled us to assess the situations of extreme movement that caused the most discomfort for crews during a trial.

- Effective value (RMS [Root Mean Square] method)

> This method enabled us to consider all of the data from each trial and to assess the effect of the sea on the vessel's movement (4 recordings per second over a 15-minute period, for a total of 3600 pieces of data). It was used to validate the variation between extreme and general conditions. In wave physics, it can be applied to describe sinusoidal movements such as swell or waves.

Figure 6 presents the processing steps for the positional data used by the STAB analysis software, in-house software developed by OpDAQ Systems. The angular position signals were first processed with a Savitzky-Golay [S-G]-type filter to eliminate noise contained in the signal.[5] With this method we were able to smooth the data to accentuate the dominant signal profile using polynomial regression. The main advantage of this approach is that it tends to preserve the distribution traits, analyzed as relative maxima and minima, and the size of peaks, which are usually flattened by other simple filtration techniques, such as moving averages.

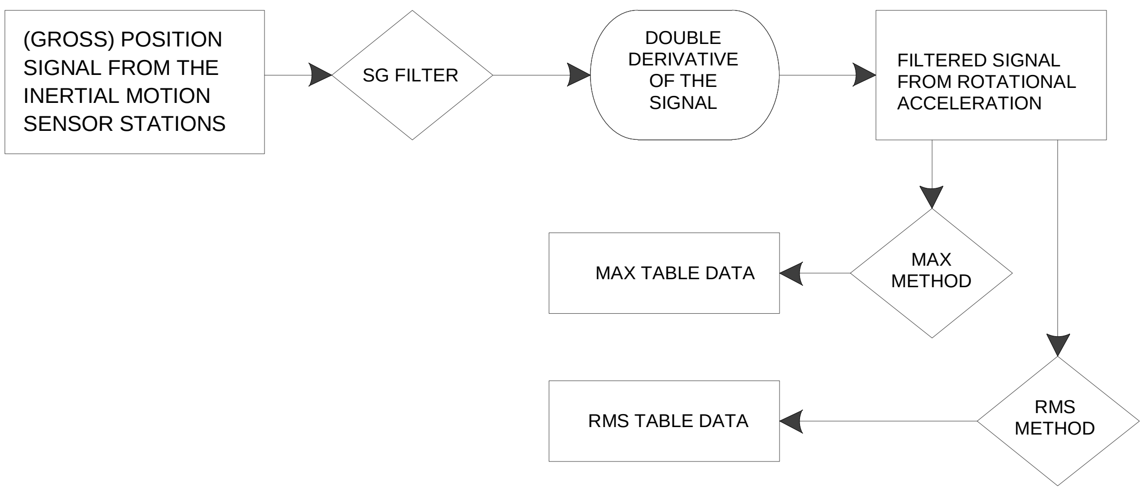

Figure 6. Steps in processing position data gathered during sea trials

In the case of the max analysis, the adjustment was made with a 19-point window, which is adequate for smoothing the signal formed by a succession of peaks based on the selection of maximal values of the angular positions, recorded by the inertial motion sensor. With the RMS method, smoothing was done with a more permissive 5-point window, because the angular position data had been transformed (Root Mean Square).

To obtain angular acceleration values (degree/sec^2), a double derivative was calculated for the angular position signals (Figure 6). These are the values, along those for the angular position, that were used to produce the data tables for statistical analysis.

The data respecting **energy consumption** were processed by calculating the total energy required to carry out the transit time of the trial. The transit time was defined as how far the vessel traveled for 15 minutes in a given direction. Given that the energy consumed is calculated

[5] http://en.wikipedia.org/wiki/Savitzky%E2%80%93Golay_smoothing_filter, [Last consulted February 3, 2013].

as the product of instantaneous power and time, we calculate the energy consumed per interval by multiplying mean power by time. Power at the shaft was obtained by combining the values measured by the torque indicator and the speed indicator using the following formula:

$$P = \tau * \omega$$

Where:

P: Shaft power (Watts)
τ: Torque at the shaft (Newton * metre)
ω: Angular velocity of the shaft (radians/second)

Note: Conversion factor of turns/minute to radians/second: 2π/60

The energy used is directly proportional to the fuel consumption per transit according to the following equation:

$$\text{Energy} = \int_{t=0}^{15\,min} P * dt$$

5.7.2 Statistical Analysis of Data

Both the RMS and max data regarding angular position and acceleration had their means and their standard deviations established for the three days and the 21 navigation and roll-reduction system deployment conditions on the *Danie Martine* and the *Rudy L1*.

The series were transcribed two by two (*Danie Martine* vs *Rudy L1*) on Cartesian coordinate graphs, in which the navigation and deployment conditions were illustrated to show which vessel had the advantage for a given combination of parameters, using the *Danie Martine* as the baseline (figures 9 to 16).

Afterward, a statistical comparison of the amplitude and acceleration of movement of both vessels while underway, with their respective roll-damping systems immersed (trials 16 to 21), was carried out, as it was the condition that appeared to be the most important in the eyes of the fishers, the manufacturers and the regulatory bodies (Table 2).

Table 2. List of variables (8) for which statistical comparisons were carried out between the *Danie Martine* and the *Rudy L1*

Variable	Roll (axis X)		Pitch (axis Y)	
Amplitude	RMS	MAX	RMS	MAX
Rotational acceleration	RMS	MAX	RMS	MAX

A Kolmogorov-Smirnov test ($p \geq 0.20$; d.o.f.=16) was used to verify the normality of the continuous distributions of the mean values that were obtained for each variable. If the response was positive, an F test was used to verify the homogeneity of variances. If such was the case, a

Student's *t*-test was applied to the matched data for each of the six navigation conditions, to determine whether the set of means differed significantly. Otherwise, an equivalent nonparametric test, the Wilcoxon test, was used. All these tests were carried out using WinSTAT software for Excel spreadsheets. The significance threshold accepted for all the tests was 0.05.

A different approach was adopted to compare energy consumption between the *Danie Martine* and the *Rudy L1*. First, the speed of both vessels was compared side-by-side for all of the trials. If the difference in speed was less than 0.2 knots, it was considered equivalent. The energy consumption values obtained using the previously described method (section 5.7.1) are presented in Table 4.

A relative difference of less than 10% was considered equivalent, although there was a clear advantage for one or the other of the vessels if the reduction in energy consumption was equal to or more than 10%. Three tones from grey to black were used to illustrate the conditions in which one vessel had the advantage:

- Light grey = equivalent;
- Mid-grey = advantage in favour of the Danie Martine, with paravanes;
- Black = advantage in favour of the Rudy L1, with hinged fins.

6. RESULTS

6.1 Inventory of the Fleet and Roll-damping Equipment

In 2010, the total number of fishing boats of more than 15 gross tonnage was estimated at 292 (Figure 7). Trap setters, mainly used for fishing snow crab, represented over 44% of boats in that category. They were followed by multipurpose fishing boats (26%), used for more than one type of fishing, such as for bottom fish like Greenland halibut. Next were trawlers, representing 24%, which are mainly shrimp fishing boats. Scallop draggers bring up the rear, with 6% of all fishing boats of more than 15 gross tonnage.

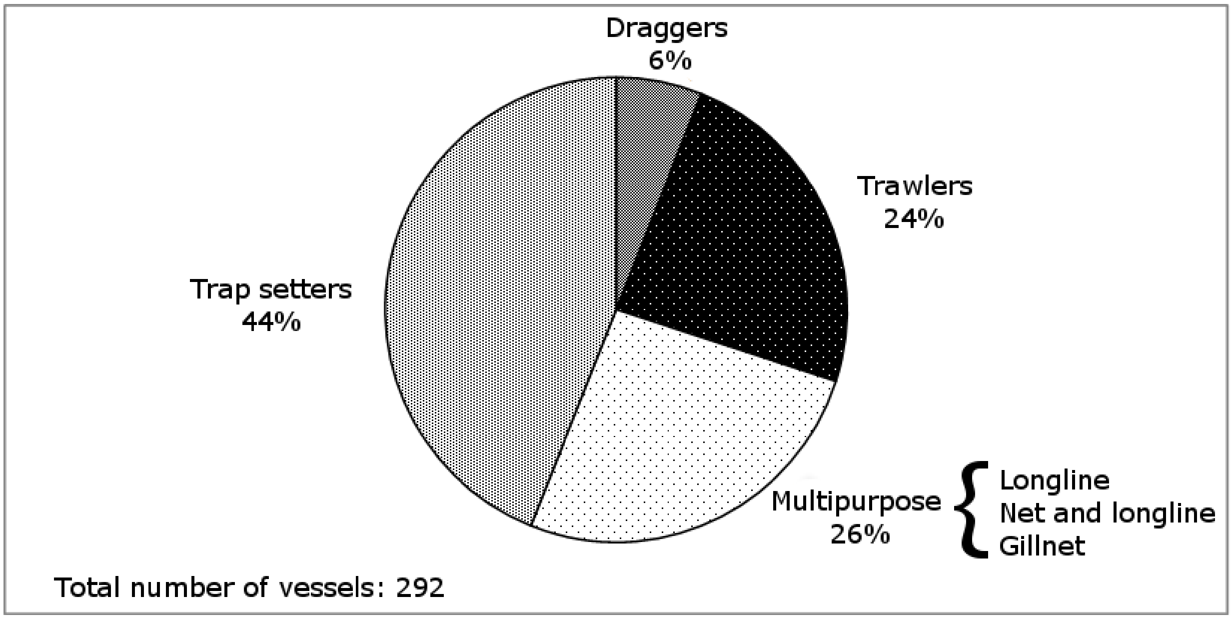

Figure 7. Relative distribution of the various maritime commercial fishing fleets in Québec (over 15 gross tonnage), 2010.

Of these 292 vessels, almost two thirds were equipped with at least one roll-damping system, while the rest had no such system (Figure 8). Half the fleet were equipped with paravanes. Vessels equipped with hinged fins came in second place, with 11% of boats in the fleet, even though their appearance is relatively recent. Bilge keels, an older technology, were installed on 9% of vessels of over 15 gross tonnes. Fishing boats with winglets or flume tanks were much more rare, making up, respectively, 2% and 1% of boats in this category.

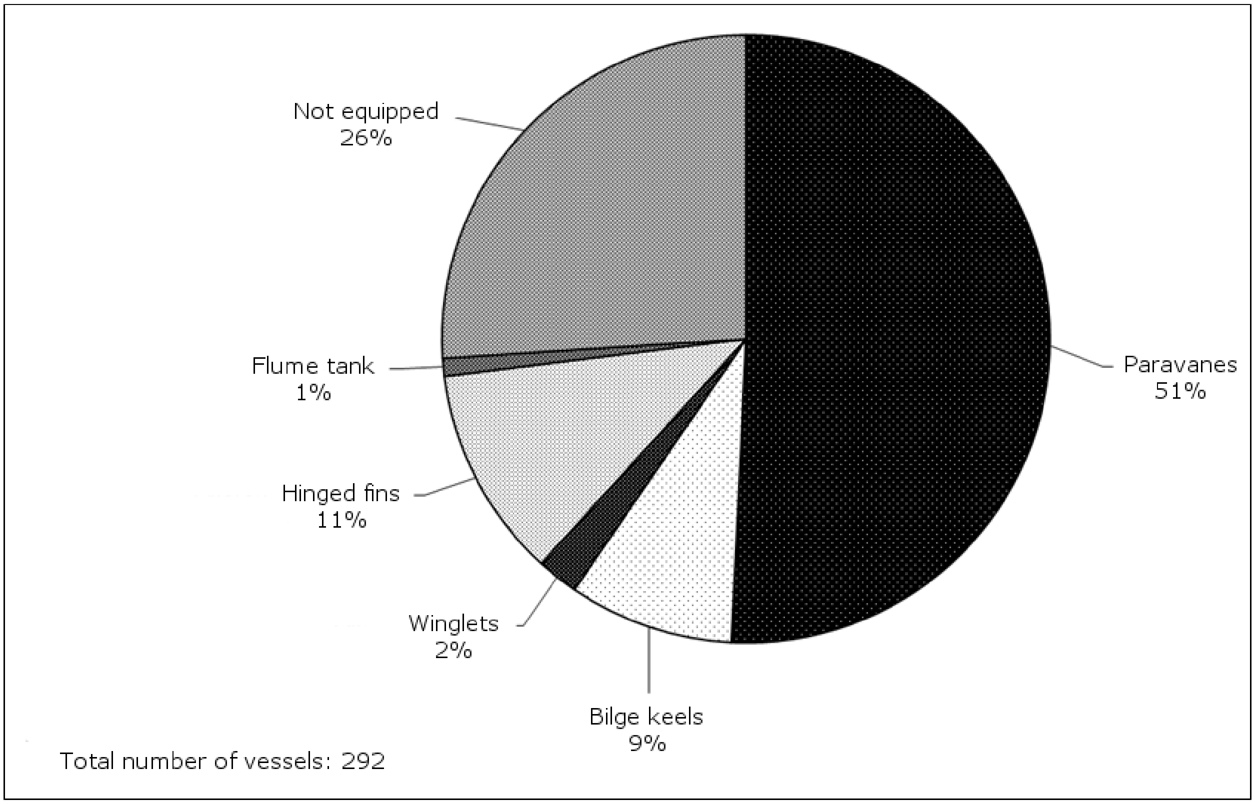

Figure 8. Distribution of roll-damping systems in the commercial marine fishing fleet in Québec, 2010

This general portrait becomes more nuanced when the distribution of roll-damping systems according to type of fishing fleet is examined. Appendices 1 to 4 present the distribution of roll-damping systems for trap setters, multipurpose vessels, trawlers and draggers.

With respect to the inventory, we did not feel it was necessary to analyze the results in detail, because there is no scientific hypothesis to explain the distribution of the various roll-damping systems in the fleet. It is our intent to present the relative significance of fleets by fishery, and subsequently, the distribution of the main roll-damping systems used among them all, and by fleet. The diversity of vessel types is implicitly related to the characteristics of the fisheries concerned (locations, season, distance from the coast, resource management, economic returns, etc.).

The dominance of the paravane system can be explained by the simple fact that, as previously stated, they were introduced in Québec in the 1980s, while hinged fins only appeared in the middle of the 2000–2010 decade, when they were introduced by the Forillon shipyard. Before then, fishers here were unaware of the system's existence.

In the 1980s, because they were aware that bilge keels only reduced roll by 20%, Québec fishers were seeking a better system to improve comfort at sea, which is how the emergence of and increase in the numbers of boats equipped with paravanes came about. Paravanes were recognized as being more efficient, with a roll reduction rate of 45% (Sterling et Klaka, 2007).

6.2 Assessment of Degree of Satisfaction Experienced by Fishers on Vessels Equipped with Hinged Fins

The degree of satisfaction experienced by fishers on vessels equipped with hinged fins is presented in Table 3. For all the subjects discussed, except energy consumption, fishers rated the system as good to excellent. In terms of energy consumption, with respect to their vessels equipped with hinged fins, three fishers stated that their degree of satisfaction was average to nil. A quarter of the fishers assessed their level of satisfaction as good, while half of them qualified it as excellent.

We note that general satisfaction was higher at the beginning of the interview (question 1), when 11 out of 16 fishers qualified it as excellent. However, by the end of the interview (question 8), after thinking about the questions in between, 3 of these 11 fishers scaled back their level of general satisfaction to "good."

Table 3. Assessment of degree of satisfaction experienced by fishers on vessels equipped with hinged fins (questions presented according to their order in the interview)

	Degree of satisfaction				
	Nil	**Low**	**Average**	**Good**	**Excellent**
General Satisfaction (beginning)			1	4	11
Ease of positioning				1	14
Manœuvres while fishing				3	13
Manœuvres in port			2	4	10
Manœuvres when underway				3	13
Fuel consumption	1	1	1	4	8
Improvement in working conditions				4	12
General satisfaction (end)		1		7	8

In support of these figures, we present some of the most significative comments made by the captains/operators interviewed:

- "The vessel reacts better at the wheel, it responds rapidly while tacking, and heels less (manœuvres while underway)." *Captain of boat no. 1*
- "I find the paravanes are more efficient in certain conditions, but I wouldn't go back to them." *Captain of boat no. 2*
- "On the other hand, they're much easier and safer to deploy than paravanes." *Captain of boat no. 3*
- "The fins reduce the vessel's speed less than paravanes." *Captain of boat no. 3*

- "You can work with only one fin deployed." *Captain of boat no. 3*
- "I'm thinking of replacing the guide rails with fixed bar linkages, because they're supposed to be easier to operate." *Captain of boat no. 10*
- "The addition of this roll-limiting system is appreciated, the lateral movements of the vessel are slower, the vessel is very stable, it rights itself quickly, the fins have decreased the roll, so it's more comfortable." *Captain of boat no. 11*
- "The vessel is more difficult to steer in following seas, when setting the longline. Thanks to the stability afforded by the fins, she's faster, we usually have to check her by putting the gears in reverse to slow her down." *Captain of boat no. 12*
- "The vessel's speed has dropped by 2.5 knots more than with the paravanes, and even when they're up, speed is reduced." *Captain of boat no. 13*
- "I estimate my loss of speed at less than 1 knot with the fins, much less than with the paravanes." *Captain of boat no. 14*
- "For me, I had no choice but to get rid of of the paravane system. I did appreciate it, but I always found it dangerous; and it was after one of those incidents that I decided to change it." *Captain of boat no. 15*
- "A simpler system, no top-heaviness." *Captain of boat no. 15*
- In light condition, the vessel gets some spray. *Captain of boat no. 16*

6.3 Experimental Assessment of Performances at Sea of the *Rudy L1* (hinged fins) and the *Danie Martine* (paravanes)

6.3.1 Effect on Roll

Roll Amplitude

The roll amplitude, derived from the RMS method, varies from 1 to 6 degrees for the 21 conditions tested at sea (Figure 9). For the *Rudy L1*, the angles are consistently greater than those recorded for the *Danie Martine*, with a difference of 2 to 4 degrees. When the *Rudy L1* and the *Danie Martine* are moving with their roll damping systems immersed, the statistical comparison (test *t* on matched data, trials 16 to 21) shows that this difference is highly significant (N= 17; $p=0.0000$).

On board the *Rudy L1*, roll amplitude becomes more pronounced when a single fin is immersed (trials 10 to 15), especially at full speed. If the hinged fins are in vertical position, lifted alongside the vessel (trials 4 to 9), the angles recorded have intermediate values. The pattern of roll angles recorded by the *Danie Martine* is about the same as those for the *Rudy L1*. The exception is the series of trials (10 to 16) in which the booms were deployed symmetrically from either side of the boat, without the paravanes in the water. In that case, the angle values remained comparable to those observed when the paravanes were immersed (trials 16 to 21). Finally, when drifting, the effect of immersing the roll damping systems is obvious, especially for the *Rudy L1*, for which the mean roll amplitude went from 5.5 to 3.8 degrees, a relative decrease of approximately 40%, while the deployment of a single fin reduced the amplitude of the movement to 4.7 degrees, or about 17%.

The roll amplitude, derived from the max method, is *de facto* greater than that obtained with the RMS method (Figure 10). The distribution of points on the graph is comparable to that of the RMS method, with a few exceptions. Nevertheless, those angles are 2 to 3 times greater than the preceding, most often varying from 4 to 12 degrees. When the *Rudy L1* deploys its hinged fins at full speed (trials 19 to 21), the roll amplitude values are lowest (6 to 8 degrees, according to wind direction) and tend to be closer to those recorded on the *Danie Martine* with the paravanes immersed. The values observed on the *Rudy L1* are even sometimes less (trial 17). However, the difference, generally in favour of the *Danie Martine*, is very significant (matched test t: N=17; $p=0,0000$). While drifting, the effect of deploying these two systems is analogous to what is observed using the RMS method, while the extreme roll values are significantly reduced.

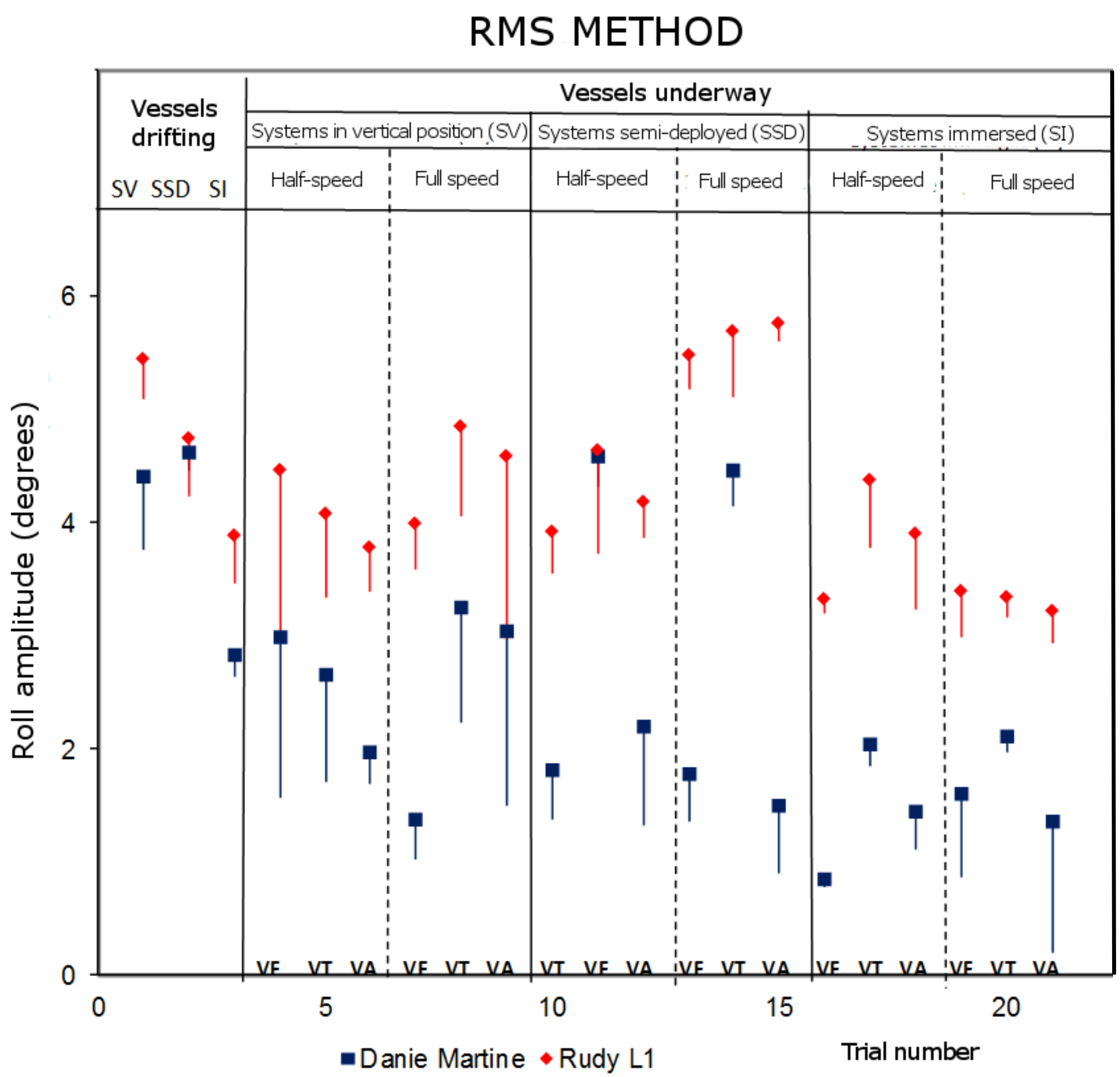

Figure 9. Comparison of roll amplitude between the *Danie Martine* and the *Rudy L1*, using the RMS method

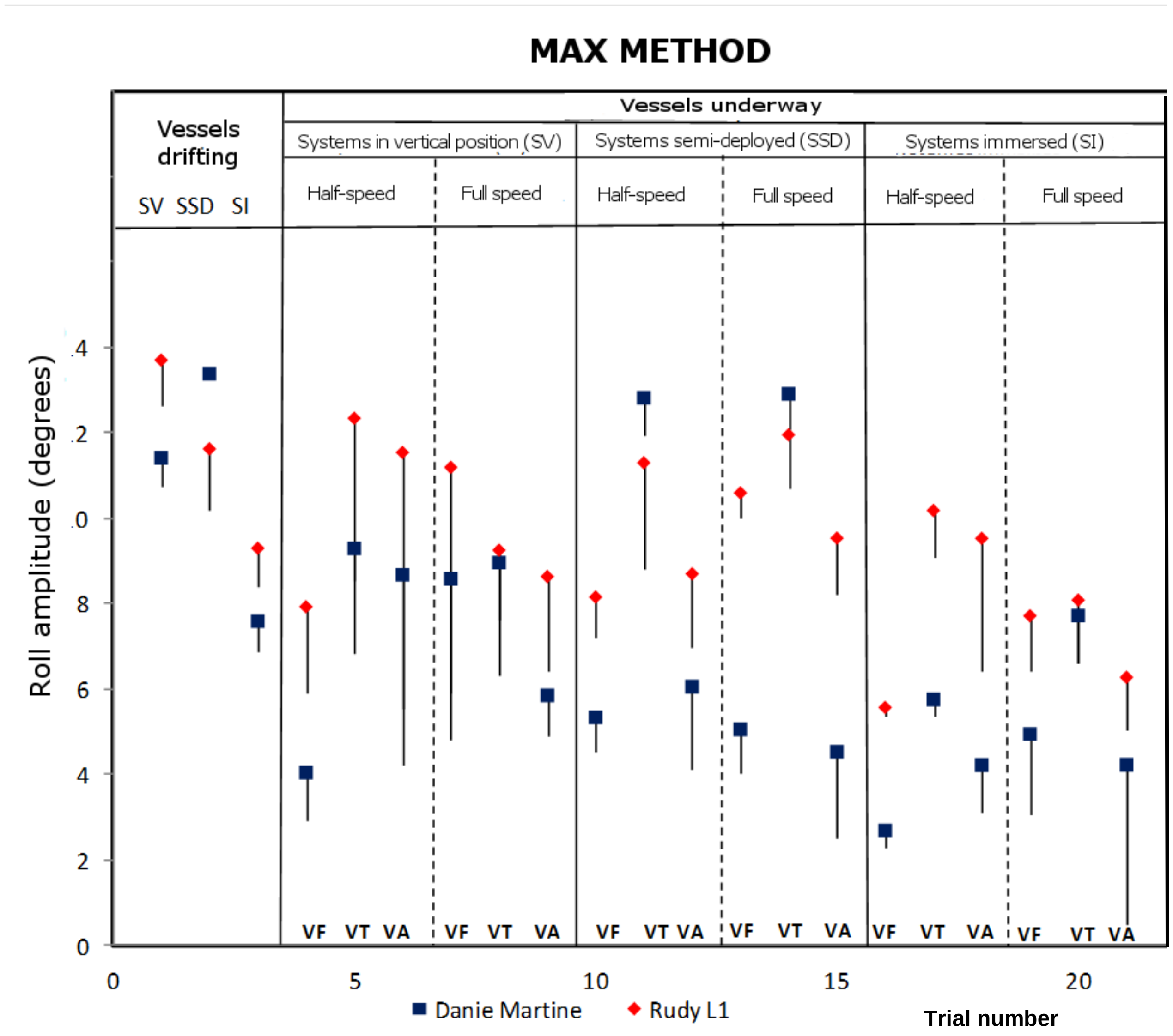

Figure 10. Comparison of roll amplitude between the *Danie Martine* and the *Rudy L1*, using the max method

Angular Acceleration in Roll

With respect to angular acceleration in roll (acceleration around axis X), according to the RMS method, the general picture is more varied (Figure 11). When the roll damping systems are positioned vertically or are semi-deployed (trials 4 to 15), we observe a random alternation in the values observed for the two vessels.

In addition, as for roll amplitude, the mean values are lower when the vessels are moving with their roll damping systems deployed (trials 16 to 21). Under these conditions, the accelerations observed on the *Rudy L1* tend to approach those of the *Danie Martine*. They remain greater, although the difference between them lessens (matched test t: N=17; $p=0.003$), especially at full speed.

With the max method, we see that angular acceleration in roll does not follow a defined pattern, with the values of the *Rudy L1* sometimes greater than those of the *Danie Martine* and vice versa, under all deployment conditions tested (Figure 12). When the vessels move with their roll damping systems immersed, the accelerations recorded are more or less the same as those obtained under other conditions of deployment.

Statistically speaking, the difference between the two vessels is significant (matched test t: N=17; $p=0.001$), with the data coming from two randomly different statistical populations. As with the RMS method, the test indicates that the accelerations measured on the *Rudy L1* are greater than those of the *Danie Martine*, for most of the trials, with a decrease in the standard deviation at full speed.

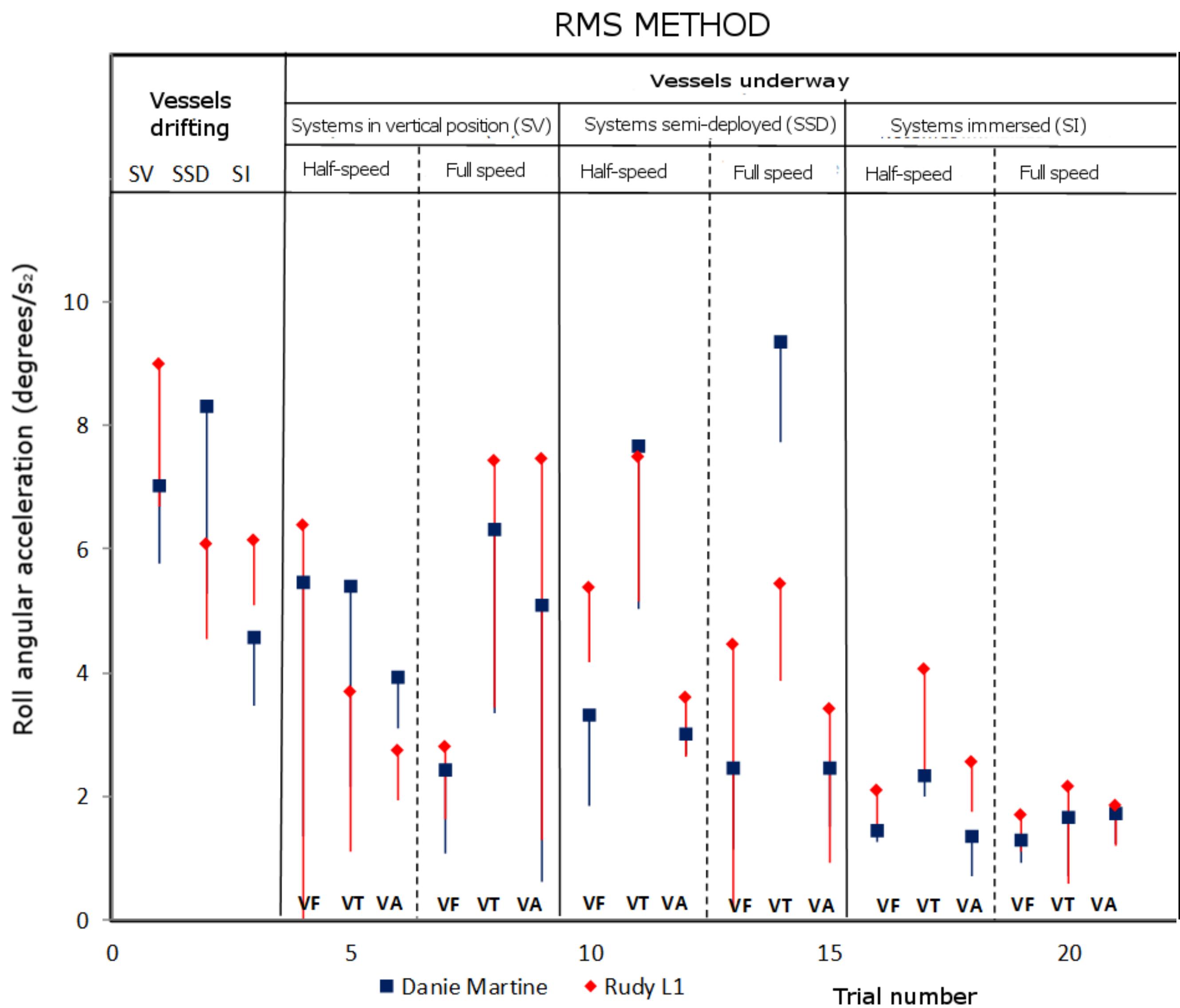

Figure 11. Comparison of angular acceleration in roll between the *Danie Martine* and the *Rudy L1*, using the RMS method

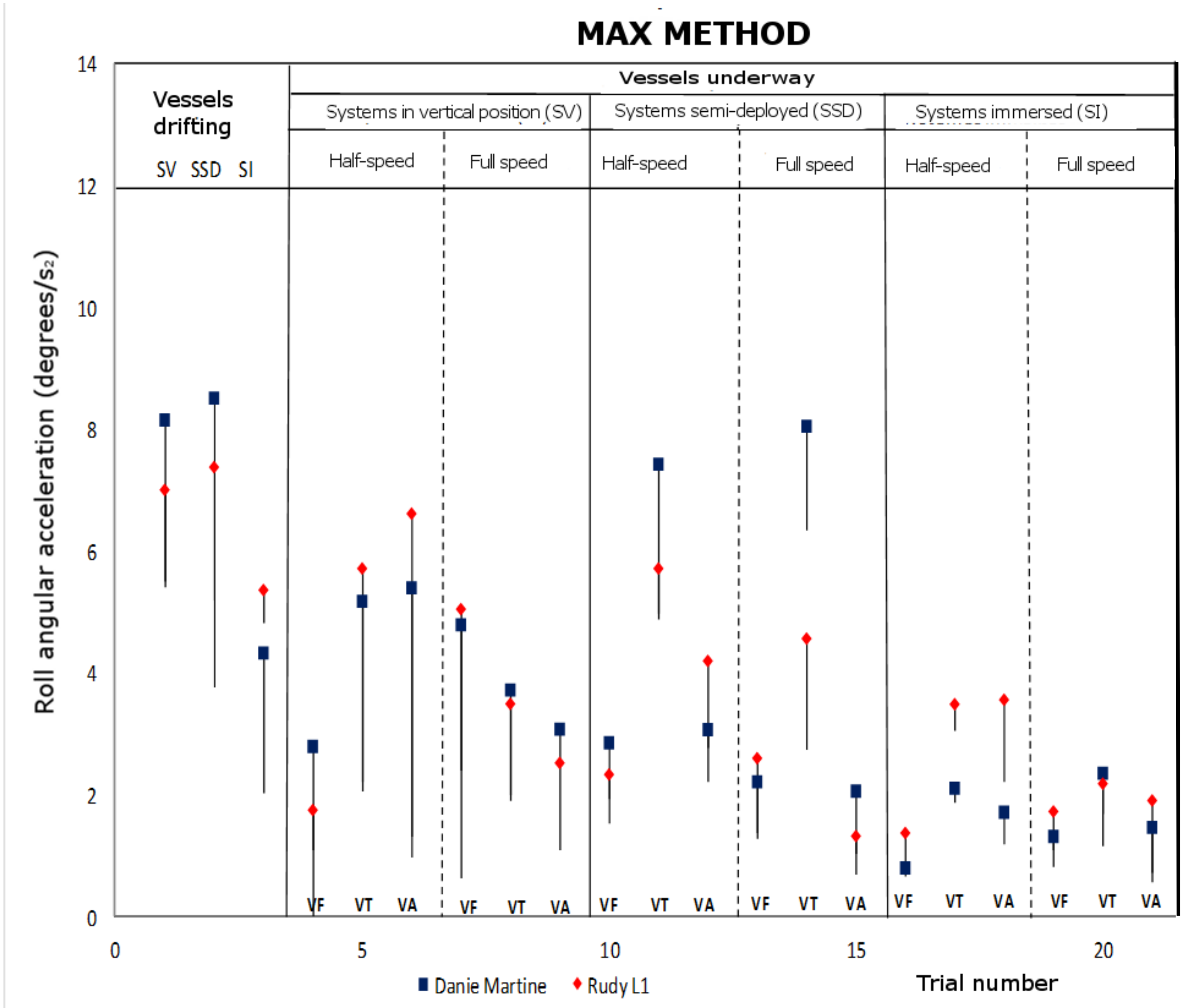

Figure 12. Comparison of angular acceleration in roll between the *Danie Martine* and the *Rudy L1*, using the max method

6.3.2 Effect on Pitch

Pitching Amplitude

The RMS method shows that the data derived for the pitching amplitude are positioned along a more reduced scale than that calculated for the roll of the two boats (Figure 13). The minimal values are situated around 1 degree, while the maximal values are on the order of 2.5 degrees. There is less pitching when the vessels are drifting or navigating at half speed and the roll damping systems are not fully deployed. When the vessels are moving with their systems immersed, the pitching amplitude measured on the *Rudy L1* is greater than that on the *Danie Martine*. The mean difference seems low, but it is nonetheless significantly greater (matched test t: N=17; $p=0.0028$).

Using the max method, the values calculated are greater and more or less uniform from one navigation condition to another (Figure 14). The maximum angles vary from 3 to 5 degrees, with one exception (trial 10). In general, pitching on the *Rudy L1* is greater than on the *Danie Martine*. When the systems are immersed, the values observed are significantly higher (matched test t: N=17; $p=0.0078$), but the two series of values tend to be close.

Angular Acceleration in Pitch

Using the RMS method, angular acceleration in pitch (acceleration around the Y axis) shows a situation as varied as that for roll, without a well-defined pattern (Figure 15). Depending on the navigation conditions, the *Rudy L1* is stiffer than the *Danie Martine*. Immersion of the roll damping systems when the vessels are in movement does not reduce the mean acceleration values by much. Statistically, the analysis reveals that there is no difference for angular acceleration in pitch (matched test t: N=17; $p=0.443$), whether the vessels are sailing at half or full speed.

The max method (Figure 16) shows that acceleration follows an equally variable pattern, depending on the navigation conditions of both vessels. When they are moving, the accelerations observed on the *Rudy L1* at half speed are superior to those observed on the *Danie Martine*. At full speed, the opposite is true, although that observation was not confirmed by statistical tests (Wilcoxon test: N=17; $p=0.169$).

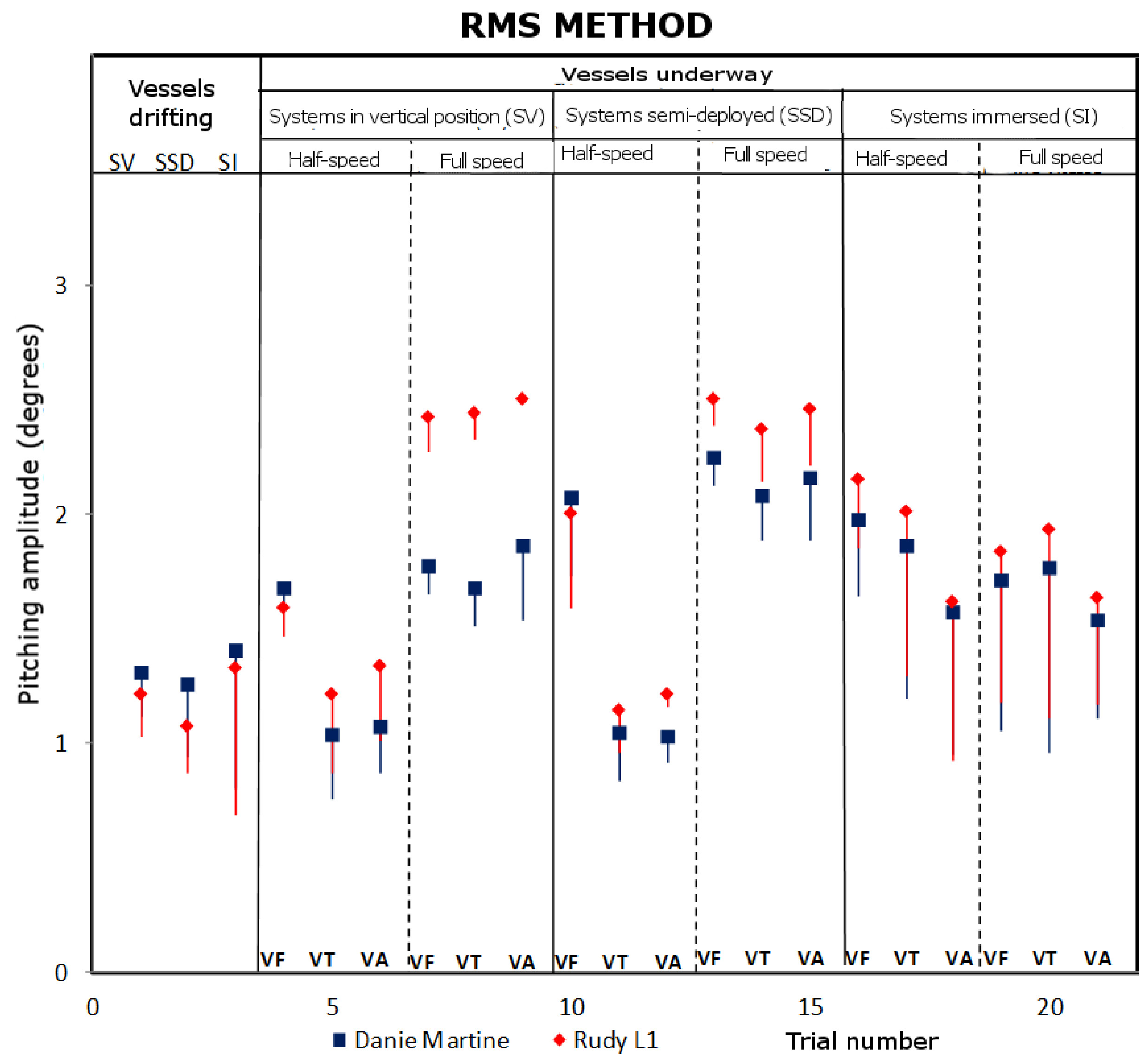

Figure 13. Comparison of pitching amplitude between the *Danie Martine* and the *Rudy L1*, using the RMS method

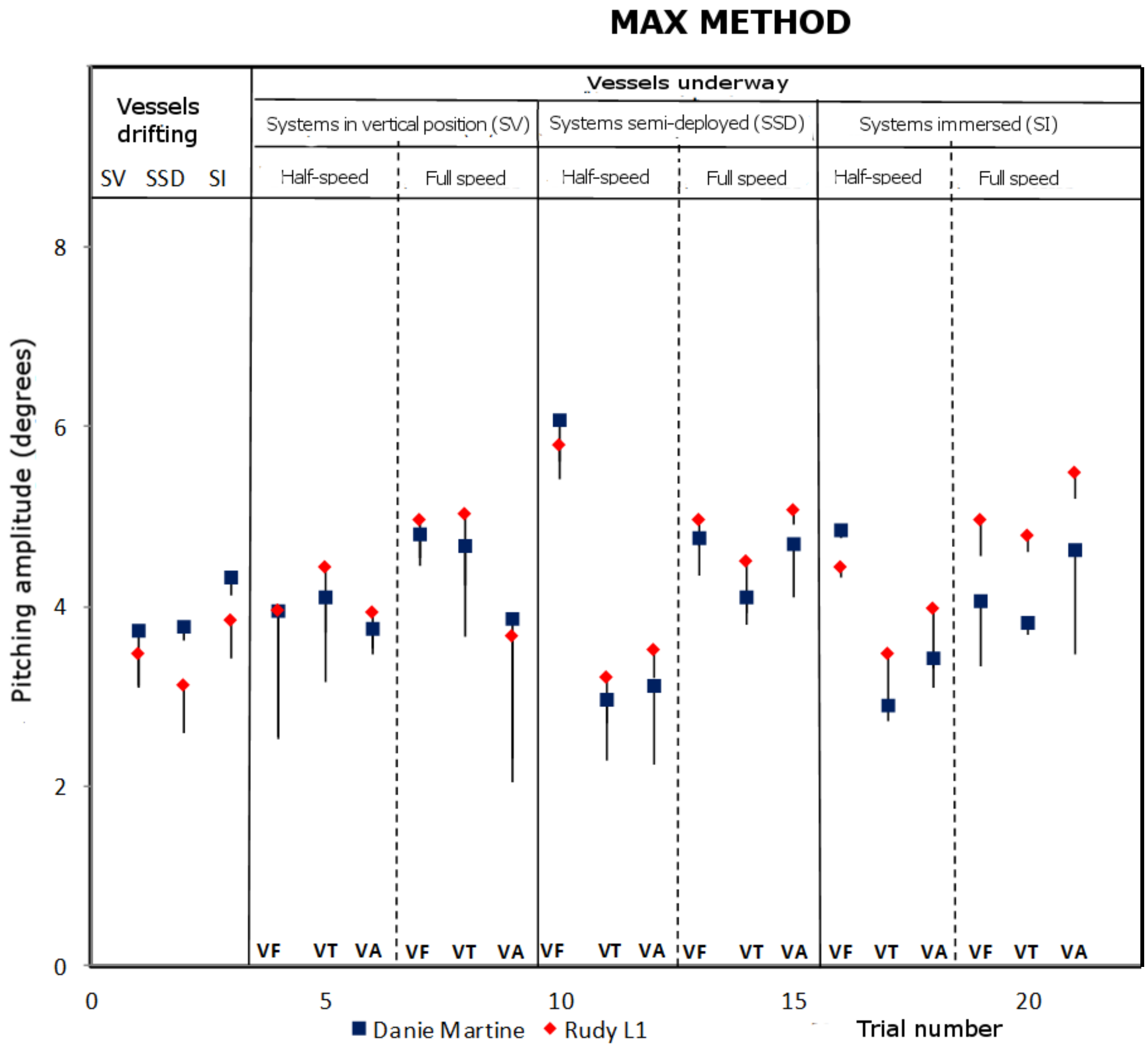

Figure 14. Comparison of pitching amplitude between the *Danie Martine* and the *Rudy L1*, using the max method

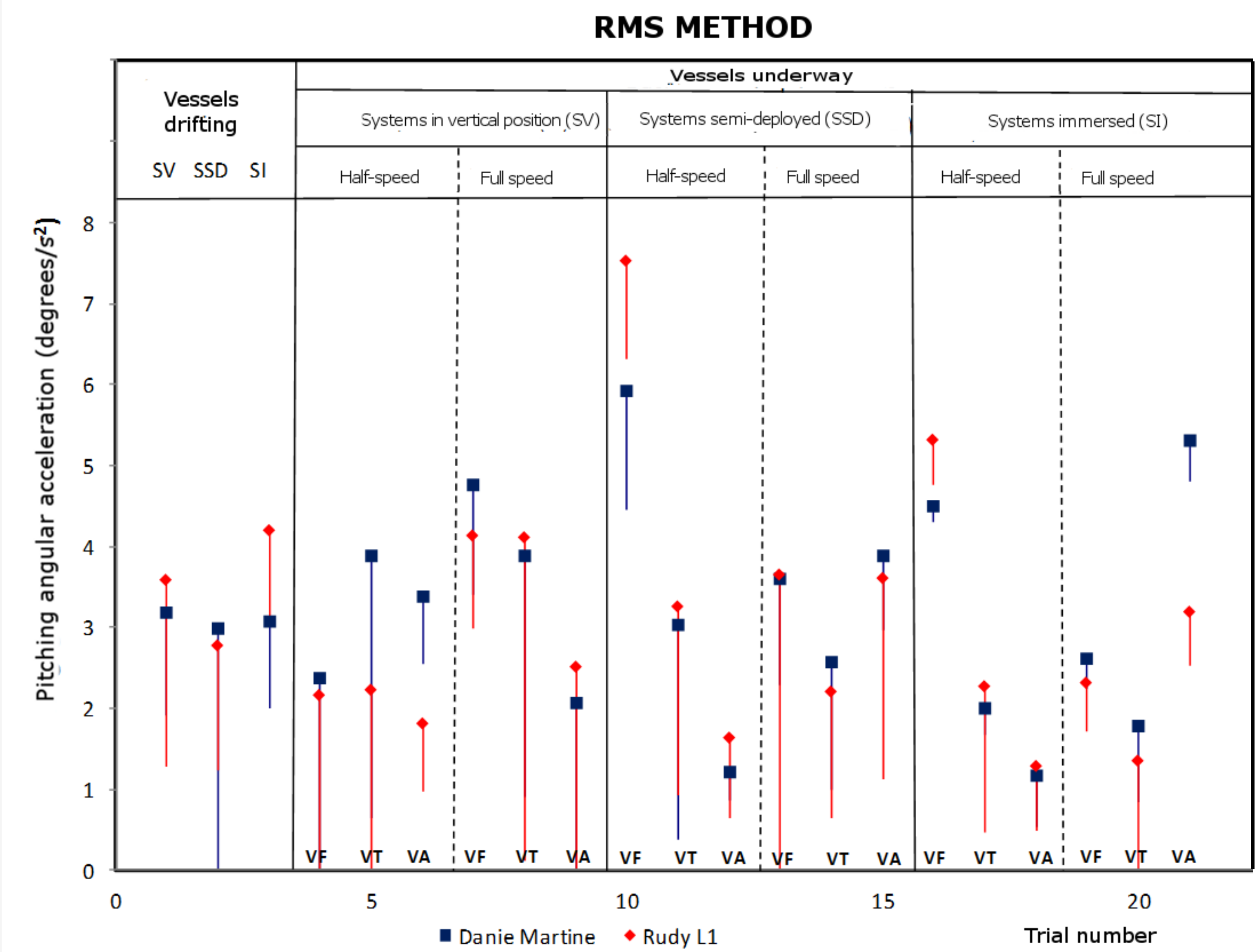

Figure 15. Comparison of angular acceleration in pitch between the *Danie Martine* and the *Rudy L1*, using the RMS method

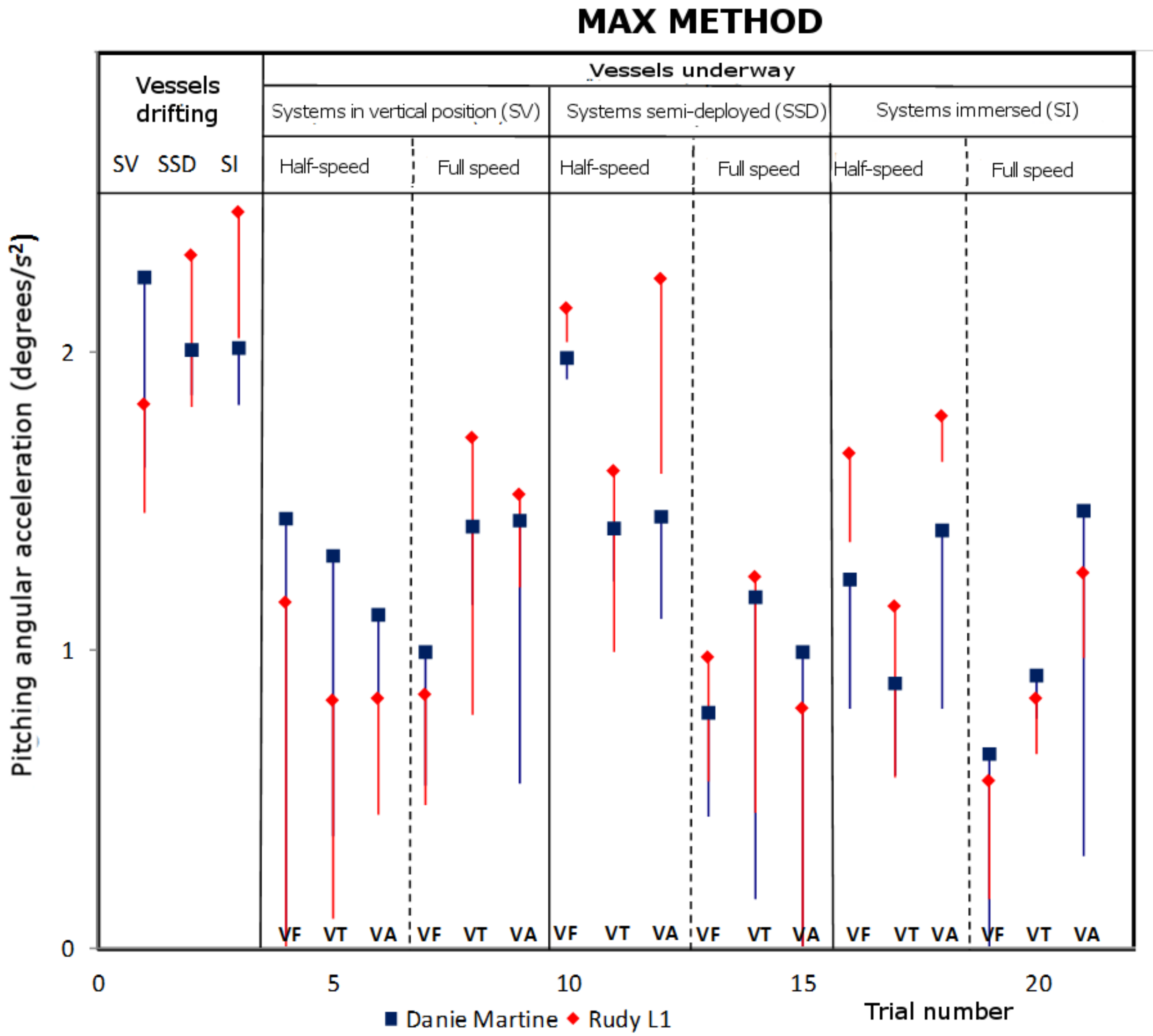

Figure 16. Comparison of angular acceleration in pitch between the *Danie Martine* and the *Rudy L1*, using the max method

6.3.3 Energy Consumption

In terms of the energy consumption required for propulsion (Table 4), we note that the *Danie Martine* has the advantage when the two types of roll-damping systems are raised or partially deployed, at both half and full speed. However, when the two crabbers navigate at half speed, with their roll-damping systems deployed, the *Rudy L1* has the advantage. When the boats reach full speed, their energy consumption is equivalent.

Table 4. Summary of the comparative analysis of energy consumption

Navigation Conditions			Energy Consumption		
Position of roll-damping system	**Vessel speed**	**Wind direction**	**Day 1 (May 27)**	**Day 2 (June 1)**	**Day 3 (June 3)**
SV	Adrift				
SSD					
SI					
SV	Half-speed	TW			
		HW			
		CW			
SSD		TW			
		HW			
		CW			
SI		TW			
		HW			
		CW			
SV	Full speed	TW			
		HW			
		CW			
SSD		TW			
		HW			
		CW			
SI		TW			
		HW			
		CW	n.a.		

Systems in vertical position (SV) Systems semi-deployed (SSD) Systems immersed (SI)
TW: Tailwind HW: Headwind CW: Crosswind (starboard or port)

Advantage for hinged fins – *Rudy L1* (> 10% reduction)
The same for both systems (± 10%)
Advantage for paravanes – *Danie Martine* (> 10% reduction)

7. DISCUSSION

There appears to be a trend for the paravane roll-damping system, by far the most widely used system in Québec in the commercial fishing fleets of more than 15 gross tonnage, to be replaced with hinged fins. The number of boats equipped with the latter is constantly rising, going from 20 units in 2009 to 30 by the end of October 2010.

A survey carried out with about half of the boat owners who have switched to the hinged fin system and informal exchanges between the research team and other fishers and staff from the industries that manufacture these systems reveal the popularity of that technology.

While the safety level of the hinged fin roll-damping system has not yet been assessed, fishers appear convinced of the advantages of the system in terms of safety and ease of operation at a reasonable cost. Initially, some fishers who operated fishing boats with the paravane roll-reduction system had reserves about the energy consumption performance of the hinged fin system. According to the interviews, this concern appears to be baseless, given that 12 operators out of 15 indicated a degree of satisfaction of "good" or "excellent" with respect to that issue.

7.1 Influence on Vessel Movements

7.1.1 Roll

Through the experimental phase of observation at sea on the *Rudy L1*, we were able to see that average roll angles were generally greater than those on the *Danie Martine*. Nevertheless, for all weather conditions experienced during the trials at sea, the roll amplitude of the *Rudy L1* remained within the safe values expressed in the literature (Fairlie-Clarke, 1980; cited by Molland, 2008), i.e., 4 to 5 degrees for small boats.

This disadvantage was more pronounced when a single fin was immersed (for the *Rudy L1*), compared to semi-deployed booms (for the *Danie Martine*). Through their symmetry, the booms partially increase the overall width of the *Danie Martine*, thus giving it an advantage in terms of reducing roll amplitude. According to our observations on board the crabbers during the 2010 fishing season and from the comments of fishers who participated in our survey, we know that having a single fin in the water is now a rare occurrence. In addition, the roll amplitude of the *Rudy L1*, with hinged fins immersed and the boat traveling at full speed, approaches that measured aboard the *Danie Martine*.

The sometimes greater angular acceleration observed on the *Rudy L1* means that the roll period is shorter and the righting movement is stiffer, especially under deteriorating sea conditions. This is an advantage with respect to boat safety. Many people also find that a prolonged roll, such as that experienced on the *Danie Martine*, is more uncomfortable (Molland, 2008). Nevertheless, abrupt accelerations are more difficult to anticipate, and therefore are more destabilizing for the crew.

Once again, we saw that the difference in oscillation speeds observed between the two boats tends to disappear when the *Rudy L1* has both fins immersed and is steaming at full speed.

According to our experimental plan, it is impossible to predict whether these speeds, in addition to the roll amplitude, reach a threshold that could lead to postural changes that could cause the crew to lose their balance (Kimura et al., 1989; Akinturk et al., 2006).

7.1.2 Pitch

With respect to pitching (the alternating rising and falling movement of the vessel's bow and stern), the recordings of the mean angles obtained with the inertial motion sensor show that the performance of the *Rudy L1* is comparable to the *Danie Martine*.

Headwinds provoke generally stronger pitching angles for the *Rudy L1*, as they do for the *Danie Martine*, because the boats sail with their bows against the swell and the waves. Immersion of a single fin on the *Rudy L1* provokes greater pitching angles when it is moving at full speed. The asymmetry of the boat is probably responsible for the decrease in hydrodynamism, but as we previously mentioned, this situation is increasingly rare in practice.

According to the graphs and the statistical analysis, we can see that pitching on the *Rudy L1* is equivalent to that of the *Danie Martine*. These results confirm the preponderant role of the equipment studied, which is designed to reduce roll, with a lesser effect on the oscillating movements along the bow-stern axis of the vessel. Furthermore, the relative consistency of the values of angular acceleration in pitch (acceleration around the Y axis) support this conclusion, i.e., that fins and the paravanes have less of an effect on pitch.

7.2 Energy Consumption

The previous sections have shown that the *Rudy L1* behaved somewhat differently than the *Danie Martine* in the experimental conditions, but the difference did not appear substantial enough to affect its stability and safety in terms of navigation.

With that in mind, apart from the initial investment cost, one of fishers' main concerns is the energy consumption of boats equipped with hinged fins. Because of their geometry and the fact that their immersed volume is greater than paravanes, hinged fins may indeed provide greater resistance in the water.

However, the data recorded on the boats when their respective roll damping systems were immersed showed that the *Rudy L1* has the advantage at half speed. In addition, the *Rudy L1's* energy expenditure is equivalent to that of the *Danie Martine* at full speed, corresponding to travel to and from the wharf and the fishing grounds. Overall, these observations are corroborated by the fishers/operators of boats equiped with hinged fin systems we met with during the survey, who stated that, since they had added this equipment to their boats, 80% of the time, energy efficiency was good, even excellent.

One explanation could be that the immersed fins improve the hydrodynamic performance of the boat. This energy consumption advantage may be more pronounced if speed is reduced. In fact, resistance to forward movement due to the hinged fins was compensated, up to a certain point, by reduction in the resistance caused by rolling movements, with the boat steering better (Dallinga, 1994; cited in Molland, 2008). Some fishers said as much in the interviews.

7.3 Operation of Hinged Fins and Associated Risks

Roll damping systems with fins are generally divided into two main categories, i.e., passive (or fixed) systems and active (or mobile) systems. For reasons of cost, maintenance or ease of use, many small boats have non-retractable or fixed fins (Lloyd, 1998). Normally, the fins do not extend past the side of the boat, in order to facilitate mooring and manoeuvring at the dock. As a result, their hydrodynamic lift and effectiveness are reduced.

The hinged fin system is an intermediate system. It is a good compromise, because it is on a scale sufficient to have an impact on roll when deployed, while reducing the risks of damage from contact with the wharf when the fins are pulled up against the hull. It is of interest to note that as more vessels are equipped with the system, their owners have developed techniques to better protect the fins and the other exposed parts.

Another important advantage of the hinged fin system is that the captains have a clear picture of the dimensions and position of the roll-damping components with respect to the hulls of their boats. This is not the case for the paravanes, as their geometry varies with the speed of navigation. Operators may find it more difficult to avoid obstacles that are floating on or just below the surface. The risk of the paravanes or tow wires becoming entangled in other floating objects is therefore greater.

Moreover, the action of hinged fins is doubled, because they operate symmetrically on the vertical plane when the vessel heels to port: the underside of the proximal fin resists sinking into the water while the upper surface of the distal fin slows the rising movement. In the case of paravanes, the same movement causes the port paravane to release or plunge vertically into the water, with the restraining effect being ensured solely by the starboard paravane. In rough seas, the latter may emerge completely from the water and start to swing, as some fishers have experienced. In addition, over time, paravanes and all the associated rigging have become increasingly massive. They can therefore turn into huge pendulums that pose a danger to the crew members who are at work.

With respect to deployment, the hinged fin system has the advantage in that fewer tasks are required to operate them. The use of simplified hydraulic cylinders and locking devices decreases the chance of crew members being in risky positions, which could cause falls, for example.

8. CONCLUSION

The main objective of this study was to respond to an issue of great importance to Québec fishers: whether it is worth it to equip boats with the hinged fin roll-damping system. The results of our study show no negative indicators regarding this new hinged fin technology. The expansion of its use throughout the Québec fishing fleet is, therefore, to be expected.

The experimental data gathered aboard the *Rudy L1* show that hinged fins reduce roll when they are deployed. However, the operational conditions experienced during experimentation were less extreme than those sometimes experienced by fishers. Moreover, during the trials, the vessels were sailing light. These two factors do not enable us to prove that the hinged fin roll damping system is better or worse than paravanes. The *Rudy L1* showed rougher accelerations that could increase the risk of falling. On the other hand, the fact that the vessel rights itself rapidly means that it may be less liable to capsize. The results of the survey of captains who had switched to hinged fins reveal that most of them are satisfied with their decision overall.

With respect to safety, during the same given time period, incidents/accidents reported by fishers with boats equipped with paravanes were significantly higher, in numbers and in seriousness, than those equipped with hinged fins. However, hinged fins are a more recent innovation, and only time and experience will enable us to judge that aspect properly. From our own observations of the two systems aboard the crabbers used for the experiment, we could see that the hinged fins are much easier to handle than the paravanes.

An important issue for fishers is that of fuel oil consumption. While fishing (at half speed), the crabber deploying a single fin to simulate the situation in which the traps can be handled easily is disadvantaged compared to the crabber with booms that are symmetrically deployed without immersion of the paravanes. When steaming from the home port to the fishing ground (full speed), energy consumption is similar for the two crabbers, especially when their roll damping systems are completely immersed. The hinged fin system may have a greater advantage when travelling speed is reduced, based on the results observed at half speed. Given that the hinged fin system is relatively new, it is possible that it will be modified, thus improving the navigatability of a boat equipped with this system, and reducing its impact on energy consumption even more.

Our study was carried out with a single type of boat, the crabber. However crabbers represent almost half of the fishing vessels of more than 15 gross tonnage in Québec. The scope of this study is thus significant. However, before carrying out a similar study on other fleets, such as shrimpers, longliners and draggers, more thought must be put into the kind of fishing they do.

The survey of fishers practicing different types of fishing revealed a high degree of satisfaction from representative operators of diverse fleets, suggesting that the performance of their vessels with hinged fins is better than that of their previous system. As with any new technology, the establishment of hinged fin systems as roll reduction equipment has progressed on the basis of the experience of users, without real contraindications. It would be possible to optimize the hydrodynamics of the systems through a rigorous scientific approach using engineering calculations. But before moving forward, the costs and benefits of such an operation must be estimated (Helmore, 2000).

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APPENDIX 1

Additional information on the inventory of roll-damping systems

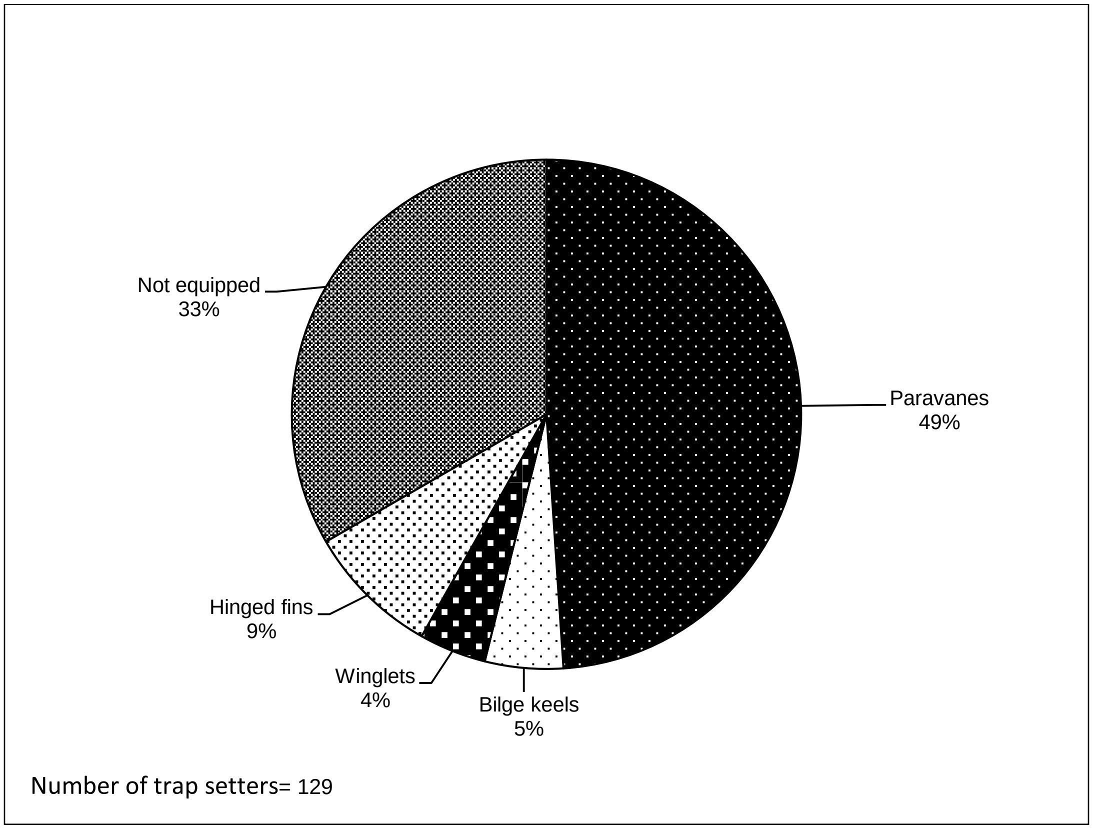


Figure 17. Distribution of various roll-damping systems on trap setters in Québec's maritime commercial fishing fleet (those over 15 gross tonnage)

The distribution of roll damping systems among the 129 trap setters analyzed follows the general pattern for the fleet as a whole. In fact, 49% of boats are equipped with paravanes, 33% are not equipped. After those, in order, for this type of fishing boat: 9% with hinged fins; 5% with bilge keels; and 4% with winglets.

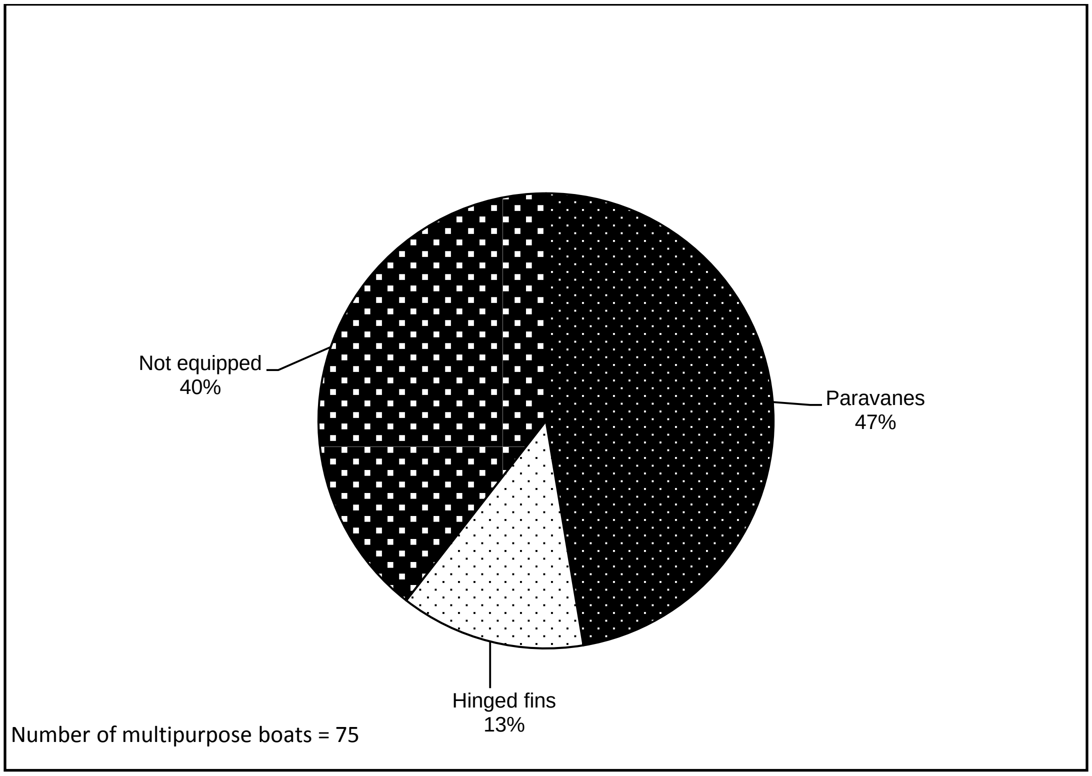


Figure 18. Distribution of various roll-damping systems on multipurpose boats in Québec's maritime commercial fishing fleet (those over 15 gross tonnage)

The distribution of the various systems among multipurpose boats follows a similar pattern, as 48% are paravane systems, 13% are hinged fin systems, while 39% of boats are not equipped with any roll-damping system.

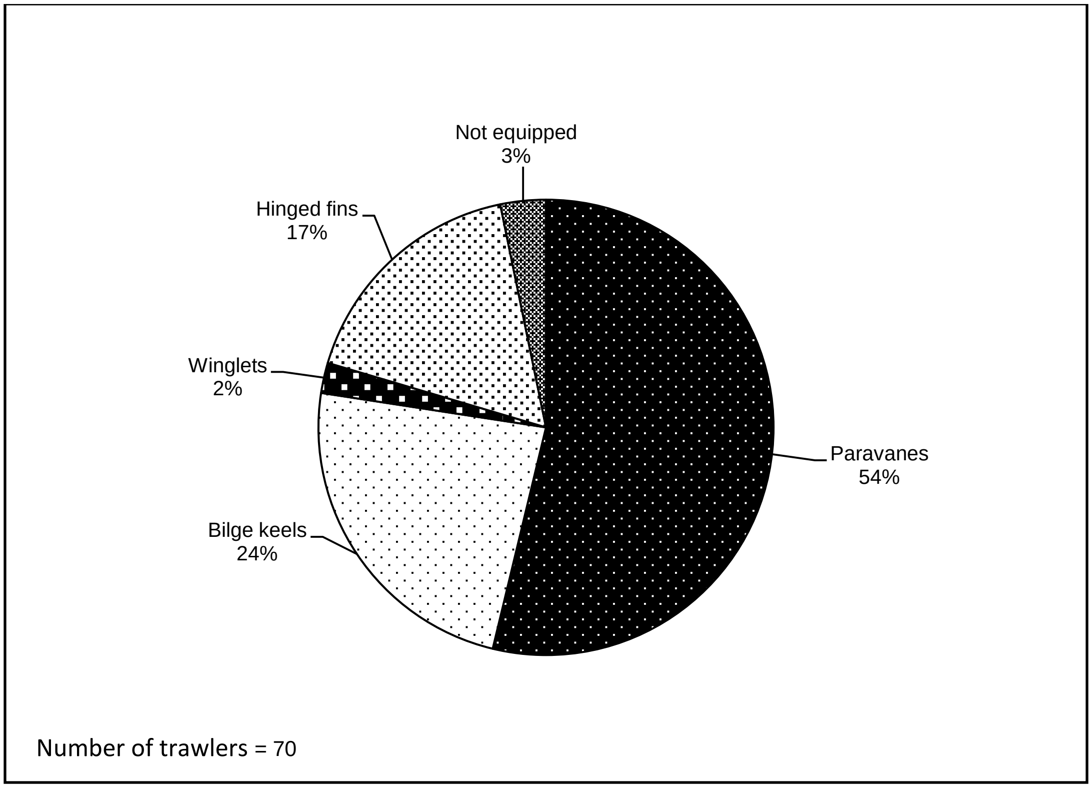


Figure 19. Distribution of various roll-damping systems on trawlers in Québec's maritime commercial fishing fleet (those over 15 gross tonnage).

The breakdown of data for trawlers shows a slightly different picture. Boats equipped with paravanes still dominate this segment of the fleet, which counts some 70 fishing units, with 54%. Boats equipped with bilge keels make up 24% of the total, while the percentage of trawlers equipped with hinged fins is significantly higher (17% of the fleet) than for trap setters and multipurpose vessels. Boats with winglets bring up the rear at 2%, a long way behind, as in the other segments of the fleet.

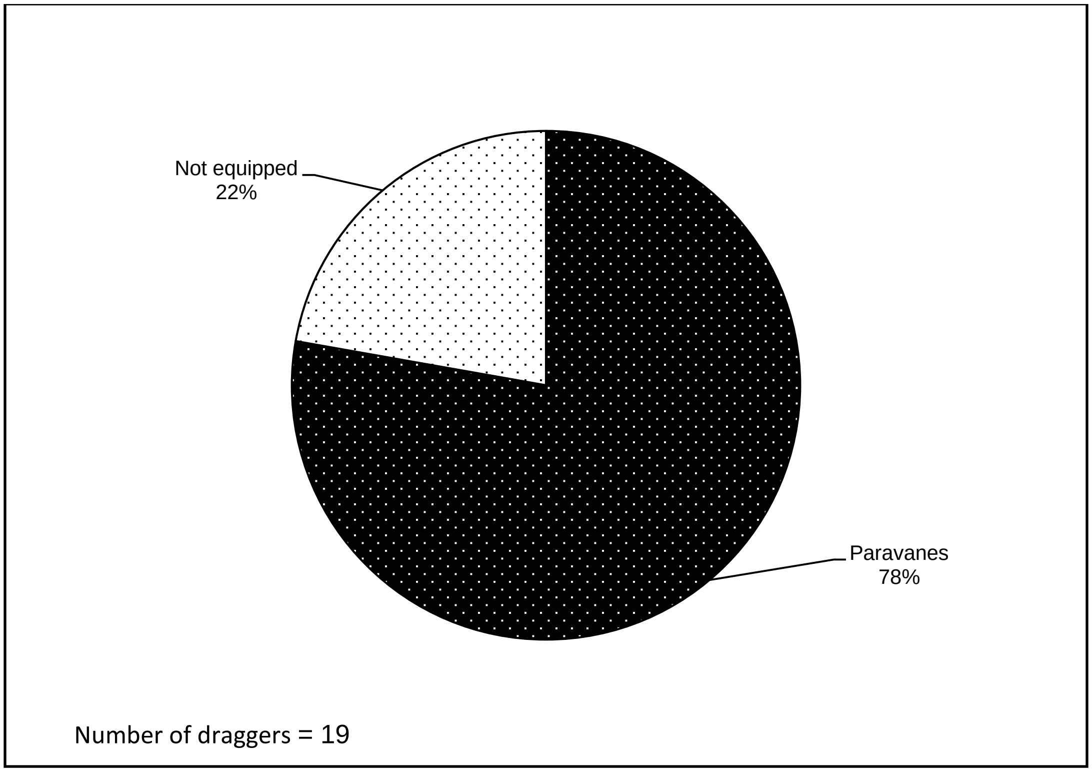


Figure 20. Distribution of various roll-damping systems on draggers in Québec's maritime commercial fishing fleet (those over 15 gross tonnage)

For scallop draggers, the picture is very simple, 78% of the 19 boats of that capacity are equipped with paravanes, one boat has hinged fins, while the rest of the boats are not equipped with any particular system.

APPENDIX 2

Nautical Terms[6]

Bilge: the rounded portion of a boat's hull, from the bottom to the sides.

Bilge keel: Lengthwise fins or plates attached along a ship's bilge on each side. The bilge keels provide stability by slowing the flow of water when the vessel rolls, thus damping the roll. Bilge keels are used mainly on narrow vessels (such as frigates) or on vessels that are too small for a more effective roll-damping system (such as tugboats).

Boom: Long pole made of wood, metal or plastic, generally placed in a horizontal position, to hold an object over the side, such as an anchor, boat, fishing line, or paravanes, as in this document.

Fittings: The equipment found on the deck of a vessel (e.g., pulleys, shackles, storage boxes, pump, stove).

Freeboard: The space or distance between the load waterline and the main deck of a vessel.

Gross tonnage: Measurement of the transportation capacity of a vessel, expressed in tons.

Heel: The tilt of a boat to one side (to port or starboard).

Pitch: The rotation of a vessel (or a vehicle) around its transverse axis (from bow to stern).

Register tonnage: Unit of volume used to measure the capacity of a vessel.

Roll: The alternating lateral rotation of a vessel to starboard and port. If the vessel tilts only to one side, it is said to be heeling.

Shackle: A metal U-shaped link, closed by a pin or a bolt and used to connect a variety of objects.

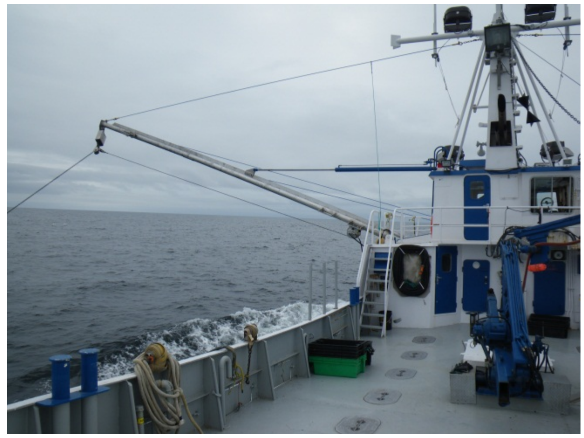
Side: Lateral surface of a boat's hull.

Trim: Longitudinal angle of a vessel.

[6] Source : Bruno, A. and C. Mouilleron-Bécar (1994). Dictionnaire maritime thématique anglais et français. Bibliothèque de l'institut français d'aide à la formation professionnelle maritime. 2nd edition, revised and expanded. Masson, Paris, 442 p.

Glossary of Roll-damping Systems[7]

Boom[8]: Moveable spar attached to each side of the vessel to keep the paravanes as far as possible from the vessel, to improve their effectiveness.



Fin: Acts to control movement in the water. Vessel movements are slowed and limited because of the resistance exercised by the fin.

[7] In the absence of formal definitions, those presented here have been written to the best of the knowledge of the members of the research team, to assist readers less familiar with the subject.

[8] Source: Bruno, A. and C. Mouilleron-Bécar (1994). Dictionnaire maritime thématique anglais et français. Bibliothèque de l'institut français d'aide à la formation professionnelle maritime. 2nd edition revised and expanded. Masson, Paris, 442 p.

Fixed bar linkage: Enables the sliding arm to be guided when the fin is deployed. The latch is attached this part.

Guide rail: Holds and guides the sliding arms when the fins are deployed. A retaining pin is recessed in the bottom of the rail to hold the sliding arm in place.

Latch: This is a moving part attached to the fixed bar linkage, it snaps back against the end of the sliding arm to hold it in place when the fin is deployed.

Paravane[9]: Delta-shaped device towed from the ends of outrigger booms on either side of a vessel to reduce the amplitude of its roll.

[9] Source: http://www.tsb.gc.ca/eng/rapports-reports/marine/1990/m90n5017/m90n5017.asp [Last consulted September 24, 2013]

Retaining pin: Metal rod that holds the sliding arm in place.

Sliding arm: Rod that keeps the fin immersed at a given angle and depth so that it will fulfil its function.