UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

PETROLEUM GEO-SERVICES INC.,
Petitioner

v.

WESTERNGECO LLC
Patent Owner

Cases
IPR2014-00687 (U.S. Patent No. 7,162,967)
IPR2014-00688 (U.S. Patent No. 7,080,607)
IPR2014-00689 (U.S. Patent No. 7,293,520)

DECLARATION OF MICHAEL S. TRIANTAFYLLOU

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IPR2014-01475,
-1477, -1478
PGS Exhibit
1107

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I, Dr. Michael S. Triantafyllou, hereby state the following:

I. INTRODUCTION

1. I have over 40 years of research and development experience in the dynamics and control of marine vehicles and structures. I specialize in two fields: (1) control theory; and (2) the interactions between fluids and structures, including fluid mechanics and structural dynamics. A copy of my *curriculum vitae*, including a list of the publications I have authored within the last 10 years, is attached hereto as Exhibit A. I have provided testimony at a deposition and at trial in the past 4 years. These engagements are listed in Exhibit B. I am being compensated at a rate of $350 per hour for the time I devote to this matter. I have no financial interest in the outcome of this litigation. The information I considered in forming my opinions is attached hereto as Exhibit C.

2. I earned a bachelor's degree in Naval Architecture and Marine Engineering in 1974 from the National Technical University of Athens in Athens, Greece. I have also earned the degrees of Masters of Science in Mechanical Engineering, and Masters of Science in Ocean Engineering, both awarded in 1977 from the Massachusetts Institute of Technology ("MIT"). In 1979, I earned a Doctorate of Science in Ocean Engineering from MIT. During the course of my doctorate studies, I conducted research on the dynamics and control of ships and positioning structures for the oil industry.

3. Since 1979, I have been a faculty member first in MIT's Ocean Engineering department and then in MIT's Mechanical Engineering department. I was an Assistant Professor from 1979 to 1983, and Associate Professor without tenure from 1983 to 1986. Much of my research during this time focused on cable mechanics, and specifically on the design of marine cable

lines subject to large forces, such as ocean currents. Many of the principles of cable mechanics are equally applicable to streamers used in marine seismic surveys. In addition to my research, I taught courses in the design of floating structures and the dynamics of ocean structures.

4. I earned permanent tenure status in 1986. I continued my research on cable mechanics, focusing specifically on towed cables, including streamers and towed arrays. In conjunction with the United States Navy, I studied the fluid mechanics of towed arrays for use behind submarines for the detection of other vessels. Though the precise nature of my work for the Navy remains confidential, it involved the development of the boundary layer theory around towed cables, as well as their hydrodynamics and maneuverability.

5. In 1990, I earned the title of Professor. I continued to work on the development of cables and towed arrays for the United States Navy, specifically focusing on conducting modeling studies for the hydrodynamics of marine cables.

6. Since 2004, I have served as the Director of the Center for Ocean Engineering at MIT. In 2008, I was named Associate Department Head of the Mechanical Engineering Department, and I currently serve as the William I. Koch Chair in Marine Technology. During 2007-2014, I conducted research focused on developing steering capabilities for the Navy's acoustic towed arrays. The technology is similar to the steerable streamer concepts employed by the oil exploration industry. Part of my research focused on simulating the overall performance of underwater arrays towed by helicopter at high speed for underwater detection. Arrays towed by helicopter present many of the same challenges as arrays towed by marine seismic vessels, but also present many additional challenges. For example,

helicopters tow arrays at much faster speeds, up to twenty miles per hour, than seismic vessels, adding to the complexity of the system.

7. In 2013, I became Chairman of the Board of the National Technical University of Athens.

8. For approximately twenty years, my research at MIT has also included the development of marine robots with flexible hulls that propel themselves through water, or "swim," much like fish. In its initial stages, the project involved the design and control of robot bodies that swim like marine creatures, such as dolphins and tuna. These robots are capable of sensing their surrounding environmental conditions in order to achieve optimal propulsion and maneuverability. The robots are capable of adjusting their motion to account for ocean currents and turbulence from structures in the water. They can be controlled remotely, but are also capable of autonomous control. More recently, my research efforts have been focused on the development of specialized pressure and velocity sensors distributed throughout the robot bodies, which allow the robots to detect flow patterns and other objects in the water. This research has been featured several times in industry and academic publications, including Physics of Fluids, Discovery Magazine, and The Scientific American. Ultimately, the practical application of this project will be to apply these principles to larger marine vessels for faster turning and more precise control of, for example, marine cables. In 2014 I was elected fellow of the American Physical Society for "pioneering the use of biomimetic robots."

9. In addition to my responsibilities at MIT, since 1979 I have been a visiting research scientist at the Woods Hole Oceanographic Institute ("WHOI") in Woods Hole, Massachusetts. WHOI is one of the world's largest ocean research and engineering organizations. Its work

focuses on all aspects of ocean research, including the development of technology for natural resource exploration beneath the ocean subsurface. As part of my research at WHOI, I was part of the team that developed the WHOI-Cable, a simulation program that simulates the fluid mechanics and dynamics for moorings and towed marine cables and arrays.

10. I routinely consult on issues related to marine exploration for the petroleum industry, including projects on behalf of ExxonMobil, Mobil, Conoco Philips, Chevron, and Technip. I am also a frequent presenter at several professional society conventions, including the International Society of Offshore Mechanics and Polar Engineers and the Society of Naval Architects and Naval Engineers. My research has been published in a variety of industry and scientific journals, including the Journal of Fluid Mechanics and the Journal of Fluids and Structures.

11. In my career I was involved in the design and implementation of advanced filtering and control systems. My doctoral thesis (1976-1979) was on the dynamic positioning control system used for ships drilling for oil and gas (funded by NSF). From 1979 through 1984 I studied the problem of landing VTOL aircraft on smaller Navy ships using Kalman filtering techniques to estimate and predict ship motions (funded by NASA). In 1986 through 1991 I studied with a colleague at WHOI the dynamic positioning for ships that tow remotely operated vehicles such as the ARGO and JASON vehicles of WHOI (funded by the Navy). From 1991 through 1999 I directed the effort for designing the control systems for the laboratory robot RoboTuna and the autonomous robot RoboPike (funded by ONR, DARPA, and NOAA). From 1996 through 2006 I directed the development of hybrid control systems that combine in real time simulation and experimentation, a methodology that is now used by several groups worldwide (funded by ONR). From 2000 through 2006 I directed the

development of the autonomous robot RoboTurtle (funded by DARPA-CEROS and NOAA). Since 2007, I have been involved with the development of pressure sensor arrays for real time estimation of the flow around moving robots and structures, as well as with the design of advanced biomimetic robots.

II. LEGAL STANDARDS

A. Claim Construction

12. I understand that in an *inter partes* review proceeding, the terms in the claims of the patent are given their broadest reasonable interpretation in light of the specification, as understood by one having ordinary skill in the relevant art as of the priority date of the patent at issue. I have been informed that the priority date of the patents at issue is October 1, 1998.[1]

B. Anticipation

13. I understand that a claim is unpatentable if it is anticipated. Anticipation of a claim requires that every element of a claim be disclosed expressly or inherently in a single prior art reference, arranged in the prior reference as arranged in the claim. I understand that for a feature to be "inherent" in a reference, the feature must ***necessarily*** be present based on the details that are disclosed. I also understand that in order to anticipate, a reference must enable one of skill in the art to practice an embodiment of the claimed invention without undue experimentation.

C. Obviousness

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[1] My opinions would not change if the U.S. PCT filing date of September 28, 1999 were used as the priority date.

14. I understand that a claim is unpatentable if it is obvious. Obviousness of a claim requires that the claim would have been obvious from the perspective of a person having ordinary skill in the relevant art at the time the invention was made. I understand that a claim may be obvious from a combination of two or more prior art references.

15. I understand that an obviousness analysis requires an understanding of the scope and content of the prior art, any differences between the claims of the patent in question and the prior art, and the level of ordinary skill in the pertinent art.

16. I also understand that objective evidence of nonobviousness should be considered when evaluating the obviousness of a claim. I understand that this objective evidence may include the commercial success of the patented invention, any long-felt but unsolved need in the art that was satisfied by the invention, the failure of others to make the invention, skepticism of those having ordinary skill in the art at the time of the invention, unexpected results of the invention, praise of the invention by those having ordinary skill in the art, and copying of the invention by others in the field.

D. Person of Ordinary Skill in the Art

17. I understand that a person of ordinary skill in the art ("POSA") is a hypothetical person that is presumed to have the level of skill of a typical practitioner of the art at issue and is also presumed to be aware of all relevant prior art. I also understand that multiple factors are relevant in determining the level of ordinary skill in the art including, among other things, the educational level of the inventor, the sophistication of the technology, the type of problems encountered in the art, and prior art solutions to those problems.

18. Based on my consideration of those factors and my own experience in the field, it is my opinion that one of ordinary skill in the art at the time of the '520 patent, '607 patent, and '967 patent would have a Bachelor of Science in ocean engineering or control systems; or five years of experience in the field of ocean engineering or marine seismic surveys.

III. SUMMARY OF OPINIONS

19. I have been asked to give an opinion on whether certain claims of the '520 patent (Ex. 2063), '607 patent (Ex. 1001), and the '967 (Ex. 2044) patent are anticipated or obvious based on certain references. This section contains a summary of my opinions in this matter, which I explain in further detail below.

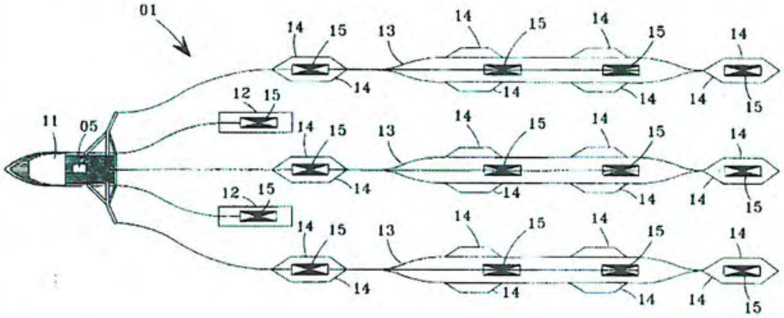
20. I have included a table below listing the patents and claims I was asked to consider:

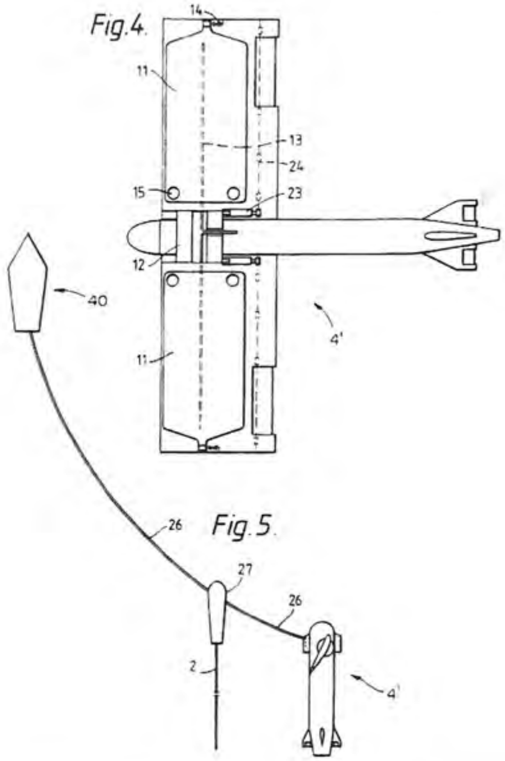
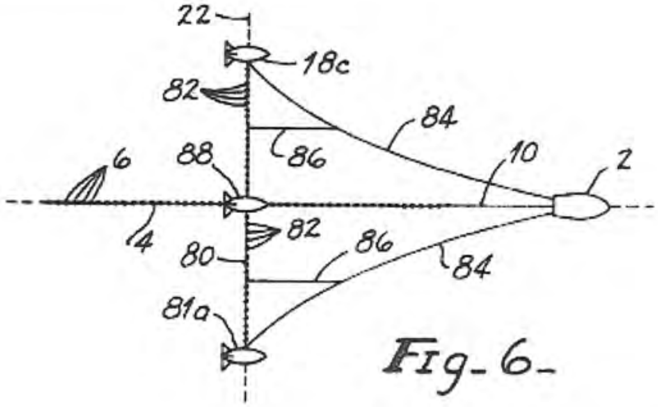
WesternGeco's Patents At Issue	
Patent Number	**Claims at Issue**
U.S. Pat. No. 7,080,607 **(the '607 patent)**	**1**. A method comprising: (a) towing an a array of streamers each having a plurality of streamer positioning devices there along; (b) predicting positions of at least some of the streamer positioning devices; (c) using the predicted positions to calculate desired changes in position of one or more of the streamer positioning devices; and (d) implementing at least some of the desired changes. **15**. An array of seismic streamers towed by a towing vessel comprising: (a) a plurality of streamer positioning devices on or inline with each streamer; (b) a prediction unit adapted to predict positions of at least some of the streamer positioning devices; and (c) a control unit adapted to use the predicted positions to calculate

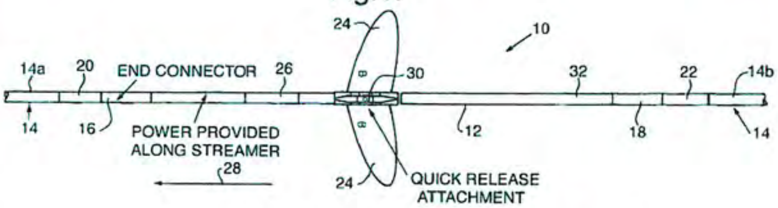
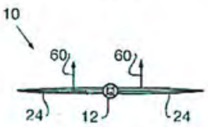
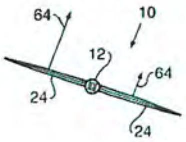
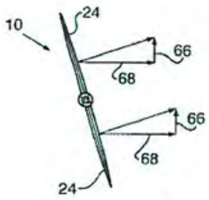
WesternGeco's Patents At Issue	
Patent Number	**Claims at Issue**
	desired changes in positions of one or more of the streamer positioning devices.
U.S. Pat. No. 7,162,967 **(the '967 patent)**	**1**. A method comprising: (a) towing an array of streamers each having a plurality of streamer positioning devices there along, at least one of the streamer positioning devices having a wing; (b) transmitting from a global control system location information to at least one local control system on the at least one streamer positioning devices having a wing; and (c) adjusting the wing using the local control system. **15**. An array of seismic streamers towed by a towing vessel comprising: (a) a plurality of streamer positioning devices on or inline with each streamer, at least one of the streamer positioning devices having a wing; (b) a global control system transmitting location information to at least one local control system on the at least one streamer positioning device having a wing, the local control system adjusting the wing.
U.S. Pat. No. 7,293,520 **(the '520 patent)**	**1**. A method comprising: (a) towing an array of streamers each having a plurality of streamer positioning devices there along contributing to steering the streamers; (b) controlling the streamer positioning devices with a control system configured to operate in one or more control modes selected from a feather angle mode, a turn control mode, and a streamer separation mode. **2**. The method of claim **1** wherein the control mode is the feather angle mode, and the controlling comprises the control system attempting to keep each streamer in a straight line offset from a towing direction by a feather angle. **18**. An apparatus comprising: (a) an array of streamers each having a plurality of streamer positioning devices there along;

WesternGeco's Patents At Issue	
Patent Number	**Claims at Issue**
	(b) a control system configured to use a control mode selected from a feather angle mode, a turn control mode, a streamer separation mode, and two or more of these modes. **19**. The apparatus of claim **18** wherein the control mode is the feather angle mode, and the controlling comprises the control system attempting to keep each streamer in a straight line offset from a towing direction by a feather angle.

21. The following table lists the references the Board granted institution on:

Alleged Prior Art	
Reference Title	**Exemplary Figure**
U.S. Pat. No. 5,790,472 Inventors: Ricky L. Workman and Ronald Edward Chambers **(the Workman patent** or **Workman)** Title: Adaptive Control of Marine Seismic Streamers	Fig. 1 

Alleged Prior Art	
Reference Title	**Exemplary Figure**
U.S. Pat. No. 5,532,975 Inventor: Tor Elholm (**the Elholm patent** or **Elholm**) Title: Device and Method for Positioning of Towing Systems for Use in Marine Seismic Surveys	Fig.4. Fig.5. 
U.S. Pat. No. 3,581,273 Inventor: Ronald M. Hedberg (**the Hedberg patent** or **Hedberg**) Title: Marine Seismic Exploration	 Fig-6-

Alleged Prior Art	
Reference Title	**Exemplary Figure**
International Application WO 98/28636 PCT **(the '636 PCT)** Inventor: Simon Bittleston Title: Control Devices for Controlling the Position of a Marine Seismic Streamer	Fig.1.  Fig.3.  Fig.4.  Fig.5. 

A. Summary of Opinions Regarding the '607 Patent

22. Claims 1 and 15 of the '607 patent are not anticipated by Workman.

23. Claims 1 and 15 of the '607 patent are not obvious over Workman.

24. Claims 1 and 15 of the '607 patent are not obvious over Workman and Elholm.

A. Summary of Opinions Regarding the '967 Patent

25. Claims 1 and 15 of the '967 patent are not anticipated by the '636 PCT.

26. Claims 1 and 15 of the '967 patent are not obvious over the '636 PCT.

B. Summary of Opinions Regarding the '520 Patent

27. Claims 1 and 18 of the '520 patent are not anticipated by Workman.

28. Claims 1, 2, 18, and 19 of the '520 patent are not obvious over Workman.

29. Claims 1, 2, 18, and 19 of the '520 patent are not anticipated by Hedberg.

30. Claims 1, 2, 18, and 19 of the '520 patent are not obvious over Hedberg.

IV. BACKGROUND OF THE TECHNOLOGY

A. Background Technical Principles

31. Marine seismic surveys use specialized equipment to discover oil and gas deposits below the bottom of the ocean. A seismic vessel typically tows a portion of this equipment through the water, and there is also equipment located on the seismic vessel itself. Devices in the water are usually called "wet" devices because they are in the water, while devices on the boat are typically called "dry" devices. A piece of equipment, usually called an "air gun," is towed in the water behind the seismic vessel and causes a small, controlled explosion underwater. This explosion generates sound waves that travel through the water and penetrate the surface of the earth; the waves travel through the layers of the earth that lie beneath the ocean floor, each layer in a different way based on the geological formations found within the earth, and some of the energy is reflected at the interfaces between layers. Underwater sensors known as hydrophones pick up these reflections — many sensors are needed to measure the reflections at several locations, in order to be able to determine the shape of the earth layers that cause the reflections. Based on these reflected signals, special computer programs are used to reconstruct the shape of the earth layers based on the hydrophone measurements as well as to provide information regarding the contents of those layers to reveal whether oil or another natural resource is present. In order for the measurements to cover a large area, yet

still be accurate, many hydrophones are towed behind the vessel and spread over a large area, like a large antenna. The hydrophones are contained inside several very long cables called streamers, which are typically several miles long, and are connected through wires to a computer system on the towing vessel.

32. Environmental factors, such as current speed and direction, can significantly influence the path of the towed array. Currents often contain turbulent eddies and therefore exert a non-uniform force on the streamers. The irregular force of the current changes the shape of the highly flexible streamers, causing inaccuracies in the hydrophone measurements. Changes in streamer shape can also result in streamer entanglement, causing significant damage to equipment and delay of the exploration.

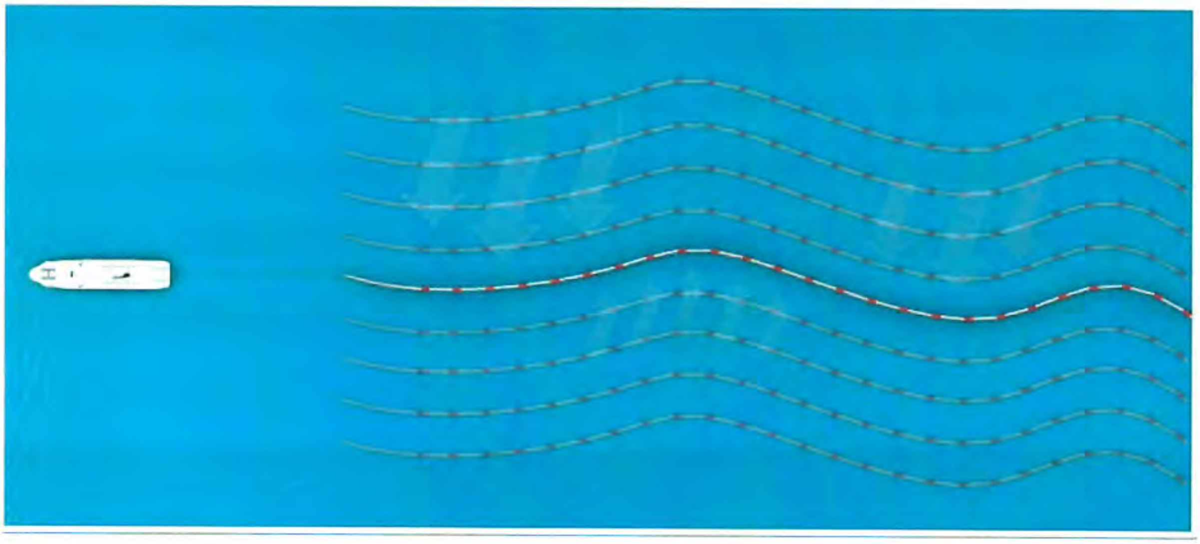


Figure 1 - Example of the effect of currents on a streamer.

33. In 2D surveys, one streamer cable (containing within it many hydrophones) is towed behind the vessel. That allows for an image of a flat slice through the earth. In order to get a 3D image, one needs to combine multiple slices next to each other. For that reason, in a 3D

survey, typically multiple streamers are towed next to each other, in what is typically known as a streamer array.

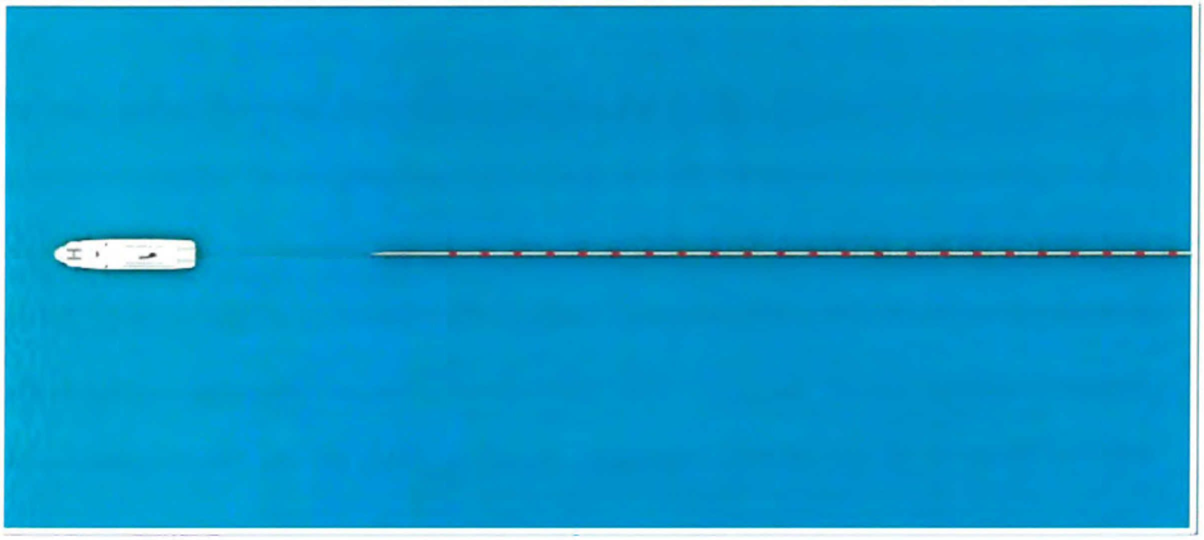


Figure 2 - An idealized single seismic streamer in a 2D survey.

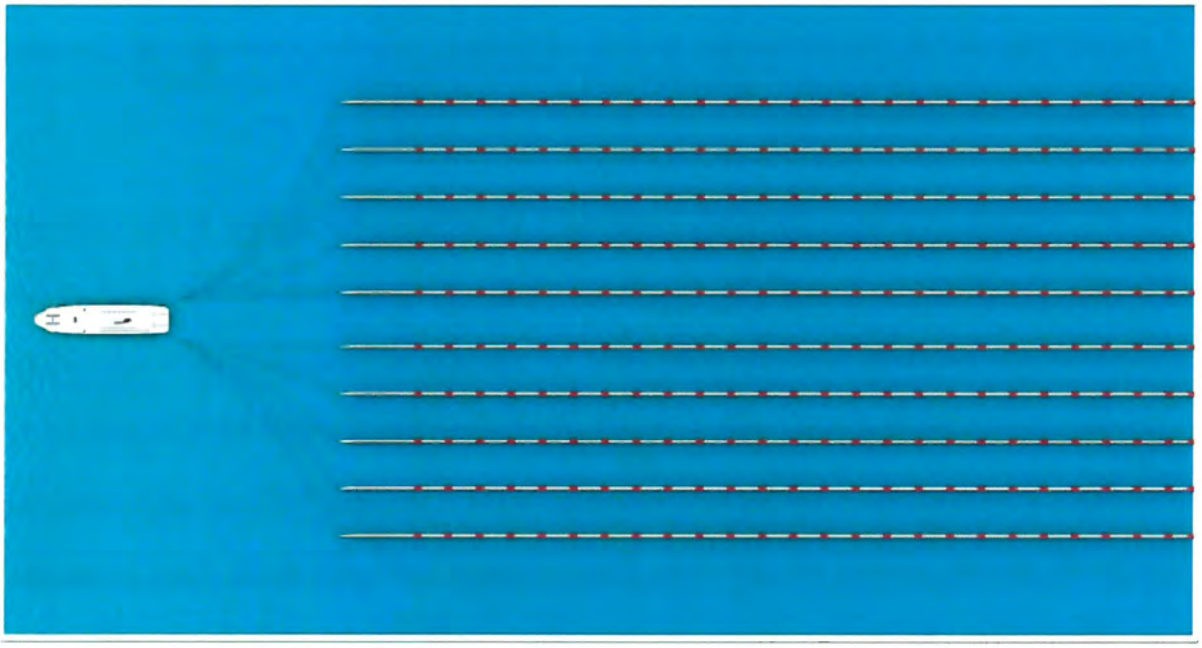


Figure 3 - An idealized seismic streamer array in a 3D survey.

34. These surveys typically consist of a series of "lines" where seismic data is gathered (sometimes known as "shooting") along a specified path. At the end of each line, a vessel completes a "line change." A line change is a turn a ship completes between shooting lines.

35. It is crucial for the accuracy of oil and gas detection in all types of surveys that the hydrophones are spread out and that by the time for data processing their locations are known with high accuracy. Because the hydrophones are inside the streamers, the position of the streamers must be known very accurately. Indeed, the processing of the collected data is dependent on knowing the locations of the hydrophones. Another important concern is that adjacent streamers do not become entangled. However, when towing the streamers in the ocean, currents and waves cause them to move away from their ideal configuration. Also, when the towing ship is maneuvering, as she turns, for example, to reach a position that must be investigated, the streamers become highly curved. It takes a long time for a curved streamer to return to a straight shape, because of the large drag forces acting over a streamer that can be several miles long.

36. A streamer has significant dynamics, which were understood only starting in the 1970s and through the 1990s, because of the complexity of the interaction between the structure (the streamer) and the flow. If at any point along the streamer an unsteady force is applied, the streamer will bend and will create "waves"; in other words, a lateral local motion of the streamer does not stay in the location where the force is applied, but propagates along the streamer, mainly towards the tail. The speed of travel decreases as the wave propagates towards the tail end of the streamer, but is relatively slow, 5 m/s to 2 m/s, typically. On a typical seismic streamer of several miles, a disturbance wave might take 10 minutes or more to travel the length of the streamer. If multiple forces are applied simultaneously, *e.g.*, by

lateral steering devices along the streamer, they will create several such traveling disturbances that will reach the downstream birds in several seconds or minutes. Applying such forces without an appreciation of or accounting for these traveling disturbances could lead to unexpected and uncontrolled results and likely cause more harm than good.

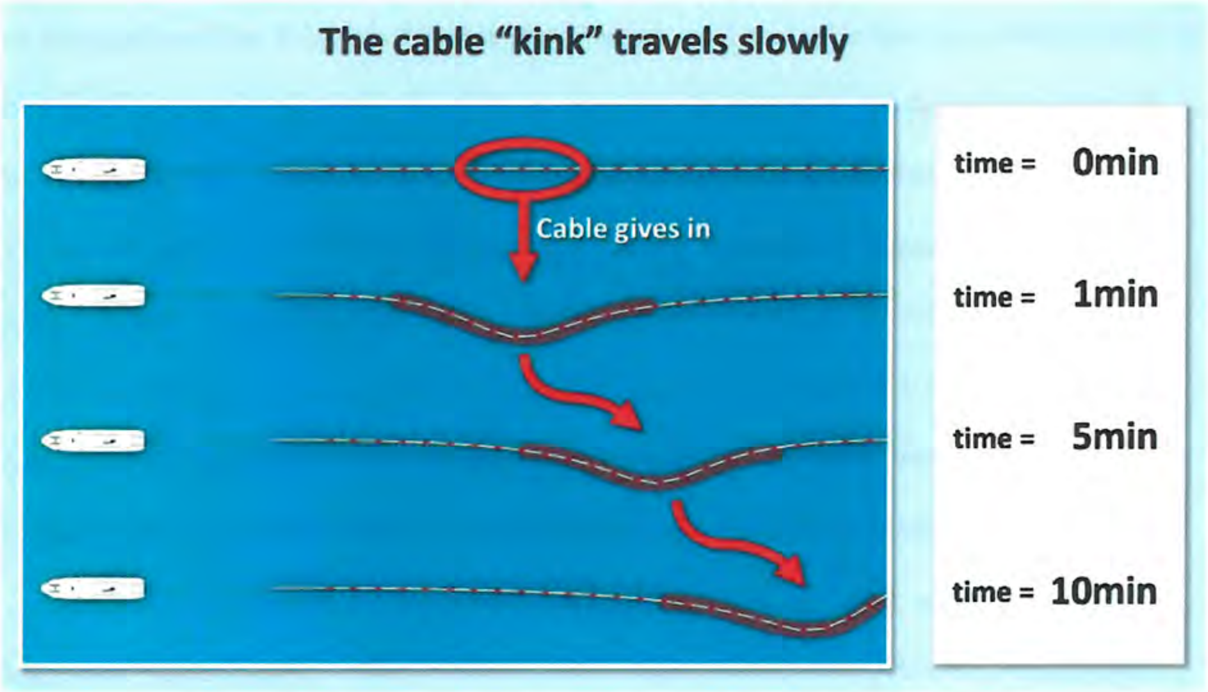


Figure 4 - Force applied by one device will affect others downstream.

37. As shown in Dowling's 1988 study in the Journal of Fluid Mechanics (the premier journal in fluid mechanics), there were several issues with the proper understanding of the dynamics of streamers, even when towed under steady conditions. (Ex. 2045, A. Dowling, *The Dynamics of Towed Flexible Cylinders, Part I: Neutrally Buoyant Elements*, 187 J. Fluid Mech., at 507-532 (1988).) The difficulty in modeling the fluid forces is outlined in the paper by Dowling and in the definitive book on the topic by Paidoussis. (Ex. 2046, M.P. Paidoussis, *Fluid-Structure Interactions: Slender Structures and Axial Flow* (1998).) In 1991, I was asked to

review the literature on this and related topics, where I outlined the problems with the various efforts to model and simulate the dynamics of streamers. (Ex. 2047, M.S. Triantafyllou, *Dynamics of Cables, Towing Cables and Mooring Systems*, 23 Shock & Vibration Dig., No. 7, at 3-8 (1991).)

38. The mechanics of cables and hawsers in the ocean are very complex and the capability to properly model and simulate these dynamics is a relatively recent development. Concepts such as effective tension, and complex phenomena such as the "worm-in-hole" effect of lateral drag, are some examples of recent developments that are critical to the proper simulation of underwater systems. I have published on the topic extensively, and also have co-developed with Dr. Mark Grosenbaugh of Woods Hole Oceanographic Institution the theory and algorithms that led to WHOI-CABLE, a program supported by the US Navy, that is in the public domain and can be used to simulate, among other things, the cable dynamics of towed systems. (Ex. 2048, Jason I. Gobat, Mark A. Grosenbaugh, & Michael S. Triantafyllou, Woods Hole Oceanographic Inst., *WHOI Cable: Time Domain Numerical Simulation of Moored and Towed Oceanographic Systems*, (November 1997); Ex. 2049, Jason I. Gobat, Mark A. Grosenbaugh, & Michael S. Triantafyllou, *Generalized-α Time Integration Solutions for Hanging Chain Dynamics*, 128 J. of Engineering Mech., No. 6, at 677-687 (2002).) I have developed a similar, proprietary program (RISERSIM) for the offshore industry.

39. The dynamics of the streamer that I describe in the previous paragraphs must be accounted fully within a control system design. If the dynamics are omitted, then the closed-loop system will perform poorly or may become unstable. For example, if one designs a controller for a system and omits one of its poles in the modeling, although the controller

may be designed nominally with adequate stability margins (typically 60 degree phase margin, for example, which is also the guaranteed phase margin of an optimal controller), it may turn unstable because the omitted pole can add up to 90 degree phase lag.

40. An important aspect of the system behavior that I explained above is the inherent delay in the response. When the force acting at a point of the streamer is viewed as the input and the response at a downstream point on the streamer as the output, the traveling wave nature of the streamer motion causes the response to appear several seconds or minutes later, depending on the relative distance. Systems that contain delays are inherently difficult to control with conventional methods.

41. Next, we address the turning maneuvers of the streamers. If we use first as an example a water skier towed by a powerboat, when the boat turns to the right, the skier would tend to continue on his or her previous path (as Newton's first law requires), except for the effect of the tension from the towing cable, which is at an angle to the right, due to the turn of the boat. As the skier is forced to the right by the cable, and starts turning, the skier is also subject to a centrifugal force pulling to the left, away from the turn (as for example, a passenger in a car that turns to the right feels a centrifugal force pulling to the left), and also some drag and lift forces from the water skis that oppose the motion away from the turn, in addition to the forward motion drag. The skier will move, under the influence of the centrifugal force, to the other side of the boat's wake (that's how they can make large zig-zag motions, as the boat turns to the right and then to the left, and so on).

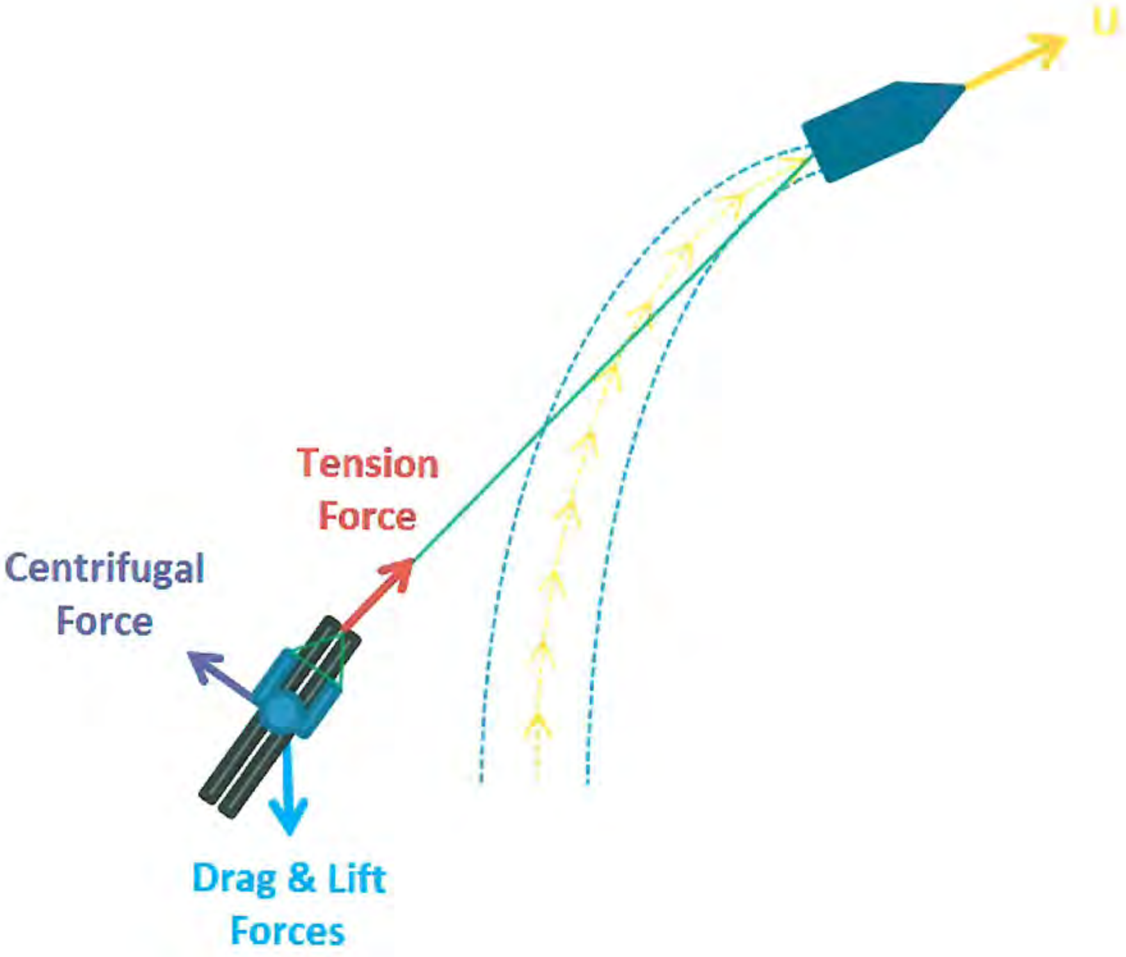


Figure 5 - The forces on a turning water-skier.

42. The same arguments apply when the vessel turns; but there is also a difference, due to the much larger transverse (perpendicular to the streamer) drag forces. The ship's rudders (and lateral thrusters, if available) provide the force and moment needed for the ship's maneuver. The streamers would tend, again, to continue on their previous path except for the effect of the tension from the ship, which pulls them in the direction of the turn. Hence, as in the case of the water skier, the front end of the streamer is subject to the tension coming at an angle and is forced to start turning, pulling the rest of the streamer progressively to follow it.

Hence, the streamers are subject to centrifugal forces pulling them away from the turn, but also (because of the range of towing speeds and large turning radius) to much larger transverse (normal to the cable configuration) drag forces, following the so-called "separation principle" (at each point of the streamer, the normal force is proportional to the square of the normal velocity and the axial force proportional to the square of the tangential velocity between fluid and streamer).

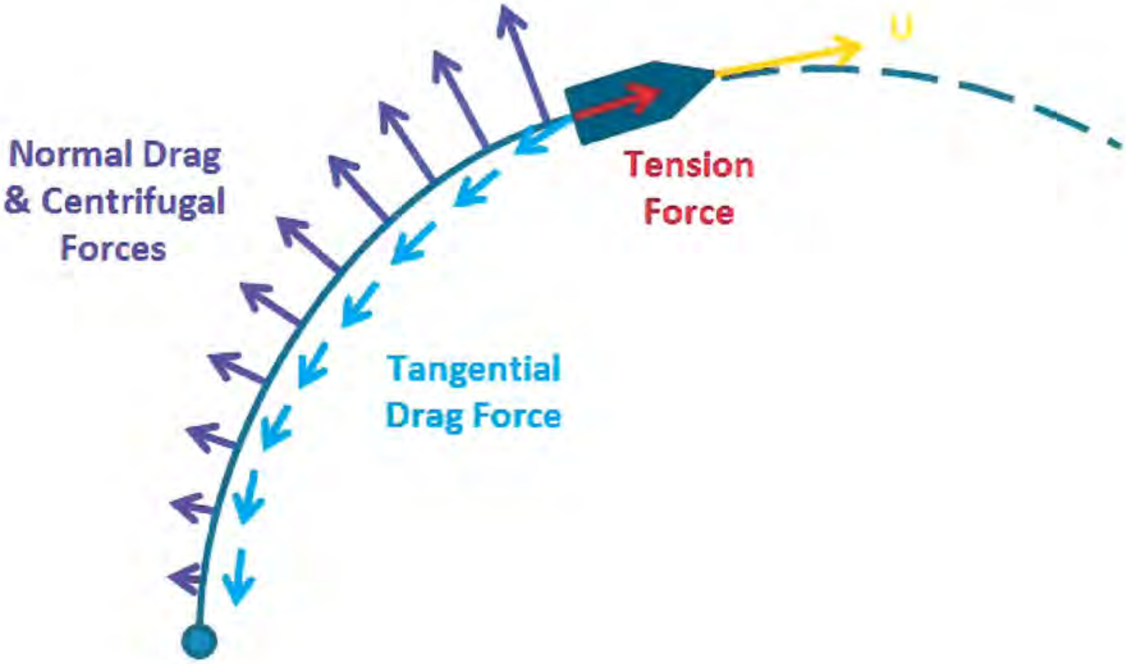


Figure 6 - The forces on a seismic streamer during a turn.

43. Hence, an important difference between the skier and the streamers is that the streamers are subject to a large side drag force along their length, which is normally much larger than the centrifugal force (because streamers move slowly and turn with a large radius of turning and also have a "bluff" cross section that causes large drag, unlike the skis of a skier). These drag forces cause the streamer to have a strongly curved configuration and prevent them from

straightening out quickly after the ship has completed its turn — they take extra time to complete the turn. "Birds," as described in the '520, '967, and '607 patents, can help by providing extra force "in the opposite direction of the turn" (Ex. 2063, '520 patent at 10:40-43), especially at the posterior half of the streamer, to shorten the duration of the maneuver. Even if no bird forces are applied, of course, the streamers would eventually turn anyway (but slower) thanks to the centrifugal and (primarily) drag forces.

44. In his declaration and deposition, Dr. Evans shows an incorrect depiction of these forces. He refers to "centripetal forces" on the streamers and shows them in the accompanying sketches. (Ex. 2040, Evans Dep. Tr. at 247:10-249:18; Ex. 2064, Evans '520 Decl. at ¶¶ 40-43, 51, 209-211.) In classical dynamics of a turning rigid body, the *centripetal* force is an ***external*** force that must be applied to the body to oppose the *centrifugal* force, which is the inertia force acting on the body. As we mentioned above, a passenger in a turning car is aware of the centrifugal force (pushing away from the turn, not inside the turn). The water skier, in our example above, feels a centrifugal force that pulls him or her away from the turn, but is forced to turn as the result of the tension of the towing line from the turning boat. The streamers during a turn are subject to the centrifugal force, as we analyzed above, and drag forces away from the turn, and the turn is driven ***only*** by the tension from the towing line at the front of the streamer. There is no "centripetal force" distributed along the streamers.

45. The lateral dynamics of the towed streamers are subject to complex dynamics as we discussed above. While the vertical-plane dynamics of the streamer are governed by the same equations, there is a basic difference in terms of the external fluid forces acting in the two planes. In the vertical plane, the only forcing consists primarily of possible differences in density of the water; there is no significant motion of the ocean in the vertical plane except

during sea storms (due to water waves), when operations are suspended. Also, the only desirable configuration in the vertical plane discussed in the art is a configuration parallel to the ocean surface. Because of this, pressure gauges can easily provide accurate reference of the submergence of the streamer relative to the free surface, and relatively small control forces can control any deviations. In addition, there is no danger of tangling, due to the control action, with other seismic streamers when only depth is controlled, because there are only additional streamers in the horizontal plane, not in the vertical plane.

46. In contrast, in the horizontal plane the ocean currents can be as strong as the towing speed, and of variable velocity and direction even along the streamer. Also, currents are turbulent and contain large eddies that add to the non-uniformity of the loads on the streamers, causing them to deviate substantially from the direction of tow, or to fish-tail and entangle. Also, during turning, large motions of the streamers are required to accomplish the maneuver, with the streamers inside the turn following different paths than the streamers outside the turn; ocean currents further complicate turning maneuvers. An elaborate sensing scheme must be established to track the motions of the array of streamers using system-behavior models.

47. An additional complication arises from the fact that these arrays are very long; a streamer array can be over six miles long and a half-mile wide. These are the largest moveable structures in the world. Moving and monitoring systems of this size comes with another set of challenges. First, due to the number of sensors and electronics in an array of this size, as well as the amount of data involved, the sampling period or cycle time of the electronics is relatively long, typically on the order of many seconds. Second, there is typically a delay between sensor data collection and any resulting calculations due to the amount of

information processed, the size of the array, and the irregularity of measurements. The following diagrams demonstrate the size of these arrays.

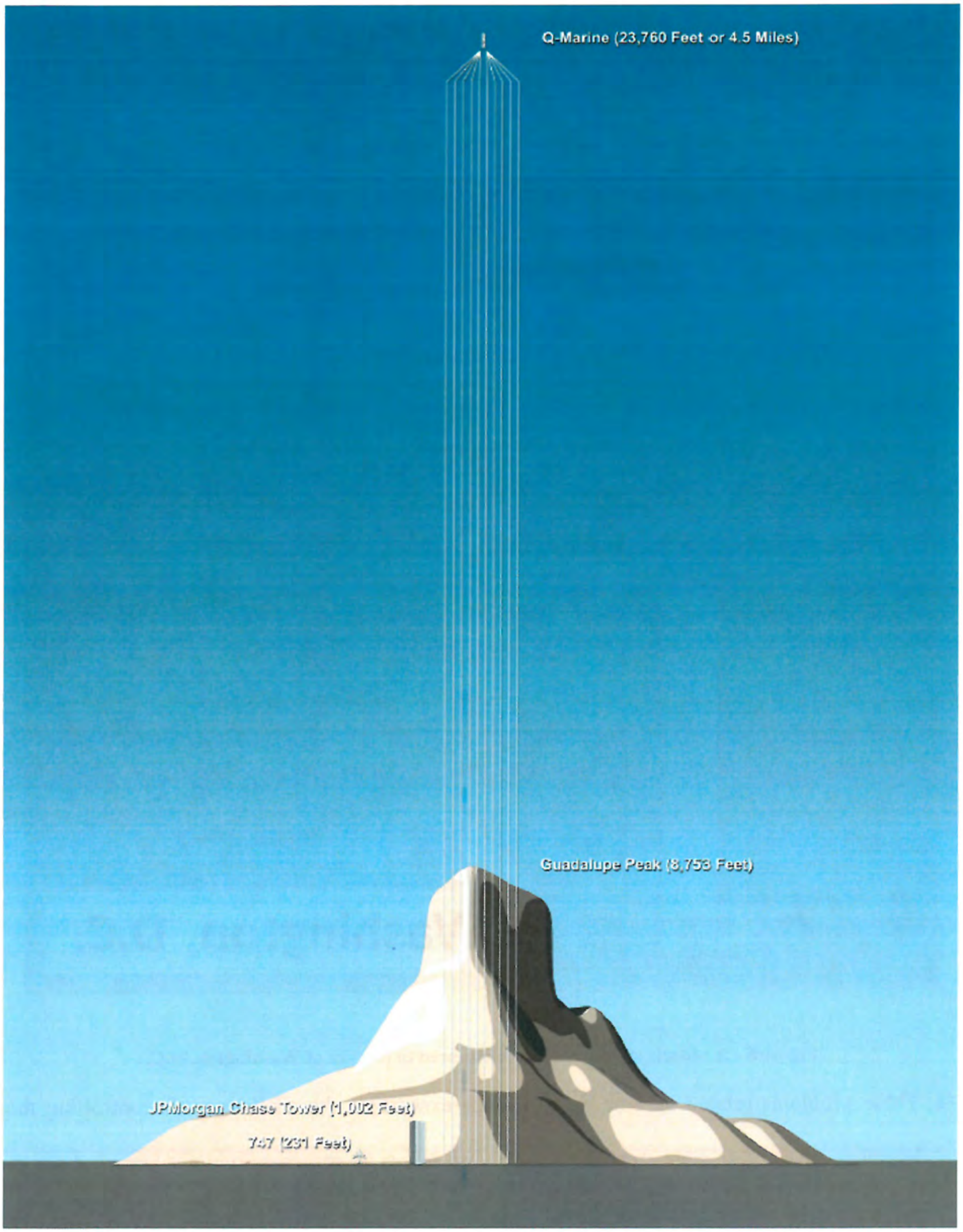


Figure 7 - A 747 airliner is barely visible when compared to the size of a seismic streamer array.

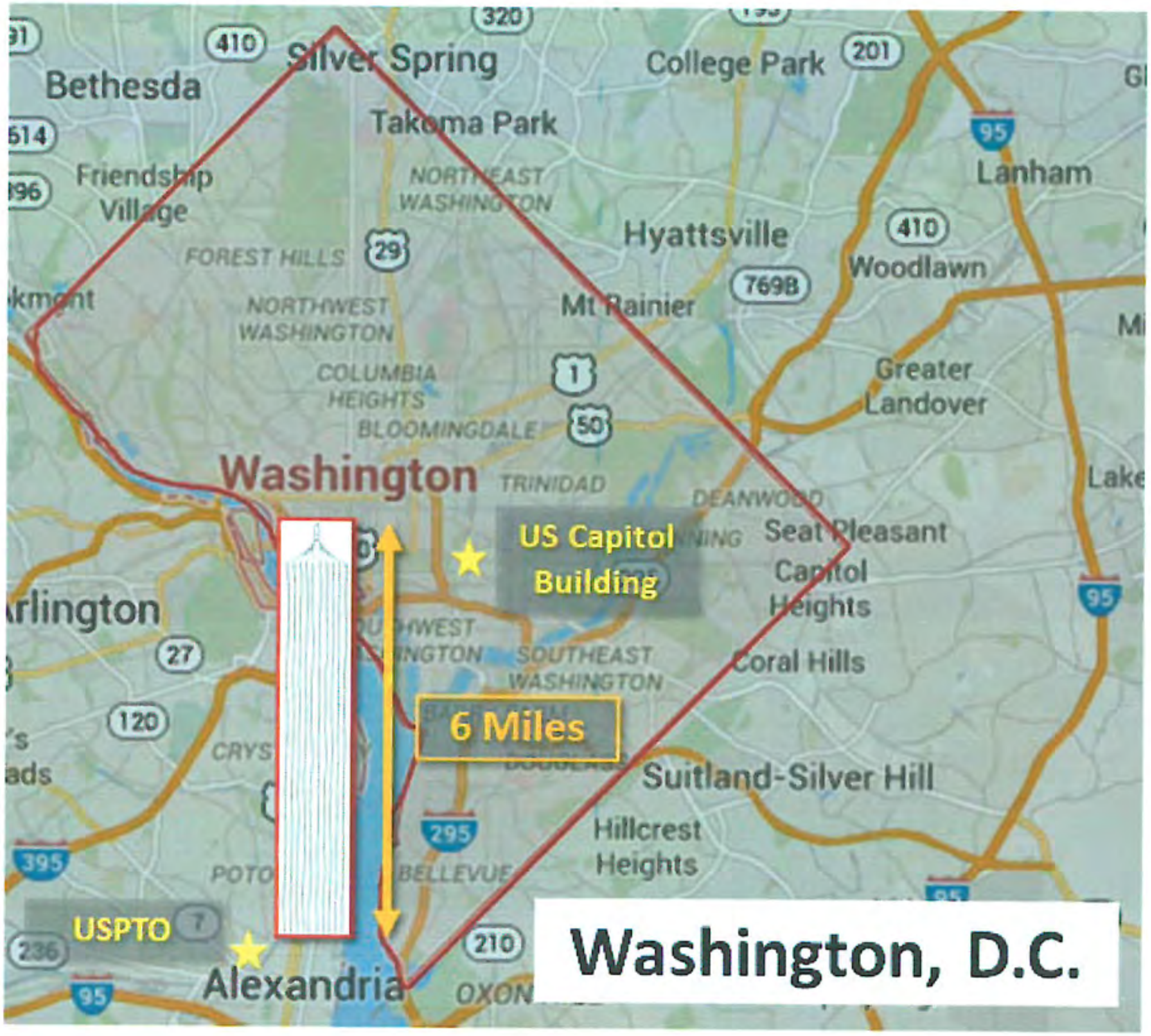


Figure 8 - A seismic streamer array compared to the size of Washington, D.C.

48. These problems related to time delay further exacerbate the challenges of controlling the lateral position of seismic streamers. Applying forces to streamers without knowing where the streamers are or how they move — or being limited to old data provided at irregular intervals — could result in more dangers than no lateral control at all.

B. Dr. Bittleston and Mr. Hillesund's Work

49. In July and August of 2012, I attended the trial and testified as an expert in *WesternGeco L.L.C. v. ION Geophysical Corp. et al.*, Civ. No. 09-1827 (S.D. Tex.).

50. During the trial, Dr. Bittleston, one of the named inventors on the patents at issue here, testified about his work at WesternGeco and its predecessor companies. Mr. Hillesund, the other inventor, testified via depositions, which I have also had the chance to review in their entirety.

51. Specifically, Dr. Bittleston discussed how he started thinking about lateral streamer steering in 1993 (Ex. 2050, Trial Tr. (July 24, 2012) at 521:2-522:3):

> Q. What led you to start investigating streamer steering in Bergen?
>
> A. Well, I'm a scientist originally, at least. And so, I started to look at it from a very scientific point of view. I was curious about how these cables were moving in water, not necessarily very first putting forces on them, but just how they moved when the vessel moved about, and working out that problem. And I started to look what would happen if you put the force on the cable. So I went about it in a very -- really quite academic way trying to work out the exact motion of these things in the water from a theoretical point of view.

52. Dr. Bittleston created a notebook where he started investigating the behavior of streamers in the water. (Ex. 2051, Trial Ex. PTX 73, "Streamer Dynamics Calculations".)

53. This early work shows Dr. Bittleston's derivation of streamer positioning equations and his appreciation for their ability to predict the motion of the streamer (Ex. 2050, Trial Tr. (July 24, 2012) at 522:4-523:13, 524:15-24)[2]:

> So ***full derivation of streamer positioning equations. So what they show basically is if you can solve these equations, you can find out the motion of these cables***. That's what it is. It's Newton's equation of cables and you need to solve them. And it's a bit of work as you'll see to do that.
>
> * * *
>
> I ended up with a description of the dynamics of the cable. And in order to then go ahead ***you have to write a computer code, computer program to solve those equations, which I did***. I wrote that in a language called C. ***And then you run the code and you can predict what's going to happen. I mean, you can predict everything about the motion of these cables*** and hope we're just going to look at a couple of examples of that.

54. In addition, Dr. Bittleston analyzed streamer dynamics using forces to turn streamers and match a particular feather angle. (Ex. 2050, Trial Tr. (July 24, 2012) at 525:24-528:19.) Dr. Bittleston led the project to develop lateral streamer steering at WesternGeco, which lasted several years and resulted in, among other things, the patents at issue here.

C. The Patents At Issue

55. While the goal of streamer steering was long-known, no one had solved how to implement it as of October 1, 1998. Indeed, there were many attempts at creating devices that imparted lateral forces to underwater cables. However, none of these attempts disclose the claimed inventions in the patents at issue or successfully solved the problems associated with laterally steering an array of streamers.

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[2] All emphasis is added unless otherwise noted.

56. There are three core and related requirements recognized and solved by the patents at issue: large transverse motions governed by complex traveling wave dynamics, resulting in the need for lateral steering to employ behavior-based prediction, especially because delays in data acquisition are invariably involved (as opposed to depth control, which can rely exclusively on local control); use of distributed control to apportion intelligence between ship-board global control and local control, and coordinate all actuators; and use of global steering modes rather than just setting thresholds for individual devices.

57. Merely putting a force on the streamer is not enough because, as recognized by the patents' specification, "[i]f the birds 18 are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers." (Ex. 1001, '607 patent at 4:5-7.) In a typical seismic streamer array there could be hundreds of birds, each imparting forces to the streamers. As noted above, these forces cause waves to travel along the streamer. With hundreds of such birds acting on the streamer array the dynamics of the streamer quickly become very complex. In addition, the streamer has changing environmental forces acting on it in the form of currents and eddies that can change over time or even along the lengths of the miles-long streamers. One cannot simply tell the birds to move left or right and expect the streamer array to move in an orderly fashion. Precise knowledge of array behavior is needed for regular operations, *i.e.*, during towing for data acquisition, performing normal maneuvers and other normal operations other than emergency maneuvers. Control along the streamer in this manner is quite different from prior art devices such as paravanes that were located at the front-end of the array or tail buoys that were located at the end of the streamer, which did not have to account for many varying

forces acting along the streamer (or the complex streamer dynamics that are introduced by such forces).

58. Each patent is discussed in more detail below.

1. ’607 Patent

59. The ’607 patent identified an important problem not solved — or even appreciated — by the prior art: “the ***delay period*** and the relatively ***long cycle time*** between position measurements prevents this type of [prior art] control system from rapidly and efficiently controlling the horizontal position of the bird.” (Ex. 1001, ’607 patent at 2:40-43.)

60. The ’607 patent provided a solution to this problem: using a control system that incorporates behavior-predictive model-based control to remedy the delays inherent in positional measurements and to dynamically steer the streamers.

61. The ’607 patent ties its invention to this problem: “Due to the relatively ***low sample rate*** and ***time delay*** associated with the horizontal position determination system, the global control system 22 runs ***position predictor software*** to estimate the actual locations of each of the birds 18.” (Ex. 1001, ’607 patent at 4:51-55.)

62. The specification expands on the inventive control system and how the position predictor software operates by predicting behavior: “[T]he inventive control system utilizes . . . ***behavior-predictive model-based control logic*** to properly control the streamer positioning devices.” (Ex. 1001, ’607 patent at 4:11-14) This disclosure is critical. The ’607 patent recognizes that proper lateral control calls for the use of a behavior-predictive model in the control system.

63. This model is further described later in the specification: "***The global control system*** 22 preferably ***calculates*** the desired vertical and horizontal forces ***based on the behavior of each streamer*** and also ***takes into account the behavior of the complete streamer array***." (Ex. 1001, '607 patent at 4:48-51.) "***The global control system*** 22 preferably maintains ***a dynamic model of each of the seismic streamers*** 12 and utilizes the desired and actual positions of the birds 18 ***to regularly calculate updated desired vertical and horizontal forces the birds should impart on the seismic streamers*** 12 to move them from their actual positions to their desired positions." (Ex. 1001, '607 patent at 4:28-34.)

64. A basic feature of successful lateral control is to incorporate the dynamics of the streamers, *i.e.*, to acknowledge the traveling waves that are set up by unsteady forcing of the streamers, which will affect the behavior of the entire streamer, not just the location where the force is applied. For this reason, predictive control should include the ability to predict where these waves will arrive next so as to factor their effects into the overall control action. Likewise, when the information is not current, due to delays, it is important to predict the evolution of the system to the current state, or, in more elaborate schemes, even to the future, to avoid taking action that will adversely affect the behavior of the streamer at other locations.

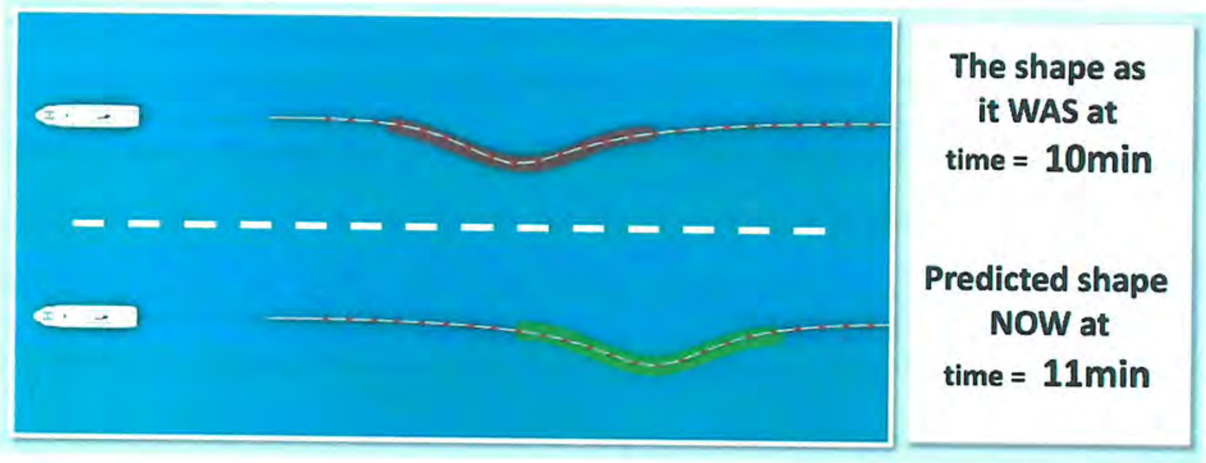

Figure 9 - Predicting each streamer helps address time delay in measurements.

65. In a complex dynamical system with delayed responses, such as a moving streamer, this behavior-predictive dynamic model is essential for effective control. A behavior-predictive model uses past information and knowledge about the dynamics of a system to determine how that system configuration will change over time. The dynamic model of the streamers takes into account forces acting upon the streamer array, both external forces, such as those from cross-currents, and control forces, such as those applied by the birds. A computer model is needed because a human cannot keep up with a changing system involving hundreds of birds and many streamers with significant time delays involved. If these dynamics of the streamer are not taken into account, imparting lateral forces into such a complex system can make things worse. And if one relies on past measured data without projecting them to at least the current time, active steering will not accomplish its goals and is likely to have negative consequences. The '607 patent discloses and claims this critical behavior-prediction requirement for lateral steering of seismic streamer arrays.

2. '967 Patent

66. The '967 patent addressed another problem that the prior art did not disclose or solve: the problem of simultaneously controlling multiple devices spread out throughout the many square-miles of the streamer array. Without that coordinated control across the entire array, the prior art could not effectively laterally steer the streamers to prevent tangling and overcorrection.

67. The '967 patent discloses a distributed control system architecture, using a global control system and local control systems to address these challenges: ***"[T]he inventive control system utilizes a distributed processing control architecture*** and behavior-predictive model-based control logic to properly control the streamer positioning devices." (Ex. 2044, '967 patent at 4:17-20.) I would like to note that although Figure 1 is labeled as "prior art," there are many components and most functions of the system in that figure are described only in the detailed description section of the patents. These include the global control system, the functionality of this system (*e.g.*, behavior-predictive control and the various control modes), as well as the distributed processing control architecture. (*See, e.g.*, Ex. 2044, '967 patent at 4:21-40, 5:20-24.) The global control system, its functionality, and the distributed processing control architecture are claimed by the '520, '967, and '607 patents, which share the same specification. (*See* Exs. 2044, 2063, 1001, '967, '520, and '607 patents.) Therefore, one of ordinary skill in the art would recognize that Figure 1 is depicting a towed array of streamers that includes some prior art components, but that it also includes components, such as those mentioned above, that are inventive and are not present in the prior art.

68. The global control system's role in this distributed control system architecture is to manage continuous coordination of all streamer positioning devices and streamers in the array. "The force and velocity values are ***delivered by the global control system 22 as separate values***

for each bird ***18 on each streamer 12*** continuously during operation of the control system."[3] (Ex. 2044, '967 patent at 5:20-24.)

69. The global control system's continuous coordination of every streamer positioning device involves taking into account the forces and dynamics affecting each streamer: "***The global control system*** 22 preferably calculates the desired vertical and horizontal forces based on ***the behavior of each streamer*** and also takes into account ***the behavior of the complete streamer array***." (Ex. 2044, '967 patent at 4:54-57.)

70. Beyond coordinating control of every streamer positioning device in the streamer array, the global control system also uses a dynamic model of each streamer to prevent issues related to long delay periods and cycle times: "***The global control system*** 22 preferably ***maintains a dynamic model of each of the seismic streamers*** 12 and utilizes the desired and actual positions of the birds 18 ***to regularly calculate*** updated desired vertical and horizontal forces the birds should impart on the seismic streamers 12 to move them from their actual positions to their desired positions." (Ex. 2044, '967 patent at 4:34-40.)

71. The global control system's ability to continuously coordinate all the streamer positioning devices in the array, combined with a behavior-based predictive model, and then send commands to each local control system helps prevent the type of overcorrection that can increase the likelihood of streamer tangling. Taking the behavior of each streamer into

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[3] The '967 patent explains that location information can be sent in lieu of force information. (Ex. 2044, '967 patent at 6:45-47 ("Using this type of embodiment, the global control system 22 can transmit location information to the local control system 36 instead of force information.").)

account, using a dynamic model of each streamer, allows for more accurate lateral steering that is less prone to overcorrect a streamer, which might cause tangles.

72. It is this coordination of all the streamer positioning devices via the global control system that overcomes the problem of steering an entire array of seismic streamers. Although the claims require that the global control system only send commands to at least one local control system at a given instant, the specification and claim language specify clearly that the global control system oversees the entire array.

73. The global control system in the '967 patent is the source of much of the functionality discussed in the '967 patent's specification. The feather angle, turn control, and streamer separation operation modes involve simultaneous, coordinated control of the entire streamer array. For example: "In the feather angle control mode, ***the global control system 22 attempts to keep each streamer in a straight line offset*** from the towing direction by a certain feather angle." (Ex. 2044, '967 patent at 10:32-35.)

74. The global control system in the '967 patent also enables the "untwist" function described in the patent's specification: "***The untwist function is implemented by the global control system 22 which monitors the splay angle for all of the birds 18 in each streamer 12.*** At regular intervals or when the splay angle has reached a critical value, ***the global control system 22 instructs each local control system*** 36 to rotate each bird 18 in the opposite direction of the twist." (Ex. 2044, '967 patent at 7:66-8:4.)

75. Other approaches, where control does not account for coordinated — *i.e.*, global — control of all birds, or systems without model-based prediction would be ineffective, potentially causing entanglements, or even stability problems. As discussed above, this need for global

control is unique to lateral steering and is not required for depth birds. For this reason, prior art references that mention the concept of lateral steering often incorrectly assume that it could be as simple as vertical control, such as Workman, as discussed below. This approach would not work, and would likely lead to streamer tangling. If an upstream bird, for example, has applied a strong force several seconds before the present time, its action may be felt at exactly the time when control is applied to the downstream bird; but this oncoming wave would be unknown to the control system without a model-based predictive controller, which can track the actions of all birds at previous times. The position, separation, velocity, and acceleration of the downstream bird could be quite different than presumed from previous measurements and, hence, the second steering command could be just as likely to harm the system as help.

3. '520 Patent

76. The '520 patent discloses some of the benefits to properly controlled lateral steering: "[t]he benefits that can be obtained by using properly controlled horizontally steerable birds can include ***reducing horizontal out-of-position conditions*** that necessitate reacquiring seismic data in a particular area (i.e. ***in-fill shooting***), ***reducing the chance of tangling*** adjacent streamers, and ***reducing the time required to turn*** the seismic acquisition vessel when ending one pass and beginning another pass during a 3D seismic survey." (*See, e.g.*, Ex. 2063, '520 patent at 2:4-12.)

77. In order to achieve lateral control of streamers, the inventors also created a control system capable of using steering control modes, and taught three specific modes of operating the

streamer spreads: feather angle mode, streamer separation mode, and turn control mode. (Ex. 2063, '520 patent at 10:27-65.)

78. "In the feather angle control mode, the global control system 22 attempts to keep each streamer in a straight line offset from the towing direction by a certain feather angle." (Ex. 2063, '520 patent at 10:29-32). In this mode, the streamers are kept in a "straight line," so that even when "current fluctuations . . . dramatically influence" the streamers, the control system works to maintain their shape in a straight line, parallel to each other, at a particular feather angle. (Ex. 1001, '520 Patent at 4:14.)

79. Streamer separation mode is a mode to control separation, or spacing, between streamers. From Dr. Bittleston and Mr. Hillesund's inventor's materials and testimony, I have seen that they envisioned many types of separation — "streamer separation steering" to maintain a given separation, a separation mode that targeted equal separation between adjacent streamers, and a bad weather mode that sought to protect against tangling in negative conditions. (Ex. 2050, Trial Tr. (July 24, 2012) at 499:14-500:1, 514:11-21; Ex. 2052, Hillesund Dep. Tr. (October 20, 2010) at 223:7-23.) For example, the specification discloses "regular horizontal spacing" of 100 meters in some configurations. (Ex. 2063, '520 patent at 3:38-41.) In some embodiments, the streamer separation mode implements "regular spacing" between all adjacent streamers. (*See* Ex. 2063, '520 patent at 10:61.) In some circumstances, *e.g.*, extreme weather, streamer separation mode can prevent streamer tangling and is characterized primarily by "the global control system attempt[ing] to maximize the distance between adjacent streamers." (Ex. 2063, '520 patent at 10:53-58.)

80. "The turn control mode is used when ending one pass and beginning another pass during a … line change." (*See* Ex. 2063, '520 patent at 10:38-53.) The turn control mode is made up of two phases. "In the first part of the turn, every bird 18 tries to 'throw out' the streamer 12 by generating a force in the opposite direction of the turn." (Ex. 2063, '520 patent at 10:40-42.) "In the last part of the turn, the birds 18 are directed to go to the position defined by the feather angle control mode." (Ex. 2063, '520 patent at 10:42-44.) As the inventors recognized, "[b]y doing this, a tighter turn can be achieved and the turn time of the vessel and equipment can be substantially reduced." (Ex. 2063, '520 patent at 10:44-46.)

81. These control modes involve configuring the control system to automatically achieve particular configurations despite variable environments. In order to do so, the control system "utilizes a distributed processing control architecture and behavior-prediction model-based control logic to properly control the streamer positioning devices." (Ex. 2063, '520 patent at 4:17-20.) Indeed, the control system is described as "preferably calculat[ing] the desired vertical and horizontal forces based on the behavior of each streamer" and "tak[ing] into account the behavior of the complete streamer array." (Ex. 2063, '520 patent at 4:54-57.) The specification also notes that the system preferably maintains a "dynamic model of each of the seismic streamers" so that desired forces can be "regularly calculate[d]" based on the desired and actual positions of the birds. (Ex. 2063, '520 patent at 4:34-40.)

82. Each of the control modes mentioned above, *i.e.*, feather angle mode, turn control mode, and streamer separation mode, invokes and is reliant on this "global control system." (*See*, *e.g.*, Ex. 2063, '520 patent at 10:29-32, 10:50-53, 10:57-59.)

V. CLAIM CONSTRUCTION

83. I have reviewed WesternGeco's proposed claim constructions (which I have listed below), and I agree with those claim constructions. I have added some additional comments based on the patents' specifications and how a POSA would interpret the terms based on my experience in the field.

A. "Streamer Positioning Device"

84. After having read the patents at issue and their specifications, it is clear to me that these inventions are directed to the lateral control of seismic streamers. For example, the patents describe the "present invention" as "having respective streamer positioning devices . . . so as to steer the streamer positioning device ***laterally***." (*E.g.*, Ex. 2063, '520 patent at 3:3-10.) Moreover, the advantages of streamer positioning discussed in the patents are only achieved through the use of lateral steering, not through the use of depth control — *e.g.*, reducing infill, reducing turn time, and avoiding streamer tangles. (Ex. 2063, '520 patent at 2:4-12.)

85. Similarly, the claimed inventions make no sense without lateral steering. For example, there is no need to use predicted positions of streamer positioning devices when steering only in depth — one need only use a simple feedback loop and a pressure sensor. In contrast, streamer separation mode, feather angle mode, and turn control mode all require the use of streamer positioning devices that exert horizontal forces.

86. The broadest reasonable interpretation of "streamer positioning device," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the

relevant art as of the priority date of the patent at issue is "a device that controls at least the lateral position of a streamer as it is towed."[4]

B. "Predicting Positions"

87. The '607 patent's inventors recognized a serious problem with the prior art: "[t]he actual horizontal positions of the birds may be determined every 5 to 10 seconds and there may be a 5 second delay between the taking of measurements and the determination of actual streamer positions." (Ex. 1001, '607 patent at 2:35-38.) "Due to the relatively ***low sample rate*** and ***time delay*** associated with the horizontal position determination system, the global control system 22 runs ***position predictor software*** to ***estimate the actual locations*** of each of the birds 18." (Ex. 1001, '607 patent at 4:51-55.) The patent further describes this predictive aspect of the control system: "***the inventive control system*** utilizes . . . ***behavior-predictive model-based control logic*** to properly control the streamer positioning devices." (Ex. 1001, '607 patent at 4:11-14.) The '607 patent describes the use of these predictions, which can be determined using a dynamic streamer model, to calculate the actual locations of the streamer positioning devices. (Ex. 1001, '607 patent at 4:28-34, 4:48-51.) Because behavior-predictive modeling is used to "predict" the position of the streamer positioning devices, a prediction in the context of the '607 patent is more than a mere estimate of position.

88. The broadest reasonable interpretation of "predicting positions," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the relevant art as of

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[4] My opinions would not change even if the Board adopts the construction from its institution decision, *i.e.*, "a device that positions a streamer as it is towed."

the priority date of the patent at issue is "determining positions using a behavior-predictive model."[5]

C. "Calculate Desired Changes"

89. The claims of the '607 patent also state that the predicted positions should be used "to calculate desired changes in position of one or more of the streamer positioning devices." (Ex. 1001, '607 patent at claim 1; *see also* Ex. 1001, '607 patent at claim 15.) The specification of the '607 patent further describes the calculation of desired changes. "The global control system 22 preferably calculates the desired vertical and horizontal forces ***based on the behavior of each streamer*** and also takes into account ***the behavior of the complete streamer array***." (Ex. 1001, '607 patent at 4:48-51.) In addition, "[t]he global control system 22 preferably ***maintains a dynamic model of <u>each</u> of the seismic streamers*** 12 and ***utilizes the desired and actual positions of the birds 18 to regularly <u>calculate</u> updated desired vertical and horizontal forces*** the birds should impart on the seismic streamers 12 to move them from their actual positions to their desired positions." (Ex. 1001, '607 patent at 4:28-34.) One of the goals of the '607 patent is to precisely control the movement of the seismic streamers. (Ex. 1001, '607 patent at 2:49-57 ("An advantage of the present invention is that the position of the streamer may be better controlled…"), 4:39-47.) In order to accomplish this goal, one must take into account the behavior of the system. Using a model of streamer behavior to calculate forces ensures that the forces sent to the

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[5] My opinions would not change even if the Board adopts the construction from its institution decision, *i.e.*, "estimating the actual locations." The Board recognized that a "prediction" cannot be plucked form thin air. It must be based on prior data. ('607 Institution Decision at 9 ("the received position data of any bird 18 is old, *i.e.*, not instantaneous, or current, but is used to estimate a position of bird 18").)

streamer positioning devices will move the device from its current position to its desired position, while accounting for the complex dynamics of the seismic streamers discussed above. And as explained above and recognized in the '607 patent, sending forces to streamer position devices without any consideration of the dynamics of the streamer could cause more harm than good. (Ex. 1001, '607 patent at 4:5-7 ("If the birds 18 are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers.").) This dual use of a model of the system in both estimation and control is used in "model-based compensators" (*i.e.*, controllers which are based on a model of the dynamics of the system). For example, in LQG (Linear Quadratic Gaussian) control, a Kalman filter (optimal observer) that contains a model of the system is used to estimate the "state" of the system (the set of parameters that describe the system fully at any instant of time) from noisy measurements, combined with a full-state feedback controller whose gains are calculated using a second identical model of the system (optimal controller). In other words, a person of skill in the art reading the specification of the Bittleston patents would appreciate that a system model of streamer and array behavior would be used in both the "predicting" and also the "calculating" aspects of the invention, and as an expert in the art I readily recognize the benefits for streamer steering in doing so.

90. The broadest reasonable interpretation of "calculate desired changes," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the relevant art as of the priority date of the patent at issue is "determine forces based on streamer and array behavior."

D. "Global Control System"

91. My understanding of a "global control system" stems from the use of the word "global." This term is specific. To a POSA, it means that the control system oversees and affects the entire system. It is aimed at ***coordinated*** control. In the context of seismic surveying, a POSA would have understood that the global control system coordinated the control of the entire array of streamers. For example, the '967 patent's specification describes the "global control system" as delivering force values "as separate values for ***each bird*** 18 on ***each streamer*** ***continuously*** during operation of the control system." (Ex. 2044, '967 patent at 5:20-23.) In addition, the '967 patent specifies that "[t]he global control system 22 preferably calculates the desired vertical and horizontal forces based on the behavior of each streamer and also takes into account the behavior of ***the complete streamer array***." (Ex. 2044, '967 patent at 4:54-57.)

92. Moreover, the specification makes it clear that a "global control system" is different from a "remote control system." (Ex. 2044, '967 patent at 2:40-54.) And a POSA would not consider these two types of control systems the same. "Remote" control simply implies control at a distance. There is no indication that a "remote" control system coordinates control or takes into account the functioning of the whole system.

93. The broadest reasonable interpretation of "global control system," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the relevant art as of the priority date of the patent at issue is "a control system configured to coordinate all streamer positioning devices in the array."

E. "Streamer Separation Mode"

94. The broadest reasonable interpretation of "streamer separation mode," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the relevant art as of the priority date of the patent at issue is "a control mode that attempts to set and maintain the spacing between adjacent streamers." As shown below, streamer separation mode attempts to keep or maintain streamer spacing to improve data collection and avoid potentially hazardous situations such as streamer tangling. This precise control is helpful in avoiding over-correction and streamer positioning error. (Ex. 2063, '520 patent at 2:64-67, 4:45-53.)

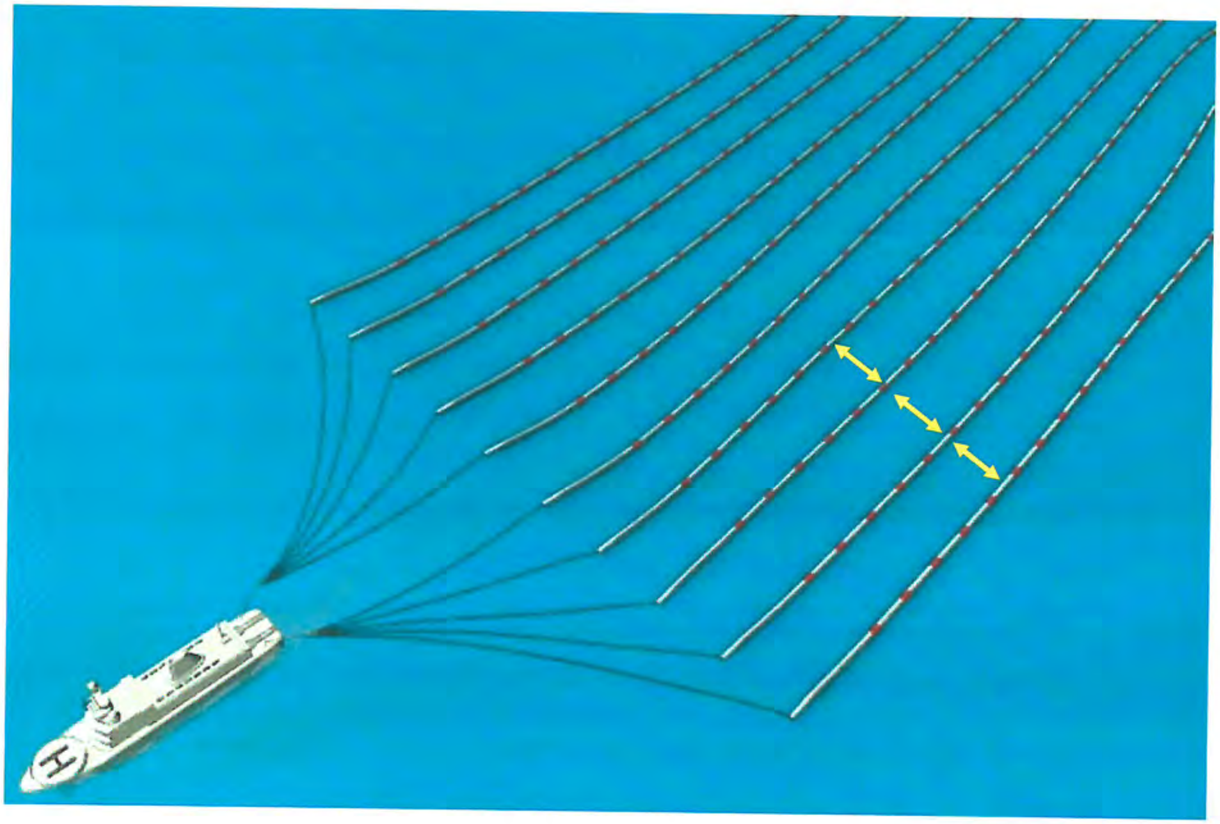

Figure 10 - An idealized example of streamer separation mode.

F. "Feather Angle Mode"

95. The broadest reasonable interpretation of "feather angle mode," based on the specification of the patents at issue, from the standpoint of one having ordinary skill in the relevant art as of the priority date of the patent at issue is "a control mode that attempts to set and maintain each streamer in a straight line offset from the towing direction by a certain feather angle."[6]

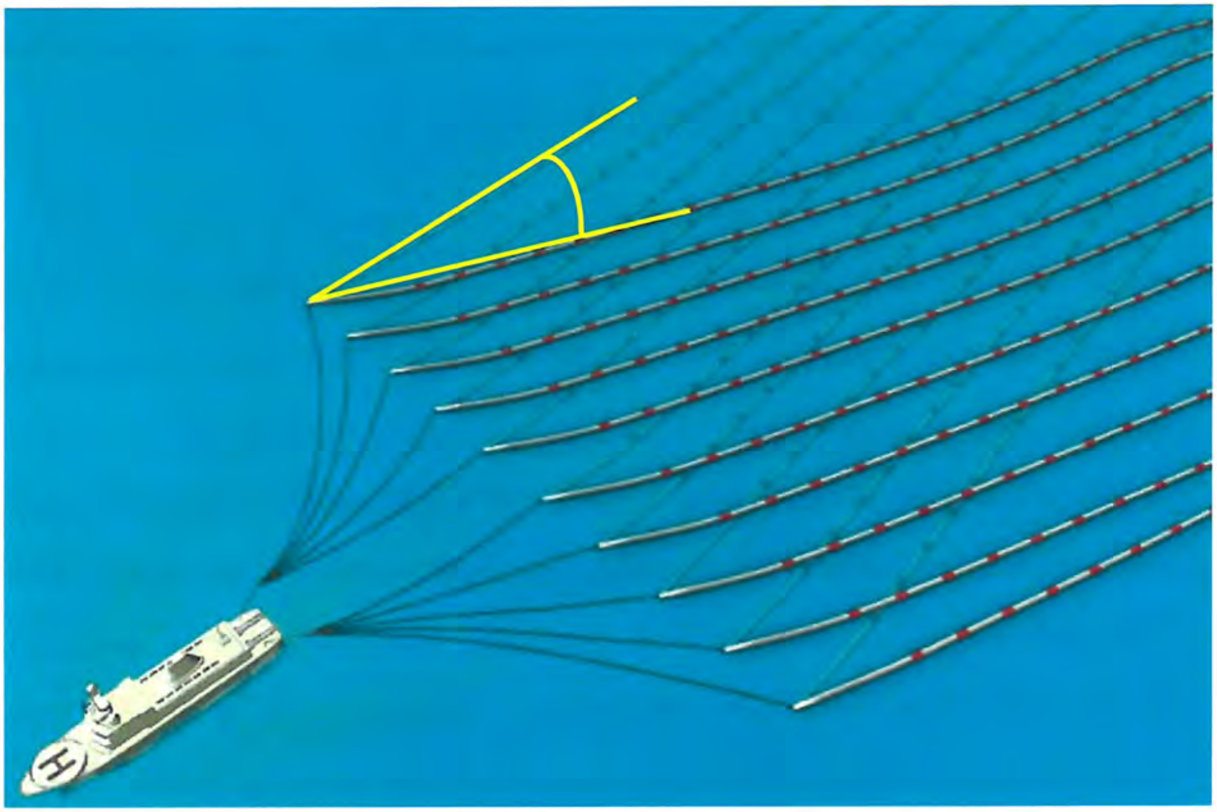

Figure 11 - An idealized example of feather angle mode.

VI. THE ALLEGED PRIOR ART

A. Workman

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[6] My opinions would not change even if the Board adopts the construction from its institution decision, *i.e.*, "a control mode that attempts to keep each streamer in a straight line offset from the towing direction by a certain feather angle." In my understanding, there is no difference between WesternGeco's proposed construction and the Board's initial construction.

96. U.S. Patent No. 5,790,472 names Ricky L. Workman and Ronald Edward Chambers as its inventors ("the Workman patent" or "Workman"). The Workman patent was filed on December 20, 1996 and issued on August 4, 1998. It is titled "Adaptive Control of Marine Seismic Streamers."

97. Workman addresses two main concerns when conducting a seismic survey: keeping noise low and avoiding a catastrophic streamer tangle or accident.

98. Workman first notes that noise may be caused on seismic streamers by devices attached on them. (Ex. 1004, Workman at 1:62-2:9.) Indeed, noise can get so bad that the data is worthless and must be repeated. (Ex. 1004, Workman at 1:62-2:9.) Next Workman points out that streamers may encounter "at risk" situations, where they might be damaged or become tangled. (Ex. 1004, Workman at 2:20-30.) Workman attempts to address these two issues, but he considers them to be opposed to each other. In contrast to the patents at issue here, Workman was not concerned about signal delay, behavior-based active steering, or control modes to achieve the desired array behavior. Instead, the claims of Workman focus primarily on noise reduction and ***limiting*** streamer movement within (unspecified) bounds, through the use of restrictive "threshold parameters."

99. Workman attempts to accomplish this in three ways:

100. First, Workman uses the concept of a "threshold parameter" before any forces are ever applied. This is a value entered via a terminal that is used in Workman's "Streamer Control Processor" control loop. (*See* Ex. 1004, Workman Fig. 3, 3:62-4:8.) If the threshold is not exceeded, then the system restarts and ***no commands are sent to any devices in the system***. (Ex. 1004, Workman at Fig. 3.) In other words, "threshold parameters are established for

determining when the streamer cables should be repositioned." (Ex. 1004, Workman at 3:63-65.) There are no target shapes, only thresholds not to exceed. (Ex. 1004, Workman at 4:12-17.) If no threshold parameter is exceeded, ***the system does nothing and is restarted***. (Ex. 1004, Workman at 4:31-35.)

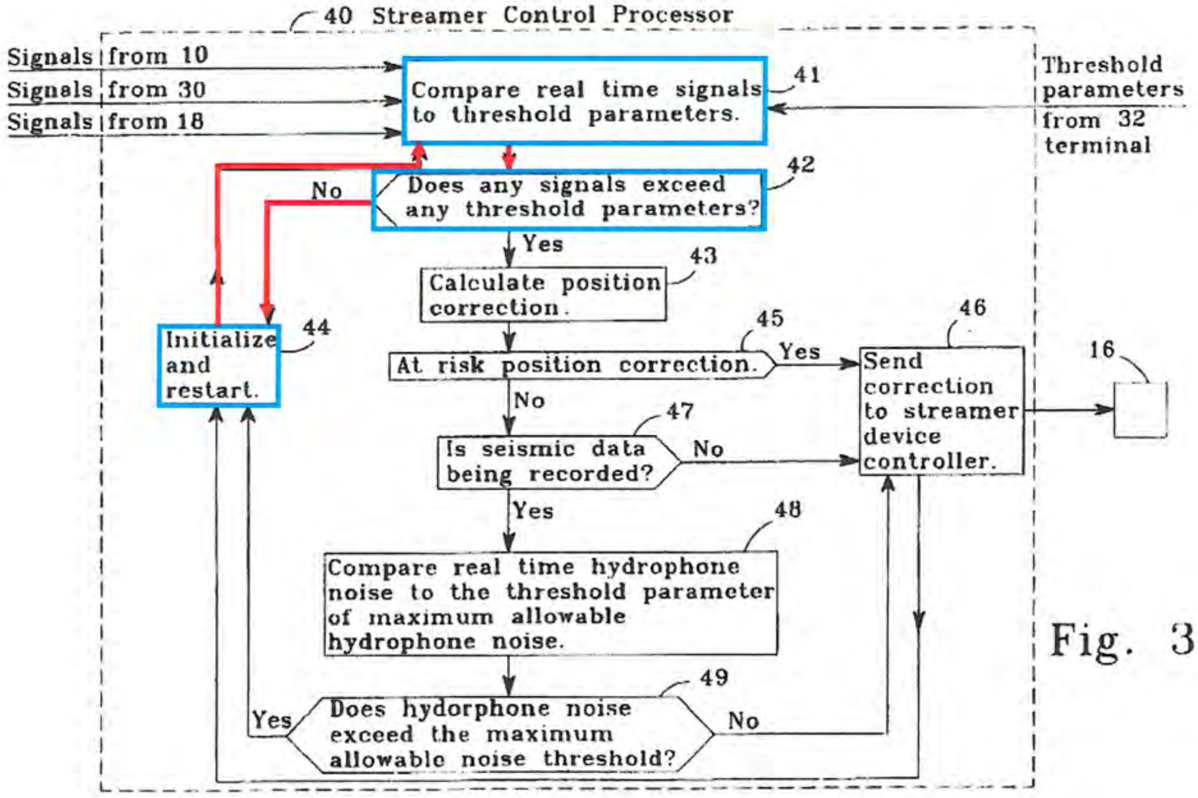

Figure 12 - Workman Fig. 3, emphasis added.

101. During his deposition, Dr. Evans did not appear to appreciate that the Workman system operates only if a threshold value is exceeded (Ex. 2039, Evans Dep. Tr. at 216:7-21, 218:4-12):

> Q. ***Okay. So, it is your testimony that, nevertheless, even though that threshold is not exceeded, that Workman would describe a calculating position?***
> A. ***It constantly calculates position and adjusts position even if the adjustment is 0.***

> Q. It constantly calculates a corrected position?
> A. It constantly calculates -- it constantly outputs a predicted position and compares that with other data. And then moves, provides signals to move equipment, whether that is a 0, it irrespective. It still puts out a 0.
>
> * * *
>
> Q. ***So, it is your testimony that commands are calculated regardless of whether or not a threshold is exceeded?***
> A. ***Commands are provided*** from the marine seismic data acquisition out to, well, to the -- there we go, from the, ***from Workman's streamer control process to the streamer cable controllers, constantly, even if they have no value.***

102. But a review of Figure 3 above shows that the Workman system does not do any sort of position correction calculation unless and until a signal exceeds a threshold parameter. Dr. Evans is simply not correct when he states that the Workman system always sends commands to Workman's streamer cable controller.

103. Second, if a threshold parameter is exceeded, Workman's system checks to see if the system is in an "at risk" situation. (Ex. 1004, Workman at Fig. 3.) Workman identifies two "at risk" situations: "[the streamer cables] face the possibility of becoming entangled with each other or . . . colliding with an obstructive hazard." (Ex. 1004, Workman at 4:40-43.) If such a situation exists, a force is applied. (Ex. 1004, Workman at 4:43-46.) If the streamers are not "at risk" then the system goes to its third step.

104. Workman's third step prioritizes noise control over streamer control when seismic data are being recorded (*i.e.*, during system operation). In short, if noise levels are too high, the system does not attempt to move the streamers despite a threshold parameter being exceeded. (Ex. 1004, Workman at Fig. 3; *see also* Ex. 1004, Workman at 5:14-30.)

105. Throughout this process, no attention is given to maintaining the streamers in any particular configuration. The only goal is to move streamers out of "at risk" situations. Nor does the Workman system give any indication of specific configurations that streamers should be moved to, beyond avoiding the threshold. And after they have been moved out of those situations, the Workman system does nothing — it does not maintain any particular streamer configuration.

106. Workman also does not disclose predicting the positions of the streamer positioning devices or using those predicted positions to calculate desired changes in the positions of the streamer positioning devices. There is no disclosure of any sort of behavior-predictive control at all. At best, Workman determines the "real time position of the seismic sources and seismic streamer cables" using a Kalman filter, which I discuss in greater detail below in the context of the '607 patent. (Ex. 1004, Workman at 2:15-19.)

107. Workman has no recognition of the unique problems associated with lateral control of seismic streamers and streamer positioning devices. It contains no discussion of streamer dynamics, the time lag problem, and its effect on streamer positioning device control at all, and it contains no discussion of moving streamer positioning devices to desired positions.

108. The types of force devices contemplated by Workman would not be capable of achieving the steering taught and claimed by the Bittleston patents, which I also address below.

109. Workman's lack of recognition of the inherent effect of the dynamics of the streamers, the effect of the time delay, and low sample rate makes sense because Workman focuses on the minimization of streamer movement for noise control rather than effective control of streamer positioning devices.

B. Elholm

110. U.S. Patent No. 5,532,975 names Tor Elholm as its inventor ("the Elholm patent" or "Elholm"), and is assigned to Geco A.S., a predecessor to WesternGeco. The Elholm patent was filed on February 8, 1994, claims priority to an earlier foreign application dated February 23, 1993, and issued on July 2, 1996. It is titled "Device and Method for Positioning of Towing Systems for Use in Marine Seismic Surveys."

111. Elholm describes a device that can be used to position seismic equipment by creating tension at the front-end of an array using a spreading device — also known as a paravane — without having a connection to the surface.

112. Paravanes were initially developed to destroy naval mines, strung out from the bow, so its wings would force it away from the ship and keep a constant tension on the towing line. Hence, a paravane is a towed structure equipped with foils to provide lateral force, like a water kite. Paravanes and similar devices, such as diverters, otter boards, *etc.*, are used in commercial fishing, marine scientific and commercial exploration, and the military. For streamer arrays, they are bulky, and primarily used to support the tension in the front-end of the streamers to provide sufficient force to space the front of the array apart. Paravanes are not good positioning devices along streamers, because they are bulky, causing additional, slow dynamics; also they can cause significant flow noise that is adverse to the hydrophone operation.

113. Elholm recognized that it is sometimes desirable to increase the width between seismic streamers at the head of the array as they are towed. (Ex. 1017, Elholm at 1:49-53.) Elholm also recognized that there were already several solutions to creating tension or increasing the

width between streamers at the head of the towed array. (Ex. 1017, Elholm at 1:59-2:6.) But prior front end devices had many problems. (Ex. 1017, Elholm at 2:7-38.) For example, Elholm describes how surface paravanes are vulnerable to flotsam, which can cause extensive damage to the equipment. Elholm also recognized that paravanes create "a great deal of friction" that can increase fuel costs and hurt tow width. In addition, prior art systems connected to the surface introduced unwanted noise and wear and tear into the system. (Ex. 1017, Elholm at 2:7-38.)

114. Elholm's goal was to replace old front end devices that relied on connections to the surface. (Ex. 1017, Elholm at 2:7-48.) Elholm's solution was to create a vessel without surface connections that induced tension at the front end of a seismic streamer system.

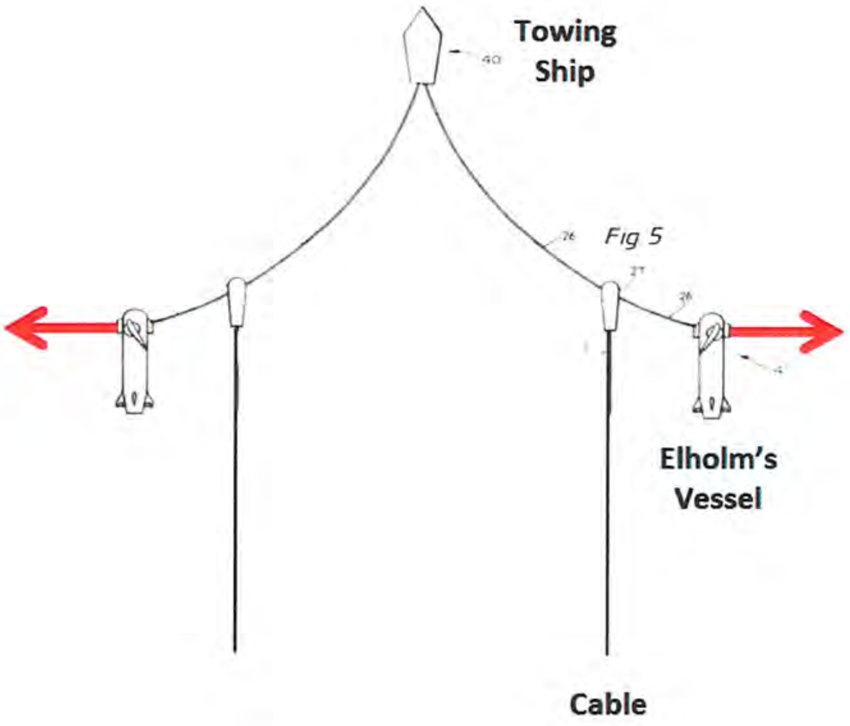

Figure 13 - Elholm's Fig. 5, modified to show how the device creates tension in the front end of the array.

115. The Elholm device was meant to be an alternative to preexisting "otter-like devices with one or more foils" that were "connected with a float on the surface" and created tension at the front end of the seismic tow. (Ex. 1017, Elholm at 1:59-67.) In order to replace these "otterboards," Elholm's device would have to impart large forces at the front end, necessitating a very large wing.

116. Figure 9 shows a photograph of a front-end paravane that PGS was using on one of its vessels in 2009. (Ex. 2053, *Acquisition Technology Snapshots*, 9 PGS Tech Link, No. 12, at 1-2 (2009).) As PGS explains:

> ***Paravanes*** are used to maintain streamer separation, and ***represent the outermost component of any towed streamer spread***. Vertical foils are kept in position by a float at the top (refer to Figure 2). ***The largest paravanes used in operation have foils with a height of 10 m***, suspended below cylindrical floats more than 9 m in length. ***Tension in the "superwide" towing rope can exceed 20 tons***.

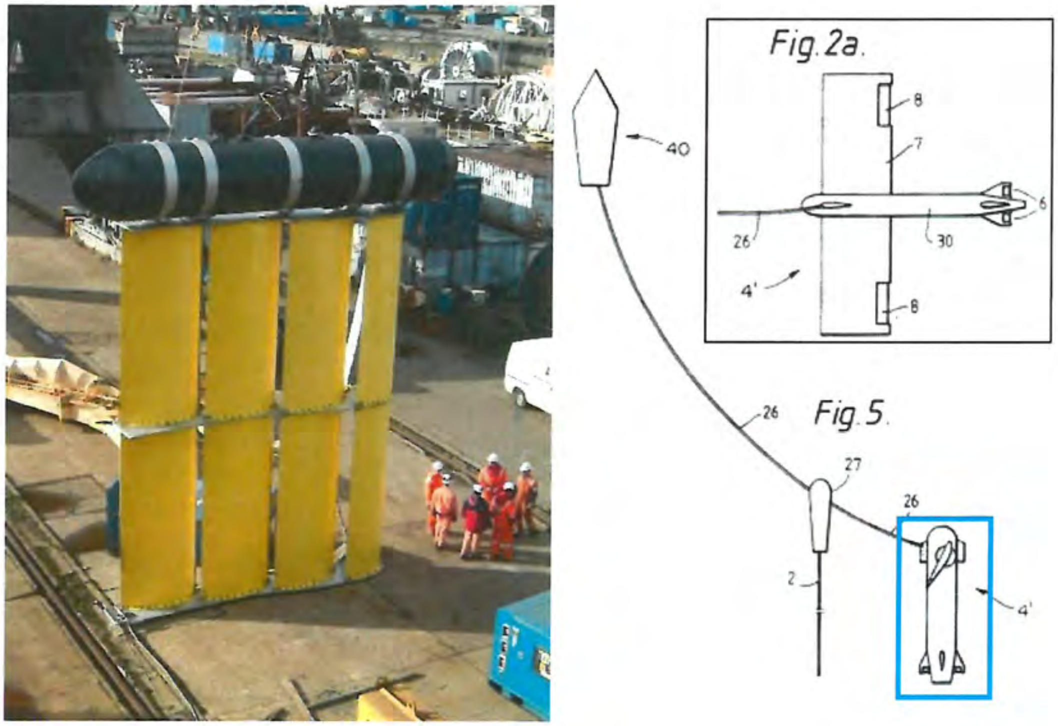

Figure 14 - An example of a massive front-end paravane or otterboard compared to Elholm Figs. 2a & 5.

117. In contrast, the devices used in WesternGeco's QMarine system (the commercial embodiment of the '520, '607, and '967 patents) and the DigiFIN system are much smaller, usually on the order of a few feet wide.

Figure 15 - The QFin (left) and DigiFIN (right).

118. Elholm does not disclose the use of lateral control devices along the length of an array of seismic streamers. Nor does Elholm disclose the use of predicted positions to calculate desired changes in the positions of streamer positioning devices.

119. Like Workman, Elholm has no recognition of the unique problems associated with lateral control of seismic streamers and streamer positioning devices.

C. Hedberg

120. U.S. Patent No. 3,581,273 names Ronald M. Hedberg as its inventor ("the Hedberg patent" or "Hedberg"). The Hedberg patent was filed on November 10, 1969, claims priority to an application dated June 13, 1967, and issued May 25, 1971. It is titled "Marine Seismic Exploration."

121. Hedberg discusses old technology — positioning of "spreads" of hydrophones and echo responsive means along either a single towed cable behind the towing vessel, and in particular as part of a "cross-spread" arrangement (Ex. 1005, Hedberg at 1:25-38, 1:54-2:2):

> It has been common practice heretofore to carry out marine seismic surveys by employing a number of hydrophones that are connected by electrical conductors to recording equipment, and are towed behind a boat moving over the area to be surveyed. ***The hydrophones are thereby stretched out in a straight line or "spread," after which an echo producing impulse, such as an explosive blast, spark or the like, is generated at a point along or beside the spread of hydrophones.*** . . . Such systems serve to produce a record which indicates the profile of the strata ***in a single, substantially vertical plane beneath the "spread"*** . . .
>
> * * *
>
> In some instances "cross-spread" arrangements of impulse generating means and geophones have been used in seismic prospecting on land. ***However, cross spreads in marine areas have not heretofore been practical because of the problems of handling a main cable of the requisite length, and because of the transverse spread required to obtain meaningful results*** . . . [I]mproved and more complete records indicating the structural configuration in three dimensional space of an area under marine survey are obtained rapidly and accurately by locating and maintaining the hydrophones or other echo responsive means at predetermined points spaced apart in two directions to provide a 'cross spread' within the horizontal plane."

122. Hedberg's emphasis is on "generat[ing] a set of echo producing impulses from which accurate records may be obtained by energizing ***one or more impulse sources located*** at the desired and predetermined points which may be spaced with respect to each other ***in two directions in a horizontal plane above the area under [the] survey***," *i.e.*, in its "cross spread," indicated below in red and blue. (Ex. 1005, Hedberg at 2:12-17.)

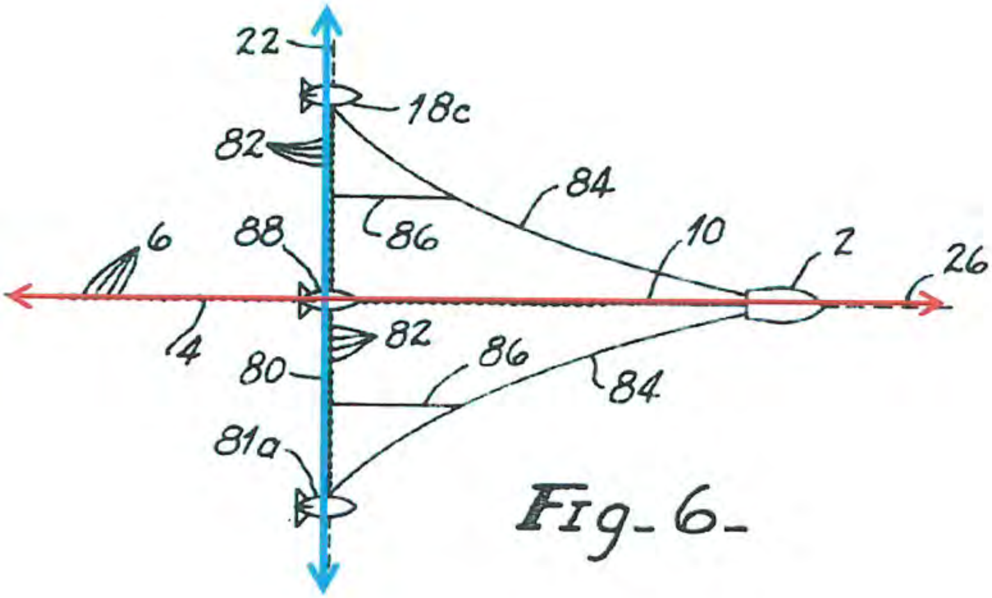

Figure 16 - Hedberg Fig. 6 with annotations.

123. The "spreads" discussed in Hedberg do not refer to streamers, but rather discuss a series of "hydrophones or other echo responsive elements 6 extend[ing] rearwardly in a straight line." (Ex. 1005, Hedberg at 3:1-8.)

124. Notably, the cables in Hedberg are primarily controlled through front-end paravanes. This is because Hedberg is concerned with "spreading out" the front end of the cables until they are "spaced apart." (Ex. 1005, Hedberg at 3:66-75.) The goal in Hedberg is to have large distances between the cables — 1/4 to 1/2 mile — to permit resolution of signals from respective sources. (Ex. 1005, Hedberg at 3:66-75.) No control of the spacing is taught or desired — merely that the separation be large enough to permit signal resolution. While Hedberg states that the spreads of Figure 8 "may be arranged in three parallel lines extending parallel to the direction of transverse of the area under survey," (Ex. 1005, Hedberg at 6:14-

16), Hedberg does not disclose any "control modes" for maintaining those cables in parallel positions to each other once surveying has begun.

125. Hedberg recognizes that its disclosed configuration "is subject to error due to the set and drift or displacement of the spread [of hydrophones] by marine currents at the successive times when shots or impulses are generated for recording purposes." (Ex. 1005, Hedberg at 6:27-32.)

126. To solve this problem, Hedberg proposes placing paravanes spaced apart at various points along a cable, but does not disclose any specific mode of control. (Ex. 1005, Hedberg at 6:33-57.) Hedberg states that it may be possible to vaguely hold the seismic means "in such consistent and related positions during traverse of the area under survey that the records obtained will be capable of ready and accurate correlation and interpretation." (Ex. 1005, Hedberg at 6:54-57.) Thus Hedberg shows some consideration for the relative spacing between sources and receivers, but provides no discussion or consideration of the spacing or separation ***between streamers***. Hedberg shows in Figure 8 that when multiple cables are towed — without any steering devices along their length — they may assume a roughly parallel pattern. No spacing or separation of those cables is set or maintained, nor is any desire to do so disclosed.

127. Hedberg proposes the use of radar reflections in order to control the paravanes — but there is no recognition of the unique problems associated with lateral control of seismic streamers and streamer positioning devices. The use of radar to control the paravanes would require surface connections, creating additional drag and flow noise. Overall the use of

bulky paravanes with radar control would render lateral control unworkable, *e.g.*, when used for the control modes recited in the '520 patent.

128. And, in contrast to the '520 patent, Hedberg does not disclose maintaining any streamer at a set feather angle. Nor does Hedberg, in Figures 10-12 or elsewhere, disclose relative steering or positioning of streamers in an array. Hedberg contains no discussion of a behavior-predictive model to be used in predicting the positions of the streamer positioning devices or in calculating the desired change in positions of the streamer positioning devices.

D. '636 PCT

129. The international application WO 98/28636 PCT names Simon Bittleston as its inventor ("the '636 PCT"). The '636 PCT was filed on December 19, 1997, claims priority to a foreign application dated December 20, 1996, and published on July 2, 1998. It is titled "Control Devices for Controlling the Position of a Marine Seismic Streamer."

130. The '636 PCT is directed to a bird itself rather than a distributed control system.

131. The '636 PCT has very little disclosure of any control system beyond a local control system. It only notes that "[w]hen the streamer also includes a control line, the control means is preferably arranged in use to receive control signals from the control line." (Ex. 1006, '636 PCT at 3.) Simply receiving control signals, however, does not imply any sort of ***global*** control of the array of streamers.

132. The '636 PCT does not mention a "global" control system, and it does not address control of a large, complex array of birds, which requires more coordinated control.

133. The '636 PCT covers a conventional approach to control — using a feedback loop that does not require behavior-based predictive global control.

VII. WESTERNGECO'S PATENTS ARE NOT ANTICIPATED OR OBVIOUS

A. The '607 Patent

1. Claims 1 & 15

134. I have reproduced Claims 1 and 15 below:

> 1. A method comprising:
> (a) towing an a array of streamers each having a plurality of streamer positioning devices there along;
> (b) predicting positions of at least some of the streamer positioning devices;
> (c) using the predicted positions to calculate desired changes in position of one or more of the streamer positioning devices; and
> (d) implementing at least some of the desired changes.

> 15. An array of seismic streamers towed by a towing vessel comprising:
> (a) a plurality of streamer positioning devices on or inline with each streamer;
> (b) a prediction unit adapted to predict positions of at least some of the streamer positioning devices; and
> (c) a control unit adapted to use the predicted positions to calculate desired changes in positions of one or more of the streamer positioning devices.

2. Claims 1 & 15 Are Not Anticipated or Rendered Obvious Due to Workman

a. Workman Does Not Anticipate the '607 Patent

i. Missing Elements from Workman

135. The claims of the '607 patent require, among other things, predicting the position of at least some of the streamer positioning devices and then using those predicted positions to calculate desired changes in the position of one or more streamer positioning devices. This

claimed prediction has two parts. The first part is moving forward in time. One of the '607 patent's critical insights was that delayed response and signal latency and sampling associated with horizontal position determination systems were serious shortcomings of the prior art. The '607 patent solved these problem by using "position predictor software to estimate the actual locations of each of the birds 18." (Ex. 1001, '607 patent at 4:51-55.) The '607 patent does not claim specifically a Kalman filter.

136. As I explained above, Workman was focused on two things: (i) avoiding noise and (ii) avoiding a catastrophic streamer tangle or accident. In an attempt to achieve this, Workman uses so-called "threshold parameters" in conjunction with devices that determine "the real time position of the seismic sources and seismic streamer cables by computing a network solution to a Kalman filter." (Ex. 1004, Workman at 2:15-18, 2:47-49.)

137. The Kalman filter was developed, as it name implies, as a filter. Its structure is such that it uses noisy measurements and, based on the values of its state from the previous time step and a model of the system that is studied, provides an optimal estimate of the true (non-noisy) state of the system. In order to do this, it uses what is often referred to as a "predictor", which is used to propagate the state from the previous step to the present, and compares the difference between the "predicted" values and the measurements; then it uses optimal gains to arrive at the estimate of the state. Kalman filters can be used either (a) to remove noise from measurements, in which case even a very rough and simplistic model can be effective; or, (b) in conjunction with a controller as part of an overall control scheme; or, (c) to actually predict the behavior of the system in the future. In the latter two cases, successful control or prediction is conditional on having included an adequate model of the principal dynamics of the system. Although the conceptual form of the Kalman filter is the

same, each filter implementation depends entirely on the specific structure of the system (*i.e.*, the model of its dynamics) and the noise statistical properties. Merely stating that Workman uses a Kalman filter is not equivalent to the '607 patent's use of "prediction."

138. There are many possible differences between various implementations of Kalman filters. For example, the nodes in a "network solution" can vary from filter to filter even when representing the same physical system. The node number and node locations must be chosen carefully and connected with system dynamic equations in order to construct a meaningful model. Merely stating that a Kalman filter uses its "predictor" in a network solution does not disclose behavior-based prediction unless it includes a model that contains the dynamics of the system. Workman does not describe such a Kalman filter implementation. Dr. Evans recognizes that not all Kalman filters are the same. (*See* Ex. 2040, Evans Dep. Tr. at 246:6-14 ("The Kalman filter has many forms.").)

139. In the case of using a Kalman filter, merely mentioning this type of filter without further detail, does not provide adequate disclosure that such a method is actually predicting positions of the streamer positioning devices based on the system dynamics and then further calculating desired lateral steering of those streamer positioning devices using those predicted positions. ION Geophysical's own programmers — who helped create the infringing DigiFIN system — recognized this fact as shown in this excerpt from the text of ION's source code presented at the *ION* trial (Ex. 2054, Leonard Trial Demonstrative 8; *see also* Ex. 2055, Trial Tr. (July 27, 2012) at 1513:3-8):

> In order to solve a particular problem, ***this generic Kalman Filter software must be populated with data and equations which fully specify the particular problem which is to be solved***. This process can be thought of as the compilation or ***building of the problem***

> ***specific Kalman Filter***. This module contains routines to perform this compilation process.

140. The second part of the prediction claimed by the '607 patent deals with understanding the behavior of the system as a whole. As I explained above, any force or motion on the streamer will have propagative (traveling wave) effects along the streamer. The '607 patent's specification captures this aspect of the control system when it discloses that "the inventive control system" uses "behavior-predictive model-based control logic" to control the streamer positioning devices. (Ex. 1001, '607 patent at 4:11-14.) Dr. Bittleston's early work also demonstrates this aspect of "prediction." (Ex. 2051, Trial Ex. PTX 73, "Streamer Dynamics Calculations".)

141. Workman does not disclose the importance of the model of the system, or disclose any model at all, which would be necessary to turn a generic "Kalman filter" into a behavior-based predictor of future response that is essential to the effective control of streamers. We can bring in a simple analogy, since the Kalman filter is a real-time, causal implementation of the least-squares method: If we have measured noisy data, and we try to fit them with a least-square straight line, whereas the true curve is a quadratic, we will get very poor estimation. Choosing the proper fit (straight line versus quadratic) is equivalent to using a proper system "model" in the Kalman filter.

142. Workman simply suggests using a Kalman filter to "determine the real time position of the seismic sources and seismic streamer cables." (Ex. 1004, Workman at 2:15-19.) Workman is missing the '607 patent's critical insight — that behavior-predictive model-based control logic is needed to properly control the streamer positioning devices. Workman does not contain any discussion regarding the dynamic modeling of streamer behavior at all.

Without this model, Workman's system would be reactive, that is, it has to wait for something to happen (*i.e.*, a violation of a threshold parameter) and then reacts, provided certain other parameters are not exceeded (*e.g.*, noise). In contrast, the '607 patent describes a system that takes into account the behavior of the streamer so that precise control of streamer positioning devices can be achieved.

143. The Norton patent (U.S. Pat. No. 5,353,223, Ex. 2056) referred to in Workman does not address these failings. Norton is directed to combining irregularly timed observations using an extended sequential Kalman filter. Norton is not directed to laterally steering streamers. Instead, Norton describes a way to combine observations in an extended sequential Kalman filter so that source and receiver points can be located (not streamer positioning devices) (Ex. 2056, Norton at 4:17-21):

> The present invention provides a method for sequentially processing all observations obtained from the network in a Kalman filter in the order they are received to determine the positions of the source and the receiver points.

144. There is no recognition of the latency problems identified by the '607 patent, or the need to have a dynamical model of the system. The patent focuses on ways to de-correlate the measurements for Kalman filtering use.

145. Workman also does not disclose using predicted positions of the streamer positioning devices to calculate the desired changes in the position of one or more streamer positioning devices. Instead, Workman merely checks to see if a threshold parameter is exceeded and, under certain conditions, will apply control action to move the streamer back toward the threshold parameter, until that threshold is overshot in the "correct" direction. (Ex. 1004, Workman at 4:23-36, Fig. 3.) For example, if no threshold is exceeded, Workman's system

is restarted without making any sort of position correction calculation. (Ex. 1004, Workman at Fig. 3.) Even when a threshold is exceeded, Workman says nothing about using predicted positions of the streamer positioning devices to calculate desired changes in the positions of one or more of the streamer positioning devices. Instead, Workman vaguely indicates that the system determines "a position correction to reposition ***the streamer cables***" so that they fall "within the threshold parameters." (Ex. 1004, Workman at 3:59-65, 4:12-21.) There is no disclosure of ***how*** Workman determines the position correction to move within the threshold parameter.

146. In contrast, the '607 patent describes a system that continuously sends desired forces to the local control systems on the streamer positioning devices to achieve a desired position. (Ex. 1001, '607 patent at 4:28-34, 5:13-15, 6:13-17.) The '607 patent also describes the system as preferably using a dynamic streamer model of the entire array for calculating desired changes of individual streamer positioning devices. (Ex. 1001, '607 patent at 4:48-51, 4:28-34.) With this dynamic model, the system continually updates the "desired changes in the position" of the streamer positioning devices. Workman lacks this behavior-predictive model-based control architecture and does not mention streamer dynamics.

147. The '607 patent describes using the predicted positions "to calculate desired changes in position of one or more of the streamer positioning devices." (Ex. 1001, '607 patent at claims 1 & 15.) In order to calculate the forces required to move the streamer positioning devices to their desired locations, the '607 patent describes using calculations that take into account the behavior of the individual streamers and the array as a whole. (Ex. 1001, '607 patent at 4:28-34, 4:48-51.)

148. On the other hand, Workman does not take into account the behavior of the streamer or streamer array, and there is no discussion of streamer dynamics. Instead, Workman describes a system that compares the cable position to threshold parameters and moves the cable back within the threshold without disclosing how any commands are determined. But, as explained above, if one does not take into account the dynamics of the streamers when sending commanded forces to the birds, one could cause more harm than good attempting to steer streamers laterally.

149. Workman was attempting to minimize movement such that noise control was elevated over streamer control, and so is fundamentally different than the '607 patent. Workman contains no recognition of the unique time delay problem when steering streamers laterally (Ex. 1001, '607 patent at 2:38-43), and a POSA would find nothing in Workman that would lead him or her to arrive at the solution set forth by the '607 patent.

ii. Workman Does Not Enable a Streamer Positioning Device

150. The '607 patent's claims also require the use of "an array of streamers each having a plurality of streamer positioning devices there along." But, critically, Workman does not enable a streamer positioning device as claimed by the '607 patent.

151. Workman discusses four types of SPDs. I discuss each of these devices in turn below.

152. The first category are front-end separating devices (Ex. 1004, Workman at 1:45-50):

> Streamer positioning devices are well known in the art. ***Apparatus***, such as those disclosed in U.S. Pat. Nos. 5,532,975, 4,729,333, and 4,463,701, ***have been devised for attachment to the front end of streamer cables*** for the purpose of maintaining them at a lateral offset to the pathway of the towing vessel.

153. U.S. Patent No. 5,532,975 ("Elholm," Ex. 1017): I have discussed Elholm at length above. Workman itself recognizes that Elholm describes a "vessel" that is used at the head of the array to separate the streamers at the front end. Elholm does not disclose the use of these vessels along the length of a streamer. Elholm describes a device that is massive, designed to tow a whole streamer, but too bulky to be attached along the streamer, when side currents would exert large drag forces. The large span of the wings and the attachment through a rope shows clearly that this is a device for large forces at the front or back end of a streamer. Attaching such a device along a streamer would also create a large amount of noise, something that could make the seismic data useless.

154. U.S. Patent Nos. 4,729,333 (filed July 9, 1986) ("Kirby," Ex. 2057) & 4,463,701 (filed Feb. 28, 1980) ("Pickett," Ex. 2057): Kirby and Pickett describe front-end tensioning systems that use paravanes to keep a cable at a lateral offset from the path of the vessel. These paravanes are massive and could not be used along a seismic streamer for lateral steering. Moreover, they are not meant to be connected along the seismic streamers but only at the front.

155. Workman's second category of devices are steerable tail buoys. (Ex. 1004, Workman at 1:50-53 ("Steerable tail buoys, as described in US. Pat. No. 4,890,568, have also been designed for controlling the position of the tail end of towed seismic streamer cables.").)

156. U.S. Patent No. 4,890,568 (filed Aug. 24, 1988) ("Dolengowski," Ex. 1008): As Workman recognizes, Dolengowski describes a steerable tail buoy. Dolengowski does not describe the use of such a buoy attached along a seismic streamer to steer laterally, nor could

it, because such a system would add large drag at the location of attachment and would not be effective for lateral control.

157. Workman's third category of devices consists of external hydrofoils or angled wings (Ex. 1004, Workman at 1:53-58):

> The prior art also discloses streamer positioning devices that may be attached externally to the streamer cables. For example, devices to control the lateral positioning of streamer cables by using ***camber-adjustable hydrofoils or angled wings*** are disclosed in US. Pat. Nos. 4,033,278 and 5,443,027.

158. U.S. Patent No. 4,033,278 (filed Feb. 25, 1976) ("Waters," Ex. 1032): Waters dates from 1977. Waters discloses an externally-mounted paravane device, which depends on a float device to control cable depth, and a group of four vertically-oriented hydrofoils to control lateral thrust. (Ex. 1032, Waters at Abstract, Fig. 4.) The goal of the Waters reference is to control a single streamer's lateral movement enough to prevent bowing of that single streamer. (Ex. 1032, Waters at 1:31-53, 2:15-41.) But Waters suffers from several design flaws that ultimately render this device inadequate to be used for the same purposes as the streamer positioning devices disclosed by the '607 patent. Generally, the design of Waters having the entire device — including the upper and lower sets of wings — attached externally and above the axis of the cable, inherently can produce an unacceptable level of unwanted torque, especially when a strong corrective force is needed, that prevents adequate control of a streamer. The float device that is meant to ensure a constant depth of the streamers can create extra drag in both the towing and cross-line directions, further complicating actual streamer control. For these reasons, the Waters device is not suitable for use as a streamer positioning device capable of steering the streamer laterally as claimed in the Bittleston patents.

159. U.S. Patent No. 5,443,027 (filed Dec. 20, 1993) ("Owsley," Ex. 2059): Owsley discloses a paravane with a winged fuselage, bearing a fixed wing that exerts a lateral force on a streamer as it is towed through the water. (Ex. 2059, Owsley at Abstract.) The goal of Owsley is to control the lateral displacement of a towed acoustic cable while creating a minimum of turbulence and noise. (Ex. 2059, Owsley at 2:10-15.) In addition to the fixed wing angle for lateral control, the Owsley reference discloses that the vertical orientation of the device is controlled by utilizing the difference in buoyancy between the upper and lower winged fuselage halves and the smaller winglets at the tips of the main wings. (Ex. 2059, Owsley at 2:20-35.) The buoyancy of the entire device is constant, in order to allow the device to maintain a desired depth. The wing angle of the Owsley device is fixed, and the depth is fixed by buoyancy, hence, there is no way for a control system to implement a change in the wing angle or position of this device, let alone use a predicted position to calculate or determine the desired changes in position of the streamer positioning device. Owsley does not specify actively steering a streamer laterally by changing the position of a streamer positioning device. Therefore, the Owsley device cited in Workman does not anticipate or make obvious the claim inventions of the '607 patent.

160. Workman's fourth category of devices consists of depth birds. (Ex. 1004, Workman at 1:58-61 ("U.S. Pat. No. 3,931,608 describes an apparatus, typically known as a 'bird', to control the vertical positioning of streamer cables with diving planes and a preset depth control means.").)

161. U.S. Patent No. 3,931,608 (filed Apr. 25, 1974) ("Cole," Ex. 2060): Cole dates from 1976 and describes specifically a depth control bird. It cannot control a seismic streamer cable laterally.

162. The devices Workman references cannot impart lateral forces along the length of the streamer as contemplated by the '607 patent. Because Workman does not enable this element (a streamer positioning device), it does not anticipate the '607 patent.

b. Workman Does Not Render the '607 Patent Obvious

163. As of the priority date of the '607 patent, there was no reason for a POSA to modify Workman in order to meet the elements of the '607 patent. Such modifications (*e.g.*, predicting the position of the streamer positioning devices, behavior-predictive model-based control) were not needed for the problem Workman was addressing — the minimization of noise using threshold parameters. Critically, Dr. Evans does not point to any prior art that discloses the unique problems of streamer dynamics, time delay, and long cycle times in connection with lateral streamer steering. I am also unaware of any prior art addressing this problem and arriving at the solution claimed in the '607 patent.

164. Dr. Evans states that "[b]y the time of the priority date, lateral steering was long known and practiced." (Ex. 1002, Evans '607 Decl. at ¶ 126, ¶ 136 ("As noted above, ***for the decades in which streamer steering had been known*** in the field, ascertaining the position of the streamer positioning devices was part of that process.").) But as of 1998, lateral steering of seismic streamers along their length was not a trivial problem. At that time, no one had a working commercial lateral streamer steering system. WesternGeco created the first commercial lateral steering system (QMarine) and launched it in 2000. The next commercial system, the DigiFIN system developed by ION Geophysical Corporation, was not launched until seven years later.

165. The ’607 patent’s insight and solution are not obvious. Even today, for example, PGS’s expert, Dr. Cole, states that there is no time delay problem associated with lateral steering of seismic streamers, which, if true, would render using predictions unnecessary (Ex. 1003, Cole ’607 Decl. at ¶ 71):

> Thus, communications systems and distributed computer control technology available on the priority date allowed seismic surveyors to easily control a substantial number of streamer positioning devices ***at near-instantaneous response times***.

166. Dr. Cole’s opinions further demonstrate, rather than refute, the inventive nature of the ’607 patent (Ex. 1003, Cole ’607 Decl. at ¶ 77):

> ***From a control systems perspective, whether positions are obtained by prediction*** or some other method ***is irrelevant*** to implementing Claim 1 and 15’s limitation of calculating desired changes in position of one or more of the streamer positioning devices.

167. He does not recognize that the use of predicted positions based on a behavior-predictive model is critical to properly steering streamer positioning devices, because of the traveling wave nature of the response of streamers. And, in contrast to prior art systems, the ’607 invention discloses a more sophisticated control system that is not merely a feedback loop. (*See*, *e.g.*, Ex. 1001, ’607 patent at 2:29-45, 4:48-51.)

168. In addition, using a Workman-type system, a POSA would assume that there is no need to know precisely where the streamer positioning devices were located, and that it is sufficient to keep the overall shape of the streamers within certain minimum threshold parameters. Therefore, there would be no motivation or reason to use “predicted positions” of the streamer positioning devices in a Workman-type system as claimed in the ’607 patent, an essential element for effective lateral streamer control.

3. Claims 1 & 15 Are Not Rendered Obvious Due to Workman in view of Elholm

a. Missing Elements from Elholm

169. As explained above, Workman does not anticipate or make obvious the claims of the '607 patent. The addition of Elholm does not cure Workman's deficiencies.

170. First, Elholm fails to disclose the use of multiple streamer positioning devices on a single streamer. Second, Elholm does not disclose the use of streamer positioning devices along the length of seismic streamers in an array. Rather, Elholm specifies the use of only a single device attached at the front of an array. Using an Elholm-type device would not result in effective lateral control of the streamer, because knowing the position of the paravane would not give any indication of how the streamer is behaving miles down the length of the streamer.

171. In addition, Elholm does not specify obtaining the predicted position of the streamer positioning devices, nor using the predicted position to calculate desired changes in in the positions of one or more of the streamer positioning devices. Instead, Elholm describes traditional location sensing equipment such as pressure sensors and angle indicators. (Ex. 1017, Elholm at 5:35-43.) There is no mention of a prediction or a streamer model and no mention of the unique problems associated with lateral control of seismic streamers. Thus, even if combined with Workman, the result would not be a behavior-predictive model-based system as claimed by the '607 patent, which is essential for effective lateral streamer control.

b. The Combination Does Not Make the '607 Patent Obvious

172. As of 1998, there would be no motivation to combine Elholm with Workman for the purpose of arriving at the invention claimed in the '607 patent. As I explained above, Elholm's large front-end device would not be used for lateral steering along the length of a seismic streamer due to the large forces and noise inherent in such a system. Instead, Elholm is a specialized device meant for the front-end of the streamer array. Elholm aimed to reduce the noise and wear and tear on the system (by removing float connections to the surface), and introducing many such devices along a streamer would be completely at odds with Elholm's stated purpose. Similarly, Workman's stated purpose is to minimize noise. Therefore, a POSA would not combine Elholm's large device with Workman as it would increase, rather than decrease, the amount of noise in the system.

173. In addition, both Elholm and Workman were solving completely different problems than the '607 patent. There would be no motivation to pick and choose features from Elholm's submersible front-end tensioning equipment and combine it with Workman's noise minimization system to get the lateral streamer steering system the '607 patent discloses and claims. Even if one were to assume that Elholm identifies a goal to "accurately reposition streamers" to facilitate marine seismic surveying, as stated by Dr. Evans (Ex. 1002, Evans '607 Decl. at ¶ 131), that goal does not lead to the use of behavior-predictive model-based control. Indeed, the goal to reposition streamers existed for decades before the '607 patent and, as I noted above, the '607 patent is the first reference that I am aware of to provide the necessary information to a POSA.

174. In any event, neither Elholm nor Workman disclose predicting the positions of the streamer positioning devices or using predicted positions to calculate desired changes in the position of the streamer positioning devices. Hence, even if combined, the combination does

not provide the missing pieces of prediction-based lateral streamer control and does not provide a POSA with the inventions claimed by the '607 patent. It was not until the '607 patent described the problem of lateral streamer steering as one of latency and recognized the need for a behavior-predictive model that a workable lateral streamer steering system became a reality. It is the recognition of this problem that is the key to the '607 patent, which was not a trivial or obvious undertaking in view of the prior art. If it was, the invention claimed by the '607 patent would have been described in the prior art long before 1998 because there was a long-felt need to accurately position seismic streamers.

175. Workman and Elholm do not make the claims of the '607 patent obvious.

B. The '967 Patent

1. Claims 1 & 15

I have reproduced Claims 1 & 15 below:

1. A method comprising:
(a) towing an array of streamers each having a plurality of streamer positioning devices there along, at least one of the streamer positioning devices having a wing;
(b) transmitting from a global control system location information to at least one local control system on the at least one streamer positioning devices having a wing; and
(c) adjusting the wing using the local control system.

15. An array of seismic streamers towed by a towing vessel comprising:
(a) a plurality of streamer positioning devices on or inline with each streamer, at least one of the streamer positioning devices having a wing;
(b) a global control system transmitting location information to at least one local control system on the at least one streamer positioning device having a wing, the local control system adjusting the wing.

2. Claims 1 & 15 Are Not Anticipated or Rendered Obvious by the '636 PCT

a. Missing Elements from the '636 PCT

176. The claims of the '967 patent require, among other things, that the global control system transmit location information to at least one local control system.

177. The '636 PCT fails to disclose a global control system. Indeed, the reference itself does not even mention a remote control system. Nonetheless, even if one were to assume that the '636 PCT disclosed a remote control system, a remote control system is simply a control system that exerts control at a distance. In contrast, a ***global*** control system involves continuous coordination of all birds considering the system as a whole.

178. At the time of the '636 PCT or the '967 patent, there were simply no commercial steering systems that allowed for the continuous coordination of the seismic array as a whole. The '967 patent's global control system moved away from prior art approaches, including the '636 PCT, that used conventional feedback loops. Indeed, the '967 patent specifically distinguished the '636 PCT (Ex. 2044, '967 patent at 2:48-53):

> While this type of system allows for more automatic adjustment of the bird wing angles, ***the delay period and the relatively long cycle time between position measurements prevents this type of control system from rapidly and efficiently controlling the horizontal position of the bird.***

179. The '967 patent, instead, uses continuous, coordinated control with a dynamic streamer model that accounts for streamer behavior as well as the overall array behavior. (Ex. 2044, '967 patent at 4:34-40, 4:54-57, 5:20-24.)

180. The '967 patent's global control system delivers information "***as separate values for each bird* 18 on each streamer 12 *continuously*** during operation of the control system." (Ex. 2044, '967 patent at 5:20-24.) The specification describes the global control system as preferably taking into account "the behavior of each streamer" and "the behavior of the

complete streamer array." (Ex. 2044, '967 patent at 4:54-57; *see also* Ex. 2044, '967 patent at 4:17-20 ("***the inventive control system utilizes*** a ***distributed processing control*** architecture and ***behavior-predictive model-based control*** logic to properly control the streamer positioning devices.").) This is accomplished by using "a dynamic model of each seismic streamer." (Ex. 2044, '967 patent at 4:34-40.) In contrast, the '636 PCT does not discuss this continuous monitoring and distribution of information using a behavior-predictive model. Without a global control system monitoring and distributing information, the streamers would be more likely to tangle and the position of the streamer array would not be maintained during towing.

181. Completely absent in the '636 PCT is the global control, which is also necessary to enable operation modes such as feather angle, turn control, and streamer separation mode.

b. Missing Elements Would Not be Obvious

182. The '967 patent is directed towards a more complex problem than the '636 PCT, coordinated control. Specifically, the use of global control to allow streamer steering via a dynamic model based on streamer behavior prediction rather than a feedback approach. The '636 PCT is focused on the much simpler problem of the bird itself and its local control loops. The '636 PCT simply does not disclose a global control system that coordinates multiple birds to maintain the position of an array of seismic streamers.

183. While the '636 PCT indicates that there are inputs into the bird's local control system, those inputs could come from sensors or a manual terminal. There is no indication in the '636 PCT of where those inputs come from, and nothing in the '636 PCT's Figure 2 suggests or discloses a global control system. The '636 PCT does not describe the need for a global

control system, as it is directed only to the bird's local control system, and does not suggest or disclose a global control system. One of ordinary skill would not have modified the '636 PCT to include a global control system.

184. The '636 PCT's reference to U.S. Pat. No. 4,992,990 (filed June 6, 1989) ("Langeland," Ex. 1055) does not fill this gap. Langeland describes using acoustics to determine the position of two or more seismic streamers. (Ex. 1055, Langeland at Abstract.) It does not describe a system for steering streamers laterally, sending location information from a global control system to a local control system, or globally controlling streamer positioning devices.

185. The claims of the '967 patent are not obvious in light of the '636 PCT.

C. The '520 Patent

1. Claims 1, 2, 18, 19

186. I have reproduced Claims 1 and 18 below:

> 1. A method comprising:
> (a) towing an array of streamers each having a plurality of streamer positioning devices there along contributing to steering the streamers;
> (b) controlling the streamer positioning devices with a control system configured to operate in one or more control modes selected from a feather angle mode, a turn control mode, and a streamer separation mode.

> 18. An apparatus comprising:
> (a) an array of streamers each having a plurality of streamer positioning devices there along;
> (b) a control system configured to use a control mode selected from a feather angle mode, a turn control mode, a streamer separation mode, and two or more of these modes.

187. Claims 2 and 19 limit the recited mode to feather angle mode.

2. Claims 1, 2, 18, and 19 Are Not Anticipated or Rendered Obvious Due to Workman

a. Workman Does Not Anticipate the '520 Patent

188. The '520 patent is not anticipated or rendered obvious by Workman for several reasons. First, as explained above, streamer positioning devices as contemplated by the '520 patent are not enabled by Workman. Second, Workman does not disclose a control system that is configured to work in one or more control modes, let alone a streamer separation mode or feather angle mode, as I explain below.[7]

189. As noted above in my discussion of the '607 patent, Workman does not enable "streamer positioning devices" that could be used along the length of a seismic streamer for lateral steering.

190. Workman does not disclose model-based control. Instead, Workman discloses the use of "threshold parameters" that are manually input via a terminal. (Ex. 1004, Workman at 4:3-5.) These are not modes for controlling streamers — there is no goal-oriented steering disclosed at all. Nor does Workman discuss streamer dynamics — a critical element to successful lateral steering.

191. In contrast, the '520 patent describes goal-oriented automated configurations maintained by "control modes": feather angle mode automatically steers to achieve a particular feather angle, turn control mode automatically steers to turn faster, and streamer separation mode automatically steers to achieve and maintain desired separations. (Ex. 2063, '520 patent at 10:27-65.)

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[7] I understand that the Board declined to institute review of the '520 patent's turn control mode, finding that it was not disclosed by any of PGS's cited references. I also note that both Workman and Hedberg are silent with respect to streamer control during a turn.

192. These control modes are implemented by "the inventive control system [which] utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices." (Ex. 2063, '520 patent at 4:17-20.) This global control system sends "separate values for ***each bird*** 18 on ***each streamer*** 12 ***continuously*** during operation of the control system" in order to implement these control modes. (Ex. 2063, '520 patent at 5:21-23, 10:27-65.) The global control system preferably commands the birds "based on the behavior of each streamer and also takes into account the behavior of the complete streamer array" and uses "a dynamic model of each streamer." (Ex. 2063, '520 at 4:54-57, 4:34-40.)

193. In addition, Workman does not disclose the '520 patent's specifically claimed control modes. For example, Workman does not disclose a "streamer separation mode." "Streamer separation mode" is "a control mode that attempts to set and maintain the spacing between adjacent streamers." Under Workman's "threshold parameter" system, if a streamer separation falls outside of the set minimum separation, Workman's system would take no action. This is the case, despite the fact that the separations may vary between streamers over time. Nothing about this system sets and maintains (or keeps) the streamers at a particular spacing. Rather, the streamer cables are uncontrolled until a threshold is violated, and provided noise is sufficiently low.

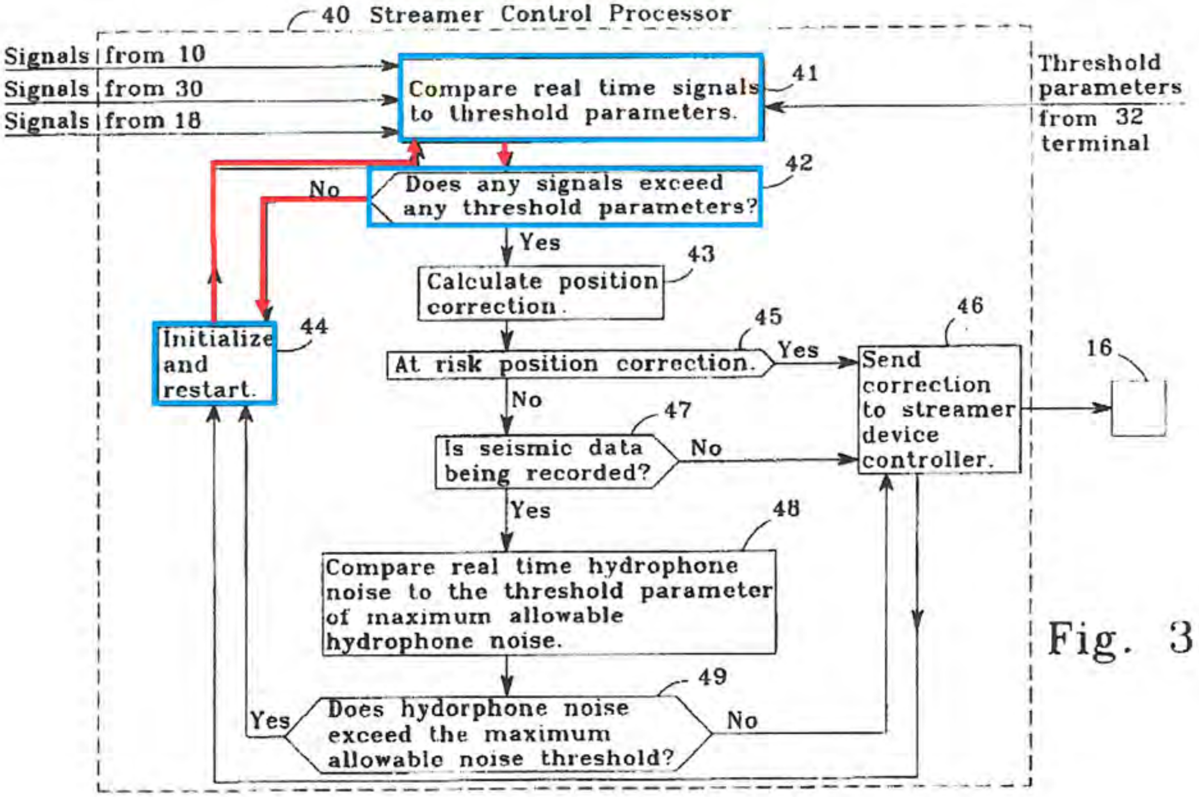

Figure 17 - Workman Figure 3, emphasis added.

194. Visualized another way, Workman's system allows for "zones of uncertainty." That is, the system does not attempt to keep the streamer in any particular location or pattern, and therefore does not act to "control" the configuration of the streamers as understood by a POSA. The system merely checks to see if set "threshold parameters" are violated. Because Workman does not move the streamers unless it violates a minimum threshold, it can vary anywhere from the "threshold parameter" to the system's physical limits, as shown in the example below. No particular streamer configuration is sought or achieved. Further, even if a maximum limit were also set, which is not disclosed in Workman, this would somewhat shrink the "zones of uncertainty," but would not offer any greater control over streamer configuration and spacing.

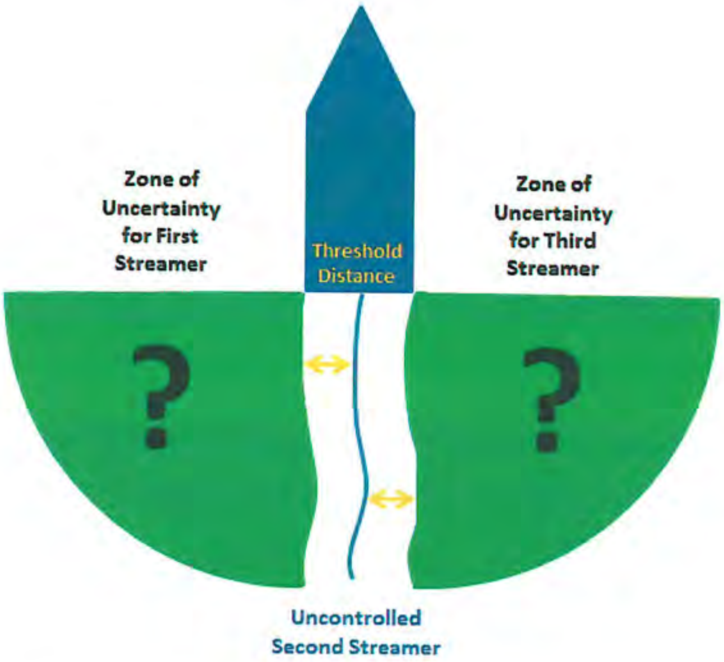

Figure 18 - A visualization of the effect of Workman's "threshold parameters" in a three streamer array when the threshold parameter is a minimum separation.

195. Workman also does not disclose a "feather angle mode." "Feather angle mode" is "a control mode in which the global control system attempts to set and maintain each streamer in a straight line offset from the towing direction by a certain feather angle."

196. First, Workman does not disclose to input a particular feather angle into the system, nor is there any description of how Workman's "threshold parameter" system might be modified so as to even accommodate, let alone achieve, a desired feather angle.

197. And, as explained above, simply implementing Workman's minimum separation threshold parameter does not ensure that streamers are kept in straight-line (or parallel) configurations. Similarly, Workman does not set and maintain streamers at a particular feather angle. Therefore, Workman does not anticipate the claims of the '520 patent.

b. Workman Does Not Render the '520 Patent Obvious

198. Dr. Evans states that a POSA would have to alter Workman to achieve the claimed modes in the '520 patent. (Ex. 2039, Evans Dep. Tr. at 169:15-20 ("And as a person skilled in the art, ***I would alter that***, variations on depth, ***variations on feather location*** with respect to preplotted values, seismic source positions and their location, with respect to preplotted values.").) However, modifying Workman to achieve the modes described and claimed in the '520 patent would not have been obvious in 1998 because it was not until the Bittleston patents described the problem of streamer steering as one of latency, introduced the concepts of behavior-predictive model-based lateral control, and distributed control for lateral steering, that such control modes became possible.

199. Dr. Evans also states that a POSA would have wanted to keep streamers in a straight line and at a particular feather angle due to the benefits rendered by such a configuration, *e.g.*, replicating positions during a 4D survey. (Ex. 2064, Evans '520 Decl. at ¶¶ 150-151.) But there is a critical difference between recognizing the benefits of a feather angle mode, and establishing ***how to achieve*** such a mode. Workman does not disclose a feather angle mode, nor how to implement it. And Dr. Evans does not explain ***how he would modify*** Workman to achieve such a mode. Being able to keep streamers at a minimum allowable separation, as specified by Workman, will not keep the streamers in any particular arrangement or at a particular angle offset from the towing direction. Indeed, Workman does not even mention the issue of streamer feathering. The claimed motivation of 4D survey replication is not mentioned at all in Workman.

200. Workman addressed Dr. Evans' other alleged motivation, *i.e.*, noise reduction, completely differently through the use of "threshold parameters." Workman discloses a system that ***stops any action*** when noise exceeds a set threshold. (Ex. 1004, Workman at

Fig. 3, 5:14-24 ("If the real time hydrophone noise exceeds any threshold parameter of maximum allowable noise, at step 44 ***the streamer control processor 40 is initialized and restarted***").) Hence, in contrast to the claimed motivation, Workman's system stops using streamer positioning devices when noise levels are a concern. Workman does not even hint at a system that actively attempts to keep streamers in a straight line at a particular feather angle. Neither PGS in its Petition nor Dr. Evans in his declaration point to any disclosure in Workman, or any motivation in the prior art in general, that would have prompted a POSA to modify Workman's noise-reduction system to continually steer streamer positioning devices to maintain a specified streamer separation or feather angle. One of ordinary skill would not have modified Workman's system to include active steering as part of the modes disclosed in the '520 patent.

201. Workman does not render the '520 patent anticipated or obvious.

3. Claims 1, 2, 18, and 19 Are Not Anticipated by or Obvious Over Hedberg

202. As with Workman, Hedberg does not anticipate or render obvious the claims of the '520 patent.

203. Hedberg, a reference that is approximately 30 years prior to the '520 patent, lacks any disclosure of actively controlling the separation of or spacing of seismic streamers. Instead, Hedberg contemplates the use of "conventional paravanes" to create front-end separation between the "impulse generating means" and the "sensing or echo responsive means." (Ex. 1005, Hedberg at 6:20-27.) Hedberg describes using paravanes to create space between the acoustic source and hydrophones, but Hedberg does not disclose any "control modes" for maintaining those cables in positions relative to each other once surveying has begun.

Hedberg merely specifies that the cables should be spread enough — at least 1/4 to 1/2 mile — to permit temporal resolution. No benefits for any specific spacing or streamer configuration are provided, nor any means to achieve them are described.

204. Creating separation at the front of a streamer is different than controlling separation between streamers using several streamer positioning devices along the length of each streamer and throughout the streamer array. Creating separation, as done in Hedberg, is passive, whereas controlling separation requires active steering as claimed in the '520 patent. Hedberg's passive system cannot anticipate the challenged claims, and PGS has provided no reason why a POSA would attempt to convert Hedberg's passive system into an active system. Indeed, Dr. Evans stated during his deposition that he recommended to clients in the mid-1970s ***not*** use the Hedberg configuration. (Ex. 2040, Evans Dep. Tr. at 256:14-258:18; *see also* Ex. 2040, Evans Dep. Tr. at 257:21-25.) In any event, a POSA would not attempt to redesign Hedberg's system into an active system with paravanes located along the length of the streamer because it would not be suitable for steering streamers laterally, as I explain below.

205. Hedberg describes locating these "conventional paravanes" using "radar reflectors." (Ex. 1005, Hedberg at 6:43-49.) But such a system would rely on surface connections and not be suitable for steering streamers laterally. In any case, Hedberg does not discuss controlling a target separation or spacing and, therefore, fails to disclose both the streamer separation mode and the feather angle mode of the '520 patent. In particular, there is no description associated with Hedberg's Figure 8 that describes a control system to maintain separation or spacing between streamers, or maintain a certain feather angle, and the paravanes disclosed in Hedberg would be unable to provide such control.

206. Similarly, Hedberg does not disclose maintaining any streamer at a set feather angle. PGS claims that Hedberg "expressly refers to the feathering problem in his Figure 9," and then claims that Figure 9 demonstrates a feather angle mode. This is not correct. The legend for Figure 9 states that it is "a diagrammatic illustration of a condition which may be encountered in the prior art" (Ex. 1005, Hedberg at 2:67-68), and hence describes a problem that may be encountered, in the form of "drift" on streamers. It does not disclose any sort of desirable feather angle mode. Indeed, Hedberg states that such tilting or feathering is an undesirable error (Ex. 1005, Hedberg at 6:20-36):

> "However, as shown in FIG. 9, the use of a conventional spread of hydrophones, located in a single dimension of a horizontal plane, ***is subject to error due to the set and drift or displacement of the spread by marine currents*** at the successive times when shots or impulses are generated for recoding purposes. In accordance with a preferred embodiment of the present invention it is possible to ***overcome the foregoing source of error and to compensate for any deviations of the paravanes, elements, or devices from predetermined positions***."

207. Hedberg sought to eliminate drift, not maintain a single streamer, or an array of streamers in a straight-line configuration, offset by a certain feather angle. Further, there is no disclosure in Hedberg (in Figure 9 or elsewhere) about how to make corrections to compensate for marine currents, or how to program a control system to do so. At most, Hedberg notes that the paravanes may be controlled to adjust the spacing between paravanes (Ex. 1005, Hedberg at 6:51-53), but such control would not maintain the spacing between streamers along the length of the streamer array or maintain a particular feather angle. Thus, Hedberg does not describe to a POSA how to adjust the position of a streamer relative to the towing direction and, in fact, the objective of Hedberg is opposed to utilizing a feather angle. A feather angle mode is not rendered obvious in view of Hedberg.

208. Dr. Evans does not explain how the streamer arrangements described in Hedberg would be modified to convert its passive system to one that actively operates in a feather angle mode as recited in the challenged claims. This makes sense because, as noted above, Hedberg attempts to ***eliminate*** feathering, not control or utilize it to the advantage of the survey.

209. Hedberg, like Workman, also does not recognize the unique problems associated with lateral control of seismic streamers. Hedberg contains no discussion of time lag and streamer positioning device control at all or using predictions from a behavior-predictive model as part of a control strategy. As with Workman, it was not until the Bittleston patents described the problem of streamer steering as one of latency, introduced the concepts of behavior-predictive model-based lateral control, and distributed control for lateral steering, that such control modes became possible.

210. Hedberg does not anticipate or render obvious the claims of the '520 patent.

VIII. CONCLUSION

211. I understand that this report will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States patent and Trademark Office. I also understand that I may be subject to cross-examination concerning this report, and I will appear for cross-examination, if required of me, during the time allotted for cross-examination.

212. This report is based on information currently available to me. I reserve the right to continue my investigation and analysis, which may include a review of documents and

information not yet produced. I further reserve the right to expand or otherwise modify my opinions and conclusions as my investigation and study continues, and to supplement my opinions and conclusions in response to any additional information that becomes available to me.

213. I hereby declare that all of the statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with knowledge that willful false statements are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

I declare under penalty of perjury that the foregoing is true and correct.

Michael S. Triantafyllou

March 20, 2015

Singapore

EXHIBIT A

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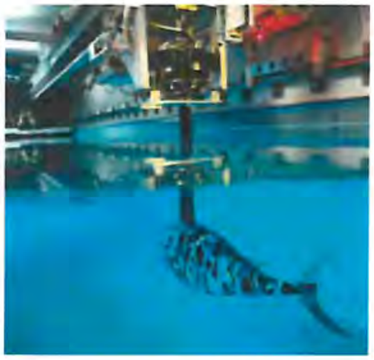
http://oe.mit.edu/

Michael Triantafyllou is the William I. Koch Professor of Marine Technology at the Massachusetts Institute of Technology. He is the Director of the Center for Ocean Engineering in the Department of Mechanical Engineering, with thirteen primary faculty members and ten associated faculty members.



He teaches and has published over 250 journal articles and refereed conference papers in the areas of biomimetics, dynamics and control of marine systems, and experimental fluid mechanics. He pioneered the development of science-driven biomimetic robots to study the basic mechanisms of flow control that lead to the outstanding agility of fish and cetaceans. The *RoboTuna* original design is at the Science Museum in London, while a second version of the robot shown at left, is on exhibit at the MIT Museum. He is currently studying the physics of flow sensing in fish and marine mammals to achieve super-maneuverability in ocean vehicles through flow feedback control.

He has served as Associate Department Head in the Department of Mechanical Engineering (2008-2010) and has been a Visiting Scientist at the Woods Hole Oceanographic Institution since 1991. He is Chairman of the Board of the National Technical University of Athens (2013-2017).

Google Scholar: http://scholar.google.com/citations?user=Q7BIbQ8AAAAJ&hl=en

Professional Experience

CURRENT POSITION: William I. Koch Professor of Marine Technology
Director, Center for Ocean Engineering (2004 -)
Director, Chevron-MIT University Partnership Program (2007 -)
Director, O. E. Testing Tank Facility (1988-) and Propeller Tunnel (2002 -)
Department of Mechanical Engineering, Massachusetts Institute of Technology

Visiting Scientist (1991 -) *Woods Hole Oceanographic Institution*

PREVIOUS POSITIONS:

Massachusetts Institute of Technology:

Department of Ocean Engineering: Research Associate (1978-1979); Assistant Professor (1979-1983); Associate Professor (1983-1990); Professor (1990-2005); Chairman, Joint Committee, Applied Ocean Sciences & Engineering, MIT/WHOI Joint Program in Oceanography (1997-2002).

Department of Mechanical Engineering: Professor of Mechanical and Ocean Engineering (2005-); Head, Area of Ocean Science & Engineering (2005- 2008); Associate Department Head for Ocean Engineering (2008-2010).

Woods Hole Oceanographic Institution:

Guest Investigator (Summers 1989 through 1996)

Research Interests

Biomimetic Robotics. Flow-structure interaction and vorticity control. Dynamics and control of marine vehicles and structures.

Education

Massachusetts Institute of Technology:

ScD in Ocean Engineering (1979)
SM in Naval Architecture & Marine Engineering (1977)
SM in Mechanical Engineering (1977)

National Technical University of Athens:

Diploma in Naval Architecture & Marine Engineering (1974)

Consulting Record

Ropes & Gray, Endeco, EG&G, Conoco USA, Conoco UK, Conoco Indonesia, Noble & Denton, D.S. Tein Consulting Engrs., Chevron, Exxon, Noble Drilling, Stone & Webster, Woods Hole Oceanographic Institution, Amoco, Sedco-Forex (Schlumberger), SAIC, ExxonMobil, Chevron-Texaco, BP, Akker, Deepstar. Conducted Joint Industry Projects with multiple industrial sponsors: Resulting vortex-induced vibration software VIVA and VIVARRAY in use by more than 30 offshore companies worldwide.

Honors and Awards

- Fellow, American Physical Society, 2014
- Aurel Stodola Medal and Lecture "Biomimetic survival hydrodynamics and sensing", ETH Zurich, May 2014.
- William I. Koch Professor of Marine Technology (2008 -).
- Guest Editor, Special issue on animal swimming, *Experiments in Fluids*, November 2007; edited as a book by Springer-Verlag, *Animal Locomotion: The Physics of Flying, The Hydrodynamics of Swimming* (2010).
- Article on trout swimming in vortices also on cover of Science, Nov. 28, 2003.
- First generation RoboTuna on permanent exhibit at the Museum of Science, London (since 1998). Prototype RoboTuna in national traveling exhibit on robots, organized by the Science Museum of Minnessota (2003-2004); currently on permanent exhibit at the MIT Museum.
- Smithsonian Magazine Article on Robotic Tuna (August 2000).

- Discover Magazine Awards for Technological Innovation (1998).
- ABS/Linnard Prize for best paper in the Transactions of SNAME (1997).
- Work on Robotic Tuna on the cover of Scientific American (March 1995).
- Highlight Paper of 1995 Scientific American.
- Visiting Professor: Singapore–MIT Alliance, NUS, Singapore (2012), NTNU, Trondheim, Norway (1993, 2001, & 2011); ETH Zurich (April 1999); National Technical University of Athens, Greece (1994-1995 & 2007-2008); Kyushu University, Japan (April 1986).
- H. L. Doherty Professorship in Ocean Utilization (1983-1985).
- Best Graduate paper award (SNAME) 1978.
- Special award for top performance, National Technical University of Athens (1972).
- Merit scholarship, National Technical University of Athens (1969-1974).

Former Students and Post-docs in Faculty Positions

D. Barrett (Olin College), R. Bourguet (U. Toulouse), J. Dahl (U. Rhode Island), F. Hover (MIT), Y.C. Kim (Korea), S. Licht (U. Rhode Island), D. Lucor (U. Paris VI), Y. Modarers-Sadeghi (U. Massachusetts, Amherst), P. Prempraneerach (Rajamangala U., Thailand), D. Rival (U. Calgary), L. Shen (U. Minnesota), H. Shin (Korea), A. Techet (MIT), J. Stettler (Naval Academy), G. Weymouth (U. Southampton), Q. Zhu (UCSD).

Professional Societies

American Physical Society: Life member. Society of Naval Architects and Marine Engineers (SNAME): Life member. International Society of Offshore Mechanics and Polar Engineers (ISOPE). American Society of Mechanical Engineers (ASME).

PUBLICATIONS

Journal Articles

1. M.S. Triantafyllou, 1979, "Computer Aided Propeller Preliminary Design Using the B – series", *Marine Technology*, **16** (4), 381-391.
2. M.S. Triantafyllou, 1980, "Strip Theory of Ship Motions in the Presence of a Current", *Journal of Ship Research*, **24** (1), 40-44.
3. M.S. Triantafyllou, 1982, "Preliminary Design of Mooring Systems", *Journal of Ship Research*, **26** (1), 25-35.
4. M.S. Triantafyllou, 1982, "A Consistent Hydrodynamic Theory for Moored and Positioned Vessels", *Journal of Ship Research*, **26** (2) 97-105.
5. M.S. Triantafyllou, M. Bodson, & M. Athans, 1983, "Real Time Estimation of Ship Motions Using Kalman Filtering Techniques", *Journal of Oceanic Engineering* (IEEE), **OE-8** (1), 9-20.
6. M.S. Triantafyllou, 1984, "The Dynamics of Taut Inclined Cables", *Quarterly Journal of Mechanics and Applied Mathematics*, **37**, 421-440.
7. Y.C. Kim, & M.S. Triantafyllou 1984, "The Nonlinear Dynamics of Long Slender Cylinders", *Journal of Energy Resources Technology*, **106** (2), 250-256.
8. M.S. Triantafyllou 1985, "The Dynamics of Translating Cables", *Journal of Sound and Vibration*, **103** (2), pp. 171-182.

9. M.S. Triantafyllou, A. Bliek, & H. Shin, 1985, "Dynamic Analysis as a Tool for Mooring System Design", *Transactions of the Society of Naval Architects and Marine Engineers*, **93**, 303-324.
10. M.S. Triantafyllou, & L. Grinfogel, 1985, "Natural Frequencies and Natural Mode Shapes of Inclined Cables", *Journal of Structural Engineering* (ASCE), **112** (1), 139-148.
11. G.S. Triantafyllou, M.S. Triantafyllou & C. Chryssostomidis, 1986, "On the formation of vortex streets behind stationary cylinders", *Journal of Fluid Mechanics*, **170**, 461-477.
12. G.S. Triantafyllou, M.S. Triantafyllou, & C. Chryssostomidis, 1987, "Stability Analysis to Predict Vortex Street Characteristics and Forces on Circular Cylinders", *Journal of Offshore Mechanics and Arctic Engineering* (ASME), **109**, 148-154.
13. J.H. Milgram, M.S. Triantafyllou, F. Frimm, & G. Anagnostou, 1988, "Seakeeping and Extreme Tensions in Offshore Towing", *Transactions of the Society of Naval Architects and Marine Engineers*, **96**, 35-72.
14. J.J. Burgess, & M.S. Triantafyllou, 1988, "The Elastic Frequencies of Cables", *Journal of Sound and Vibration*, **120** (1), pp. 153-165.
15. V. Papazoglou, S. Mavrakos, & M.S. Triantafyllou, 1990, ``Nonlinear cable response and model testing in water", *Journal of Sound and Vibration*, **140** (1), 103-115.
16. M.S. Triantafyllou, & M.A. Grosenbaugh, 1991, "Robust Control for Underwater Vehicle Systems with Time Delays", *Journal of Oceanic Engineering* (IEEE), **OE-16** (1), 146-151.
17. D.R. Yoerger, M.A. Grosenbaugh, M.S. Triantafyllou, & J.J. Burgess, 1991, "Drag Forces and Flow-Induced Vibrations of a Long Vertical Tow Cable - Part I: Steady-State Towing Conditions", *Journal of Offshore Mechanics and Arctic Engineering* (ASME), **113**, 117-127.
18. M.A. Grosenbaugh, D.R. Yoerger, M.S. Triantafyllou, & F.S. Hover, 1991, "Drag Forces and Flow-Induced Vibrations of a Long Vertical Tow Cable - Part II: Unsteady Towing Conditions", *Journal of Offshore Mechanics and Arctic Engineering* (ASME), **113** (3), 199-204.
19. M.S. Triantafyllou, & G.S. Triantafyllou, 1991, "The Paradox of the Hanging String: An Explanation using Singular Perturbations", *Journal of Sound and Vibration*, **148** (2), 343-351.
20. M.S. Triantafyllou, & G.S. Triantafyllou, 1991, "Frequency Coalescence and Mode-Localization Phenomena: A Geometric Theory", *Journal of Sound and Vibration*, **150** (3), 485-500.
21. M.S. Triantafyllou, G.S. Triantafyllou, & R. Gopalkrishnan, 1991, "Wake Mechanics for Thrust Generation in Oscillating Foils", *Physics of Fluids A*, **3** (12), 2835-2837.
22. M.S. Triantafyllou, & C.T. Howell, 1992, "Nonlinear Impulsive Motions of Low Tension Cables", *Journal of Engineering Mechanics*, **118** (4), 807-830.
23. C.T. Howell, & M.S. Triantafyllou, 1993, "Stable and Unstable Nonlinear Resonant Response of Hanging Chains: Theory and Experiment", *Proceedings of the Royal Society of London,* **A 440**, 345-364.
24. G.S. Triantafyllou, M.S. Triantafyllou, & M.A. Grosenbaugh, 1993, "Optimal Thrust Development in Oscillating Foils with Application to Fish Propulsion", *Journal of Fluids and Structures*, **7**, 205-224.
25. M.S. Triantafyllou, & C.T. Howell, 1993, "Nonlinear unstable response of hanging chains", *Journal of Sound and Vibration*, **162** (2), 263-280.
26. C.T. Howell, & M.S. Triantafyllou, 1993, "Investigation of Large Amplitude Nonlinear Dynamics of Hanging Chains"', *Int. J. Offshore Polar Engng.*, **3** (3), 162-167.

27. M.S. Triantafyllou, & C.T. Howell, 1993, "The Ill-Posed Problem of a Cable in Compression", *Int. J. Offshore Polar Engng.*, **3** (3), 168-171.
28. C.N. White, R.G. Goldsmith, & M.S. Triantafyllou, 1993, "Heave restrained platform reduces costs and eases operations", *J. Petrol. Technol.*, **45** (8), 752-761.
29. F.S. Hover, M.A. Grosenbaugh, & M.S. Triantafyllou, 1994, "Calculation of Dynamic Motions and Tensions in Towed Underwater Cables", *IEEE Journal of Oceanic Engineering*, **19** (3), 449-457.
30. M.S. Triantafyllou, & C.T. Howell, 1994, "Dynamic Response of Cables under Negative Tension: An Ill-Posed Problem", *Journal of Sound and Vibration*, **173** (4), 433-447.
31. R. Gopalkrishnan, M.S. Triantafyllou, G.S. Triantafyllou, & D.S. Barrett, 1994, "Active Vorticity Control in a Shear Flow Using a Flapping Foil", *Journal of Fluid Mechanics*, **274**, 1-21.
32. K. Streitlien, & M.S. Triantafyllou, 1995, "Force and Moment on a Joukowski Profile in the Presence of Point Vortices", *AIAA Journal*, **33** (4), 603-610.
33. M.S. Triantafyllou, & G.S. Triantafyllou, 1995, "An Efficient Swimming Machine", *Scientific American*, **272** (3), 64-70.
34. M.S. Triantafyllou, & D.K.P. Yue, 1995, "Damping Amplification in Highly Extensible Hysteretic Cables", *Journal of Sound and Vibration*, **186** (3), 355-368.
35. T. Tjavaras, & M.S. Triantafyllou, 1996, "Nonlinear response of two disordered pendula", *Journal of Sound and Vibration*, **190**, 65-76.
36. T. Tjavaras, & M.S. Triantafyllou, 1996, "Shock waves in curved synthetic cables", *Journal of Engineering Mechanics*, **122** (4), 308-315.
37. S. Mavrakos, V. Papazoglou, M.S. Triantafyllou, & J. Chatjigeorgiou, 1996, "Deep Water Mooring Dynamics", *Marine Structures*, **9** (1), 181-209.
38. M.S. Triantafyllou, D.S. Barrett, D.K.P. Yue, J.M. Anderson, M.A. Grosenbaugh, K. Streitlien, & G.S. Triantafyllou, 1996, "A New Paradigm of Propulsion and Maneuvering for Marine Vehicles", *Transactions of the Society of Naval Architects and Marine Engineers*, **104**, 81-100.
39. K. Streitlien, G.S. Triantafyllou, & M.S. Triantafyllou, 1996, "Efficient Foil Propulsion through Vortex Control", *AIAA Journal*, **34** (11), 2315-2319.
40. F.S. Hover, S.N. Miller, & M.S. Triantafyllou, 1997, "Vortex induced vibration of marine cables: Experiments using force feedback", *Journal of Fluids and Structures*, **11**, 307-326.
41. F.S. Hover, S.N. Miller, & M.S. Triantafyllou, 1997, "Vortex-induced oscillations in inclined cables", *Journal of Wind Engineering and Industrial Aerodynamics*, **69-71**, 203-211.
42. J.M. Anderson, K. Streitlien, D.S. Barrett, & M.S. Triantafyllou, 1998, "Oscillating foils of high propulsive efficiency", *Journal of Fluid Mechanics*, **360**, 41-72.
43. A.H. Techet, F.S. Hover, & M.S. Triantafyllou, 1998, "Vortical patterns behind tapered cylinders oscillating transversely to a uniform flow", *Journal of Fluid Mechanics*, **363**, 79-96.
44. F.S. Hover, A.H. Techet, & M.S. Triantafyllou, 1998, "Forces on oscillating uniform and tapered cylinders in crossflow", *Journal of Fluid Mechanics*, **363**, 97-114.
45. A.A. Tjavaras, Q. Zhu, Y. Liu, M.S. Triantafyllou & D.K.P. Yue, 1998, "The mechanics of highly-extensible cables", *Journal of Sound and Vibration*, **213**, 709-737.
46. Q. Zhu, Y. Liu, A.A. Tjavaras, M.S. Triantafyllou, & D.K.P. Yue, 1999, "Mechanics of nonlinear short-wave generation by a moored near-surface buoy", *Journal of Fluid Mechanics*, **381**, 305-335.

47. M.J. Wolfgang, J.M. Anderson, M.A. Grosenbaugh, D.K.P. Yue, & M.S. Triantafyllou, 1999, "Near-body flow dynamics in swimming fish", *Journal of Experimental Biology*, **202**, 2303-2327.
48. D.S. Barrett, M.S. Triantafyllou, D.K.P. Yue, M.A. Grosenbaugh, & M.J. Wolfgang, 1999, "Drag reduction in fish-like locomotion", *Journal of Fluid Mechanics*, **392**, 183-212.
49. M.J. Wolfgang, D.K.P. Yue, & M.S. Triantafyllou, 1999, "Visualization of complex near-body transport processes in flexible-body propulsion", *Journal of Flow Visualization*, **2**(2), 143-151.
50. F.S. Hover, & M.S. Triantafyllou, 1999, "Linear dynamics of curved tensioned elastic beams", *Journal of Sound and Vibration*, **228**(4), 923-930.
51. K. Burr, D.K.P. Yue, & M.S. Triantafyllou, 2000, "Asymptotic analysis of wave propagation along weakly non-uniform repetitive systems", *Journal of Sound and Vibration*, **229** (1), 21-64.
52. M.S. Triantafyllou, G.S. Triantafyllou, & D.K.P. Yue, 2000, "Hydrodynamics of Fish Swimming", *Annual Review of Fluid Mechanics*, **32**, 33-53.
53. H. Kagemoto, M.J. Wolfgang, M.S. Triantafyllou, & D.K.P. Yue, 2000, "Force and power estimation in fish-like locomotion using a vortex-lattice method", *Journal of Fluids Engineering*, **122**, 239-253.
54. T.R. Consi, P.A. Seifert, M.S. Triantafyllou, & E.R. Edelman, 2001, "The Dorsal Fin Engine of the Seahorse, *Hippocampus sp.*", *Journal of Morphology*, **248** (1), 80-97.
55. F.S. Hover, & M.S. Triantafyllou, 2001, "Galloping response of a cylinder with upstream wake interference", *Journal of Fluids and Structures*, **15**, 503-512.
56. K. Burr, D.K.P. Yue, & M.S. Triantafyllou, 2001, "Asymptotic governing equation for wave propagation along weakly non-uniform Euler-Bernoulli beams", *Journal of Sound and Vibration*, **247** (4), 577-613.
57. J.C. Liao, D.N. Beal, G.V. Lauder, & M.S. Triantafyllou, 2001, "Novel body kinematics of trout swimming in a von Karman trail; can fish tune to vortices", *American Zoologist*, **41** (6), 1505-1506.
58. S.J. Brown, M.S. Triantafyllou, & D.K.P. Yue, 2001, "Complex analysis of resonance conditions for coupled capillary and dilational waves", *Proc. Roy. Soc. London A*, **A 458**, 1167-1187.
59. F.S. Hover, H. Tvedt, & M.S. Triantafyllou, 2001, "Vortex-induced vibrations of a cylinder with tripping wires", *Journal of Fluid Mechanics*, **448**, 175-195.
60. Q. Zhu, M.J. Wolfgang, D.K.P. Yue, & M.S. Triantafyllou, 2002, "Three-dimensional flow structures and vorticity control in fish-like swimming", *Journal of Fluid Mechanics*, **468**, 1-28.
61. J.I Gobat, M.A. Grosenbaugh, & M.S. Triantafyllou, 2002, "Generalized-a time integration solutions for hanging chain dynamics", *Journal of Engineering Mechanics*, **128** (6), 677-687.
62. D.A. Read, F.S. Hover, & M.S. Triantafyllou, 2003, "Forces on oscillating foils for propulsion and maneuvering", *Journal of Fluids and Structures*, **17**, 163-183.
63. M.S. Triantafyllou, A.H. Techet, Q. Zhu, D.N. Beal, F.S. Hover, & D.K.P. Yue, 2003, "Vorticity control in fish-like propulsion and maneuvering", *Integ. Comp. Biol.*, **42** (5), 1026-1031.
64. J.C. Liao, D.N. Beal, G.V. Lauder, & M.S. Triantafyllou, 2003, "The Karman gait: novel body kinematics of rainbow trout swimming in a vortex street", *Journal of Experimental Biology*, **206**, 1059-1073.

65. A.H. Techet, F.S. Hover, & M.S. Triantafyllou, 2003, "Separation and Turbulence Control in Biomimetic Flows", *Flow, Turbulence and Combustion*, **71** (1-4), 105-118.
66. L. Shen, X. Zhang, D.K.P. Yue, & M.S. Triantafyllou, 2003, "Turbulent Flow over a Flexible Wall Undergoing a Streamwise Traveling Wavy Motion", *J. Fluid Mech.*, **484**, 197-221.
67. J.C. Liao, D.N. Beal, G.V. Lauder, & M.S. Triantafyllou, 2003, "Fish exploiting vortices use less muscle", *Science*, **302** (5650), 1566-1569, November 28, 2003.
68. F.S. Hover, O. Haugsdahl, & M.S. Triantafyllou, 2004, "Control of angle of attack profiles in flapping foil propulsion", *Journal of Fluids and Structures*, **19**, 37-47.
69. F.S. Hover, J.T. Davis, & M.S. Triantafyllou 2004, "Three-dimensionality of mode transition in vortex-induced vibrations of a circular cylinder", *European Journal of Mechanics B - Fluids*, **23** (1), 29-40.
70. R. Pouliot, R. Azhari, H.F. Qanadilo, M.S. Triantafyllou, & R. Langer, 2004, "Tissue engineering of fish skin: behavior of fish cells on poly(ethylene glycol terephthalate) /poly(butylene terephthalate) copolymers in relation to the composition of the polymer substrate as an initial step in constructing a robotic/living tissue hybrid", *Tissue Engineering*, **10** (1-2), 7-21.
71. M.S. Triantafyllou, A.H. Techet, & F.S. Hover, 2004, "Review of Experimental Work in Biomimetic Foils", *J. Oceanic Engng. (IEEE)*, **29** (3), 585-594.
72. S. Licht, V. Polidoro, M. Flores, F.S. Hover, & M.S. Triantafyllou, 2004, "Design and Projected Performance of a Flapping Foil AUV", *J. Oceanic Engng. (IEEE)*, **29** (3), 786-794.
73. P. Blondeaux, L. Guglielmini, & M.S. Triantafyllou, 2005, "Chaotic flow generated by an oscillating foil", *AIAA J.*, 43 (4), 918-921.
74. L. Schouveiler, F.S. Hover, & M.S. Triantafyllou, 2005, "Performance of flapping foil propulsion", *Journal of Fluids and Structures*, **20**, 949-959.
75. J.R. Chaplin, P.W. Bearman, Y. Cheng, E. Fontaine, J.M.R. Graham, K. Herfjord, F.J. Huera Huarte, M. Isherwood, K. Lambrakos, C.M. Larsen, J.R. Meneghini, G. Moe, R.J. Pattenden, M.S. Triantafyllou, & R.H.J. Willden, 2005, "Blind predictions of laboratory measurements of vortex-induced vibrations of a tension riser", *Journal of Fluids and Structures*, **21**, 25-40.
76. J.W. Stettler, F.S. Hover, & M.S. Triantafyllou, 2005, "Investigating the steady and unsteady maneuvering dynamics of an azimuthing podded propulsor, *Transactions of the Society of Naval Architects and Marine Engineers*, **113**.
77. P. Blondeaux, F. Fornarelli, L. Guglielmini, M.S. Triantafyllou, & R. Verzicco, 2005, "Numerical experiments on flapping foils mimicking fish-like locomotion", *Physics of Fluids*, **17**, 113601.
78. M.S. Triantafyllou, F.S. Hover, A.H. Techet, & D.K.P. Yue, 2005, "Review of Hydrodynamic Scaling Laws in Aquatic Locomotion and Fish-Like Swimming", *Applied Mechanics Reviews*, **58**, (4), 226-237.
79. F.S. Hover, & M.S. Triantafyllou, 2006, "Application of polynomial chaos in stability and control", *Automatica*, **42**, 789-795.
80. D.N. Beal, F.S. Hover, M.S. Triantafyllou, J.C. Liao, & G.V. Lauder, 2006, "Passive propulsion in vortex wakes", *Journal of Fluid Mechanics*, **549**, 385-402.
81. G.V. Papaioannou, D.K.P. Yue, M.S. Triantafyllou, & G.E. Karniadakis, 2006, "Evidence of holes in the Arnold tongues of flow past two oscillating cylinders", *Physical Review Letters*, **96**, 014501 (4 pp).

82. G.V. Papaioannou, Dick K.P. Yue, M.S. Triantafyllou, & G.E. Karniadakis, 2006, "Three-dimensionality effects on the flow around two tandem cylinders in the lower subcritical regime", *Journal of Fluid Mechanics*, **558**, 387-413.
83. J.M. Dahl, F.S. Hover, & M.S. Triantafyllou, 2006, "Two-degree-of-freedom vortex-induced vibrations using a force assisted apparatus", *Journal of Fluids and Structures*, **22**, 807-818.
84. D. Lucor, H. Mukundan, & M.S. Triantafyllou, 2006, "Riser modal identification in CFD and full-scale experiments", *Journal of Fluids and Structures*, **22**, 905–917.
85. Q. Zhu, J. Zeng, M.S. Triantafyllou, & D.K.P. Yue, 2006, "Direct numerical simulation of single-molecule DNA by cable dynamics", *IEEE Journal of Microelectromechanical Systems (MEMS)*, **15** (5), 1078-1087.
86. J.M. Dahl, F. Hover, M.S. Triantafyllou, S. Dong, & G.E. Karniadakis, 2007, "Resonant vibrations of bluff bodies cause multi-vortex shedding and high frequency forces", *Physical Review Letters*, **99** (14) Article 144503, 5 October, 2007.
87. P. Prempraneerach, F.S. Hover, M.S. Triantafyllou, T.J. McCoy, C. Chryssostomidis, & G.E. Karniadakis, 2007, "Sensitivity Analysis of the Shipboard Integrated Power System", *Naval Engineers Journal*, **12**, article 25.
88. D. Lucor, H. Mukundan, & M.S. Triantafyllou, 2008, "Parametric study of a two degree–of–freedom cylinder subject to vortex–induced vibrations", *Journal of Fluids and Structures*, **24**, 1284-1293.
89. D. Lucor, & M.S. Triantafyllou, 2008, "Riser response analysis by modal phase reconstruction", *J. Offshore Mech. Arct. Eng.*, **130**, 011008.
90. R. Galvao, E. Lee, D. Farrell, F.S. Hover, M.S. Triantafyllou, N. Kitney, & P. Beynet, 2008, "Flow Control in Flow-Structure Interaction", *Journal of Fluids and Structures*, **24**, 1216-1226.
91. G.V. Papaioannou, D.K.P. Yue, M.S. Triantafyllou, & G.E. Karniadakis, 2008, "On the effect of spacing on the vortex-induced vibrations of two tandem cylinders", *J. Fluids Struct.*, **24**, 833-854.
92. H. Mukundan, Y. Modarres-Sadeghi, F.S. Hover, & M.S. Triantafyllou, 2009, "Monitoring fatigue damage on marine risers", *Journal of Fluids and Structures*, **25**, 617-628.
93. H. Mukundan, F. Chasparis, F.S. Hover, & M.S. Triantafyllou, 2010, "Optimal lift coefficient databases from riser experiments", *Journal of Fluids and Structures*, **26**, 160-175.
94. Y. Modarres-Sadeghi, H. Mukundan, J.M. Dahl, F.S. Hover, & M.S. Triantafyllou, 2010, "The effect of higher harmonic forces on fatigue life of marine risers", *Journal of Sound and Vibration*, **329**, 43-55.
95. J.M. Dahl, F. Hover, M.S. Triantafyllou, & O.H. Oakley, 2010, "Dual resonance in VIV at subcritical and supercritical Reynolds numbers", *Journal of Fluid Mechanics*, **643**, 395-424.
96. S. Licht, M. Wibawa, F. S. Hover, & M.S. Triantafyllou, 2010, "In-line motion causes high thrust and efficiency in flapping foils that use power downstroke", *Journal of Experimental Biology*, **213**, 63-71.
97. P. Prempraneerach, F.S. Hover, M.S. Triantafyllou, & G.E. Karniadakis, 2010, "Uncertainty Quantification in Simulations of Power Systems: Multi-Element Polynomial Chaos Methods", *Reliability Engineering and System Safety*, **95**, 632-646.
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EXHIBIT B

Michael S. Triantafyllou, Ph. D.
Detail of Prior Four Years Testimony as of March 2015

CASE	COURT	CAUSE NUMBER	TESTIMONY
WesternGeco, L.L.C. v. Ion Geophysical Corporation	U.S. District Court, Southern District of Texas, Houston Division	CA No. 4:09-CV-01827	Deposition / Trial
Swimways Corporation and VAP Creative Ltd. v. Zuru, LLC.	U.S. District Court, Eastern District of Virginia, Norfolk Division	CA No. 2:13-CV-334	Declaration in Support of Summary Judgment

EXHIBIT C

Materials Considered by Michael S. Triantafyllou, Ph.D.

DATE	DESCRIPTION
4/23/2014	Petition for *Inter Partes* Review of United States Patent No. 7,162,967 Under 35 U.S.C. §§ 311-319 and 37 C.F.R. §§ 42.1-.80, 42.100-.123 (Paper No. 0001)
4/23/2014	[Unredacted] Petition for *Inter Partes* Review of United States Patent No. 7,162,967 Under 35 U.S.C. §§ 311-319 and 37 C.F.R. §§ 42.1-.80, 42.100-.123 (Paper No. 0002)
12/15/2014	Decision on Institution of *Inter Partes* Review 37 C.F.R. § 42,108 (Paper No. 0033)
1/16/2007	United States Patent No. 7,162,967 (Ex. 1001)
4/17/2014	Declaration of Dr. Brian J. Evans, PhD. (Ex. 1002)
4/17/2014	[Unredacted] Declaration of Dr. Brian J. Evans, PhD. (Ex. 1002)
4/22/2014	Declaration of Dr. Jack H. Cole, PhD. (Ex. 1003)
4/22/2014	[Unredacted] Declaration of Dr. Jack H. Cole, PhD. (Ex. 1003)
7/2/1998	International Patent No. WO 98/28636 (Ex. 1004)
1/4/2000	United States Patent No. 6,011,752 (Ex. 1005)
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9/20/1971	United States Patent No. 3,605,674 (Ex. 1007)
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