IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF TEXAS
HOUSTON DIVISION

WESTERNGECO L.L.C.,	)	
	)	
Plaintiff,	)	
	)	
v.	)	Civil Action No. 4:09-cv-1827
	)	
ION GEOPHYSICAL CORPORATION,	)	
FUGRO-GEOTEAM, INC.,	)	
FUGRO-GEOTEAM AS,	)	Hon. Keith Ellison
FUGRO NORWAY MARINE SERVICES	)	
AS, FUGRO, INC., FUGRO (USA), INC.,	)	
and FUGRO GEOSERVICES, INC.	)	JURY DEMANDED
	)	
Defendants.	)	

AMENDED FUGRO COMPLAINT

DEMAND FOR JURY TRIAL

Plaintiff WesternGeco L.L.C., for its Complaint against Defendants Fugro-Geoteam, Inc., Fugro-Geoteam AS, Fugro Norway Marine Services AS, Fugro, Inc., Fugro (USA), Inc. and Fugro GeoServices, Inc. (collectively, "Fugro" or the "Fugro entities"), hereby alleges as follows and demands a jury trial on all issues so triable.

THE PARTIES

1. Plaintiff WesternGeco L.L.C. ("WesternGeco") is a Delaware corporation having a principal place of business at 10001 Richmond Avenue, Houston, Texas 77042-4299.

2. Upon information and belief, Fugro-Geoteam, Inc. is a Texas corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at 6100 Hillcroft, Houston, Texas 77081.

3. Upon information and belief, Defendant Fugro-Geoteam AS is a Norwegian corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at Hoffsveien 1C, Oslo, 0213, Norway.

4. Upon information and belief, Defendant Fugro Norway Marine Services AS is a Norwegian corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at Hoffsveien 1C, Oslo, 0213, Norway.

5. Upon information and belief, Fugro, Inc. is a Texas corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at 6100 Hillcroft, Houston, Texas 77081.

6. Upon information and belief, Fugro (USA), Inc. is a Delaware corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at 6100 Hillcroft, Houston, Texas 77081.

7. Upon information and belief, Fugro GeoServices, Inc. is a Delaware corporation and a wholly-owned subsidiary of Fugro N.V. having a place of business at 6100 Hillcroft, Houston, Texas 77081.

PRIOR PLEADINGS

8. This Amended Complaint amends WesternGeco's June 16, 2010 Complaint against Fugro in Case No. 4:10-cv-02120. This amended complaint does not affect or modify WesternGeco's June 12, 2009 Complaint against ION Geophysical Corp. in the above-captioned matter. (D.I. 1) To the extent necessary, WesternGeco hereby incorporates that Complaint against ION Geophysical Corp. (D.I. 1) in its entirety into this Amended Complaint.

NATURE OF THE ACTION

9. This is a civil action for the willful infringement of United States Patents No. 6,691,038 ("the '038 patent"), 6,932,017 ("the '017 patent"), 7,080,607 ("the '607 patent"), 7,162,967 ("the '967 patent"), and 7,293,520 ("the '520 patent"). This action arises under the Patent Laws of the United States, 35 U.S.C. § 1 *et seq*.

JURISDICTION AND VENUE

10. This Court has subject matter jurisdiction over the infringement action pursuant to 28 U.S.C. §§ 2201–2202, and 28 U.S.C. §§ 1331 and 1338(a).

11. Fugro is subject to personal jurisdiction in this Court as evidenced by, *inter alia*, its presence in Texas and its systematic and continuous contacts with the State of Texas.

12. Upon information and belief, Fugro is also subject to personal jurisdiction in this Court because Fugro regularly sells products and services to customers within this District, and has also sold infringing products and services to customers within this District. For example, upon information and belief, the Fugro entities have offered for sale infringing products and services relying, at least in part, on equipment, services and/or support provided from this judicial district.

13. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391 and 1400(b).

THE PATENTS

14. On February 10, 2004, the '038 patent, titled "Active Separation Tracking And Positioning System For Towed Seismic Arrays," was duly and legally issued to WesternGeco as assignee. WesternGeco is the current assignee of the '038 patent, and is the

owner of the right to sue and to recover for any current or past infringement of that patent. A copy of the '038 patent is attached hereto as Exhibit A.

15. On August 23, 2005, the '017 patent, titled "Control System For Positioning Of Marine Seismic Streamers," was duly and legally issued to WesternGeco as assignee. WesternGeco is the current assignee of the '017 patent, and is the owner of the right to sue and to recover for any current or past infringement of that patent. A copy of the '017 patent is attached hereto as Exhibit B.

16. On July 25, 2006, the '607 patent, titled "Seismic Data Acquisition Equipment Control System," was duly and legally issued to WesternGeco as assignee. WesternGeco is the current assignee of the '607 patent, and is the owner of the right to sue and to recover for any current or past infringement of that patent. A copy of the '607 patent is attached hereto as Exhibit C.

17. On January 16, 2007, the '967 patent, titled "Control System For Positioning Of Marine Seismic Streamers," was duly and legally issued to WesternGeco as assignee. WesternGeco is the current assignee of the '967 patent, and is the owner of the right to sue and to recover for any current or past infringement of that patent. A copy of the '967 patent is attached hereto as Exhibit D.

18. On November 13, 2007, the '520 patent, titled "Control System For Positioning Of A Marine Seismic Streamers," was duly and legally issued to WesternGeco as assignee. WesternGeco is the current assignee of the '520 patent, and is the owner of the right to sue and to recover for any current or past infringement of that patent. A copy of the '520 patent is attached hereto as Exhibit E.

FACTUAL BACKGROUND

19. Upon information and belief, Fugro operates as a single, world-wide, integrated company with substantial contacts in Houston, Texas.

20. For example, the Fugro entities share the same website, http://www. fugro.com. Upon information and belief, Fugro's website is accessible nationally and internationally, and is active in interstate commerce.

21. The 2009 Annual Report of Fugro N.V. states that "[e]ffective cooperation between [Fugro's] business units is promoted at various levels. . . . Capacity utilisation and cooperation are optimised through the exchange of equipment, employees and expertise between the various activities . . . [and] [t]he integration of information systems and the utilisation of scale advantages enhance the service provided to clients."

22. For example, upon information and belief, the Fugro entities share overlapping directors and management with each other and with their parent, Fugro N.V.

23. Upon information and belief, Fugro conducts marine towed streamer surveys using, *inter alia*, ION Geophysical Corporation's ("ION's") DigiFIN and Compass Birds or DigiBIRD and/or Orca command and control software.

Fugro's Activities in the United States

24. Upon information and belief, "Fugro-Geoteam," a business or marketing brand encompassing some or all of the Fugro entities, has worldwide responsibility for marine seismic data acquisition services within Fugro.

25. According to a December 18, 2009 Request for Geological and Geophysical Permit (the "2009 Request"), Fugro-Geoteam, Inc. has contracted with Statoil USA E&P, Inc. ("Statoil") to conduct "[g]eophysical data acquisition activities" for the collection of

three-dimensional (3D) marine seismic data (the "2009 planned marine seismic survey"). (2009 Request, Plan of Operations, p. 1) A copy of the 2009 Request is attached hereto as Exhibit F.

26. The 2009 planned marine seismic survey will be conducted in the Chukchi Sea, near the coast of Alaska. (Ex. F at Plan of Operations, p. 1)

27. The 2009 planned marine seismic survey is scheduled to start on July 15, 2010 and end on November 30, 2010. (Ex. F at Plan of Operations, p. 3)

28. Fugro's services in conducting the 2009 planned marine seismic survey include providing a marine vessel and towing an "array of airgun and hydrophone streamers for data acquisition." (Ex. F at Plan of Operations, p. 1)

29. The M/V Geo Celtic, the seismic vessel being used for the 2009 planned marine seismic survey, is operated by Fugro-Geoteam AS and managed by Fugro Norway Marine Services AS. (Ex. F at Appx. A, p. 3) The survey will be conducted by Fugro-Geoteam, Inc. (*Id.* at Plan of Operations, p. 1)

30. The listed contact addresses for the Fugro entities for the 2009 planned marine seismic survey is "6100 Hillcroft" in Houston, Texas ("Fugro's Houston office"). (*Id.* at Appx. C, MMS Form 327, p. 6)

31. Fugro-Geoteam, Inc., Fugro, Inc., Fugro (USA), Inc., and Fugro GeoServices, Inc. are all located at Fugro's Houston office.

32. Upon information and belief, Fugro's 2009 planned marine seismic survey will utilize ION's DigiFIN, Compass Bird or DigiBIRD, DigiRANGE II, and Orca command and control software. According to the 2009 Request, Fugro's 2009 planned marine seismic survey achieves "[s]treamer control" and "[s]treamer positioning" through the use of, ***inter alia***, these products and systems. (*Id.* at Appx. A, pp. 9, 11)

33. Upon information and belief, the Fugro entities have offered for sale products and services for Fugro's 2009 planned marine seismic survey relying, in part, on equipment, services and/or support provided from Fugro's Houston office.

COUNT I – INFRINGEMENT OF THE '038 PATENT

34. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-33 above.

35. Fugro has infringed the '038 patent, literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a),[1] (b), (c) and/or (f).

36. Fugro does not have any license or other authority from WesternGeco or any other person or entity to practice the subject matter claimed by the '038 patent.

37. WesternGeco has, at all relevant times, complied with the notice provisions of 35 U.S.C. § 287(a) with respect to the '038 patent.

38. Upon information and belief, Fugro has been aware of the '038 patent at all relevant times.

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1 On March 2, 2011, the Court found that "the acts of direct infringement the Fugro Norway Defendants are alleged to have performed while surveying Statoil's lease holdings in the Chukchi Sea are outside the territory of the United States and thus not actionable under 35 U.S.C. § 271(a)." (D.I. 144 at 43) WesternGeco respectfully disagrees with this determination, and reserves the right to seek reconsideration and/or appeal of this decision as this case proceeds.

39. Upon information and belief, Fugro has willfully infringed the '038 patent. Fugro's willful infringement of the '038 patent renders this an exceptional case pursuant to 35 U.S.C. § 285.

COUNT II – INFRINGEMENT OF THE '017 PATENT

40. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-39 above.

41. Fugro has infringed the '017 patent, literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a), (b), (c) and/or (f).

42. Fugro does not have any license or other authority from WesternGeco or any other person or entity to practice the subject matter claimed by the '017 patent.

43. WesternGeco has, at all relevant times, complied with the notice provisions of 35 U.S.C. § 287(a) with respect to the '017 patent.

44. Upon information and belief, Fugro has been aware of the '017 patent at all relevant times.

45. Upon information and belief, Fugro has willfully infringed the '017 patent. Fugro's willful infringement of the '017 patent renders this an exceptional case pursuant to 35 U.S.C. § 285.

COUNT III – INFRINGEMENT OF THE '607 PATENT

46. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-45 above.

47. Fugro has infringed the '607 patent, literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a), (b), (c) and/or (f).

48. Fugro does not have any license or other authority from WesternGeco or any other person or entity to practice the subject matter claimed by the '607 patent.

49. WesternGeco has, at all relevant times, complied with the notice provisions of 35 U.S.C. § 287(a) with respect to the '607 patent.

50. Upon information and belief, Fugro has been aware of the '607 patent at all relevant times.

51. Upon information and belief, Fugro has willfully infringed the '607 patent. Fugro's willful infringement of the '607 patent renders this an exceptional case pursuant to 35 U.S.C. § 285.

COUNT IV – INFRINGEMENT OF THE '967 PATENT

52. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-51 above.

53. Fugro has infringed the '967 patent, literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a), (b), (c) and/or (f).

54. Fugro does not have any license or other authority from WesternGeco or any other person or entity to practice the subject matter claimed by the '967 patent.

55. WesternGeco, has at all relevant times, complied with the notice provisions of 35 U.S.C. § 287(a) with respect to the '967 patent.

56. Upon information and belief, Fugro has been aware of the '967 patent at all relevant times.

57. Upon information and belief, Fugro has willfully infringed the '967 patent. Fugro's willful infringement of the '967 patent renders this an exceptional case pursuant to 35 U.S.C. § 285.

COUNT V – INFRINGEMENT OF THE '520 PATENT

58. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-57 above.

59. Fugro has infringed the '520 patent, literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a), (b), (c) and/or (f).

60. Fugro does not have any license or other authority from WesternGeco or any other person or entity to practice the subject matter claimed by the '520 patent.

61. WesternGeco has, at all relevant times, complied with the notice provisions of 35 U.S.C. § 287(a) with respect to the '520 patent.

62. Upon information and belief, Fugro has been aware of the '520 patent at all relevant times.

63. Upon information and belief, Fugro has willfully infringed the '520 patent. Fugro's willful infringement of the '520 patent renders this an exceptional case pursuant to 35 U.S.C. § 285.

COUNT VI – DECLARATORY JUDGMENT OF INFRINGEMENT

64. WesternGeco repeats and incorporates by reference the allegations set forth in paragraphs 1-63 above.

65. According to a September 1, 2010 Request for Geological and Geophysical Permit (the "2010 Request"), Fugro-Geoteam AS and/or Fugro Geoteam, Inc. did or will conduct "[g]eophysical exploration for mineral resources" on behalf of Fugro Multi Client Services, Inc. (the "2010 planned marine seismic survey"). (2010 Request at WG00898418-419, D.I. 143-1 at 11-12) A copy of the 2010 Request is attached hereto as Ex. G.

66. The 2010 planned marine seismic survey was and/or will be conducted in the Gulf of Mexico. (Ex. G at WG00898418)

67. Fugro's 2010 planned marine seismic survey did and/or will operate out of Galveston, Texas and/or Fourchon, Louisiana. (Ex. G at WG00898419, D.I. 143-1 at 12)

68. The 2010 planned marine seismic survey was and/or is scheduled to start on October 1, 2010 and end on September 31, 2011 and/or is scheduled for March 21, 2011 through March 20, 2012. (Ex. G at WG00898419, D.I. 143-1 at 12)

69. Fugro's services in conducting the 2010 planned marine seismic survey include providing a marine vessel and "Wide Azimuth Multi streamer, multi airgun source recording seismic data (approximately 3,150 [or 3,500] square miles), and gravity." (Ex. G at WG00898420; D.I. 143-1 at 12)

70. The R/V Geo Pacific, M/V Geo Coral, M/V Geo Caspian, and R/V Geo Barents, the seismic vessels being used for the 2010 planned marine seismic survey, are operated by Fugro-Geoteam AS or Fugro Norway Marine Services AS and managed by Fugro Norway Marine Services AS. (Ex. G at WG00898424-425, WG00898428-433) The survey was and/or will be conducted by Fugro-Geoteam AS and/or Fugro Geoteam, Inc. (Ex. G at WG00898419, D.I. 143-1 at 12)

71. The listed contact addresses for the Fugro entities for the 2010 planned marine seismic survey are 6100 Hillcroft in Houston, Texas (Fugro-Geoteam AS and/or Fugro Geoteam, Inc.) and 6100 Hillcroft in Houston, TX (Fugro Multi Client Services, Inc.). (Ex. G at WG00898419, D.I. 143-1 at 12)

72. Upon information and belief, Fugro's 2010 planned marine seismic survey did and/or will utilize ION's DigiFIN, Compass Bird or DigiBIRD, DigiRANGE II, and Orca command and control software. According to the 2010 Request, Fugro's planned marine seismic survey records seismic data with "Wide Azimuth Multi streamer" and "Solid Streamers" through the use of, *inter alia*, these products and systems. (Ex. G at WG00898420, WG00898435)

73. To the extent that Fugro has not already performed all or a portion of the infringing acts indicated in the 2009 Request and/or the 2010 Request, and/or is planning additional acts of direct, contributory or inducing infringement within the United States of America, its territories and possessions similar to those set forth in the 2009 Request and/or the 2010 Request, an actual controversy has arisen and now exists between the parties concerning Fugro's infringement of the '038 patent, the '017 patent, the '607 patent, the '967 patent and the '520 patent.

74. Pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq.*, WesternGeco requests a declaration of the Court that Fugro's prospective actions, including the 2009 planned marine seismic survey to be conducted in the Chukchi Sea operating out of Dutch Harbor, Nome, Barrow, and/or Wainwright, Alaska and the 2010 planned marine seismic survey to be conducted in the Gulf of Mexico operating out of Galveston, Texas and/or Fourchon, Louisiana or other similar activities within the United States, its territories and possessions, infringe the '038 patent, the '017 patent, the '607 patent, the '967 patent and/or the '520 patent literally and/or under the doctrine of equivalents, by making, using, offering to sell, selling and/or supplying in or from the United States products and services relating to steerable streamers (including but not limited to products and services incorporating DigiFIN and ORCA) and/or inducing and/or contributing to such conduct, without authority and in violation of 35 U.S.C. § 271(a), (b), (c) and/or (f).

PRAYER FOR RELIEF

WHEREFORE, Plaintiff WesternGeco prays for judgment:

A. Adjudging that Defendant Fugro has infringed the '038 patent;

B. Adjudging that Defendant Fugro has infringed the '017 patent;

C. Adjudging that Defendant Fugro has infringed the '607 patent;

D. Adjudging that Defendant Fugro has infringed the '967 patent;

E. Adjudging that Defendant Fugro has infringed the '520 patent;

F. Awarding WesternGeco damages adequate to compensate for Fugro's infringement of the '038 patent, the '017 patent, the '607 patent, the '967 patent, and the '520 patent, together with interest and costs as fixed by the Court;

G. Adjudging that Fugro's infringement of the '038 patent, the '017 patent, the '607 patent, the '967 patent, and the '520 patent has been willful and trebling all damages awarded to WesternGeco for such infringement pursuant to 35 U.S.C. § 284;

H. Declaring that Fugro's prospective actions, including the 2009 planned marine seismic survey to be conducted in the Chukchi Sea operating out of Dutch Harbor, Nome, Barrow, and/or Wainwright, Alaska, and the 2010 planned marine seismic survey to be conducted in the Gulf of Mexico operating out of Galveston, Texas and/or Fourchon, Louisiana or other similar activities within the United States, its territories and possessions, infringe the '038 p atent, the '017 patent, the '607 patent, the '967 patent and/or the '520 patent.

I. Enjoining Fugro or any of its agents or related entities from making, using, offering to sell, selling and/or supplying in or from the United States products and services that practice the subject matter of the '038 patent, the '017 patent, the '607 patent, the '967 patent, and the '520 patent pursuant to 35 U.S.C. § 283;

J. Enjoining Fugro or any of its agents or related entities from making, using, offering to sell, selling and/or supplying in or from the United States components of systems or methods that practice, or otherwise aiding or inducing Fugro's customers or other persons or entities to practice, the subject matter of the '038 patent, the '017 patent, the '607 patent, the '967 patent, and the '520 patent pursuant to 35 U.S.C. § 283;

K. Declaring this case to be exceptional within the meaning of 35 U.S.C. § 285 and awarding WesternGeco the attorney fees, costs and expenses it incurs in this action; and

L. Awarding WesternGeco such other and further relief as the Court deems just and proper.

DEMAND FOR JURY TRIAL

Pursuant to Federal Rule of Civil Procedure 38, Plaintiff WesternGeco hereby demands a trial by jury for all the issues so triable.

Dated: March 14, 2011

By: Lee L. Kaplan

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Fax: (212) 446-4900

CERTIFICATE OF SERVICE

I hereby certify that a true and correct copy of the above and foregoing instrument has been forwarded to all counsel of record pursuant to Federal Rules of Civil Procedure on this the 14th day of March, 2011.

Lee L. Kaplan

Exhibit A

US006691038B2

(12) **United States Patent**
Zajac

(10) **Patent No.: US 6,691,038 B2**
(45) **Date of Patent: Feb. 10, 2004**

(54) **ACTIVE SEPARATION TRACKING AND POSITIONING SYSTEM FOR TOWED SEISMIC ARRAYS**

(75) Inventor: **Mark Zajac**, Katy, TX (US)

(73) Assignee: **WesternGeco L.L.C.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 174 days.

(21) Appl. No.: **09/882,952**

(22) Filed: **Jun. 15, 2001**

(65) **Prior Publication Data**

US 2003/0208320 A1 Nov. 6, 2003

(51) **Int. Cl.**[7] **G01V 1/38**
(52) **U.S. Cl.** **702/14; 367/20**
(58) **Field of Search** 702/14, 16; 367/16, 367/72, 20, 19, 17; 114/244, 245, 246

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WO	WO 01/16623	3/2001	G01V/1/38

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Marine Lateral Steering Advance Unveiled, Petroleum Engineer International, Hart Publications, US, vol. 73, No. 8, Aug. 2000, p. 113.

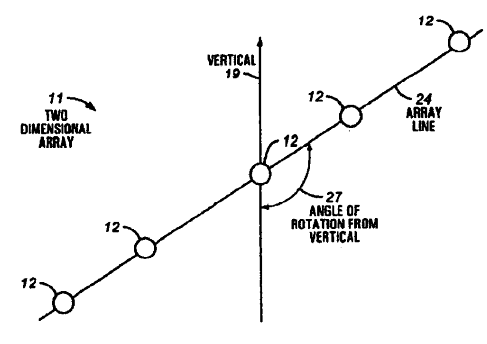
* cited by examiner

Primary Examiner—John Barlow
Assistant Examiner—Victor J. Taylor
(74) *Attorney, Agent, or Firm*—Madan, Mossman & Sriram, P.C.

(57) **ABSTRACT**

A method and apparatus comprising an active control system for a towed seismic streamer array that enables any relative positional control of any number of towed seismic streamers. The streamer positions are controlled horizontally and vertically using active control units positioned within the seismic array. The three component (x, y, z) position of each streamer element, relative to the vessel and relative to each other is controlled, tracked and stored during a seismic data acquisition run. The present invention enables a seismic array to be maneuvered as the towing vessel maintains course, enables maintenance of specific array position and geometry in the presence of variable environmental factors and facilitates four-dimensional seismic data acquisition by sensing and storing the position of the array and each array element with respect to time.

50 Claims, 6 Drawing Sheets



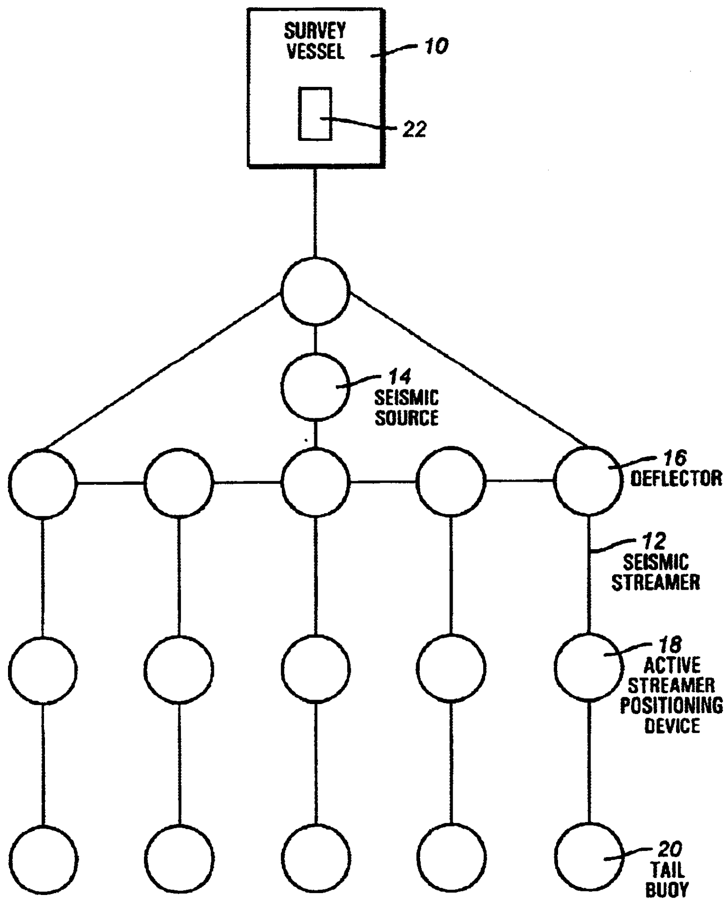
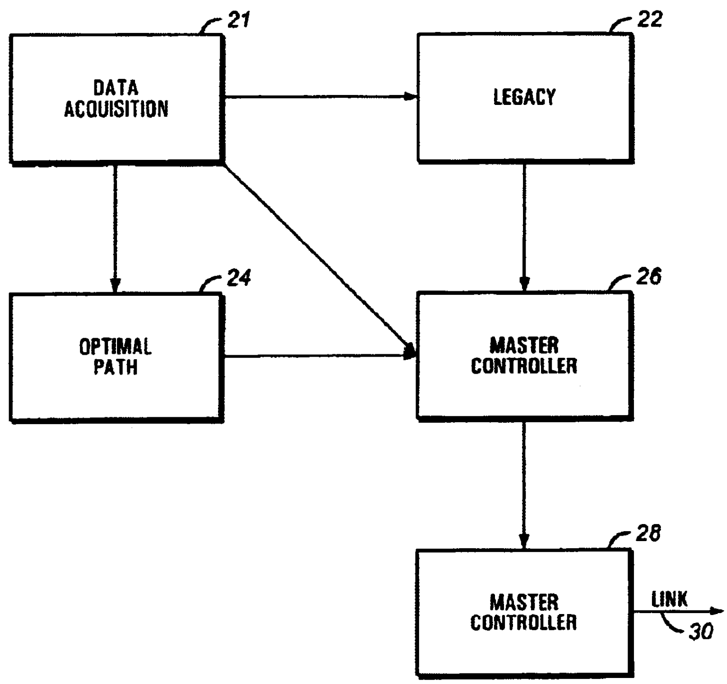

SURVEY VESSEL
10
22
14
SEISMIC SOURCE
16
DEFLECTOR
12
SEISMIC STREAMER
18
ACTIVE STREAMER POSITIONING DEVICE
20
TAIL BUOY

FIG. 1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OPTIMAL PATH
26
MASTER CONTROLLER
28
MASTER CONTROLLER
LINK
30

FIG. 2

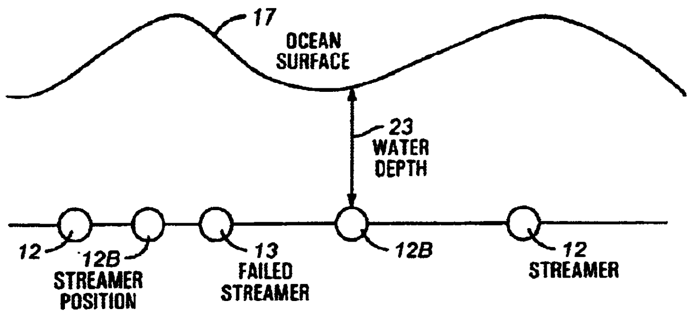
17
OCEAN SURFACE
23
WATER DEPTH
12
12B
STREAMER POSITION
13
FAILED STREAMER
12B
12
STREAMER

FIG. 3A

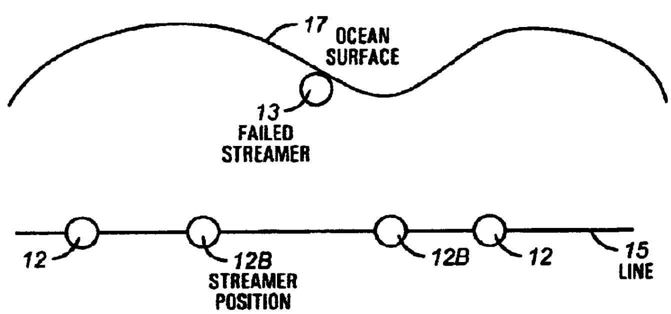
17
OCEAN SURFACE
13
FAILED STREAMER
12
12B
STREAMER POSITION
12B
12
15
LINE

FIG. 3B

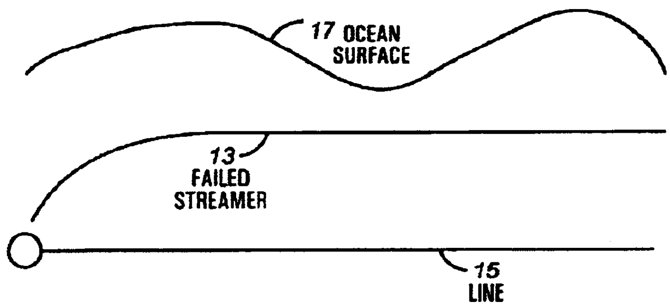
17 OCEAN SURFACE
13
FAILED STREAMER
15
LINE

FIG. 3C

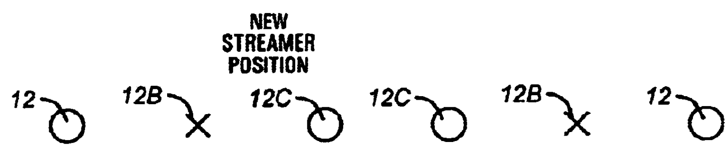
NEW STREAMER POSITION
12
12B
12C
12C
12B
12

FIG. 3D

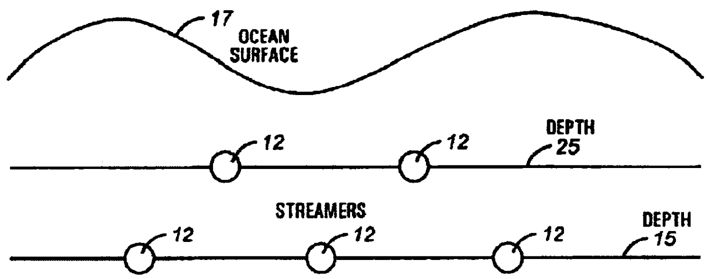
17
OCEAN
SURFACE
12
12
DEPTH
25
STREAMERS
12
12
12
DEPTH
15

FIG. 4

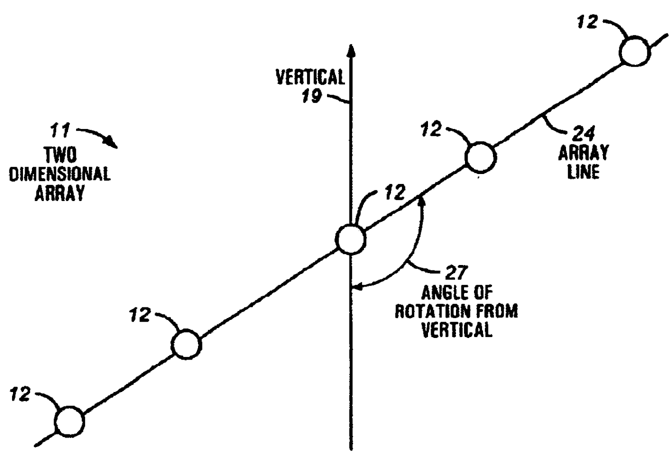
12
VERTICAL
19
11
TWO
DIMENSIONAL
ARRAY
12
24
ARRAY
LINE
12
27
ANGLE OF
ROTATION FROM
VERTICAL
12
12

FIG. 5

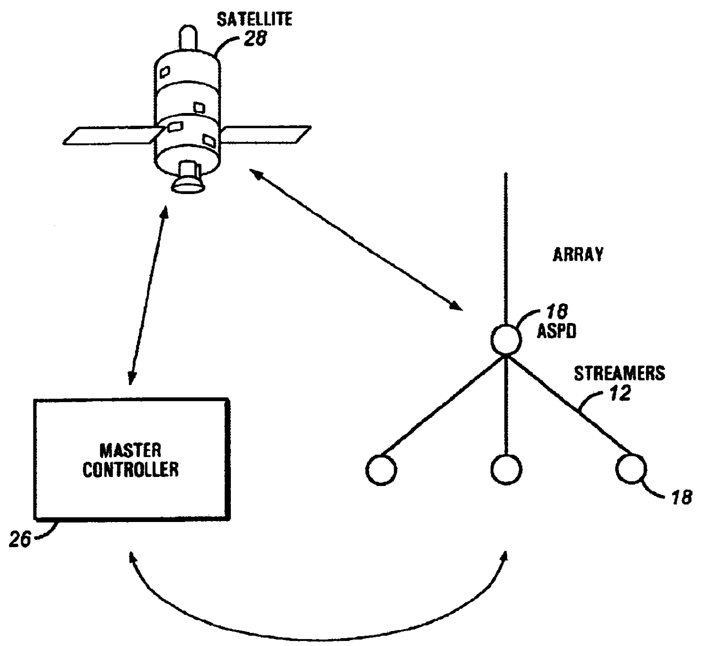
SATELLITE
28
ARRAY
18
ASPD
STREAMERS
12
MASTER
CONTROLLER
18
26

FIG. 6

ACTIVE SEPARATION TRACKING AND POSITIONING SYSTEM FOR TOWED SEISMIC ARRAYS

CROSS REFERENCE TO RELATED APPLICATIONS

This is related to U.S. patent application Ser. No. 09/603,068, filed on Jun. 26, 2000 entitled "Optimal Paths for Marine Data Collection" which is hereby incorporated herein by reference. This is related to U.S. patent application Ser. No. 09/658,846, filed on Nov. 11, 2000 entitled "Neural Network Prediction of Seismic Streamer Shape" which is hereby incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for controlling sea borne seismic data acquisition systems comprising an array of streamers, and in particular to the relative vertical and horizontal positioning of seismic streamers forming a seismic array towed behind a sea borne towing vessel.

DESCRIPTION OF THE RELATED ART

The related art discloses a wide variety of towed marine seismic tracking and positioning systems and methods typically comprising one or more seismic streamers and/or one or more seismic sources. Some these seismic tracking and positioning systems and methods utilize a main or host vessel and/or other-associated unmanned vessels or vehicles to tow the seismic array. Typically towing is controlled or guided by a central control system. The known marine seismic tow tracking and positioning systems and methods are comprised of apparatuses such as seismic hydrophone streamers and attached floats, paravanes, and/or buoyant members. Typically each streamer and control apparatus is connected to the host vessel by a line, cable or tether. Considerable towing power is required of a host vessel to tow existing seismic streamer systems, cables and interconnecting sensing devices. A typical host vessel is capable of towing a plurality of tow vessels and/or carrying a plurality of seismic streamers or arrays and associated support apparatus on the vessel's deck awaiting deployment.

One such tracking and positioning system for positioning and control of marine seismic streamers is taught in the international application published under the Patent Cooperation Treaty (PCT), International Publication Number WO 00/20895, international publication date Apr. 13, 2000. A marine seismic system with independently power tow vehicles is taught by U.S. Pat. No. 6,028,817. A control device for controlling the position of a marine seismic streamer is taught in the international application published under the Patent Cooperation Treaty (PCT), International Publication Number WO 98/28636, international publication date Jul. 2, 1998.

With known seismic cable tracking and positioning systems, the location and spacing of system components is limited by the type, size, and length of cables used and by the characteristics of the towing vehicles and other control devices utilized by the known seismic tracking and positioning systems. Typically, the plurality of towed seismic streamers form an array which is towed behind the host vessel. Typically, changing the configuration of such a towed streamer array, comprised of known components is a complex, cumbersome, time-consuming operation and can often become somewhat unwieldy. Moreover, the spatial and

temporal positioning capability of known towing and tracking and positioning systems is limited.

There is no known seismic tracking and positioning system that enables independent and relative positioning of individual seismic streamer array elements, for example "birds", seismic streamers, comprising sensors, sources and depth and position controls, for example to configure, manipulate and/or maintain a desired geometry of and within a towed seismic streamer array. There is also no known seismic tracking and positioning system that enables relative positioning and manipulation of an entire seismic streamer array. There is also no known tracking and positioning system that enables specification of a plurality of diverse acquisition and ancillary non-acquisition array geometries that facilitates run-time maintenance, retrieval and deployment of a towed seismic array. Moreover, there is no known seismic tracking and positioning system that tracks the geometry of the seismic streamer array and the relative positions of the individual streamers comprising array elements with respect to time and with respect to the earth's latitude and longitude so that towed seismic array data acquisition runs are repeatable, thereby enabling acquisition of four-dimensional geophysical data (x, y, z, time).

Thus, there is a need for a seismic acquisition tracking and positioning system that overcomes the above-mentioned shortcomings of known seismic data acquisition tracking and positioning systems. There has been a long-felt need for an efficient and effective towed marine seismic tracking and positioning system having system components that are easily and reliably tracked, controlled and positioned. There has also been a long-felt need for seismic data acquisition towing, tracking and positioning systems to provide sufficient positioning flexibility to enable efficient, accurate, and repeatable control of the relative and absolute horizontal and vertical positions of towed arrays and the streamers, sensors and sources within a towed array during seismic data acquisition.

SUMMARY OF THE INVENTION

The present position invention provides a method and apparatus for an active tracking and positioning system for a towed seismic streamer array. The present invention recognizes and addresses the previously mentioned shortcomings, problems and long-felt needs associated with known towed seismic tracking and positioning systems. The present invention provides a solution to the aforementioned problems and provides satisfactory meeting of those needs in its various embodiments and equivalents thereof.

The active tracking and positioning system of the present invention provides a method and apparatus that enables relative positional control of any number of towed seismic streamers. The present invention controls streamer positions horizontally and vertically using active control units positioned on each streamer within the seismic array. The three component (x, y, z) position of each streamer element, relative to the vessel, relative to each other and relative Earth coordinate latitude and longitude is controlled, tracked and stored with respect to time during each seismic data acquisition run. This stored data is referred to as legacy data. Environmental factors (wind speed, currents, temperature, salinity, etc), and maneuverability data for the streamers and geometry of the towed array (cable diameter, array type, deployed configuration, vessel type, device type, etc.) for the seismic data acquisition run are also sensed with respect to time and stored as legacy data. The acquisition of legacy data enables repetition of seismic data acquisition runs.

The present invention provides active streamer positioning devices (ASPDs) as control elements, which are installed on individual streamers comprising an array, alternatively at the diverter position, streamer head, along the length of the streamer or at the tail of the streamer. One or more ASPD is employed on each seismic array. The active control elements are also installed at the head tow point of an array, at the head or tail of one or more streamers comprising an array, and/or along any streamer comprising an element of an array. The control elements attached at the streamer head are alternatively detachably connected to the front of the array to facilitate detachment and removal of a single streamer element from the array during a data acquisition run.

The apparatus and method of the present invention enables a seismic array to be maneuvered as the towing vessel maintains it desired course or as the towing vessel maneuvers to assist in the repositioning of the array during a seismic data acquisition run. The present invention may alternatively employ methods such as force vectoring, active wings, or other known means of changing the spatial or temporal, that is the vertical or z-depth position of the streamer elements comprising the array. In addition to enabling change in the spatial and temporal positions of individual array elements, the tracking and positioning system enables maintenance of specific array position and geometry in the presence of variable environmental factors. In this mode, the control system of the present invention adjusts the lifting force of the streamer to accommodate variations in the tide, real-time current velocity and direction, water depth, towed speed, cable maneuverability, towed direction and water salinity, and salinity variations, all of which may affect the buoyancy and position of the towed seismic array. The salinity of the water in which the array is towed may vary abruptly when a salt water towing operation passes by the mouth of a fresh water supply such as a river. The salinity may diminish considerably in the fresh water region near the mouth of a river, thereby requiring adjustment of the array towing forces to maintain desired array geometry and depth.

The present invention enables repeatable, four-dimensional seismic data acquisition by sensing and storing environmental data, temperature sensitive array maneuverability data and positional tracking data for a towed array and each individual element of the towed array with respect to time. The relative horizontal and vertical positioning of each seismic cable and energy source independent of the streamer attached to the array or streamer is controlled, monitored and stored, along with real-time environmental data during a seismic data acquisition operation. The composite stored data comprises legacy data for the data acquisition run. Thus, a seismic data acquisition run can be duplicated at a later date to reproduce the same array geometry and path during subsequent data acquisition runs, in the presence of varying environmental and maneuverability conditions. That is, a particular seismic data acquisition operation is repeatable based on the legacy data, thereby enabling repeatable four-dimensional data (x, y, z, time) gathering for multiple runs over a seismic target area. The present invention also enables implementation of non-acquisition ancillary array configurations such as augmented array geometry for collapsing or expanding an array during deployment or retrieval. The present invention also enables raising a single array element for retrieval from a deployed array during acquisition.

One array section or one streamer of an array section can be deflected out of the array geometry during a data acquisition run and vertically to the surface for detachment, retrieval and/or maintenance. The present invention also enables compensation for a failed or missing streamer. Streamers adjacent a failed or missing/removed streamer can be moved closer together to compensate for the failed or missing streamer array element with or without removal of the element. This enables repair and/or removal and replacement of such a failed array element during a seismic data acquisition run without interruption of the data acquisition run to repair and or replace the disabled streamer. Runtime removal of streamers and compensation for failed streamers enables continuation of data acquisition without causing the vessel and/or array to deviate from its planned data acquisition path.

It is time consuming, difficult and expensive to interrupt the towing vessel during a data acquisition run. Interruption for replacement or repair a streamer element in a data acquisition array and a subsequent attempt to duplicate array geometry and reposition the array and necessitates starting the vessel and array again at the exact location and array geometry where the run data acquisition run was interrupted. This process is difficult and time consuming, if not impossible. The present invention enables compensation for an array element and continuation of a data acquisition run during repair and replacement of the array streamer element.

The instant invention also enables configuring the towed array geometry to compensate for changing environmental and operational conditions that affect maneuverability. The array geometry can also be configured to increase or decrease the temporal resolution and spacing of the array to avoid ghost notching. Deployment and ancillary configurations are also provided wherein, for example, the width of an array may be increased to reduce chances of streamer tangling during deployment. The present invention also enhances in fill shooting where an optimal path has been selected. The present invention enables movement of the array in conjunction with movement of the vessel along an optimal in fill shooting path. The present invention individually controls positioning of the vessel and positioning of the array. Thus, the present invention also enables the towing vessel to account for a portion of the positioning along the selected optimal in fill path or data acquisition path and positioning of the array to account for the remainder of the positioning along the path. This division of positioning movements between the vessel and the array provides a more flexible and efficient positioning system for use during in fill shooting and/or other data acquisition positioning maneuvers.

In one aspect of the invention a seismic streamer array tracking and positioning system is presented comprising a towing vessel for towing a seismic array; an array comprising a plurality of seismic streamers; an active streamer positioning device (ASPD) attached to at least one seismic streamer for positioning the seismic streamer relative to other seismic streamers within the array; and a master controller for issuing positioning commands to each ASPD for maintaining a specified array geometry. In another aspect of the invention the apparatus further comprises an environmental sensor for sensing environmental factors which influence the path of the towed array. In another aspect of the invention the apparatus further comprises a tracking system for tracking the streamer positions versus time during a seismic data acquisition run and storing the positions versus time in a legacy database for repeating the positions versus time in a subsequent data acquisition; and an array geometry tracking system for tracking the array geometry versus time during a seismic data acquisition run and storing the array geometry versus time in a legacy database for repeating the array geometry versus time in a subsequent data acquisition run.

In another aspect of the invention the apparatus further comprises a master controller which compares the positions of the streamers versus time and the array geometry versus time to a desired streamer position and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired streamer position and array geometry versus time. In another aspect of the invention the apparatus further comprises a master controller that factors in environmental factors into the positioning commands to compensate for environmental influences on the positioning of the streamers and the array geometry.

In another aspect of the invention the apparatus further comprises a master controller which compensates for maneuverability in the positioning commands to compensate for maneuverability influences on the positioning of the streamers and the array geometry. In another aspect of the invention the apparatus further comprises a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer. In another aspect of the invention the apparatus further comprises a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to move a failed streamer out of the array. In another aspect of the invention the apparatus further comprises a monitor for determining the status of each streamer, wherein the master controller detaches a failed streamer from the array. In another aspect of the invention the apparatus further comprises an array geometry which comprises a plurality of streamers positioned at a uniform depth. In another aspect of the invention the apparatus further comprises array geometry comprising a plurality of streamers positioned at a plurality of depths for varying temporal resolution of the array.

In another aspect of the invention the apparatus further comprises an array geometry comprising a plurality of streamers positioned along a plane, wherein the plane is rotated at an angel theta with respect to the longitudinal axis of the array. In another aspect of the invention the apparatus further comprises an apparatus wherein the array geometry is tracked via satellite and communicated to the master controller.

In another aspect of the invention a method is provided for tracking and positioning a seismic streamer array comprising a towing vessel for towing a seismic array; providing a seismic streamer array comprising a plurality of seismic streamers; providing an active streamer positioning device (ASPD) attached to each seismic streamer for positioning each seismic streamer; providing a master controller for issuing positioning commands to each ASPD and to the towing vessel for maintaining an optimal path, wherein the master controller further comprises a processor for calculating an optimal path for the seismic array for optimal coverage during seismic data acquisition over a seismic field, and a streamer behavior prediction processor which predicts array behavior, wherein the master controller compensates for predicted streamer behavior in issuing positioning commands to the towing vessel and the ASPDs for positioning the array along the optimal path, wherein the master controller compensates for environmental and maneuverability factors in the positioning commands.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram of a seismic survey vessel and associated seismic data acquisition tracking and positioning system;

FIG. 2 is a schematic diagram for the preferred array geometry tracking and positioning system showing real-time and legacy data storage and acquisition;

FIGS. 3A, 3B, 3C and 3D illustrate a schematic diagram of a towed seismic streamer array showing deflection of a failed streamer to the surface and compensation for the failed streamer by adjacent streamers;

FIG. 4 is a schematic diagram of a towed seismic streamer array showing a alternative array geometry for increasing temporal resolution of the towed array;

FIG. 5 is a schematic diagram of a towed seismic streamer array showing rotation of the array about the longitudinal axis of the array; and

FIG. 6 is a schematic diagram showing the tracking and positioning communication path provided by the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

To one skilled in this art who has the benefit of this invention's realizations, teachings, disclosures, and suggestions, other purposes and advantages will be appreciated from the following description of preferred embodiments, given for the purpose of disclosure, when taken in conjunction with the accompanying drawings. The detail in these descriptions is not intended to thwart this patent's object to claim this invention no matter how others may later disguise it by variations in form or additions of further improvements.

Turning now to FIG. **1**, a seismic survey vessel **10** is shown towing a plurality of marine seismic streamers **12** that may, for instance be 3000 meters in length. The outermost streamers **12** in the array can be as much as 400 meters apart, resulting in a horizontal displacement between each streamer of 100 meters, in an equally-spaced array configuration. A seismic source **14**, typically an airgun or one or more array of airguns, is also shown towed behind the seismic survey vessel **10**.

As shown in FIG. **1**, at the front of each streamer **12** is shown a detachable deflector **16** and at the rear of every streamer is shown a detachable tail buoy **20**. In a preferred embodiment, a detachable, active streamer positioning device **18** (ASPD) can be supplemented or substituted for the deflector **16** and/or tail buoy **20**. The detachable deflector **16** is used to horizontally position the front end of the streamer nearest to the seismic survey vessel **10**. The tail buoy **20** creates drag at the backend of the streamer farthest away from the seismic vessel **10** and provides a platform for absolute positioning or relative positioning at the tail of the streamer. The tension created on the seismic streamer by the deflector **16** and the tail buoy **20** results in the roughly rectilinear shape of the seismic streamer **12** shown in FIG. **1**.

The rectilinear shape of the streamer can be maintained by the present invention to overcome side currents and tides which may affect the shape of the towed cable and cause it to deviate from a preferred rectilinear shape. A rectilinear shape is preferred to maintain array geometry for accurate and repeatable seismic data acquisition runs. Deviation from a rectilinear cable shape can cause undesirable variations in the data gathered from the array. The present invention enables sensing and correction of deviations is the preferred shape of a towed streamer array.

Located between the deflector 16 and the tail buoy 20 are a plurality of ASPDs 18. Preferably the ASPDs 18 are both vertically and horizontally steerable. These ASPDs 18 may, for instance, be located at regular intervals along the individual streamers, such as every 200 to 400 meters. The vertically and horizontally steerable ASPDs 18 can be used to constrain and configure the shape of the seismic streamer 12 between deflector 16 and the tail buoy 20 in the vertical (z or depth) and horizontal (x, y) directions. The ASPDs 18 can be placed at the head end of a streamer, at the tail end of the streamer or at any place along the streamer in between the streamer head end and streamer tail end.

Turning now to FIG. 2, in a preferred embodiment of the present invention, the control system for the ASPD 18 may be distributed between a master controller 26 located remotely on the towing vessel (or at any other location on land, sea or satellite) and a group of one or more separate controllers 18 built into one or more ASPDs 18, which is positioned on streamer 12 within the seismic array. The master controller 26 may be located remotely and communicate via satellite or other communication means as shown in FIG. 6. The master controller receives data representing individual position of at least one point on the array, but preferably one or more points on each streamer element. These streamer positions from individual ASPDs 18, are processed, compared to the desired positions and commands are transmitted to the individual ASPD 18. The link between the active controllers on ASPD 18 and the main controller 26 can be accomplished by any suitable electronic cable, such as coaxial or fiber-optic cable attached to the towed array, via point to point communications or RF communications facilitated by a transceiver attached to the towed array. As shown in FIG. 6, the tracking information from a plurality of points on individual streamers comprising the seismic array can be obtained and transmitted to the master controller 26 via satellite or radio frequency or any other means of communication.

The master controller may be connected via an electronic data bus, via any other suitable physical data interface, or via a wireless communication data interface to collect inputs from environmental sensors associated with vessel 10. Sensed environmental data comprises wind speed and direction; tidal currents velocity and direction; ocean bottom depth/angle; local current velocity and direction; wave height and direction; ocean bottom depth/angle; and water temperature and salinity.

Turning now to FIG. 2, the master controller 26 of the present invention receives the three component position of each active controller in the array, as shown in FIG. 6. Thus, the present invention enables tracking with respect to time, of each individual ASPD and the streamer cable with which the ASPD is associated. Each active controller element is also equipped with a receiver for receipt of commands generated and formatted by the master control 26 and transmitted by active position commander 28. The commands are sent to the ASPDs 18, to instruct each of the ASPDs regarding commands for changing the position of each individual streamer to maintain desired array geometry and overall position. The positioning commands can be absolute commands or represent changes in position from the last command to the particular ASPD. The flexibility of the individual ASPD 18 enables precise positioning of each individual ASPD and associated streamer within the towed streamer array. The present invention enables control of the horizontal, vertical and depth position of the entire array geometry comprising the individual streamers, individual streamers and attached ASPDs, with respect to time.

The array, streamer and individual ASPD three-component (x, y, z) position data with respect to time is stored along with real time environmental data. Environmental data is received via cable or radio from sensors deployed from the vessel or the array. The stored position and environmental data is stored as legacy data in the legacy data storage 22. Optimal path data, is generated by Optimal path processor 24, which may be generated by a neural network or some other methodology such as human input or mathematical formulae, is input to master controller 26. Optimal path data may be provided as a desired seismic acquisition path during primary seismic data acquisition or during in fill shooting. Optimal path data steering is preferably divided between an optimal path for the tow vessel 10 and an optimal path for the towed array. During seismic data acquisition utilizing an optimal path 24, vessel, array, array element and ASPD positions are sensed along with environmental data are transmitted to and received by the data acquisition unit 21. The data acquisition unit 21 stores these inputs with respect to time as legacy data in the legacy data storage 22. The data acquisition unit 21 also passes the array and environmental tracking data to the master controller 26. The maneuverability of the particular cable, ASPD and vessel under the particular sensed environmental conditions are also factored into the active positioning commands. For example, a cable that becomes stiffer in colder water or more buoyant in higher salinity receives an augmented steering command depending on the sensed environmental data. Master controller 26 compares the current vessel and array position data with the desired position or optimal vessel and array path position. The master controller 26 then determines, in light of the current environmental conditions and the maneuverability of the vessel, ASPDs and towed streamers comprising the array, the timing and magnitude of positioning commands to be sent to the ASPDs on the array. The positioning commands are formatted and transmitted by active position commander 28 over link 30. Link 30 may be hardwired or wireless via satellite, laser or radio link.

In a preferred embodiment optimal path processor 24 collects real-time positioning data for the seismic array and for the towing vessel along with environmental data and maneuverability data for the array and towing vessel. The optimal path processor 24 computes predictions for the array behavior and computes the optimal path through the seismic survey area during a data acquisition run. The master control receives the predicted array behavior and takes it into account in generating and issuing positioning commands to the array ASPDs and the towing vessel. The division of the steering commands between the towing vessel and the ASPDs provides additional flexibility and control over the array along the optimal path. The additional flexibility and control of the array long the optimal path reduces the amount of in fill shooting required after a primary data acquisition run and reduces the amount of decision making required of a navigator striving to properly steer the towing vessel during a data acquisition run.

In a preferred embodiment of the present invention, the master controller monitors the actual position of each ASPD to determine the position of the streamers and the composite array geometry comprising the streamers and control elements are tracked and stored as legacy data. The actual positions of vessel, streamers, ASPDs and array geometry are compared to the desired vessel/streamers/ASPD positions and array geometry and corrective position commands are sent to the control elements to move the vessel/streamers/ASPDs to the desired position and array geometry. Tracking data and positioning commands are transmitted between the master controller and active positioners via a cable connecting the master controller and the active positioners or via wireless communications.

The horizontal positions of the ASPDs **18** and/or active controllers can be derived using acoustic position systems as described in U.S. Pat. No. 4,992,990. In the alternative, satellite-based global positioning systems may be utilized separately or in conjunction to determine the positions of the array and the active controllers and streamers comprising the array. The depth of the arrays, and of the individual streamers and individual streamer elements can be determined using pressure sensors.

In calculating desired or necessary movements by vessel, streamers/array and individual ASPDs, to maintain the desired array geometry and position and the relative position of the array elements as well as the desired array position and geometry during four-dimensional data acquisition, the master controller **26** takes into account environmental factors including but not limited to water salinity, current velocity and direction as well as legacy tracking data to adjust the positioning commands provided to the active controller. The master controller also factors in the maneuverability of the streamer cable and streamer array based on the cable diameter and cable type. The master controller sends position correction commands to the active controller either as a desired position or as a force vector comprising the vertical deflection, horizontal deflection, towing velocity and cross current velocity.

The vessel towing velocity and cross current velocity may be calculated from the vessel speed and heading values and the current speed and heading values to determine the relative velocities of the streamers, active controllers and the array. In an alternative embodiment, the towing velocity and/or cross current velocity can be determined using flow meters or other commercially available water velocity meters. Thus, the present invention enables dynamic adaptive geometric configuration, tracking and control to compensate for changes in local currents, tides and salinity of the water during seismic data acquisition.

In an alternative embodiment, a neural network is provided to model and predict cable and array behavior in the presence of changing currents, tides and salinity, or other environmental factors such as wave height, wind, water temperature, etc. The present invention may also factor in compensation for streamer buoyancy, streamer diameter, maneuverability of the cable with respect to the current temperature, streamer and vessel maneuverability and combined streamer/ASPD positioning maneuverability as well as particular array geometry and spacing. The neural network is preferably trained to compensate for changes in such environmental factors in combination with the vessel and streamer/ASPD positioning maneuverability. The present invention thereby enables repeatable and consistent array geometry and positioning for collection of four-dimensional data on separate seismic data acquisition runs using different streamers having different streamer/ASPD maneuverability and under different environmental conditions.

For example, a first data acquisition run may occur during the summer when the water temperature, salinity, tides, winds and currents comprise a first set of data for a first streamer system having a first maneuverability. A second data acquisition run may occur during the winter, years later, when the water temperature, salinity, tides, winds and currents comprise a second set of data for a second streamer/ASPD system possessing a second maneuverability. In order to replicate the first data acquisition run and obtain four-dimensional data during the second data acquisition run; the present invention compensates for the differences between the environmental factors and the differences in vessel/streamers/ASPD maneuverability of the first and second run to accurately repeat the array positioning and geometry during the second run, thereby enabling repeatable seismic acquisition runs and the acquisition of four-dimensional data. The difference maneuverability of the first and second vessels is also considered by the master controller in selecting ASPD positioning commands.

The present invention enable precise maneuvering the individual streamers, the array position and the array geometry, thereby reducing in fill shooting caused by array geometry that is either too broad, too narrow or simply out of position. The present invention also determines and corrects for inappropriately shaped arrays, for example, elements in the array which become non symmetric are adjusted and moved into position so that array geometry errors in x, y, and z space are corrected and compensated by the present invention. The present invention also enables placement of streamers in close proximity without entanglement.

Turning now to FIG. **3A**, a cross section is illustrated, taken perpendicular to the longitudinal axis of the towed array of streamers **12** shown in FIG. **1**. In FIG. **3A**, the array of streamers **12** is positioned at the same water depth **23**, along line **15** at depth **23**, and beneath the ocean surface **17**. A failed streamer **13** originally positioned along line **15** is detected as failed by the master controller. The master controller issues a positioning command to the ASPD on the failed streamer **13**. As shown FIG. **3B**, the failed streamer cable **13** is maneuvered and lifted above line **15** to the surface of the water and out of the array geometry for replacement and or repair during a data acquisition run. A side view of failed streamer **13**, is shown in the raised position in FIG. **3C**. As shown in FIG. **3D**, array geometry can also be altered by the present invention to alter the beam pattern and/or coverage of the array by moving the streamers adjacent the failed streamer to replace and compensate for failed streamer cable **13**. As shown in FIG. **3D**, the streamers in position **12B** adjacent streamer **13** are moved closer together, from position **12B** to position **12C**, to compensate for streamer **13** which has been removed from the array. In a preferred embodiment, all streamers including streamer **13** are detachably connected to the streamer array so that each streamer can be easily removed during seismic data acquisition operations. The master controller **26** detects the failed streamer **13**, commands the ASPD attached to failed streamer **13** to raise streamer **13** to the surface **17**. Once on or near the surface, or simply physically displaced from the array, a manned or unmanned support vehicle can retrieve and or remove and replace streamer **13**. The master controller issues positioning commands to adjust the position of streamers adjacent streamer **13** without interrupting the seismic data acquisition run.

Thus, the present invention senses a failed streamer cable in an array geometry and adjusts the position of adjacent streamer cables so that the beam pattern of the sensing array covers the area covered by the failed streamer. The compensation for a failed array streamer and associated compensation array geometry are noted and stored by the present invention so that post processing analysis compensates for variations in the data caused by the compensation array geometry.

Turning now to FIG. **4**, a three-dimensional array of streamers **12** is shown. The three-dimensional array of FIG. **4** positions the streamers **12** at varying depths **15** and **25**, rather than along a single line at a uniform depth. The varying depths of the streamers increases the temporal resolution of the streamer and substantially eliminates ghost notching. The depths can vary between two or more depths.

Turning now to FIG. 5, a two-dimensional array 11, positioned along line 24, is shown rotated at an angel theta 27 rotated theta degrees from vertical 19. The ability to rotate the array enables maneuvering the array in shallow water near a steep ocean bottom 14 inclined at angle theta.

The foregoing description is for purposes of example only and not intended to limit the scope of the present invention which is defined by the following claims.

What is claimed is:

1. A seismic streamer array tracking and positioning system comprising:

a towing vessel for towing a seismic array;

an array comprising a plurality of seismic streamers;

an active streamer positioning device (ASPD) attached to at least one seismic streamer for positioning the seismic streamer relative to other seismic streamers within the array; and

a master controller for issuing positioning commands to each ASPD to adjust a vertical and horizontal position of a first streamer relative to a second streamer within the array for maintaining a specified array geometry.

2. The apparatus of claim 1 further comprising:

an environmental sensor for sensing environmental factors which influence the path of the towed array.

3. The apparatus of claim 1 further comprising:

a tracking system for tracking the streamer positions versus time during a seismic data acquisition run and storing the positions versus time in a legacy database for repeating the positions versus time in a subsequent data acquisition; and

an array geometry tracking system for tracking the array geometry versus time during a seismic data acquisition run and storing the array geometry versus time in a legacy database for repeating the array geometry versus time in a subsequent data acquisition run.

4. The apparatus of claim 3 wherein the master controller compares the positions of the streamers versus time and the array geometry versus time to a desired streamer position and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired streamer position and array geometry versus time.

5. The apparatus of claim 4 wherein the master controller factors in environmental factors into the positioning commands to compensate for environmental influences on the positioning of the streamers and the array geometry.

6. The apparatus of claim 4 wherein the master controller compensates for maneuverability in the positioning commands to compensate for maneuverability influences on the positioning of the streamers and the array geometry.

7. The apparatus of claim 1 further comprising:

a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer.

8. The apparatus of claim 1 further comprising:

a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to move a failed streamer out of the array.

9. The apparatus of claim 1 further comprising:

a monitor for determining the status of each streamer, wherein the master controller detaches a failed streamer from the array.

10. The apparatus of claim 1 wherein the array geometry comprises a plurality of streamers positioned at a uniform depth.

11. The apparatus of claim 1 wherein the array geometry comprises a plurality of streamers positioned at a plurality of depths for varying temporal resolution of the array.

12. The apparatus of claim 1 wherein the array geometry comprises a plurality of streamers positioned along a plane, wherein the plane is rotated at an angel theta with respect to the longitudinal axis of the array.

13. The apparatus of claim 4 wherein the array geometry is tracked via satellite and communicated to the master controller.

14. A seismic streamer array tracking and positioning system comprising:

a towing vessel for towing a seismic array;

a seismic streamer array comprising a plurality of seismic streamers;

an active streamer positioning device (ASPD) attached to each seismic streamer for positioning each seismic streamer;

a master controller for issuing vertical and horizontal positioning commands to each ASPD for maintaining a specified array geometry;

an environmental sensor for sensing environmental factors which influence the towed path of the towed array;

a tracking system for tracking the streamer horizontal and vertical positions versus time during a seismic data acquisition run;

an array geometry tracking system for tracking the array geometry versus time during a seismic data acquisition run, wherein the master controller compares the vertical and horizontal positions of the streamers versus time and the array geometry versus time to desired streamer positions and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired streamer positions and array geometry versus time.

15. The apparatus of claim 14 wherein the master controller factors in environmental measurements into the positioning commands to compensate for environmental influences on the positions of the streamers and the array geometry.

16. The apparatus of claim 14 wherein the master controller compensates for maneuverability in the positioning commands to compensate for maneuverability influences on the positioning of the streamers and the array geometry.

17. The apparatus of claim 14 further comprising:

a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer.

18. The apparatus of claim 14 further comprising:

a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to move the failed streamer out of the array.

19. A seismic streamer array tracking and positioning system comprising:

a towing vessel for towing a seismic array;

a seismic streamer array comprising a plurality of seismic streamers;

an active streamer positioning device (ASPD) attached to each seismic streamer for vertically and horizontally positioning each seismic streamer relative to the array;

a master controller for issuing positioning commands to each ASPD for maintaining a specified array geometry;

an environmental sensor for sensing environmental factors which influence the path of the towed array;

a tracking system for tracking the streamer positions versus time during a seismic data acquisition run;

an array geometry tracking system for tracking the array geometry versus time during a seismic data acquisition run, wherein the master controller compares the positions of the streamers versus time and the array geometry versus time to a desired position and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired position and array geometry versus time, wherein the master controller factors in environmental and maneuverability factors into the positioning commands to compensate for environmental and maneuverability influences on the position of the streamers and the array geometry; and

a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer and removes the failed streamer from the array.

20. A seismic streamer array tracking and positioning system comprising:

a towing vessel for towing a seismic array;

a seismic streamer array comprising a plurality of seismic streamers;

an active streamer positioning device (ASPD) attached to each seismic streamer for vertically and horizontally positioning each seismic streamer relative to the array; and

a master controller for issuing positioning commands to each ASPD for maintaining a specified array path.

21. The apparatus of claim **20** wherein the master controller issues positioning commands to the towing vessel for maintaining a specified array path.

22. The apparatus of claim **20** further comprising:

a processor for calculating an optimal path for the seismic array for optimal coverage during seismic data acquisition over a seismic field;

a streamer behavior prediction processor which predicts array behavior; and

wherein the master controller compensates for predicted streamer behavior in issuing vertical and horizontal positioning commands to the towing vessel and the ASPDs for positioning the array along the optimal path.

23. The apparatus of claim **22** wherein the master controller compensates for environmental factors in the positioning commands.

24. The apparatus of claim **23** wherein the master controller compensates for maneuverability factors in the positioning commands.

25. A seismic streamer array tracking and positioning system comprising:

a towing vessel for towing a seismic array;

a seismic streamer array comprising a plurality of seismic streamers;

an active streamer positioning device (ASPD) attached to each seismic streamer for vertically and horizontally positioning each seismic streamer relative to the array;

a master controller for issuing positioning commands to each ASPD and to the towing vessel for maintaining an optimal path, wherein the master controller further comprises a processor for calculating an optimal path for the seismic array for optimal coverage during seismic data acquisition over a seismic field, and a streamer behavior prediction processor which predicts array behavior, wherein the master controller compensates for predicted streamer behavior in issuing positioning commands to the towing vessel and the ASPDs for positioning the array along the optimal path, wherein the master controller compensates for environmental and maneuverability factors in the positioning commands.

26. A method for tracking and positioning a seismic streamer array comprising:

for towing a seismic array comprising a plurality of seismic streamers;

attaching an active streamer positioning device (ASPD) each seismic streamer for positioning the seismic streamer relative to other seismic streamers within the array; and

issuing vertical and horizontal positioning commands to each ASPD for maintaining a specified array geometry.

27. The method of claim **26** further comprising:

providing an environmental sensor for sensing environmental factors which influence the path of the towed array.

28. The method of claim **26** further comprising:

providing a tracking system for tracking the streamer positions versus time during a seismic data acquisition run and storing the positions versus time in a legacy database for repeating the positions versus time in a subsequent data acquisition; and

providing an array geometry tracking system for tracking the array geometry versus time during a seismic data acquisition run and storing the array geometry versus time in a legacy database for repeating the array geometry versus time in a subsequent data acquisition run.

29. The method of claim **28** wherein the master controller compares the positions of the streamers versus time and the array geometry versus time to a desired streamer position and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired streamer position and array geometry versus time.

30. The method of claim **29** wherein the master controller factors in environmental factors into the positioning commands to compensate for environmental influences on the positioning of the streamers and the array geometry.

31. The method of claim **30** wherein the master controller compensates for maneuverability in the positioning commands to compensate for maneuverability influences on the positioning of the streamers and the array geometry.

32. The method of claim **26** further comprising:

providing a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer.

33. The method of claim **26** further comprising:

providing a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to move a failed streamer out of the array.

34. The method of claim **26** further comprising:

providing a monitor for determining the status of each streamer, wherein the master controller detaches a failed streamer from the array.

35. The method of claim **26** wherein the array geometry comprises a plurality of streamers positioned at a uniform depth.

36. The method of claim **26** wherein the array geometry comprises a plurality of streamers positioned at a plurality of depths for varying temporal resolution of the array.

37. The method of claim 26 wherein the array geometry comprises a plurality of streamers positioned along a plane, wherein the plane is rotated at an angel theta with respect to the longitudinal axis of the array.

38. The method of claim 29 wherein the array geometry is tracked via satellite and communicated to the master controller.

39. A method for tracking and positioning a seismic streamer array comprising:

towing a seismic array comprising a plurality of seismic streamers from a towing vessel;

attaching an active streamer positioning device (ASPD) to each seismic streamer for positioning each seismic streamer;

issuing positioning commands from a master controller to each ASPD to adjust vertical and horizontal position of a first streamer relative to a second streamer in the array for maintaining a specified array geometry;

sensing environmental factors which influence the towed path of the towed array;

tracking the streamer positions versus time during a seismic data acquisition run;

tracking the array geometry versus time during a seismic data acquisition run, wherein the master controller compares the positions of the streamers versus time and the array geometry versus time to desired streamer positions and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired streamer positions and array geometry versus time.

40. The method of claim 39 wherein the master controller factors in environmental measurements into the positioning commands to compensate for environmental influences on the positions of the streamers and the array geometry.

41. The method of claim 39 wherein the master controller compensates for maneuverability in the positioning commands to compensate for maneuverability influences on the positioning of the streamers and the array geometry.

42. The method of claim 39 further comprising:

determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer.

43. The method of claim 39 further comprising:

providing a monitor for determining the status of each streamer, wherein the master controller adjusts the array geometry to move the failed streamer out of the array.

44. A method for tracking and positioning a seismic streamer array comprising:

towing a seismic array comprising a plurality of seismic streamers from a towing vessel;

issuing vertical and horizontal positioning commands to each ASPD for maintaining a specified array geometry;

sensing environmental factors which influence the path of the towed array;

tracking the streamer positions versus time during a seismic data acquisition run;

tracking the array geometry versus time during a seismic data acquisition run, wherein the master controller compares the positions of the streamers versus time and the array geometry versus time to a desired position and array geometry versus time and issues positioning commands to the ASPDs to maintain the desired position and array geometry versus time, wherein the master controller factors in environmental and maneuverability factors into the positioning commands to compensate for environmental and maneuverability influences on the position of the streamers and the array geometry; and

determining the status of each streamer, wherein the master controller adjusts the array geometry to compensate for a failed streamer and removes the failed streamer from the array.

45. A method for tracking and positioning seismic streamer array comprising:

towing a seismic array comprising a plurality of seismic streamers;

attaching an active streamer positioning device (ASPD) attached to each seismic streamer for positioning each seismic streamer; and

issuing vertical and horizontal positioning commands to each ASPD for maintaining a specified array path.

46. The method of claim 45 wherein a master controller issues positioning commands to the towing vessel for maintaining a specified array path.

47. The method of claim 45 further comprising:

calculating an optimal path for the seismic array for optimal coverage during seismic data acquisition over a seismic field;

predicting array behavior; and

compensating for predicted streamer behavior in issuing positioning commands to the towing vessel and the ASPDs for positioning the array along the optimal path.

48. The method of claim 47 wherein the master controller compensates for environmental factors in the positioning commands.

49. The method of claim 48 wherein the master controller compensates for maneuverability factors in the positioning commands.

50. A method for tracking and positioning a seismic streamer array comprising:

towing a seismic array comprising a plurality of seismic streamers;

attaching an active streamer positioning device (ASPD) attached to each seismic streamer for positioning each seismic streamer;

issuing horizontal and vertical positioning commands to each ASPD and to the towing vessel for maintaining an optimal path, calculating an optimal path for the seismic array for optimal coverage during seismic data acquisition over a seismic field, and a behavior prediction processor which predicting array behavior, wherein the master controller compensates for predicted streamer behavior in issuing positioning commands to the towing vessel and the ASPDs for positioning the array along the optimal path, wherein the master controller compensates for environmental and maneuverability factors in the positioning commands.

* * * * *

Exhibit B

US006932017B1

(12) **United States Patent**
Hillesund et al.

(10) **Patent No.: US 6,932,017 B1**
(45) **Date of Patent: Aug. 23, 2005**

(54) **CONTROL SYSTEM FOR POSITIONING OF MARINE SEISMIC STREAMERS**

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(73) Assignee: **Westerngeco, L.L.C.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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PCT Pub. Date: **Apr. 13, 2000**

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(52) **U.S. Cl.** **114/244**; 114/253
(58) **Field of Search** 114/242, 244–246, 114/253, 162, 163

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Primary Examiner—Jesus D. Sotelo
(74) *Attorney, Agent, or Firm*—Westerngeco, L.L.C.

(57) **ABSTRACT**

A method of controlling a streamer positioning device **(18)** configured to be attached to a marine seismic streamer **(12)** and towed by seismic survey vessel **(10)** and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The invention also involves an apparatus for controlling a streamer positioning device including means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to produce the desired change in the orientation of the wing.

26 Claims, 3 Drawing Sheets

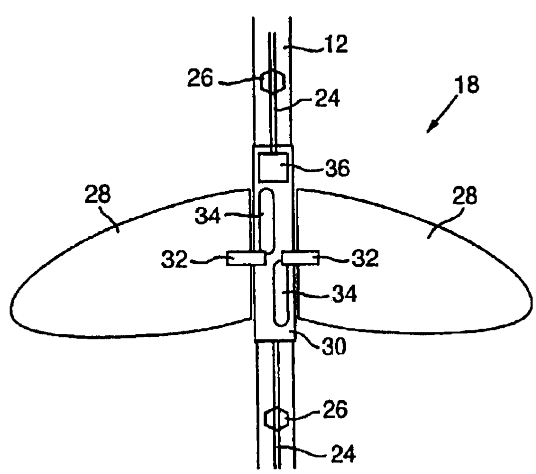


Fig.1.

Prior Art

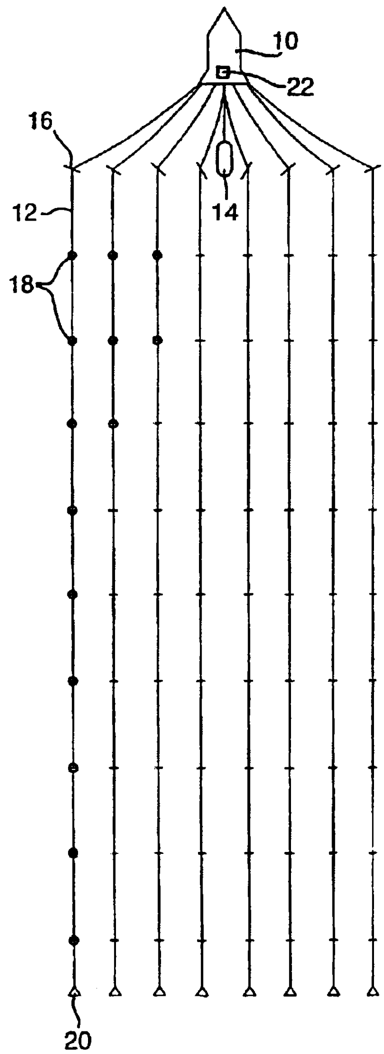
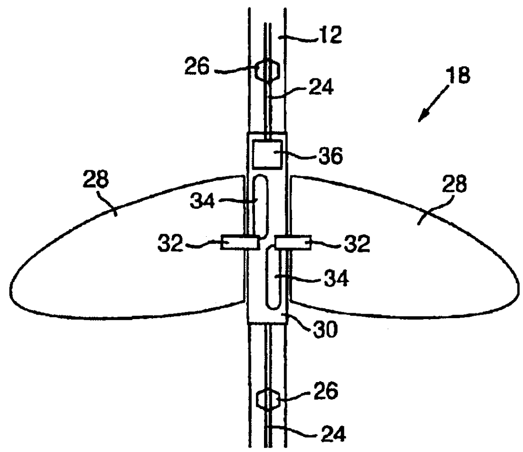


Fig.2.



12
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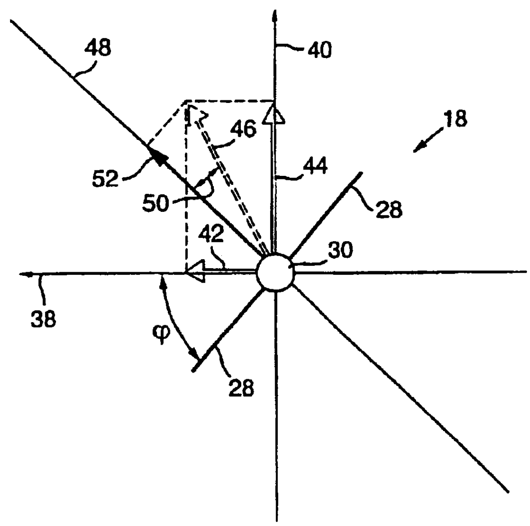
Fig.3.



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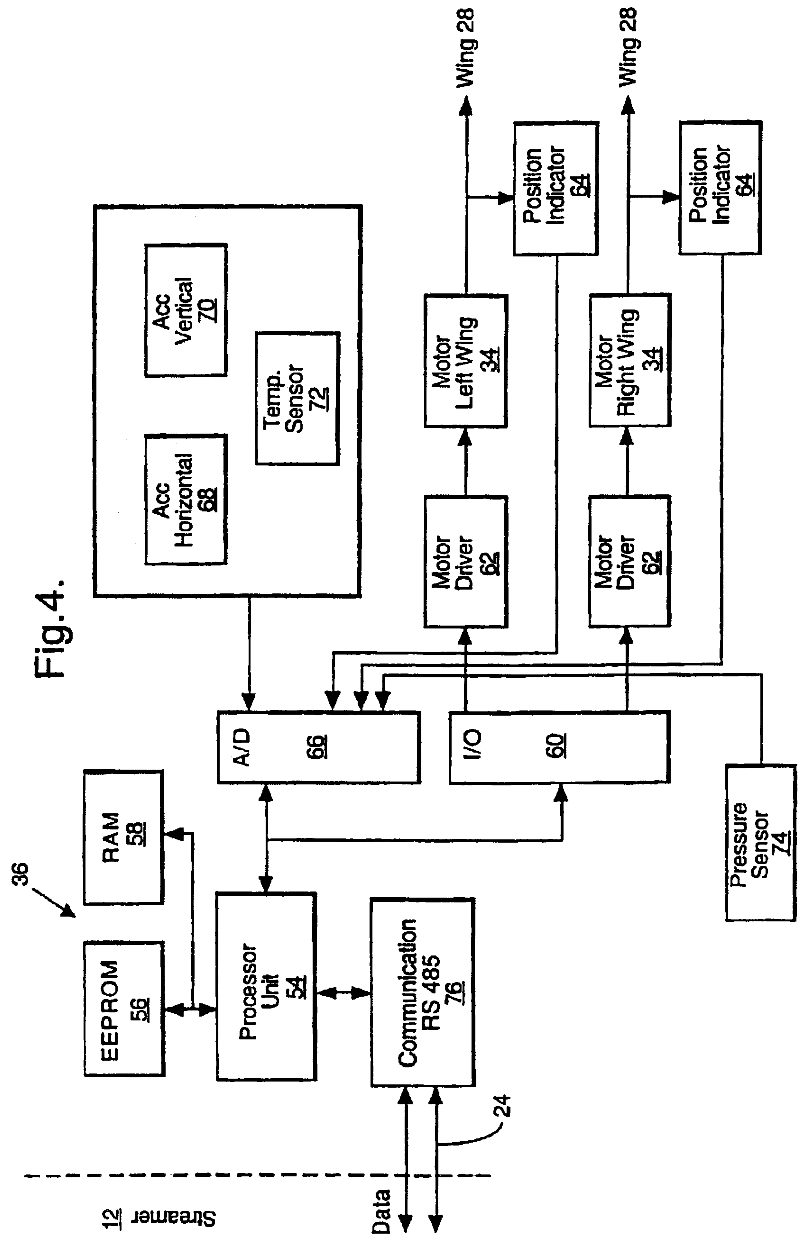
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RAM 58
Processor Unit 54
Communication RS 485 76
A/D 66
I/O 60
Acc Horizontal 68
Acc Vertical 70
Temp. Sensor 72
Motor Driver 62
Motor Left Wing 34
Motor Right Wing 34
Position Indicator 64
Wing 28
Pressure Sensor 74
Streamer 12
Data
24

Fig.4.

CONTROL SYSTEM FOR POSITIONING OF MARINE SEISMIC STREAMERS

BACKGROUND OF THE INVENTION

This invention relates generally to systems for controlling seismic data acquisition equipment and particularly to a system for controlling a marine seismic streamer positioning device.

A marine seismic streamer is an elongate cable-like structure, typically up to several thousand meters long, which contains arrays of seismic sensors, known as hydrophones, and associated electronic equipment along its length, and which is used in marine seismic surveying. In order to perform a 3D marine seismic survey, a plurality of such streamers are towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones, and then digitized and processed to build up a representation of the subsurface geology.

The horizontal positions of the streamers are typically controlled by a deflector, located at the front end or "head" of the streamer, and a tail buoy, located at the back end or "tail" of the streamer. These devices create tension forces on the streamer which constrain the movement of the streamer and cause it to assume a roughly linear shape. Cross currents and transient forces cause the streamer to bow and undulate, thereby introducing deviations into this desired linear shape.

The streamers are typically towed at a constant depth of approximately ten meters, in order to facilitate the removal of undesired "ghost" reflections from the surface of the water. To keep the streamers at this constant depth, control devices known as "birds", are typically attached at various points along each streamer between the deflector and the tail buoy, with the spacing between the birds generally varying between 200 and 400 meters. The birds have hydrodynamic deflecting surfaces, referred to as wings, that allow the position of the streamer to be controlled as it is towed through the water. When a bird is used for depth control purposes only, it is possible for the bird to regularly sense its depth using an integrated pressure sensor and for a local controller within the bird to adjust the wing angles to maintain the streamer near the desired depth using only a desired depth value received from a central control system.

While the majority of birds used thus far have only controlled the depth of the streamers, additional benefits can be obtained by using properly controlled horizontally steerable birds, particularly by using the types of horizontally and vertically steerable birds disclosed in our published PCT International Application No. WO 98/28636. The 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.

It is estimated that horizontal out-of-position conditions reduce the efficiency of current 3D seismic survey operations by between 5 and 10%, depending on weather and current conditions. While incidents of tangling adjacent streamers are relatively rare, when they do occur they invariably result in prolonged vessel downtime. The loss of efficiency associated with turning the seismic survey vessel will depend in large part on the seismic survey layout, but typical estimates range from 5 to 10%. Simulations have concluded that properly controlled horizontally steerable birds can be expected to reduce these types of costs by approximately 30%.

One system for controlling a horizontally steerable bird, as disclosed in UK Patent GB 2093610 B, is to utilize a manually-operated central control system to transmit the magnitudes and directions of any required wing angle changes to the birds. While this method greatly simplifies the circuitry needed within the bird itself, it is virtually impossible for this type of system to closely regulate the horizontal positions of the birds because it requires manual input and supervision. This becomes a particularly significant issue when a substantial number of streamers are deployed simultaneously and the number of birds that must be controlled goes up accordingly.

Another system for controlling a horizontally steerable bird is disclosed in our published PCT International Application No. WO 98/28636. Using this type of control system, the desired horizontal positions and the actual horizontal positions are received from a remote control system and are then used by a local control system within the birds to adjust the wing angles. The 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. 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. A more deterministic system for controlling this type of streamer positioning device is therefore desired.

It is therefore an object of the present invention to provide for an improved method and apparatus for controlling a streamer positioning device.

An advantage of the present invention is that the position of the streamer may be better controlled, thereby reducing the need for in-fill shooting, reducing the chance of streamer tangling, and reducing the time needed to turn the seismic survey vessel.

Another advantage of the present invention is that noise in marine seismic data associated with streamer position overcorrection and streamer positioning errors can be significantly reduced.

SUMMARY OF THE INVENTION

The present invention provides methods and apparatus for controlling the positions of marine seismic streamers in an array of such streamers being towed by a seismic survey vessel, the streamers having respective streamer positioning devices disposed therealong and each streamer positioning device having a wing and a wing motor for changing the orientation of the wing so as to steer the streamer positioning device laterally, said methods and apparatus involving (a) obtaining an estimated velocity of the streamer positioning devices, (b) for at least some of the streamer positioning devices, calculating desired changes in the orientation of their wings using said estimated velocity, and (c) actuating the wing motors to produce said desired changes in wing orientation.

The invention and its benefits will be better understood with reference to the detailed description below and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a seismic survey vessel and associated seismic data acquisition equipment;

FIG. 2 is a schematic horizontal cross-sectional view through a marine seismic streamer and an attached streamer positioning device;

FIG. 3 is a schematic vertical cross-sectional view through the streamer positioning device from FIG. 2; and

FIG. 4 is a schematic diagram of the local control system architecture of the streamer positioning device from FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. 1, a seismic survey vessel 10 is shown towing eight marine seismic streamers 12 that may, for instance, each be 3000 meters in length. The outermost streamers 12 in the array could be 700 meters apart, resulting in a horizontal separation between the streamers of 100 meters in the regular horizontal spacing configuration shown. A seismic source 14, typically an airgun or an array of airguns, is also shown being towed by the seismic survey vessel 10. At the front of each streamer 12 is shown a deflector 16 and at the rear of every streamer is shown a tail buoy 20. The deflector 16 is used to horizontally position the end of the streamer nearest the seismic survey vessel 10 and the tail buoy 20 creates drag at the end of the streamer farthest from the seismic survey vessel 10. The tension created on the seismic streamer by the deflector 16 and the tail buoy 20 results in the roughly linear shape of the seismic streamer 12 shown in FIG. 1.

Located between the deflector 16 and the tail buoy 20 are a plurality of streamer positioning devices known as birds 18. Preferably the birds 18 are both vertically and horizontally steerable. These birds 18 may, for instance, be located at regular intervals along the streamer, such as every 200 to 400 meters. The vertically and horizontally steerable birds 18 can be used to constrain the shape of the seismic streamer 12 between the deflector 16 and the tail buoy 20 in both the vertical (depth) and horizontal directions.

In the preferred embodiment of the present invention, the control system for the birds 18 is distributed between a global control system 22 located on or near the seismic survey vessel 10 and a local control system located within or near the birds 18. The global control system 22 is typically connected to the seismic survey vessel's navigation system and obtains estimates of system wide parameters, such as the vessel's towing direction and velocity and current direction and velocity, from the vessel's navigation system.

The most important requirement for the control system is to prevent the streamers 12 from tangling. This requirement becomes more and more important as the complexity and the total value of the towed equipment increases. The trend in the industry is to put more streamers 12 on each seismic survey vessel 10 and to decrease the horizontal separation between them. To get better control of the streamers 12, horizontal steering becomes necessary. If the birds 18 are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers. Localized current fluctuations can dramatically influence the magnitude of the side control required to properly position the streamers. To compensate for these localized current fluctuations, the inventive control system utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices.

In the preferred embodiment of the present invention, the global control system 22 monitors the actual positions of each of the birds 18 and is programmed with the desired positions of or the desired minimum separations between the seismic streamers 12. The horizontal positions of the birds 18 can be derived, for instance, using the types of acoustic positioning systems described in our U.S. Pat. No. 4,992,990 or in our PCT International Patent Application No. WO 98/21163. Alternatively, or additionally, satellite-based global positioning system equipment can be used to determine the positions of the equipment. The vertical positions of the birds 18 are typically monitored using pressure sensors attached to the birds, as discussed below.

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. Because the movement of the seismic streamer 12 causes acoustic noise (both from seawater flow past the bird wing structures as well as cross current flow across the streamer skin itself), it is important that the streamer movements be restrained and kept to the minimum correction required to properly position the streamers. Any streamer positioning device control system that consistently overestimates the type of correction required and causes the bird to overshoot its intended position introduces undesirable noise into the seismic data being acquired by the streamer. In current systems, this type of over-correction noise is often balanced against the "noise" or "smearing" caused when the seismic sensors in the streamers 12 are displaced from their desired positions.

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. 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. The global control system 22 also checks the data received from the vessel's navigation system and the data will be filled in if it is missing. The interface between the global control system 22 and the local control system will typically operate with a sampling frequency of at least 0.1 Hz. The global control system 22 will typically acquire the following parameters from the vessel's navigation system: vessel speed (m/s), vessel heading (degrees), current speed (m/s), current heading (degrees), and the location of each of the birds in the horizontal plane in a vessel fixed coordinate system. Current speed and heading can also be estimated based on the average forces acting on the streamers 12 by the birds 18. The global control system 22 will preferably send the following values to the local bird controller: demanded vertical force, demanded horizontal force, towing velocity, and crosscurrent velocity.

The towing velocity and crosscurrent velocity are preferably "water-referenced" values that are calculated from the vessel speed and heading values and the current speed and heading values, as well as any relative movement between the seismic survey vessel 10 and the bird 18 (such as while the vessel is turning), to produce relative velocities of the bird 18 with respect to the water in both the "in-line" and the "cross-line" directions. Alternatively, the global control system 22 could provide the local control system with the horizontal velocity and water in-flow angle. 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.

The "water-referenced" towing velocity and crosscurrent velocity could alternatively be determined using flowmeters or other types of water velocity sensors attached directly to the birds 18. Although these types of sensors are typically quite expensive, one advantage of this type of velocity determination system is that the sensed in-line and cross-line velocities will be inherently compensated for the speed and heading of marine currents acting on said streamer positioning device and for relative movements between the vessel **10** and the bird **18**.

FIG. **2** shows a type of bird **18** that is capable of controlling the position of seismic streamers **12** in both the vertical and horizontal directions. A bird **18** of this type is also disclosed in our PCT International Application No. WO 98/28636. While a number of alternative designs for the vertically and horizontally steerable birds **18** are possible, including those utilizing one full-moving wing with ailerons, three full-moving wings, and four full-moving wings, the independent two-wing principal is, conceptually, the simplest and most robust design.

In FIG. **2**, a portion of the seismic streamer **12** is shown with an attached bird **18**. A communication line **24**, which may consist of a bundle of fiber optic data transmission cables and power transmission wires, passes along the length of the seismic streamer **12** and is connected to the seismic sensors, hydrophones **26**, that are distributed along the length of the streamer, and to the bird **18**. The bird **18** preferably has a pair of independently moveable wings **28** that are connected to rotatable shafts **32** that are rotated by wing motors **34** and that allow the orientation of the wings **28** with respect to the bird body **30** to be changed. When the shafts **32** of the bird **18** are not horizontal, this rotation causes the horizontal orientation of the wings **28** to change and thereby changes the horizontal forces that are applied to the streamer **12** by the bird.

The motors **34** can consist of any type of device that is capable of changing the orientation of the wings **28**, and they are preferably either electric motors or hydraulic actuators. The local control system **36** controls the movement of the wings **28** by calculating a desired change in the angle of the wings and then selectively driving the motors **34** to effectuate this change. While the preferred embodiment depicted utilizes a separate motor **34** for each wing **28**, it would be also be possible to independently move the wings **28** using a single motor **34** and a selectively actuatable transmission mechanism.

When the bird **18** uses two wings **28** to produce the horizontal and vertical forces on the streamer **12**, the required outputs of the local control system **36** are relatively simple, the directions and magnitudes of the wing movements required for each of the wings **28**, or equivalently the magnitude and direction the motors **34** need to be driven to produce this wing movement. While the required outputs of the local control system **36** for such a two full moving wing design is quite simple, the structure and operation of the overall system required to coordinate control of the device is relatively complicated.

FIG. **3** shows a schematic vertical cross-sectional view through the streamer positioning device shown in FIG. **2** that will allow the operation of the inventive control system to be described in more detail. The components of the bird **18** shown in FIG. **3** include the wings **28** and the body **30**. Also shown in FIG. **3** are a horizontal coordinate axis **38** and a vertical coordinate axis **40**. During operation of the streamer positioning control system, the global control system **22** preferably transmits, at regular intervals (such as every five seconds) a desired horizontal force **42** and a desired vertical force **44** to the local control system **36**.

The desired horizontal force **42** and the desired vertical force **44** are combined within the local control system **36** to calculate the magnitude and direction of the desired total force **46** that the global control system **22** has instructed the local control system to apply to the streamer **12**. The global control system **22** could alternatively provide the magnitude and direction of the desired total force **46** to the local control system **36** instead of the desired horizontal force **42** and the desired vertical force **44**.

While the desired horizontal force **42** and the desired vertical force **44** are preferably calculated by the global control system **22**, it is also possible for the local control system **36** in the inventive control system to calculate one or both of these forces using a localized displacement/force conversion program. This type of localized conversion program may, for instance, use a look-up table or conversion routine that associates certain magnitudes and directions of vertical or horizontal displacements with certain magnitudes and directions of changes in the vertical or horizontal forces required. Using this type of embodiment, the global control system **22** can transmit location information to the local control system **36** instead of force information. Instead of the desired vertical force **44**, the global control system **22** can transmit a desired vertical depth and the local control system **36** can calculate the magnitude and direction of the deviation between the desired depth and the actual depth. Similarly, instead of transmitting a desired horizontal force **42**, the global control system **22** can transmit the magnitude and direction of the displacement between the actual horizontal position and the desired horizontal position of the bird **18**. One advantage to this alternative type of system is that the required vertical force can be rapidly updated as the local control system receives updated depth information from the integrated pressure sensor. Other advantages of this type of alternative system include reducing communication traffic on the communication line **24** and simplifying the programming needed to convert the measured vertical and/or horizontal displacements into corresponding forces to be applied by the birds **18**.

When the local control system **36** has a new desired horizontal force **42** and desired vertical force **44** to be applied, the wings **28** will typically not be in the proper orientation to provide the direction of the desired total force **46** required. As can be seen in FIG. **3**, the wings **28** introduce a force into the streamer **12** along an axis perpendicular to the rotational axis of the wings **28** and perpendicular to the streamer. This force axis **48** is typically not properly aligned with the desired total force **46** when new desired horizontal and vertical force values are received from the global control system **22** or determined by the local control system **36** and some rotation of the bird **18** is required before the bird can produce this desired total force **46**. As can be seen, the force axis **48** is directly related to the bird roll angle, designated in FIG. **3** as ϕ.

The local control system **36** optimizes the control process by projecting the desired total force **46** onto the force axis **48** (i.e. multiplying the magnitude of the desired total force by the cosine of the deviation angle **50**) to produce an intermediate desired force **52** and then adjusting the wing common angle α (the angle of the wings with respect to the bird body **30**, or the average angle if there is a non-zero splay angle) to produce this magnitude of force along the force axis. The calculated desired common wing angle is compared to the current common wing angle to calculate a desired change in the common wing angle and the wing motors **34** are actuated to produce this desired change in the orientation of the wings.

A splay angle is then introduced into the wings **28** to produce a rotational movement in the bird body **30** (i.e. to rotate the force axis **48** to be aligned with the desired total force **46**). The splay angle is the difference between the angles of the wings **28** with respect to the bird body **30**. As the bird body **30** rotates and the force axis **48** becomes more closely aligned with the desired total force **46**, the bird roll angle and the bird roll angular velocity are monitored, the splay angle is incrementally reduced, and the common angle is incrementally increased until the intermediate desired force **52** is in the same direction and of the same magnitude as the desired total force. The local control system **36** carefully regulates the splay angle to ensure that the streamer is stable in roll degree of freedom. The calculated common wing angle and the splay angle are also regulated by the local control system 36 to prevent the wings 28 from stalling and to ensure that the splay angle is prioritized.

When using the type of birds described in our published PCT International Application No. WO 98/28636, where the bird 18 is rigidly attached, and cannot rotate with respect, to the streamer 12, it is important for the control system to take the streamer twist into account. If this is not taken into account, the bird 18 can use all of its available splay angle to counter the twist in the streamer 12. The bird 18 will then be unable to reach the demanded roll angle and the generated force will decrease. The inventive control system incorporates two functions for addressing this situation; the anti-twist function and the untwist function.

In the anti-twist function, the streamer twist is estimated by weightfunction filtering the splay angle measurements instead of simply averaging the splay angle measurements to improve the bandwidth of the estimation. The anti-twist function engages when the estimated twist has reached a critical value and it then overrides the normal shortest path control of the calculated roll angle. The anti-twist function forces the bird 18 to rotate in the opposite direction of the twist by adding +/−180 degrees to the demanded roll angle. Once the twist has been reduced to an acceptable value, the anti-twist function disengages and the normal shortest path calculation is continued.

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. The number of revolutions done by each bird 18 is monitored and the untwist function is disengaged once the twist has reached an acceptable level. FIG. 4 is a schematic diagram of the architecture of the local control system 36 for the bird 18. The local control system 36 consists of a central processor unit 54, having EEPROM 56 and RAM 58 memory, an input/output subsystem 60 that is connected to a pair of motor drivers 62, and an analog to digital conversion unit 66. The motor drivers 62 are connected to and actuate the wing motors 34 to produce the desired change the orientation of the wings 28 with respect to the bird body 30.

The wing motor 34/wing 28 units are also connected to wing position indicators 64 that sense the relative positions of the wings and provide measurements to the analog to digital conversion unit 66 which converts the analog wing position indicator 64 measurements into digital format and conveys these digital values to the central processor unit 54. Various types of wing position indicators 64 can be used, including resistive angle or displacement sensors inductive sensors, capacitive sensors, hall sensors, or magneto-restrictive sensors.

A horizontal accelerometer 68 and a vertical accelerometer 70, placed at right angles with respect to one another, are also connected to the analog to digital conversion unit 66 and these accelerometers convey measurements that allow the central processor unit 54 to determine the roll angle and roll rate of the bird 18. An angular velocity vibrating rate gyro (rategyro) can also be used to measure the roll rate of the bird 18. A temperature sensor 72 is connected to the analog to digital conversion unit 66 to provide temperature measurements that allow the horizontal accelerometer 68 and the vertical accelerometer 70 to be calibrated.

A pressure sensor 74 is also connected to the analog to digital conversion unit 66 to provide the central processor unit 54 with measurements of the water pressure at the bird 18. To calculate an appropriate depth value, the measured pressure values must be filtered to limit the disturbance from waves. This is done in the inventive control system with a weightfunction filter that avoids the large phase displacements caused by mean value filters. Instead of using an instantaneous depth value or simply calculating an average depth value over a given period of time (and thereby incorporating a large phase displacement into the depth value), the inventive control system uses a differentially weighted pressure filtering scheme. First the pressure values are transformed into depth values by dividing the pressure sensor reading by the seawater density and gravitational acceleration. These depth values are then filtered using a weight function filter. Typical incremental weighting functions values range from 0.96 to 0.90 (sample weights of 1.0, 0.9, 0.81, 0.729, etc.) and the filter will typically process depth values received over a period of at least 100 seconds.

The central processor unit 54 is also connected to a RS485 communications unit 76 that allows information to be exchanged between the local control system 36 and the global control system 22 over the communication line 24 that passes through the streakier 12. The RS485 bus may, for instance, utilize Neuron chips that communicate using a Local Operating Network protocol to control the data transfer.

Preferably, the central processor unit 54 and associated components comprise a MicroChip 17C756 processor. This type of microprocessor has very low power requirements, a dual UART on-chip, 12-channel, 10 bit ADC on-chip, 908x8 RAM, 16kx16 ROM, and 50 digital I/O channels. The software running on the central processor unit 54 will typically consist of two units, the local control unit and the hardware control unit. It is typically not possible to pre-load both of these program units into the EEPROM 56 and it is possible to update these program units without having to open the bird 18. The on-chip memory may thus only initially contain a boot-routine that enables the loading of software units into the external memory via the RS485 communication unit 76. The external program memory (EEPROM 56) will typically be a non-volatile memory so that these program units do not have to be re-loaded after every power down.

The central processor unit 54 must be able to run the local control system software fast enough to secure the sampling frequency needed for effective local bird control. This may mean, for instance, a sample rate of 10 Hz, which may be 10 to 100 times faster than the sample rate of the communications between the global control system 22 and the local control system 36. As discussed above, the central processor unit 54 will also receive data from sensors attached to the bird 18. The sensed values include bird roll angle, bird roll angular velocity (roll rate), the wing angles, and the static pressure of the water. These values are typically delivered to the central processor unit 54 at a sample rate of at least 10 Hz. The following values may be transmitted from the local control system 36 to the global control system 22 using the RS485 communication unit 76: the measured roll angle, the measured roll rate, the measured wing angles, the measured water pressure, the calculated depth, and the calculated wing forces.

The system has been designed with a redundant communication system to increase its overall reliability. The bird 18 will typically have a backup communications channel, such as by overlaying a backup control signal on top of the power line current. This backup communications channel is particularly important because in the event of loss of communications to the bird 18 there would otherwise be no method for instructing the bird 18 to bring the streamer 12 to surface so the defective communications equipment can be repaired or replaced.

In contrast to previous streamer position device control systems, the present control system converts the desired horizontal force 42 and the desired vertical force 44 into a desired roll angle ϕ and a desired common wing angle α by deterministic calculations, rather than using an "incremental change/measured response/further incremental change based on measured response" type of feedback control circuit. The desired roll angle ϕ can be calculated in the manner discussed in the text describing FIG. 3 above. The magnitude of the force F imparted by the wings 28 along the force axis 48 can, for instance, be deterministically calculated using the following formula:

$$F = \frac{1}{2}\rho * A * C_L(v_{tow}\cos(\alpha) - v_{current}\sin(\alpha))^2$$

where:

ρ=water density

A=wing area

C_L=wing lift coefficient

α=common wing angle

V_{tow}=towing velocity

$V_{current}$=crosscurrent velocity

A similar deterministic calculation could be made using a calculated coefficient that incorporates the towing velocity of the bird 18. A gain factor GF, for instance, could be calculated as follows:

$$GF = \frac{1}{2}\rho * A * C_L(v_{tow})^2$$

which could be simply multiplied by $\cos(\alpha)^2$ to estimate the force that would be applied for a given common angle.

One of the beneficial elements of the inventive control system is that the desired change in the orientation of the wing 28 is calculated using an estimate of the velocity of the bird 18 rather than simply relying on a feedback-loop type of control system that operates in the same manner regardless of the vessel speed. Because the force produced by wing 28 is proportional to the velocity of the device squared, a much more precise calculation of the desired change in the wing orientation can be made by using an estimate of the device velocity.

The inventive control system is based on shared responsibilities between the global control system 22 located on the seismic survey vessel 10 and the local control system 36 located on the bird 18. The global control system 22 is tasked with monitoring the positions of the streamers 12 and providing desired forces or desired position information to the local control system 36. The local control system 36 within each bird 18 is responsible for adjusting the wing splay angle to rotate the bird to the proper position and for adjusting the wing common angle to produce the magnitude of total desired force required.

The inventive control system will primarily operate in two different control modes: a feather angle control mode and a turn control mode. 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. The feather angle could be input either manually, through use of a current meter, or through use of an estimated value based on the average horizontal bird forces. Only when the crosscurrent velocity is very small will the feather angle be set to zero and the desired streamer positions be in precise alignment with the towing direction.

The turn control mode is used when ending one pass and beginning another pass during a 3D seismic survey, sometimes referred to as a "line change". The turn control mode consists 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. In the last part of the turn, the birds 18 are directed to go to the position defined by the feather angle control mode. By doing this, a tighter turn can be achieved and the turn time of the vessel and equipment can be substantially reduced. Typically during the turn mode adjacent streamers will be depth separated to avoid possible entanglement during the turn and will be returned to a common depth as soon as possible after the completion of the turn. The vessel navigation system will typically notify the global control system 22 when to start throwing the streamers 12 out, and when to start straightening the streamers.

In extreme weather conditions, the inventive control system may also operate in a streamer separation control mode that attempts to minimize the risk of entanglement of the streamers. In this control mode, the global control system 22 attempts to maximize the distance between adjacent streamers. The streamers 12 will typically be separated in depth and the outermost streamers will be positioned as far away from each other as possible. The inner streamers will then be regularly spaced between these outermost streamers, i.e. each bird 18 will receive desired horizontal forces 42 or desired horizontal position information that will direct the bird 18 to the midpoint position between its adjacent streamers.

While the embodiment of the inventive control system described above is shown in connection with a "bird" type of streamer positioning device, it will be readily understood that the control system method and apparatus may also be used in connection with streamer positioning devices that are characterized as "deflectors" or steerable "tail buoys" because they are attached to either the front end or the back end of the streamer 12.

The present invention includes any novel feature or novel combination of features disclosed herein, either explicitly or implicitly.

What is claimed is:

1. A method of controlling the positions of marine seismic streamers in an array of such streamers being towed by a seismic survey vessel, the streamers having respective streamer positioning devices disposed therealong and each streamer positioning device having a wing and a wing motor for changing the orientation of the wing so as to steer the streamer positioning device laterally, said method comprising the steps of:

obtaining a predicted position of the streamer positioning devices;

obtaining an estimated velocity of the streamer positioning devices;

for at least some of the streamer positioning devices, calculating desired changes in the orientation of their wings using said predicted position and said estimated velocity; and

actuating the wing motors to produce said desired changes in wing orientation.

2. A method as claimed in claim 1, wherein said estimated velocity is calculated using a vessel speed received from said seismic survey vessel's navigation system.

3. A method as claimed in claim 2, in which said estimated velocity is a water referenced towing velocity that compensates for the speed and heading of marine currents acting on said streamer positioning devices.

4. A method as claimed in claim 3, in which said estimated velocity is compensated for relative movement between said seismic survey vessel and said streamer positioning devices.

5. A method as claimed in claim 4, in which said step of calculating a desired change in wing orientation further uses an estimate of the crosscurrent velocity at the respective streamer positioning device.

6. A method as claimed in claim 5, in which said step of calculating a desired change in wing orientation is regulated to prevent the wing from stalling.

7. A method as claimed in claim 6, in which said step of calculating a desired change in wing orientation is regulated by a global control system located on or near said seismic survey vessel that is configured into a feather angle mode, wherein said global control system attempts to direct the streamer positioning devices to maintain each of said streamers in a straight line offset from the towing direction of said marine seismic vessel by a certain feather angle, and into a turn control mode, wherein said global control system directs said streamer positioning devices to generate a force in the opposite direction of a turn at the beginning of the turn.

8. A method as claimed in claim 7, in which said global control system is further configured into a streamer separation mode, wherein said global control system attempts to direct said streamer positioning device to maintain a minimum separation distance between adjacent streamers.

9. A method as claimed in claim 8, further including the step of displaying the position of said streamer positioning devices on said seismic survey vessel.

10. A method as claimed in claim 9, in which each streamer positioning device is attached to and unable rotate with respect to its streamer and further comprising the step of monitoring twist in said marine seismic streamers and calculating a desired change in the orientation of the wings of the streamer positioning devices to reduce said twist.

11. A method as claimed in claim 10, further including the step of obtaining estimates of the respective current positions of at least some of said streamer positioning devices and the step of obtaining the desired positions of each of said at least some streamer positioning devices.

12. A method as claimed in claim 11, wherein the estimate of the current position of a streamer positioning device and the desired position of that same streamer positioning device are used to produce a desired force to be applied to its streamer by that streamer positioning device.

13. A method as claimed in claim 12, in which said desired force is projected onto the current force axis and the wing orientation is calculated that will produce said projected force at said estimated velocity.

14. A method as claimed in claim 13, in which the streamer positioning device is rotated to align the current force axis with said desired force and its wing orientation is changed as the current force axis becomes more closely aligned with said desired force.

15. The method of claim 1, wherein the step of calculating desired changes in the orientation of at least some of the streamer positioning device's wings using said predicted position and said estimated velocity comprises:

calculating desired horizontal and vertical forces to be imparted by the streamer positioning devices on marine seismic streamers using said predicted position; and

calculating desired roll angles and common wing angles for the streamer positioning devices to impart the desired horizontal and vertical forces using said estimated velocity.

16. Apparatus for controlling the positions of marine seismic streamer in an array of such streamers being towed by a seismic survey vessel, the streamers having respective streamer positioning devices disposed therealong and each streamer positioning device having a wing and a wing motor for changing the horizontal orientation of the wing so as to steer the streamer positioning device laterally, said apparatus comprising:

means for obtaining a predicted position of the streamer positioning devices;

means for obtaining an estimated velocity of the streamer positioning devices,

means for calculating desired changes in the orientations of the respective wings of at least some of the streamer positioning devices using said predicted position and said estimated velocity; and

means for actuating the wing motors to produce said desired changes in wing orientation.

17. Apparatus as claimed in claim 16, in which each streamer positioning device has a first wing and a second wing, said first wing, and said second wing being independently moveable to steer the streamer positioning device laterally and vertically.

18. Apparatus as claimed in claim 17, wherein each streamer positioning device is rigidly attached to and unable to rotate with respect to its streamer.

19. Apparatus as claimed in claim 18, further including means for determining the angular velocity of each streamer positioning device.

20. Apparatus as claimed in claim 19, wherein a global control system is located on or near said seismic vessel and a respective local control system is located within or near each streamer positioning device and said global control system and said local control systems communicate using a respective communication line passing through each streamer.

21. Apparatus as claimed in claim 20, in which input values for said local control systems are downloaded over said communication lines.

22. Apparatus as claimed in claim 21, further including a respective backup communications channel in each streamer between the global control system and the local control systems of the streamer positioning devices of the streamer.

23. Apparatus as claimed in claim 22, in which each local control system has a cycle rate that is at least 10 times greater than the data transfer rate of said communication line.

24. Apparatus as claimed in claim 23, in which each local control system comprises a microprocessor programmed to monitor the current orientation of the wing of its streamer positioning device and to calculate desired changes to the orientation of said wing based on inputs from said global control system.

25. Apparatus as claimed in claim 24, further including means for producing a weight function filtered depth value.

26. The apparatus of claim 16, wherein the means for calculating desired changes in the orientations of the respective wings of at least some of the streamer positioning devices comprises:

means for calculating desired horizontal and vertical forces to be imparted by the streamer positioning devices on marine seismic streamers using said predicted position; and

means for calculating desired roll angles and common wing angles for the streamer positioning devices to impart the desired horizontal and vertical forces using said estimated velocity.

* * * * *

Exhibit C

US007080607B2

(12) **United States Patent**
Hillesund et al.

(10) **Patent No.: US 7,080,607 B2**
(45) **Date of Patent: *Jul. 25, 2006**

(54) **SEISMIC DATA ACQUISITON EQUIPMENT CONTROL SYSTEM**

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(73) Assignee: **WesternGeco, L.L.C.**, Houston, TX (US)

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This patent is subject to a terminal disclaimer.

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(52) **U.S. Cl.** **114/244**

(58) **Field of Classification Search** 114/162, 114/163, 242–246, 253

See application file for complete search history.

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(74) *Attorney, Agent, or Firm*—WesternGeco, L.L.C.

(57) **ABSTRACT**

A method of controlling a streamer positioning device configured to be attached to a marine seismic streamer and towed by a seismic survey vessel and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The invention also involves an apparatus for controlling a streamer positioning device including means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to produce the desired change in the orientation of the wing.

25 Claims, 3 Drawing Sheets

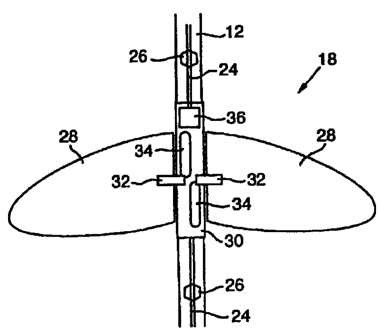

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Fig.1.

Prior Art

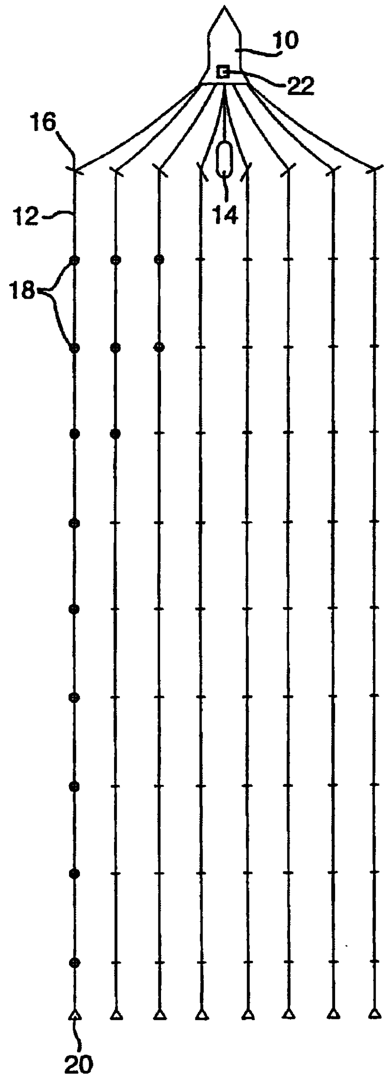


Fig.2.

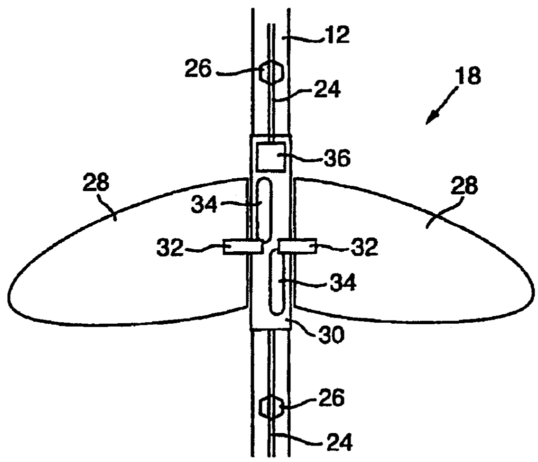
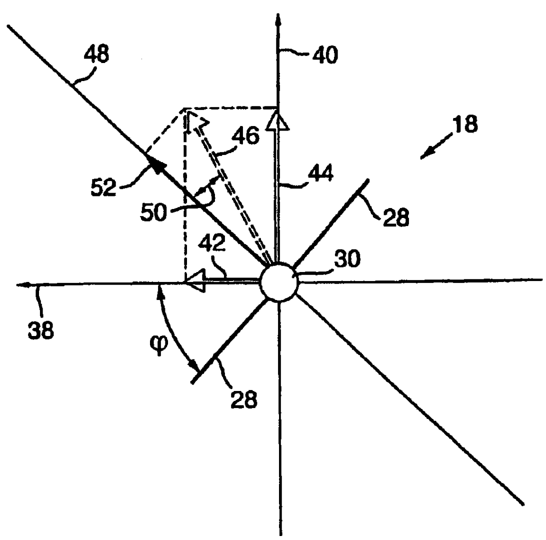

12
26
24
18
36
28
28
34
32
32
34
30
26
24

Fig.3.


48
40
18
46
44
52
50
28
42
30
38
φ
28

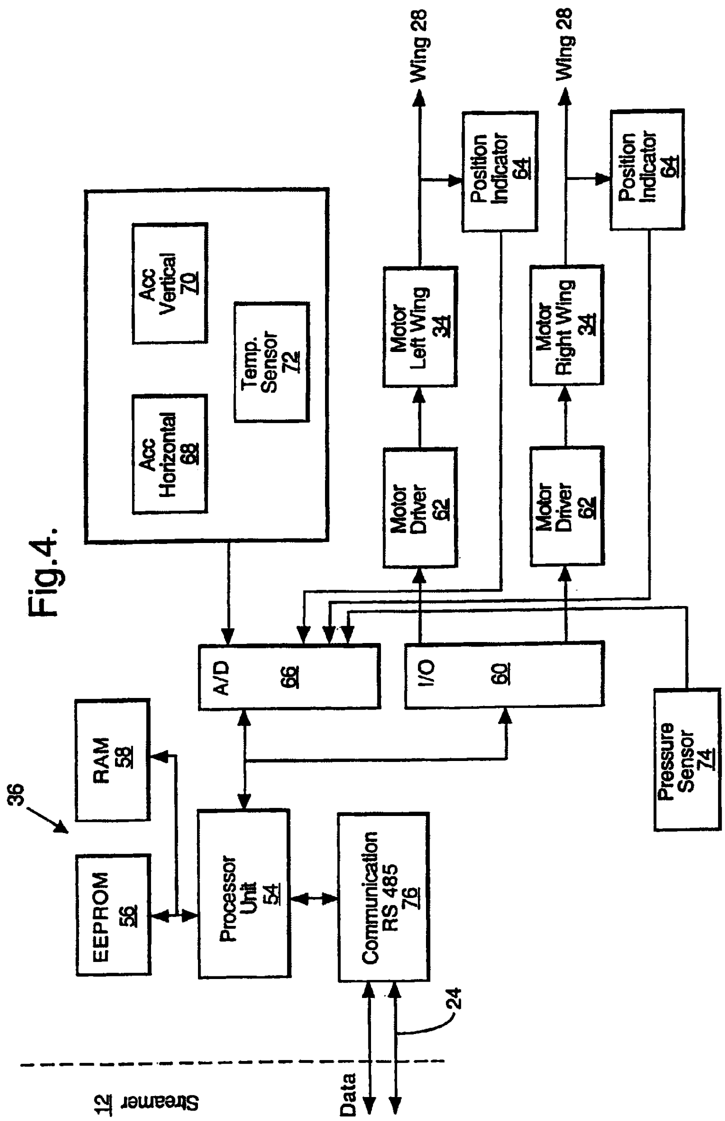

36
EEPROM 56
RAM 58
Processor Unit 54
Communication RS 485 76
A/D 66
I/O 60
Acc Horizontal 68
Acc Vertical 70
Temp. Sensor 72
Motor Driver 62
Motor Left Wing 34
Motor Right Wing 34
Position Indicator 64
Wing 28
Pressure Sensor 74
Streamer 12
Data
24

Fig.4.

SEISMIC DATA ACQUISITON EQUIPMENT CONTROL SYSTEM

Applicant claims priority and continuation under 35 U.S.C. § 120 from parent application Ser. No. 09/787,723, filed Jul. 2, 2001, now U.S. Pat. No. 6,932,017, which was a 35 U.S.C. § 371 national stage filing from Patent Cooperation Treaty application number PCT/IB99/01590, filed Sep. 28, 1999, which in turn claimed priority from Great Britain patent application number 9821277.3, filed Oct. 1, 1998, from which Applicant has claimed foreign priority under 35 U.S.C. § 119.

BACKGROUND OF THE INVENTION

This invention relates generally to systems for controlling seismic data acquisition equipment and particularly to a system for controlling a marine seismic streamer positioning device.

A marine seismic streamer is an elongate cable-like structure, typically up to several thousand meters long, which contains arrays of seismic sensors, known as hydrophones, and associated electronic equipment along its length, and which is used in marine seismic surveying. In order to perform a 3D marine seismic survey, a plurality of such streamers are towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones, and then digitized and processed to build up a representation of the subsurface geology.

The horizontal positions of the streamers are typically controlled by a deflector, located at the front end or "head" of the streamer, and a tail buoy, located at the back end or "tail" of the streamer. These devices create tension forces on the streamer which constrain the movement of the streamer and cause it to assume a roughly linear shape. Cross currents and transient forces cause the streamer to bow and undulate, thereby introducing deviations into this desired linear shape.

The streamers are typically towed at a constant depth of approximately ten meters, in order to facilitate the removal of undesired "ghost" reflections from the surface of the water. To keep the streamers at this constant depth, control devices known as "birds", are typically attached at various points along each streamer between the deflector and the tail buoy, with the spacing between the birds generally varying between 200 and 400 meters. The birds have hydrodynamic deflecting surfaces, referred to as wings, that allow the position of the streamer to be controlled as it is towed through the water. When a bird is used for depth control purposes only, it is possible for the bird to regularly sense its depth using an integrated pressure sensor and for a local controller within the bird to adjust the wing angles to maintain the streamer near the desired depth using only a desired depth value received from a central control system.

While the majority of birds used thus far have only controlled the depth of the streamers, additional benefits can be obtained by using properly controlled horizontally steerable birds, particularly by using the types of horizontally and vertically steerable birds disclosed in our published PCT International Application No. WO 98/28636. The 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.

It is estimated that horizontal out-of-position conditions reduce the efficiency of current 3D seismic survey operations by between 5 and 10%, depending on weather and current conditions. While incidents of tangling adjacent streamers are relatively rare, when they do occur they invariably result in prolonged vessel downtime. The loss of efficiency associated with turning the seismic survey vessel will depend in large part on the seismic survey layout, but typical estimates range from 5 to 10%. Simulations have concluded that properly controlled horizontally steerable birds can be expected to reduce these types of costs by approximately 30%.

One system for controlling a horizontally steerable bird, as disclosed in UK Patent GB 2093610 B, is to utilize a manually-operated central control system to transmit the magnitudes and directions of any required wing angle changes to the birds. While this method greatly simplifies the circuitry needed within the bird itself, it is virtually impossible for this type of system to closely regulate the horizontal positions of the birds because it requires manual input and supervision. This becomes a particularly significant issue when a substantial number of streamers are deployed simultaneously and the number of birds that must be controlled goes up accordingly.

Another system for controlling a horizontally steerable bird is disclosed in our published PCT International Application No. WO 98/28636. Using this type of control system, the desired horizontal positions and the actual horizontal positions are received from a remote control system and are then used by a local control system within the birds to adjust the wing angles. The 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. 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. A more deterministic system for controlling this type of streamer positioning device is therefore desired.

It is therefore an object of the present invention to provide for an improved method and apparatus for controlling a streamer positioning device.

An advantage of the present invention is that the position of the streamer may be better controlled, thereby reducing the need for in-fill shooting, reducing the chance of streamer tangling, and reducing the time needed to turn the seismic survey vessel.

Another advantage of the present invention is that noise in marine seismic data associated with streamer position overcorrection and streamer positioning errors can be significantly reduced.

SUMMARY OF THE INVENTION

The present invention involves a method of controlling a streamer positioning device configured to be attached to a marine seismic streamer and towed by a seismic survey vessel and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The present invention also involves an apparatus for controlling a streamer positioning device. The apparatus includes means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to effectuate the desired change in the orientation of the wing. The invention and its benefits will be better understood with reference to the detailed description below and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a seismic survey vessel and associated seismic data acquisition equipment,

FIG. **2** is a schematic horizontal cross-sectional view through a marine seismic streamer and an attached streamer positioning device;

FIG. **3** is a schematic vertical cross-sectional view through the streamer positioning device from FIG. **2**; and

FIG. **4** is a schematic diagram of the local control system architecture of the streamer positioning device from FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. **1**, a seismic survey vessel **10** is shown towing eight marine seismic streamers **12** that may, for instance, each be 3000 meters in length. The outermost streamers **12** in the array could be 700 meters apart, resulting in a horizontal separation between the streamers of 100 meters in the regular horizontal spacing configuration shown. A seismic source **14**, typically an airgun or an array of airguns, is also shown being towed by the seismic survey vessel **10**. At the front of each streamer **12** is shown a deflector **16** and at the rear of every streamer is shown a tail buoy **20**. The deflector **16** is used to horizontally position the end of the streamer nearest the seismic survey vessel **10** and the tail buoy **20** creates drag at the end of the streamer farthest from the seismic survey vessel **10**. The tension created on the seismic streamer by the deflector **16** and the tail buoy **20** results in the roughly linear shape of the seismic streamer **12** shown in FIG. **1**.

Located between the deflector **16** and the tail buoy **20** are a plurality of streamer positioning devices known as birds **18**. Preferably the birds **18** are both vertically and horizontally steerable. These birds **18** may, for instance, be located at regular intervals along the steamer, such as every 200 to 400 meters. The vertically and horizontally steerable birds **18** can be used to constrain the shape of the seismic streamer **12** between the deflector **16** and the tail buoy **20** in both the vertical (depth) and horizontal directions.

In the preferred embodiment of the present invention, the control system for the birds **18** is distributed between a global control system **22** located on or near the seismic survey vessel **10** and a local control system located within or near the birds **18**. The global control system **22** is typically connected to the seismic survey vessel's navigation system and obtains estimates of system wide parameters, such as the vessel's towing direction and velocity and current direction and velocity, from the vessel's navigation system.

The most important requirement for the control system is to prevent the streamers **12** from tangling. This requirement becomes more and more important as the complexity and the

total value of the towed equipment increases. The trend in the industry is to put more streamers **12** on each seismic survey vessel **10** and to decrease the horizontal separation between them. To get better control of the streamers **12**, horizontal steering becomes necessary. If the birds **18** are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers. Localized current fluctuations can dramatically influence the magnitude of the side control required to properly position the streamers. To compensate for these localized current fluctuations, the inventive control system utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices.

In the preferred embodiment of the present invention, the global control system **22** monitors the actual positions of each of the birds **18** and is programmed with the desired positions of or the desired minimum separations between the seismic steamers **12**. The horizontal positions of the birds **18** can be derived, for instance, using the types of acoustic positioning systems described in our U.S. Pat. No. 4,992,990 or in our PCT International Patent Application No. WO 98/21163. Alternatively, or additionally, satellite-based global positioning system equipment can be used to determine the positions of the equipment. The vertical positions of the birds **18** are typically monitored using pressure sensors attached to the birds, as discussed below.

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. Because the movement of the seismic streamer **12** causes acoustic noise (both from seawater flow past the bird wing structures as well as cross current flow across the streamer skin itself), it is important that the streamer movements be restrained and kept to the minimum correction required to properly position the streamers. Any streamer positioning device control system that consistently overestimates the type of correction required and causes the bird to overshoot its intended position introduces undesirable noise into the seismic data being acquired by the streamer. In current systems, this type of over-correction noise is often balanced against the "noise" or "smearing" caused when the seismic sensors in the streamers **12** are displaced from their desired positions.

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. 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**. The global control system **22** also checks the data received from the vessel's navigation system and the data will be filled in if it is missing. The interface between the global control system **22** and the local control system will typically operate with a sampling frequency of at least 0.1 Hz. The global control system **22** will typically acquire the following parameters from the vessel's navigation system: vessel speed (m/s), vessel heading (degrees), current speed (m/s), current heading (degrees), and the location of each of the birds in the horizontal plane in a vessel fixed coordinate system. Current speed and heading can also be estimated based on the average forces acting on the streamers **12** by the birds **18**. The global control system

22 will preferably send the following values to the local bird controller: demanded vertical force, demanded horizontal force, towing velocity, and crosscurrent velocity.

The towing velocity and crosscurrent velocity are preferably "water-referenced" values that are calculated from the vessel speed and heading values and the current speed and heading values, as well as any relative movement between the seismic survey vessel **10** and the bird **18** (such as while the vessel is turning), to produce relative velocities of the bird **18** with respect to the water in both the "in-line" and the "cross-line" directions. Alternatively, the global control system **22** could provide the local control system with the horizontal velocity and water in-flow angle. 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.

The "water-referenced" towing velocity and crosscurrent velocity could alternatively be determined using flowmeters or other types of water velocity sensors attached directly to the birds **18**. Although these types of sensors are typically quite expensive, one advantage of this type of velocity determination system is that the sensed in-line and cross-line velocities will be inherently compensated for the speed and heading of marine currents acting on said streamer positioning device and for relative movements between vessel **10** and the bird **18**.

FIG. **2** shows a type of bird **18** that is capable of controlling the position of seismic streamers **12** in both the vertical and horizontal directions. A bird **18** of this type is also disclosed in our PCT International Application No. WO 98/28636. While a number of alternative designs for the vertically and horizontally steerable birds **18** are possible, including those utilizing one full-moving wing with ailerons, three full-moving wings, and four full-moving wings, the independent two-wing principal is, conceptually, the simplest and most robust design.

In FIG. **2**, a portion of the seismic streamer **12** is shown with an attached bird **18**. A communication line **24**, which may consist of a bundle of fiber optic data transmission cables and power transmission wires, passes along the length of the seismic streamer **12** and is connected to the seismic sensors, hydrophones **26**, that are distributed along the length of the streamer, and to the bird **18**. The bird **18** preferably has a pair of independently moveable wings **28** that are connected to rotatable shafts **32** that are rotated by wing motors **34** and that allow the orientation of the wings **28** with respect to the bird body **30** to be changed. When the shafts **32** of the bird **18** are not horizontal, this rotation causes the horizontal orientation of the wings **28** to change and thereby changes the horizontal forces that are applied to the streamer **12** by the bird.

The motors **34** can consist of any type of device that is capable of changing the orientation of the wings **28**, and they are preferably either electric motors or hydraulic actuators. The local control system **36** controls the movement of the wings **28** by calculating a desired change in the angle of the wings and then selectively driving the motors **34** to effectuate this change. While the preferred embodiment depicted utilizes a separate motor **34** for each wing **28**, it would be also be possible to independently move the wings **28** using a single motor **34** and a selectively actuatable transmission mechanism.

When the bird **18** uses two wings **28** to produce the horizontal and vertical forces on the streamer **12**, the required outputs of the local control system **36** are relatively simple, the directions and magnitudes of the wing movements required for each of the wings **28**, or equivalently the magnitude and direction the motors **34** need to be driven to produce this wing movement. While the required outputs of the local control system **36** for such a two full moving wing design is quite simple, the structure and operation of the overall system required to coordinate control of the device is relatively complicated.

FIG. **3** shows a schematic vertical cross-sectional view through the streamer positioning device shown in FIG. **2** that will allow the operation of the inventive control system to be described in more detail. The components of the bird **18** shown in FIG. **3** include the wings **28** and the body **30**. Also shown in FIG. **3** are a horizontal coordinate axis **38** and a vertical coordinate axis **40**. During operation of the streamer positioning control system, the global control system **22** preferably transmits, at regular intervals (such as every five seconds) a desired horizontal force **42** and a desired vertical force **44** to the local control system **36**.

The desired horizontal force **42** and the desired vertical force **44** are combined within the local control system **36** to calculate the magnitude and direction of the desired total force **46** that the global control system **22** has instructed the local control system to apply to the streamer **12**. The global control system **22** could alternatively provide the magnitude and direction of the desired total force **46** to the local control system **36** instead of the desired horizontal force **42** and the desired vertical force **44**.

While the desired horizontal force **42** and the desired vertical force **44** are preferably calculated by the global control system **22**, it is also possible for the local control system **36** in the inventive control system to calculate one or both of these forces using a localized displacement/force conversion program. This type of localized conversion program may, for instance, use a look-up table or conversion routine that associates certain magnitudes and directions of vertical or horizontal displacements with certain magnitudes and directions of changes in the vertical or horizontal forces required. Using this type of embodiment, the global control system **22** can transmit location information to the local control system **36** instead of force information. Instead of the desired vertical force **44**, the global control system **22** can transmit a desired vertical depth and the local control system **36** can calculate the magnitude and direction of the deviation between the desired depth and the actual depth. Similarly, instead of transmitting a desired horizontal force **42**, the global control system **22** can transmit the magnitude and direction of the displacement between the actual horizontal position and the desired horizontal position of the bird **18**. One advantage to this alternative type of system is that the required vertical force can be rapidly updated as the local control system receives updated depth information from the integrated pressure sensor. Other advantages of this type of alternative system include reducing communication traffic on the communication line **24** and simplifying the programming needed to convert the measured vertical and/or horizontal displacements into corresponding forces to be applied by the birds **18**.

When the local control system **36** has a new desired horizontal force **42** and desired vertical force **44** to be applied, the wings **28** will typically not be in the proper orientation to provide the direction of the desired total force **46** required. As can be seen in FIG. **3**, the wings **28** introduce a force into the streamer **12** along an axis perpendicular to the rotational axis of the wings **28** and perpendicular to the streamer. This force axis **48** is typically not properly aligned with the desired total force **46** when new desired horizontal and vertical force values are received from the global control system **22** or determined by the local control system **36** and some rotation of the bird **18** is required before the bird can produce this desired total force **46**. As can be seen, the force axis **48** is directly related to the bird roll angle, designated in FIG. **3** as ϕ.

The local control system **36** optimizes the control process by projecting the desired total force **46** onto the force axis **48** (i.e. multiplying the magnitude of the desired total force by the cosine of the deviation angle **50**) to produce an intermediate desired force **52** and then adjusting the wing common angle α (the angle of the wings with respect to the bird body **30**, or the average angle if there is a non-zero splay angle) to produce this magnitude of force along the force axis. The calculated desired common wing angle is compared to the current common wing angle to calculate a desired change in the common wing angle and the wing motors **34** are actuated to produce this desired change in the orientation of the wings.

A splay angle is then introduced into the wings **28** to produce a rotational movement in the bird body **30** (i.e. to rotate the force axis **48** to be aligned with the desired total force **46**). The splay angle is the difference between the angles of the wings **28** with respect to the bird body **30**. As the bird body **30** rotates and the force axis **48** becomes more closely aligned with the desired total force **46**, the bird roll angle and the bird roll angular velocity are monitored, the splay angle is incrementally reduced, and the common angle is incrementally increased until the intermediate desired force **52** is in the same direction and of the same magnitude as the desired total force. The local control system **36** carefully regulates the splay angle to ensure that the streamer is stable in roll degree of freedom. The calculated common wing angle and the splay angle are also regulated by the local control system **36** to prevent the wings **28** from stalling and to ensure that the splay angle is prioritized.

When using the type of birds described in our published PCT International Application No. WO 98/28636, where the bird **18** is rigidly attached, and cannot rotate with respect, to the streamer **12**, it is important for the control system to take the streamer twist into account. If this is not taken into account, the bird **18** can use all of its available splay angle to counter the twist in the streamer **12**. The bird **18** will then be unable to reach the demanded roll angle and the generated force will decrease. The inventive control system incorporates two functions for addressing this situation; the anti-twist function and the untwist function.

In the anti-twist function, the streamer twist is estimated by weightfunction filtering the splay angle measurements instead of simply averaging the splay angle measurements to improve the bandwidth of the estimation. The anti-twist function engages when the estimated twist has reached a critical value and it then overrides the normal shortest path control of the calculated roll angle. The anti-twist function forces the bird **18** to rotate in the opposite direction of the twist by adding +/−180 degrees to the demanded roll angle. Once the twist has been reduced to an acceptable value, the anti-twist function disengages and the normal shortest path calculation is continued.

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. The number of revolutions done by each bird **18** is monitored and the untwist function is disengaged once the twist has reached an acceptable level.

FIG. **4** is a schematic diagram of the architecture of the local control system **36** for the bird **18**. The local control system **36** consists of a central processor unit **54**, having EEPROM **56** and RAM **58** memory, an input/output subsystem **60** that is connected to a pair of motor drivers **62**, and an analog to digital conversion unit **66**. The motor drivers **62** are connected to and actuate the wing motors **34** to produce the desired change the orientation of the wings **28** with respect to the bird body **30**.

The wing motor **34**/wing **28** units are also connected to wing position indicators **64** that sense the relative positions of the wings and provide measurements to the analog to digital conversion unit **66** which converts the analog wing position indicator **64** measurements into digital format and conveys these digital values to the central processor unit **54**. Various types of wing position indicators **64** can be used, including resistive angle or displacement sensors, inductive sensors, capacitive sensors, hall sensors, or magneto-restrictive sensors.

A horizontal accelerometer **68** and a vertical accelerometer **70**, placed at right angles with respect to one another, are also connected to the analog to digital conversion unit **66** and these accelerometers convey measurements that allow the central processor unit **54** to determine the roll angle and roll rate of the bird **18**. An angular velocity vibrating rate gyro (rategyro) can also be used to measure the roll rate of the bird **18**. A temperature sensor **72** is connected to the analog to digital conversion unit **66** to provide temperature measurements that allow the horizontal accelerometer **68** and the vertical accelerometer **70** to be calibrated.

A pressure sensor **74** is also connected to the analog to digital conversion unit **66** to provide the central processor unit **54** with measurements of the water pressure at the bird **18**. To calculate an appropriate depth value, the measured pressure values must be filtered to limit the disturbance from waves. This is done in the inventive control system with a weightfunction filter that avoids the large phase displacements caused by mean value filters. Instead of using an instantaneous depth value or simply calculating an average depth value over a given period of time (and thereby incorporating a large phase displacement into the depth value), the inventive control system uses a differentially weighted pressure filtering scheme. First the pressure values are transformed into depth values by dividing the pressure sensor reading by the seawater density and gravitational acceleration. These depth values are then filtered using a weight function filter. Typical incremental weighting functions values range from 0.96 to 0.90 (sample weights of 1.0, 0.9, 0.81, 0.729, etc.) and the filter will typically process depth values received over a period of at least 100 seconds.

The central processor unit **54** is also connected to a RS485 communications unit **76** that allows information to be exchanged between the local control system **36** and the global control system **22** over the communication line **24** that passes through the streamer **12**. The RS485 bus may, for instance, utilize Neuron chips that communicate using a Local Operating Network protocol to control the data transfer.

Preferably, the central processor unit **54** and associated components comprise a MicroChip 17C756 processor. This type of microprocessor has very low power requirements, a dual UART on-chip, 12-channel, 10 bit ADC on-chip, 908×8 RAM, 16k×16 ROM, and 50 digital I/O channels. The software running on the central processor unit **54** will typically consist of two units, the local control unit and the hardware control unit. It is typically not possible to pre-load both of these program units into the EEPROM **56** and it is possible to update these program units without having to open the bird 18. The on-chip memory may thus only initially contain a boot-routine that enables the loading of software units into the external memory via the RS485 communication unit 76. The external program memory (EEPROM 56) will typically be a non-volatile memory so that these program units do not have to be re-loaded after every power down.

The central processor unit 54 must be able to run the local control system software fast enough to secure the sampling frequency needed for effective local bird control. This may mean, for instance, a sample rate of 10 Hz, which may be 10 to 100 times faster than the sample rate of the communications between the global control system 22 and the local control system 36. As discussed above, the central processor unit 54 will also receive data from sensors attached to the bird 18. The sensed values include bird roll angle, bird roll angular velocity (roll rate), the wing angles, and the static pressure of the water. These values are typically delivered to the central processor unit 54 at a sample rate of at least 10 Hz. The following values may be transmitted from the local control system 36 to the global control system 22 using the RS485 communication unit 76: the measured roll angle, the measured roll rate, the measured wing angles, the measured water pressure, the calculated depth, and the calculated wing forces.

The system has been designed with a redundant communication system to increase its overall reliability. The bird 18 will typically have a backup communications channel, such as by overlaying a backup control signal on top of the power line current. This backup communications channel is particularly important because in the event of loss of communications to the bird 18 there would otherwise be no method for instructing the bird 18 to bring the streamer 12 to surface so the defective communications equipment can be repaired or replaced.

In contrast to previous streamer position device control systems, the present control system converts the desired horizontal force 42 and the desired vertical force 44 into a desired roll angle ϕ and a desired common wing angle α by deterministic calculations, rather than using an "incremental change/measured response/further incremental change based on measured response" type of feedback control circuit. The desired roll angle ϕ can be calculated in the manner discussed in the text describing FIG. 3 above. The magnitude of the force F imparted by the wings 28 along the force axis 48 can, for instance, be deterministically calculated using the following formula:

$$F = \frac{1}{2}\rho * A * C_L(v_{tow}\cos(\alpha) - v_{current}\sin(\alpha))^2$$

where:

ρ=water density

A=wing area

C_L=wing lift coefficient

α=common wing angle

V_{tow}=towing velocity

$V_{current}$=crosscurrent velocity

A similar deterministic calculation could be made using a calculated coefficient that incorporates the towing velocity of the bird 18. A gain factor GF, for instance, could be calculated as follows:

$$GF = \frac{1}{2}\rho * A * C_L(v_{tow})^2$$

which could be simply multiplied by $\cos(\alpha)^2$ to estimate the force that would be applied for a given common angle.

One of the beneficial elements of the inventive control system is that the desired change in the orientation of the wing 28 is calculated using an estimate of the velocity of the bird 18 rather than simply relying on a feedback-loop type of control system that operates in the same manner regardless of the vessel speed. Because the force produced by wing 28 is proportional to the velocity of the device squared, a much mere precise calculation of the desired change in the wing orientation can be made by using an estimate of the device velocity.

The inventive control system is based on shared responsibilities between the global control system 22 located on the seismic survey vessel 10 and the local control system 36 located on the bird 18. The global control system 22 is tasked with monitoring the positions of the streamers 12 and providing desired forces or desired position information to the local control system 36. The local control system 36 within each bird 18 is responsible for adjusting the wing splay angle to rotate the bird to the proper position and for adjusting the wing common angle to produce the magnitude of total desired force required.

The inventive control system will primarily operate in two different control modes: a feather angle control mode and a turn control mode. 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. The feather angle could be input either manually, through use of a current meter, or through use of an estimated value based on the average horizontal bird forces. Only when the crosscurrent velocity is very small will the feather angle be set to zero and the desired streamer positions be in precise alignment with the towing direction.

The turn control mode is used when ending one pass and beginning another pass during a 3D seismic survey, sometimes referred to as a "line change". The turn control mode consists 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. In the last part of the turn, the birds 18 are directed to go to the position defined by the feather angle control mode. By doing this, a tighter turn can be achieved and the turn time of the vessel and equipment reduced. Typically during the turn mode adjacent streamers will be depth separated to avoid possible entanglement during the turn and will be returned to a common depth as soon as possible after the completion of the turn. The vessel navigation system will typically notify the global control system 22 when to start throwing the streamers 12 out, and when to start straightening the streamers.

In extreme weather conditions, the inventive control system may also operate in a streamer separation control mode that attempts to minimize the risk of entanglement of the streamers. In this control mode, the global control system 22 attempts to maximize the distance between adjacent streamers. The streamers 12 will typically be separated in depth and the outermost streamers will be positioned as far away from each other as possible. The inner streamers will then be regularly spaced between these outermost streamers, i.e. each bird 18 will receive desired horizontal forces 42 or desired horizontal position information that will direct the bird **18** to the midpoint position between its adjacent streamers.

While the embodiment of the inventive control system described above is shown in connection with a "bird" type of streamer positioning device, it will be readily understood that the control system method and apparatus may also be used in connection with streamer positioning devices that are characterized as "deflectors" or steerable "tail buoys" because they are attached to either the front end or the back end of the streamer **12**.

The present invention includes any novel feature or novel combination of features disclosed herein, either explicitly or implicitly.

The invention claimed is:

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.

2. A method as claimed in claim **1**, comprising estimating velocity of at least some of the streamer positioning devices, wherein said estimated velocity is calculated using a vessel speed received from a navigation system on said seismic survey vessel.

3. A method as claimed in claim **2**, in which said estimated velocity is a water referenced towing velocity that compensates for the speed and heading of marine currents acting on said streamer positioning devices.

4. A method as claimed in claim **3**, in which said estimated velocity is compensated for relative movement between said seismic survey vessel and said streamer positioning devices.

5. A method as claimed in claim **2**, in which said step of using the predicted positions to calculate desired changes in position of one or more of the streamer positioning devices further uses an estimate of the crosscurrent velocity at the respective streamer positioning device.

6. A method as claimed in claim **5**, in which said step of using the predicted positions to calculate desired changes in position of one or more of the streamer positioning devices is regulated to prevent the positioning device from stalling.

7. A method as claimed in claim **6**, in which said step of using the predicted positions to calculate desired changes in position of one or more of the streamer positioning devices is regulated by a global control system located on or near a seismic survey vessel that is configured into a feather angle mode, wherein said global control system attempts to direct the streamer positioning devices to maintain each of said streamers in a straight line offset from the towing direction of said marine seismic vessel by a certain feather angle, and into a turn control mode, wherein said global control system directs said streamer positioning devices to generate a force in the opposite direction of a turn at the beginning of the turn.

8. A method as claimed in claim **7**, in which said global control system is further configured into a streamer separation mode, wherein said global control system attempts to direct said streamer positioning device to maintain a minimum separation distance between adjacent streamers.

9. A method as claimed in claim **8**, further including the step of displaying the position of said streamer positioning devices on said seismic survey vessel.

10. A method as claimed in claim **9**, in which each streamer positioning device is attached to and unable rotate with respect to its streamer and further comprising the step of monitoring twist in said marine seismic streamers and calculating a desired change in the orientation of hydrodynamic deflecting surfaces of the streamer positioning devices to reduce said twist.

11. A method as claimed in claim **10**, further including the step of obtaining the desired positions of at least some of the streamer positioning devices.

12. A method as claimed in claim **11**, wherein the prediction of position of a streamer positioning device and the desired position of that same streamer positioning device are used to produce a desired force to be applied to its streamer by that streamer positioning device.

13. A method as claimed in claim **12**, in which said desired force is projected onto a current force axis and orientation of hydrodynamic deflecting surfaces of the streamer positioning device is calculated that will produce said projected force at said estimated velocity.

14. A method as claimed in claim **13**, in which the streamer positioning device is rotated to align the current force axis with said desired force and its hydrodynamic deflecting surface orientation is changed as the current force axis becomes more closely aligned with said desired force.

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.

16. Apparatus as claimed in claim **15**, in which each streamer positioning device has a first hydrodynamic deflecting surface and a second hydrodynamic deflecting surface, said first deflecting surface and said second deflecting surface being independently moveable to steer the streamer positioning device laterally and vertically.

17. Apparatus as claimed in claim **16**, wherein each streamer positioning device is rigidly attached to and unable to rotate with respect to its streamer.

18. Apparatus as claimed in claim **17**, further including means for determining the angular velocity of each streamer positioning device.

19. Apparatus as claimed in claim **18**, wherein a global control system is located on or near said seismic vessel and a respective local control system is located within or near each streamer positioning device and said global control system and said local control systems communicate using a respective communication line passing through each streamer.

20. Apparatus as claimed in claim **19**, in which input values for said local control systems are downloaded over said communication lines.

21. Apparatus as claimed in claim **20**, further including a respective backup communications channel in each streamer between the global control system and the local control systems of the streamer positioning devices of the streamer.

22. Apparatus as claimed in claim **21**, in which each local control system has a cycle rate that is at least 10 times greater than the data transfer rate of said communication line.

23. Apparatus as claimed in claim **22**, in which each local control system comprises a microprocessor programmed to monitor the current orientation of the wing of its streamer positioning device and to calculate desired changes to the orientation of said wing based on inputs from said global control system.

24. Apparatus as claimed in claim **23**, further including means for producing a weight function filtered depth value.

25. A method of controlling position of a seismic streamer comprising:

(a) calculating magnitude and direction of a desired total force or displacement to apply to the seismic streamer;

(b) adjusting, based on forces exerted on the streamer by hydrodynamic deflecting surfaces in a force axis, the calculated magnitude of total force or displacement to form an intermediate desired total force;

(c) adjusting a common angle between hydrodynamic deflecting surfaces to produce the intermediate desired total force along the force axis; and

(d) introducing a splay angle in to the hydrodynamic deflecting surfaces to produce a rotational movement in a body of the streamer positioning device to align the force axis with the direction of the desired total force.

* * * * *

Exhibit D

US007162967B2

(12) United States Patent
Hillesund et al.

(10) Patent No.: US 7,162,967 B2
(45) Date of Patent: Jan. 16, 2007

(54) **CONTROL SYSTEM FOR POSITIONING OF MARINE SEISMIC STREAMERS**

(75) Inventors: **Oyvind Hillesund**, Histon (GB); **Simon Hastings Bittleston**, Bury St Edmunds (GB)

(73) Assignee: **Westerngeco, L.L.C.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/454,352**

(22) Filed: **Jun. 16, 2006**

(65) **Prior Publication Data**

US 2006/0260529 A1 Nov. 23, 2006

Related U.S. Application Data

(63) Continuation of application No. 09/787,723, filed as application No. PCT/IB99/01590 on Sep. 28, 1999, now Pat. No. 6,932,017.

(30) **Foreign Application Priority Data**

Jan. 10, 1998 (GB) 9821277.3

(51) **Int. Cl.**
B60P 3/10 (2006.01)
G01V 1/00 (2006.01)

(52) **U.S. Cl.** 114/344; 367/19

(58) **Field of Classification Search** 114/162, 114/163, 242, 244–246, 253
See application file for complete search history.

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Primary Examiner—Jesús D. Sotelo
(74) *Attorney, Agent, or Firm*—WesternGeco, L.L.C.

(57) **ABSTRACT**

A method of controlling a streamer positioning device (**18**) configured to be attached to a marine seismic streamer (**12**) and towed by seismic survey vessel (**10**) and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The invention also involves an apparatus for controlling a streamer positioning device including means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to produce the desired change in the orientation of the wing.

28 Claims, 3 Drawing Sheets

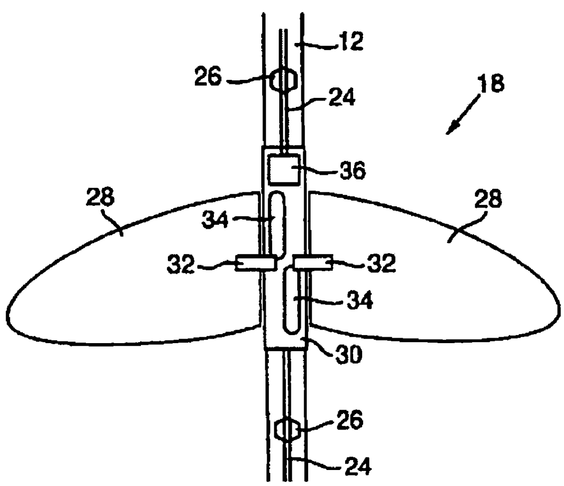

Fig.1.
Prior Art

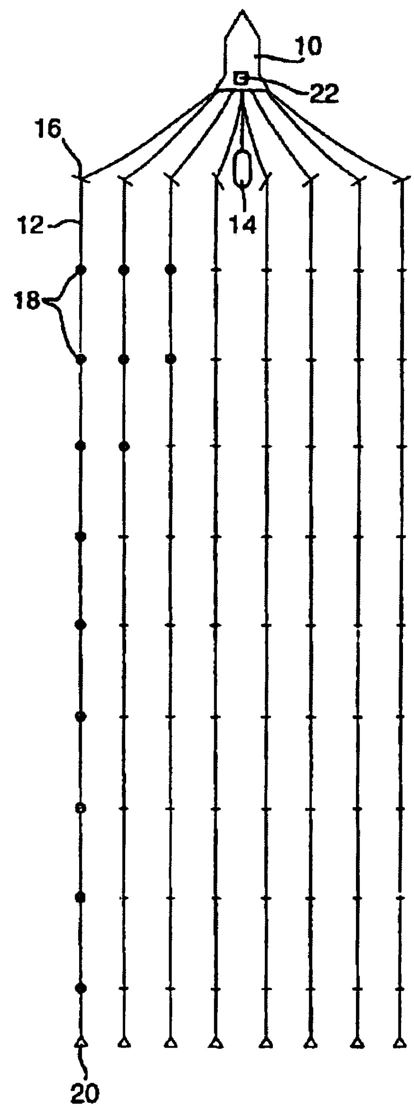

Fig.2.

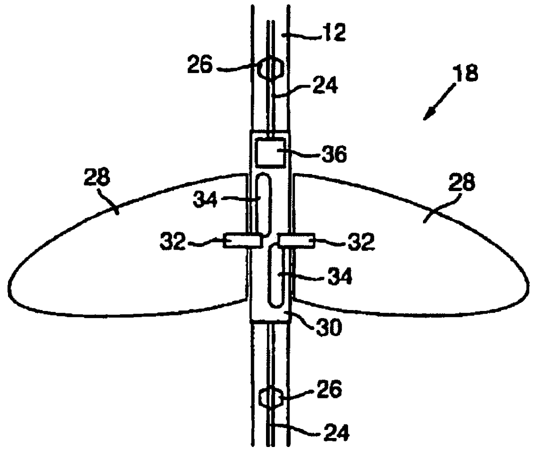
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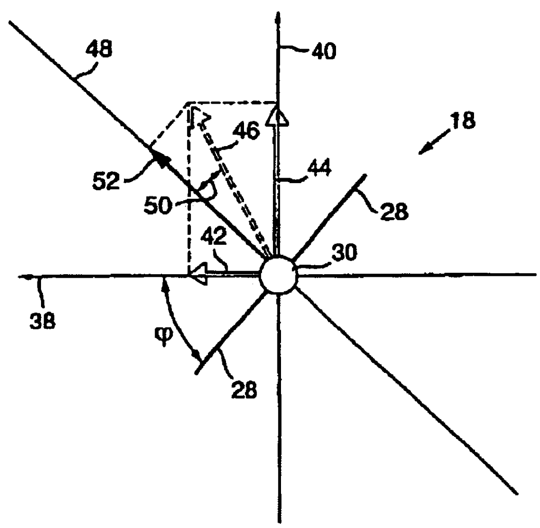
Fig.3.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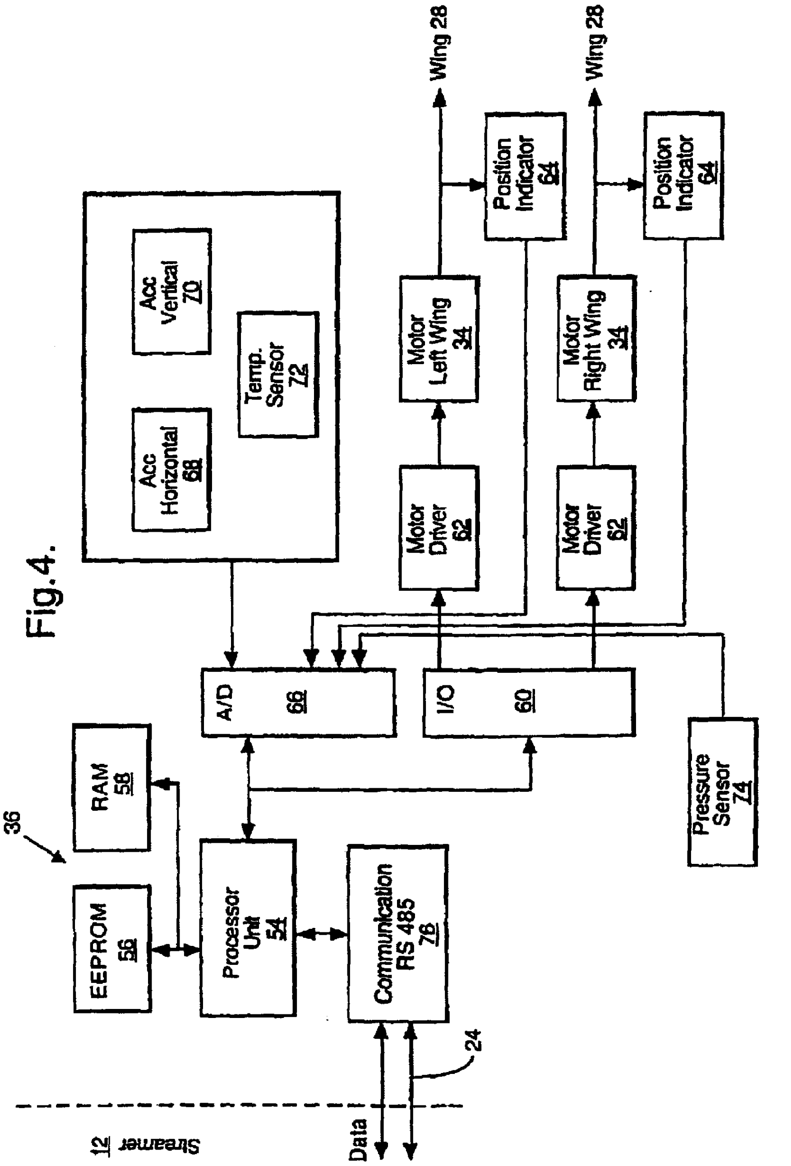
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Wing 28
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Acc Horizontal 68
Temp. Sensor 72
Motor Left Wing 34
Motor Right Wing 34
Motor Driver 62
Motor Driver 62
A/D 66
I/O 60
RAM 58
EEPROM 56
Processor Unit 54
Communication RS 485 76
Pressure Sensor 74
36
24
Streamer 12
Data

Fig.4.

CONTROL SYSTEM FOR POSITIONING OF MARINE SEISMIC STREAMERS

CROSS-REFERENCE TO RELATED APPLICATIONS

Applicant claims priority under 35 U.S.C. § 120 from Ser. No. 11/070,614, filed Mar. 2, 2005, now U.S. Pat. No. 7,080,607, which was a continuation of parent application Ser. No. 09/787,723, filed Jul. 2, 2001, now U.S. Pat. No. 6,932,017, which was a 35 U.S.C. § 371 national stage filing from Patent Cooperation Treaty application number PCT/IB99/01590, filed Sep. 28, 1999, which in turn claimed priority from Great Britain patent application number 9821277.3, filed Oct. 1, 1998, from which Applicant claims foreign priority under 35 U.S.C. § 119, all of which are incorporated herein by reference. This application is also related to application Ser. Nos. 11/454,349 and 11/455,042, both filed simultaneously herewith, which also are both incorporated herein by reference.

BACKGROUND OF THE INVENTION

This invention relates generally to systems for controlling seismic data acquisition equipment and particularly to a system for controlling a marine seismic streamer positioning device.

A marine seismic streamer is an elongate cable-like structure, typically up to several thousand meters long, which contains arrays of seismic sensors, known as hydrophones, and associated electronic equipment along its length, and which is used in marine seismic surveying. In order to perform a 3D marine seismic survey, a plurality of such streamers are towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones, and then digitized and processed to build up a representation of the subsurface geology.

The horizontal positions of the streamers are typically controlled by a deflector, located at the front end or "head" of the streamer, and a tail buoy, located at the back end or "tail" of the streamer. These devices create tension forces on the streamer which constrain the movement of the streamer and cause it to assume a roughly linear shape. Cross currents and transient forces cause the streamer to bow and undulate, thereby introducing deviations into this desired linear shape.

The streamers are typically towed at a constant depth of approximately ten meters, in order to facilitate the removal of undesired "ghost" reflections from the surface of the water. To keep the streamers at this constant depth, control devices known as "birds", are typically attached at various points along each streamer between the deflector and the tail buoy, with the spacing between the birds generally varying between 200 and 400 meters. The birds have hydrodynamic deflecting surfaces, referred to as wings, that allow the position of the streamer to be controlled as it is towed through the water. When a bird is used for depth control purposes only, it is possible for the bird to regularly sense its depth using an integrated pressure sensor and for a local controller within the bird to adjust the wing angles to maintain the streamer near the desired depth using only a desired depth value received from a central control system.

While the majority of birds used thus far have only controlled the depth of the streamers, additional benefits can

be obtained by using properly controlled horizontally steerable birds, particularly by using the types of horizontally and vertically steerable birds disclosed in our published PCT International Application No. WO 98/28636. The 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.

It is estimated that horizontal out-of-position conditions reduce the efficiency of current 3D seismic survey operations by between 5 and 10%, depending on weather and current conditions. While incidents of tangling adjacent streamers are relatively rare, when they do occur they invariably result in prolonged vessel downtime. The loss of efficiency associated with turning the seismic survey vessel will depend in large part on the seismic survey layout, but typical estimates range from 5 to 10%. Simulations have concluded that properly controlled horizontally steerable birds can be expected to reduce these types of costs by approximately 30%.

One system for controlling a horizontally steerable bird, as disclosed in UK Patent GB 2093610 B, is to utilize a manually-operated central control system to transmit the magnitudes and directions of any required wing angle changes to the birds. While this method greatly simplifies the circuitry needed within the bird itself, it is virtually impossible for this type of system to closely regulate the horizontal positions of the birds because it requires manual input and supervision. This becomes a particularly significant issue when a substantial number of streamers are deployed simultaneously and the number of birds that must be controlled goes up accordingly.

Another system for controlling a horizontally steerable bird is disclosed in our published PCT International Application No. WO 98/28636. Using this type of control system, the desired horizontal positions and the actual horizontal positions are received from a remote control system and are then used by a local control system within the birds to adjust the wing angles. The 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. 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. A more deterministic system for controlling this type of streamer positioning device is therefore desired.

It is therefore an object of the present invention to provide for an improved method and apparatus for controlling a streamer positioning device.

An advantage of the present invention is that the position of the streamer may be better controlled, thereby reducing the need for in-fill shooting, reducing the chance of streamer tangling, and reducing the time needed to turn the seismic survey vessel.

Another advantage of the present invention is that noise in marine seismic data associated with streamer position overcorrection and streamer positioning errors can be significantly reduced.

SUMMARY OF THE INVENTION

The present invention provides methods and apparatus for controlling the positions of marine seismic streamers in an array of such streamers being towed by a seismic survey vessel, the streamers having respective streamer positioning devices disposed therealong and each streamer positioning device having a wing and a wing motor for changing the orientation of the wing so as to steer the streamer positioning device laterally, said methods and apparatus involving (a) obtaining an estimated velocity of the streamer positioning devices, (b) for at least some of the streamer positioning devices, calculating desired changes in the orientation of their wings using said estimated velocity, and (c) actuating the wing motors to produce said desired changes in wing orientation.

The invention and its benefits will be better understood with reference to the detailed description below and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a seismic survey vessel and associated seismic data acquisition equipment;

FIG. **2** is a schematic horizontal cross-sectional view through a marine seismic streamer and an attached streamer positioning device;

FIG. **3** is a schematic vertical cross-sectional view through the streamer positioning device from FIG. **2**; and

FIG. **4** is a schematic diagram of the local control system architecture of the streamer positioning device from FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. **1**, a seismic survey vessel **10** is shown towing eight marine seismic streamers **12** that may, for instance, each be 3000 meters in length. The outermost streamers **12** in the array could be 700 meters apart, resulting in a horizontal separation between the streamers of 100 meters in the regular horizontal spacing configuration shown. A seismic source **14**, typically an airgun or an array of airguns, is also shown being towed by the seismic survey vessel **10**. At the front of each streamer **12** is shown a deflector **16** and at the rear of every streamer is shown a tail buoy **20**. The deflector **16** is used to horizontally position the end of the streamer nearest the seismic survey vessel **10** and the tail buoy **20** creates drag at the end of the streamer farthest from the seismic survey vessel **10**. The tension created on the seismic streamer by the deflector **16** and the tail buoy **20** results in the roughly linear shape of the seismic streamer **12** shown in FIG. **1**.

Located between the deflector **16** and the tail buoy **20** are a plurality of streamer positioning devices known as birds **18**. Preferably the birds **18** are both vertically and horizontally steerable. These birds **18** may, for instance, be located at regular intervals along the streamer, such as every 200 to 400 meters. The vertically and horizontally steerable birds **18** can be used to constrain the shape of the seismic streamer **12** between the deflector **16** and the tail buoy **20** in both the vertical (depth) and horizontal directions.

In the preferred embodiment of the present invention, the control system for the birds **18** is distributed between a global control system **22** located on or near the seismic survey vessel **10** and a local control system located within or near the birds **18**. The global control system **22** is typically connected to the seismic survey vessel's navigation system and obtains estimates of system wide parameters, such as the vessel's towing direction and velocity and current direction and velocity, from the vessel's navigation system.

The most important requirement for the control system is to prevent the streamers **12** from tangling. This requirement becomes more and more important as the complexity and the total value of the towed equipment increases. The trend in the industry is to put more streamers **12** on each seismic survey vessel **10** and to decrease the horizontal separation between them. To get better control of the streamers **12**, horizontal steering becomes necessary. If the birds **18** are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers. Localized current fluctuations can dramatically influence the magnitude of the side control required to properly position the streamers. To compensate for these localized current fluctuations, the inventive control system utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices.

In the preferred embodiment of the present invention, the global control system **22** monitors the actual positions of each of the birds **18** and is programmed with the desired positions of or the desired minimum separations between the seismic streamers **12**. The horizontal positions of the birds **18** can be derived, for instance, using the types of acoustic positioning systems described in our U.S. Pat. No. 4,992,990 or in our PCT International Patent Application No. WO 98/21163. Alternatively, or additionally, satellite-based global positioning system equipment can be used to determine the positions of the equipment. The vertical positions of the birds **18** are typically monitored using pressure sensors attached to the birds, as discussed below.

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. Because the movement of the seismic streamer **12** causes acoustic noise (both from seawater flow past the bird wing structures as well as cross current flow across the streamer skin itself), it is important that the streamer movements be restrained and kept to the minimum correction required to properly position the streamers. Any streamer positioning device control system that consistently overestimates the type of correction required and causes the bird to overshoot its intended position introduces undesirable noise into the seismic data being acquired by the streamer. In current systems, this type of over-correction noise is often balanced against the "noise" or "smearing" caused when the seismic sensors in the streamers **12** are displaced from their desired positions.

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. 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**. The global control system **22** also checks the data received from the vessel's navigation system and the data will be filled in if it is missing. The interface between the global control system **22** and the local control system will typically operate with a sampling frequency of at least 0.1 Hz. The global control system **22** will typically acquire the following parameters from the vessel's navigation system: vessel speed (m/s), vessel heading (degrees), current speed (m/s), current heading (degrees), and the location of each of the birds in the horizontal plane in a vessel fixed coordinate system. Current speed and heading can also be estimated based on the average forces acting on the streamers **12** by the birds **18**. The global control system **22** will preferably send the following values to the local bird controller: demanded vertical force, demanded horizontal force, towing velocity, and crosscurrent velocity.

The towing velocity and crosscurrent velocity are preferably "water-referenced" values that are calculated from the vessel speed and heading values and the current speed and heading values, as well as any relative movement between the seismic survey vessel **10** and the bird **18** (such as while the vessel is turning), to produce relative velocities of the bird **18** with respect to the water in both the "in-line" and the "cross-line" directions. Alternatively, the global control system **22** could provide the local control system with the horizontal velocity and water in-flow angle. 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.

The "water-referenced" towing velocity and crosscurrent velocity could alternatively be determined using flowmeters or other types of water velocity sensors attached directly to the birds **18**. Although these types of sensors are typically quite expensive, one advantage of this type of velocity determination system is that the sensed in-line and cross-line velocities will be inherently compensated for the speed and heading of marine currents acting on said streamer positioning device and for relative movements between the vessel **10** and the bird **18**.

FIG. **2** shows a type of bird **18** that is capable of controlling the position of seismic streamers **12** in both the vertical and horizontal directions. A bird **18** of this type is also disclosed in our PCT International Application No. WO 98/28636. While a number of alternative designs for the vertically and horizontally steerable birds **18** are possible, including those utilizing one full-moving wing with ailerons, three full-moving wings, and four full-moving wings, the independent two-wing principal is, conceptually, the simplest and most robust design.

In FIG. **2**, a portion of the seismic streamer **12** is shown with an attached bird **18**. A communication line **24**, which may consist of a bundle of fiber optic data transmission cables and power transmission wires, passes along the length of the seismic streamer **12** and is connected to the seismic sensors, hydrophones **26**, that are distributed along the length of the streamer, and to the bird **18**. The bird **18** preferably has a pair of independently moveable wings **28** that are connected to rotatable shafts **32** that are rotated by wing motors **34** and that allow the orientation of the wings **28** with respect to the bird body **30** to be changed. When the shafts **32** of the bird **18** are not horizontal, this rotation causes the horizontal orientation of the wings **28** to change and thereby changes the horizontal forces that are applied to the streamer **12** by the bird.

The motors **34** can consist of any type of device that is capable of changing the orientation of the wings **28**, and they are preferably either electric motors or hydraulic actuators. The local control system **36** controls the movement of the wings **28** by calculating a desired change in the angle of the wings and then selectively driving the motors **34** to effectuate this change. While the preferred embodiment depicted utilizes a separate motor **34** for each wing **28**, it would be also be possible to independently move the wings **28** using a single motor **34** and a selectively actuatable transmission mechanism.

When the bird **18** uses two wings **28** to produce the horizontal and vertical forces on the streamer **12**, the required outputs of the local control system **36** are relatively simple, the directions and magnitudes of the wing movements required for each of the wings **28**, or equivalently the magnitude and direction the motors **34** need to be driven to produce this wing movement. While the required outputs of the local control system **36** for such a two full moving wing design is quite simple, the structure and operation of the overall system required to coordinate control of the device is relatively complicated.

FIG. **3** shows a schematic vertical cross-sectional view through the streamer positioning device shown in FIG. **2** that will allow the operation of the inventive control system to be described in more detail. The components of the bird **18** shown in FIG. **3** include the wings **28** and the body **30**. Also shown in FIG. **3** are a horizontal coordinate axis **38** and a vertical coordinate axis **40**. During operation of the streamer positioning control system, the global control system **22** preferably transmits, at regular intervals (such as every five seconds) a desired horizontal force **42** and a desired vertical force **44** to the local control system **36**.

The desired horizontal force **42** and the desired vertical force **44** are combined within the local control system **36** to calculate the magnitude and direction of the desired total force **46** that the global control system **22** has instructed the local control system to apply to the streamer **12**. The global control system **22** could alternatively provide the magnitude and direction of the desired total force **46** to the local control system **36** instead of the desired horizontal force **42** and the desired vertical force **44**.

While the desired horizontal force **42** and the desired vertical force **44** are preferably calculated by the global control system **22**, it is also possible for the local control system **36** in the inventive control system to calculate one or both of these forces using a localized displacement/force conversion program. This type of localized conversion program may, for instance, use a look-up table or conversion routine that associates certain magnitudes and directions of vertical or horizontal displacements with certain magnitudes and directions of changes in the vertical or horizontal forces required. Using this type of embodiment, the global control system **22** can transmit location information to the local control system **36** instead of force information. Instead of the desired vertical force **44**, the global control system **22** can transmit a desired vertical depth and the local control system **36** can calculate the magnitude and direction of the deviation between the desired depth and the actual depth. Similarly, instead of transmitting a desired horizontal force **42**, the global control system **22** can transmit the magnitude and direction of the displacement between the actual horizontal position and the desired horizontal position of the bird **18**. One advantage to this alternative type of system is that the required vertical force can be rapidly updated as the local control system receives updated depth information from the integrated pressure sensor. Other advantages of this type of alternative system include reducing communication traffic on the communication line **24** and simplifying the programming needed to convert the measured vertical and/or horizontal displacements into corresponding forces to be applied by the birds **18**.

When the local control system **36** has a new desired horizontal force **42** and desired vertical force **44** to be applied, the wings **28** will typically not be in the proper orientation to provide the direction of the desired total force **46** required. As can be seen in FIG. **3**, the wings **28** introduce a force into the streamer **12** along an axis perpendicular to the rotational axis of the wings **28** and perpendicular to the streamer. This force axis **48** is typically not properly aligned with the desired total force **46** when new desired horizontal and vertical force values are received from the global control system **22** or determined by the local control system **36** and some rotation of the bird **18** is required before the bird can produce this desired total force **46**. As can be seen, the force axis **48** is directly related to the bird roll angle, designated in FIG. **3** as ϕ.

The local control system **36** optimizes the control process by projecting the desired total force **46** onto the force axis **48** (i.e. multiplying the magnitude of the desired total force by the cosine of the deviation angle **50**) to produce an intermediate desired force **52** and then adjusting the wing common angle α (the angle of the wings with respect to the bird body **30**, or the average angle if there is a non-zero splay angle) to produce this magnitude of force along the force axis. The calculated desired common wing angle is compared to the current common wing angle to calculate a desired change in the common wing angle and the wing motors **34** are actuated to produce this desired change in the orientation of the wings.

A splay angle is then introduced into the wings **28** to produce a rotational movement in the bird body **30** (i.e. to rotate the force axis **48** to be aligned with the desired total force **46**). The splay angle is the difference between the angles of the wings **28** with respect to the bird body **30**. As the bird body **30** rotates and the force axis **48** becomes more closely aligned with the desired total force **46**, the bird roll angle and the bird roll angular velocity are monitored, the splay angle is incrementally reduced, and the common angle is incrementally increased until the intermediate desired force **52** is in the same direction and of the same magnitude as the desired total force. The local control system **36** carefully regulates the splay angle to ensure that the streamer is stable in roll degree of freedom. The calculated common wing angle and the splay angle are also regulated by the local control system **36** to prevent the wings **28** from stalling and to ensure that the splay angle is prioritized.

When using the type of birds described in our published PCT International Application No. WO 98/28636, where the bird **18** is rigidly attached, and cannot rotate with respect, to the streamer **12**, it is important for the control system to take the streamer twist into account. If this is not taken into account, the bird **18** can use all of its available splay angle to counter the twist in the streamer **12**. The bird **18** will then be unable to reach the demanded roll angle and the generated force will decrease. The inventive control system incorporates two functions for addressing this situation; the anti-twist function and the untwist function.

In the anti-twist function, the streamer twist is estimated by weightfunction filtering the splay angle measurements instead of simply averaging the splay angle measurements to improve the bandwidth of the estimation. The anti-twist function engages when the estimated twist has reached a critical value and it then overrides the normal shortest path control of the calculated roll angle. The anti-twist function forces the bird **18** to rotate in the opposite direction of the twist by adding +/−180 degrees to the demanded roll angle. Once the twist has been reduced to an acceptable value, the anti-twist function disengages and the normal shortest path calculation is continued.

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. The number of revolutions done by each bird **18** is monitored and the untwist function is disengaged once the twist has reached an acceptable level. FIG. **4** is a schematic diagram of the architecture of the local control system **36** for the bird **18**. The local control system **36** consists of a central processor unit **54**, having EEPROM 56 and RAM **58** memory, an input/output subsystem **60** that is connected to a pair of motor drivers **62**, and an analog to digital conversion unit **66**. The motor drivers **62** are connected to and actuate the wing motors **34** to produce the desired change the orientation of the wings **28** with respect to the bird body **30**.

The wing motor **34**/wing **28** units are also connected to wing position indicators **64** that sense the relative positions of the wings and provide measurements to the analog to digital conversion unit **66** which converts the analog wing position indicator **64** measurements into digital format and conveys these digital values to the central processor unit **54**. Various types of wing position indicators **64** can be used, including resistive angle or displacement sensors inductive sensors, capacitive sensors, hall sensors, or magneto-restrictive sensors.

A horizontal accelerometer **68** and a vertical accelerometer **70**, placed at right angles with respect to one another, are also connected to the analog to digital conversion unit **66** and these accelerometers convey measurements that allow the central processor unit **54** to determine the roll angle and roll rate of the bird **18**. An angular velocity vibrating rate gyro (rategyro) can also be used to measure the roll rate of the bird **18**. A temperature sensor **72** is connected to the analog to digital conversion unit **66** to provide temperature measurements that allow the horizontal accelerometer **68** and the vertical accelerometer **70** to be calibrated.

A pressure sensor **74** is also connected to the analog to digital conversion unit **66** to provide the central processor unit **54** with measurements of the water pressure at the bird **18**. To calculate an appropriate depth value, the measured pressure values must be filtered to limit the disturbance from waves. This is done in the inventive control system with a weightfunction filter that avoids the large phase displacements caused by mean value filters. Instead of using an instantaneous depth value or simply calculating an average depth value over a given period of time (and thereby incorporating a large phase displacement into the depth value), the inventive control system uses a differentially weighted pressure filtering scheme. First the pressure values are transformed into depth values by dividing the pressure sensor reading by the seawater density and gravitational acceleration. These depth values are then filtered using a weight function filter. Typical incremental weighting functions values range from 0.96 to 0.90 (sample weights of 1.0, 0.9, 0.81, 0.729, etc.) and the filter will typically process depth values received over a period of at least 100 seconds.

The central processor unit **54** is also connected to a RS485 communications unit **76** that allows information to be exchanged between the local control system **36** and the global control system **22** over the communication line **24** that passes through the streamer **12**. The RS485 bus may, for instance, utilize Neuron chips that communicate using a Local Operating Network protocol to control the data transfer.

Preferably, the central processor unit **54** and associated components comprise a MicroChip 17C756 processor. This type of microprocessor has very low power requirements, a dual UART on-chip, 12-channel, 10 bit ADC on-chip, 908×8 RAM, 16 k×16 ROM, and 50 digital I/O channels. The software running on the central processor unit **54** will typically consist of two units, the local control unit and the hardware control unit. It is typically not possible to pre-load both of these program units into the EEPROM 56 and it is possible to update these program units without having to open the bird **18**. The on-chip memory may thus only initially contain a boot-routine that enables the loading of software units into the external memory via the RS485 communication unit **76**. The external program memory (EEPROM 56) will typically be a non-volatile memory so that these program units do not have to be re-loaded after every power down.

The central processor unit **54** must be able to run the local control system software fast enough to secure the sampling frequency needed for effective local bird control. This may mean, for instance, a sample rate of 10 Hz, which may be 10 to 100 times faster than the sample rate of the communications between the global control system **22** and the local control system **36**. As discussed above, the central processor unit **54** will also receive data from sensors attached to the bird **18**. The sensed values include bird roll angle, bird roll angular velocity (roll rate), the wing angles, and the static pressure of the water. These values are typically delivered to the central processor unit **54** at a sample rate of at least 10 Hz. The following values may be transmitted from the local control system **36** to the global control system **22** using the RS485 communication unit **76**: the measured roll angle, the measured roll rate, the measured wing angles, the measured water pressure, the calculated depth, and the calculated wing forces.

The system has been designed with a redundant communication system to increase its overall reliability. The bird **18** will typically have a backup communications channel, such as by overlaying a backup control signal on top of the power line current. This backup communications channel is particularly important because in the event of loss of communications to the bird **18** there would otherwise be no method for instructing the bird **18** to bring the streamer **12** to surface so the defective communications equipment can be repaired or replaced.

In contrast to previous streamer position device control systems, the present control system converts the desired horizontal force **42** and the desired vertical force **44** into a desired roll angle ϕ and a desired common wing angle α by deterministic calculations, rather than using an "incremental change/measured response/further incremental change based on measured response" type of feedback control circuit. The desired roll angle ϕ can be calculated in the manner discussed in the text describing FIG. **3** above. The magnitude of the force F imparted by the wings **28** along the force axis **48** can, for instance, be deterministically calculated using the following formula:

$$F=0.5\rho A C_L(V_{tow}\cos(\alpha)-V_{current}\sin(\alpha))^2$$

where: ρ=water density;

A=wing area;

C_L=wing lift coefficient;

α=common wing angle;

V_{tow}=towing velocity; and

$V_{current}$=crosscurrent velocity.

A similar deterministic calculation could be made using a calculated coefficient that incorporates the towing velocity of the bird **18**. A gain factor GF, for instance, could be calculated as follows:

$$GF=0.5\rho A C_L(V_{tow})^2$$

which could be simply multiplied by $\cos(\alpha)^2$ to estimate the force that would be applied for a given common angle.

One of the beneficial elements of the inventive control system is that the desired change in the orientation of the wing **28** is calculated using an estimate of the velocity of the bird **18** rather than simply relying on a feedback-loop type of control system that operates in the same manner regardless of the vessel speed. Because the force produced by wing **28** is proportional to the velocity of the device squared, a much more precise calculation of the desired change in the wing orientation can be made by using an estimate of the device velocity.

The inventive control system is based on shared responsibilities between the global control system **22** located on the seismic survey vessel **10** and the local control system **36** located on the bird **18**. The global control system **22** is tasked with monitoring the positions of the streamers **12** and providing desired forces or desired position information to the local control system **36**. The local control system **36** within each bird **18** is responsible for adjusting the wing splay angle to rotate the bird to the proper position and for adjusting the wing common angle to produce the magnitude of total desired force required.

The inventive control system will primarily operate in two different control modes: a feather angle control mode and a turn control mode. 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. The feather angle could be input either manually, through use of a current meter, or through use of an estimated value based on the average horizontal bird forces. Only when the crosscurrent velocity is very small will the feather angle be set to zero and the desired streamer positions be in precise alignment with the towing direction.

The turn control mode is used when ending one pass and beginning another pass during a 3D seismic survey, sometimes referred to as a "line change". The turn control mode consists 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. In the last part of the turn, the birds **18** are directed to go to the position defined by the feather angle control mode. By doing this, a tighter turn can be achieved and the turn time of the vessel and equipment can be substantially reduced. Typically during the turn mode adjacent streamers will be depth separated to avoid possible entanglement during the turn and will be returned to a common depth as soon as possible after the completion of the turn. The vessel navigation system will typically notify the global control system **22** when to start throwing the streamers **12** out, and when to start straightening the streamers.

In extreme weather conditions, the inventive control system may also operate in a streamer separation control mode that attempts to minimize the risk of entanglement of the streamers. In this control mode, the global control system **22** attempts to maximize the distance between adjacent streamers. The streamers **12** will typically be separated in depth and the outermost streamers will be positioned as far away from each other as possible. The inner streamers will then be regularly spaced between these outermost streamers, i.e. each bird **18** will receive desired horizontal forces **42** or desired horizontal position information that will direct the bird **18** to the midpoint position between its adjacent streamers.

While the embodiment of the inventive control system described above is shown in connection with a "bird" type of streamer positioning device, it will be readily understood that the control system method and apparatus may also be used in connection with streamer positioning devices that are characterized as "deflectors" or steerable "tail buoys" because they are attached to either the front end or the back end of the streamer **12**.

The present invention includes any novel feature or novel combination of features disclosed herein, either explicitly or implicitly.

What is claimed is:

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.

2. The method of claim **1** wherein the adjusting comprises calculating, with the at least one local control system, a desired force on the at least one streamer positioning device using the location information, the desired force selected from a desired horizontal force, a desired vertical force, and both.

3. The method as claimed in claim **2** wherein the calculating comprises a localized conversion program that associates magnitude and direction of vertical displacement, horizontal displacement, or both displacements with magnitude and direction of the desired vertical force, the desired horizontal force, or both forces.

4. The method as claimed in claim **1**, wherein the global control system transmits a desired vertical depth for the at least one streamer positioning device and the local control system calculates magnitude and direction of the deviation between the desired vertical depth and actual depth.

5. The method as claimed in claim **1**, wherein the global control system transmits a desired horizontal displacement for the at least one streamer positioning device and the local control system calculates magnitude and direction of the deviation between the desired horizontal displacement and actual horizontal displacement.

6. The method as claimed in claim **1**, comprising calculating velocity of at least one of the streamer positioning devices, wherein the calculating velocity comprises at least one of a) using a vessel speed received from a navigation system on a seismic survey vessel; b) compensating for the speed and heading of marine currents acting on the at least one streamer positioning device; and c) compensating for relative movement between the seismic survey vessel and the at least one streamer positioning device.

7. The method as claimed in claim **6**, in which said step of adjusting the wing using the local control system is regulated to prevent the positioning device from stalling.

8. The method as claimed in claim **7**, in which said step of using the location information to calculate desired forces on the at least one streamer positioning device is regulated by the global control system located on or near a seismic survey vessel that is configured into a feather angle mode, wherein the global control system attempts to direct the streamer positioning devices to maintain each of the streamers in a straight line offset from the towing direction of the marine seismic vessel by a certain feather angle, and into a turn control mode, wherein the global control system directs the streamer positioning devices to generate a force in the opposite direction of a turn at the beginning of the turn.

9. The method as claimed in claim **8**, which said global control system is further configured into a streamer separation mode, wherein said global control system attempts to direct said streamer positioning device to maintain a minimum separation distance between adjacent streamers.

10. The method as claimed in claim **9**, further including the step of displaying the position of said streamer positioning devices on said seismic survey vessel.

11. The method as claimed in claim **10**, in which each streamer positioning device is attached to and unable rotate with respect to its streamer and further comprising the step of monitoring twist in said marine seismic streamers and calculating a desired change in the orientation of hydrodynamic deflecting surfaces of the streamer positioning devices to reduce said twist.

12. The method as claimed in claim **11**, further including the step of obtaining the desired positions of at least some of the streamer positioning devices.

13. The method as claimed in claim **12**, in which said desired force is projected onto a current force axis and orientation of hydrodynamic deflecting surfaces of the streamer positioning device is calculated that will produce said projected force at said calculated velocity.

14. The method as claimed in claim **13**, in which the streamer positioning device is rotated to align the current force axis with said desired force and its hydrodynamic deflecting surface orientation is changed as the current force axis becomes more closely aligned with said desired force.

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.

16. The apparatus of claim **15** wherein the local control system calculates forces selected from a desired horizontal force, a desired vertical force, and both, on the at least one streamer positioning device using the location information.

17. The apparatus of claim **16** wherein local control system comprises a localized conversion program that associates magnitude and direction of vertical displacement, horizontal displacement, or both displacements with magnitude and direction of the desired vertical force, the desired horizontal force, or both forces.

18. The apparatus as claimed in claim **16**, wherein the global control system transmits a desired vertical depth for the at least one streamer positioning device and the local control system calculates magnitude and direction of the deviation between the desired vertical depth and actual depth.

19. The apparatus as claimed in claim **16**, wherein the global control system transmits a desired horizontal displacement for the at least one streamer positioning device and the local control system calculates magnitude and direction of the deviation between the desired horizontal displacement and actual horizontal displacement.

20. The apparatus as claimed in claim **16**, comprising means for calculating velocity of at least one of the streamer positioning devices, wherein the means for calculating velocity comprises means selected from at least one of a) a navigation system on a seismic survey vessel calculating vessel speed; b) a current meter compensating for the speed and heading of marine currents acting on the at least one streamer positioning device; and c) a unit measuring relative movement between the seismic survey vessel and the at least one streamer positioning device.

21. The apparatus as claimed in claim **20**, wherein the local control system adjusting the wing includes a regulator to prevent the positioning device from stalling.

22. The apparatus as claimed in claim **21**, wherein use of the location information to calculate desired forces on the at least one streamer positioning device is regulated by the global control system located on or near a seismic survey vessel that is configured into a feather angle mode, wherein the global control system attempts to direct the streamer positioning devices to maintain each of the streamers in a straight line offset from the towing direction of the marine seismic vessel by a certain feather angle, and into a turn control mode, wherein the global control system directs the streamer positioning devices to generate a force in the opposite direction of a turn at the beginning of the turn.

23. The apparatus as claimed in claim **22**, in which the global control system is further configured into a streamer separation mode, wherein said global control system attempts to direct said streamer positioning device to maintain a minimum separation distance between adjacent streamers.

24. The apparatus as claimed in claim **23**, comprising a display of the position of said streamer positioning devices on said seismic survey vessel.

25. The apparatus as claimed in claim **24**, in which each streamer positioning device is attached to and unable rotate with respect to its streamer, and further comprising a monitoring component to monitor twist in said marine seismic streamers and a calculating unit for calculating a desired change in the orientation of hydrodynamic deflecting surfaces of the streamer positioning devices to reduce said twist.

26. The apparatus as claimed in claim **25**, further including the step of obtaining the desired positions of at least some of the streamer positioning devices.

27. The apparatus as claimed in claim **26**, in which said desired force is projected onto a current force axis and orientation of hydrodynamic deflecting surfaces of the streamer positioning device is calculated that will produce said projected force at said calculated velocity.

28. The apparatus as claimed in claim **27**, in which the streamer positioning device is rotated to align the current force axis with said desired force and its hydrodynamic deflecting surface orientation is changed as the current force axis becomes more closely aligned with said desired force.

* * * * *

Exhibit E

US007293520B2

(12) **United States Patent**
Hillesund et al.

(10) **Patent No.: US 7,293,520 B2**
(45) **Date of Patent: *Nov. 13, 2007**

(54) **CONTROL SYSTEM FOR POSITIONING OF A MARINE SEISMIC STREAMERS**

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(73) Assignee: **WesternGeco, L.L.C.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 102 days.

This patent is subject to a terminal disclaimer.

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(51) **Int. Cl.**
B63B 21/66 (2006.01)
G01V 1/38 (2006.01)

(52) **U.S. Cl.** **114/244**; 367/19

(58) **Field of Classification Search** 114/162, 114/163, 242, 244, 246, 253
See application file for complete search history.

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Primary Examiner—Jesús D Sotelo
(74) *Attorney, Agent, or Firm*—Liangang (Mark) Ye; Jeffrey E. Griffin

(57) **ABSTRACT**

A method of controlling a streamer positioning device (**18**) configured to be attached to a marine seismic streamer (**12**) and towed by seismic survey vessel (**10**) and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The invention also involves an apparatus for controlling a streamer positioning device including means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to produce the desired change in the orientation of the wing.

34 Claims, 3 Drawing Sheets

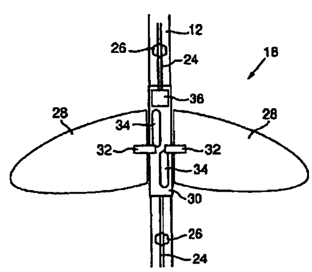

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Fig.1.

Prior Art

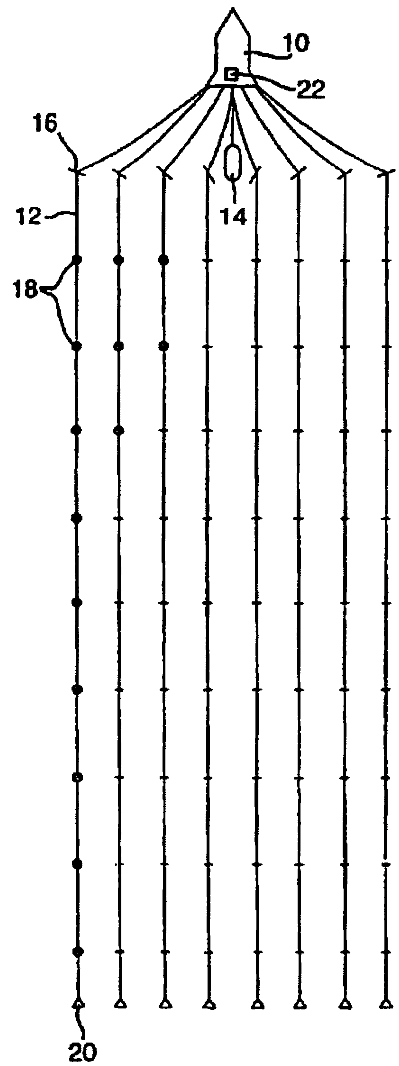

Fig.2.

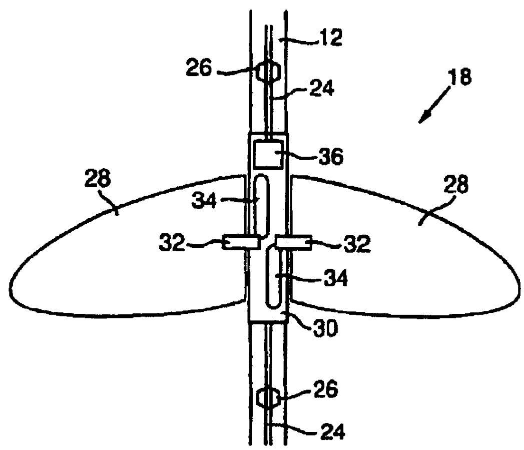
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Fig.3.

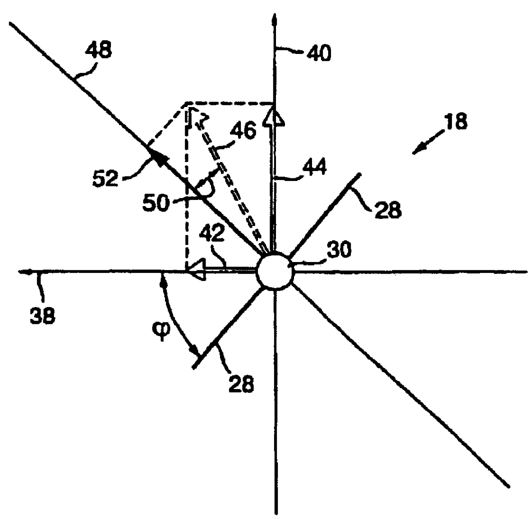
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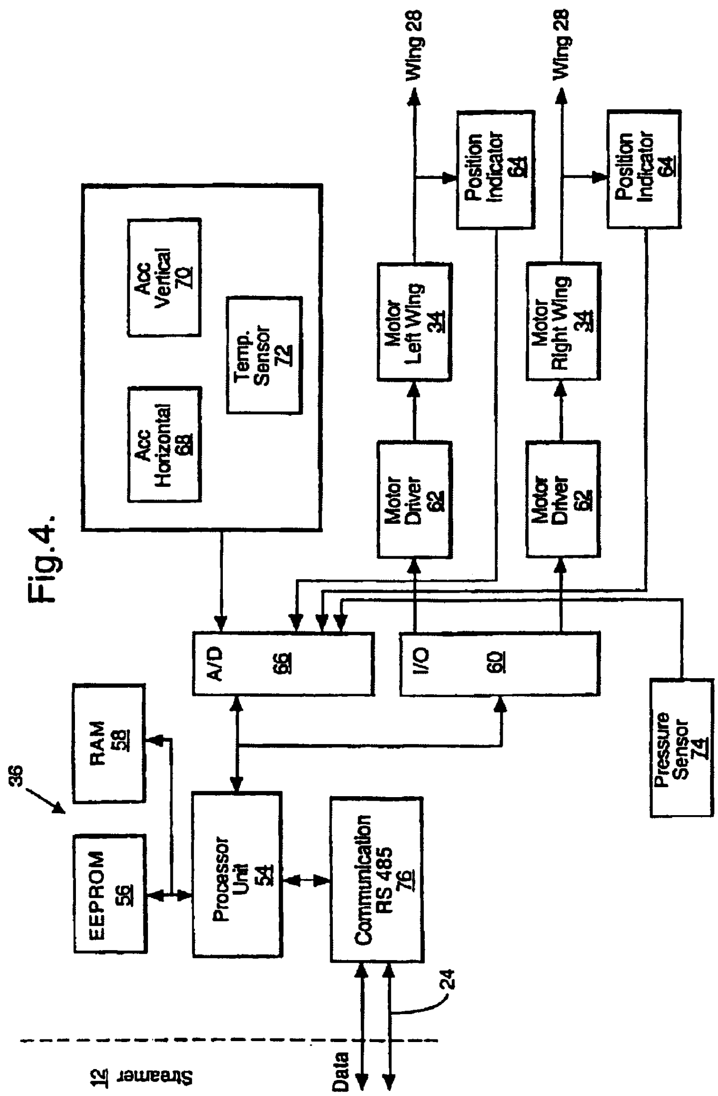
Fig.4.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RAM 58
Processor Unit 54
Communication RS 485 76
A/D 66
I/O 60
Acc Horizontal 68
Acc Vertical 70
Temp. Sensor 72
Motor Driver 62
Motor Left Wing 34
Motor Driver 62
Motor Right Wing 34
Position Indicator 64
Position Indicator 64
Wing 28
Wing 28
Pressure Sensor 74
Streamer 12
Data
24

CONTROL SYSTEM FOR POSITIONING OF A MARINE SEISMIC STREAMERS

CROSS-REFERENCE TO RELATED APPLICATIONS

Applicant claims priority under 35 U.S.C. § 120 from Ser. No. 11/070,614, filed Mar. 2, 2005, now U.S. Pat. No. 7,080,607, which was a continuation of parent application Ser. No. 09/787,723, filed Jul. 2, 2001, now U.S. Pat. No. 6,932,017, which was a 35 U.S.C. § 371 national stage filing from Patent Cooperation Treaty application number PCT/IB99/01590, filed Sep. 28, 1999, which in turn claimed priority from Great Britain patent application number 9821277.3, filed Oct. 1, 1998, from which Applicant claims foreign priority under 35 U.S.C. § 119, all of which are incorporated herein by reference. This application is also related to co-pending application Ser. Nos. 11/454,352 and 11/454,349, filed simultaneously herewith, which also are both incorporated herein by reference.

BACKGROUND OF THE INVENTION

This invention relates generally to systems for controlling seismic data acquisition equipment and particularly to a system for controlling a marine seismic streamer positioning device.

A marine seismic streamer is an elongate cable-like structure, typically up to several thousand meters long, which contains arrays of seismic sensors, known as hydrophones, and associated electronic equipment along its length, and which is used in marine seismic surveying. In order to perform a 3D marine seismic survey, a plurality of such streamers are towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones, and then digitized and processed to build up a representation of the subsurface geology.

The horizontal positions of the streamers are typically controlled by a deflector, located at the front end or "head" of the streamer, and a tail buoy, located at the back end or "tail" of the streamer. These devices create tension forces on the streamer which constrain the movement of the streamer and cause it to assume a roughly linear shape. Cross currents and transient forces cause the streamer to bow and undulate, thereby introducing deviations into this desired linear shape.

The streamers are typically towed at a constant depth of approximately ten meters, in order to facilitate the removal of undesired "ghost" reflections from the surface of the water. To keep the streamers at this constant depth, control devices known as "birds", are typically attached at various points along each streamer between the deflector and the tail buoy, with the spacing between the birds generally varying between 200 and 400 meters. The birds have hydrodynamic deflecting surfaces, referred to as wings, that allow the position of the streamer to be controlled as it is towed through the water. When a bird is used for depth control purposes only, it is possible for the bird to regularly sense its depth using an integrated pressure sensor and for a local controller within the bird to adjust the wing angles to maintain the streamer near the desired depth using only a desired depth value received from a central control system.

While the majority of birds used thus far have only controlled the depth of the streamers, additional benefits can

be obtained by using properly controlled horizontally steerable birds, particularly by using the types of horizontally and vertically steerable birds disclosed in our published PCT International Application No. WO 98/28636. The 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.

It is estimated that horizontal out-of-position conditions reduce the efficiency of current 3D seismic survey operations by between 5 and 10%, depending on weather and current conditions. While incidents of tangling adjacent streamers are relatively rare, when they do occur they invariably result in prolonged vessel downtime. The loss of efficiency associated with turning the seismic survey vessel will depend in large part on the seismic survey layout, but typical estimates range from 5 to 10%. Simulations have concluded that properly controlled horizontally steerable birds can be expected to reduce these types of costs by approximately 30%.

One system for controlling a horizontally steerable bird, as disclosed in UK Patent GB 2093610 B, is to utilize a manually-operated central control system to transmit the magnitudes and directions of any required wing angle changes to the birds. While this method greatly simplifies the circuitry needed within the bird itself, it is virtually impossible for this type of system to closely regulate the horizontal positions of the birds because it requires manual input and supervision. This becomes a particularly significant issue when a substantial number of streamers are deployed simultaneously and the number of birds that must be controlled goes up accordingly.

Another system for controlling a horizontally steerable bird is disclosed in our published PCT International Application No. WO 98/28636. Using this type of control system, the desired horizontal positions and the actual horizontal positions are received from a remote control system and are then used by a local control system within the birds to adjust the wing angles. The 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. 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. A more deterministic system for controlling this type of streamer positioning device is therefore desired.

It is therefore an object of the present invention to provide for an improved method and apparatus for controlling a streamer positioning device.

An advantage of the present invention is that the position of the streamer may be better controlled, thereby reducing the need for in-fill shooting, reducing the chance of streamer tangling, and reducing the time needed to turn the seismic survey vessel.

Another advantage of the present invention is that noise in marine seismic data associated with streamer position overcorrection and streamer positioning errors can be significantly reduced.

SUMMARY OF THE INVENTION

The present invention provides methods and apparatus for controlling the positions of marine seismic streamers in an array of such streamers being towed by a seismic survey vessel, the streamers having respective streamer positioning devices disposed therealong and each streamer positioning device having a wing and a wing motor for changing the orientation of the wing so as to steer the streamer positioning device laterally, said methods and apparatus involving (a) obtaining an estimated velocity of the streamer positioning devices, (b) for at least some of the streamer positioning devices, calculating desired changes in the orientation of their wings using said estimated velocity, and (c) actuating the wing motors to produce said desired changes in wing orientation.

The invention and its benefits will be better understood with reference to the detailed description below and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a seismic survey vessel and associated seismic data acquisition equipment;

FIG. **2** is a schematic horizontal cross-sectional view through a marine seismic streamer and an attached streamer positioning device;

FIG. **3** is a schematic vertical cross-sectional view through the streamer positioning device from FIG. **2**; and

FIG. **4** is a schematic diagram of the local control system architecture of the streamer positioning device from FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. **1**, a seismic survey vessel **10** is shown towing eight marine seismic streamers **12** that may, for instance, each be 3000 meters in length. The outermost streamers **12** in the array could be 700 meters apart, resulting in a horizontal separation between the streamers of 100 meters in the regular horizontal spacing configuration shown. A seismic source **14**, typically an airgun or an array of airguns, is also shown being towed by the seismic survey vessel **10**. At the front of each streamer **12** is shown a deflector **16** and at the rear of every streamer is shown a tail buoy **20**. The deflector **16** is used to horizontally position the end of the streamer nearest the seismic survey vessel **10** and the tail buoy **20** creates drag at the end of the streamer farthest from the seismic survey vessel **10**. The tension created on the seismic streamer by the deflector **16** and the tail buoy **20** results in the roughly linear shape of the seismic streamer **12** shown in FIG. **1**.

Located between the deflector **16** and the tail buoy **20** are a plurality of streamer positioning devices known as birds **18**. Preferably the birds **18** are both vertically and horizontally steerable. These birds **18** may, for instance, be located at regular intervals along the streamer, such as every 200 to 400 meters. The vertically and horizontally steerable birds **18** can be used to constrain the shape of the seismic streamer **12** between the deflector **16** and the tail buoy **20** in both the vertical (depth) and horizontal directions.

In the preferred embodiment of the present invention, the control system for the birds **18** is distributed between a global control system **22** located on or near the seismic survey vessel **10** and a local control system located within or near the birds **18**. The global control system **22** is typically connected to the seismic survey vessel's navigation system and obtains estimates of system wide parameters, such as the vessel's towing direction and velocity and current direction and velocity, from the vessel's navigation system.

The most important requirement for the control system is to prevent the streamers **12** from tangling. This requirement becomes more and more important as the complexity and the total value of the towed equipment increases. The trend in the industry is to put more streamers **12** on each seismic survey vessel **10** and to decrease the horizontal separation between them. To get better control of the streamers **12**, horizontal steering becomes necessary. If the birds **18** are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers. Localized current fluctuations can dramatically influence the magnitude of the side control required to properly position the streamers. To compensate for these localized current fluctuations, the inventive control system utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices.

In the preferred embodiment of the present invention, the global control system **22** monitors the actual positions of each of the birds **18** and is programmed with the desired positions of or the desired minimum separations between the seismic streamers **12**. The horizontal positions of the birds **18** can be derived, for instance, using the types of acoustic positioning systems described in our U.S. Pat. No. 4,992,990 or in our PCT International Patent Application No. WO 98/21163. Alternatively, or additionally, satellite-based global positioning system equipment can be used to determine the positions of the equipment. The vertical positions of the birds **18** are typically monitored using pressure sensors attached to the birds, as discussed below.

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. Because the movement of the seismic streamer **12** causes acoustic noise (both from seawater flow past the bird wing structures as well as cross current flow across the streamer skin itself), it is important that the streamer movements be restrained and kept to the minimum correction required to properly position the streamers. Any streamer positioning device control system that consistently overestimates the type of correction required and causes the bird to overshoot its intended position introduces undesirable noise into the seismic data being acquired by the streamer. In current systems, this type of over-correction noise is often balanced against the "noise" or "smearing" caused when the seismic sensors in the streamers **12** are displaced from their desired positions.

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. 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**. The global control system **22** also checks the data received from the vessel's navigation system and the data will be filled in if it is missing. The interface between the global control system **22** and the local control system will typically operate with a sampling frequency of at least 0.1 Hz. The global control system **22** will typically acquire the following parameters from the vessel's navigation system: vessel speed (m/s), vessel heading (degrees), current speed (m/s), current heading (degrees), and the location of each of the birds in the horizontal plane in a vessel fixed coordinate system. Current speed and heading can also be estimated based on the average forces acting on the streamers 12 by the birds 18. The global control system 22 will preferably send the following values to the local bird controller: demanded vertical force, demanded horizontal force, towing velocity, and crosscurrent velocity.

The towing velocity and crosscurrent velocity are preferably "water-referenced" values that are calculated from the vessel speed and heading values and the current speed and heading values, as well as any relative movement between the seismic survey vessel 10 and the bird 18 (such as while the vessel is turning), to produce relative velocities of the bird 18 with respect to the water in both the "in-line" and the "cross-line" directions. Alternatively, the global control system 22 could provide the local control system with the horizontal velocity and water in-flow angle. 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.

The "water-referenced" towing velocity and crosscurrent velocity could alternatively be determined using flowmeters or other types of water velocity sensors attached directly to the birds 18. Although these types of sensors are typically quite expensive, one advantage of this type of velocity determination system is that the sensed in-line and cross-line velocities will be inherently compensated for the speed and heading of marine currents acting on said streamer positioning device and for relative movements between the vessel 10 and the bird 18.

FIG. 2 shows a type of bird 18 that is capable of controlling the position of seismic streamers 12 in both the vertical and horizontal directions. A bird 18 of this type is also disclosed in our PCT International Application No. WO 98/28636. While a number of alternative designs for the vertically and horizontally steerable birds 18 are possible, including those utilizing one full-moving wing with ailerons, three full-moving wings, and four full-moving wings, the independent two-wing principal is, conceptually, the simplest and most robust design.

In FIG. 2, a portion of the seismic streamer 12 is shown with an attached bird 18. A communication line 24, which may consist of a bundle of fiber optic data transmission cables and power transmission wires, passes along the length of the seismic streamer 12 and is connected to the seismic sensors, hydrophones 26, that are distributed along the length of the streamer, and to the bird 18. The bird 18 preferably has a pair of independently moveable wings 28 that are connected to rotatable shafts 32 that are rotated by wing motors 34 and that allow the orientation of the wings 28 with respect to the bird body 30 to be changed. When the shafts 32 of the bird 18 are not horizontal, this rotation causes the horizontal orientation of the wings 28 to change and thereby changes the horizontal forces that are applied to the streamer 12 by the bird.

The motors 34 can consist of any type of device that is capable of changing the orientation of the wings 28, and they are preferably either electric motors or hydraulic actuators. The local control system 36 controls the movement of the wings 28 by calculating a desired change in the angle of the wings and then selectively driving the motors 34 to effectuate this change. While the preferred embodiment depicted utilizes a separate motor 34 for each wing 28, it would be also be possible to independently move the wings 28 using a single motor 34 and a selectively actuatable transmission mechanism.

When the bird 18 uses two wings 28 to produce the horizontal and vertical forces on the streamer 12, the required outputs of the local control system 36 are relatively simple, the directions and magnitudes of the wing movements required for each of the wings 28, or equivalently the magnitude and direction the motors 34 need to be driven to produce this wing movement. While the required outputs of the local control system 36 for such a two full moving wing design is quite simple, the structure and operation of the overall system required to coordinate control of the device is relatively complicated.

FIG. 3 shows a schematic vertical cross-sectional view through the streamer positioning device shown in FIG. 2 that will allow the operation of the inventive control system to be described in more detail. The components of the bird 18 shown in FIG. 3 include the wings 28 and the body 30. Also shown in FIG. 3 are a horizontal coordinate axis 38 and a vertical coordinate axis 40. During operation of the streamer positioning control system, the global control system 22 preferably transmits, at regular intervals (such as every five seconds) a desired horizontal force 42 and a desired vertical force 44 to the local control system 36.

The desired horizontal force 42 and the desired vertical force 44 are combined within the local control system 36 to calculate the magnitude and direction of the desired total force 46 that the global control system 22 has instructed the local control system to apply to the streamer 12. The global control system 22 could alternatively provide the magnitude and direction of the desired total force 46 to the local control system 36 instead of the desired horizontal force 42 and the desired vertical force 44.

While the desired horizontal force 42 and the desired vertical force 44 are preferably calculated by the global control system 22, it is also possible for the local control system 36 in the inventive control system to calculate one or both of these forces using a localized displacement/force conversion program. This type of localized conversion program may, for instance, use a look-up table or conversion routine that associates certain magnitudes and directions of vertical or horizontal displacements with certain magnitudes and directions of changes in the vertical or horizontal forces required. Using this type of embodiment, the global control system 22 can transmit location information to the local control system 36 instead of force information. Instead of the desired vertical force 44, the global control system 22 can transmit a desired vertical depth and the local control system 36 can calculate the magnitude and direction of the deviation between the desired depth and the actual depth. Similarly, instead of transmitting a desired horizontal force 42, the global control system 22 can transmit the magnitude and direction of the displacement between the actual horizontal position and the desired horizontal position of the bird 18. One advantage to this alternative type of system is that the required vertical force can be rapidly updated as the local control system receives updated depth information from the integrated pressure sensor. Other advantages of this type of alternative system include reducing communication traffic on the communication line 24 and simplifying the programming needed to convert the measured vertical and/or horizontal displacements into corresponding forces to be applied by the birds 18.

When the local control system 36 has a new desired horizontal force 42 and desired vertical force 44 to be applied, the wings 28 will typically not be in the proper orientation to provide the direction of the desired total force **46** required. As can be seen in FIG. **3**, the wings **28** introduce a force into the streamer **12** along an axis perpendicular to the rotational axis of the wings **28** and perpendicular to the streamer. This force axis **48** is typically not properly aligned with the desired total force **46** when new desired horizontal and vertical force values are received from the global control system **22** or determined by the local control system **36** and some rotation of the bird **18** is required before the bird can produce this desired total force **46**. As can be seen, the force axis **48** is directly related to the bird roll angle, designated in FIG. **3** as ϕ.

The local control system **36** optimizes the control process by projecting the desired total force **46** onto the force axis **48** (i.e. multiplying the magnitude of the desired total force by the cosine of the deviation angle **50**) to produce an intermediate desired force **52** and then adjusting the wing common angle α (the angle of the wings with respect to the bird body **30**, or the average angle if there is a non-zero splay angle) to produce this magnitude of force along the force axis. The calculated desired common wing angle is compared to the current common wing angle to calculate a desired change in the common wing angle and the wing motors **34** are actuated to produce this desired change in the orientation of the wings.

A splay angle is then introduced into the wings **28** to produce a rotational movement in the bird body **30** (i.e. to rotate the force axis **48** to be aligned with the desired total force **46**). The splay angle is the difference between the angles of the wings **28** with respect to the bird body **30**. As the bird body **30** rotates and the force axis **48** becomes more closely aligned with the desired total force **46**, the bird roll angle and the bird roll angular velocity are monitored, the splay angle is incrementally reduced, and the common angle is incrementally increased until the intermediate desired force **52** is in the same direction and of the same magnitude as the desired total force. The local control system **36** carefully regulates the splay angle to ensure that the streamer is stable in roll degree of freedom. The calculated common wing angle and the splay angle are also regulated by the local control system **36** to prevent the wings **28** from stalling and to ensure that the splay angle is prioritized.

When using the type of birds described in our published PCT International Application No. WO 98/28636, where the bird **18** is rigidly attached, and cannot rotate with respect, to the streamer **12**, it is important for the control system to take the streamer twist into account. If this is not taken into account, the bird **18** can use all of its available splay angle to counter the twist in the streamer **12**. The bird **18** will then be unable to reach the demanded roll angle and the generated force will decrease. The inventive control system incorporates two functions for addressing this situation; the anti-twist function and the untwist function.

In the anti-twist function, the streamer twist is estimated by weightfunction filtering the splay angle measurements instead of simply averaging the splay angle measurements to improve the bandwidth of the estimation. The anti-twist function engages when the estimated twist has reached a critical value and it then overrides the normal shortest path control of the calculated roll angle. The anti-twist function forces the bird **18** to rotate in the opposite direction of the twist by adding +/−180 degrees to the demanded roll angle. Once the twist has been reduced to an acceptable value, the anti-twist function disengages and the normal shortest path calculation is continued.

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. The number of revolutions done by each bird **18** is monitored and the untwist function is disengaged once the twist has reached an acceptable level. FIG. **4** is a schematic diagram of the architecture of the local control system **36** for the bird **18**. The local control system **36** consists of a central processor unit **54**, having EEPROM **56** and RAM **58** memory, an input/output subsystem **60** that is connected to a pair of motor drivers **62**, and an analog to digital conversion unit **66**. The motor drivers **62** are connected to and actuate the wing motors **34** to produce the desired change the orientation of the wings **28** with respect to the bird body **30**.

The wing motor **34**/wing **28** units are also connected to wing position indicators **64** that sense the relative positions of the wings and provide measurements to the analog to digital conversion unit **66** which converts the analog wing position indicator **64** measurements into digital format and conveys these digital values to the central processor unit **54**. Various types of wing position indicators **64** can be used, including resistive angle or displacement sensors inductive sensors, capacitive sensors, hall sensors, or magneto-restrictive sensors.

A horizontal accelerometer **68** and a vertical accelerometer **70**, placed at right angles with respect to one another, are also connected to the analog to digital conversion unit **66** and these accelerometers convey measurements that allow the central processor unit **54** to determine the roll angle and roll rate of the bird **18**. An angular velocity vibrating rate gyro (rategyro) can also be used to measure the roll rate of the bird **18**. A temperature sensor **72** is connected to the analog to digital conversion unit **66** to provide temperature measurements that allow the horizontal accelerometer **68** and the vertical accelerometer **70** to be calibrated.

A pressure sensor **74** is also connected to the analog to digital conversion unit **66** to provide the central processor unit **54** with measurements of the water pressure at the bird **18**. To calculate an appropriate depth value, the measured pressure values must be filtered to limit the disturbance from waves. This is done in the inventive control system with a weightfunction filter that avoids the large phase displacements caused by mean value filters. Instead of using an instantaneous depth value or simply calculating an average depth value over a given period of time (and thereby incorporating a large phase displacement into the depth value), the inventive control system uses a differentially weighted pressure filtering scheme. First the pressure values are transformed into depth values by dividing the pressure sensor reading by the seawater density and gravitational acceleration. These depth values are then filtered using a weight function filter. Typical incremental weighting functions values range from 0.96 to 0.90 (sample weights of 1.0, 0.9, 0.81, 0.729, etc.) and the filter will typically process depth values received over a period of at least 100 seconds.

The central processor unit **54** is also connected to a RS485 communications unit **76** that allows information to be exchanged between the local control system **36** and the global control system **22** over the communication line **24** that passes through the streamer **12**. The RS485 bus may, for instance, utilize Neuron chips that communicate using a Local Operating Network protocol to control the data transfer.

Preferably, the central processor unit **54** and associated components comprise a MicroChip 17C756 processor. This type of microprocessor has very low power requirements, a dual UART on-chip, 12-channel, 10 bit ADC on-chip, 908×8 RAM, 16 k×16 ROM, and 50 digital I/O channels. The software running on the central processor unit **54** will typically consist of two units, the local control unit and the hardware control unit. It is typically not possible to pre-load both of these program units into the EEPROM **56** and it is possible to update these program units without having to open the bird **18**. The on-chip memory may thus only initially contain a boot-routine that enables the loading of software units into the external memory via the RS485 communication unit **76**. The external program memory (EEPROM **56**) will typically be a non-volatile memory so that these program units do not have to be re-loaded after every power down.

The central processor unit **54** must be able to run the local control system software fast enough to secure the sampling frequency needed for effective local bird control. This may mean, for instance, a sample rate of 10 Hz, which may be 10 to 100 times faster than the sample rate of the communications between the global control system **22** and the local control system **36**. As discussed above, the central processor unit **54** will also receive data from sensors attached to the bird **18**. The sensed values include bird roll angle, bird roll angular velocity (roll rate), the wing angles, and the static pressure of the water. These values are typically delivered to the central processor unit **54** at a sample rate of at least 10 Hz. The following values may be transmitted from the local control system **36** to the global control system **22** using the RS485 communication unit **76**: the measured roll angle, the measured roll rate, the measured wing angles, the measured water pressure, the calculated depth, and the calculated wing forces.

The system has been designed with a redundant communication system to increase its overall reliability. The bird **18** will typically have a backup communications channel, such as by overlaying a backup control signal on top of the power line current. This backup communications channel is particularly important because in the event of loss of communications to the bird **18** there would otherwise be no method for instructing the bird **18** to bring the streamer **12** to surface so the defective communications equipment can be repaired or replaced.

In contrast to previous streamer position device control systems, the present control system converts the desired horizontal force **42** and the desired vertical force **44** into a desired roll angle ϕ and a desired common wing angle α by deterministic calculations, rather than using an "incremental change/measured response/further incremental change based on measured response" type of feedback control circuit. The desired roll angle ϕ can be calculated in the manner discussed in the text describing FIG. **3** above. The magnitude of the force F imparted by the wings **28** along the force axis **48** can, for instance, be deterministically calculated using the following formula:

$$F=0.5\rho A C_L(V_{tow}\cos(\alpha)-V_{current}\sin(\alpha))^2$$

where: ρ=water density;

A=wing area;

C_L=wing lift coefficient;

α=common wing angle;

V_{tow}=towing velocity; and

$V_{current}$=crosscurrent velocity.

A similar deterministic calculation could be made using a calculated coefficient that incorporates the towing velocity of the bird **18**. A gain factor GF, for instance, could be calculated as follows:

$$GF=0.5\rho A C_L(V_{tow})^2$$

which could be simply multiplied by $\cos(\alpha)^2$ to estimate the force that would be applied for a given common angle.

One of the beneficial elements of the inventive control system is that the desired change in the orientation of the wing **28** is calculated using an estimate of the velocity of the bird **18** rather than simply relying on a feedback-loop type of control system that operates in the same manner regardless of the vessel speed. Because the force produced by wing **28** is proportional to the velocity of the device squared, a much more precise calculation of the desired change in the wing orientation can be made by using an estimate of the device velocity.

The inventive control system is based on shared responsibilities between the global control system **22** located on the seismic survey vessel **10** and the local control system **36** located on the bird **18**. The global control system **22** is tasked with monitoring the positions of the streamers **12** and providing desired forces or desired position information to the local control system **36**. The local control system **36** within each bird **18** is responsible for adjusting the wing splay angle to rotate the bird to the proper position and for adjusting the wing common angle to produce the magnitude of total desired force required.

The inventive control system will primarily operate in two different control modes: a feather angle control mode and a turn control mode. 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. The feather angle could be input either manually, through use of a current meter, or through use of an estimated value based on the average horizontal bird forces. Only when the crosscurrent velocity is very small will the feather angle be set to zero and the desired streamer positions be in precise alignment with the towing direction.

The turn control mode is used when ending one pass and beginning another pass during a 3D seismic survey, sometimes referred to as a "line change". The turn control mode consists 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. In the last part of the turn, the birds **18** are directed to go to the position defined by the feather angle control mode. By doing this, a tighter turn can be achieved and the turn time of the vessel and equipment can be substantially reduced. Typically during the turn mode adjacent streamers will be depth separated to avoid possible entanglement during the turn and will be returned to a common depth as soon as possible after the completion of the turn. The vessel navigation system will typically notify the global control system **22** when to start throwing the streamers **12** out, and when to start straightening the streamers.

In extreme weather conditions, the inventive control system may also operate in a streamer separation control mode that attempts to minimize the risk of entanglement of the streamers. In this control mode, the global control system **22** attempts to maximize the distance between adjacent streamers. The streamers **12** will typically be separated in depth and the outermost streamers will be positioned as far away from each other as possible. The inner streamers will then be regularly spaced between these outermost streamers, i.e. each bird **18** will receive desired horizontal forces **42** or desired horizontal position information that will direct the bird **18** to the midpoint position between its adjacent streamers.

While the embodiment of the inventive control system described above is shown in connection with a "bird" type of streamer positioning device, it will be readily understood that the control system method and apparatus may also be used in connection with streamer positioning devices that are characterized as "deflectors" or steerable "tail buoys" because they are attached to either the front end or the back end of the streamer **12**.

The present invention includes any novel feature or novel combination of features disclosed herein, either explicitly or implicitly.

What is claimed is:

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.

3. The method of claim **2** comprising inputting the feather angle manually.

4. The method of claim **2** comprising inputting the feather angle using an estimated value based on an average of horizontal forces on the streamer positioning devices.

5. The method of claim **2** comprising setting the feather angle to zero when crosscurrent velocity is very small and desired streamer positions are in alignment with the towing direction.

6. The method of claim **1** wherein the towing comprises ending one pass, turning a towing vessel having the streamers attached thereto while throwing out the streamers before beginning another pass, with the control mode in the turn control mode during the turning and throwing out.

7. The method of claim **6** comprising turning during a 3D seismic survey.

8. The method of claim **6** comprising turning during a line change.

9. The method of claim **6** comprising commanding each streamer positioning device to generate a force in an opposite direction of the turning, and then commanding each streamer positioning device to go to a position defined by the feather angle control mode.

10. The method of claim **6** comprising separating adjacent streamers by depth during the turning mode to avoid possible entanglement during the turning.

11. The method of claim **10** comprising returning adjacent streamers to a common depth after the completion of the turning.

12. The method of claim **6** comprising notifying the control system, via a vessel navigation system, when to start throwing the streamers out, and when to start straightening the streamers.

13. The method of claim **1** wherein the control mode is the streamer separation mode, the control system attempting to minimize the risk of entanglement of the streamers.

14. The method of claim **13** comprising the control system attempting to maximize distance between adjacent streamers.

15. The method of claim **13** comprising separating the streamers in depth.

16. The method of claim **15** wherein the array of streamers comprises two streamers, and comprising positioning the two streamers as far away from each other as possible.

17. The method of claim **15** wherein the array of streamers comprises three or more streamers, the array comprising one port-most streamer, one starboard-most streamer and at least one inner streamer and comprising positioning the port-most and starboard-most streamers as far away form each other as possible.

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.

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.

20. The apparatus of claim **19** comprising inputting the feather angle manually.

21. The apparatus of claim **19** comprising inputting the feather angle using an estimated value based on an average of horizontal forces on the streamer positioning devices.

22. The apparatus of claim **19** comprising setting the feather angle to zero when crosscurrent velocity is very small and desired streamer positions are in alignment with the towing direction.

23. The apparatus of claim **18** wherein the towing comprises ending one pass, turning a towing vessel having the streamers attached thereto while throwing out the streamers before beginning another pass, with the control mode in the turn control mode during the turning and throwing out.

24. The apparatus of claim **23** comprising turning during a 3D seismic survey.

25. The apparatus of claim **23** comprising turning during a line change.

26. The apparatus of claim **23** comprising commanding each streamer positioning device to generate a force in an opposite direction of the turning, and then commanding each streamer positioning device to go to a position defined by the feather angle control mode.

27. The apparatus of claim **23** comprising separating adjacent streamers by depth during the turning mode to avoid possible entanglement during the turning.

28. The apparatus of claim **27** comprising returning adjacent streamers to a common depth after the completion of the turning.

29. The apparatus of claim **23** comprising notifying the control system, via a vessel navigation system, when to start throwing the streamers out, and when to start straightening the streamers.

30. The apparatus of claim **18** wherein the control mode is the streamer separation mode, the control system attempting to minimize the risk of entanglement of the streamers.

31. The apparatus of claim **30** comprising the control system attempting to maximize distance between adjacent streamers.

32. The apparatus of claim **30** comprising separating the streamers in depth.

33. The apparatus of claim **32** wherein the array of streamers comprises two streamers, and comprising positioning the two streamers as far away from each other as possible.

34. The apparatus of claim **32** wherein the array of streamers comprises three or more streamers, the array comprising one port-most streamer, one starboard-most streamer and at least one inner streamer and comprising positioning the port-most and starboard-most streamers as far away from each other as possible.

* * * * *

Exhibit F

Statoil

December 18, 2009

U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region
Attention: Mr. Rance Wall, Regional Supervisor
Resource Evaluation
3801 Centerpoint Drive, Suite 500
Anchorage, Alaska 99503-5820

Re: Request for Geological and Geophysical Permit; Statoil USA E&P Inc.; 2010 3D Seismic Acquisition; Chukchi Sea, Alaska

Dear Mr. Wall:

Statoil USA E&P Inc. (Statoil) plans to conduct a three-dimensional (3D) marine seismic survey in the Chukchi Sea during the 2010 open water season using a towed airgun and hydrophone streamer array. Additional stand alone two-dimensional (2D) lines designed to tie into surrounding regional geology and existing well control are a secondary priority. The seismic survey is designed to collect 3D data of the deep sub-surface in the area of Statoil's lease holdings obtained in the Minerals Management Service Outer Continental Shelf Lease Sale 193 in the Chukchi Sea Planning Area. This project is designed to support future oil and gas exploration within the area of coverage. Although data acquisition is expected to take 60 days, all permits will be requested from July 15 to November 30, 2010 to allow for contingencies and weather delays. The proposed seismic survey will be conducted by Fugro-Geoteam, Inc.

Attached please find Statoil's Geological and Geophysical (G&G) Permit Application with supporting documentation as listed below:

- Plan of Operations
  - Figure 1 - Project Area
  - Figure 2 - Seismic Survey Area
  - 3D seismic line layout (proprietary)
- Forms MMS-327 & 328
  - Form MMS-327
  - Form MMS-328
- Figures
  - Figure 1 - Project Area
  - Figure 2 - Project Location
  - Figure 3 - Seismic Survey Area
  - Figure 4 - Preplot (proprietary)
  - Figure 5 - Preplot (proprietary)
  - Figure 6 - Preplot (proprietary)
  - Figure 7 - Preplot (proprietary)
- Receipt for MMS G&G permit application fee (paid through on-line Pay.gov tracking No. 74093223452)

Statoil

The Draft Plan of Cooperation will be submitted under separate cover.

Please contact us if you have questions or need additional Information.

Sincerely,

Martin Cohen
Alaska Exploration Manager
Statoil USA E&P Inc.

Enclosures:

cc: Candace Nachman, National Marine Fisheries Service
Pete Sloan, MMS Resource Evaluation
Jeff Walker, Field Operations Supervisor, MMS
Craig Perham, U.S. Fish and Wildlife Service (USFWS)
Karin Berentsen, HSE and Stakeholder Advisor, Statoil
Sigbjorn Vigeland, Fugro-Geoteam, Inc.
Jon Kare Hovde, Statoil
Caren Mathis, AES
Lisanne Aerts, LGL
AES Project File
Administrative Record

SW/MT/MA

15325-01-09-003/09-136

Statoil

Plan of Operations
2010 3D Seismic Acquisition
Chukchi Sea, Alaska

December 2009

Prepared for

Statoil USA E&P Inc.
2103 CityWest Boulevard, Suite 800
Houston, TX 77042

Prepared by

ASRC Energy Services
a subsidiary of Arctic Slope Regional Corporation
Regulatory and Technical Services

2700 Gambell Street, Suite 200
Anchorage, Alaska 99503

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List of Figures

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ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
cu in	cubic inch
ft	foot/feet
Fugro	Fugro-Geoteam, Inc.
km	kilometer(s)
m	meter(s)
mi	mile(s)
MMO	Marine Mammal Observer
MMS	U.S. Department of the Interior, Minerals Management Service
M/V	marine vessel
NMFS	National Marine Fisheries Service
OCS	Outer Continental Shelf
POC	Plan of Cooperation
SAR	search and rescue
sq km	square kilometer(s)
sq mi	square mile(s)
Statoil	Statoil USA E&P Inc.
USFWS	U.S. Fish and Wildlife Service

1.0 INTRODUCTION

Statoil USA E&P Inc. (Statoil) plans to conduct a three-dimensional (3D) marine seismic survey in the Chukchi Sea approximately 100 miles (mi) northwest of Wainwright during the 2010 open water season using a towed airgun array. Some two-dimensional (2D) lines designed to tie the 3D data to the surrounding regional geology are a secondary priority for the 2010 seismic acquisition. The program is designed to support future oil and gas exploration within the area of coverage.

2.0 PURPOSE

Statoil acquired 16 leases in the Chukchi Sea during Lease Sale 193 held in February 2008. The lease areas in which the proposed 2010 3D seismic survey is planned are located in the Alaskan Chukchi Sea northwest of Wainwright and west of Barrow (Figures 1 and 2).

The purpose of the proposed seismic survey is to collect seismic reflection data to reveal the sub-bottom profile for assessments of petroleum reserves in the area. Ultra-deep 3D lines will be used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types.

Obtaining some stand alone 2D lines that tie the details of high resolution 3D imagery to the surrounding regional geology is a secondary priority. The limited 2D program has been designed to allow the acquisition of useful information in the region.

3.0 PROJECT OVERVIEW

Geophysical data acquisition activities will be conducted by Fugro-Geoteam, Inc. (Fugro), Statoil's seismic contractor. Three vessels – including a seismic vessel and two support vessels will mobilize out of Dutch Harbor, Alaska, to the project area in mid-July 2010, depending upon ice and weather. It is anticipated that transit time to the project area will be roughly five days. Upon arriving at the project area sound source verification measurements will be collected to determine radii for marine mammal monitoring. Data acquisition is expected to take 60 days. Upon completion of data acquisition, all vessels will demobilize to Dutch Harbor. Although data acquisition is expected to take 60 days, all permits will be requested from July 15 to November 30, 2010 to allow for contingencies and weather delays.

3.1 Vessels and Equipment

The vessels involved in the seismic survey activities will consist of the three vessels listed below. Details of these vessels (or equivalent vessels if availability changes) are provided in Appendix A.

- One (1) seismic vessel, the marine vessel (M/V) *Geo Celtic* or similar equipped vessel, towing a 3,000 cubic inch (cu in) airgun array of airgun and hydrophone streamers for data acquisition
- One (1) support/environmental monitoring vessel, the M/V *Thor Alpha* or similarly equipped vessel for marine mammal monitoring, support, and supply duties
- One (1) support/environmental monitoring/crew transfer vessel, the seismic support vessel *Gulf Provider* or similarly equipped boat for marine mammal monitoring, crew transfer, support, and supply duties.

Vessel duties will be under the supervision of the Master on M/V *Geo Celtic*. Changes will be made to adjust to the operational requirements.

Either the M/V *Thor Alpha* or seismic support vessel *Gulf Provider* will be available for deployment and retrieval of acoustic recorders for sound source verification measurements. Vessel photographs and equipment specifications are presented in Appendix A.

3.2 Operations Information

The seismic source vessel and support vessels will be self-contained and the crew will live aboard the vessels. Crew changes are planned to be conducted primarily by boat at least once during the project. Nome will be the main port for resupply and crew changes during the survey. Emergencies will be covered by a search and rescue (SAR) helicopter stationed in Barrow. However, if necessary, personnel or equipment may be transferred through Barrow or Wainwright in case of emergency or other unforeseen circumstances.

Refueling is anticipated to take place at Nome, though it is possible that fuel re-supply could occur at sea if necessary. Helicopter operations are not planned as a part of the seismic survey, although it is possible that individuals could be transported to and from vessels via helicopter. In general, helicopter operations are expected to occur only in the case of an emergency.

Marine mammal observers (MMOs) will be located on the bridge or weatherdecks of M/V *Geo Celtic* to watch for marine mammals during the transit to the survey area, seismic data acquisition, and transit back to Dutch Harbor. One or more support/environmental monitoring vessels will be used to protect the streamers from damage; for supply; and for monitoring activities, as required. All support/environmental monitoring vessels will have MMOs onboard and will be responsible for marine mammal monitoring and mitigation as required by permit stipulations. Support/environmental monitoring vessels will not be introducing sounds into the water beyond those associated with normal vessel operations.

4.0 PROJECT DETAILS

4.1 3D Seismic Survey

The 3D data acquisition will use a towed airgun array consisting of 26 active airguns with a maximum discharge volume of 3,000 cu in. The survey area has been reduced to the maximum extent possible and covers 2,368 square kilometers (sq km) area (915 square miles [sq mi]).

The M/V *Geo Celtic* has two identical airgun three-string arrays. The arrays will be discharged in an alternating mode, starting with the starboard array. The port array will be discharged eight seconds later (18.75 meters (m) [61.52 feet (ft)] along the line), and then the pattern repeats. The array will consist of 26 (plus 10 spare) Soldera G-guns (four 60 cu in, eight 70 cu in, six 100 cu in, four 150 cu in, and four 250 cu in) with a total discharge volume of 3,000 cu in. One of the smallest guns in the array (60 cu in) will be used as the mitigation gun. The airgun array will be towed at 6 m (20 ft) depth and at a distance of roughly 275 m (900 ft) behind the vessel. More details of the airgun array are the sound signature are described in Appendix B.

The vessel will travel along pre-determined lines at between 4 knots to 5 knots while the airgun array discharges at 8 second intervals (shot interval 18.75 m [61.5 ft]). The hydrophone streamer array will consist of twelve streamers of up to 4,050 m (2.5 mi) in length, with a total of 20,000 to 25,000 hydrophones spaced 2 m (6.5 ft) apart. This large hydrophone streamer receiver array is designed to maximize efficiency, minimize the number of source points, and to minimize environmental effects. The hydrophones will receive the reflected signals from the airgun array and transfer the data to an on-board processing system. A several pinger (ION DigiRANGEII acoustic) system will be used to position the streamer relative to the vessel.

The entire 3D seismic survey program will consist of 5,000 km (3,100 mi) of production line, not including transits. 3D seismic line layout scenarios are provided in Appendix C. Water depth within the survey area is roughly 30 m to 50 m (100 ft to 165 ft).

4.2 2D Seismic Survey

The 2D data acquisition will be dependent upon the 2010 open water season's weather conditions and ice coverage. Obtaining 2D seismic data is a secondary priority. 2D seismic survey data will be obtained if ice conditions restrict access to the 3D seismic survey area or if 3D seismic survey data acquisition progresses better than anticipated.

A maximum of four 2D survey lines will be collected and 2D data acquisition will not exceed 675 linear km (420 mi). 2D data acquisition will use the same vessel, airgun array, and streamer configuration as used for the 3D data acquisition. The vessel will travel along pre-determined lines at 4 knots to 5 knots while the airgun array discharges at 8 second intervals (shot interval 18.75 m [61.5 ft]).

4.3 Project Location

The proposed 3D marine survey will be conducted in the Chukchi Sea in the area of Statoil lease holdings obtained in U.S. Department of the Interior, Minerals Management Service (MMS) Outer Continental Shelf (OCS) Lease Sale 193. The lease areas are located approximately 160 km (100 mi) northwest of Wainwright and 240 km (150 mi) west of Barrow in the Alaskan Chukchi Sea (Figures 1 and 2). The 3D marine survey will take place within a 2,385 sq km (915 sq mi) area, minimum of 145 km (90 mi). The water depth in the survey area varies from 30 m to 50 m (100 ft to 165 ft). 2D survey activities will take place a minimum of 72 km (45 mi) off the coast.

4.4 Project Timeline

Statoil plans to conduct the marine seismic survey between July 15 and November 30, 2010, ice and weather permitting. Project vessels, including the source vessel and all support vessels, will arrive in Dutch Harbor by mid-July 2010. The vessels will be supplied, and the crew, including MMOs, will board at this port. Depending on ice conditions, the vessels will depart Dutch Harbor about mid- to late July and travel to the Chukchi Sea survey area. The anticipated transit time is five days (weather depending).

Upon arrival in the survey area, the source vessel will deploy the airgun array and hydrophone streamers and start operating their guns for the purpose of sound source verification measurements as required by permit stipulations. Data acquisition will take place as soon as possible. Seismic data acquisition is expected to continue for 60 days and be completed in the first half of October, weather depending. This includes seismic data acquisition and anticipated downtime. Data acquisition is expected to occur 24-hours per day. Upon completion of data acquisition, project vessels will demobilize to Dutch Harbor.

5.0 STAKEHOLDER ENGAGEMENT

Statoil intends to maintain an open and transparent process with all stakeholders throughout the life-cycle of activities in the Chukchi Sea. Statoil began the stakeholder engagement process in 2009 with meetings with Chukchi Sea community leaders at the tribal, city, and corporate level. Statoil will continue to engage with leaders, community members, and subsistence groups (as well as local, state, and federal regulatory agencies) throughout the exploration process.

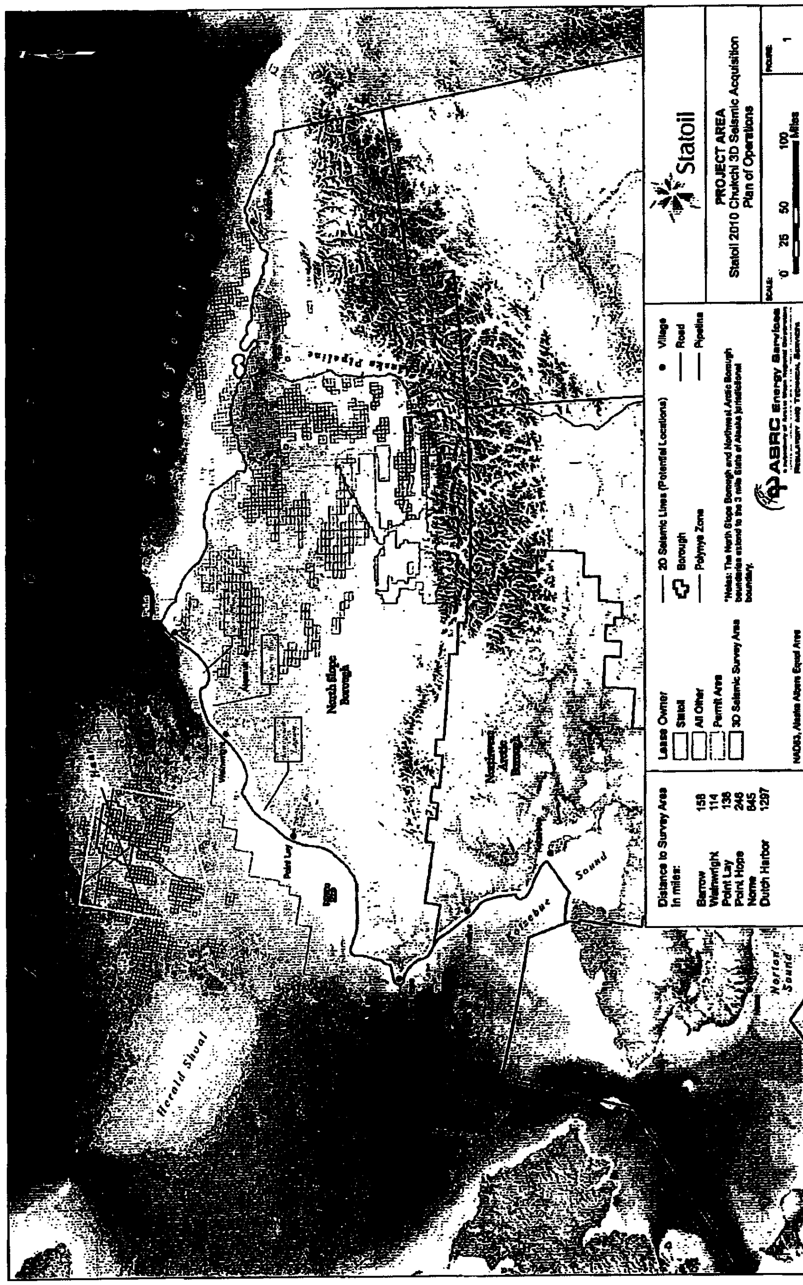
As part of stakeholder engagement, Statoil is developing a Plan of Cooperation (POC) for the proposed 2010 3D seismic acquisition. The POC identifies the actions Statoil will take to identify important subsistence activities, inform subsistence users of the proposed survey activities, and obtain feedback from subsistence users regarding how to provide cooperation between subsistence activities and the Statoil program.

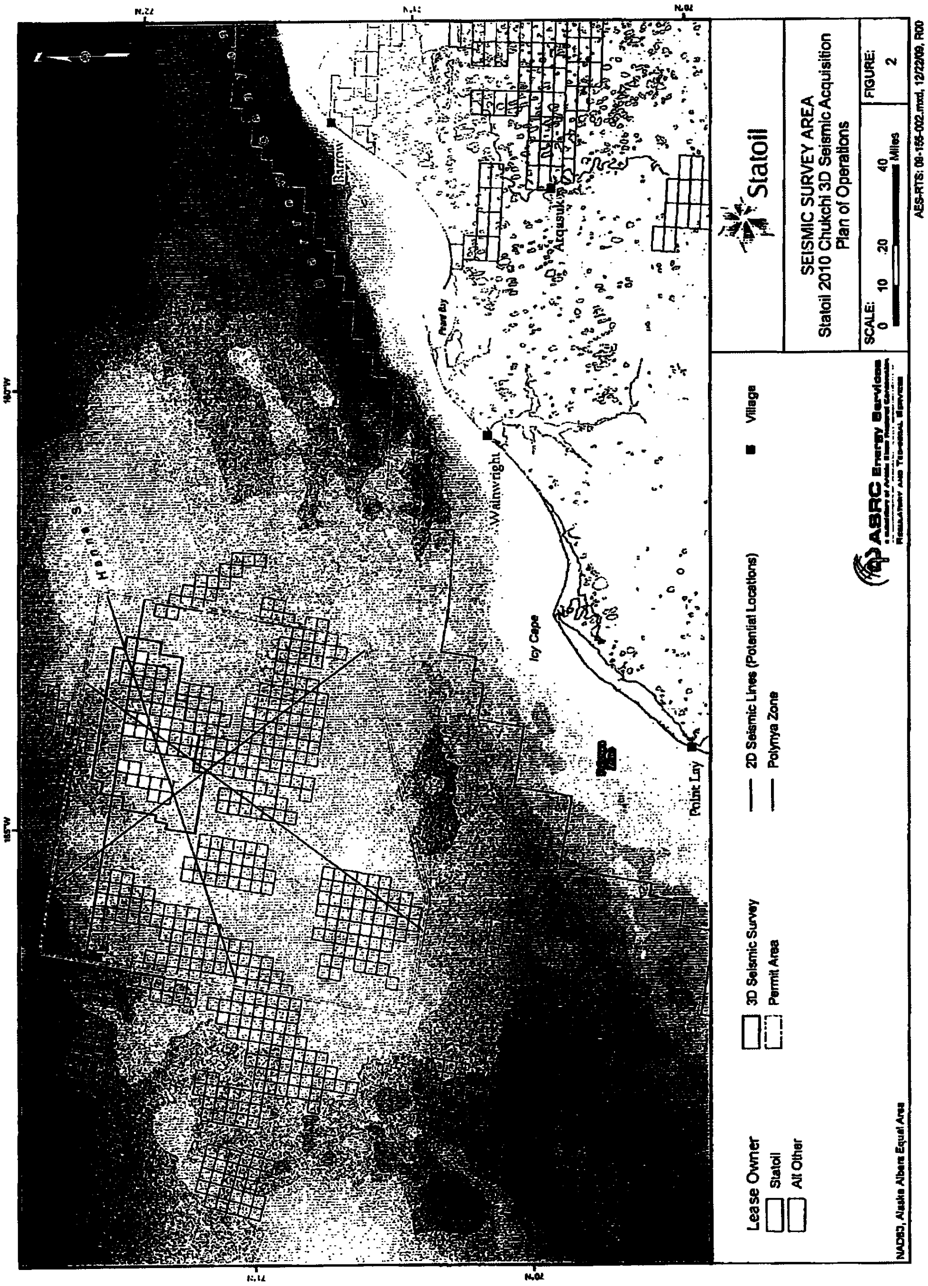
A POC is required to comply with OCS Lease Sale 193 stipulations (Stipulation No. 5) and federal regulatory requirements [50 CFR 216.104(a)(12)ii)]. The POC also fulfills the requirements of three major federal permits: the National Marine Fisheries Service (NMFS) Incidental Harassment Authorization, the U.S. Fish and Wildlife Service (USFWS) Letter of Authorization, and the MMS Geophysical and Geological permit.

Statoil met with leadership from the communities of Barrow, Wainwright, Point Lay, Point Hope, and Kotzebue during the last week of October and the first week of November 2009. Statoil met with leaders both in small groups and a one-on-one basis. These meetings enabled Statoil to introduce themselves and the 2010 3D marine seismic acquisition program to community leaders and to discuss local concerns regarding subsistence activities, timing of operations, and local hire and workforce development.

Based upon these meetings, a draft POC document is being developed. Upon completion, the draft POC will be submitted to each member of the leadership Statoil met with during their October/November leadership meetings as well as a few other community members. Statoil will also submit the draft POC to NMFS, USFWS, and MMS as part of the permit application process. Public POC meetings will be held in January in the communities of Barrow, Point Hope, Point Lay, and Wainwright to obtain input from the general public and individual subsistence hunters within these communities.

A final POC that documents all consultations with community leadership, subsistence users groups, individual subsistence users, and community members will be submitted to NMFS, USFWS, and MMS upon completion of consultation. The final POC will include feedback from the leadership meetings and POC meetings. Statoil will continue to document all consultation with the communities and subsistence stakeholders.

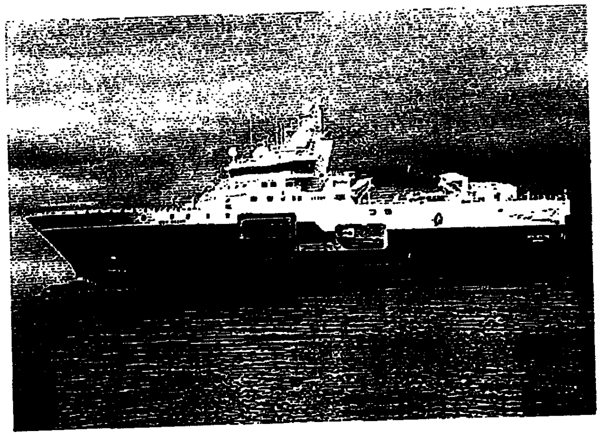

Herald Shoal
Point Lay
North Slope Borough
Northwest Arctic Borough
Alaska Pipeline
Kotzebue Sound
Norton Sound
Distance to Survey Area in miles:
Barrow 158
Wainwright 114
Point Lay 138
Point Hope 246
Nome 645
Dutch Harbor 1297
Lease Owner
Statoil
All Other
Permit Area
3D Seismic Survey Area
2D Seismic Lines (Potential Locations)
Borough
Polynya Zone
Village
Road
Pipeline
*Notes: The North Slope Borough and Northwest Arctic Borough boundaries extend to the 3 mile State of Alaska jurisdictional boundary.
NAD83, Alaska Albers Equal Area
ABRC Energy Services
Regulatory and Technical Services
Statoil
PROJECT AREA
Statoil 2010 Chukchi 3D Seismic Acquisition
Plan of Operations
SCALE:
0 25 50 100
Miles
FIGURE:
1


Barrow
Atqasuk
Peard Bay
Wainwright
Icy Cape
Point Lay
Lease Owner
Statoil
All Other
3D Seismic Survey
Permit Area
2D Seismic Lines (Potential Locations)
Polynya Zone
Village
Statoil
SEISMIC SURVEY AREA
Statoil 2010 Chukchi 3D Seismic Acquisition
Plan of Operations
SCALE:
0 10 20 40
Miles
FIGURE:
2
ASRC Energy Services
NAD83, Alaska Albers Equal Area

APPENDIX A

Vessel Specifications

FUGRO



M/V GEO CELTIC

TECHNICAL SPECIFICATIONS

FUGRO

CONTENTS

FUGRO

1. VESSEL

1.1. VESSEL GENERAL

Name	M/V Geo Celtic
Operator	Fugro-Geoteam AS
Owner	E Forland AS
Seismic Management	Fugro Norway Marine Services AS
Maritime Management	E Forland AS
Type	3D seismic survey vessel
Port of registration	Bergen, Norway
Flag	Norwegian
Class	DNV = 1A1 ICE-C SF COMF-V(3)C(3) HELDK-SH RP E0 CLEAN DK
Class registration no.	D26988
Call sign	LAKF6
IMO	9376995
MMSI	258966000
Year built/rebuilt	2006/2007
Length overall	100.80 m
Breadth moulded	24 m
Breadth maximum	28 m
Draught, loaded	7.5 m
Tonnage	12109 gross tons, 3633 net tons
Cruising speed	16.0 knots
Operation range	World wide
Endurance seismic days max load	60 days
Main engine	4 x generating set continues engine rating MCR 3780 kW 750 RPM (660 V, 3-phase, 60 Hz)
Gearbox	2 x reduction gear boxes, low noise type for driving C.P. propellers
Propulsion	2 x C.P. propellers of low noise design. Fixed nozzle
Rudder	2 x free hanging type with rope-guard fitted in lower end
Steering gear	2 x Rolls-Royce
Azimuth thruster	1 x retractable, 1500kW with complete electric AC drive
Bow thrusters	1 x fixed pitch, 1200 kW with complete electric AC drive.
Stem thruster	None
Main engine monitoring	Kongsberg-Simrad IAS
Electrical power	690V 60 Hz 3ph, 220V 50 Hz 1ph
Emergency generator	1 x 575 kW
Clean power	100 kW UPS
Fuel capacity	HFO capacity 1825 m^3
Fuel consumption	40 tons per day
Fresh water capacity	257 m^3
Fresh water consumption	15 tons per day
Fresh water generator	2 off FW generators with capacity 15 ton/day
Sewage treatment plant	Yes; for 69 persons
Incinerator	Yes; for 69 persons
Black water	Holding tank cap 32 m^3

Grey water	Holding tank cap 29 m^3
Bilge water	Bilge water separator with 3 m^3/h capacity
Sludge	Holding tank cap 33 m^3
Dirty oil	Holding tank cap 13 m^3
Stabilising system	2 off passive anti-rolling tanks
Deck machinery	
Crane	1 x 5 ton SWL, 16 m knuckle arm handling crane on hangar deck aft cl. 1 x 10 ton SWL, 16 m knuckle arm handling crane on hangar deck stb. 1 x 10 ton SWL, 16 m knuckle arm handling crane on hangar deck ps.
Source handling beams	2 x Odim gun booms with el. drive
Streamer winch	5 x Odim double streamer winch with el. drive 2 x Odim double streamer winch with PF: 12T BF 33 outer & el. drive
Lead-in winch	None
Storage winch	5 x Odim storage winch with el. drive
Spread rope winch	4 x Odim with el. drive
Source winch	8 x Odim capacity 800 m cable, el. drive
Wide-tow winch	2 x Odim wide tow winch 60 ton pulling
Auxiliary winch	5 x Auxiliary winches with el. drive
Drum handling	Electric/hydraulic drum spooling rack
Tow points	12 towing points with blocks
Wide tow shock absorbers	2 x Vestdavit 160 ton
Paravane	Barovane 48
Paravane handling	Odim handling davit
Transverse towing point	2 x Odim 5 ton winches
Hydraulic power pack	Dimo 2 x 305 l/min @ 250 bar
Accommodation	For 69 persons+hospital. All cabins with separate toilets/showers. Some cabins with radio/cd player and some with IMac CD/DVD player
Galley store	Facilities for 70 persons
Mess	Seating for 60 persons
Day rooms	Lounges for smokers and non-smokers with seating for 65 persons
Exercise room	Large exercise room with saunas
Air condition	Air condition with chilled water system for world wide conditions
Helicopter landing zone	Dimensioned and arranged for the operation of Sikorsky S61 helicopters. Deck to be arranged and equipped according to CAA rules CAP 437 / ICAO requirements

1.2. VESSEL NAVIGATION AIDS

Auto pilot	Kongsberg cJoy
DGPS	Furuno
Differential GPS	Furuno
Radar no. 1	Furuno 10 cm ARPA-radar with daylight monitor. Antenna with built-in transmitter
Radar no. 2	Furuno 3 cm ARPA-radar with daylight- and performance monitor. Antenna with built-in transmitter
Gyros	SG Brown Meridian Surveyor with • 1 x digital gyro repeater auto pilot, • 2 x digital gyro repeaters for mounting in bridge wing consoles • 1 x steering repeater • 1 x digital gyro repeater for each steering gear room • 1 x class A magnetic compass • Binnacle, reflector compass, azimuth device, straight vertical reflection tube and hood
Speed log	Furuno DS 80 2-axis doppler log
VHF direction finder	Helicopter beacon
Wind sensor	Seatex 100 HMS
Navigation echo sounder	Furuno FE 700
Electronic chart	TECDIS
Navtex	Furuno
Weather fax	Furuno

1.3. VESSEL COMMUNICATION

GMDSS	Furuno FS-2570 / 1570
Inmarsat C	2 x Furuno
Inmarsat B	Sailor
NorSat	Telenor
M/F and H/F	Furuno
VHF stationary	VHF radio, Icom IC-M401E
VHF portable	VHF radio, Entel HT640
UHF portable	UHF radio, Entel HT780
VHF helicopter communication	1 x VHF/AM 1 x portable VHF/AM with headset
Helicopter non-directional beacon	410 kHz helicopter beacon
Internal communication	PABX telephone system with 120 lines
Telephone numbers	
Inmarsat bridge	+871 600 859066
NorSat bridge	+47 23 25 42 91
NorSat captain office	+47 23 25 42 95
NorSat party chief	+47 23 25 42 92
NorSat client office	+47 23 25 42 97
Fax numbers	
Bridge	+47 23 25 42 90
Internet access via NorSat	
E-mail addresses	
Captain	geoceltic-captain@forlandship.no
Party chief	pc@celtic.fugro.geoteam.no
Client	client1@celtic.fugro.geoteam.no.

FUGRO

1.4. VESSEL SAFETY

Safety manning level	69
Covered lifeboat	2 x 90 persons, one each side
Rescue / FRC	750 Magnum
Workboat / MOB boat	1 MOB boat, fast rescue craft, 7 m long, 200 HP inboard engine and water jet drive. 1 x 9.6 m Westplast workboat, twin water jets, twin streamer winches
Inflatable life rafts	3 x 25 persons
Man overboard life raft	JonBuoy (1 man) with remote release
Survival suits	73 pcs Helly Hansen
Life jackets	73
Life rings	18
Smoke hoods	Draeger "Parat C"
Work vest	Crewsaver 275N
Emergency radios	Jotron TR20
EPIRB	Jotron 45SX
Radar transponders	Jotron Tron SART
Fire detection system	Eltek
Fire pumps	3
Fire suits	4+spares
Halon systems	No
Argonite	Yes
CO2 systems	Yes
Foam deluge system	Yes, in engine room
Lg. portable foam extinguishers	Yes

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2. SEISMIC

2.1. SEISMIC RECORDING INSTRUMENT

Type	Sercel Seal, 24 bit digital system
Number of channels	8000
Number of waterbreaks	1 pr. streamer (in HESA Section)
Auxiliary channels	36 channels
Sample rate	¼, ½, 1, 2 and 4 ms
Filters	
Low cut	3 Hz analogue 6 dB/octave plus configurable digital low cut (between 2.5 Hz and 15 Hz @ 6dB/octave). Combined filter slope 12 dB/octave
High cut	Depending on sample rate 0.8 Nyquist @ 370dB/octave linear or min phase
Recording format	SEGD 8058 or 8036
Recording medium	IBM 3592
Raid system	Argus by Profocus
QC system	Argus by Profocus
On-line display	Argus by Profocus
Single channel recorder	Argus by Profocus

2.2. STREAMERS

Type	Sercel Sentinel solid streamer
Length	12 x 6000 m Max 1000 channels pr. streamer @ 2ms sampling
Available group interval	12.5 m
Section length	150 m
Groups pr. section	12
Hydrophone type	Sercel Flexible Hydrophone
No. of hydrophones/group	8
Streamer diameter	59.5mm
Streamer sensitivity	19.73 V/Bar @ 22°C
Fault locator	Sercel Seal Digital System
Compasses	ION Model 5011 Compass Bird
Streamer control	ION DigiFIN ION Model 5011 Compass Bird
Acoustics	ION DigiRANGE II

2.3. ENERGY SOURCE

Type	Sodera G-Gun
Size of guns	Up to 250 cu. Inch
Typical volume	Single source up to 9000 cu. inch Dual source up to 5100 cu. Inch
Maximum output @6 m, 0-206 Hz	
Number of sub-arrays	2 x 3 sub-arrays
Configuration	Single source or dual source
Tow width	Typically 10 m between sub-arrays
Firing control	Seamap GunLink 4000 Digital Gun Controller
QC	Seamap GunLink 4000 Digital Gun Controller
Depth transducers	Seamap Digital, Integrated on GFSM Module
Tow system	Sercel rigid gun floats. Self deflecting
Offset	< 600m from stern of ship
Compressor	3 x LMF high pressure compressor units, each 1700 SCFM
Compressor capacity	48 m^3
Air pressure	138 bar = 2000 psig as well as 207 bar = 3000 psig

FUGRO

2.4. NAVIGATION EQUIPMENT

On-line navigation system	Concept Systems Orca
Primary navigation	Fugro Skyfix-XP DGPS
Demodulator	Fugro 4100LRS
GPS receiver	Fugro SPM2000 with internal Novatel
Secondary navigation	Fugro Starfix.HP DGPS with SPM software
Demodulator	Fugro 4100LRS
GPS receiver	Fugro SPM2000 with internal Novatel
Tailbuoy tracking	Kongsberg Seatex Seatrack 220 RGPS
Gun array tracking	Kongsberg Seatex Seatrack 320 RGPS
Gyro	2 x SG Brown Meridian Surveyor
GPS azimuth	Applanix POS MV 320
Motion sensor	Applanix POS MV 320
Echosounder	Kongsberg Simrad EA600
Echosounder transducers	12, 38, 200 kHz
Acoustic doppler profiler	RDI ADCP Mariner 600kHz type Workhorse
SVP/CTD probe	Valeport Midas SVX2
Moving vessel profiler	Odim MVP300-3400
Streamer mounted speed log	ION Model 7500 Speed Log
Streamer mounted velocity meter	ION Model 7000 Velocimeter
Streamer positioning	ION Model 5011 Compass Bird
	ION DigiRANGEII acoustics:
	Up to 180 x CMX unit
	2 x CTX transducer flanged - hull
	6 x CTX pinger towed - gun
Navigation processing	Concept Systems Sprint
	Concept Systems NRT
Binning	Concept Systems Reflex

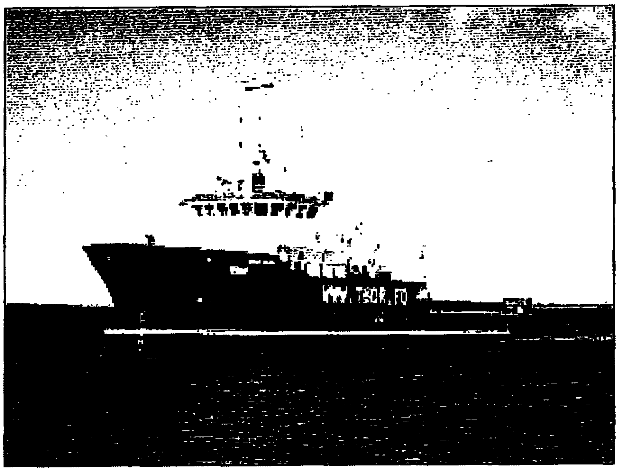
2.5. ONBOARD PROCESSING

Hardware	16 x 2 Quad Core CPU nodes HP BLc7000 Linux cluster (total 128 CPUs), 16 GB RAM per node 2 HP Proliant DL580G4 servers on Linux, 4 x dual core CPUs, 16 GB RAM per server 3 x dual monitor HP xw6400 work stations 44 TB disk space
Software	Paradigm Focus 5.4 FSI Uniseis 0804 64 bit and 32 bit RedHat Enterprise 4 Linux
Capabilities	Full 3D QC processing, fast track full fold cube at acquisition speed
Tape drives	4 x IBM Magstar 3590E 4 x IBM Jaguar-2 3592
Plotters	HP 1050C A0 plotter OYO GS 36" thermal plotter
Data compression software	Aware Seispact v 3.61

Fugro-Geoteam AS, P.O. Box 490 Skøyen, 0213 Oslo, Norway. Tel:+ 47 22 13 46 00
E-mail: geoteam@fugro.geoteam.no Web page: www.fugro.geoteam.no

FUGRO

FUGRO-GEOTEAM



"M/V Thor Alpha"

TECHNICAL SPECIFICATIONS

FUGRO

FUGRO-GEOTEAM AS

General Information	
Name	M/V Thor Alpha
Call sign	OZ 2070
Flag	Faroese
Class	DNV + 1A1 E0 SF
IMO no.	9458559
Built	2008
Length overall	55,10 m
Length bp.	50,56 m
Breath moulded	12,50 m
Depth boat deck	8,00 m
Depth main deck	5,50 m
Gross tonnage, 1969	1051 GT
Net tonnage, 1969	315 NT
Deadweight	1600 ton
Light ship weight	700 ton
Draught	4.85 m
Speed	13 knots
Speed water jet	4,5 knots
Accommodation (crew)	6 persons
Berths for passengers	10 persons
Sleeping seats	34 persons
Machinery/Diesel-electric:	
Generators	Nordhavn GASI 16-07 4 x 440 kw / 1800 o/min 3 x 440 Volt 60 Hz
Engines	Scania Type DI16 44M – 469 kw
Propulsion	
Azimuth	2 x Rolls-Royce, Aquamaster
Type	US 105 CRP
Power	2 x 650 KW
Bollard pull	19,3 ton

FUGRO

FUGRO-GEOTEAM AS

Pump Jet	
Type	Schottel, SPJ 82 SD
Power	1 x 360 KW
Thrust	2,5 ton
Cargo Discharge Pump	
Cargo pumps	2 x 120 m^2 / 15 m hight
Capacities	
Heavy fuel oil	992 m^3
Diesel oil	556 m^3
Fresh Water	69 m^3
Cargo on deck	320 m^2 / 100 ton
Sludge tank on deck	Tank for seismic sludge
Cargo hold on deck	31 m^2 cooling room
	22 m^2 freezing room
Deck Equipment	
Deck crane	ABAS
Type	5 ton SWL 1,8 – 16 m
Rope winch	1,5 ton
capstan	4 x 5 ton
Anchor winches	2
Towing hook	30 ton
Davits	1 pc Vestdavit PLR-10002 for workboat – SWL 10000 kg
	1 pc Vestdavit PL – 1500 for rescueboat – SWL 1500 kg
Rescue Boat:	
Norsafe MIDGET 530 MK II Diesel Jet Rescue Boat	
Capacity	6 persons
Standard	72 Hp inboard diesel engine with waterjet propulsion
Pumps	
Fuel Oil	2 x 120 m^3 / hour
Fresh water	1 x 50 m^3 / hour

FUGRO

FUGRO-GEOTEAM AS

A3 GMDSS – Equipment:
Furuno FS-1570 150W MF/HF SSB Transceiver
Furuno FM-8800S VHF-DSC Transceiver
Radio Ocean RO 4700 VHF Transceiver
Furuno NX-700-B Navtex Receiver
Furuno Felcom-15 Inmarsat-C
SSAS UPG for Furuno Felcom-15
McMurdo E-5-A EPIRB
McMurdo E-5-M EPIRB
McMurdo G4 SART
McMurdo R-2 portable GMDSS VHF Transceiver

2 pc. Furuno Radar:
FAR-2137S/IMO S-band 30 kW with 12 fot antenna
FAR-2117/IMO X-band 12 kW with 6.5 fot antenna

Echosounder and Speed-log:
Furuno FE-700/200 IMO
Furuno DS-80 speed-log

Navigation:
Furuno FA-150 AIS Transceiver
Furuno GP-150 GPS- Professional navigator
MaxSea Commander software
MaxSea tracking-modul for Arpa og AIS-traget
Computer for MaxSea
Gyro / Autopilot and Bridge-Alarm:
Anschuetz Standard 22 Gyro-compass
Anschuetz Digital Autopilot Pilotstar D
Furuno SC-110 Satellite-compass
RD-30 Remote display
UniSafe Bridge-alarm

Communication:
Emergency communication system wheelhouse / engine
Communication system round the ship
Telular SX5D gsm-phone with telefax
Icom portable UHF-transceiver
Safety helmet, with Peltor head-set

Camera and Sound Signal Reception System + Wind Sensor:
Camera monitoring system thruster room and deck
Vingtor VSS-111 sound signal reception system
RO-wind sensor

Safety Equipment:

Liferafts	Viking 25 DK SOLAS – 6 x 25 persons
Life-jackets	Merman 16 A SOLAS – 104 pcs
Immersion suits	Viking PS 5002 SOLAS – 54 pcs

FRC Safety Equipment:

FRC working suits	PS 5041 SOLAS – 3 pcs
Inflatable life-jackets	PV 9308 SOLAS – 3 pcs
Jofa 390 R helmets	3 pcs

Communication:

Telephone	+44 20 78 58 56 99 SevSat
Telephone	+871 764 812 338 Mini-M
E-mail	thoralpha@thor.fo
E-mail	bridge.thoralpha@skyfile.com

190' SSV

GULF FLEET

Gulf Provider

gulffleet.com

Gulf Provider

MAIN PARTICULARS

LENGTH OVERALL	190 ft	57.9 m
BEAM	38 ft	11.58 m
DEPTH	14 ft	4.27 m
LOADED DRAFT	12.33 ft	3.76 m
LIGHTSHIP	824.57 LT	838 MT

CAPACITIES

BALLAST	66,050 USG	250 m³
FUEL	161,162 USG	610 m³
POTABLE WATER	26,9481 USG	102 m³

SERVICE EQUIPMENT

DECK CRANE #1	Seattle Crane MCF-493 2755 lbs. 1250 kg
INCEINERATOR	Elastek Smart Ash
WATERMAKERS	(2) Sea Recover SC800 800 USG/Day 3.03 m³/Day Reverse Osmosis
REFRIGERATED CONTAINERS	(2) 8 ft/2.44 m x 20 ft/6.1m
DRY CONTAINER	8 ft/2.44 m x 20 ft/6.1m
STREAMER REEL	6000 m
SMALL FENDERS	(4) 7 ft/2.13 m x 5 ft/1.52 m
LARGE FENDER	12 ft/3.66 m x 7 ft/2.13 m
BUNKER HOSE with Dry Break	4 in/10.16 cm x 100 ft/30.48 m

TONNAGE

	USA	ITC
GRT	367	926
NRT	277	

MACHINERY

MAIN ENGINES	(2) Caterpillar D399 @ 1250 BHP
REDUCTION GEARS	Reintjes WGV481
GEAR RATIO	4.22:1
GENSETS	(2) Caterpillar 3406 @ 315 KW
PROPELLERS	78 x 72 Stainless Steel 4-Blade
RUDDERS	Spade Type

PERFORMANCE

MAXIMUM SPEED	12 Knots	
CRUISING SPEED	10 Knots	
MAXIMUM FUEL CONSUMPTION	110 USG/Hr.	10 m³/Day
CRUISING FUEL CONSUMPTION	77 USG/Hr.	7 m³/Day

DISCHARGE RATES

	GPM	@ FT	M³/min	@ M
FUEL	500	100	1.9	30
POTABLE WATER	420	100	1.6	30

ACCOMMODATIONS

CABINS/BERTHS	16/52
EXERCISE ROOM	Exercise Machine & Weights
LOUNGE	10
MESS	22
CERTIFIED TO CARRY	60

ELECTRONICS

RADARS	(1) Furuno FR-1525 MK III & (1) Furuno FR-2125-ARPA
GPS	(1) Garmin GP-80 & (1) Garmin GP-90D
GYRO COMPASS	Tokimec GM21
AUTOPILOT	Sperry GyroPilot
WEATHER FAX	Furuno FAX-108
NAVTEX	Furuno NX-500
RADAR TRANSPONDER	(2) Tron SART
SSB	Furuno FS-1562-15
GMDSS	Furuno Felcom-15 Inmarsat C w/ Furuno DP-6 NBD
VHF	(2) Furuno FM-8500
AIS	Bridgemate MT
FAX	Brother Intellifax 775
COPIER	Brother MFC-7820N
SHIP SECURITY ALERT	Satamatics SAT-101
E-MAIL & COMMUNICATIONS	Nera Mini-M & Iridium (Client & Crew Addressing Available)

DOCUMENTATION

CLASS	ABS A1+AMS+Load Line; SOLAS-MARPOL
FLAG	Panama
OFFICIAL NUMBER	22269-95-C
CLASS NUMBER	77901855
YEAR BUILT/REBUILT	1979/2003
BUILDER	Zigler Shipyard, Inc. Jennings, LA

NOTICE: The data contained herein is provided for convenience of reference to allow users to determine the suitability of the Company's equipment. The data may vary from the current condition of equipment which can only be determined by physical inspection. Company has exercised due diligence to insure that the data contained herein is reasonably accurate. However, Company does not warrant the accuracy or completeness of the data. In no event shall Company be liable for any damages whatsoever arising out of the use or inability to use the data contained herein.

GULF FLEET HOLDINGS
2623 SE Evangeline Thwy Lafayette, LA 70508 • P.O. Box 80707 Lafayette, LA 70598-0707
Office 337-210-2600 • Fax 337-210-1648 • Toll Free 866-857-9900

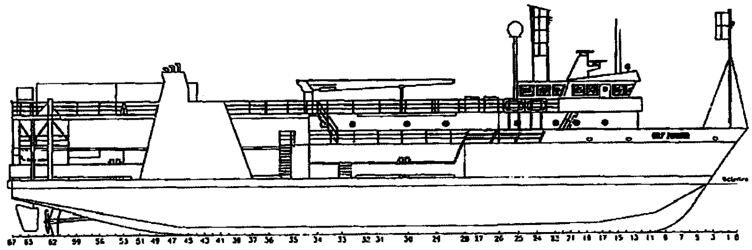
190' SSV

GULF FLEET

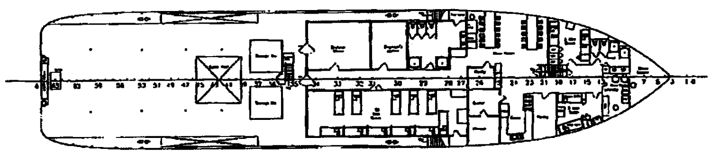
Gulf Provider

gulffleet.com

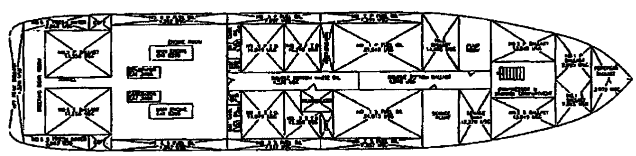
Gulf Provider

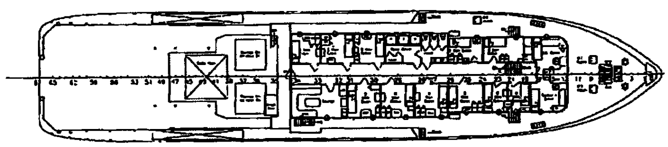


PROFILE

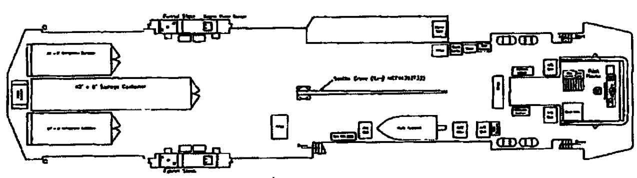


MAIN DECK





FORECASTLE DECK



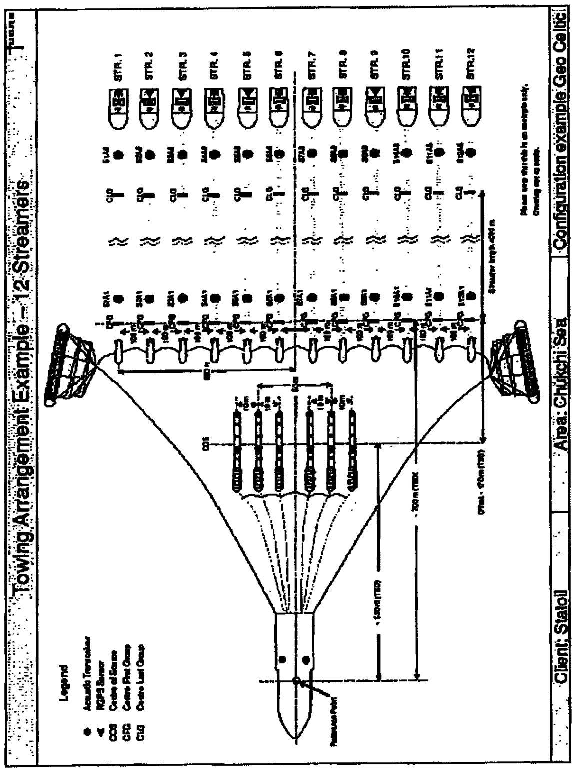
PILOT HOUSE/UPPER DECK

GULF FLEET HOLDINGS
2623 SE Evangeline Thwy Lafayette, LA 70508 • P.O. Box 80707 Lafayette, LA 70598-0707
Office 337-210-2600 • Fax 337-210-1648 • Toll Free 866-857-9900

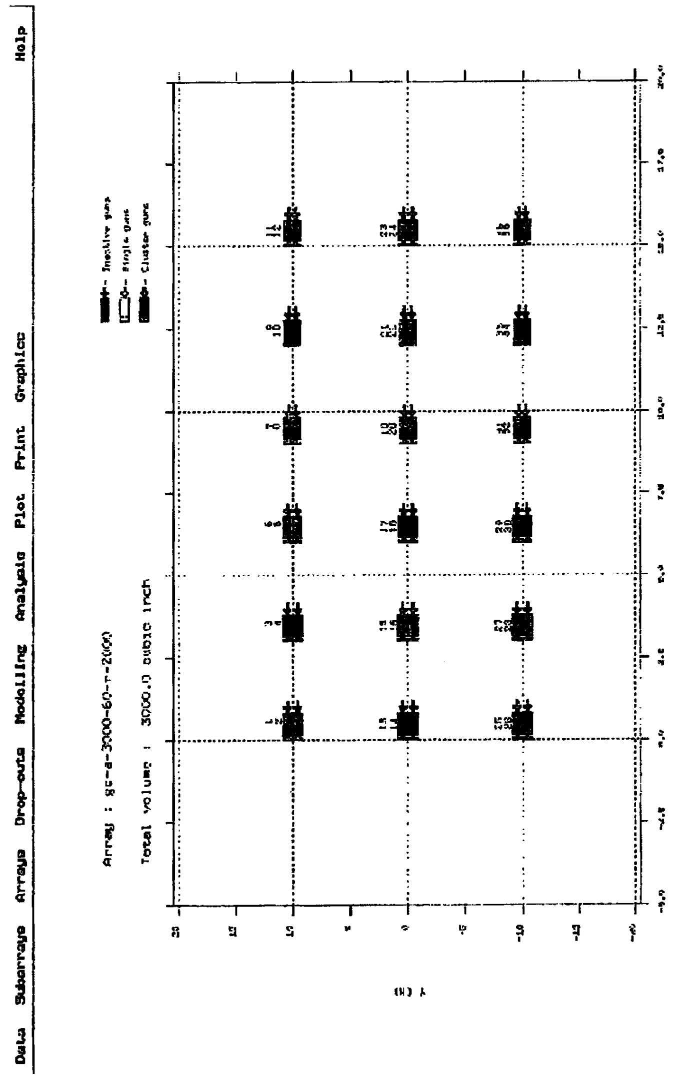
APPENDIX B

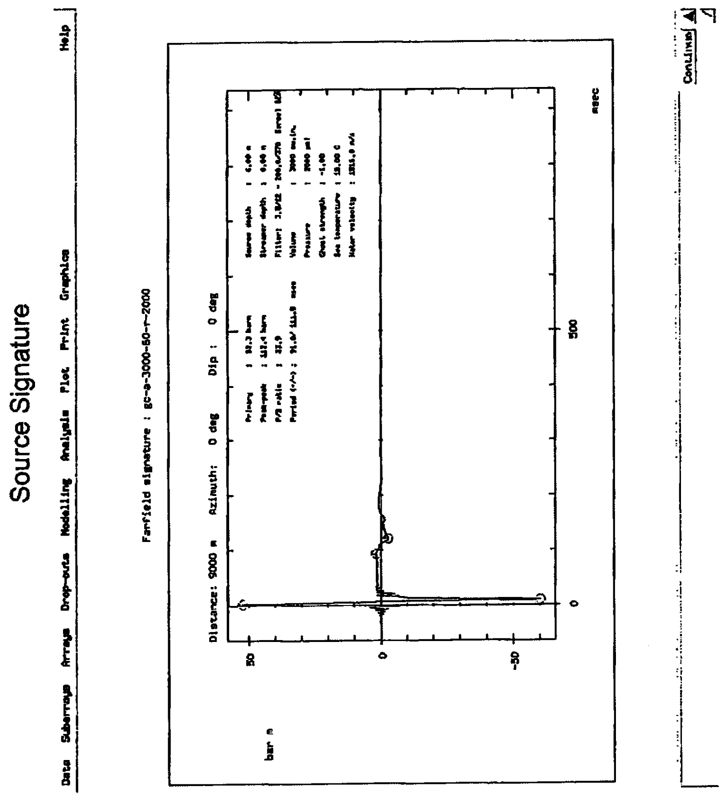
Signature and Acoustic Radiation Patterns

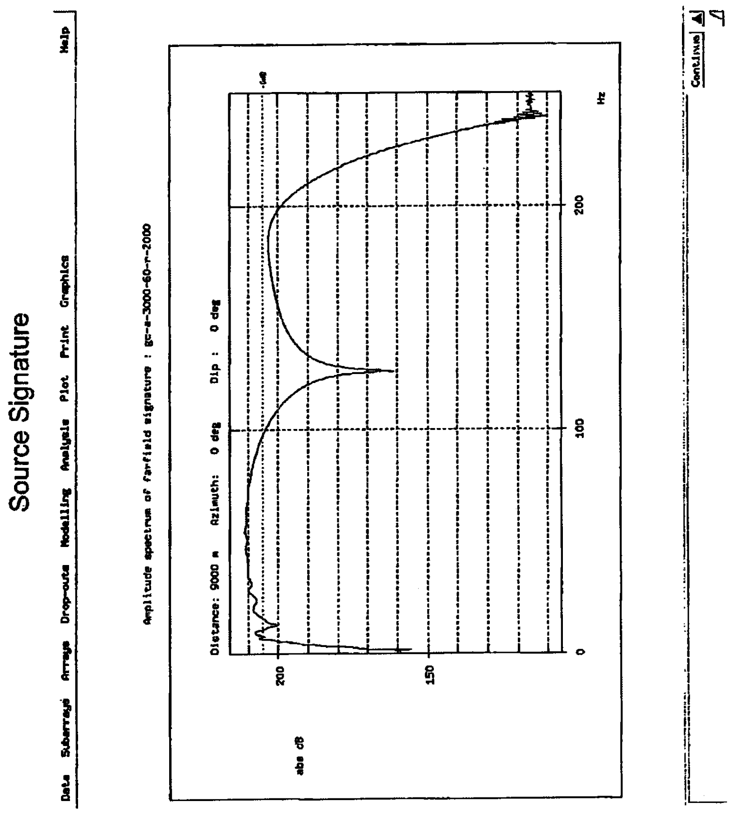
Towing Configuration

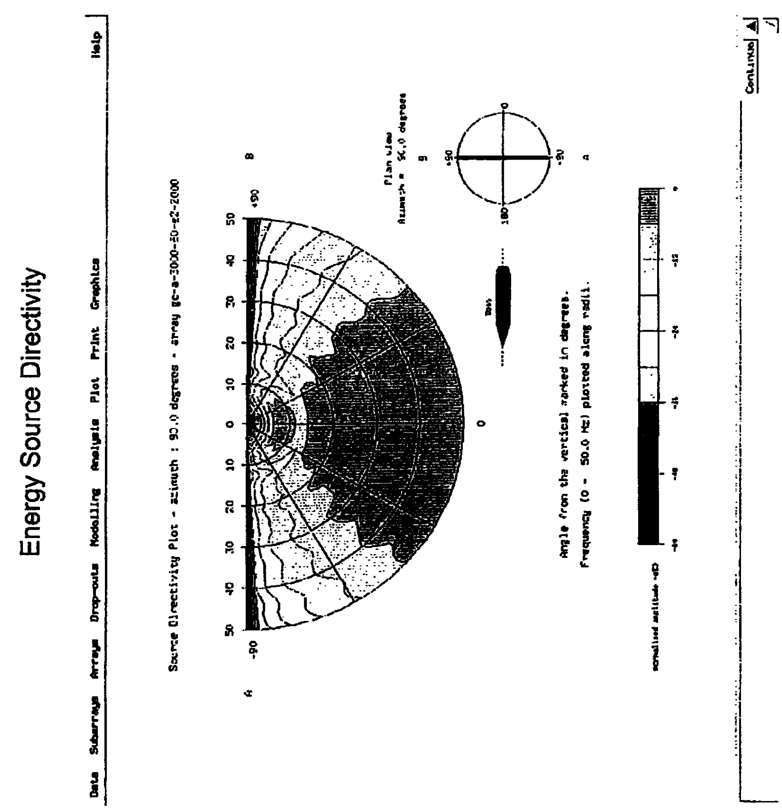


Airgun Configuration

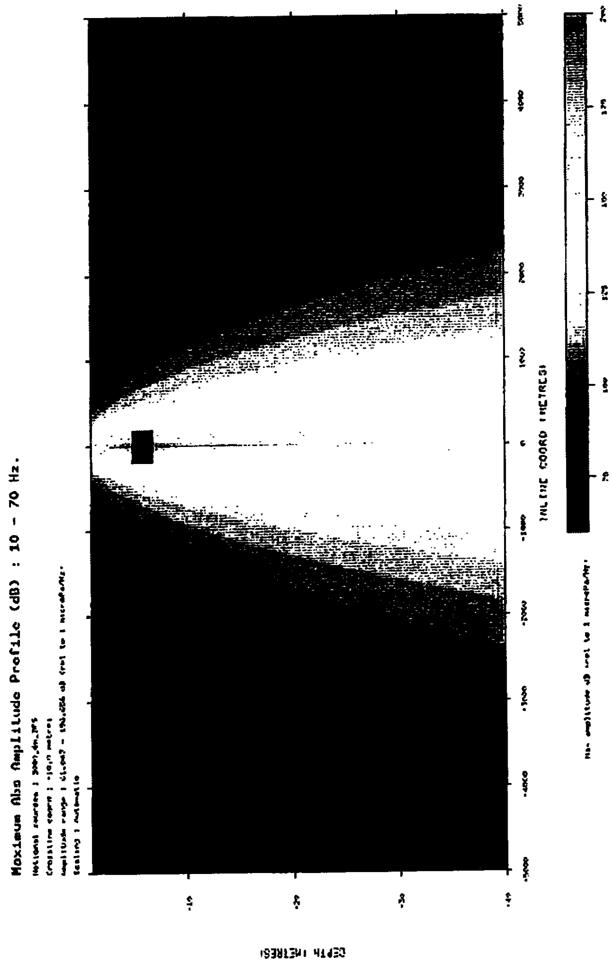



Source Signature
Data Subarrays Arrays Drop-outs Modelling Analysis Plot Print Graphics Help
Farfield signature : gc-a-3000-50-r-2000
Distance: 9000 m Azimuth: 0 deg Dip : 0 deg
bar m
50
0
-50
0
500
msec
Continue


Source Signature
Data Subarrays Arrays Drop-outs Modelling Analysis Plot Print Graphics Help
Amplitude spectrum of farfield signature
Distance: 9000 m Azimuth: 0 deg Dip : 0 deg
abs dB
200
150
0
100
200
Hz
Continue


Energy Source Directivity
Data Subarrays Arrays Drop-outs Modelling Analysis Plot Print Graphics Help
Plan view
Angle from the vertical marked in degrees.
Frequency (0 - 50.0 Hz) plotted along radii.
Continue

Energy Source Directivity



APPENDIX C

3D Seismic Line Layout Scenarios

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

QUALITY CONTROL REVIEWER
Elizabeth Benson

Technical Editor: Nikishka Stewart

MMS FORM 327

OMB Control No. 1010-0048
OMB Approval Expires: August 31, 2012

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Alaska OCS Region

(Insert Appropriate Regional Office)

Requirements for Geological and Geophysical Explorations or Scientific Research in the Outer Continental Shelf

Application for Permit to Conduct Geological or Geophysical Exploration for Mineral Resources or Scientific Research in the Outer Continental Shelf

(Attachment 1)

Nonexclusive Use Agreement for Scientific Research

(Attachment 2)

SUBMIT: Original, two copies, and one public information copy (all with original signatures).

Paperwork Reduction Act of 1995 (PRA) Statement: The PRA (44 U.S.C. 3501 et seq.) requires us to inform you that the Minerals Management Service (MMS) collects this information to evaluate applications for permits to conduct pre-lease exploration offshore and to monitor activities of scientific research conducted under notices. The MMS uses the information to ensure there is no environmental degradation, personnel harm, damage to historical or cultural sites, or interference with other uses. Responses are mandatory to obtain a benefit. Proprietary information is protected in accordance with standards established by the Federal Oil and Gas Royalty Management Act of 1982 (30 U.S.C. 1733), the Freedom of Information Act (5 U.S.C. 552(1), (4)), and the Department regulations (43 CFR 2). An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid Office of Management and Budget control number. The reporting burden for this form is estimated to average 3 hours per response, including the time for reviewing instructions, gathering and maintaining data, and completing and reviewing the form. Direct comments regarding the burden estimate or any other aspect of this form to the Information Collection Clearance Officer, Minerals Management Service, Mail Stop 5438, 1849 C Street, NW, Washington, DC 20240.

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

REQUIREMENTS FOR GEOLOGICAL AND GEOPHYSICAL EXPLORATIONS OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

Authority

You must perform all geological and geophysical explorations or scientific research activities authorized and conducted in the Outer Continental Shelf (OCS) according to the OCS Lands Act, 30 CFR Part 251, and other applicable Federal statutes and regulations, and amendments thereto.

General Requirements of Permits and Notices

You must conduct geological and geophysical activities for mineral exploration or scientific research activities authorized under 30 CFR Part 251 so that those activities do not:

A. Interfere with or endanger operations under any lease or right-of-way or permit issued or maintained pursuant to the OCS Lands Act;
B. Cause harm or damage to aquatic life or to the marine, coastal, or human environment;
C. Cause pollution;
D. Create hazardous or unsafe conditions;
E. Unreasonably interfere with or harm other uses of the area; or
F. Disturb archaeological resources.

Any person conducting geological or geophysical activities for mineral exploration or scientific research under 30 CFR Part 251 must immediately report to the Director, MMS:

A. Detection of hydrocarbon occurrences;
B. Encounters of environmental hazards that constitute an imminent threat to human activity; or
C. Activities that adversely affect the environment, aquatic life, archaeological resources, or other uses of the area in which the exploration or scientific research activities are conducted.

Any person conducting shallow or deep stratigraphic test drilling activities under a permit for mineral exploration or scientific research under 30 CFR Part 251 must utilize the best available and safest technologies that MMS determines to be economically feasible.

The authorization that MMS grants you under 30 CFR Part 251 to conduct geological and geophysical explorations for minerals or for scientific research does not confer a right to any discovered oil, gas, or other minerals, or to a lease under the OCS Lands Act.

Time Restriction for Permits and Notices

Permitted activities approved for a specified period, including requests for extensions, and activities under a notice may not exceed 1 year.

Geological and Geophysical Activities Requiring Permits and Notices

Geological and Geophysical Explorations for Mineral Resources

You may not conduct geological and geophysical explorations for mineral resources in the OCS without an approved permit unless you conduct such activities pursuant to a lease issued or maintained under the OCS Lands Act. You must obtain separate permits for either geological or geophysical explorations for mineral resources. If MMS disapproves an application, the statement of rejection will state the reasons for the denial and will advise the applicant of those changes needed to obtain approval.

Geological and Geophysical Scientific Research

You may not conduct geological and geophysical scientific research related to oil, gas, and sulphur in the OCS without an approved application for permit or filing of a notice. You must obtain separate permits for geological and geophysical scientific research that involves the use of solid or liquid explosives or the drilling of a deep stratigraphic test. If MMS disapproves an application for permit, the statement of rejection will state the reasons for the denial and will advise the applicant of the changes needed to obtain approval.

You must file a notice with the MMS at least 30 days before you begin scientific research not requiring a permit. We may inform you of all environmental laws and regulations pertaining to the OCS.

Information Required for Permits

Each applicant for a permit must complete the applicable sections of the Application for Permit (Attachment 1) and must include a page-size plat(s) showing the location of the proposed activity. The plat(s) should show geographic coordinates relative to the MMS area and block numbers, an easily identified onshore point of reference, and the distance and direction from the point of reference to area of activity. Line locations should not be included on these plat(s). In addition, each applicant for a geological or geophysical permit must submit the appropriate attachment to section D of the application. Each applicant for a scientific research permit must also complete a Nonexclusive Use Agreement (Attachment 2).

The information provided on the Application for Permit (excluding section D) and on the Nonexclusive Use Agreement, including continuation sheets and the page-size plat(s), is considered NON-PROPRIETARY INFORMATION. These non-proprietary portions of the application constitute the "public information" copy of Form 327 and with the executed permit will be available to the public upon request.

The information listed in section D is considered PROPRIETARY INFORMATION and you should NOT attach it to the public information copy. The MMS will not make this information available to the public without the consent of the potential permittee or for a period mandated by law or regulation. However, MMS may determine that earlier release is necessary for the proper development of the area permitted.

Modifications to Approved Permits

The MMS Regional Supervisor must approve any modification to the permitted operations.

Filing Locations for Permits to Conduct Explorations for Mineral Resources and for Permits or Notices to Conduct Scientific Research

File each notice or application for a permit in triplicate, plus one public information copy, at the following locations 30 days before you begin operations:

A. For the OCS off the State of Alaska:

Regional Supervisor for Resource Evaluation
Minerals Management Service
Alaska OCS Region
3801 Centerpoint Drive
Suite #500
Anchorage, Alaska 99503-5823

B. For the OCS in the Gulf of Mexico, off the Atlantic Coast:

Regional Supervisor for Resource Evaluation
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

C. For the OCS off the States of California, Oregon, Washington, or Hawaii:

Chief, Office of Reservoir Evaluation & Production
Minerals Management Service
Pacific OCS Region
770 Paseo Camarillo
Camarillo, California 93010-6092

Attachment 1

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

RECEIVED
Resource Evaluation

DEC 21 2009

U.S. Dept. of the Interior
Minerals Management Svc.
Alaska OCS Region

Alaska OCS Region

(Insert Appropriate Regional Office)

APPLICATION FOR PERMIT TO CONDUCT GEOLOGICAL OR GEOPHYSICAL EXPLORATION FOR MINERAL RESOURCES OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

(Section 11, Outer Continental Shelf Lands Act of August 7, 1953, as amended on September 18, 1978, by Public Law 95-372, 92 Statute 629, 43 U.S.C. 1340; and 30 CFR Part 251)

Statoil USA E&P Inc.
Name of Applicant

2103 CityWest Boulevard, Suite 800
Number and Street

Houston, TX 77042
City, State, and Zip Code

Fugro-Geoteam, Inc.
Name of Service Company or Purchaser
(if different from above)

Application is made for the following activity: (check one)

- ○ Geological exploration for mineral resources
- ○ Geological scientific research
- ◉ Geophysical exploration for mineral resources
- ○ Geophysical scientific research

Submit: Original, two copies, and one public information copy.

To be completed by MMS

Permit Number: 10-01 **Date:** ____________

A. General Information

1. The activity will be conducted by:

Service Company Name	For Purchaser(s) of the Data
Fugro-Geoteam, Inc.	Statoil USA E&P Inc.
Address	**Address**
6100 Hillcroft	2103 CityWest Boulevard, Suite 800
City, State, Zip	**City, State, Zip**
Houston, TX 77081	Houston, TX 77042
Telephone/FAX Numbers	**Telephone/FAX Numbers**
713-369-5591/713-778-6815 (fax)	713-918-8200/713-918-8290 (fax)
E-Mail Address	**E-Mail Address**
svigeland@fugro.com	mch@statoil.com

2. The purpose of the activity is: ⦿ Mineral exploration ○ Scientific research

3. Describe the environmental effects of the proposed activity, including potential adverse effects on marine life and what steps are planned to minimize these adverse effects (use continuation sheets as necessary):
No anticipated adverse effects. Marine mammal monitoring and mitigation are included in IHA application (NMFS) and LOA application (USFWS).

4. The expected commencement date is: July 15, 2010

   The expected completion date is: November 30, 2010

5. The name of the individual in charge of the field operation is: Sigbjorn Vigeland, Project Manager

   May be contacted at: Fugro Geoscience Division, 6100 Hillcroft, Houston, TX 77081

   Telephone (Local) 713-778-6823/713-456-9191 cell (Marine) +47 23 25 42 92 (On board Party Chief)

   Radio call sign LAKF6

6. The vessel(s) to be used in the operation is (are):

   Name M/V Geo Celtic (seismic source vessel) Registry number D26988 Bergen, Norway

   Registered owner E Forland AS

7. The port from which the vessel(s) will operate is: Dutch Harbor, Alaska: Nome, Alaska

8. Briefly describe the navigation system (vessel navigation only):
Furuno FE 700 echosounde; Furuno 10cm ARPA-radar; Furuno 3cm ARPA-radar

Section I. Authorization

The Government authorizes the permittee to conduct:

_x_ Geophysical exploration for mineral resources as defined in 30 CFR 251.1.

____ Geophysical scientific research as defined in 30 CFR 251.1. A permit is required for any geophysical investigation that involves the use of solid or liquid explosives or developing data and information for proprietary use or sale.

This permit authorizes the permittee to conduct the above geophysical activity during the period from July 15, 2010 to November 30, 2010 in the following area(s): Chukchi Sea, Alaska (see attached figures and Plan of Operations). Extensions of the time period specified above must be requested in writing. A permit plus extensions for activities will be limited to a period of not more than 1 year from the original issuance date of the permit. Inspection and reporting of geophysical exploration activities, suspension and cancellation of authority to conduct exploration or scientific research activities under permit, and penalties and appeals will be carried out in accordance with 30 CFR 251.8, 251.9, and 251.10.

The authority of the Regional Director may be delegated to the Regional Supervisor for Resource Evaluation for the purposes of this permit.

Section II. Type(s) of Operations and Technique(s)

A. The permittee will employ the following type(s) of operations:

3D seismic acquisition and 2D seismic acquisition in open waters. See Plan of Operations.;

and will utilize the following instruments and/or technique(s) in such operations:

Towed airgun source and a towed 12-streamer hydrophone array.

B. The permittee will conduct all activities in compliance with the terms and conditions of this permit, including the "Stipulations," "Special Provisions," and the approved "Application for Permit," which are attached to and incorporated into this permit.

C. The permittee will conduct all geophysical exploration or scientific research activities in compliance with the Act, the regulations in 30 CFR Part 251, and other applicable statutes and regulations whether such statutes and regulations are enacted, promulgated, issued, or amended before or after this permit is issued. Some of the provisions of 30 CFR Part 251 are restated in this permit for emphasis. However, all of the provisions of 30 CFR Part 251 apply to this permit.

Section III. Reports on Operations

A. The permittee must submit status reports on a weekly basis in a manner approved or prescribed by the Regional Supervisor, Resource Evaluation (hereinafter referred to as Supervisor). The report must include a daily log of operations and a map (preferably on a scale of 1:250,000) showing traverse lines according to Minerals Management Service (MMS) area and block numbers.

A. General Information

1. The activity will be conducted by:

Service Company Name	For Purchaser(s) of the Data
Fugro-Geoteam, Inc.	Statoil USA E&P Inc.
Address: 6100 Hillcroft	Address: 2103 CityWest Boulevard, Suite 800
City, State, Zip: Houston, TX 77081	City, State, Zip: Houston, TX 77042
Telephone/FAX Numbers: 713-369-5591/713-778-6815 (fax)	Telephone/FAX Numbers: 713-918-8200/713-918-8290 (fax)
E-Mail Address:	E-Mail Address:

2. The purpose of the activity is: ◉ Mineral exploration ◯ Scientific research

3. Describe the environmental effects of the proposed activity, including potential adverse effects on marine life and what steps are planned to minimize these adverse effects (use continuation sheets as necessary):
No anticipated adverse effects. Marine mammal monitoring and mitigation are included in IHA application (NMFS) and LOA application (USFWS).

4. The expected commencement date is: July 15, 2010

   The expected completion date is: November 30, 2010

5. The name of the individual in charge of the field operation is: Sigbjom Vigeland, Project Manager

   May be contacted at: Fugro Geoscience Division, 6100 Hillcroft, Houston, TX 77081

   Telephone (Local) 713-778-6823/713-456-9191 cell (Marine) +47 23 25 42 92 (On board Party Chief)

   Radio call sign LAKF6

6. The vessel(s) to be used in the operation is (are):
   Name M/V Geo Celtic (seismic source vessel) Registry number D26988 Bergen, Norway

   Registered owner E Forland AS

7. The port from which the vessel(s) will operate is: Dutch Harbor, Alaska: Nome, Alaska

8. Briefly describe the navigation system (vessel navigation only):
   Furuno FE 700 echosounde; Furuno 10cm ARPA-radar; Furuno 3cm ARPA-radar

B. Complete for Geological Exploration for Mineral Resources or Geological Scientific Research

1. The type of operation(s) to be employed is: (check one)

   (a) ○ Deep stratigraphic test, or

   (b) ○ Shallow stratigraphic test with proposed total depth of ________, or

   (c) ◉ Other NA

2. Exact geographic coordinates of proposed test(s) (attach a page-size plat(s)):

   NA

C. Complete for Geophysical Exploration for Mineral Resources or Geophysical Scientific Research

1. Proposed location of the activity (attach a page-size plat(s)): See attached figures

2. The type(s) of operation(s) to be employed is (are):

   Marine 3D Seismic Acquisition and Marine 2D Seismic Acquisition

   (Seismic, gravity, magnetic, etc.)

3. The instrumentation and/or technique(s) to be used in the operation(s) is (are):

   Towed airgun array and a towed 12-streamer hydrophone array

   (Air gun, sparker, etc.)

4. Explosive charges will ○ will not ◉ be used. If applicable, indicate the type of explosive and maximum charge size (in pounds) to be used:

   Type ________ Pounds ________ Equivalent Pounds of TNT ________

D. Proprietary Information Attachments

Use the appropriate form on page 9 for a "geological" permit application or the form on page 10 for a "geophysical" permit application. You must submit a separate Form MMS-327 to apply for each geological or geophysical permit.

E. Certification

I hereby certify that foregoing and attached information are true and correct.

SIGNED Martin Cohen DATE 12/17/2009

TITLE Martin Cohen, Alaska Exploration Manager

==

TO BE COMPLETED BY MMS

Permit No. 10-01 Assigned by [illegible] of MMS Date 12/21/2009

This application is hereby:

a. ____ Approved

b. ____ Returned for reasons in the attached

The approved permit is:

a. ____ Attached

b. ____ Will be forwarded at a later date

SIGNED ____________ TITLE Regional Supervisor DATE ____________

B. Complete for Geological Exploration for Mineral Resources or Geological Scientific Research

1. The type of operation(s) to be employed is: (check one)

   (a) ○ Deep stratigraphic test, or

   (b) ○ Shallow stratigraphic test with proposed total depth of _________, or

   (c) ◉ Other NA

2. Exact geographic coordinates of proposed test(s) (attach a page-size plat(s)):

   NA

C. Complete for Geophysical Exploration for Mineral Resources or Geophysical Scientific Research

1. Proposed location of the activity (attach a page-size plat(s)): See attached figures

2. The type(s) of operation(s) to be employed is (are):

   Marine 3D Seismic Acquisition and Marine 2D Seismic Acquisition
   (Seismic, gravity, magnetic, etc.)

3. The instrumentation and/or technique(s) to be used in the operation(s) is (are):

   Towed airgun array and a towed 12-streamer hydrophone array
   (Air gun, sparker, etc.)

4. Explosive charges will ○ will not ◉ be used. If applicable, indicate the type of explosive and maximum charge size (in pounds) to be used:

   Type _________ Pounds _________ Equivalent Pounds of TNT _________

D. Proprietary Information Attachments

Use the appropriate form on page 9 for a "geological" permit application or the form on page 10 for a "geophysical" permit application. You must submit a separate Form MMS-327 to apply for each geological or geophysical permit.

Section D Proprietary Information Attachment
Required for an Application for Geological Permit

1. Brief description of method of shallow drilling or sampling: ______
   NA

2. Brief description of shallow drilling or sampling equipment to be used: ______
   NA

3. Number of boring or sample locations to be occupied:
   NA

4. Navigation system or method to be used to position sample locations: ______
   NA

5. Method of sample analyses, storage, and handling: ______
   NA

6. Description and list of the final analyzed and/or processed data that will result from operations under the proposed activity: ______
   NA

7. Estimated date on which samples, logs, and analyzed and/or processed data will be ready for inspecti on: NA

8. Attach map(s), plat(s), and chart(s) (preferably at a scale of 1:250,000) showing latitude and longitude, scale, specific block numbers, specific boring sample locations, and total number of borings or samples proposed.

Section D Proprietary Information Attachment
Required for an Application for Geophysical Permit

1. Brief description of the energy source and streamer (receiving array): __________

   THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY ~~INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC INFORMATION COPY OF THE~~ EXPLORATION PLAN

2. Total energy output per impulse: __________

3. Number of impulses per linear mile: __________

4. Towing depth of the energy source: __________

5. Towing depth of the streamer:

6. Navigation system or method to be used to position shotpoint locations: __________

7. Area of activity and total number of line miles proposed: __________

8. Description and list of the final processed data that will result from operations under the proposed activity :

9. Estimated date on which processed data will be available for inspection:

10. Attach map(s), plat(s), and chart(s) (preferably at a scale of 1:250,000) showing latitude and longitude, scale, specific block numbers, specific track lines with line identifications, and the total number of line miles proposed.

Attachment 2

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Alaska OCS Region

(Insert Appropriate Regional Office)

NONEXCLUSIVE USE AGREEMENT FOR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

A. State the time and manner in which data and information resulting from the proposed activity will be made available to the public for inspection and reproduction, such time being the earliest practicable time.

NA

B. ______________________________ (applicant) agrees that the data and information resulting from the proposed activity will not be sold or withheld for exclusive use.

(Signature of Applicant)

(Type or Print Name of Applicant)

(Title)

(Date)

Submit: Original, two copies, and one public information copy.

MMS FORM 328

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

ALASKA OCS REGION

(Insert Appropriate Regional Office)

RECEIVED
Resource Evaluation
DEC 21 2009
U.S. Dept. of the Interior
Minerals Management Svc.
Alaska OCS Region

PERMIT FOR GEOPHYSICAL EXPLORATION FOR MINERAL RESOURCES OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

In consideration of the terms and conditions contained herein and the authorization granted hereby, this permit is entered into by and between the United States of America (the Government), acting through the Minerals Management Service (MMS) of the Department of the Interior, and

Statoil USA E&P Inc.
(Name of Permittee)

2103 CityWest Boulevard, Suite 800
(Number and Street)

Houston, TX 77042
(City, State, and Zip Code)

PERMIT NUMBER: 10-01 DATE: ______________

This permit is issued pursuant to the authority of the Outer Continental Shelf Lands Act, as amended, (43 U.S.C. 1331 et seq.), hereinafter called the "Act," and Title 30 Code of Federal Regulations Part 251 (Geological and Geophysical (G&G) Explorations of the Outer Continental Shelf).

Paperwork Reduction Act of 1995 (PRA) Statement: This permit refers to information collection requirements contained in 30 CFR part 251 regulations. The Office of Management and Budget (OMB) has approved those reporting requirements under OMB Control Number 1010-0048.

Section I. Authorization

The Government authorizes the permittee to conduct:

_x_ Geophysical exploration for mineral resources as defined in 30 CFR 251.1.

____ Geophysical scientific research as defined in 30 CFR 251.1. A permit is required for any geophysical investigation that involves the use of solid or liquid explosives or developing data and information for proprietary use or sale.

This permit authorizes the permittee to conduct the above geophysical activity during the period from July 15, 2010 to November 30, 2010 in the following area(s): Chukchi Sea, Alaska (see attached figures and Plan of Operations). Extensions of the time period specified above must be requested in writing. A permit plus extensions for activities will be limited to a period of not more than 1 year from the original issuance date of the permit. Inspection and reporting of geophysical exploration activities, suspension and cancellation of authority to conduct exploration or scientific research activities under permit, and penalties and appeals will be carried out in accordance with 30 CFR 251.8, 251.9, and 251.10.

The authority of the Regional Director may be delegated to the Regional Supervisor for Resource Evaluation for the purposes of this permit.

Section II. Type(s) of Operations and Technique(s)

A. The permittee will employ the following type(s) of operations:

3D seismic acquisition and 2D seismic acquisition in open waters. See Plan of Operations.;

and will utilize the following instruments and/or technique(s) in such operations:

Towed airgun source and a towed 12-streamer hydrophone array.

B. The permittee will conduct all activities in compliance with the terms and conditions of this permit, including the "Stipulations," "Special Provisions," and the approved "Application for Permit," which are attached to and incorporated into this permit.

C. The permittee will conduct all geophysical exploration or scientific research activities in compliance with the Act, the regulations in 30 CFR Part 251, and other applicable statutes and regulations whether such statutes and regulations are enacted, promulgated, issued, or amended before or after this permit is issued. Some of the provisions of 30 CFR Part 251 are restated in this permit for emphasis. However, all of the provisions of 30 CFR Part 251 apply to this permit.

Section III. Reports on Operations

A. The permittee must submit status reports on a weekly basis in a manner approved or prescribed by the Regional Supervisor, Resource Evaluation (hereinafter referred to as Supervisor). The report must include a daily log of operations and a map (preferably on a scale of 1:250,000) showing traverse lines according to Minerals Management Service (MMS) area and block numbers.

Section I. Authorization

The Government authorizes the permittee to conduct:

_x_ Geophysical exploration for mineral resources as defined in 30 CFR 251.1.

____ Geophysical scientific research as defined in 30 CFR 251.1. A permit is required for any geophysical investigation that involves the use of solid or liquid explosives or developing data and information for proprietary use or sale.

This permit authorizes the permittee to conduct the above geophysical activity during the period from July 15, 2010 to November 30, 2010 in the following area(s): Chukchi Sea, Alaska (see attached figures and Plan of Operations). Extensions of the time period specified above must be requested in writing. A permit plus extensions for activities will be limited to a period of not more than 1 year from the original issuance date of the permit. Inspection and reporting of geophysical exploration activities, suspension and cancellation of authority to conduct exploration or scientific research activities under permit, and penalties and appeals will be carried out in accordance with 30 CFR 251.8, 251.9, and 251.10.

The authority of the Regional Director may be delegated to the Regional Supervisor for Resource Evaluation for the purposes of this permit.

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and will utilize the following instruments and/or technique(s) in such operations:

Towed airgun source and a towed 12-streamer hydrophone array.

B. The permittee will conduct all activities in compliance with the terms and conditions of this permit, including the "Stipulations," "Special Provisions," and the approved "Application for Permit," which are attached to and incorporated into this permit.

C. The permittee will conduct all geophysical exploration or scientific research activities in compliance with the Act, the regulations in 30 CFR Part 251, and other applicable statutes and regulations whether such statutes and regulations are enacted, promulgated, issued, or amended before or after this permit is issued. Some of the provisions of 30 CFR Part 251 are restated in this permit for emphasis. However, all of the provisions of 30 CFR Part 251 apply to this permit.

Section III. Reports on Operations

A. The permittee must submit status reports on a weekly basis in a manner approved or prescribed by the Regional Supervisor, Resource Evaluation (hereinafter referred to as Supervisor). The report must include a daily log of operations and a map (preferably on a scale of 1:250,000) showing traverse lines according to Minerals Management Service (MMS) area and block numbers.

B. The permittee must submit to the Supervisor a final report within 30 days after the completion of operations. The final report must contain the following:

1. A description of the work performed including number of line miles or OCS blocks of geophysical data acquired;

2. Chart(s), map(s), or plat(s) depicting the areas and blocks in which any exploration or scientific research activities were conducted. These graphics must clearly indicate the location of the activities so that the data produced from the activities can be accurately located and identified;

3. The dates on which the actual geophysical exploration or scientific research activities were performed;

4. A narrative summary of any: (a) hydrocarbon occurrences or environmental hazards observed and (b) adverse effects of the geophysical exploration or scientific research activities on the environment, aquatic life, archaeological resources, or other uses of the area in which the activities were conducted;

5. The estimated date on which the processed or interpreted data or information will be available for inspection by the MMS;

6. A final edited navigation file on suitable storage medium of all data or sample locations in latitude/longitude degrees including datum used. The navigation for 2D lines should include line name and locations for the first, last and every tenth SP. For 3D surveys, please supply a navigation file for the acquired track lines that includes the location of the first and last SP and/or the corner locations for the area acquired. Contact the G&G permitting office for the specific navigation required for this permitted activity. The digital file is to be formatted in standard SEG-P1, UKOOA P1-90 or other current, standard industry format, coded in ASCII. A printed data listing and a format statement are to be included;

7. Identification of geocentric ellipsoid (NAD 27 or NAD 83) used as a reference for the data or sample locations; and

8. Such other descriptions of the activities conducted as may be specified by the Supervisor.

C. The last status report and the final report can be combined into one report.

Section IV. Submission, Inspection, and Selection of Geophysical Data and Information

A. The permittee must notify the Supervisor, in writing, when the permittee has completed the initial processing and interpretation of any geophysical data and information collected under an exploration permit or a scientific research permit that involves developing data and information for proprietary use or sale. If the Supervisor asks if the permittee has further processed or interpreted any geophysical data and information collected under a permit, the permittee must respond within 30 days. If further processing of the data and information is conducted, it is the responsibility of the permittee to keep the most current resulting products available in the event the Supervisor requests the current status of data processing. At any time within 10 years after receiving notification of the completion of the acquisition activities conducted under the permit, the Supervisor may request that the permittee submit for inspection and possible retention all or part of the geophysical data, processed geophysical information, and interpreted geophysical information.

B. The Supervisor will have the right to inspect and select the geophysical data, processed geophysical information, or interpreted geophysical information. This inspection will be performed on the permittee's premises unless the Supervisor requests that the permittee submit the data or information to the Supervisor for inspection. Such submission must be within 30 days following the receipt of the Supervisor's request unless the Supervisor authorizes a later delivery date. If the inspection is done on the permittee's premises, the permittee must submit the geophysical data or information selected within 30 days following receipt of the Supervisor's request, unless the Supervisor authorizes a longer period of time for delivery. The data or information requested for inspection or selected by the Supervisor must be submitted regardless of whether the permittee and the Government have or have not concluded an agreement for reimbursement. If the Supervisor decides to retain all or a portion of the geophysical data or information, the Supervisor will notify the permittee, in writing, of this decision.

C. In the event that a third party obtains geophysical data, processed geophysical information, or interpreted geophysical information from a permittee, or from another third party, by sale, trade, license agreement, or other means:

1. The third party recipient of the data and information assumes the obligations under this section except for notification of initial processing and interpretation of the data and information and is subject to the penalty provisions of 30 CFR Part 250, Subpart N; and

2. A permittee or third party that sells, trades, licenses, or otherwise provides the data and information to a third party must advise the recipient, in writing, that accepting these obligations is a condition precedent of the sale, trade, license, or other agreement; and

3. Except for license agreements, a permittee or third party that sells, trades, or otherwise provides data and information to a third party must advise the Supervisor in writing within 30 days of the sale, trade, or other agreement, including the identity of the recipient of the data and information; or

4. With regard to license agreements, a permittee or third party that licenses data and information to a third party, within 30 days of a request by the Supervisor, must advise the Supervisor, in writing, of the license agreement, including the identity of the recipient of the data and information.

D. Each submission of geophysical data, processed geophysical information, and interpreted geophysical information must contain, unless otherwise specified by the Supervisor, the following:

1. An accurate and complete record of each geophysical survey conducted under the permit, including digital navigational data and final location maps of all surveys;

2. All seismic data developed under a permit presented in a format and of a quality suitable for processing;

3. Processed geophysical information derived from seismic data with extraneous signals and interference removed, presented in a format and of a quality suitable for interpretive evaluation, reflecting state-of-the-art processing techniques; and

4. Other geophysical data, processed geophysical information, and interpreted geophysical information obtained from, but not limited to, shallow and deep subbottom profiles, bathymetry, side-scan sonar, gravity, magnetic, and electrical surveys, and special studies such as refraction, shear wave, and velocity surveys.

Section V. Reimbursement to Permittees

A. After the delivery of geophysical data, processed geophysical information, and interpreted geophysical information requested by the Supervisor in accordance with subsection IV of this permit, and upon receipt of a request for reimbursement and a determination by MMS that the requested reimbursement is proper, MMS will reimburse the permittee or third party for the reasonable costs of reproducing the submitted data and information at the permittee's or third party's lowest rate or at the lowest commercial rate established in the area, whichever is less.

B. If the processing was in a form and manner other than that used in the normal conduct of the permittee's business at MMS's request, MMS will reimburse the permittee or third party for the reasonable costs of processing or reprocessing such data. Requests for reimbursement must identify processing costs separate from acquisition costs.

C. The permittee or third party will not be reimbursed for the costs of acquiring or interpreting geophysical information.

D. Data and information required under section IV.D.1. of this permit are not considered to be geophysical data or processed geophysical information and must be provided by the permittee at no cost to the Government.

Section VI. Disclosure of Data and Information to the Public

A. The MMS will make data and information submitted by a permittee available in accordance with the requirements and subject to the limitations of the Freedom of Information Act (5 U.S.C. 552) and the implementing regulations (43 CFR Part 2), the requirements of the Act, and the regulations contained in 30 CFR Part 250 (Oil and Gas and Sulphur Operations in the Outer Continental Shelf), 30 CFR Part 251, and 30 CFR Part 252 (Outer Continental Shelf (OCS) Oil and Gas Information Program).

B. Except as specified in this section, or Section VIII, or in 30 CFR Parts 250 and 252, no data or information determined by MMS to be exempt from public disclosure under subsection A of this section will be provided to any affected State or be made available to the executive of any affected local government or to the public, unless the permittee or third party and all persons to whom such permittee has sold, traded, or licensed the data or information under promise of confidentiality agree to such an action.

C. Geophysical data and processed or interpreted geophysical information submitted under a permit, and retained by MMS, will be disclosed as follows:

   1. Except for deep stratigraphic tests, the MMS will make available to the public geophysical data 50 years after the date of issuance of the permit under which the data were collected (See 251.12 (a) (b) (c) and (d)).

   2. Except for deep stratigraphic tests, the MMS will make available to the public processed geophysical information and interpreted geophysical information 25 years after the date of issuance of the permit under which the original data were collected (See 251.12 (a) (b) (c) and (d)).

3. The MMS will make available to the public all geophysical data and information and geophysical interpretations related to a deep stratigraphic test, at the earlier of the following times: (a) 25 years after the completion of the test, or (b) for a lease sale held after the test well is completed, 60 calendar days after the Department of the Interior executes the first lease for a block, any part of which is within 50 geographic miles (92.6 kilometers) of the site of the completed test.

D. All line-specific preplot or postplot plat(s), and navigation tapes, including but not limited to seismic survey traverses and shotpoint locations, submitted as a requirement of 30 CFR 251.7 or 251.12, will be considered as "PROPRIETARY INFORMATION." Such information will not be made available to the public without the consent of the permittee for a period of 25 years from the date of issuance of the permit, unless the Director, MMS, determines that earlier release is necessary for the proper development of the area permitted.

E. All other information submitted as a requirement of 30 CFR 251.8 and determined by MMS to be exempt from public disclosure will be considered as "PROPRIETARY." Such data and information will not be made available to the public without the consent of the permittee for a period of up to 25 years from the date of issuance of the permit as addressed in 30 CFR 251.14, unless the Director, MMS, determines that earlier release is necessary for the proper development of the area permitted. The executed permit will be considered as "PROPRIETARY" except the public information copy which will be available to the public upon request.

F. The identities of third party recipients of data and information collected under a permit will be kept confidential. The identities will not be released unless the permittee and the third parties agree to the disclosure.

Section VII. <u>Disclosure to Independent Contractors</u>

The MMS reserves the right to disclose any data or information acquired from a permittee to an independent contractor or agent for the purpose of reproducing, processing, reprocessing, or interpreting such data or information. When practicable, MMS will advise the permittee who provided the data or information of intent to disclose the data or information to an independent contractor or agent. The MMS's notice of intent will afford the permittee a period of not less than 5 working days within which to comment on the intended action. When MMS so advises a permittee of the intent to disclose data or information to an independent contractor or agent, all other owners of such data or information will be deemed to have been notified of MMS's intent. Prior to any such disclosure, the contractor or agent will be required to execute a written commitment not to sell, trade, license, or disclose any data or information to anyone without the express consent of MMS.

Section VIII. <u>Sharing of Information with Affected States</u>

A. At the time of soliciting nominations for the leasing of lands within 3 geographic miles of the seaward boundary of any coastal State, MMS, pursuant to the provisions of 30 CFR 252.7 and subsections 8(g) and 26(e) (43 U.S.C. 1337(g) and 1352(e)) of the Act, will provide the Governor of the State (or the Governor's designated representative) the following information that has been acquired by MMS on such lands proposed to be offered for leasing:

1. All information on the geographical, geological, and ecological characteristics of the areas and regions proposed to be offered for leasing;

2. An estimate of the oil and gas reserves in the area proposed for leasing; and

3. An identification of any field, geological structure, or trap located within 3 miles of the seaward boundary of the State.

B. After the time of receipt of nominations for any area of the OCS within 3 geographic miles of the seaward boundary of any coastal State and Area Identification in accordance with the provisions of Subparts D and E of 30 CFR Part 256, MMS, in consultation with the Governor of the State (or the Governor's designated representative), will determine whether any tracts being given further consideration for leasing may contain one or more oil or gas reservoirs underlying both the OCS and lands subject to the jurisdiction of the State.

C. At any time prior to a sale, information acquired by MMS that pertains to the identification of potential and/or proven common hydrocarbon-bearing areas within 3 geographic miles of the seaward boundary of any such State will be shared, upon request by the Governor and pursuant to the provisions of 30 CFR 252.7 and subsections 8(g) and 26(e) of the Act, with the Governor of such State (or the Governor's designated representative).

D. Knowledge obtained by a State official who receives information under subsections A, B, and C of this section will be subject to the requirements and limitations of the Act and the regulations contained in 30 CFR Part 250, Part 251, and Part 252.

Section IX. Permit Modifications

The Department will have the right at any time to modify or amend any provisions of this permit, except that the Department will not have such right with respect to the provisions of Sections VI, VII, and VIII hereof, unless required by an Act of Congress.

IN WITNESS WHEREOF the parties have executed this permit and it will be effective as of the date of signature by the Supervisor.

PERMITTEE:	THE UNITED STATES OF AMERICA:
Martin Cohen [signature]	
(Signature of Permittee)	(Signature of Regional Supervisor)
Martin Cohen	Rance R. Wall
(Type or Print Name of Permittee)	(Type or Print Name of Regional Supervisor)
Alaska Exploration Manager	
(Title)	(Date)
12/17/2009	
(Date)	

FIGURE 1
Chukchi Seismic Acquisitions

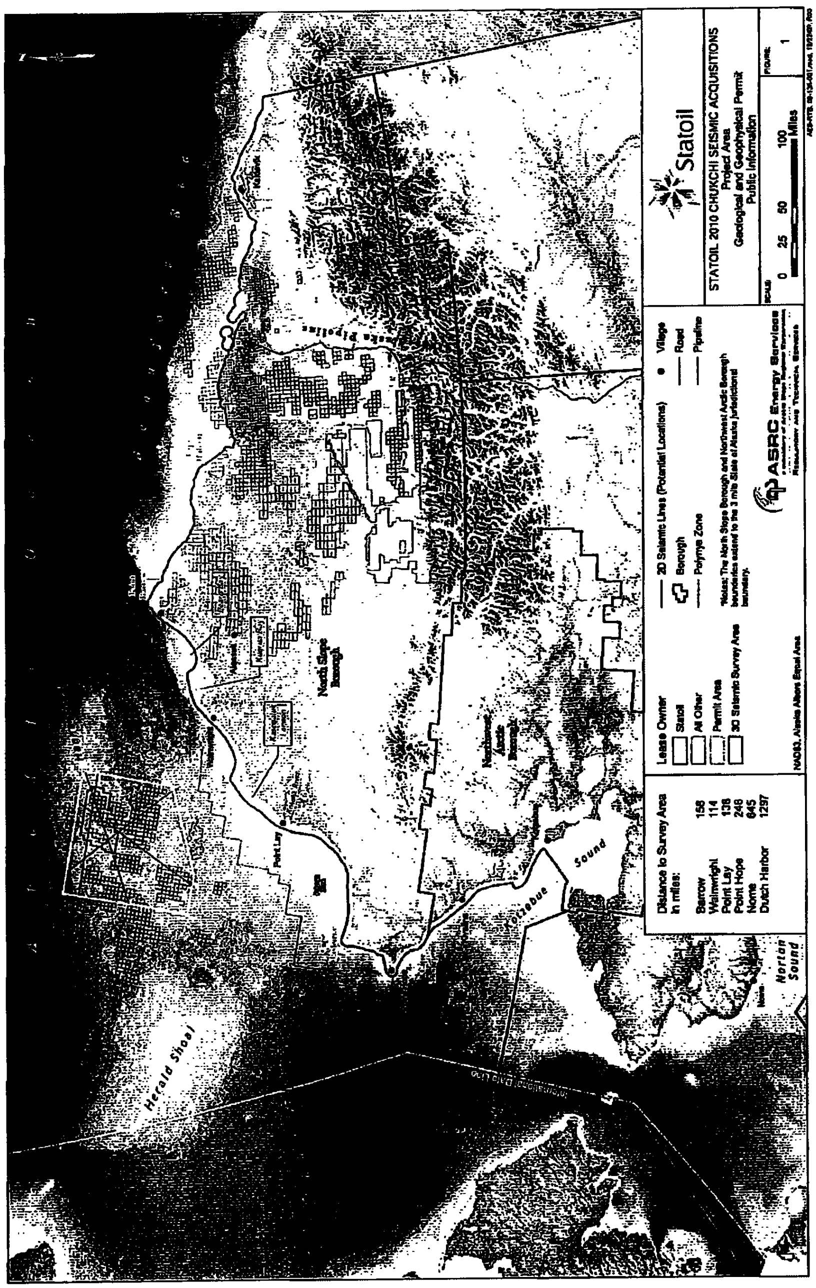

Statoil
STATOIL 2010 CHUKCHI SEISMIC ACQUISITIONS
Project Area
Geological and Geophysical Permit
Public Information
0 25 50 100 Miles
Distance to Survey Area in miles:
Barrow 158
Wainwright 114
Point Lay 136
Point Hope 248
Nome 645
Dutch Harbor 1297
Lease Owner
Statoil
All Other
Permit Area
3D Seismic Survey Area
2D Seismic Lines (Potential Locations)
Borough
Polynya Zone
Village
Road
Pipeline
ASRC Energy Services
North Slope Borough
Point Lay
Kotzebue
Sound
Norton Sound
Nome
Herald Shoal

FIGURE 2
Chukchi Seismic Acquisitions Project Area

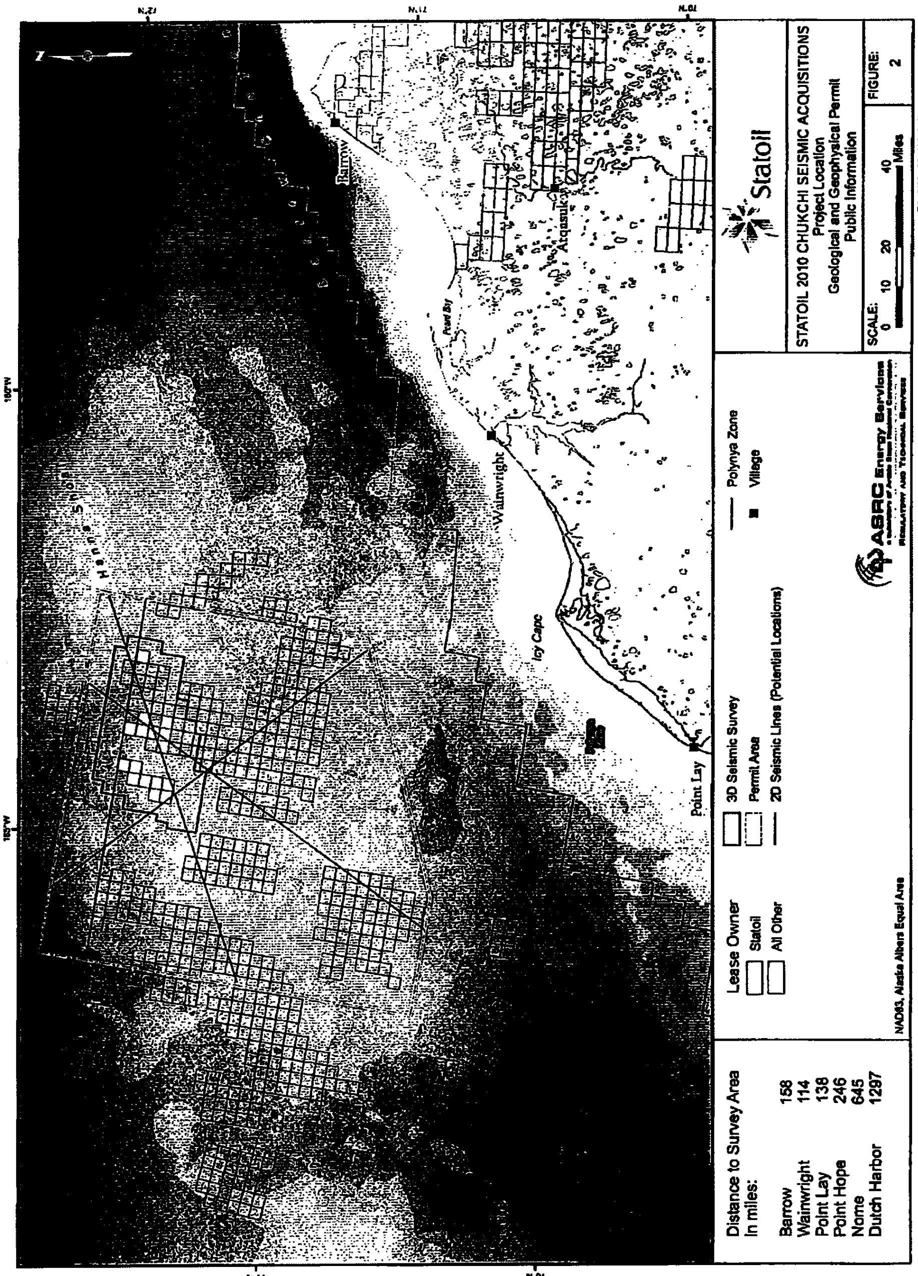

Barrow
Atqasuk
Wainwright
Icy Cape
Point Lay
Distance to Survey Area
In miles:
Barrow 158
Wainwright 114
Point Lay 138
Point Hope 246
Nome 645
Dutch Harbor 1297
Lease Owner
Statoil
All Other
3D Seismic Survey
Permit Area
2D Seismic Lines (Potential Locations)
Polynya Zone
Village
Statoil
STATOIL 2010 CHUKCHI SEISMIC ACQUISITIONS
Project Location
Geological and Geophysical Permit
Public Information
SCALE:
0 10 20 40
Miles
FIGURE:
2
ASRC Energy Services
NAD83, Alaska Albers Equal Area

FIGURE 3
Seismic Survey Area

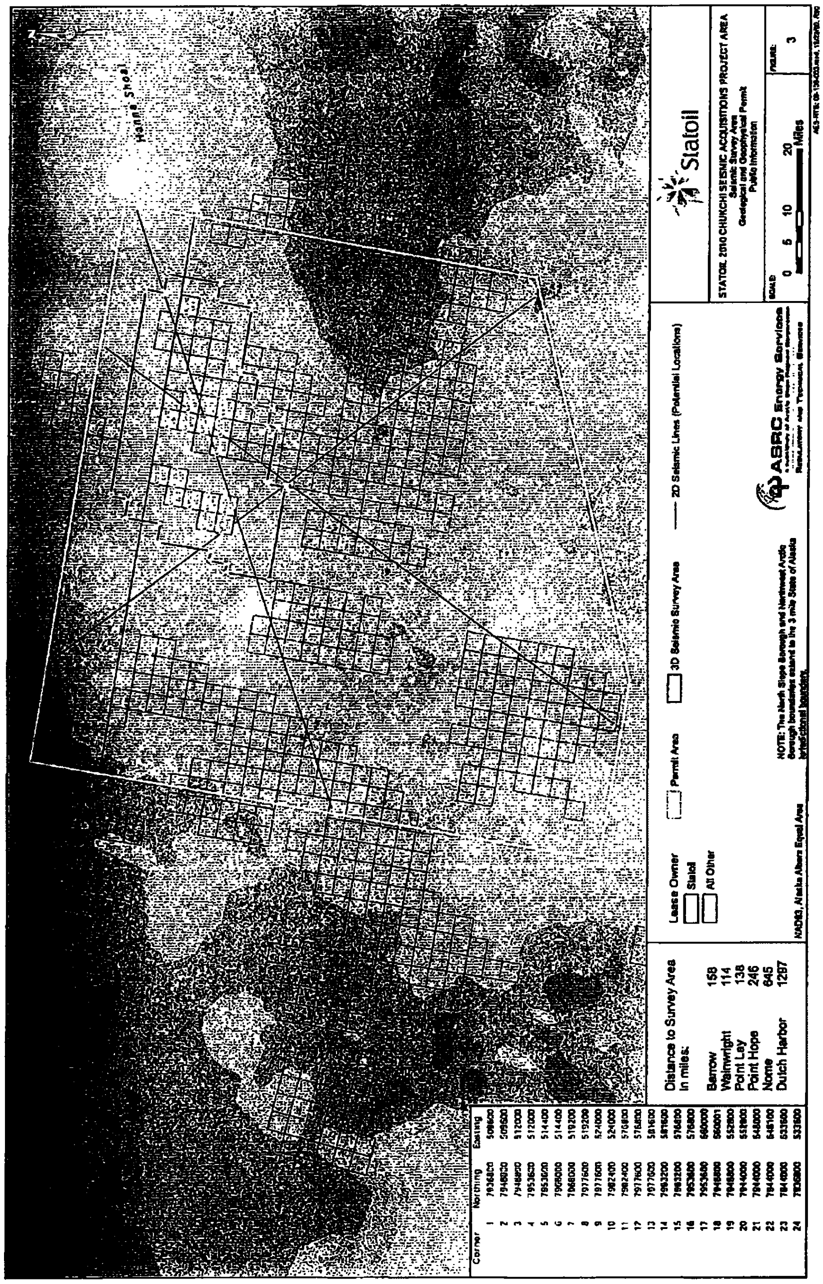

Hanna Shoal
Distance to Survey Area in miles:
Barrow 158
Wainwright 114
Point Lay 138
Point Hope 246
Nome 645
Dutch Harbor 1287
Lease Owner
Statoil
All Other
Permit Area
3D Seismic Survey Area
2D Seismic Lines (Potential Locations)
NAD83, Alaska Albers Equal Area
NOTE: The North Slope Borough and Northwest Arctic Borough boundaries extend to the 3 mile State of Alaska jurisdictional boundary.
ASRC Energy Services
Statoil
STATOIL 2010 CHUKCHI SEISMIC ACQUISITIONS PROJECT AREA
Seismic Survey Area
Geological and Geophysical Permit
Public Information
SCALE
0 5 10 20
Miles
FIGURE:
3

FIGURE 4
Preplot

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

FIGURE 5
Preplot

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

FIGURE 6
Preplot

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

FIGURE 7
Preplot

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

RECEIPT FOR
MMS G & G PERMIT

THE INFORMATION IN THIS SECTION CONTAINS CONFIDENTIAL/PROPRIETARY INFORMATION AND IS NOT AVAILABLE IN THIS PUBLIC COPY OF THE PLAN OF OPERATIONS

Exhibit G

Attachment 1

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico Region
(Insert Appropriate Regional Office)

GOM OCS REGION BOEMRE RECEIVED SEP 03 2010 New Orleans, LA OFFSHORE RESOURCE EVALUATION

APPLICATION FOR PERMIT TO CONDUCT GEOLOGICAL OR GEOPHYSICAL EXPLORATION FOR MINERAL RESOURCES OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

(Section 11, Outer Continental Shelf Lands Act of August 7, 1953, as amended on September 18, 1978, by Public Law 95-372, 92 Statute 629, 43 U.S.C. 1340; and 30 CFR Part 251)

Fugro Multi Client Services, Inc.
Name of Applicant

6100 Hillcroft Ave
Number and Street

Houston, TX 77081
City, State, and Zip Code

Fugro Geoteam, AS
Name of Service Company or Purchaser (if different from above)

GOM OCS REGION, BOEMRE SEP 01 2010 New Orleans OFFSHORE RESOURCE EVALUATION

Application is made for the following activity: (check one)

_______Geological exploration for mineral resources

_______Geological scientific research

__X__ Geophysical exploration for mineral resources

_______Geophysical scientific research

Submit: Original, two copies, and one public information copy.

To be completed by MMS

Permit Number: L10-041 **Date:** 01-Sep-2010

WG00898418

A. General Information

1. The activity will be conducted by:

Service Company		Purchaser(s)
Fugro Geoteam, AS Service Company Name	For	Fugro Multi Client Services, Inc. Purchaser(s) of the Data
6100 Hillcroft Address		6100 Hillcroft Address
Hoston, TX 77081 City, State, Zip		Houston, TX 77081 City, State, Zip
713-369-5898/713-369-5811 Telephone/FAX Numbers		713-369-5859/713-369-5860 Telephone/FAX Numbers
hcvaage@fugro.com E-Mail Address		kmohn@fugro.com E-Mail Address

2. The purpose of the activity is: X Mineral exploration

   ____ Scientific research

3. Describe the environmental effects of the proposed activity, including potential adverse effects on marine life and what steps are planned to minimize these adverse effects (use continuation sheets as necessary):
   Expect minimal environmental effects. Vessel will adhere strictly to BOEMRE regulations regarding marine mammal procedures and sightings (& recording of these).

4. The expected commencement date is: October 1, 2010

   The expected completion date is: September 31, 2011

5. The name of the individual in charge of the field operation is: Michael Whitehead/Steve Garrison

   May be contacted at: 713-369-5862/713-778-6824

   Telephone (Local) 713-369-5859 (Kenneth Mohn) (Marine) 713-778-6824

   Radio call sign 3FCZ6/LAIE7

6. The vessel(s) to be used in the operation is (are):

   Name See attached documents Registry number IMO no. 9525560/9492579

   Registered owner See attached documents

7. The port from which the vessel(s) will operate is: Galveston, TX: Fourchon, LA

8. Briefly describe the navigation system (vessel navigation only): Vessels are equipped with GPS Saab R4 systems and DGPS Saab R4 Systems.

B. Complete for Geological Exploration for Mineral Resources or Geological Scientific Research

1. The type of operation(s) to be employed is: (check one)

   (a) N/A Deep stratigraphic test, or

   (b) N/A Shallow stratigraphic test with proposed total depth of _________, or

   (c) N/A Other ________________________________

2. Exact geographic coordinates of proposed test(s) (attach a page-size plat(s)): ____________

C. Complete for Geophysical Exploration for Mineral Resources or Geophysical Scientific Research

1. Proposed location of the activity (attach a page-size plat(s)): Ship Shoal, EW, GC
2. The type(s) of operation(s) to be employed is (are): Wide Azimuth Multi streamer, multi airgun source recording seismic data (approximately 3,150 square miles), and gravity,
   (Seismic, gravity, magnetic, etc.)
3. The instrumentation and/or technique(s) to be used in the operation(s) is (are): Airgun source recorded by digital instrumentation, vessel gravity meter
   (Air gun, sparker, etc.)
4. Explosive charges will _____ will not X be used. If applicable, indicate the type of explosive and maximum charge size (in pounds) to be used:

   Type ____________ Pounds _________ Equivalent Pounds of TNT _________

D. Proprietary Information Attachments

Use the appropriate form on page 9 for a "geological" permit application or the form on page 10 for a "geophysical" permit application. You must submit a separate Form MMS-327 to apply for each geological or geophysical permit.

E. Certification

I hereby certify that foregoing and attached information are true and correct.

SIGNED ____________ DATE 8-31-2010

TITLE Exploration V.P. - Fugro Multi Client Services, Inc.

TO BE COMPLETED BY MMS

Permit No. L10-044 Assigned by R Murphey of MMS Date 08-Sep-2010

This application is hereby:

a. ✓ Approved

b. _____ Returned for reasons in the attached

The approved permit is:

a. _____ Attached

b. _____ Will be forwarded at a later date

SIGNED ____________ TITLE Regional Supervisor DATE 12/2/10

WG00898421

Attachment 2

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico Region
(Insert Appropriate Regional Office)

NONEXCLUSIVE USE AGREEMENT FOR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

A. State the time and manner in which data and information resulting from the proposed activity will be made available to the public for inspection and reproduction, such time being the earliest practicable time.

Tapes will be available in SEGY format in December 31, 2012.

B. ______________________ (applicant) agrees that the data and information resulting from the proposed activity will not be sold or withheld for exclusive use.

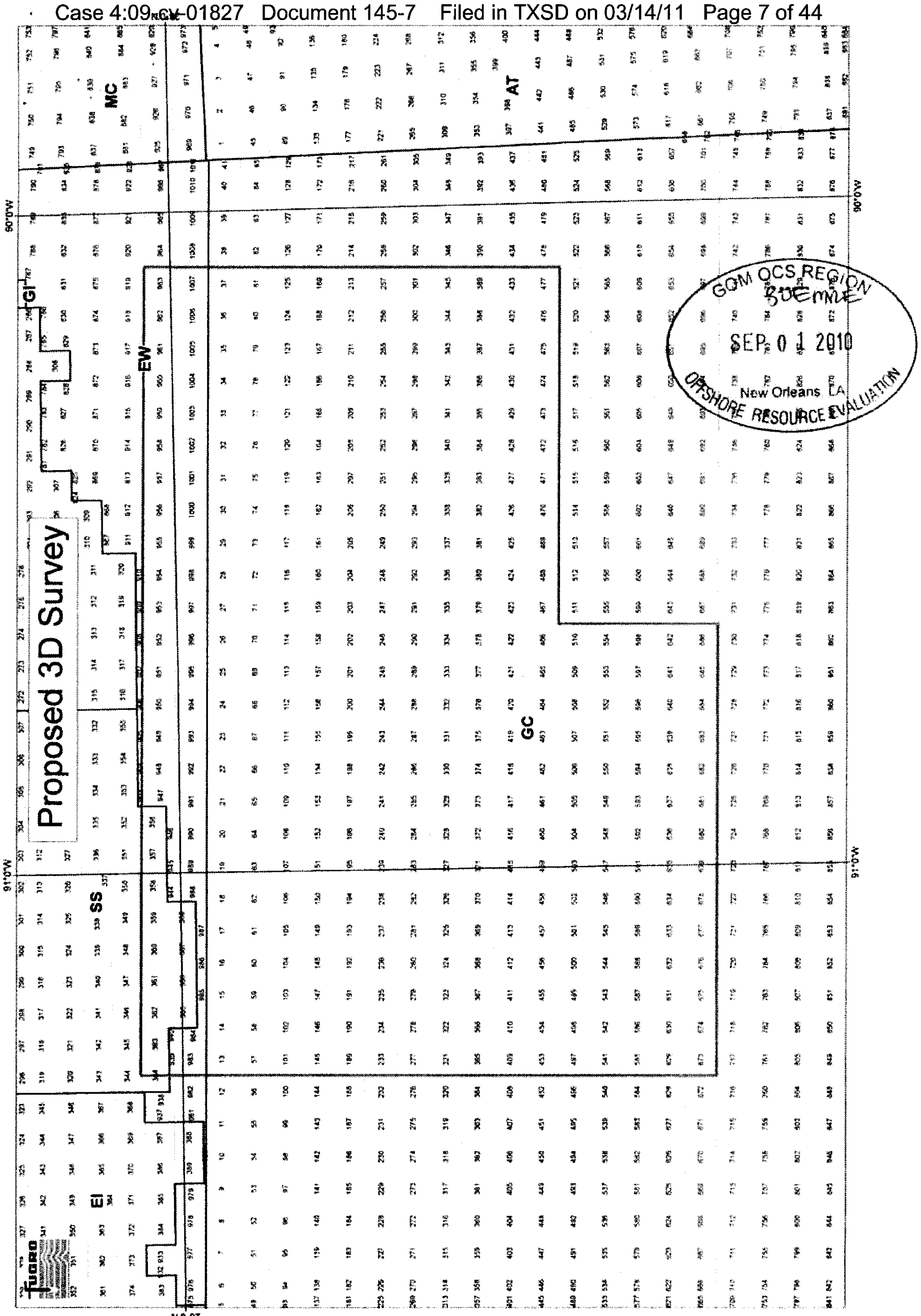
[signature]
(Signature of Applicant)

Kenneth W. Mohn
(Type or Print Name of Applicant)

Exploration V.P. - Fugro Multi Client Services, Inc.
(Title)

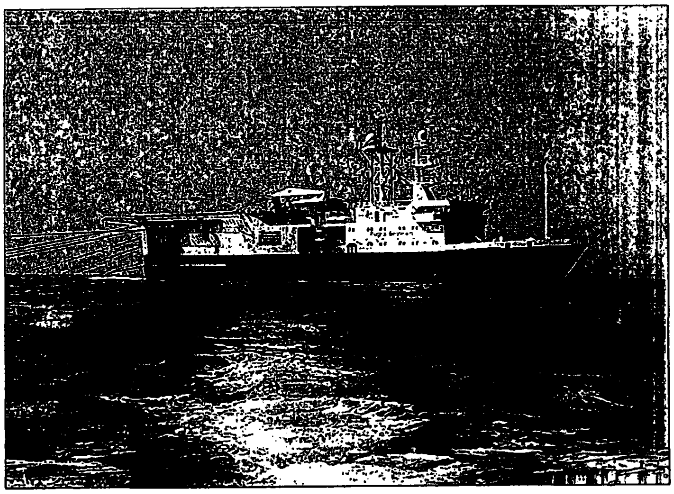
____
(Date)

Submit: Original, two copies, and one public information copy.


Proposed 3D Survey
MC
AT
GI
EW
SS
GC
EI
90°0'W
91°0'W
28°N
FUGRO
GOM OCS REGION
SEP 01 2010
New Orleans LA
OFFSHORE RESOURCE EVALUATION

WG00898423

FUGRO



R/V GEO PACIFIC

TECHNICAL SPECIFICATIONS

WG00898424

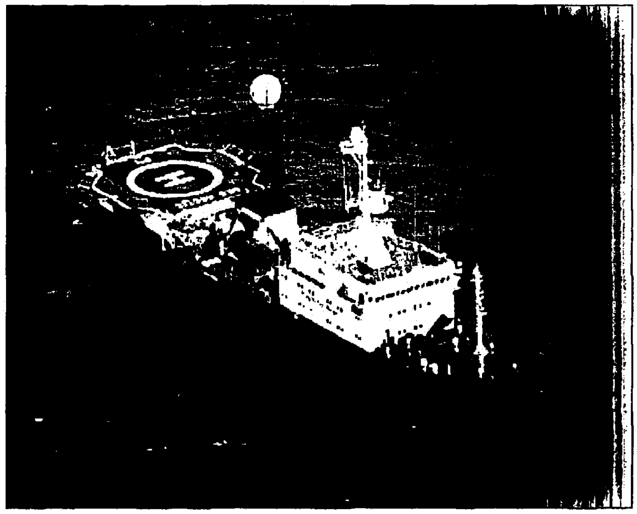
FUGRO

1. VESSEL

1.1. VESSEL GENERAL

Name	R/V Geo Pacific
Operator	Fugro-Geoteam AS
Owner	Fugro Geo Pacific Inc
Seismic Management	Fugro Norway Marine Services AS
Marine management	GC Rieber Shipping AS
Type	3D seismic vessel
Port of registration	Majuro
Flag	Marshall Islands
Class	DNV
Class registration no	20281
Class notation	1A1 HELDK SH
Call sign	V7MV9
IMO	8408973
MMSI	538002914
Year built/rebuilt	1987 /1998 /2003
Length overall	81.85 m
Breadth	14.8
Draught, loaded	5.7 m
Tonnage	4582 gross tons, 1375 net tons
Cruising speed	8.5 knot
Operation range	70 days cruising, 16000 nmi
Endurance seismic days max load	50 days
Main engine	Zgoda-Zulcer, type 6ZL 40/48, 4200 HP (3090 Kw)
Gearbox	Zamen MA90-10, ratio 505/222,6
Propulsion	Zamen, controllable pitch, LN 13 NM, 4 blade stainless steel
Rudder	Traditional w fishtail
Steering gear	Zamech M200-11-2
Azimuth thruster	Ulstein, 2040 HP (1500 kW)
Bow thruster	Electrical, 300 HP
Main engine monitoring	Polish
Electrical power	Total power 4620 kW) Voltage: 3 x 380 (220) VAC, 50 Hz. Shaft generator: 1 x 1200 kW Generator: Wartsila 6L20: 2 x 1140 kW) Mitsubishi: 1 x 1140 kW)
Emergency generator	Elmor 125 kW
Clean power	INV SitePro 60 kVA UPS
Fuel capacity	1568 m3 (90% = 1400 m3)
Fuel consumption	Sailing 22 t, production 28 t, port 3 t/day
Fresh water capacity	207 ton
Fresh water consumption	10 t/day
Fresh water generator	Full speed 10 t, production 10 t, port 1 t/day
Sewage treatment plant	Gertsen & Olufsen AS model MBR 60BG
Incinerator	Team Tech AS, built 2004
Black water	N/A
Grey water	10 m^3
Bilge water	12 m^3
Sludge	47 m^3

FUGRO



R/V GEO ARCTIC

TECHNICAL SPECIFICATIONS

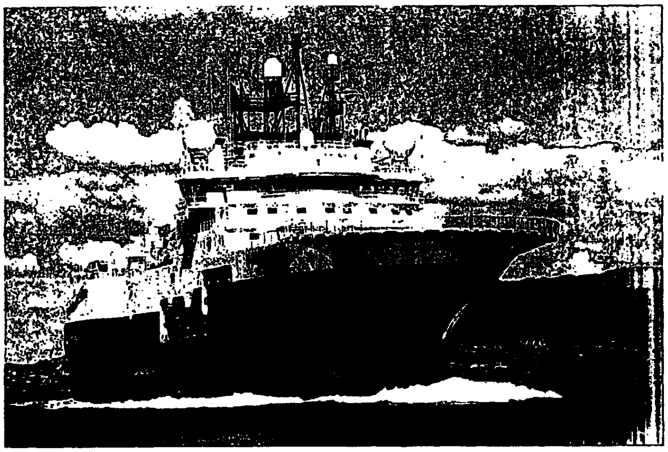
WG00898426

Fugro

1. VESSEL

1.1. VESSEL GENERAL

Name	R/V Geo Arctic
Operator	Amige SE, Murmansk
Owner	Amige SE, Murmansk
Seismic Management	Fugro Norway Marine Services AS
Maritime Management	Amige SE, Murmansk
Type	2D seismic survey vessel
Port of registration	Murmansk
Flag	Russian
Class	KM UL 1 A2
Class registration no.	M-42019
Call sign	UGXK
IMO	8409018
MMSI	273458600
Year built/rebuilt	1988 Poland/1997 Norway. Upgraded 2006
Length overall	81.85 m
Beam	14.8 m
Draught, loaded	5.23 m
Tonnage	3225 gross tons, 967 net tons
Cruising speed	Max 14.5 knots, cruising 12.5 knots
Operation range	18 000 nmi
Endurance seismic production	72 days
Main engine	Zgoda-Zulcer, type 6ZL 40/48, 4200 HP/3090 kW
Gearbox	Zamech MA90-10, ratio 505/222
Propulsion	Zamen, controllable pitch. LN 13 NM, 4 blade stainless steel
Rudder	Simplex NACA-0018
Steering gear	Zamech M200-11-2
Azimuth thruster	N/A
Bow thruster	Brunvoll FU-45-LTC-1225, electrical, 600 HP/441 kW
Main engine monitoring	CPS-2
Electrical power	Total power: 2200 kW Voltage: 3 x 380 (220) VAC, 50 Hz Shaft generator: 1 x 1200 kW Generator: 2 x 500 kW
Emergency generator	217 PMa-39H6, 121 kW
Clean power	INV SitePro, 40 kVA UPS
Fuel capacity	1000 m^3
Fuel consumption	Sailing 12.0 t, working 10.0 t, in port 2.8 t
Fresh water capacity	200 ton
Fresh water generators	1 x Aqvamar AQ-16/20A, capacity 16 m^3 per day
Sewage treatment plant	Omnipure, installed 2006
Incinerator	TeamTecOGS 200C, installed 2007
Black water	9.9 m^3
Grey water	N/A
Bilge water	12.0 m^3



M/V GEO CORAL

VESSEL SPECIFICATIONS

TECHNICAL SPECIFICATIONS

WG00898428

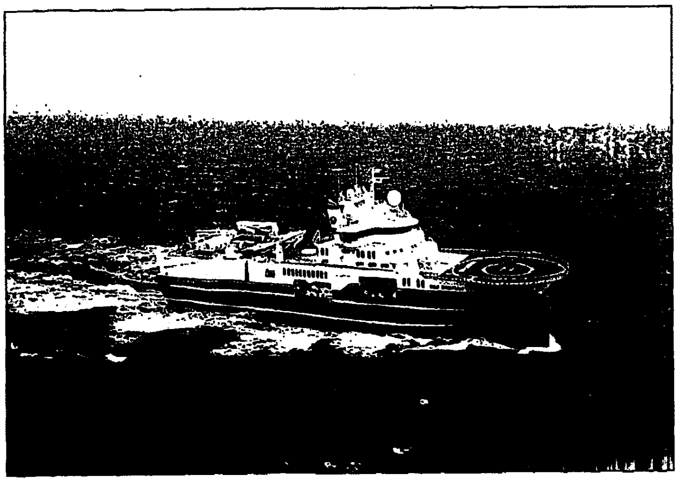
FUGRO

1. VESSEL

1.1. VESSEL GENERAL

Name	Geo Coral
Owner	Fugro Geo Coral Inc.
Operator	Fugro Norway Marine Services AS
Seismic management	Fugro Norway Marine Services AS
Maritime management	Wilhelmsen Ship Management
Type	3D seismic survey vessel
Port of registration	Bergen
Flag	Norway
Class	DNV
Class register no.	29519
Class notation	1A1 ICE-C SF COMF-V(3)C(3) HELDK-SH RP E0 NAUT-AW CLEAN DK(+) TMON
Call sign	LAIE7
IMO no.	9492579
MMSI	
Year built	2010
Length overall	108.3 m
Breadth overall	28.0 m
Draught	7.5 m
Tonnage	12812 gross tonnes, 3844 net tonnes
Cruising speed	15.0 knots
Operation range	World wide
Endurance seismic days max. load	
Main engine	4 x generating sets, each 3800 kW
Gearbox	2 x reduction, low noise type, ratio 6.5: 1
Propulsion	2 x 4200 KW Seimans, 720 rpm.
Rudder	2 x free hanging Becker type
Steering gear	Rolls Royce Tenfjord or similar
Bow thruster	1 x Retractable thruster 1500 kW 1 x Tunnel thruster 2000 kW
Main engine monitoring	Kongsberg-Simrad
Electrical power	4 x 3800 kW
Emergency generator	1 x 550 kW
Clean power	UPS
Fuel capacity	MDO 800 m^3, HFO 1700 m^3
Fuel consumption	App. 35 m^3 /day
Fresh water capacity	App. 475 m^3
Fresh water consumption	App. 15 t/day
Fresh water generator	2 x 25 m^3/24 hrs
Sewage treatment plant	Yes
Incinerator	Yes
Black water	23 m^3
Grey water	26 m^3
Bilge water	31 m^3 (18 m^3 + 13 m^3)
Sludge	17 m^3
Condens water compressors:	19 m^3
Waste water	
Lube oil	178 m^3 (120 m^3 LO + 58 m^3 HO)
Dirty oil	22.7 m^3

FUGRO



M/V GEO CASPIAN

VESSEL SPECIFICATIONS

TECHNICAL SPECIFICATIONS

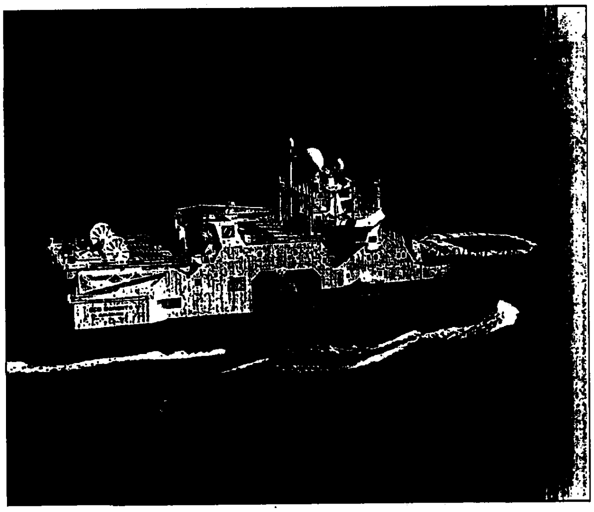
WG00898430

FUGRO

1. VESSEL

1.1. VESSEL GENERAL

Name	M/V Geo Caspian
Owner	Volstad Maritime AS
Operator	Fugro Norway Marine Services AS
Seismic management	Fugro Norway Marine Services AS
Maritime management	Volstad Maritime AS
Type	3D seismic survey vessel
Port of registration	Panama
Flag	Panama
Class	DNV; +1A1, RP, E0, COMF C3 COMF-V3, CLEAN DESIGN, NAUT AW, Helidk SH, ICE C
Class register no.	D29463
Call sign	3FCZ6
IMO no.	9525560
MMSI	371235000
Year built/rebuilt	2010
Length overall	108.30 m
Breadth	24.00/28.00 m
Draught, loaded	6.7 m (approx)
Tonnage	12708 gross tonnes, 3813 net tonnes
Cruising speed	15.0 knots
Operation range	World wide
Endurance seismic days max. load	60 days
Main engine	2 x Wartsila 9L32 4300 kW, 720 rpm 4 x Wartsila 9L20 1600 kW, 900 rpm
Gearbox	2 x Wartsila SV85, Single Input / Single output
Propulsion	2 x Wartsila 4500 kW, 4 blades in a nozzle
Rudder	2 x Rolls Royce Ulstein Hinze rudder
Steering gear	2 x Tenfjord SR722 FCP
Thrusters in bow	1 x Retractable thruster 2200 kW 1 x Tunnel thruster 2000 kW
Main engine monitoring	Høglund Marine
Electrical power	15000 kW (2 x 4300 kW + 4 x 1600 kW)
Emergency generator	1 x 315 kW
Clean power	UPS
Fuel capacity	2450 m^3
Fuel consumption	35 m^3
Fresh water capacity	Approx. 475 m^3
Fresh water consumption	22-25 m^3
Fresh water generator	2 x 25 m^3/24 hrs
Biological sewage treatment plant	Jets Biomaster DVZ - SKA
Incinerator	Saniterm SH-20-SM/SR
Black water	23 m^3
Grey water	26 m^3
Bilge water	31 m^3 (18 m^3 + 13 m^3)
Sludge	17 m^3
Condense water compressors	19 m^3
Lube oil	178 m^3 (120 m^3 LO + 58 m^3 HO)
Dirty oil	22.7 m^3
Stabilising system	Anti Rolling Tank



R/V GEO BARENTS

TECHNICAL SPECIFICATIONS

WG00898432

1. VESSEL

1.1. VESSEL GENERAL

Name	R/V Geo Barents
Operator	Fugro-Geoteam AS
Owner	Uksnøy Barents K/S
Seismic Management	Fugro Norway Marine Services AS
Maritime Management	Uksnøy and Co. AS
Type	3D seismic survey vessel
Port of registration	Bergen
Flag	Norway
Class	DNV
Class registration no.	23187
Class notation	1A1 SF COMF-V(3) HELDK-SH E0
Call sign	LAKK6
IMO	9252503
MMSI	258826000
Year built/rebuilt	2007
Length overall	76.95 m
Breadth	14.6 m
Draught	6.85
Tonnage	4979 gross tons, 1494 net tonnes
Cruising speed	App. 13 knots
Operation range	9360 nmi
Endurance seismic days max load	26
Main engine	ABC 2x3600 BHP@1000 rpm
Gearbox	1 x Finnøy dual input single out
Propulsion	1 x 4000 mm, 4 blades in a nozzle
Rudder	1 flap rudder
Steering gear	1 x RRM
Azimuth thrusters	Forward: 1 retractable CP prop. 880 kW AR63 LNC1650
Bow thrusters	1 fixed tunnel CP prop. 880 kW
Stern thruster	1 fixed tunnel CP prop. 880 kW
Main engine monitoring	Høglund Marine
Electrical power	4 x Cummins 1291 kW KTA50
Emergency generator	1 x Cummins 350 kW KTA19
Clean power	UPS
Fuel capacity	850 m^3
Fuel consumption	Approx 31 m^3/day in production
Fresh water capacity	90.34 m^3
Fresh water consumption	Approx 14 m^3/day
Fresh water generator	Alfa Laval 15 m^3/day
Sewage treatment plant	Jets
Incinerator	Kay Lindegard
Black water	9.2 m^3
Grey water	9.2 m^3

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SEP 0 1 2010
New Orleans LA
OFFSHORE RESOURCE EVALUATION

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico
(Insert Appropriate Regional Office)

PERMIT FOR GEOPHYSICAL EXPLORATION FOR MINERAL RESOURCES OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

In consideration of the terms and conditions contained herein and the authorization granted hereby, this permit is entered into by and between the United States of America (the Government), acting through the Minerals Management Service (MMS) of the Department of the Interior, and

Fugro Multi Client Services, Inc.
(Name of Permittee)

6100 Hillcroft
(Number and Street)

Houston, TX 77081
(City, State, and Zip Code)

PERMIT NUMBER: L10-0014 **DATE:** 01-Sep-2010

This permit is issued pursuant to the authority of the Outer Continental Shelf Lands Act, as amended, (43 U.S.C. 1331 et seq.), hereinafter called the "Act," and Title 30 Code of Federal Regulations Part 251 (Geological and Geophysical (G&G) Explorations of the Outer Continental Shelf).

Paperwork Reduction Act of 1995 (PRA) Statement: This permit refers to information collection requirements contained in 30 CFR part 251 regulations. The Office of Management and Budget (OMB) has approved those reporting requirements under OMB Control Number 1010-0048.

Section I. Authorization

The Government authorizes the permittee to conduct:

__X__ Geophysical exploration for mineral resources as defined in 30 CFR 251.1.

____ Geophysical scientific research as defined in 30 CFR 251.1. A permit is required for any geophysical investigation that involves the use of solid or liquid explosives or developing data and information for proprietary use or sale.

This permit authorizes the permittee to conduct the above geophysical activity during the period from 03-DEC-2010 to 02-FEB-2011 in the following area(s): GC, SS, EW __________. Extensions of the time period specified above must be requested in writing. A permit plus extensions for activities will be limited to a period of not more than 1 year from the original issuance date of the permit. Inspection and reporting of geophysical exploration activities, suspension and cancellation of authority to conduct exploration or scientific research activities under permit, and penalties and appeals will be carried out in accordance with 30 CFR 251.8, 251.9, and 251.10.

The authority of the Regional Director may be delegated to the Regional Supervisor for Resource Evaluation for the purposes of this permit.

Section II. Type(s) of Operations and Technique(s)

A. The permittee will employ the following type(s) of operations:
3D seismic recording (approximately 3,150 square miles),and gravity data
________________;

and will utilize the following instruments and/or technique(s) in such operations:
DGPS, Airguns, Solid Streamers, Shipboard Gravity Meter, Wide Azimuth Acquisition
________________.

B. The permittee will conduct all activities in compliance with the terms and conditions of this permit, including the "Stipulations," "Special Provisions," and the approved "Application for Permit," which are attached to and incorporated into this permit.

C. The permittee will conduct all geophysical exploration or scientific research activities in compliance with the Act, the regulations in 30 CFR Part 251, and other applicable statutes and regulations whether such statutes and regulations are enacted, promulgated, issued, or amended before or after this permit is issued. Some of the provisions of 30 CFR Part 251 are restated in this permit for emphasis. However, all of the provisions of 30 CFR Part 251 apply to this permit.

Section III. Reports on Operations

A. The permittee must submit status reports on a bimonthly basis in a manner approved or prescribed by the Regional Supervisor, Resource Evaluation (hereinafter referred to as Supervisor). The report must include a daily log of operations and a map (preferably on a scale of 1: 40,000) showing traverse lines according to Minerals Management Service (MMS) area and block numbers.

B. The permittee must submit to the Supervisor a final report within 30 days after the completion of operations. The final report must contain the following:

1. A description of the work performed including number of line miles or OCS blocks of geophysical data acquired;

2. Chart(s), map(s), or plat(s) depicting the areas and blocks in which any exploration or scientific research activities were conducted. These graphics must clearly indicate the location of the activities so that the data produced from the activities can be accurately located and identified;

3. The dates on which the actual geophysical exploration or scientific research activities were performed;

4. A narrative summary of any: (a) hydrocarbon occurrences or environmental hazards observed and (b) adverse effects of the geophysical exploration or scientific research activities on the environment, aquatic life, archaeological resources, or other uses of the area in which the activities were conducted;

5. The estimated date on which the processed or interpreted data or information will be available for inspection by the MMS;

6. A final edited navigation tape or other suitable storage medium of all data or sample locations in latitude/longitude degrees. The tape is to be formatted in SEG P1, coded in ASCII with fixed record length and fixed block size. A printed listing and a format statement are to be included;

7. Identification of geocentric ellipsoid (NAD 27 or NAD 83) used as a reference for the data or sample locations; and

8. Such other descriptions of the activities conducted as may be specified by the Supervisor.

C. The last status report and the final report can be combined into one report.

Section IV. <u>Submission, Inspection, and Selection of Geophysical Data and Information</u>

A. The permittee must notify the Supervisor, in writing, when the permittee has completed the initial processing and interpretation of any geophysical data and information collected under an exploration permit or a scientific research permit that involves developing data and information for proprietary use or sale. If the Supervisor asks if the permittee has further processed or interpreted any geophysical data and information collected under a permit, the permittee must respond within 30 days. If further processing of the data and information is conducted, it is the responsibility of the permittee to keep the most current resulting products available in the event the Supervisor requests the current status of data processing. At any time within 10 years after receiving notification of the completion of the acquisition activities conducted under the permit, the Supervisor may request that the permittee submit for inspection and possible retention all or part of the geophysical data, processed geophysical information, and interpreted geophysical information.

B. The Supervisor will have the right to inspect and select the geophysical data, processed geophysical information, or interpreted geophysical information. This inspection will be performed on the permittee's premises unless the Supervisor requests that the permittee submit the data or information to the Supervisor for inspection. Such submission must be within 30 days following the receipt of the Supervisor's request unless the Supervisor authorizes a later delivery date. If the inspection is done on the permittee's premises, the permittee must submit the geophysical data or information selected within 30 days following receipt of the Supervisor's request, unless the Supervisor authorizes a longer period of time for delivery. The data or information requested for inspection or selected by the Supervisor must be submitted regardless of whether the permittee and the Government have or have not concluded an agreement for reimbursement. If the Supervisor decides to retain all or a portion of the geophysical data or information, the Supervisor will notify the permittee, in writing, of this decision.

C. In the event that a third party obtains geophysical data, processed geophysical information, or interpreted geophysical information from a permittee, or from another third party, by sale, trade, license agreement, or other means:

1. The third party recipient of the data and information assumes the obligations under this section except for notification of initial processing and interpretation of the data and information and is subject to the penalty provisions of 30 CFR Part 250, Subpart N; and

2. A permittee or third party that sells, trades, licenses, or otherwise provides the data and information to a third party must advise the recipient, in writing, that accepting these obligations is a condition precedent of the sale, trade, license, or other agreement; and

3. Except for license agreements, a permittee or third party that sells, trades, or otherwise provides data and information to a third party must advise the Supervisor in writing within 30 days of the sale, trade, or other agreement, including the identity of the recipient of the data and information; or

4. With regard to license agreements, a permittee or third party that licenses data and information to a third party, within 30 days of a request by the Supervisor, must advise the Supervisor, in writing, of the license agreement, including the identity of the recipient of the data and information.

D. Each submission of geophysical data, processed geophysical information, and interpreted geophysical information must contain, unless otherwise specified by the Supervisor, the following:

1. An accurate and complete record of each geophysical survey conducted under the permit, including digital navigational data and final location maps of all surveys;

2. All seismic data developed under a permit presented in a format and of a quality suitable for processing;

3. Processed geophysical information derived from seismic data with extraneous signals and interference removed, presented in a format and of a quality suitable for interpretive evaluation, reflecting state-of-the-art processing techniques; and

4. Other geophysical data, processed geophysical information, and interpreted geophysical information obtained from, but not limited to, shallow and deep subbottom profiles, bathymetry, side-scan sonar, gravity, magnetic, and electrical surveys, and special studies such as refraction, shear wave, and velocity surveys.

Section V. Reimbursement to Permittees

A. After the delivery of geophysical data, processed geophysical information, and interpreted geophysical information requested by the Supervisor in accordance with subsection IV of this permit, and upon receipt of a request for reimbursement and a determination by MMS that the requested reimbursement is proper, MMS will reimburse the permittee or third party for the reasonable costs of reproducing the submitted data and information at the permittee's or third party's lowest rate or at the lowest commercial rate established in the area, whichever is less.

B. If the processing was in a form and manner other than that used in the normal conduct of the permittee's business at MMS's request, MMS will reimburse the permittee or third party for the reasonable costs of processing or reprocessing such data. Requests for reimbursement must identify processing costs separate from acquisition costs.

C. The permittee or third party will not be reimbursed for the costs of acquiring or interpreting geophysical information.

D. Data and information required under section IV.D.1. of this permit are not considered to be geophysical data or processed geophysical information and must be provided by the permittee at no cost to the Government.

Section VI. Disclosure of Data and Information to the Public

A. The MMS will make data and information submitted by a permittee available in accordance with the requirements and subject to the limitations of the Freedom of Information Act (5 U.S.C. 552) and the implementing regulations (43 CFR Part 2), the requirements of the Act, and the regulations contained in 30 CFR Part 250 (Oil and Gas and Sulphur Operations in the Outer Continental Shelf), 30 CFR Part 251, and 30 CFR Part 252 (Outer Continental Shelf (OCS) Oil and Gas Information Program).

B. Except as specified in this section, or Section VIII, or in 30 CFR Parts 250 and 252, no data or information determined by MMS to be exempt from public disclosure under subsection A of this section will be provided to any affected State or be made available to the executive of any affected local government or to the public, unless the permittee or third party and all persons to whom such permittee has sold, traded, or licensed the data or information under promise of confidentiality agree to such an action.

C. Geophysical data and processed or interpreted geophysical information submitted under a permit, and retained by MMS, will be disclosed as follows:

1. Except for deep stratigraphic tests, the MMS will make available to the public geophysical data 50 years after the date of issuance of the permit under which the data were collected (See 251.12 (a) (b) (c) and (d)).

2. Except for deep stratigraphic tests, the MMS will make available to the public processed geophysical information and interpreted geophysical information 25 years after the date of issuance of the permit under which the original data were collected (See 251.12 (a) (b) (c) and (d)).

3. The MMS will make available to the public all geophysical data and information and geophysical interpretations related to a deep stratigraphic test, at the earlier of the following times: (a) 25 years after the completion of the test, or (b) for a lease sale held after the test well

is completed, 60 calendar days after the Department of the Interior executes the first lease for a block, any part of which is within 50 geographic miles (92.6 kilometers) of the site of the completed test.

D. All line-specific preplot or postplot plat(s), and navigation tapes, including but not limited to seismic survey traverses and shotpoint locations, submitted as a requirement of 30 CFR 251.7 or 251.12, will be considered as "PROPRIETARY INFORMATION." Such information will not be made available to the public without the consent of the permittee for a period of 25 years from the date of issuance of the permit, unless the Director, MMS, determines that earlier release is necessary for the proper development of the area permitted.

E. All other information submitted as a requirement of 30 CFR 251.8 and determined by MMS to be exempt from public disclosure will be considered as "PROPRIETARY." Such data and information will not be made available to the public without the consent of the permittee for a period of up to 25 years from the date of issuance of the permit as addressed in 30 CFR 251.14, unless the Director, MMS, determines that earlier release is necessary for the proper development of the area permitted. The executed permit will be considered as "PROPRIETARY" except the public information copy which will be available to the public upon request.

F. The identities of third party recipients of data and information collected under a permit will be kept confidential. The identities will not be released unless the permittee and the third parties agree to the disclosure.

Section VII. Disclosure to Independent Contractors

The MMS reserves the right to disclose any data or information acquired from a permittee to an independent contractor or agent for the purpose of reproducing, processing, reprocessing, or interpreting such data or information. When practicable, MMS will advise the permittee who provided the data or information of intent to disclose the data or information to an independent contractor or agent. The MMS's notice of intent will afford the permittee a period of not less than 5 working days within which to comment on the intended action. When MMS so advises a permittee of the intent to disclose data or information to an independent contractor or agent, all other owners of such data or information will be deemed to have been notified of MMS's intent. Prior to any such disclosure, the contractor or agent will be required to execute a written commitment not to sell, trade, license, or disclose any data or information to anyone without the express consent of MMS.

Section VIII. Sharing of Information with Affected States

A. At the time of soliciting nominations for the leasing of lands within 3 geographic miles of the seaward boundary of any coastal State, MMS, pursuant to the provisions of 30 CFR 252.7 and subsections 8(g) and 26(e) (43 U.S.C. 1337(g) and 1352(e)) of the Act, will provide the Governor of the State (or the Governor's designated representative) the following information that has been acquired by MMS on such lands proposed to be offered for leasing:

1. All information on the geographical, geological, and ecological characteristics of the areas and regions proposed to be offered for leasing;

2. An estimate of the oil and gas reserves in the area proposed for leasing; and

3. An identification of any field, geological structure, or trap located within 3 miles of the seaward boundary of the State.

B. After the time of receipt of nominations for any area of the OCS within 3 geographic miles of the seaward boundary of any coastal State and Area Identification in accordance with the provisions of Subparts D and E of 30 CFR Part 256, MMS, in consultation with the Governor of the State (or the Governor's designated representative), will determine whether any tracts being given further consideration for leasing may contain one or more oil or gas reservoirs underlying both the OCS and lands subject to the jurisdiction of the State.

C. At any time prior to a sale, information acquired by MMS that pertains to the identification of potential and/or proven common hydrocarbon-bearing areas within 3 geographic miles of the seaward boundary of any such State will be shared, upon request by the Governor and pursuant to the provisions of 30 CFR 252.7 and subsections 8(g) and 26(e) of the Act, with the Governor of such State (or the Governor's designated representative).

D. Knowledge obtained by a State official who receives information under subsections A, B, and C of this section will be subject to the requirements and limitations of the Act and the regulations contained in 30 CFR Part 250, Part 251, and Part 252.

Section IX. Permit Modifications

The Department will have the right at any time to modify or amend any provisions of this permit, except that the Department will not have such right with respect to the provisions of Sections VI, VII, and VIII hereof, unless required by an Act of Congress.

IN WITNESS WHEREOF the parties have executed this permit and it will be effective as of the date of signature by the Supervisor.

PERMITTEE:	THE UNITED STATES OF AMERICA:
[signature]	[signature]
(Signature of Permittee)	(Signature of Regional Supervisor)
Kenneth W. Mohn	David W. Cooke
(Type or Print Name of Permittee)	(Type or Print Name of Regional Supervisor)
Exploration V.P. Fugro Multi Client Services, Inc.	12/2/10
(Title)	(Date)
8-31-2010	
(Date)	

ENVIRONMENTAL PROTECTIVE MEASURES

1. Comply with the provisions of NTL No. 2007-G02, Implementation of Seismic Survey Measures and Protected Species Observer Program, effective February 7, 2007 (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/2007NTLs/07-g02.pdf).

2. Comply with the provisions of NTL No. 2007-G03, Marine Trash and Debris Awareness and Elimination, effective February 7, 2007 (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/2007NTLs/07-g03.pdf).

3. Comply with the provisions of NTL No. 2007-G04, Vessel Strike Avoidance and Injured/Dead Protected Species Reporting, effective February 7, 2007 (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/2007NTLs/07-g04.pdf).

4. Man-made structure(s) such as pipeline(s) or other potential hazard(s) may be located in the permitted work area; therefore, prior to performing operations that involve bottom surface disturbance (e.g., coring), take precautions in accordance with Notice to Lessees and Operators No. 2008-G05, Section VI.B. (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/2008NTLs/08-g05.pdf)

5. If you conduct activities that could disturb the seafloor in an Ordnance Dumping Area (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/jl06006.pdf for a map), exercise caution, since this area might contain old ordnance, including unexploded shells and depth charges, dumped before 1970. In addition, the U.S. Air Force has released an undeterminable amount of unexploded ordnance in Water Test Areas 1 through 5 (most of the Eastern Planning Area of the GOM).

6. If you discover any site, structure, or object of potential archaeological significance (i.e., cannot be definitively identified as modern debris or refuse) while conducting operations, the provisions of 30 CFR 250.194(c) and NTL 2005-G07 require you to immediately halt operations within 1,000 feet of the area of discovery and report this discovery to the Regional Supervisor of Leasing and Environment (RSLE) within 48 hours. Every reasonable effort must be taken to preserve the archaeological resource from damage until the RSLE has told you how to protect it.

7. If you conduct activities within a military warning or water test area (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/MWA_boundaries.pdf for a map), or if the associated boat or aircraft traffic will traverse a military warning or water test area, contact the commander(s) of the appropriate command headquarters having jurisdiction over the respective area(s) before you commence such traffic. You can obtain the names and telephone numbers of the command headquarters for each military warning and water test area by consulting the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/Military%20Contacts.pdf.

8. Comply with the provisions of NTL 2004-G05, Biologically Sensitive Areas of the Gulf of Mexico, effective April 1, 2004, (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl04-g05.pdf). If you conduct activities near an identified biologically sensitive topographic feature (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/topoblocks.pdf for a list and http://www.gomr.mms.gov/homepg/regulate/environ/topomap.pdf for a map), make sure that you do not anchor or otherwise disturb the seafloor within 152 meters (500 feet) of its designated "No Activity Zone." Within 90 calendar days after completing activities that disturbed the seafloor within 305 meters (1,000 feet) of the "No Activity Zone" of a biologically sensitive topographic feature, submit to the MMS GOMR Data Acquisition and Special Project Unit (see page 4 of these "Protective Measures" for the address) a map at a scale of 1 inch = 1,000 feet with DGPS accuracy, showing the location of the seafloor disturbance relative to these features.

9. Comply with the provisions of NTL 2004-G05, Biologically Sensitive Areas of the Gulf of Mexico, effective April 1, 2004, (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl04-g05.pdf). If you conduct activities in the Live Bottom "Pinnacle Trend" area (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/topoblocks.pdf for a list and http://www.gomr.mms.gov/homepg/regulate/environ/topomap.pdf for a map), make sure that you do not anchor or otherwise disturb the seafloor within 30 meters (100 feet) of any identified pinnacles or other hard bottoms that have a vertical relief of eight feet or more. Within 90 calendar days after completing an ancillary activity that disturbed the seafloor within 61 meters (200 feet) of pinnacles in the "Pinnacle Trend" area, submit to the MMS GOMR Data Acquisition and Special Project Unit (see page 4 of these "Protective Measures" for the address) a map at a scale of 1 inch = 1,000 feet with DGPS accuracy, showing the location of the seafloor disturbance relative to these features.

10. Comply with the provisions of NTL 2004-G05, Biologically Sensitive Areas of the Gulf of Mexico, effective April 1, 2004, (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl04-g05.pdf). If you conduct activities in the Live Bottom "Low Relief" area (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/topomap.pdf for a map), make sure that you do not anchor or otherwise disturb the seafloor near any identified live bottom low relief features. Within 90 calendar days after completing an ancillary activity that disturbed the seafloor within 30 meters (100 feet) of live bottom low relief features, submit to the MMS GOMR Data Acquisition and Special Project Unit (see page 4 of these "Protective Measures" for the address) a map at a scale of 1 inch = 1,000 feet with DGPS accuracy, showing the location of the seafloor disturbance relative to these features.

11. If you conduct activities in water depths 400 meters (1,312 feet) or greater, make sure that you do not anchor, use anchor chains wire ropes or cables, or otherwise disturb the seafloor within 76 meters (250 feet) of any features or areas that could support high-density chemosynthetic communities. The known chemosynthetic community sites are listed in Appendix A of NTL No. 2000-G20, Deepwater Chemosynthetic Communities, effective December 6, 2000 (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl00-g20.html). Within 90 calendar days after completing an ancillary activity that disturbed the seafloor within 152 meters (500 feet) of features or areas that could support high-density chemosynthetic communities, submit to the MMS GOMR Data Acquisition and Special Project Unit (see page 4 of these "Protective Measures" for the address) a map at a scale of 1 inch = 1,000 feet with DGPS accuracy, showing the location of the seafloor disturbance relative to these features.

12. Comply with the provisions of NTL 2004-G05, Biologically Sensitive Areas of the Gulf of Mexico, effective April 1, 2004, (see the MMS website at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl04-g05.pdf). If you discover any high-relief topographic feature with a relief greater than eight (8) feet while conducting activities, report the discovery to the MMS GOMR Regional Director. Make sure you do not anchor on or otherwise disturb such a feature. Within 90 calendar days after completing an ancillary activity that disturbed the seafloor within 30 meters (100 feet) of such a feature, submit to the MMS GOMR Data Acquisition and Special Project Unit (see page 4 of these "Protective Measures" for the address) a map at a scale of 1 inch = 1,000 feet with DGPS accuracy, showing the location of the seafloor disturbance relative to the feature.

13. Before you conduct activities that could disturb the seafloor within 254 meters (1,000 feet) of a Texas artificial reef site or artificial reef permit area, within152 meters (500 feet) of a Louisiana artificial reef site or artificial reef permit area, or could disturb the seafloor within a General Permit Area established by the States of Texas, Alabama or Florida for the placement of artificial reef material, contact the appropriate State reef management agency. See the MMS websites at http://www.gomr.mms.gov/homepg/regulate/environ/artreefmap.pdf for a map and http://www.gomr.mms.gov/homepg/regulate/environ/artreefcontacts.pdf for State contacts.

14. If you conduct activities within the boundaries of the Flower Gardens National Marine Sanctuary (Flower Gardens Banks and Stetson Bank), exercise caution to ensure that such activities do not endanger any other users of the Sanctuary. See the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/FGNMSmap.pdf for map. Additionally, if the activities involve moving the marker buoys at the Sanctuary, contact Mr. G. P. Schmahl, the current Sanctuary Manager, for instructions. See the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/FGNMScontacts.pdf for Mr. Schmahl's contact information. See the MMS website at http://www.gomr.mms.gov/homepg/regulate/environ/FGNMSbuoys.pdf for the locations of the Flower Gardens' marker buoys.

15. If your proposed activities will involve using boats from a port located south of the Suwannee River mouth in Florida, make sure that you adhere to the following manatee protection plan:

a. Advise your personnel of the possibility of the presence of manatees in the inland and coastal waters of Florida in the Eastern GOM.

b. Advise your personnel that there are civil and criminal penalties for harming, harassing, or killing manatees, which are protected under the Endangered Species Act, the Marine Mammal Protection Act, and the Florida Manatee Sanctuary Act of 1978.

c. Advise your vessel operators to (1) use the deeper ship channels to the maximum extent possible; (2) avoid collisions with manatees and to stay within the existing channels; and (3) obey all speed restrictions and travel at "no wake/idle" speeds at all times while operating in shallow water or in channels where the draft of the vessel provides less than four (4) feet of clearance. (Areas of manatee concentrations have been identified and speed limit signs have been erected in accordance with Federal, State, and local regulations.)

d. While vessels are berthed in port, advise your vessel operators to use fenders between the dock and the vessel and/or between adjacent vessels berthed side-by-side. Make sure that the fenders have a minimum clearance of three feet when compressed between the dock and the vessel.

e. Ensure that your vessel operators keep logs detailing any sighting of, collision with, damage to, or death of manatees that occur while you conduct an ancillary activity. If a mishap involving a manatee should occur, make sure that the vessel operator immediately calls the "Manatee Hotline" ((888) 404-3922), and the U.S. Fish and Wildlife Service, Jacksonville Field Office ((904) 232-2580) for north Florida or the U.S. Fish and Wildlife Service, Vero Beach Ecosystem Office ((772) 562-3909) for south Florida.

f. Within 60 calendar days after completing the ancillary activity, submit a report summarizing all manatee incidents and sightings to the Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission, 100 Eighth Avenue SE, St. Petersburg, FL 33701-5095; and to the U.S. Fish and Wildlife Service, 6620 Southpoint Drive South, Suite 310, Jacksonville, FL 32216-0958, for north Florida, or to the U.S. Fish and Wildlife Service, 1339 20th Street, Vero Beach, Florida 32960-3559, for south Florida.

16. The Magnuson-Stevens Fisheries Conservation and Management Act (see 50 CFR 600.725) prohibits the use of explosives to take reef fish in the Exclusive Economic Zone. Therefore, if your activities involve the use of explosives, and the explosions result in stunned or killed fish, do not take such fish on board your vessels. If you do, you could be charged by the National Oceanic and Atmospheric Administration Fisheries Service (NOAA Fisheries Service) with a violation of the aforementioned Act. If you have any questions, contact NOAA Fisheries Service, Office for Law Enforcement, Southeast Division, at (727) 824-5344.

17. When operations extend south of approximately 26 degrees north latitude in the Western Gulf of Mexico or 24 degrees to 25 degrees north latitude in the Eastern Gulf (the 200-nautical mile provisional maritime also called the Exclusive Economic Zone Conservation Zone Limit), notify the Department of State: Ms. Liz Tirpak Room 5801, OES/OA, Department of State, Director, Office of Ocean Affairs, Washington, D.C., 20520, at (202) 647-1106.

18. MMS GOMR Data Acquisition and Special Project Unit Address:

Regional Supervisor, Resource Evaluation
Resource Studies Section
Data Acquisition and Special Project Unit (MS 5123)
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

(Rev. 03/2010)

Stipulations

In performance of any operations under the Permit and Agreement for Outer Continental Shelf Geophysical or Geological Exploration for Mineral Resources or Scientific Research, the Permittee shall comply with the following Stipulations:

1. As part of the requirements of 30 CFR 251.6(a), if any operation under this Permit and Agreement is to be conducted in a leased area, the Permittee shall take all necessary precautions to avoid interference with operations on the lease and damage of existing structures and facilities. The lessee (or operator) of the leased area will be notified, in writing, before the Permittee enters the leased area, or commences operations, and a copy of the notification will be sent to the Regional Supervisor executing this Permit and Agreement.

2. (a) Solid or liquid explosives shall not be used, except pursuant to written authorization from the Regional Supervisor. Requests of the use of such explosives must be in writing, giving the size of charges to be used, the depth at which they are to be detonated, and the specific precautionary methods proposed for the protection of fish, oysters, shrimp, and other natural resources. The use of explosives represents a may affect situation under Section 7 of the Endangered Species Act of 1973, as amended.

   (b) The following provisions are made applicable when geophysical exploration on the Outer Continental Shelf using explosives is approved:

      (i) Each explosive charge will be permanently identified by markings so that unexploded charges may be positively traced to the Permittee and to the specific field party of the Permittee responsible for the explosive charge.

(ii) The placing of explosive charges on the seafloor is prohibited. No explosive charges shall be detonated nearer to the seafloor than five (5) feet (1.52 meters).

(iii) No explosive shall be discharged within 1,000 feet (304.8 meters) of any boat not involved in the survey.

3. Any serious accident, personal injury, or loss of property shall be immediately reported to the Regional Supervisor.

4. All pipes, buoys, and other markers used in connection with seismic work shall be properly flagged and lighted according to the navigation rules of the U.S. Corps of Engineers and the U.S. Coast Guard.

5. In compliance with Section III- B(6) of this permit, digital navigation data shall be recorded on tape or other suitable storage media for seismic reflection surveys. The navigation data shall be in a format according to SEG P1 (Morgan, J.G., et al, 1983, SEG Standard Exchange Formats for Positional Data, Society of Exploration Geophysicists, Special Report). For 2-dimensional seismic events, a geographic location shall be reported for every shot point, irrespective of SEG P1 specifications. For 3-dimensional surveys, the first and last binned and centered locations for each line only shall be reported in SEG P1 format. Suitable media include, but are not limited to, 3 ½ inch diskettes or CD-ROM coded in ASCII. All formatting are to be in accordance with Exchange Format for Postplot Location Data presented in Notice to Permittees dated August 14,1990.

6. In addition to the Stipulations above, the Environmental Protective Measures attached hereto shall apply.

Fugro Multi Client Services

FUGRO

6100 Hillcroft (77081)
P.O. Box 740010
Houston, Texas 77274, U.S.A.
Phone: +1 713 369 5800
Fax: +1 713 369 5860

January 12, 2010

United States Department of the Interior
Bureau of Ocean Energy Management, Regulation, and Enforcement
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, LA 70123-2394

Attn: Ms. Rebecca Murphy

SUBJECT: PERMIT NO. L10-044

Dear Ms. Murphy:

We write to request amendment of Permit No. L 10-044:

1. Fugro Multi Client Services, Inc. requests an amendment of the acquisition timing and survey area under permit L10-044. Due to the uncertainty of when the permit would arrive, we have temporarily lost to other work two of the vessels that will be acquiring data on this permit. The vessels currently have acquisition commitments until the end of February. Because of these commitments, which are beyond our control, Fugro Multi Client Services, Inc. requests that the period to conduct geophysical activity be set to begin on March 21, 2011 with a completion date of March 20th 2012. This would make the permit valid for extensions for 1 year from the March 21, 2011 date.

2. Fugro requests that the permit outline be amended. We have modified the shooting direction and we want to extend the survey to make the acquisition more efficient. We need to enlarge the area to get better aperture to image the deeper structures. The northern portion will be reduced to keep the square mileage as close to the original as possible. The permit was approved for a full fold area of 3,150 square miles. The proposed new area is approximately 3,500 square miles. Please refer to the map below, which reflects the change request.

3. In the General Information section of the Permit, under Section A, 1., the information regarding 'Name of the Service Company or Purchaser' and 'the activity will be conducted by:' is incorrect on the permit application. It should read: Fugro Geoteam, Inc. in both instances. The address and contact information are correct for Fugro Geoteam Inc.; the incorrect company name was used. The work is to be conducted by Fugro Geoteam Inc.

4. The Phone Number and Fax Number for Fugro Geoteam Inc. are corrected to reflect the Switchboard and the correct Fax number.

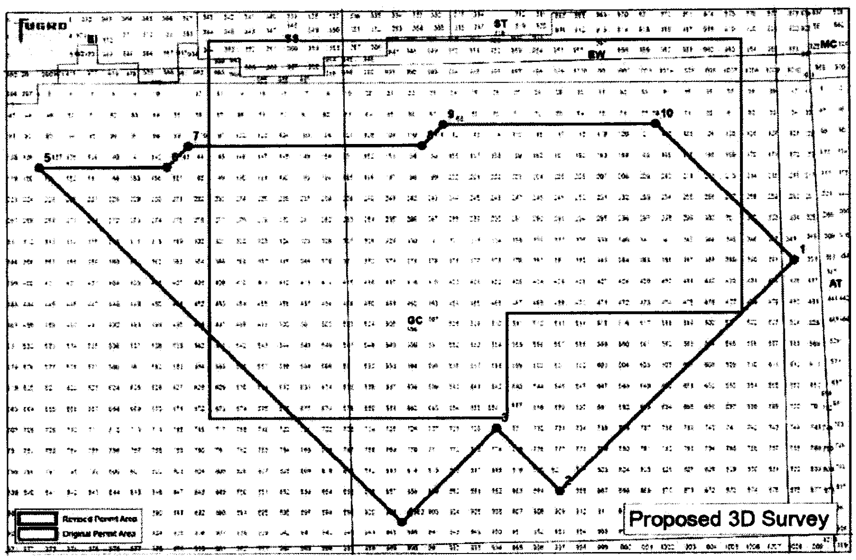
5. Finally, upon review of the survey area, the port from which the vessels will operate is Fourchon, LA. Galveston, TX should be removed.

All of the above requests are part of the Attachment 1 of form 327r. We have updated the Attachment and highlighted the updates. We hope these amendments are acceptable and we look forward to hearing from you if you have any questions. We would very much appreciate your acknowledgment of receipt of this amendment request by return facsimile to 713 369-5860.

Sincerely,

Kenneth Mohn
Exploration Vice President
Fugro Multi Client Services, Inc.

Approved area in Red
Amend request in Purple



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OMB Control No. 1010-0048
OMB Approval Expires: August 31, 2012

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico Region
(Insert Appropriate Regional Office)

Requirements for Geological and Geophysical Explorations or Scientific Research in the Outer Continental Shelf

Application for Permit to Conduct Geological or Geophysical Exploration for Mineral Resources or Scientific Research in the Outer Continental Shelf

(Attachment 1)

Nonexclusive Use Agreement for Scientific Research

(Attachment 2)

SUBMIT: Original, two copies, and one public information copy (all with original signatures).

Paperwork Reduction Act of 1995 (PRA) Statement: The PRA (44 U.S.C. 3501 et seq.) requires us to inform you that the Minerals Management Service (MMS) collects this information to evaluate applications for permits to conduct pre-lease exploration offshore and to monitor activities of scientific research conducted under notices. The MMS uses the information to ensure there is no environmental degradation, personnel harm, damage to historical or cultural sites, or interference with other uses. Responses are mandatory to obtain a benefit. Proprietary information is protected in accordance with standards established by the Federal Oil and Gas Royalty Management Act of 1982 (30 U.S.C. 1733), the Freedom of Information Act (5 U.S.C. 552(1), (4)), and the Department regulations (43 CFR 2). An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid Office of Management and Budget control number. The reporting burden for this form is estimated to average 3 hours per response, including the time for reviewing instructions, gathering and maintaining data, and completing and reviewing the form. Direct comments regarding the burden estimate or any other aspect of this form to the Information Collection Clearance Officer, Minerals Management Service, Mail Stop 5438, 1849 C Street, NW, Washington, DC 20240.

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

REQUIREMENTS FOR GEOLOGICAL AND GEOPHYSICAL EXPLORATIONS OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

Authority

You must perform all geological and geophysical explorations or scientific research activities authorized and conducted in the Outer Continental Shelf (OCS) according to the OCS Lands Act, 30 CFR Part 251, and other applicable Federal statutes and regulations, and amendments thereto.

General Requirements of Permits and Notices

You must conduct geological and geophysical activities for mineral exploration or scientific research activities authorized under 30 CFR Part 251 so that those activities do not:

A. Interfere with or endanger operations under any lease or right-of-way or permit issued or maintained pursuant to the OCS Lands Act;
B. Cause harm or damage to aquatic life or to the marine, coastal, or human environment;
C. Cause pollution;
D. Create hazardous or unsafe conditions;
E. Unreasonably interfere with or harm other uses of the area; or
F. Disturb archaeological resources.

Any person conducting geological or geophysical activities for mineral exploration or scientific research under 30 CFR Part 251 must immediately report to the Director, MMS:

A. Detection of hydrocarbon occurrences;
B. Encounters of environmental hazards that constitute an imminent threat to human activity; or
C. Activities that adversely affect the environment, aquatic life, archaeological resources, or other uses of the area in which the exploration or scientific research activities are conducted.

Any person conducting shallow or deep stratigraphic test drilling activities under a permit for mineral exploration or scientific research under 30 CFR Part 251 must utilize the best available and safest technologies that MMS determines to be economically feasible.

The authorization that MMS grants you under 30 CFR Part 251 to conduct geological and geophysical explorations for minerals or for scientific research does not confer a right to any discovered oil, gas, or other minerals, or to a lease under the OCS Lands Act.

Time Restriction for Permits and Notices

Permitted activities approved for a specified period, including requests for extensions, and activities under a notice may not exceed 1 year.

Geological and Geophysical Activities Requiring Permits and Notices

Geological and Geophysical Explorations for Mineral Resources

You may not conduct geological and geophysical explorations for mineral resources in the OCS without an approved permit unless you conduct such activities pursuant to a lease issued or maintained under the OCS Lands Act. You must obtain separate permits for either geological or geophysical explorations for mineral resources. If MMS disapproves an application, the statement of rejection will state the reasons for the denial and will advise the applicant of those changes needed to obtain approval.

Geological and Geophysical Scientific Research

You may not conduct geological and geophysical scientific research related to oil, gas, and sulphur in the OCS without an approved application for permit or filing of a notice. You must obtain separate permits for geological and geophysical scientific research that involves the use of solid or liquid explosives or the drilling of a deep stratigraphic test. If MMS disapproves an application for permit, the statement of rejection will state the reasons for the denial and will advise the applicant of the changes needed to obtain approval.

You must file a notice with the MMS at least 30 days before you begin scientific research not requiring a permit. We may inform you of all environmental laws and regulations pertaining to the OCS.

Information Required for Permits

Each applicant for a permit must complete the applicable sections of the Application for Permit (Attachment 1) and must include a page-size plat(s) showing the location of the proposed activity. The plat(s) should show geographic coordinates relative to the MMS area and block numbers, an easily identified onshore point of reference, and the distance and direction from the point of reference to area of activity. Line locations should not be included on these plat(s). In addition, each applicant for a geological or geophysical permit must submit the appropriate attachment to section D of the application. Each applicant for a scientific research permit must also complete a Nonexclusive Use Agreement (Attachment 2).

The information provided on the Application for Permit (excluding section D) and on the Nonexclusive Use Agreement, including continuation sheets and the page-size plat(s), is considered NON-PROPRIETARY INFORMATION. These non-proprietary portions of the application constitute the "public information" copy of Form 327 and with the executed permit will be available to the public upon request.

The information listed in section D is considered PROPRIETARY INFORMATION and you should NOT attach it to the public information copy. The MMS will not make this information available to the public without the consent of the potential permittee or for a period mandated by law or regulation. However, MMS may determine that earlier release is necessary for the proper development of the area permitted.

Modifications to Approved Permits

The MMS Regional Supervisor must approve any modification to the permitted operations.

Filing Locations for Permits to Conduct Explorations for Mineral Resources and for Permits or Notices to Conduct Scientific Research

File each notice or application for a permit in triplicate, plus one public information copy, at the following locations 30 days before you begin operations:

A. For the OCS off the State of Alaska:

Regional Supervisor for Resource Evaluation
Minerals Management Service
Alaska OCS Region
3801 Centerpoint Drive
Suite #500
Anchorage, Alaska 99503-5820

B. For the OCS in the Gulf of Mexico, off the Atlantic Coast:

Regional Supervisor for Resource Evaluation
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

C. For the OCS off the States of California, Oregon, Washington, or Hawaii:

Chief, Office of Reservoir Evaluation & Production
Minerals Management Service
Pacific OCS Region
770 Paseo Camarillo
Camarillo, California 93010-6092

Attachment 1

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico Region
(Insert Appropriate Regional Office)

APPLICATION FOR PERMIT TO CONDUCT GEOLOGICAL OR GEOPHYSICAL EXPLORATION FOR MINERAL RESOURCES OR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

(Section 11, Outer Continental Shelf Lands Act of August 7, 1953, as amended on September 18, 1978, by Public Law 95-372, 92 Statute 629, 43 U.S.C. 1340; and 30 CFR Part 251)

Fugro Multi Client Services, Inc.
Name of Applicant

6100 Hillcroft Ave
Number and Street

Houston, TX 77081
City, State, and Zip Code

Fugro Geoteam, Inc
Name of Service Company or Purchaser
(if different from above)

Application is made for the following activity: (check one)

______Geological exploration for mineral resources

______Geological scientific research

___X___Geophysical exploration for mineral resources

______Geophysical scientific research

Submit: Original, two copies, and one public information copy.

To be completed by MMS

Permit Number: ______________________ **Date:** ______________________

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A. General Information

1. The activity will be conducted by:

Service Company		Purchaser
Fugro Geoteam, Inc. (Service Company Name)	For	Fugro Multi Client Services, Inc. (Purchaser(s) of the Data)
6100 Hillcroft (Address)		6100 Hillcroft (Address)
Houston, TX 77081 (City, State, Zip)		Houston, TX 77081 (City, State, Zip)
713-369-5800/713-346-4054 (Telephone/FAX Numbers)		713-369-5859/713-369-5860 (Telephone/FAX Numbers)
hcvaage@fugro.com (E-Mail Address)		kmohn@fugro.com (E-Mail Address)

2. The purpose of the activity is: X Mineral exploration

   ______ Scientific research

3. Describe the environmental effects of the proposed activity, including potential adverse effects on marine life and what steps are planned to minimize these adverse effects (use continuation sheets as necessary):
   Expect minimal environmental effects. Vessel will adhere strictly to MMS regulations regarding marine mammal procedures and sightings (& recording of these).

4. The expected commencement date is: March 21, 2011

   The expected completion date is: March 20, 2012

5. The name of the individual in charge of the field operation is: Michael Whitehead/Steve Garrison

   May be contacted at: 713-369-5862/713-778-6824

   Telephone (Local) 713-369-5859 (Kenneth Mohn) (Marine) 713-778-6824

   Radio call sign 3FCZ6/LAIE7

6. The vessel(s) to be used in the operation is (are):

   Name MV Geo Caspian/MV Geo Coral Registry number IMO no. 9525560/9492579

   Registered owner Volstad Maritime AS/Fugro Geo Coral Inc.

7. The port from which the vessel(s) will operate is: Fourchon, LA

8. Briefly describe the navigation system (vessel navigation only): Vessels are equipped with GPS Saab R4 systems and DGPS Saab R4 Systems.

B. Complete for Geological Exploration for Mineral Resources or Geological Scientific Research

1. The type of operation(s) to be employed is: (check one)

   (a) N/A______ Deep stratigraphic test, or

   (b) N/A______ Shallow stratigraphic test with proposed total depth of __________, or

   (c) N/A______ Other ______________________________

2. Exact geographic coordinates of proposed test(s) (attach a page-size plat(s)): _______________

   ____

C. Complete for Geophysical Exploration for Mineral Resources or Geophysical Scientific Research

1. Proposed location of the activity (attach a page-size plat(s)): Central Gulf of Mexico - plat attached

2. The type(s) of operation(s) to be employed is (are): Wide Azimuth Multi streamer, multi airgun source recording seismic data (approximately 3,500 square miles), and gravity.
   (Seismic, gravity, magnetic, etc.)

3. The instrumentation and/or technique(s) to be used in the operation(s) is (are): Airgun source recorded by digital instrumentation, vessel gravity meter
   (Air gun, sparker, etc.)

4. Explosive charges will ______ will not X be used. If applicable, indicate the type of explosive and maximum charge size (in pounds) to be used:

   Type _______________ Pounds __________ Equivalent Pounds of TNT __________

D. Proprietary Information Attachments

Use the appropriate form on page 9 for a "geological" permit application or the form on page 10 for a "geophysical" permit application. You must submit a separate Form MMS-327 to apply for each geological or geophysical permit.

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E. Certification

I hereby certify that foregoing and attached information are true and correct.

SIGNED ______________________ DATE ____________

TITLE Exploration V.P. - Fugro Multi Client Services, Inc.

TO BE COMPLETED BY MMS

Permit No.____________ **Assigned by** ______________________ **Date** ______
of MMS

This application is hereby:

a. _____ Approved

b. _____ Returned for reasons in the attached

The approved permit is:

a. _____ Attached

b. _____ Will be forwarded at a later date

SIGNED ______________ TITLE Regional Supervisor DATE ________

Section D Proprietary Information Attachment
Required for an Application for Geological Permit

1. Brief description of method of shallow drilling or sampling: ______________________________

____

2. Brief description of shallow drilling or sampling equipment to be used: ______________________

____

____

3. Number of boring or sample locations to be occupied: ______________________________

____

4. Navigation system or method to be used to position sample locations: ______________________

____

____

5. Method of sample analyses, storage, and handling: ______________________________

____

6. Description and list of the final analyzed and/or processed data that will result from operations under the proposed activity: ______________________________

____

____

7. Estimated date on which samples, logs, and analyzed and/or processed data will be ready for inspection: ______________________________

8. **Attach map(s), plat(s), and chart(s) (preferably at a scale of 1:250,000) showing latitude and longitude, scale, specific block numbers, specific boring sample locations, and total number of borings or samples proposed.**

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Section D Proprietary Information Attachment
Required for an Application for Geophysical Permit

1. Brief description of the energy source and streamer (receiving array): Airgun source utilizing pressured air; ramp-up at start of lines. Streamer is Sercel Sentinel solid streamer with Sercel Flexible Hydrophone.

2. Total energy output per impulse: 138 bar-m

3. Number of impulses per linear mile: 22 (150m shot interval per source)

4. Towing depth of the energy source: 6-10 meters

5. Towing depth of the streamer: 6-20 meters

6. Navigation system or method to be used to position shotpoint locations: DGPS

7. Area of activity and total number of line miles proposed: Central Gulf of Mexico - (approx. 3,150 sqaure miles)

8. Description and list of the final processed data that will result from operations under the proposed activity: Multiple offset stacked data, stacked migrated data, Pre-stacked Depth migrated data. Reduced processed gravity.

9. Estimated date on which processed data will be available for inspection: December 31, 2012

10. Attach map(s), plat(s), and chart(s) (preferably at a scale of 1:250,000) showing latitude and longitude, scale, specific block numbers, specific track lines with line identifications, and the total number of line miles proposed.

Attachment 2

UNITED STATES
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

Gulf of Mexico Region
(Insert Appropriate Regional Office)

NONEXCLUSIVE USE AGREEMENT FOR SCIENTIFIC RESEARCH IN THE OUTER CONTINENTAL SHELF

A. State the time and manner in which data and information resulting from the proposed activity will be made available to the public for inspection and reproduction, such time being the earliest practicable time.

Tapes will be available in SEGY format in December 31, 2012.

B. ______________________ (applicant) agrees that the data and information resulting from the proposed activity will not be sold or withheld for exclusive use.

____
(Signature of Applicant)

Kenneth W. Mohn
(Type or Print Name of Applicant)

Exploration V.P. - Fugro Multi Client Services, Inc.
(Title)

____
(Date)

Submit: Original, two copies, and one public information copy.