High Mode Number VIV Experiments in the Gulf Stream

This document provides an overview of the Deepstar sponsored high mode-number VIV experiments done in the Gulf Stream in 2006. It also provides the necessary information required to get started with using the data that is being released in the public domain along with this document. The usage of this document is governed by the terms and conditions that the user agreed to at the time of downloading the document. Please visit: http://oe.mit.edu/VIV/home.html for more information.
This document prepared by Vivek Jaiswal on November 4th 2007.

General Information

Experiment dates: The Miami 2006 experiments were conducted between October 19th and October 26th, 2006.
Donor organization: MIT and Deepstar.
Donor contact info: Prof. J. Kim Vandiver (kimv@mit.edu), Vivek Jaiswal (vivekj@mit.edu).
Test facility and location: The Miami 2006 experiments were conducted in the Gulf of Mexico off the coast of Miami, Florida.
Experiment type: Field, model-scale experiments.

The Gulf Stream Test: Overview

The Gulf Steam test was conducted in October 2006. The main objectives of the Gulf Stream test were the following:

- Collect vortex-induced vibration response data on densely instrumented cylinder responding at high mode numbers.
- Test full and partial coverage configurations for triple-helical strakes and fairings.
- Estimate drag coefficients for bare pipe and pipe covered with strakes and fairings.

The Gulf Stream test was conducted on the Research Vessel F. G. Walton Smith out of the University of Miami using a composite pipe of length 500.4 feet and an outer diameter 1.43 inches. The length and diameter of the pipe were chosen such that high mode numbers were possible; where high mode numbers are defined as modes greater than approximately 10th mode. The experiments were conducted by towing the pipe from the boat. A railroad wheel, weighing 805 pounds in air and 725 pounds in water, was attached at the bottom end of the pipe to provide tension. The pipe simulated a pinned-pinned tensioned beam. The pipe's dynamic response was tension dominated with the bending stiffness of the pipe having negligible effect. Universal joints were used at both ends of the pipe to create the pinned connection.

The pipe was instrumented with fiber optic strain gauges to monitor the vibrations. Additional instrumentation included a tiltmeter to measure the pipe top end angle of inclination, a load cell to measure the tension at the top end and two mechanical current meters located near the top and bottom ends. A pressure transducer was also installed on the railroad wheel in order to measure its depth. An Acoustic Doppler Current Profiler (ADCP) was used to measure the magnitude and direction of the incident flow profile. The set-up for the experiment is shown in Figure 1.

NOTE: The pipe used during the 2006 Gulf Stream tests is in good condition and can be made available to anyone interested in doing experiments with it. Please contact Prof. J. Kim Vandiver (kimv@mit.edu) for more information.

Pipe Properties

The properties of the pipe tested during the 2006 Gulf Stream test are listed in Table 1.

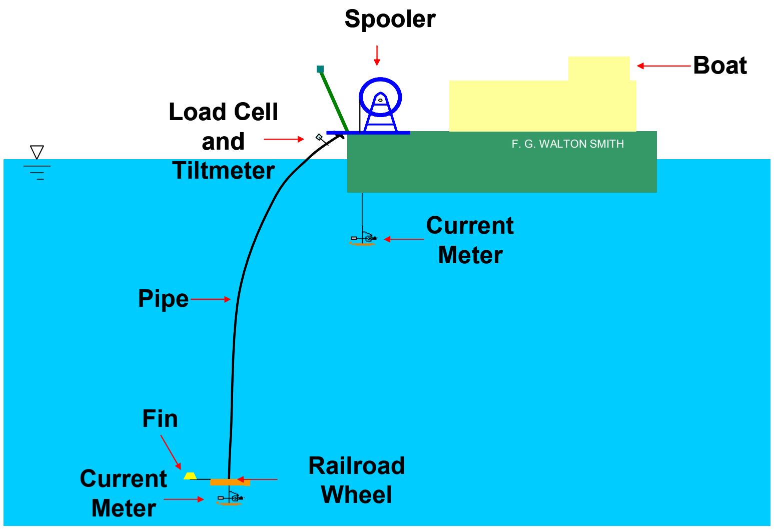

Figure 1 Experiment set-up for the Gulf Stream tests.

Table 1 Pipe properties.

Inner Diameter	0.98 in. (0.0249 m)
Outer Diameter	1.43 in. (0.0363 m)
EI	1.483e3 lb ft^2 (613 N m^2)
EA	7.468e5 lb (3.322e6 N)
Weight in Seawater	0.1325 lb/ft (0.1972 kg/m)
Weight in air	0.511 lb/ft (0.760 kg/m)
Density of pipe material	86.39 lb/ft^3 (1383 kg/m^3)
Effective mean tension	725 lb (3225 N, wet weight of railroad wheel)
Material	Glass fiber epoxy composite
Length	500.4 ft (152.524 m)
Manufactured by	FiberSpar Inc.

Data Acquisition System

The data acquisition (DAQ) system consisted of three components:

1. The Insensys FSI DAQ system which recorded the data from the strain gauges.
2. Acoustic Doppler Current Profiler (ADCP) that recorded the current profile data.
3. National Instruments system that recorded the tiltmeter, load cell, bottom end pressure transducer and mechanical current meter data.

All three systems were run in parallel. A typical experiment run lasted approximately three minutes. The details for each system are given below.

Insensys Fiber Optic System:

Fiber optic strain gauges were used to measure the vibrations in the pipe. Eight separate fibers were embedded into the pipe during its manufacturing process at a radius of 0.685 inches from the center.

Each fiber contained 35 strain gauges. Two fibers were located in each of the four quadrants of the pipe. The two fibers had strain gauges located every 14 feet; though the strain gauges from the two fibers were off-set from each other to allow measurement every 7 feet along the pipe. An Insensys Fiber Optic System (FSI unit) was used to record the data. The system was limited to a sampling rate of 2000 Hz divided by the number of strain gauges being sampled in the fiber.

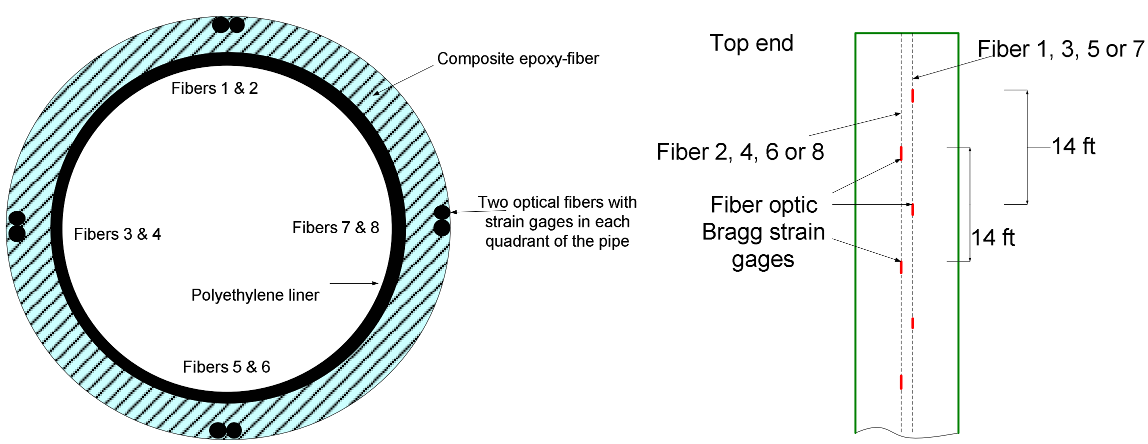

Figure 2 Pipe cross-section (left) showing the orientation of the fibers and side-view (right) showing the location of sensors on the fibers.

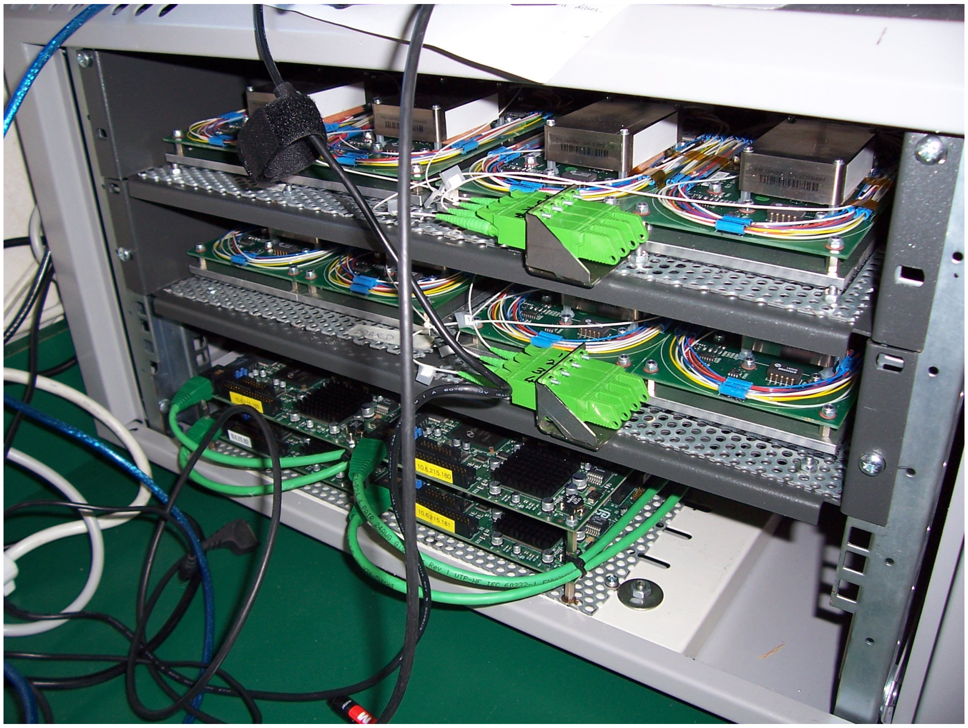

Figure 3 Insensys topside data acquisition unit.

Acoustic Doppler Current Profiler (ADCP):

An ADCP uses acoustic sound waves to extract current information from the ocean. The ADCP sends out an acoustic ping and then waits for the return sound. Depending on the time the ping takes to return and the Doppler shift in its frequency, the ADCP extracts the different current speeds and direction at different depths.

On the R/V F. G. Walton Smith, there were two ADCPs – a broadband ADCP and a narrowband ADCP. Each ADCP used a different frequency to obtain current data at different depths. The broadband ADCP was used to get greater resolution in space and accuracy at the shallow depths, whereas the narrowband ADCP was used for deeper depths with lesser resolution. Both the ADCPs recorded current data and the time throughout the day. At the end of a day's experiments, the current data for each individual test was extracted from the day's record based on the starting time and duration of the test.

National Instruments system:

The National Instruments (NI) hardware (model: USB 6251) used was a 16-channel single input (8-channel differential) DAQ system. It interfaced with the computer through the USB port. Out of the eight available differential analog input channels, seven were used to record the data while one of the channels was used for the trigger signal. The FSI computer sent a trigger signal to the NI DAQ system so as to synchronize the data acquisition start times.

The data acquisition application was built using LabVIEW 8.0. The application was designed to acquire as well as display data in real time. The acquisition started when the trigger signal was sent by the Insensys fiber optic DAQ computer. The termination of acquisition was achieved by manually stopping the application from acquiring data.

Figure 4 National Instruments USB 6251 data acquisition system.

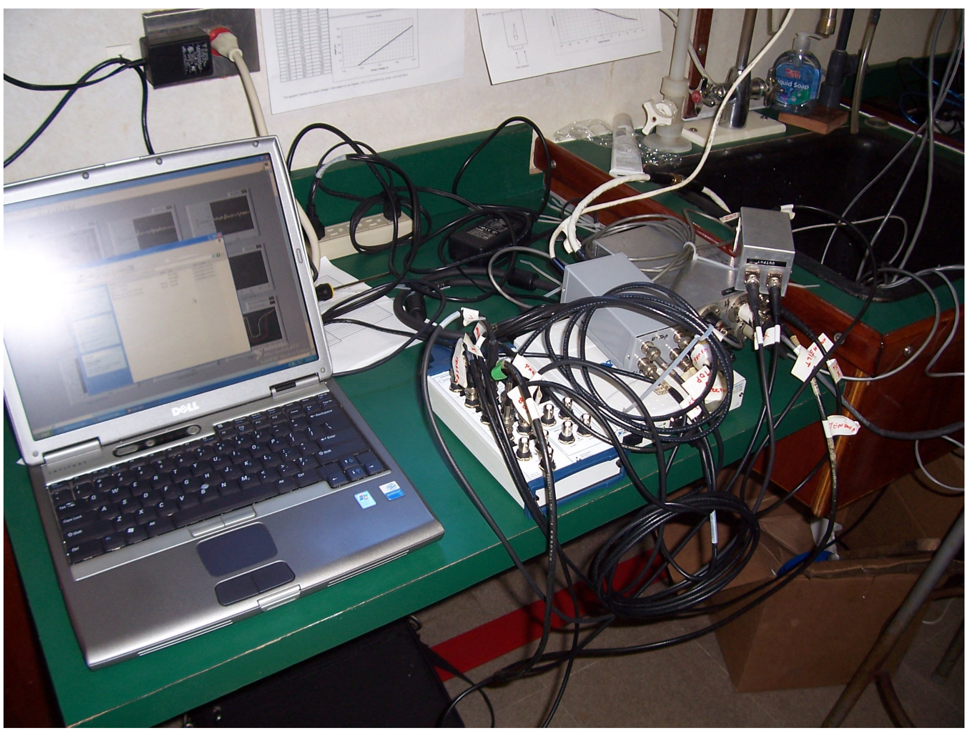

Figure 5 National Instruments USB 6251 DAQ system connected to a laptop and the data cables from the instruments.

Tiltmeter:

The tiltmeter consisted of a two gravity sensitive IC Sensors Model 3150 accelerometers. They were mounted inside a protective case with their sensitive axes oriented in two orthogonal directions. The tiltmeter was attached to a bracket mounted very close to the pivot point of the U-joint. When hanging vertically, the two axes of sensitivity lay in the horizontal plane. One axis was nominally parallel with the long axis of the boat and the other transverse to the boat. In the actual installation the axes were rotated 13.8 degrees clockwise, when looking down on the instrument. This may be seen in Figure 6, which was taken looking directly forward on the vessel. The two sides of the case of the tiltmeter are aligned with the principal axes. The case is seen to be rotated approximately 13.8 degrees to starboard. Since this miss-alignment is known, it may be corrected for numerically in the data processing. For most purposes, the total vector magnitude contributed by both axes is all that is required. Therefore this miss-alignment is of little practical consequence.

When the pipe hangs vertically, the two axes are in the horizontal plane and do not sense the effect of gravity. When tilted, both the accelerometers measure a component of gravity, from which the total angle of inclination may be computed.

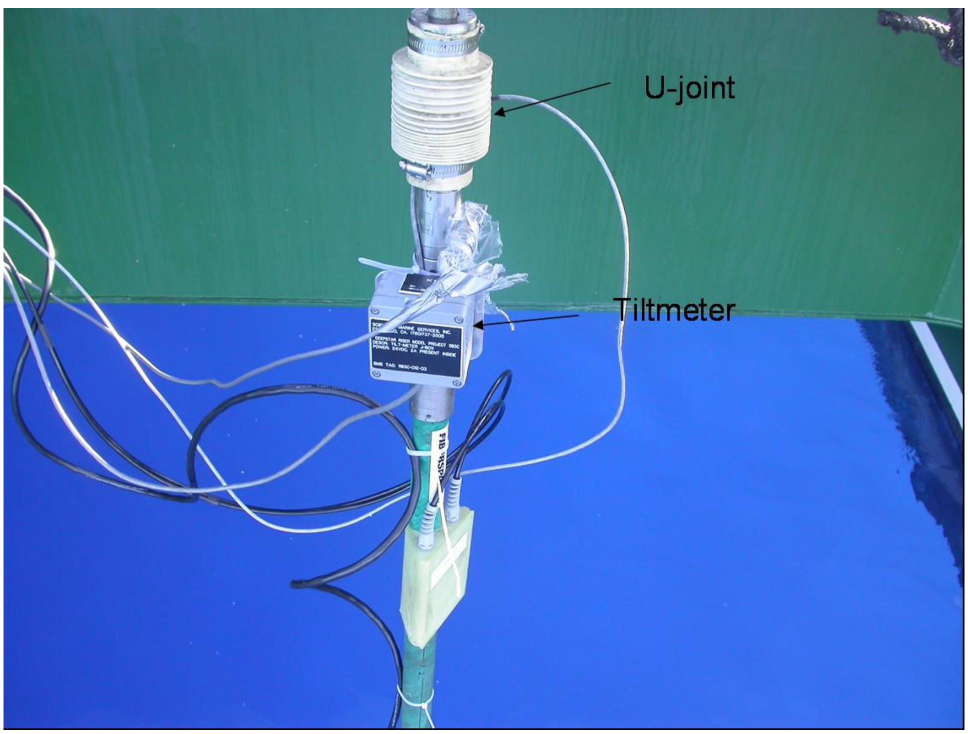

Figure 6 The tiltmeter and U-joint at the top end.

Load Cell:

The tension at the top end of the pipe was measured using a load cell. The load cell was a Honeywell Sensotec In-Line 4000 Pound Load Cell, Model RM, (AL413DP, 13c). The load cell measured both the static and the dynamic component of the tension.

The specifications for the load cell are as follows:
Full Scale Range: 4000 lbs
Calibrated sensitivity including all filters: 1.25 mV per pound.
Excitation: 10VDC
Input Impedance: 389 Ohm
Output Impedance: 352 Ohm
Electrical Leakage: Infinity MegOhm
Calibration Factor: 1.9811 mV/V
Shunt Cal Factor: 1.4847 mV/V
Shunt Cal Resistor: 59 kOhm

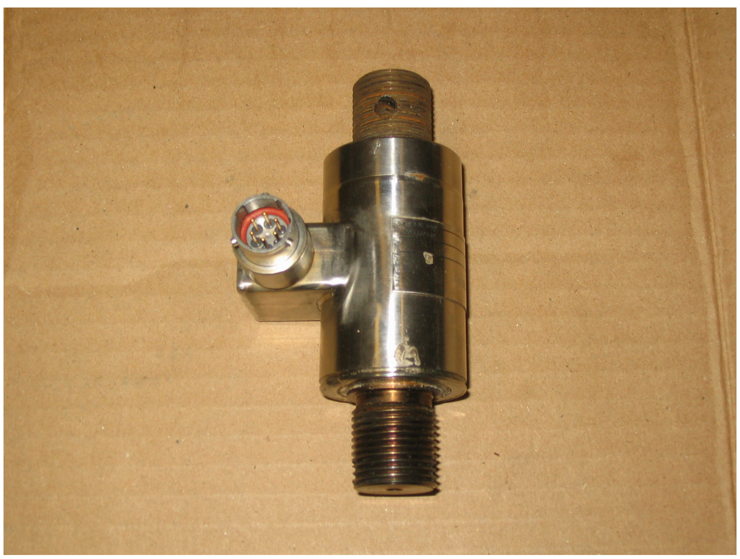

Figure 7 Sensotec load cell model RM.

Current Meter:

The current meter uses a simple switch closure, which indicates each revolution of the current meter rotor. The voltage output of the switch closure is a variable period square wave. The voltage output of the switch closure was recorded by the NI DAQ system. In post processing the period of the square wave was calculated. Equation (1.1) was supplied by the current meter manufacturer to calculate the current velocity in feet per second based on the period in seconds of the square wave, T.

$$v(ft/s) = \frac{2.2048}{T} + 0.0178 \quad (1.1)$$

Figure 8 Mechanical current meter.

Pressure Transducer:

A transducer was used to monitor the hydrostatic pressure at the depth of the railroad wheel. The pressure was used to determine the depth of the railroad wheel below the free surface of the water. It was mounted inside of the aluminum pressure housing shown in Figure 9. The transducer was screwed into a threaded hole which penetrated the case and was exposed to external pressure. The threads were backed up by an O-ring seal which prevented flooding of the casing.

The pressure transducer was manufactured by Cooper Instruments. The specifications for the transducer are as follows:
Model number: PTG-402
Full Scale Range: 300 psi
Error: 0.5 % F.S. Amplified
Excitation: 10-28 VDC
Output: 4-20 mA

The output of the transducer was a current. In order to record the output as a voltage, a circuit was designed so that the current passes through a precision 100 Ω resistance. The voltage drop across this resistance was recorded as the transducer reading.

The equation for conversion from voltage (*V*) to depth in feet is given below:

$$Depth(ft) = \left[V - 0.365\right] * 412.448 \quad (1.2)$$

Figure 9 Aluminum casing for the pressure transducer.

Strake Experiments

The strakes were a triple helix design made of polyethylene, with a pitch of 17.5 times the diameter of the pipe. This represents a typical design for strakes in the industry. The properties of the strakes are shown in Table 2. The strakes had a slit down the side that allowed them to be snapped over the outside of the pipe. The strakes were then secured to the pipe using tie wraps. The strakes were manufactured by AMS International.

For the 40% coverage tests, the strakes were applied from 300 feet to 500 feet (distances measured from top end). The strakes were applied with 52 inches of strakes (2 strakes) and then a 10 inch gap of bare cylinder. This pattern (see Figure 10) was repeated for the entire 200 ft of coverage.

Table 2 Strake properties.

Material	Polyethylene
Length	26.075 in. (0.662 m)
Shell OD	1.49 in. (0.038 m)
Shell ID	1.32 in. (0.034 m)
Strake Height	0.375 in. (0.0095 m, 25% of shell OD)
Wall thickness	0.09 in. (0.002 m)
Pitch	17.5 times the diameter
Weight	0.11 lb/ft ±10% (0.164 kg/m,large variation)

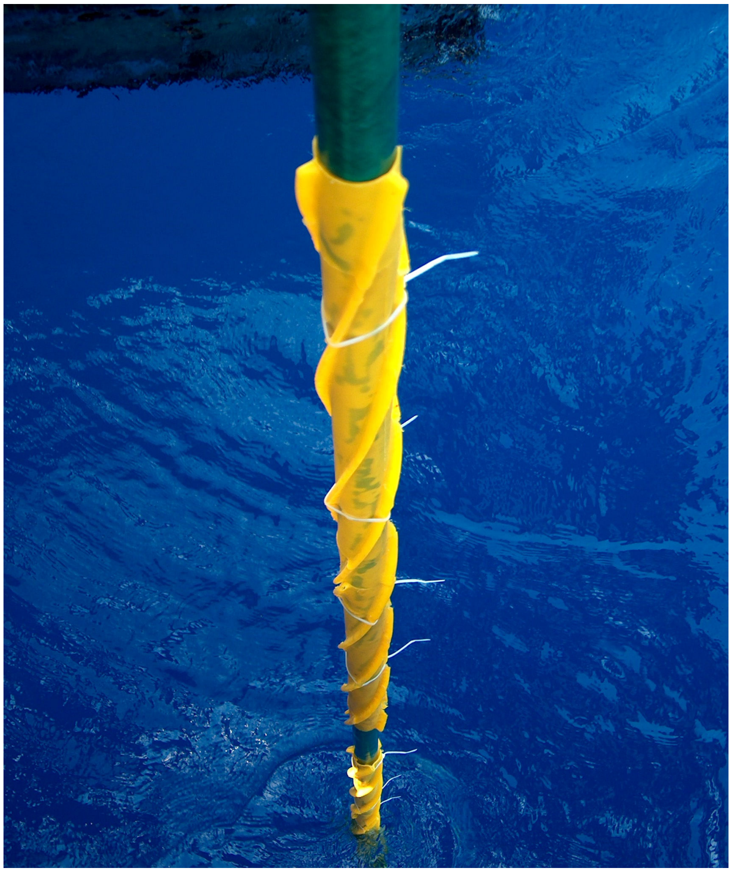

Figure 10 Strakes tested during the Gulf Stream tests. The strakes were applied with 52 inches of strakes and then 10 inches of bare pipe gap configuration.

Data Files

Data from three different test cases is provided. The files are given in *.mat format and can be read using Matlab. The filename is of the format YYYYMMDDhhmmss.mat (YYYY – year, MM – month, DD – day, hhmmss - military time). The date and time at the start of a test is used for naming the file for that test. Example: 20061020164517.mat refers to a test started on 20th October 2006 at 16 hr 45 min 17 second (GMT).
Two of the cases are from bare pipe tests and one from 40% strake coverage tests. The file identifiers and brief descriptions of the tests are given in Table 3. Measured time series for all the strain gauges and the load cell have been provided. Mean values of the measured tilts at the top and the mean current readings from the ADCP as well as mechanical current meters are also included.

Table 3 Benchmark test cases.

S No.	File Identifier	Description
1	20061020174124.mat	Bare pipe test case
2	20061023205557.mat	Bare pipe test case
3	20061021213742.mat	40% bottom-end strake coverage case

Each file contains 20 variables in all. Table 4 lists the variables contained in the data files and also gives a brief description for each of them. A description of each of the variables can also be found in the variable 'ReadMe' in the data file. The raw data from the experiments has been converted to engineering units.

Table 4 Variables contained in the data file.

Variable Name	Variable Class	Description
Current	struct array	A structured array containing information about the incident current
Fs	double array	Sampling rate in Hz
PipeL	double array	Pipe length in feet between the top and bottom U-joints.
Position	struct array	A structured array containing information about the position of the sensors
Q1	double array	Quadrant 1 filtered strain (in microstrain) time series at all sensor locations
Q1_uf	double array	Quadrant 1 unfiltered strain (in microstrain) time series at all sensor locations
Q2	double array	Quadrant 2 filtered strain (in microstrain) time series at all sensor locations
Q2_uf	double array	Quadrant 2 unfiltered strain (in microstrain) time series at all sensor locations
Q3	double array	Quadrant 3 filtered strain (in microstrain) time series at all sensor locations
Q3_uf	double array	Quadrant 3 unfiltered strain (in microstrain) time series at all sensor locations
Q4	double array	Quadrant 4 filtered strain (in microstrain) time series at all sensor locations
Q4_uf	double array	Quadrant 4 unfiltered strain (in microstrain) time series at all sensor locations
ReadMe	char array	Describes all the variables in the data file
TopAng	double array	Mean angle that the pipe axis makes with the vertical at the top end (degrees)
date	char array	Date on which the test was conducted
init_time	char array	Start time for test run
mean_tiltx	double array	Mean tilt of the x-direction tilt meter (degrees)
mean_tilty	double array	Mean tilt of the y-direction tilt meter (degrees)
tension	double array	Tension time series recorded by the load cell (lbs)
time	double array	Time stamp for the strain data (seconds)

Sensor Locations

The sensors in each quadrant are numbered from 1 to 70. All the even numbered sensors are on the even numbered fibers and all the odd numbered sensors on the odd numbered fibers. Sensor 1 is closest to the top end while sensor 70 is the farthest (see Figure 11). The axial distance of sensor number 'j' is given by the variable `Position.axialPipe(j)`.

Table 5 Sensor numbers present on each fiber and their axial distance from the top end.

	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Axial Distance (ft)	Fiber 1	Fiber 2	Fiber 3	Fiber 4	Fiber 5	Fiber 6	Fiber 7	Fiber 8
8.50	1	--	1	--	1	--	1	--
15.50	--	2	--	2	--	2	--	2
22.50	3	--	3	--	3	--	3	--
29.51	--	4	--	4	--	4	--	4
36.51	5	--	5	--	5	--	5	--
43.51	--	6	--	6	--	6	--	6
50.51	7	--	7	--	7	--	7	--

57.51	--	8	--	8	--	8	--	8
64.51	9	--	9	--	9	--	9	--
71.51	--	10	--	10	--	10	--	10
78.51	11	--	11	--	11	--	11	--
85.52	--	12	--	12	--	12	--	12
92.52	13		13	--	13	--	13	--
99.52	--	14	--	14	--	14	--	14
106.52	15	--	15	--	15	--	15	--
113.52	--	16	--	16	--	16	--	16
120.52	17	--	17	--	17	--	17	--
127.52	--	18	--	18	--	18	--	18
134.52	19	--	19	--	19	--	19	--
141.53	--	20	--	20	--	20	--	20
148.53	21	--	21	--	21	--	21	--
155.53	--	22	--	22	--	22	--	22
162.53	23	--	23	--	23	--	23	--
169.53	--	24	--	24	--	24	--	24
176.53	25	--	25	--	25	--	25	--
183.53	--	26	--	26	--	26	--	26
190.54	27	--	27	--	27	--	27	--
197.54	--	28	--	28	--	28	--	28
204.54	29	--	29	--	29	--	29	--
211.54	--	30	--	30	--	30	--	30
218.54	31	--	31	--	31	--	31	--
225.54	--	32	--	32	--	32	--	32
232.54	33	--	33	--	33	--	33	--
239.54	--	34	--	34	--	34	--	34
246.55	35	--	35	--	35	--	35	--
253.55	--	36	--	36	--	36	--	36
260.55	37	--	37	--	37	--	37	--
267.55	--	38	--	38	--	38	--	38
274.55	39	--	39	--	39	--	39	
281.55	--	40	--	40	--	40	--	40
288.55	41	--	41	--	41	--	41	--
295.56	--	42	--	42	--	42	--	42
302.56	43	--	43	--	43	--	43	--
309.56	--	44	--	44	--	44	--	44
316.56	45	--	45	--	45	--	45	--
323.56	--	46	--	46	--	46	--	46
330.56	47	--	47	--	47	--	47	--
337.56	--	48	--	48	--	48	--	48
344.56	49	--	49	--	49	--	49	--
351.57	--	50	--	50	--	50	--	50
358.57	51	--	51	--	51	--	51	--
365.57	--	52	--	52	--	52	--	52
372.57	53	--	53	--	53	--	53	--
379.57	--	54	--	54	--	54	--	54
386.57	55	--	55	--	55	--	55	--

393.57	--	56	--	56	--	56	--	56
400.57	57	--	57	--	57	--	57	--
407.58	--	58	--	58	--	58	--	58
414.58	59	--	59	--	59	--	59	--
421.58	--	60	--	60	--	60	--	60
428.58	61	--	61	--	61	--	61	--
435.58	--	62	--	62	--	62	--	62
442.58	63	--	63	--	63	--	63	--
449.58	--	64	--	64	--	64	--	64
456.59	65	--	65	--	65	--	65	--
463.59	--	66	--	66	--	66	--	66
470.59	67	--	67	--	67	--	67	--
477.59	--	68	--	68	--	68	--	68
484.59	69	--	69	--	69	--	69	--
491.59	--	70	--	70	--	70	--	70

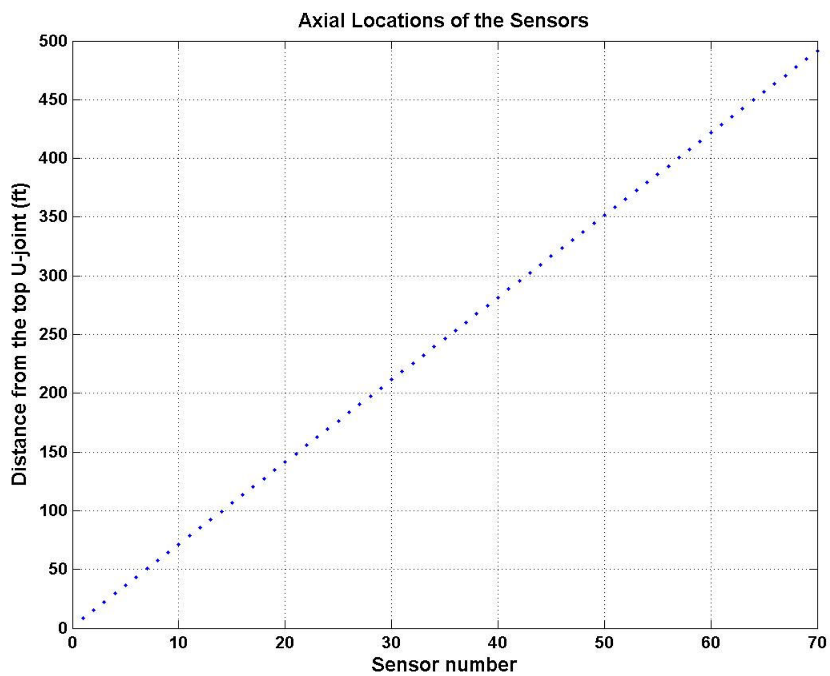

Figure 11 Axial distance of sensors from the top end U-joint.

Normal-Incidence Current

Drag forces on the pipe and railroad wheel resulted in the top end of the pipe being inclined to the current (see Figure 1). It has been shown in numerous laboratory studies that the vortex shedding frequency is dependent on the flow velocity component normal to the axis of the pipe. That is, the Strouhal formula may be used to predict the vortex shedding frequency if one uses the normally incident component of the velocity. This requires that one know the angle of inclination of the pipe at all axial positions. Given the measured current profile, the measured depth of the bottom weight, and the measured top angle, we were able to match these measurements with a fitted shape computed with a finite element model of the pipe. With a known static equilibrium shape it was then possible to compute the normal incidence flow velocity component.

The normal incident current profiles of the selected cases are shown in Figure 12 and the directions of the currents relative to the boat are shown in Figure 13. The normal incident current at all sensor locations can be found in the variable `Current.Pipe` and the directions relative to the boat can be found in the variable `Current.DirPipe`.

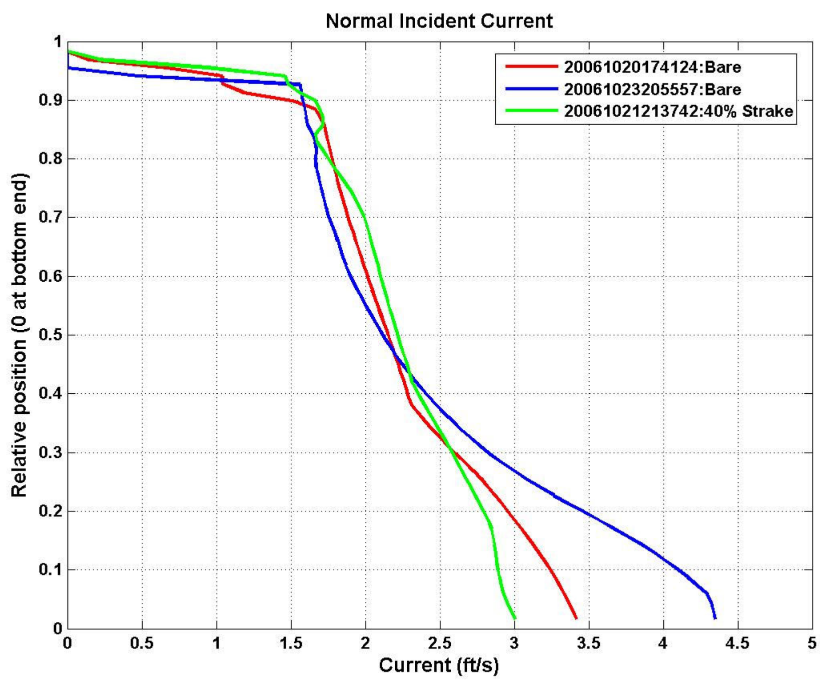

Figure 12 Normal incident current for all the cases. The relative position is the normalized axial distance x/L of the sensors with 0 at the bottom end U-joint.

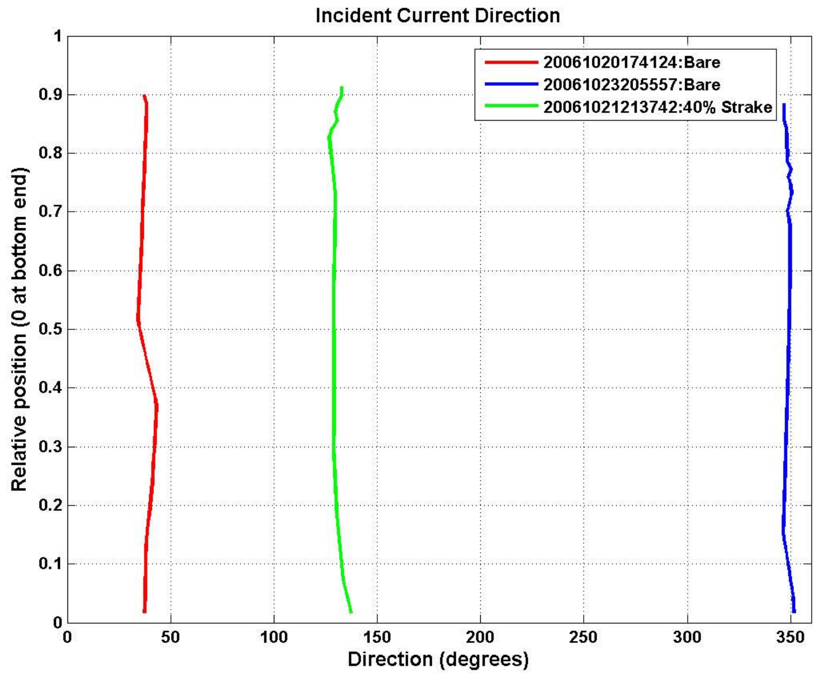

Figure 13 Incident current directions relative to the boat for all the cases. The relative position is the normalized axial distance x/L of the sensors with 0 at the bottom end U-joint.

Strain Data

Measured time series for all the strain gauges and the load cell have been provided. The strain measurements were affected by the motion of the boat. The boat motions lead to a low frequency (boat heave, pitch and roll frequency) axial strain component. This component was at a frequency well below the VIV frequency. A digital high-pass elliptical filter with a cutoff of 1 Hz was used to remove this component from the data. The filter removed all frequency components below 1 Hz but did not affect the VIV frequencies and their phase. The filtered strain series represents the dynamic bending strain since the static and low frequency dynamic axial strains were removed. Both the filtered and unfiltered time series have been provided in the data files.

Sample Code for Data Processing

```
clear;
load('20061021213742.mat'); % load the data
whos; % display the variables
ReadMe
% ReadMe gives the details of the all the variables saved in the file

% plot the filtered time series for sensor# 15 in Quadrant 3
figure;
plot(time,Q3(:,15));
xlabel('Time (sec)');
ylabel('Strain (microstrain)');

% plot the unfiltered time series for sensor# 15 in Quadrant 3
figure;
plot(time,Q3_uf(:,15));
xlabel('Time (sec)');
```

```
ylabel('Strain (microstrain)');

% Axial distance of sensor# 15 from top U-joint
distTop = Position.axialPipe(15)

% Axial distance of sensor# 15 from bottom U-joint
distBottom = PipeL - Position.axialPipe(15)

% Non-dimensional axial coordinates with origin or zero at top U-joint
xByL = Position.axialPipe/PipeL
```

Note: It is easier to visualize data if the origin or zero is taken at the bottom U-joint

```
% Non-dimensional axial coordinates with origin or zero at bottom U-joint
xByL = 1 - (Position.axialPipe/PipeL)

% plot the normal incident current vs depth
figure;
plot(Current.Pipe, Position.axialPipe);
xlabel('Normal incident current (ft/s)');
ylabel('Axial Location (ft), zero or origin at the top end');

% plot the normal incident current vs non-dimensional axial distance
xByL = 1 - (Position.axialPipe/PipeL);
figure;
plot(Current.Pipe,xByL);
xlabel('Normal incident current (ft/s)');
ylabel('Relative position, zero or origin at the bottom end');
```

Sample Plots

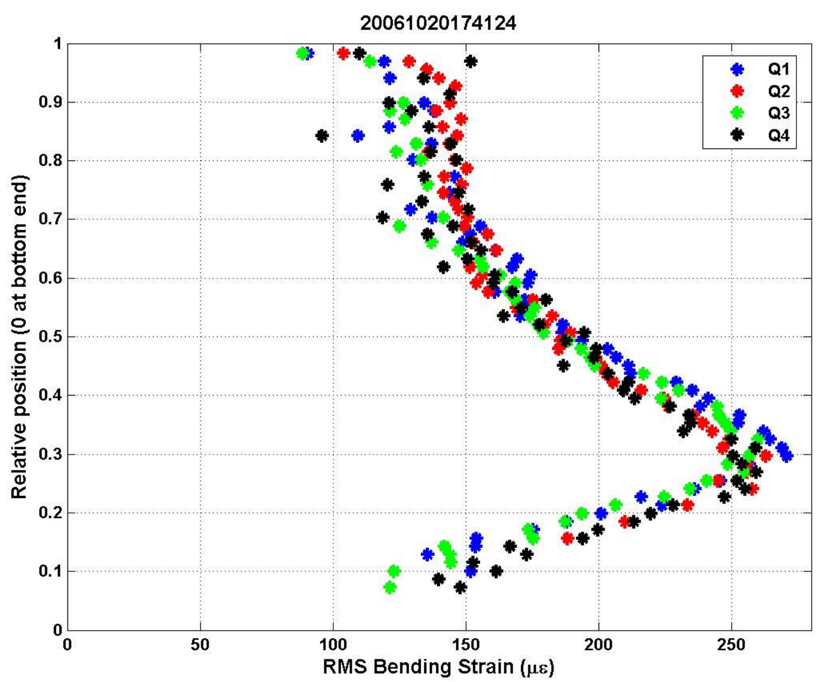

Figure 14 Root Mean Square (RMS) bending strain for case 20061020174124 (bare pipe)

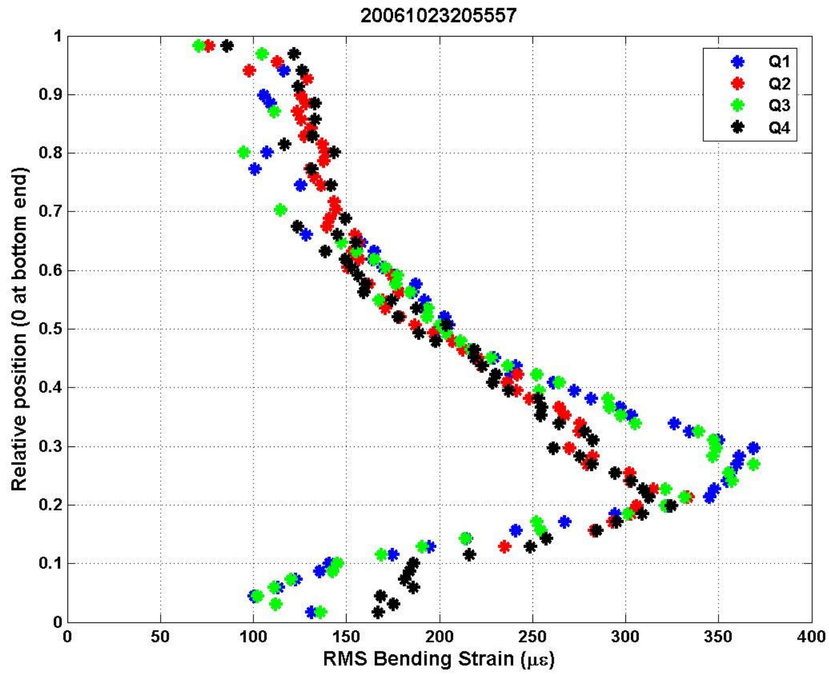

Figure 15 Root Mean Square (RMS) bending strain for case 20061023205557 (bare pipe)

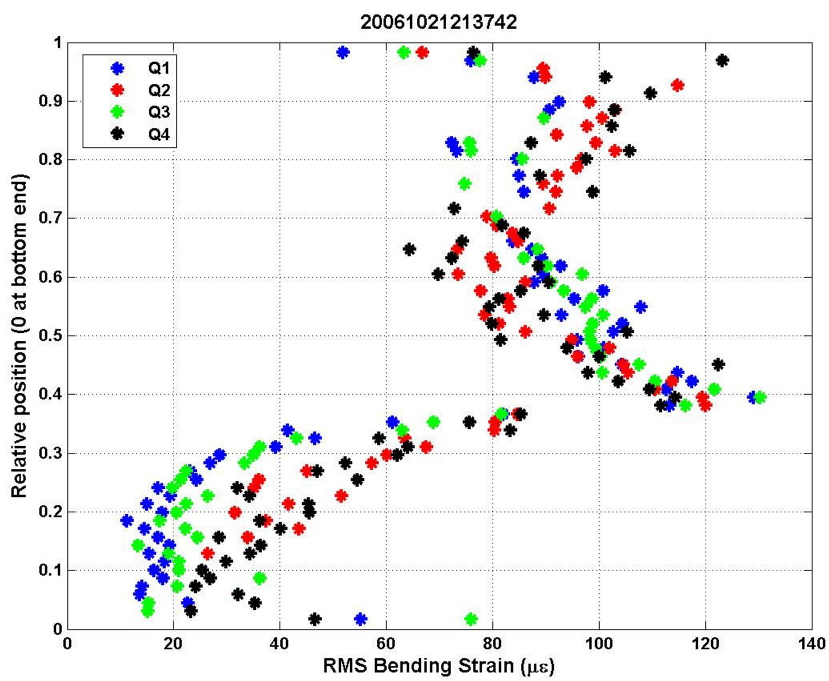

Figure 16 Root Mean Square (RMS) bending strain for case 20061021213742 (bottom 40% strake coverage case)

Known Problems with the Data

There were three problems that occurred during the second Gulf Stream experiment which compromised a portion of the data from several tests.

Strain over range:
Each strain gauge has a limited dynamic range. During manufacture a pretension is applied to the fiber as it is embedded in the pipe. This pretension must be controlled so that when the railroad wheel is suspended from the pipe, the mean axial strain in the pipe is centered in the dynamic range of the instrumentation. This process did not work perfectly and some of the strain gauges at the top of the pipe were near the upper limit of their dynamic stress range with just the bare pipe and railroad wheel hanging still in the water. The addition of strakes, fairings, or large curvature in the pipe caused some of the strain gauges at the top end of the pipe to go outside of the acceptable dynamic range. Strain gauges that were over their stress range are not readable by the fiber optic system and appear as missing data (zeros) in the collected data. This problem affected a few out of the 280 sensors on each run.

Sampling rate irregularities:
A sample rate problem, similar to the one seen during the first Gulf Stream tests in 2004, was seen in the second Gulf Stream experiment as well. This problem was detected earlier this time because of the previous experience. After further investigation, the sample rate problem was diagnosed as a time of flight issue. The fiber optic system is set-up to ping each the Bragg cell forty times for each measurement sample. When the amount of time required to ping the Bragg grating forty times exceeds the time interval allowed, that particular measurement is dropped from the data for every sensor on that fiber. Sensors located at or near the bottom end of the pipe were always the source of this problem, because the time of flight for the light inside the fiber is greatest for the most distant sensors. The solution is to either decrease the sampling rate to less than 50 Hz per sensor, or choose not to attempt measurements from the most distant sensors. We chose to progressively remove sensors from the measurement, beginning with the most distant one. After sampling again, if the problem persisted then additional sensors were dropped until the problem was solved. For some fibers we had to drop up to eight sensors out of the maximum number, 35. This is seen in the actual data as missing measurements (zeros) congregating near the bottom. The time of flight issue was largely accounted for by excluding the bottom measurements from the data. This worked, but occasionally the same problem came up with one or more of the remaining sensors. Any time the DAQ was unable to complete sampling of a sensor in the allocated time, the entire sample from every sensor on that fiber would be dropped from the record. This was done without making a record of the event. Each time a sample is dropped for a fiber, the subsequent measurements on that fiber become out of synch with the time histories on other fibers. When this occurs, samples are dropped at random times throughout the test. Unfortunately, no way is known after the fact, to find out which samples have been dropped. This causes the fibers to become asynchronous with one another. This sample rate issue was largely seen on fiber 4 (all even numbered sensor locations in quadrant 2). At the beginning of the test this problem was seen on almost all the fibers. After correctly

diagnosing this problem, the sample rate issue was fixed on all the fibers except fiber 4. The problem could not be fixed on fiber 4 for unknown reasons.

Irregular stop and start signals:
The micro-controller that controlled the computers which read the fiber optics did not send a synchronous signal to stop the data acquisition. Instead the four sampling computers turned off at varying times. Additionally, there is some evidence that on some occasions the fiber optics may not have started synchronously.

In spite of these problems a great deal of high quality synchronous data was obtained. The data can be used for Root Mean Squared (RMS) computations. Further investigation needs to be done on some fibers before time series analysis and differential strain can be used.

Other Know Problems or Limitations of the Tests

Optical Fiber Twist:
A twist of 180 degrees in the fibers was introduced during the manufacture of the pipe. This twist was noticed by looking at the strain data when the pipe was spooled on the drum. This resulted in no fibers being perfectly aligned with either the cross-flow or in-line VIV direction for the whole length of the pipe. A detailed method to evaluate the cross-flow and in-line flow components from the measured data is given in [3].

Variability in Current:
The current profiles presented in the data files are time averaged profiles. During the course of a test run, effort was made to keep the boat moving at a steady speed. However, given the ocean environment in which the test was done, it was not possible to maintain steady speed during the entire run. Additionally, errors in measurements were present due to the motion of the boat (heave, pitch and roll). While post-processing the data, it was found that the best way to minimize the errors induced due to boat motion was to take an average of 15 seconds of data. By comparing multiple averages obtained by taking continuous 15-second window of data, we were able to identify cases in which the flow relative to the boat was more or less steadily during the tests. The variable `Current.Pipe` stores the average current profile while `Current.Var` gives the variability in the measured profile.

Published Papers based on Gulf Stream Test Data

1. Jaiswal, V. and Vandiver, J.K., 2007, *"VIV Response Prediction for Long Risers with Variable Damping"*, Proceedings of OMAE2007, OMAE2007-29353
2. Jhingran, V. and Vandiver, J.K., 2007, *"Incorporating the Higher Harmonics in VIV Fatigue Predictions"*, Proceedings of OMAE2007, OMAE2007-29352
3. Marcollo, H., Chaurasia H. and Vandiver J. K., *"Phenomena Observed in VIV Bare Riser Field Tests"*, Proceedings of OMAE2007, OMAE2007-29562
4. Swithenbank, S. and Vandiver, J.K., 2007, *"Identifying the Power-in Region for Vortex-Induced Vibration on Long Flexible Cylinders"*, Proceedings of OMAE2007, OMAE2007- 29156