Spar Vortex-Induced Motions

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Executive Summary by:

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Table of Contents

Executive Summary

Background and Objectives

Since 1996 eight spar-based floating production systems have been installed in the Gulf of Mexico. Another five production spars are slated for installation in the next two years. For spars the Vortex-Induced Motion (VIM) responses of the hull under current flow is an important consideration for the design of the mooring and riser systems.

Throughout the past decade a number of operators and engineering firms have made substantial investments in technology related to spar VIM, whether it be in sophisticated model tests, advanced computer models, or full scale performance data. Much of the information and knowledge derived from these technology development efforts is proprietary and has understandably been kept confidential. The state-of-the-art that has evolved is largely based on fragments of proprietary empirical knowledge held by relatively few organizations.

Industry has not yet had the opportunity to share and review the collective data/knowledge on spar VIM in order to establish a common understanding of the problem and an industry consensus on how to deal with spar VIM in design. Currently there are multiple perceptions of spar VIM, with different organizations having different design procedures along with different views on the associated design uncertainties.

It is clear that the industry needs widely accepted and consistent practices for addressing spar VIM in order to ensure the integrity of existing and future spar designs. Such practices must be based on verifiable data if they are to be credible and must allow for any perceived uncertainties.

Motivated by these considerations and under funding provided by the US Minerals Management Service, the OTRC organized and hosted an industry workshop on spar VIM to establish a shared vision for an effective path forward. A Technical Steering Group representing the major industry stakeholders was formed to assist with the planning of the workshop.

The Technical Steering Group met on a monthly basis from March to September, 2003. The primary members of the Technical Steering Group were:

Don Allen – Shell Global Solutions
Luis Bensimon – Kerr-McGee
Mehernosh Irani – Technip Offshore
Rick Mercier - OTRC
Bob Sandström – ExxonMobil
Hugh Thompson - ChevronTexaco
Adam Bangs – SparTEC
Skip Ward – OTRC

Others participated in the Technical Steering Group meetings and provided valuable guidance, including:

Ro Lokken – ExxonMobil
Pierre Beynet, Hugh Banon – BP
Jen-Hwa Chen – ChevronTexaco
Stergios Liapis, Lee Li – Shell
Charles Smith – MMS

The workshop had the following major objectives:

- initiate a path for development of an industry-acceptable design practice/methodology on spar VIM,
- identify uncertainties and technical needs in spar VIM and a path forward to fill the identified gaps,
- educate industry on the technical challenges involved.

The workshop was held at Camp Allen Retreat & Conference Center, Navasota, Texas (http://campallen.org/) from October 22 to 24, 2003. Over 100 professionals from industry, government and academia participated in the workshop. A list of the workshop participants is provided in Appendix A.

Workshop Agenda and Format

The workshop was structured in two parts in order to best achieve the objectives. The first part of the workshop was devoted to invited presentations organized so as to review

- the regulatory perspective on current issues associated with spar VIM,
- the state-of-the-art of our fundamental understanding of the mechanics of vortex-induced vibrations as applicable to spar platforms,
- current design and model test practices among the organizations engaged in the design of spars, and
- field and model test data and experiences for existing or planned Gulf of Mexico spars, as relevant to validation of modeling and design practices.

The second part of the workshop was devoted to structured discussions among the workshop participants to

- identify and prioritize technical uncertainties and gaps on the basis of design impact, and
- recommend new initiatives to resolve the identified gaps and advance spar VIM design practice.

The agenda for the 3-day workshop is provided in Appendix B. A total of 25 invited presentations were delivered in the first two days of the workshop. The PowerPoint slides for all presentations are included in Appendix F. Hyperlinks are provided between agenda items in Appendix C and individual presentations in Appendix F to facilitate navigation through the report. Note that some presentations contain links to movie clips. Comments have been added to the PowerPoint slides to indicate the links to the movie clips.

Following the presentations, three break-out group discussion sessions were held. The first two discussion sessions addressed uncertainties that engineers must manage in designing spar platforms to withstand VIM. The last discussion session addressed technology gaps responsible for these uncertainties.

The first discussion session was aimed at identifying the uncertainties and describing their impact. These included uncertainties in characterizing the ocean environment, in designing and interpreting scale model tests, and in design analysis of VIM for particular spar designs. The workshop participants were divided into three broad specialty areas: metocean, model testing practice, and design practice. Due to the large number of participants there were two separate discussion groups addressing model testing practice and five separate discussion groups addressing design practice. This amounted to a total of 8 separate discussion groups, each comprising some 7 to 15 participants.

Each discussion group was charged with identifying and listing uncertainties, describing the impact of each uncertainty on the design of a spar, and making a first pass at prioritizing the uncertainties based on the importance of the impact in design. To assist the discussions, the different specialty areas were given separate starter lists with itemized uncertainties to consider. Each break-out group was assigned a discussion leader. Following the 90-minute break-out discussions, the participants came back together to hear each discussion leader present a summary report of his group's discussion. Appendix C contains the summary reports from each of the 8 groups for the first break-out session, as transcribed from their flip-charts. Appendix C also contains the written instructions and starter lists provided to each discussion group.

In the evening following the first break-out discussion the uncertainty items identified by the separate groups were compiled into four separate spreadsheet lists (one each for metocean, model test practice, design tools, and design practice) and further organized by general topic within each area. The objective of the second discussion session, held the following day, was to validate and rank the items in the consolidated lists based on their importance to spar design. Unlike the first session where the intent was to populate each group with specialists from the same area (metocean, model testing, design), for the second session each discussion group was populated by specialist from all three general areas. This was achieved by re-assigning individuals from the original Metocean and Model Testing Practice groups to one of the original five Design Practice groups.

All five groups were given the same consolidated lists of uncertainties and asked to rank each item as having either a high (H), medium (M), or low (L) impact on spar design relative to VIM. As for the first session, each break-out group was assigned a discussion leader and following the 60-minute break-out discussions the participants came back together to hear each discussion leader present a summary report of his group's discussion. Appendix D contains the spreadsheet lists given to the groups and the rankings for each item returned by each group. Upon reviewing the collected results, items that received high rankings by at least four groups were identified as "consensus high priority uncertainties" (identified in bold red font in Appendix D).

Based on the results of the second discussion session, the objective of the third discussion session was to identify technology gaps responsible for the consensus high priority uncertainties, and to propose initiatives to resolve the technology gaps. The intent was to develop initiatives to address both interim improvements to the state-of-practice and longer term resolutions of uncertainties through advancing basic knowledge.

For the final discussion session the participants were divided into four specialty areas: the original three areas (Metocean, Model Testing, Design Practice) plus an additional group on Numerical Modeling. As with the previous sessions, each group was assigned a discussion leader and following the 90-minute break-out discussions the participants came back together to hear each discussion leader present a summary report of his group's discussion. Appendix E contains the summary reports from each group, as transcribed from their flip-charts.

VIM Uncertainties and Technology Gaps

The discussion group reports provided in Appendices C, D, and E document a thorough process of identification and consensus prioritization of a myriad of issues related to vortex-induced motions of spar platforms.

In the metocean area there were two major issues identified:

1. The existing data base on Loop eddy currents covers only the past 25 years at best so there is limited data available for estimation of site-dependent extreme value statistics and for empirical modeling of current profiles, persistence and gustiness.
2. Fully dynamic numerical models are not ready for use in developing Loop eddy current criteria through hindcasting or for providing insight on the interaction of hurricanes and Loop current eddies.

As a result of these deficiencies, there is a need for better communication between oceanographers and designers so that better use with greater understanding is made of the existing data and models.

Since accurate analytical methods for predicting VIM are not available, model testing of VIM performance is a necessary part of the design process. Model tests are used to develop prototype VIM design criteria (simultaneous inline and transverse A/D and Cd/Cl as a function of reduced velocity and current heading; reduced velocity at lock-in, locked-in, and lock-out). However the inability to preserve Reynolds number similitude between full and model scales results in distortion of the boundary layer flow around the spar at model scale, which introduces fundamental uncertainties in the design and interpretation of spar VIM model tests.

While measures can be taken to minimize the boundary layer distortion by testing at the highest Reynolds numbers possible with existing test facilities (around 10^6, compared with the desired full scale Reynolds numbers of 10^7 and higher), the vortex-induced motions must be constrained to one or two degrees of freedom with existing test rigs. Since spar

VIM involves highly coupled surge/pitch, sway/roll, and yaw effects, there is a need to be able to perform high Reynolds number VIM tests with the spar model free to vibrate in all 6 rigid body degrees of freedom. Currently, 6-degree-of-freedom VIM testing is limited to the 10^4 to 10^5 Reynolds number range. Lower Reynolds number 6 DOF testing is much less expensive and less complicated, and therefore more popular, than higher Reynolds number 1 DOF testing.

The central issue is that model test results indicate a strong (and perhaps unrealistic) sensitivity of VIM to current heading, and therefore to the detailed configuration of the hull appurtenances, yet the consequence of not being able to preserve full scale Reynolds number is that the boundary layer flow in which the appurtenances are located is distorted.

In order to accurately simulate resonant vortex-induced vibrations experimentally it is also necessary to model the damping of the prototype system provided by relative velocity drag on the hull, truss (in the case of truss spars), mooring and risers, as well as damping provided by other mechanisms (e.g. Coulomb friction between the riser buoyancy cans and their guides). Procedures for quantifying such damping at full and model scale, or for controlling damping at model scale, are not well established. Other important effects that need to be considered include the shear in the current profile, and nonlinear, asymmetric stiffness effects due to the mooring and risers.

As a result of the difficulties associated with Reynolds number scaling, constrained modes of vibration, modeling of damping, current shear and other three-dimensional effects, there is a need to understand how these difficulties affect the VIM design criteria derived from model tests and to ensure that appropriate measures of conservatism are incorporated in the criteria to ensure robustness.

While different organizations had different background data and procedures for developing metocean (Loop current eddy) and spar VIM performance (A/D, Cd/Cl) criteria, there were remarkable similarities in how different organizations applied this information in design analysis. Apart from the need to manage uncertainties in metocean and VIM criteria, the design group identified two major issues that they have to face:

1. For most Gulf of Mexico spars, the accumulation of fatigue damage in the mooring system resulting from exposure to Loop current eddies for extended periods of time occurs near the strength limit of the mooring. There is concern that the practice of applying API strength design safety factors calibrated for hurricane conditions to Loop current eddy conditions may be unconservative.
2. The lack of data on high stress/low cycle fatigue (T-N curves) for mooring chain.

There is also strong concern about the impact of hull VIM on riser design and how this is being accounted for in design.

A major gap that is responsible for uncertainties in the development of VIM design criteria is limited understanding of the fundamental physics at the requisite level of detail. In addition to experimental investigations, computational fluid dynamics (CFD) is another tool that can be used to interrogate the VIM physics. However, here again, the resources needed to perform CFD simulations for full scale Reynolds numbers are currently out of reach.

With modest research funding, CFD modeling capabilities have been steadily improving for the last decade. Like experimental model testing, there is a need for benchmark field and laboratory scale data to validate CFD modeling practices.

New Initiatives

The oceanographic community has a couple of long term JIPs in place (CASE, EJIP) that, with the benefit of the Spar VIM Workshop results, could be better focused to address the identified technology gaps. New initiatives in this area would greatly benefit from increased communication between oceanographers and designers so that each group could better understand the needs and capabilities of the other. For example, studies could be performed to quantify the error bounds in the metocean criteria provided to designers and to refine the types of criteria provided so they are more fit-for-purpose. Statistical procedures for developing joint Loop/hurricane current criteria could be developed.

The industry would greatly benefit from more field data and greater access to existing field data, but individual organizations must be willing to share the cost of maintaining the data collection network. Subsequent to the MMS requirement for operators to monitor current profiles from their Gulf of Mexico platforms, mechanisms need to be set up to archive and interpret the data. To supplement the data collected by industry and the MMS, NOOA should be encouraged to deploy current meters on its deepwater buoys.

The need for high quality field data includes simultaneous measurements of ocean currents and spar responses (motions, mooring line tensions, riser stroke). Such data is needed to

1. validate the existing model testing practices (6 DOF/lower Reynolds number and 1 DOF/higher Reynolds number) and establish confidence in the scaling of model test data up to prototype,
2. support the development of new, more robust and fit-for-purpose model test/ Reynolds number scaling practices that can be performed at a larger number of test facilities, and
3. validate and guide the continued development of numerical CFD models of Gulf of Mexico currents and spar VIM.

Since most spars deployed in the Gulf of Mexico are equipped with metocean and structural monitoring systems, the primary need is for sharing mechanisms that allow broader access to the field data for those engaged in spar design (including those involved in the development of experimental and analytical tools and procedures for spar design). The workshop participants proposed the formation of an industry-wide JIP (Motion Net) by which near-real-time spar response data could be made available to subscribers (similar to the on-going Eddy Net/Watch for monitoring Loop current eddies).

As with high quality field data, providing broader access to existing benchmark model test data is of substantial interest as it would enable independent interpretation of test results and serve as a basis for leveraging follow-on studies to advance the state-of-the-art in spar model testing, data interpretation and design analysis procedures.

Finally, a rational consensus basis for verifying the acceptability of mooring and riser designs under vortex-induced motion scenarios should be established by industry for incorporation in API Recommended Practice. This will require re-assessment of safety factors for strength and fatigue, extension of chain fatigue and wear data for high stress/low cycle damage accumulation, and evaluation of hull, mooring, and riser design checks for VIM to ensure consistency. To this end, a Riser VIV Workshop should be planned as a follow-on activity to the Spar VIM Workshop.

Conclusions and Recommendations

The Spar VIM Workshop was an ambitious undertaking requiring extensive planning by the Technical Steering Group, thoughtful preparation by the invited presenters, and intensive participation by the Workshop attendees. It appears that the workshop was successful in achieving its objectives, largely due to MMS' support, industry's willingness to share certain proprietary information, and broad participation in the workshop representing every corner of the business.

The workshop discussions identified an extensive list of prioritized issues and yielded a large number of new (and on-going) initiatives that could be pursued to address the technology gaps. Some of the higher priority gaps that were identified included:

- a need for oceanographers and designers to work more closely together in understanding the uncertainties associated with
    - metocean (particularly current) data and criteria and
    - modeling and prediction of spar VIM,

  so that credible cost-benefit trade-offs can be made to justify future investments in sophisticated field and laboratory measurement programs,

- a need to better understand the uncertainties associated with existing model testing and data interpretation practices (which vary significantly from one organization to the next) and to validate these practices using benchmark field data,

- a need for broader access to existing benchmark field and model test data, and to on-going field monitoring programs, in order to share costs and leverage future opportunities for advancing the state-of-the-art, and

- a need for test data on high stress/low cycle fatigue behavior of mooring chain and industry consensus design criteria for strength design of mooring and risers under repeated high stress fatigue loading associated with spar VIM.

The success of new initiatives aimed at closing these gaps will require broad interest and participation among industry stakeholders, and will largely depend on industry's willingness to seek equitable arrangements for sharing costs and valuing existing proprietary technology. The Spar VIM Workshop was an important first step in this direction.

Appendix A: List of Workshop Participants

2H Offshore Inc.
Karan Kakar
David Walters

ABB - DTE
Shihwei Liao
Chandra Nair
Tao Wang
Xinyu Zhang
Zhengquan Zhou

ABB Lummus Global
Jayant Basak
Jeremy Denman
Allen Magnuson
Jun Zou

American Bureau of Shipping
Ken Huang
Tuanjie Liu

Atlantia Offshore Ltd.
Steve Leverette

BMT Scientific Marine Services
Roderick Edwards
Tom Johnson
Igor Prislin

BP
Pierre Beynet
David Driver
Jeff Geyer

BPP Technical Services Ltd.
Geoffrey Lyons

ChevronTexaco
Jose Abadin
Irv Brooks
Tim Finnigan
Todd Jones
Wei Ma
Owen Oakley
James Stear
Hugh Thompson

Cornell University
Charles Williamson

David Tein Consulting
Chi-Tat (tom) Kwan

Det Norske Veritas
Craig Colby
Vigleik Hansen

Exmar Offshore
Fernando Frimm

ExxonMobil
Mark Danaczko
John Ding
Ted Kokkinis
Roald Lokken
Robert Sandström
Markku Santala
David Smith
Tin Woo Yung

Fugro GEOS Inc.
Rob Smith

GCG Consultants
G. Curtis Gibby

High Seas Engineering, LLC
Neal Brown

INTEC Engineering
Fauzi Hardjanto
Sandeep Jesudasen
Ian Neill
Armin Tavassoli

J. Ray McDermott Engineering
Chuck Kasischke
John (Tim) Nolte
Balakrishna Padmanabhan
Jianan (Jay) Wan

KBR
Rajiv Aggarwal
Bill Greiner

Kerr-McGee Oil & Gas
Michael Beattie
Luis Bensimon
Eric Pulpan

MARIN
Radboud Van Dijk

MARINTEK (USA), Inc.
Svein Karlsen

Minerals Management Service
Mike Conner
Bryan Domangue
Richard Giangerelli
Angie Gobert
Fred Hefren
Tommy Laurendine
Alexis Lugo-Fernandez
Mike Saucier
Arvind Shah
Charles Smith
Michael Tolbert
Troy Trosclair

MODEC International
Shukai Wu

NTNU
Geir Moe

Oceanic Consulting
Tim Moore
Shawn Searle

Offshore Model Basin
Victor Grinius

OTRC
Debra Meador
Richard Mercier
Skip Ward

Petroleum Composites
Jerry G. Williams

Sea Engineering, Inc.
Hans Treu
Chunfa Wu

Shell
Don Allen
Paul Dixon
Wanjun Kim
Li Lee
Stergios Liapis
George Rodenbusch
Hongbo Shu

SparTEC, Inc.
Adam Bangs
Cheng-Yo Chen
Robin Converse
Ann Kristin Indrebo
Philip Winsor

Starmark Offshore Inc.
Robert M. Sexton

Technip Offshore, Inc.
Indra Datta
Lyle Finn
John Halkyard
Mehernosh Irani
Gengshen Liu
Chih-Hung Luk
Allan Magee

Texas A&M University
John Niedzwecki

Transocean
Riddle Steddum

University of Houston
Charles Dalton

University of Michigan
Robert Beck

Virginia Tech
Ali Nayfeh

Wes Schott International
Wes Schott

Appendix B: Workshop Agenda

<u>Day 1 – October 22</u>

9:00 – 9:20	Welcome and Introductory Comments • Mercier, OTRC • Sandström, ExxonMobil
9:20 – 10:10	Regulatory Perspective • Laurendine, MMS • Mercier for McAvoy, USCG • Rodenbusch, API • Huang, ABS • Colby, DNV
10:10 – 10:30	Break
10:30 – 11:45	VIM Fundamentals • Beck, U. Michigan • Williamson, Cornell U.
11:45 – 12:45	Lunch
12:45 – 3:15	Current VIM Design Practice • Ward, OTRC • Halkyard, Technip • Bangs, SparTEC • Break • Lokken, ExxonMobil • Stear, ChevronTexaco • Thompson, ChevronTexaco
3:15 – 5:30	Model Test Practices • Allen, Shell • Break • Yung, ExxonMobil • Finn, Technip • Bangs, SparTEC
5:30 – 5:45	Day 1 Closing Remarks
5:45 – 7:00	Social Hour

Day 2 – October 23

8:30 – 8:40 Day 2 Logistics

8:40 – 12:00 Comparison of Model Tests w/ Design Basis & Field Observations I

- Beattie, Kerr-McGee – Neptune
- Sandström, ExxonMobil – Hoover
- Santala, ExxonMobil – Neptune Inertial Current Event
- Break
- Finnigan, ChevronTexaco – Genesis
- Jones, ChevronTexaco - Genesis
- Irani, Technip – Genesis

12:00 – 1:00 Lunch

1:00 – 2:30 Comparison of Model Tests w/ Design Basis & Field Observations II

- Winsor, SparTEC – Medusa and Front Runner
- Allen, Shell – Classic/Step/Gap/Truss Spars

2:30 – 2:50 Break

2:50 – 5:50 VIM Uncertainty and Design Impacts I (Break-Out Sessions)

- Group I – Metocean
- Group II – Model Testing
- Group III – Design Practice

5:50 – 6:00 Day 2 Closing Remarks

6:00 – 7:00 Social Hour

7:00 – 8:30 Dinner

<u>Day 3 – October 24</u>

8:30 – 8:40	Day 3 Logistics
8:40 – 10:40	VIM Uncertainty and Design Impacts II (Break-Out Sessions)
10:40 – 11:00	Break
11:00 – 3:15	Technology Gap Identification and Resolution (Break-Out Sessions) • Group I – Metocean • Group II – Model Testing • Group III – Design • Group IV – Numerical Modeling
3:15 – 3:30	Break
3:30 – 4:30	Wrap-Up/Way Forward • OTRC • MMS
4:30	Adjourn

Appendix C: Discussion Group Reports – VIM Uncertainty and Design Impacts I

REPORTS BREAK-OUT SESSION I:
VIM UNCERTAINTIES BY SPECIALTY AREAS

Broad Objectives

1. Discuss & list uncertainties in the following Specialty Areas:
    a. Metocean
    b. Model testing practice
    c. Design practice
2. Describe the impact of each uncertainty on the design of a spar
3. Prioritize the uncertainties based on the importance of their impact on design

Organization of Breakout Session

1. Breakout by Specialty Areas (90 minute sessions)
    a. Each Specialty Area Breakout Session to discuss & list uncertainties
    b. Discuss issues on Starter Lists
    c. Add additional issues as appropriate
    d. Order uncertainties based on perceived importance to spar design

2. Report out to entire workshop (90 minutes)
    a. Ordered uncertainties based on Specialty Areas perceived importance
    b. Questions for clarification
    c. Moderators to develop consolidated lists by Specialty Areas

Starter Lists for Items Causing Uncertainties in VIM & Design Practice

Metocean (Loop Currents, Inertial Currents, & Hurricanes)

1. Frequency of large currents;
2. Importance of turbulence,
3. Current profile (shear)
4. Field data quality & quantity
5. Waves in presence of currents
6. Role of models in criteria
    a. accuracy of hindcast models
    b. numerical current models
    c. extreme value estimates
7. Impact on metocean criteria.

Model Testing Practices

1. Scaling (model vs. prototype)
    a. Reynolds number
    b. Damping
    c. Turbulence
    d. Current profile (shear)
2. Modeling of spar
    a. Sensitivity to hull form
    b. Appurtenance details
    c. Modeling of mooring system
    d. VIM suppression method
3. Modeling currents with associated waves
4. Directional sensitivity of VIM response
5. Trade-offs & compromises in experimental design
6. VIM design data from model tests
    a. Statistical characterization of the data
    b. Characterization of experimental uncertainties
    c. Model test results – interpret as scaled model test or use to validate/calibrate physical model?
    d. How best to express VIM design parameters?
        i. C_d & A/D?
        ii. General trajectories?
        iii. Force characterizations.

Design Practice

1. Metocean criteria
2. VIM criteria from model tests
3. Extreme value estimation
4. Managing uncertainties associated with incorporating VIM in design
5. Impacts on mooring & riser analysis procedures
6. Design philosophy for mooring, riser & VIM suppression design
7. Directional sensitivity of VIM response
8. Design parameters from model tests
9. Design validation using field data
10. How to express VIM design parameters
    a. C_d & A/D?
    b. General trajectories?
    c. Force characterizations?

Summaries of Break-Out Group Discussions

Report From Metocean Group

Markku Santala	Tom Johnson
James Stear	Rob Smith
David Driver	Alexis Lugo-Fernandez
John Halkyard	

Basis/Assumptions
- Discussion limited to GoM current phenomena (not RoW, wind, waves, etc.)
- Considered 2 classes of currents: Loop current (incl. eddies) vs hurricane

Uncertainties for Loop eddy currents:
- Need criteria for profile shape, persistence, current gustiness
- Lack of (limited duration) field data -Existing data base is order 25 years at best (in certain areas)
- Parametric modeling and estimation of extreme value statistics based on limited data
- Fully dynamic modeling not ready for use in developing criteria

Uncertainties for hurricane currents:
- Lack of definitive current hindcasting method
- Very little good data for profiles
- Time evolution of "inertial currents"

New initiatives
- Measured current & position data from existing floating structures can/will provide useful information for validation
- Measurements are being made during drilling but more could be done, e.g., measurement current through entire water column & involving more operators
- Set up long term current monitoring systems on existing platforms
- Need mechanism to pool data (archive & interpret data)
- Current practice in developing metocean criteria does have some built-in conservatism (to mitigate uncertainties)
    - Resolving these uncertainties may lead to optimatization of criteria setting process (i.e. removal of conservatism)

Comments from floor:
- Need techniques for setting combined Loop current + hurricane current criteria
    - Probabilistic techniques (are the 2 event statistically independent? How to establish join probability distributions)
    - Mechanistic model (do hurricanes intensify as they pass over eddies? How to handle density stratification and non-colinearity of component current profiles?)

Report From Model Test Group 1

Ro Lokken	Svein Karlsen
Owen Oakley	Philip Winsor
Ted Kokkinis	Bryan Domangue
Li Lee	Michael Tolbert
Mehernosh Irani	Ken Huang
Shawn Searle	John Ding
Bob Beck	Wabjun Kim
Neal Brown	

Areas of agreement

- Since we don't have an accurate analytical method to predict VIM, model tests are a necessary part of the process
- We need to investigate a large number of headings when we model test

Uncertainties (in decreasing priority)

9 Number of degrees of freedom in model test
What is needed/acceptable - 1 dof --> 6 dof

8 Reynolds scaling - field vs (various) model scales
Are appurtenances in or out of the boundary layer?
3D flow regimes
Can't achieve high Re and 6 dof tests simultaneously today

8 Need to continue gathering high quality validation data (field & model scale)

4 Techniques for processing VIM data (full scale & other) and establishing statistical confidence

3 Effect of waves on VIM

2 Understanding the physics that cause the sensitivity to heading

1 Turbulence in current

0 Damping of rig setup

0 Free vs forced vibration testing

0 What does it mean to "model the mooring system accurately"?

Report From Model Test Group 2

Tim Finnigan	Indra Datta
Tin-Woo Yung	Arvind Shah
Victor Grinius	Angie Gobert
Don Allen	Jose Abadin
Tim Moore	G. Curtis Gibby
Radboud Van Dijk	Robert Sexton
Geir Moe	

Basis

- Uncertainties that model testing introduces
- Uncertainties that model testing can help to resolve

Uncertainties (in decreasing priority)

14 Full scale validation of model tests
10 Appurtenances - Re no., effect of boundary layer on how uncertainties affect VIM (and directionality) - what's the impact and how do you model?
10 Modeling "full scale" damping at model scale (e.g. truss damping)
8 Modeling shear currents
7 How to model the effect of SCRs, risers, "other", moorings
6 Why concern about VIM
    riser offsets (strength, fatigue, wear)
    SCR design limits (fatigue, wear)
    topsides processes
    cell spar design strategy
6 Effect of length of tests on statistical stability of results
6 Nonlinear asymmetric stiffness (mooring)
5 Single vs multi-DOF
5 Re no. effect on hull
5 Definition and modeling of actual k/D (surface roughness) - prototype vs model
5 Lock-in stability - what does it do to your results
3 Understanding turbulence impact on VIM, especially strakes (in the ocean, how to model in the basin)
2 How to model effect of vertical stiffness
2 Completeness of test program - how many tests are enough?
2 Strake geometry - similarity with bilge keels
1 How to increase effective Re - use of "traditional" techniques to trip boundary layer are uncertain
1 Effect of vortex re-organization on strake performance
Modeling realistic stratified flow combined with current shear
Avoid "2:1" period modeling
Necessary angular resolution
Effect of waves (when important, how?)
Fundamental flow behavior (PIV measurements)
Data presentation

Report From Design Practice Group 1

Bob Sandstrom
Craig Colby
Jun Zou
Tao Wang
Todd Jones
Luis Bensimon
Cheng-Yo Chen
Chih-Hung Luk
Riddle Steddum
Armin Tavassoli
Richard Giangerelli
Thomas Meyer

Lots of consensus on design analysis process once VIM criteria are specified

Uncertainties

- High stress fatigue and mooring factors - fatigue damage accumulation for extended periods of time near strength limit (80% MBL) - are API safety factors for hurricane conditions applicable?

- Currents - profile/depth, turbulence/shear, statistical descriptions (distributions & probabilities)

- Need a responsed-based procedure for VIM criteria (considering joint probability of eddies & hurricanes)

- Derivation of VIM criteria from model tests - criteria for extremes should be different than criteria for fatigue

- What should pitch & roll VIM critera be for design of topsides, facilities, risers?

- Impact of hull VIM on riser design

Report From Design Practice Group 2

Mark Danaczko	Karan Kakar
Michael Beattie	Chuck Kasischke
Xinyu Zhang	Hongbo Shu
Allen Magnuson	Jerry Williams
Irv Brooks	Troy Trosclair
Hans Treu	Mike Saucier
Adam Bangs	

Metocean

- Long-term distribution - current speed, directions, durations
- Confidence in models (in predicting loop currents)
- Importance of inertia current and associated wind/wave

VIM Criteria From Model Tests

- Prediction of extreme values from short tests
- Confidence in lock-in and lock-out
- Confidence in directional behavior
- Validation with field data

Mooring Line Design Criteria

- Appropriateness of RP2SK - use of 0.6 B.S. vs 0.8 B.S. for strength design with repeated high loading
- Fatigue behavior of chain at stresses higher than typical T-N curves (new tests for high stress/low cycle fatigue)
- Initiation of VIM for fatigue - which bins will have responses
- Criteria for robustness checks
- Criteria for design with combined waves & VIM

Strake Design/VIM Mitigation

- Strake width - 0.10? 0.14?
- Cut-outs for transportation: can directional response be relied on?
- Importance of lengthwise coverage
- Importance of interaction with other appurtenances & chains
- Tensioning as an initial design strategy to avoid lock-in (passive vs active mooring system)

Comment from floor:

- Mismatch between directional resolution of current criteria and directional resolution of test results

<u>Report From Design Practice Group 3</u>

Vigleik Hansen	Tim Nolte
Jayant Basak	Gengshen Liu
Chandra Nair	David Walters
Steve Leverette	Ali Nayfeh
Wei Ma	Tuanjie Liu
David Smith	Fred Hefren
Chunfa Wu	

Metocean

- Current characteristics - speed, direction, duration, profile, turbulence, site-to-site variability)

- Current criteria
    - Appropriate combined WWC criteria
    - Standard way to express WWC criteria
    - Seasonal/monthly criteria for fatigue
    - Criteria for RP's in 5 - 50 year range

- VIM criteria from model tests
    - Ur for lock-in, locked-in, lock out
    - Appropriate statistical characterization for VIV response data
        - A/D inline & transverse - max or rms?
        - Cd inline & transverse
        - Robustness check for A/D criteria

- Design checks
    - Design factor for fatigue life - 10X years or 20X years?
    - T-N curves for mooring line fatigue (high stress, low cycle)
    - Fatigue damage from multiple loadings (loop current, hurricanes, inertial)

- Field data
    - Means to readily share response & current data, e.g., "Motion Net"

- Comments from the floor:
    - Statistical process for estimating extreme values from finite record lengths
    - Need simultaneous Cd and Cl (drag and lift) coefficients to be able to model proper force vector

Report From Design Practice Group 4

Robin Converse	Jianan Wan
Rajiv Aggarwal	Shukai Wu
Shihwei Liao	Stergios Liapis
Igor Prislin	Geoffrey Lyons
Ian Neill	Charles Smith
Fernando Frimm	

Metocean Criteria
- Frequency of eddy currents
- Joint probability of currents + wind & waves

Method
- Need a model test guideline
- Are we capturing "real" damping
- How to capture truss Cd vs hard tank Cd (Cd determination is crude)
- How to correct for appurtenances

Design
- Generate a toolbox of what works and what doesn't (strake height, cut-outs)

Report From Design Practice Group 5

Lyle Finn	Sandeep Jesudasen
Hugh Thompson	Paul Dixon
Jeremy Denman	Ann Kristin Indrebo
Zhengquan Zhou	Fauzi Hardjanto
Jeff Geyer	Rod Edwards
Tom Kwan	Tommy Laurendine
Balakrishna Padmanabhan	Mike Conner

Metocean
- Not enough data sharing
- Possible MMS requirement to monitor currents
- Currents are most uncertain of all criteria?
- Wave/current interaction for hull VIV

VIM Criteria From Model Tests
- Reynolds number uncertainty
- Lock-in Vr
- 2D vs 3D tests
- We are able to design for current criteria - problem is ensuring criteria are conservative
- Need to model test specific geometry

Managing Uncertainty - Use pretension or stepped line tensioning

Use max response for fatigue

Use full scale data (but only classic spar data available, except for one high current event for Horn Mountain - non VIV observed)

Biggest Uncertainties
- Directional sensitivity
- Effectiveness of strakes - 10% vs 14%
- Lock-in Vr, A/D response

Appendix D: Discussion Group Reports – VIM Uncertainty and Design Impacts II

REPORTS FROM BREAK-OUT SESSION II: DESIGN IMPACT OF UNCERTAINTIES

Broad Objectives

1. Discuss list of uncertainties consolidated from break-out session I group reports and provided as a spreadsheet to all break-out groups, organized according to the following Specialty Areas:
   a. Metocean
   b. Model test practice
   c. Design tools
   d. Design practice
2. Prioritize the uncertainties based on the importance of their impact on design

Breakout Session Plan

1. Breakout sessions Design Practice Specialty (60 minutes)
   a. Specialists from Metocean & Model Test breakout groups melded into existing Design specialists breakout groups
   b. Breakout groups to rank all uncertainties in consolidated lists based on their importance to spar design
      i. Discussions & prioritization to be coordinated by Design specialists
      ii. Metocean & Model Test specialists to support discussions & clarify issues from their specialties

2. Report out to entire Workshop (60 minutes)
   a. Uncertainties from the 4 Specialty Areas prioritized by importance to design
   b. Develop a consensus on priorities

Summaries of Break-Out Group Discussions

The following tables summarize the priorities assigned by each of the 5 groups to the uncertainties developed from the first break-out session. Items which were ranked high priority by at least four groups are identified in red font as overall High Priority.

METOCEAN						
Priority (High, Medium, Low)						
Group 1 Colby	**Group 2** Danaczko	**Group 3** Hansen	**Group 4** Frimm	**Group 5** Finn	**High Priority**	
						LOOP EDDY CURRENTS:
						Characteristics
H	H	H	H	M	**H**	Need statistics & criteria for profile shape, direction, duration, current gustiness, site-to-site variability
M		M	M	M		Modeling realistic stratified flow combined with current shear
M	M	M		M		Wave/current interaction for hull VIV
M	M	H	M	M		Understanding turbulence impact on VIM, especially strakes (in the ocean, how to model in the basin)
						Criteria (long term statistics)
H	H	H	H	H	**H**	Lack of (limited duration) field data -Existing data base is order 25 years at best (in certain
H	H	H		H	**H**	Parametric modeling and estimation of extreme value statistics based on limited data
L	M	H	M+	H		Fully dynamic modeling not ready for use in developing criteria
H				H		Resolving uncertainties may enable removal of conservatism in criteria
H	H	H		H	**H**	Appropriate combined WWC criteria
M	L	M		M		Standard way to express WWC criteria
L	L	M	L	M		Seasonal/monthly criteria for fatigue
	L	H	L	M		Criteria for RP's in 5 - 50 year range
H				L		We are able to design for current criteria - problem is ensuring criteria are conservative
L	H		L	M		Mismatch between directional resolution of current criteria & directional resolution of test
						Criteria - Loop Current + Hurricanes
H	H	H	H	H	**H**	Need techniques for setting combined Loop current + hurricane current criteria
H		H	H	H	**H**	Probabilistic techniques (are the 2 events statistically independent? How to establish joint probability distributions)
						Field Data
H	H	H	H	H	**H**	Set up long term current monitoring systems on existing drilling and production platforms
H	H		H	H	**H**	Need mechanism to pool data (archive & interpret data), e.g. "Motion Net"
H		H	H	M	**H**	Possible MMS requirement to monitor currents
						HURRICANE/INERTIAL CURRENTS:
H	H	H	M	H	**H**	Lack of definitive current hindcasting method
H	H	H	M	M		Very little good data for profiles
M	H	H	M	M		Time evolution of "inertial currents"
M	H	H	M	M		DW currents (near the slope) resulting from storm surge

MODEL TEST PRACTICE						
Priority (High, Medium, Low)						
Group 1 Colby	Group 2 Danaczko	Group 3 Hansen	Group 4 Frimm	Group 5 Finn	High Priority	
M						**Test Plan/Measurement Objectives**
	M	L	M	M		Effect of waves on VIM (when important, how?)
	H	H	M	M		Lock-in stability - what does it do to your results
		H		H		Completeness of test program - how many tests are enough?
	M		M	M		Understanding turbulence impact on VIM, especially strakes (in the ocean, how to model in the basin)
			L	L		Effect of vortex re-organization on strake performance
	H	H	H	M		Necessary angular resolution
	H	H	M	M		Need a model test guideline
						Test Techniques
H	H	Case by case	M,H	H	**H**	No. of degrees of freedom in model test (what is needed/acceptable - 1 dof --> 6 dof)
H	H	H	H	H	**H**	(Understanding of) Reynolds scaling - field vs (various) model scales
				H		Are appurtenances in or out of the boundary layer?
				H		3D flow regimes
				H		Can't achieve high Re and 6 dof tests simultaneously today
M	M	H	M	M		Turbulence in current
M	L	H	M+	M		Damping of rig setup
H	H	H	H	H	**H**	Modeling "full scale" damping at model scale (e.g. truss damping)
L	H			M		Free vs forced vibration testing (slope of lock-in curve)
H	H	H	H	H	**H**	Modeling shear currents
	L	H	M+	H		How to model the effect of SCRs, risers, "other", moorings (nonlinear asymmetric stiffness)
	M	H	M	M		Definition & modeling of actual surface roughness - prototype vs model (tie w/ field
L	L	H		L		How to model effect of vertical stiffness
	L	H	L	L		Strake geometry - similarity with bilge keels
	H	H	M	H		How to increase effective Re - use of "traditional" techniques to trip boundary layer are uncertain
	M	H	L	L		Modeling realistic stratified flow combined with current shear (depends on how well other methods work)
	H	H	L	L		Fundamental flow behavior (PIV measurements)
	H	H	M	M		How to capture truss C_D vs hard tank C_D (C_D determination is crude)
	YES	H	H	H	**H**	Need to model test specific geometry

MODEL TEST PRACTICE						
Priority (High, Medium, Low)						
Group 1 Colby	**Group 2** Danaczko	**Group 3** Hansen	**Group 4** Frimm	**Group 5** Finn	**High Priority**	
						Data Processing/Interpretation
H	H	H	M	M		Techniques for establishing statistical confidence
H	H	H	M	M		Effect of length of tests on statistical stability of results
H	H	H	M	M		Statistical process for estimating extreme values from finite record lengths
						VIM Criteria From Model Tests
H	H	H	H	M	**H**	Confidence in Ur for lock-in, locked-in and lock-out
H	H	H	H	M	**H**	Confidence in directional behavior
H	H	H		M	**H**	Need simultaneous C_D and C_L coefficients to be able to model proper force vector
H	H	H	L/H	M	**H**	Robustness check for A/D criteria
H	H	H	H	M	**H**	Appropriate statistical characterization for VIV response data
				M		A/D inline & transverse - max or rms?
				M		C_D inline & transverse
				M		criteria for extremes should be different than criteria for fatigue

DESIGN TOOLS						
Priority (High, Medium, Low)						
Group 1 Colby	**Group 2** Danaczko	**Group 3** Hansen	**Group 4** Frimm	**Group 5** Finn	**High Priority**	**VIM Mechanics**
	H	H	H	M	**H**	Understanding the physics that cause the sensitivity to heading
	M	M	M	M		Effect of waves on VIM
	M	H	M	M		Understanding turbulence impact on VIM, especially strakes (in the ocean, how to model in the basin)

DESIGN PRACTICE						
Priority (High, Medium, Low)						
Group 1 Colby	Group 2 Danaczko	Group 3 Hansen	Group 4 Frimm	Group 5 Finn	High Priority	
						Field Data
H	H	H+	H	H	**H**	Full scale validation of model tests - need to continue gathering high quality data
H	M	H	M	M		Techniques for processing VIM data (full scale & other) and establishing statistical
H	H	H	H	H	**H**	Means to readily share response & current data, e.g., "Motion Net"
						VIM Design Criteria
M	H	H	M	M		Need a response-based procedure for VIM criteria (considering joint probability of eddies & hurricanes)
M	L	M	M	L		What should pitch & roll VIM criteria be for design of topsides, facilities, risers?
H	H	H	M	L		Lock-in stability - what does it do to your results
M	H	H	M	M		What angular resolution is necessary (mismatch between directional resolution of current criteria and directional resolution of test results)
H	H	H		M		Initiation of VIM for fatigue - which bins will have responses
H	H	H	M	M		Criteria for fatigue analysis - max response? rms response?
H	H	H	M	M		Criteria for robustness checks
M	?	M	H	M		Criteria for design with combined waves & VIM
						Mooring Line Design
H	H	???	H	H	**H**	Appropriateness of RP2SK - use of 0.6 B.S. vs 0.8 B.S. for strength design with repeated high stress fatigue loading
H	H	H	H	H	**H**	Fatigue behavior of chain at stresses higher than typical T-N curves (new tests for high stress/low cycle fatigue)
H	H	M	M	M		Design factor for fatigue life - 10X years or 20X years?
L	H	M	M	M		Fatigue damage from multiple loadings (loop current, hurricanes, inertial) - how to combine?
						Strake Design/VIM Mitigation
H	H	H	M	M		Strake width - 0.10? 0.14?
H	H	H	M	M		Cut-outs for transportation: can directional response be relied on?
H	M	H	M	M		Importance of lengthwise coverage
H	H	H	H	M		Importance of interaction with other appurtenances & chains
L		H	M	M		Tensioning as an initial design strategy to avoid lock-in (passive vs active mooring system)
L		H	M	M		Tensioning as an backup design strategy to avoid lock-in (passive vs active mooring
L	Whatever	H		M		Avoid "2:1" period modeling
						Riser Design
H	H	H+	H	M	**H**	Impact of hull VIM on riser design

Appendix E: Discussion Group Reports – Technology Gap Identification and Resolution

REPORTS FROM BREAK-OUT SESSION III: TECHNOLOGY GAP IDENTIFICATION AND RESOLUTION

Broad Objectives

1. Identify technology gaps responsible for uncertainties in the following areas:
    a. Metocean
    b. Model testing
    c. Design practice
    d. Numerical modeling
2. Develop initiatives to resolve technology gaps
3. Initiatives should address both
    a. Interim improvements to the state-of-practice
    b. Longer term resolutions of uncertainties through advancing the state-of-knowledge
4. Prioritize initiatives based on impact, time to achieve, & resource requirements

Breakout Session Plan

1. Breakout by Specialty Areas (90 minutes)
    a. Begin with list of uncertainties prioritized by Specialty Groups based on design impact (compiled from previous Breakout Session)
    b. Consider following types of recommendations
        i. Interim improvements to the state-of-practice
        ii. Longer term resolutions of uncertainties through advancing the state-of-knowledge
    c. Specifically consider these as potential recommendations in the appropriate Specialty Areas
        i. Metocean
            1. Need for field data?
        ii. Model testing
            1. Need to test at high Reynolds number?
        iii. Design practice
            1. Need for a consensus guideline or standard?

2. Report out (105 minutes)

Summaries of Break-Out Group Discussions

Report From Metocean Group

1. Need statistics for profile shape, duration and direction, and appropriate wind, wave & current
    a. Thought is needed on how to characterize
    b. Quite a bit of data is available, some of which hasn't been analyzed
    c. More communication between oceanographers & designers, including design process & data collection activities

2. lack of field data in certain areas/parametric model
    a. get JIPs already set up to focus on filling gaps
        i. CASE JIP – Dave Peters, Mike Vogel, Cort Cooper
        ii. DeepStar – Dave Driver
    b. Eddy Net is ongoing – Horizon Marine (Jim Feeney), Cort Cooper
        i. Data is contributed or cash participants
    c. Study uncertainties to quantify error bounds in criteria
        i. CASE/EJIP task

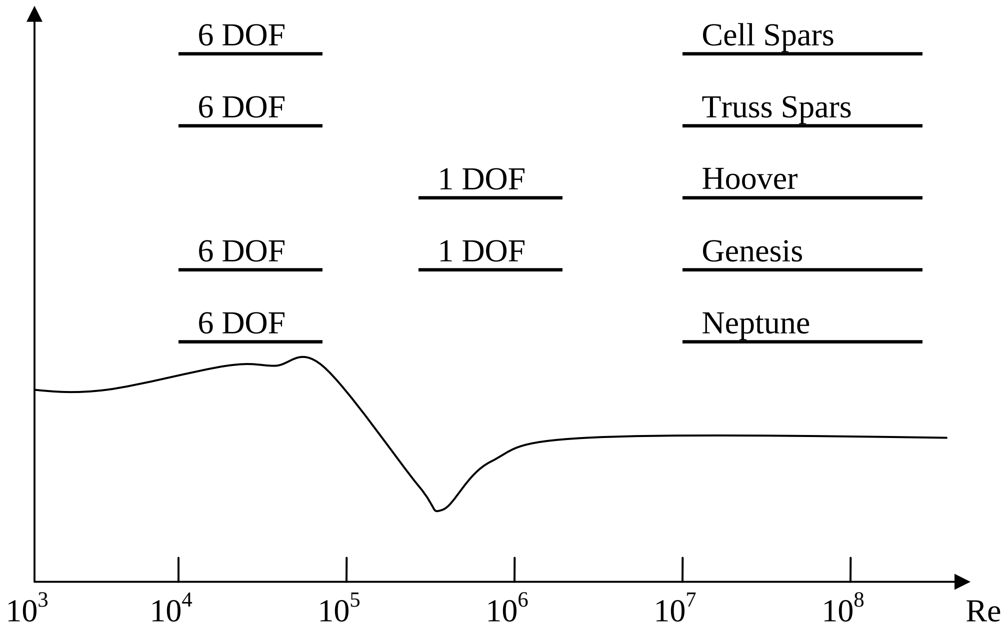
3. Joint probability of Loop current and hurricane
    a. Statistically can be done
    b. Outstanding issues
        i. How to combine currents
        ii. Intensification of hurricanes over loops
        iii. Wave-current interaction (may not be a VIM issue)
            1. kinematics
            2. steepening
            3. refraction

4. Field Data
    a. Ongoing, could be better for drilling
    b. MMS is filling gaps in some areas
    c. Get current meters on deepwater NOAA buoys
    d. Industry network is taking shape
        i. Equitable arrangement for access

5. Hurricane currents
    a. Ongoing effort with MMS
        i. Wait and see on results
        ii. Possible follow-on JIP
    b. Ensure monitoring stays on in evacuation situation

Report From Model Test Group

1. 1-DOF vs 6-DOF testing
    a. both are important
    b. need better definition of criteria to decide which one is needed (1-DOF, 6-DOF, or both)



2. Reynolds Number Scaling Issue
    a. Full scale data (8 votes)
    b. 1-DOF truss/cell spar tests at "high" Reynolds no. (6 votes)
    c. even larger (1:30) towed models (4 votes)
        i. Holstein (1:45)
        ii. Basin deep/long enough?
    d. Desire to have multiple basins capable of testing (competition, schedule) (4 votes)
    e. 1-DOF spar tests at low Reynolds no. (3 votes)
    f. boundary layer scaling? (2 votes)
        i. study depth/impact on appurtenances
            1. LCC flow visualization to 10^7
        ii. Release classic data to researchers
    g. 2-DOF spar testing

3. Sheared Currents - Gaps
    a. Develop a way to produce a low turbulence, sheared current in a tank
    b. Measurement of turbulence in the ocean

Report From Design Group 1

1. Current Data/Collection & Criteria
    a. Continue Eddy Net/Watch
    b. Pooling & sharing of existing data
    c. Numerical modeling (HYCOM)

2. Establish confidence from scaling to prototype
    a. Field validation
    b. Performance benchmark
    c. Fundamental research

3. Rational method to assess risers/moorings
    a. Extend performance data for fatigue & wear
    b. API/industry to establish acceptance basis

4. Periodic review/improvement
    a. Industry workshops
    b. Industry committee/API
    c. ITTC for offshore

Report From Design Group 2

1. Metocean
    a. Continue support for industry-wide data collection (eg. Eddy Net) – metocean and platform motions
    b. Calibrate GEM model, continue development
    c. Promote standards for data collection and description
    d. Increase focus on inertial currents

2. Model Tests
    a. Share Genesis data from DTMB and MARIN to enable wider interpretation
    b. Perform DTMB (high Re) tests for a truss spar to compare with low Re tests (and comparable low Re tests if not available) – select spar with field data collection system for eventual comparison
    c. Develop improved techniques for sheared current tests
    d. Increase emphasis on flow visualization in tests to help understand the influence of appurtenances

3. VIM Mechanics
    a. See model test – flow visualization above
    b. Propose separate meeting for CFD application to VIM – possible JIP in future?
    c. Better definition of boundary layer behavior

4. Design
    a. Extend chain fatigue testing for low cycle/high stress fatigue
    b. Recommend fatigue analysis for extreme event as well as long term conditions
    c. Obtain additional spar field response data

Report From Design Group 3

1. Establish Criteria – Data – Knowledge of Ocean
    a. Take data (only until critical mass – allow alternates)
        i. MMS – concerned about what data
        ii. Alternate coordinated plan (JIP) (Test Plan)
    b. Modeling – will come when data there
    c. Current energy spectrum – DeepStar

2. Model Tests
    a. Issue of low Re, 6 dof versus high Re, 1 dof
        i. Feedback from designers
        ii. Depends on project
        iii. Continue current debate
    b. Design Information
        i. Directional dependence of VIM
        ii. Mean force by direction
            1. base C_D and C_L
            2. C_D with VIM
            3. designer feedback
        iii. force data
        iv. validation of above
            1. field data (also as-built) in process
            2. sharing mechanism
        v. riser – mooring information flow
        vi. relative velocity basis

Report From Numerical Modeling Group

1. What benchmarks are needed?
    a. If at low Re – OK for high Re?
    b. Need checks for VIM at each Re

2. Empirical models - hard to tailor to variable configurations, short 3D effects, …

3. Visualizations – big benefit

4. Limited CFD use now, but great future

5. CFD Options
    a. DNS
        i. most exact (least inexact) solution capability
        ii. presently restricted to Re < 3,000 due to hardware, but bigger machines are on the way
        iii. limited application to VIM for spars at present, but need to keep working on DNS modeling!
    b. URANS, LES, DES – more approximations

6. CFD Engineering Models
    a. URANS, LES, DES – how to benchmark?
        i. PIV data for Re ~ 1,000,000
        ii. Match C_D, C_L, C_a, … under VIV
            1. bare cylinders
            2. straked cylinders
            3. …
            4. appurtenances? (engineering models)
        iii. blind tests
        iv. qualitative versus quantitative?

7. Barriers
    a. $$ for developing capability, tools, hardware access,…
    b. must demonstrate value to project teams before they will fund
    c. slow research funding (oil, contractor)
    d. lack of awareness in oil industry eg. for high Re concerns
    e. universities cannot respond like contractors
    f. will we have sufficient benchmarks (eg. at Re=50,000,000)?

8. Hardware
    a. 96 node, 32 bit Linux cluster - $200,000
    b. 1100 node, 64 bit OSX Apple cluster - $5,200,000 (/computing.UT.edu/terascale)
    c. small clusters are still useful

Appendix F: Workshop Presentations

F-1: Mercier Introduction

F-2: Sandström Introduction

F-3: MMS Perspective – Laurendine

F-4: API Perspective – Rodenbusch

F-5: ABS Perspective – Huang

F-6 : DNV Perspective – Colby

F-7 : VIM Fundamentals – Beck

F-8 : VIM Fundamentals – Williamson

F-9: Current VIM Design Practice – Ward

F-10: Current VIM Design Practice – Halkyard (Technip)

F-11: Current VIM Design Practice – Bangs (SparTEC)

F-12: Current VIM Design Practice – Lokken (ExxonMobil)

F-13: Current VIM Design Practice – Stear (ChevronTexaco)

F-14: Current VIM Design Practice – Thompson (ChevronTexaco)

F-15: Model Test Practices – Allen (Shell)

F-16: Model Test Practices – Yung (ExxonMobil)

F-17: Model Test Practices – Finn (Technip)

F-18: Model Test Practices – Bangs (SparTEC)

F-19: Neptune Spar Observations – Beattie

F-20: Hoover Spar Observations – Sandström

F-21: Neptune Spar Inertial Current Event – Santala

F-22: Genesis Spar Observations – Finnigan

F-23: Genesis Spar Observations – Jones

F-24: Genesis Spar Observations – Irani

F-25: Medusa and Front Runner Spar Observations – Winsor

F-26: Classic/Step/Gap/Truss Spars - Allen