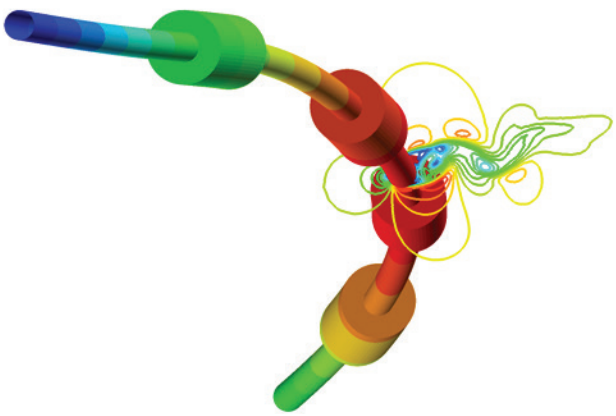


Improving the Design of Subsea Riser Systems

A Cray-Altair-Intel Solution

for Improved Oil & Gas Component Engineering

This paper describes a high-performance computing (HPC) solution that gives engineers the computational systems they need to perform advanced subsea computational fluid dynamics (CFD) analysis with better speed, scalability and accuracy. With Altair's AcuSolve CFD solver running on Cray® XC30™ supercomputer systems powered by Intel® Xeon® processors, operators and engineers responsible for riser system design and analysis can increase component life, reduce uncertainty and improve the overall safety of their ultra-deep-water systems while still meeting their demanding development schedule.

Solution Highlights

- Speed up simulations significantly, even at 4000+ cores
- Achieve a 20x L/D ratio increase on a single Cray XC30 cabinet
- Design longer-lasting riser systems with better performance and integrity

In this document:

- Solution features
- Benchmark results
- Configuration recommendations on Cray hardware

Challenge: Predicting Riser Behavior to Improve Performance and Lifespan

Subsea riser systems are conduits that safely transport hydrocarbon products from subsea wells and equipment up to fixed and floating structures operating on the ocean surface, such as semi-submersibles, spars, and floating production, storage and offloading (FPSO) vessels.

As the oil and gas industry has made advances in topside performance, drilling techniques, and subsea equipment, riser systems have continued to increase in complexity. In the harsh environment of the ultra-deep-water play, the safety, reliability and performance of the riser system is of great importance. Furthermore, the longevity of the riser system has a direct impact on overall field performance, since cost and downtime associated with replacement and repair are very high. The reliability and fatigue life of the riser system is largely dependent on subsea currents and the risers' response to them; this response is primarily driven by vortex-induced vibration (VIV) and vortex-induced motion (VIM).

Though CFD simulations have been successfully employed by top tier global Oil & Gas companies to conduct small-scale analyses of risers and their VIV countermeasures, large scale numerical simulations of VIV and VIM have proven to be a challenge for most general purpose CFD codes. In particular, due to the riser system's very large ratio of length to diameter (L/D), the number of nodes required for a full-scale simulation has historically challenged the capacity of many computational facilities and were thus not feasible for real product development cycles.

Improving the Design of Subsea Riser Systems

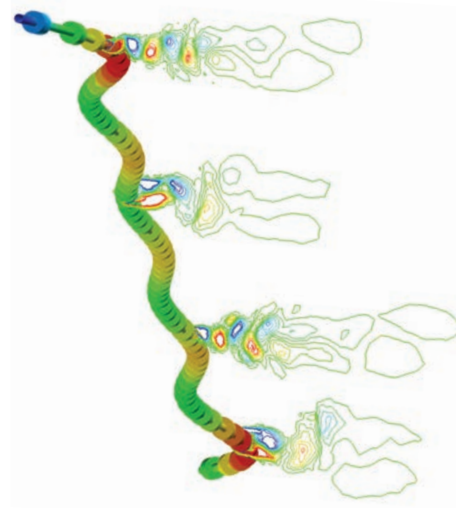
To address these challenges, high-performance computing (HPC) technology providers like Altair, Cray and Intel have continued to advance their technology for scalable and realistic simulations. As a result, engineers now have the ability to conduct these simulations successfully and still stay well within their system development schedule.

Altair's Solution for Riser Analysis

The HyperWorks suite includes all the software applications required for full-scale riser VIV simulations:

- **AcuSolve**, a leading general-purpose CFD solver, is the most validated CFD solution for the offshore industry. AcuSolve's robust and scalable technology is capable of solving the most demanding industrial and scientific applications, and provides unparalleled accuracy on fully unstructured meshes. Applications ranging from steady RANS simulations to complex, transient, multiphysics simulations are handled with ease and accuracy. AcuSolve uses its Arbitrary Lagrangian-Eulerian (ALE) mesh motion and free-surface, Fluid/Structure Interaction (FSI), Detached-Eddy Simulation (DES), and transient turbulence model capabilities to analyze the effects of wave motion, multiple structures, riser shapes and other motions (including nonlinear response, interaction with the sea bottom, transient turbulence with boundary layer, flow separation, wake-free shear and other complex problems found offshore).
    - AcuSolve provides two powerful capabilities for simulating FSI and response to fluid forces: 1) Practical FSI (P-FSI) predicts linear solid/structural responses; and 2) Direct-Coupled FSI (DC-FSI) predicts large deformation and non-linear solid/structural responses. The linear model is solved within AcuSolve as part of the FSI solution.
    - Via linear superposition, AcuSolve can predict the response of riser structural components from a sweep of structural modes. The coupled methodology is superior for transient applications that exhibit nonlinear response due to large deformations, material nonlinearities, or complex contact.
- The structural modes can be calculated quickly and easily using Altair's **OptiStruct** finite element analysis (FEA) solver, the market-leading solution for structural design and optimization.
- In addition to the AcuSolve and OptiStruct solvers, the HyperWorks suite also includes pre- and post-processors **HyperMesh**, **AcuConsole** and **AcuFieldView**, which provide state-of-the-art meshing, model definition, and flow visualization capabilities that are ideal for riser FSI design.
- Altair is also a leader in high-performance computing (HPC) workload management; HyperWorks simulation products integrate with Altair's **PBS Works** HPC products to optimize resource utilization on Cray hardware.

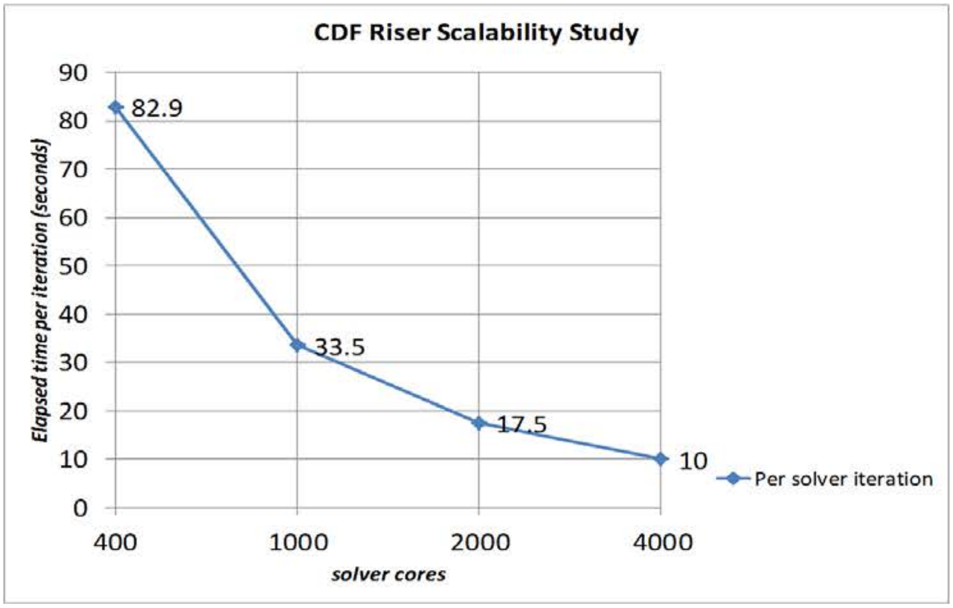
In addition to its software offerings, Altair is a leader in CAE consulting services. The Altair ProductDesign (APD) division employs 700+ engineers in over 40 offices worldwide, providing engineering consulting and custom software solutions in a variety of verticals such as automotive, energy, aerospace, consumer goods and more. APD excels in delivering game-changing engineering support for advanced CFD, especially when coupled with mechanical responses in FSI. In particular, simulations of risers and other offshore equipment have become a cornerstone of this team's capability.



Full-Scale Riser VIV Motion [L/D:10,000]

Key Features & Benefits:

- Fastest solver-neutral CAE environment for high fidelity modeling
- Powerful CFD solver with leading FSI technology and unparalleled accuracy on fully unstructured meshes
- Market-leading structural design and optimization solver for rapidly developing more lightweight and structurally efficient designs
- Interconnect architecture designed for maximum scalability and performance
- Available HPC workload management software
- ROI from a consolidated HPC platform for both seismic processing and subsea CFD
- Unparalleled expertise and support from the leaders in HPC and CAE



Running AcuSolve for riser simulation on a Cray XC30 system yields dramatic performance improvements, as shown in the chart above.

Cray Supercomputers for Riser Analysis

The Cray XC30 supercomputer is a node interconnect architecture designed for maximum scalability and performance. It incorporates the latest Intel® processors and is based on the Cray proprietary high speed "Aries" interconnect. The Aries interconnect and associated system software delivers industry-leading scalability and performance.

Proof Point: HyperWorks Riser Solution on Cray Systems

To study the scalability of HyperWorks riser simulation software at varying core counts, Cray and Altair utilized a real-world model with the following characteristics:

- L/D ratio of 10,000, which is roughly 10-20x the typical size used in current industrial applications. (Generally, industrial applications are limited to looking at a local region of the riser section since computing resources are limited.)
- The fluid volume used for the model contains a scale model of a riser with a diameter measuring 12 in and height measuring 10,000 ft.
- The fluid-structure analysis included 20 structural modes.
- The model contains 43M nodes and 193M elements.

The HyperWorks application chosen for this study was AcuSolve, a leading general-purpose CFD solver with rich multiphysics capabilities, including leading FSI solutions.

The Cray system used for testing was a Cray XC30 with up to 400 Intel® Xeon® E5-2600-v2 "IvyBridge" 10-core processors (2 processors per compute node), and processing frequencies in the range of 2.7 GHz – 3.0 GHz.

- Scalability (as compared against the 400 solver core run) at 2,000 solver cores is excellent: Elapsed time per solver step is in the 17.5-18s range, for a speedup of 4.68 out of a perfect 5.
- Even at 4,000 solver cores, elapsed times per step are in the 10-11 second range, for a very good speedup of 7.9 out of a possible 10.

The Cray XC30 has established itself as the premier capability system in the industry for oil exploration and production companies pursuing important processing techniques such as Reverse Time Migration (RTM) and Full Waveform Inversion (FWI) in their ultra-deep-water exploration activities. As demonstrated here, however, the XC30 is equally capable when applied to challenging upstream production engineering problems. For oil companies, as the focus shifts from exploration to production, the XC30 can effortlessly take on the expanded workload.

Key Benchmark Results:

- Near-perfect (linear scaling) speedup at 2000 cores – 94% of ideal
- Very good speedup even at 4000 cores
- Results obtained in ~5.5 hours – less than a day!

Configuration Recommendations

The Cray XC30 is a modularly configured platform for capability computing, where compute nodes are densely packaged and tightly interconnected in a chassis of 128 Intel® Xeon® processor E5 family processors (with up to 64 GB of memory per processor, 10 or 12 cores per processor) and up to 3 chassis per physical cabinet for over 4,000 solver cores in the liquid-cooled version (LC). A single cabinet XC30-LC provides the processing power required to take oil and gas component engineering to a 20X L/D ratio, better than current industry practice within current product development life cycles.

Alternatively, the Cray XC30-AC air cooled member of the XC30 family provides slightly smaller and less dense supercomputing cabinets without the requirement for liquid coolants or extra blower cabinets, but otherwise leveraging the same advanced processor and interconnect technology as in the liquid-cooled version. In this option, a self-contained two cabinet XC30-AC system, including storage and network, continues to demonstrate substantial engineering capabilities and excellent application scalability at over 2,400 solver cores.

Cray XC30 Configuration	LC for simulations scaling above 4000 cores; AC for scaling to 2400+ cores
Hardware	Cray XC30; Cray "Aries" interconnect
Compute Nodes	Two Intel® Xeon® E5 family processors per node (10 or 12 cores/processor)
Memory	64 GB per node
Storage	Starting at 80 TB of storage; high performance parallel Lustre file system

"The volatile nature of deep sea installations presents a difficult challenge for engineers to create products which can withstand extremely high pressures in a variety of weather conditions. Duco selected HyperWorks to model subsea umbilicals, resulting in improvements to their analysis productivity allowing models to be constructed faster than before."

Duco (Altair customer)

"[The] Riser is therefore considered as a vital element for offshore oil platforms.... the impact of a riser failure involves a high risk of human injury leading to death, a considerable amount of pollution in the environment as well as very high economic and political consequences."

Bibi W. Kaudur,
Sciences360

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