White Paper

CFD on SGI® Altix® ICE:

A Winning Combination

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1.0 Executive Summary

Computational fluid dynamics (CFD) continues to push the edge of high performance computing (HPC) with the need to solve ever larger problems at ever greater speed. Delivering compute resources that can handle the accelerating demands of CFD is an ongoing challenge. While conventional clusters provide an economical and effective solution for smaller-sized HPC applications, they have difficulty scaling to the larger-sized systems required to solve cutting-edge problems. Consequently, system reliability and manageability become problematic, and time-to-solution suffers. Ancillary costs also increase, and the data center strains at the burden of increasing demands for power, cooling, and space.

The design of the SGI® Altix® ICE integrated blade platform surmounts the difficulties that pertain to scaling conventional cluster systems. With Altix ICE, SGI introduces a new standard of achievement in cluster-based high performance computing, delivering a platform far exceeding the capabilities of traditional clusters in nearly every measure of reliability, manageability, data center efficiencies, and price/performance value – of particular benefit for systems scaling beyond one hundred processor nodes. Altix ICE offers an ideal platform for next-generation CFD.

2.0 Taking CFD to the Next Level

Time-to-solution represents the key success indicator for CFD compute environments. Several trends, including the use of CFD tools earlier in the design cycle, increases in model complexity and resolution, the use of stochastic methods, and the reliance on Design for Six Sigma (DFSS) processes for robust design, are driving explosive growth in CFD compute resource needs. As demand to solve ever larger and more complex problems, with greater speed and finer granularity, continues to accelerate, careful selection of optimal compute resources becomes increasingly critical.

2.1 Surmounting the Limitations of Clusters

Clusters dominate in today's CFD systems, with their advantages of relatively low up-front cost and seeming ease of scalability. As organizations attempt to scale their cluster environments to address more complex problems, they find themselves hitting a wall on both price/performance and scalability. While conventional clusters can represent right-sizing for small- to medium-size application workloads, organizations need to weigh the initial advantages of quick deployment and small-scale extensibility against the increasing complexity and cost that go with attempting to scale clusters past a certain limit. All too frequently, system costs and manageability issues spiral out of control, sapping time and resources from fundamental productivity. Time spent on configuring, managing, and stabilizing the compute environment is time diverted away from solving engineering problems.

When dealing with larger-scale CFD application requirements, traditional clusters founder, their early advantages subverted by issues of reliability and manageability. Managing time-to-solution in CFD and other CAE application environments requires close attention, in particular, to maximizing these aspects of an organization's computing resources:

- Price/performance
- Reliability and serviceability
- Ease of system management and scalability
- Data center resource optimization – power/cooling/space

To tame the complexity and cost associated with scale-out clusters and provide the capability to handle complex HPC application areas such as CFD, SGI offers a revolutionary new type of cluster system – the SGI Altix ICE integrated blade platform. Altix ICE achieves unprecedented scalability with a design that focuses on overcoming the weaknesses inherent in larger-sized conventional clusters. Altix ICE is particularly suitable for installations requiring one hundred or more cores.

2.2 SGI: Providing Leadership in CFD Solutions

With over 25 years of experience tackling the most demanding compute and data-intensive problems, SGI provides leadership in HPC technical innovation through its SGI® Altix® family of servers. The SGI Altix server platform encompasses a set of architectures to meet the diverse needs of high performance computing, from capability to capacity, with systems that focus on both performance and economic requirements. SGI's leadership in HPC includes far-reaching experience with the CAE market, including CFD.

Figure 1: CFD Analysis of Full Vehicle Air Flow of a Class 5 Truck

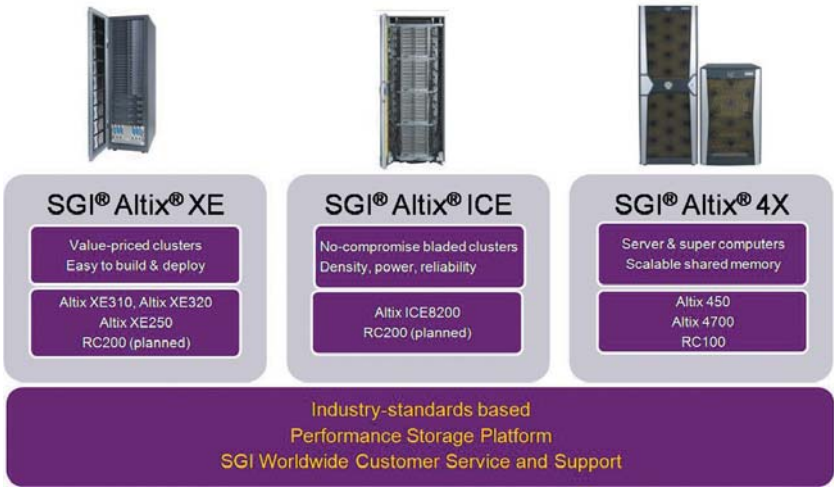

Figure 2. SGI Altix Server Portfolio

The SGI Altix server family comprises the most advanced HPC platforms commercially available, providing solutions that maximize performance while minimizing overall cost. Altix servers meet the challenges of high performance computing head on, with technology that addresses all key issues, including scalability, manageability, reliability, and data center constraints. Altix installations occupy prominent positions on the Top500 list of supercomputers worldwide. The technology that drives these supercomputers underlies SGI's HPC solutions for the entire spectrum of CFD requirements. SGI's technological leadership brings the power of high performance computing to bear on the real-world challenges of CFD problem-solving.

With its Altix family of servers and clusters, SGI takes the lead in hybrid computing, offering a full range of systems to fulfill the precise requirements of any CFD application type, whether the need be for capability or capacity computing, or for some mix of both. SGI simplifies the process of management and application development within a hybrid environment by providing centralized data storage and a common software environment spanning the Altix family, including open-source Linux® and the SGI® ProPack™ software suite of optimization and enhancement tools. SGI will configure your hybrid environment to meet optimal price/performance criteria without compromise on absolute performance.

SGI systems are currently in use solving CFD problems for a wide range of customers:

- The **Honda Racing F1 Team** chose Altix ICE to replace its conventional cluster system, enabling the team to increase their processing of complete vehicle CFD models for Formula One racing by a factor of five. In its pre-purchase survey of available technology, Honda found Altix ICE to be the performance solution. "It quickly became clear to us that for the same number of processors, the performance of the SGI Altix ICE system was in a league of its own," stated Henrik Diamant, Head of CFD, Honda Racing F1 Team. "In fact, we were absolutely amazed when we benchmarked two systems of what would appear to be an identical specification and noted that our CFD calculations ran 18% faster on the SGI Altix ICE. For us, that means places gained on the grid!"
- At **NASA Ames Research Center**, a 4,096 core, 4TB Altix ICE system was up and running in only eight days. This system, ranked number 34 on the 11/07 Top500 list, serves NASA's Aeronautics Research Mission Directorate by supporting CFD research in fundamental aeronautics, paving the way to transforming America's air transportation system and supporting the design of future air and space vehicles. "Whenever we can find ways to either shorten the time it takes for researchers to see results or to increase the level of fidelity of our simulations, we can speed the pace of discovery," said Juan J. Alonso, Director of the Fundamental

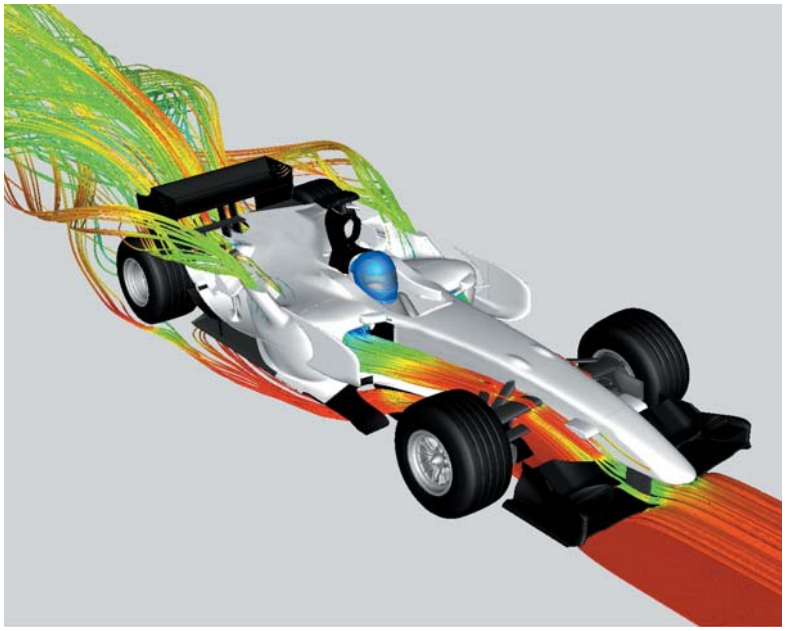

Figure 3. Streamlines Colored by Pressure. (Courtesy of Honda Racing F1 Team)

Aeronautics Program at NASA. “The SGI Altix ICE system makes thousands more processor cores available for research, and will be especially useful for running simulation codes that are optimized for distributed cluster architectures.”

- **Vodafone McLaren Mercedes** deploys SGI® Altix® 4700 capability systems for its Formula One aerodynamics design efforts for key application areas like wind tunnel testing. “SGI is our high performance partner of choice for CFD supercomputing and visualization, because we share the same high levels of innovation, strong execution, and desire for a long-term relationship,” explained Jonathan Neale, Managing Director, McLaren Racing.

3.0 SGI Altix ICE: Delivering No-Compromise Computing

The SGI Altix ICE integrated blade cluster platform raises CFD computing to a new level of performance. SGI Altix ICE 8200, the first product in this line, includes these key features:

- Scalability to thousands of compute nodes per system.
- Unprecedented performance density. The Altix ICE blade uses an innovative board design that accommodates two Dual-Core or Quad-Core Intel® Xeon® 5000 Series processors per blade and enables connectivity directly to InfiniBand and Ethernet networks. A single 42U rack can support up to 512 processor cores and deliver up to 6 teraflops/second of compute power.
- Diskless compute blades, for enhanced reliability, performance density, and image control.
- Fast 4X DDR InfiniBand interconnect integrated into a cable-free blade enclosure utilizing onboard switches, resulting in a steep reduction in overall system complexity along with corresponding increases in reliability and ease of scalability.
- Modular design with hot-swappable components, for higher reliability and availability.
- Power and cooling optimizations to minimize impact on the data center.
- Standards-based, all-Linux integrated software solution stack.
- Hierarchical management node structure, ensuring fine granularity control, easy scalability, and simplified management.
- Power-up-and-go design, with factory integration and testing, for easy deployment and immediate productivity.

The Altix ICE platform’s integrated approach to system design provides HPC data centers with greater productivity and return on investment (ROI). This design philosophy meshes well with the needs of CFD computing. Altix ICE provides a robust solution to the challenges of scaling CFD compute resources. Its wealth of capabilities, offered at a competitive price point, make it a revolutionary alternative to the hidden costs of cluster-based scale-out systems. The Altix ICE platform design deftly handles the critical issues inherent to larger-scale CFD computing by offering unprecedented capabilities in the areas of:

- Price/performance value
- Reliability and serviceability
- Simplified management and scalability
- Power/cooling/space efficiencies

Figure 4: SGI Altix ICE Platform

3.1 Price/Performance Value

The Altix ICE blade provides exactly the hardware necessary to get the job done. Everything on board serves to boost performance; there's nothing extraneous. The integrated blade approach enables the Altix ICE platform to focus all resources on delivering maximum performance for size and cost. The attention to paring away the non-essential results in a highly dense platform, supporting up to 512 Intel Xeon processor cores and up to 6 teraflops per 42U rack. With its unmatched performance density and low node cost, Altix ICE offers an aggressive price/performance value proposition, especially in large-scale configurations.

Altix ICE includes software enhancements to address a key performance issue often encountered in parallel systems: operating system synchronization. An SGI-engineered software mechanism synchronizes operating system overhead – OS jitter and noise – to improve performance significantly on parallel workloads.

The Altix ICE compute network also contributes significant performance boost. The dual-plane network runs on 4X DDR InfiniBand, providing maximum bandwidth for both MPI and I/O traffic. With its high speed and low latency characteristics, InfiniBand enhances the performance of the network, and thus the system as a whole.

	Gigabit Ethernet	DDR InfiniBand
Bandwidth (MPI)	85 MBps	~1460 MBps
Latency	30 uSec	3.4 uSec
Link Rate (Bidirectional)	1 Gbps	20 Gbps

Table 1. Interconnect Performance Characteristics

To further boost throughput, management communications run across a separate GigE administrative network, segregated entirely from the InfiniBand compute network.

The basic Altix ICE unit is the cable-free blade enclosure, which supports up to 128 core processors on 16 blades. All interconnect for the blade enclosure is on board. Up to four blade enclosures fit in a single Altix ICE rack, and multiple racks can be easily networked together. The onboard interconnect, in combination with integrated InfiniBand switches, serves to minimize overall cabling, as well as the hops and latency, even for very large installations. A single rack, 128 socket (256 or 512 core) installation with four blade enclosures requires a total of only 24 cables. Its maximum hop count is just three and its MPI latency is 3,446 nS.

The SGI Altix ICE value proposition extends far beyond the price/performance story to encompass virtually every aspect of its design and implementation. The sections that follow describe other Altix ICE key strengths.

3.2 Reliability and Serviceability

Reliability is a critical area for concern when venturing into larger-scale clusters. Compute nodes and other components inevitably malfunction over time, and cluster installations often lack sufficient redundancy to deal robustly with component failures. The networks tying the cluster nodes together can also suffer from reliability issues that grow exponentially as clusters scale. The complexity of scale-out cluster environments, with their multiplying points of failure, leads to further reliability problems.

Altix ICE, with its focus on component integration along with other innovative features, achieves a new standard of reliability for scale-out configurations. Key reliability features include:

- Diskless blades with automatic hot-swap capabilities
- Cable-free blade enclosures, for reduced potential points of failure
- Redundant, hot-swappable system components
- High-efficiency power architecture, for reduced heat dissipation
- Optimal thermal design
- Fully buffered DIMMs, to reduce transient errors
- InfiniBand backplane, for high signal reliability

Figure 5: Traditional Cluster Cabling

Figure 6: Multiple SGI Altix ICE Racks, Reduced Cabling

The Altix ICE blade has no onboard disk, instead using diskless booting from the chassis management controller at the blade enclosure level. This innovation offers a number of benefits. It increases blade reliability by eliminating a key failure point. It increases performance density by reducing the blade footprint. It lowers the cost of powering the blade, as well as reducing the cost of the blade component itself. The Altix ICE off-blade storage design also provides an enhanced level of serviceability and administrative control, especially beneficial for managing secure or classified data. This reduces the problems often encountered with the management of classified information in a distributed environment.

The Altix ICE cable-free blade enclosure and integrated switching provides another significant boost in overall system reliability. The Altix ICE approach to interconnect stands in sharp contrast to the cable chaos endemic to cluster systems. This clean and lean design markedly increases both the reliability and the serviceability of the overall system.

To further enhance reliability and maximize uptime, Altix ICE includes redundant, hot-swappable power supplies and blowers.

The Altix ICE high-efficiency power architecture reduces heat dissipation and associated temperature rises within the system. By so doing, it decreases the likelihood of a common cause of system failure – unsustainable temperatures in crowded data centers.

The reliability of Altix ICE is additionally enhanced by its optimal thermal design. A common issue with blade-based architectures is the crowding of I/O options across the backplane or mid-plane of the enclosure. The result is often a complex series of baffles and airflow management structures that require small fans or blowers. SGI has greatly improved over other blade-based designs by placing the I/O switches to the sides of the enclosure, enabling large perforations in the backplane. This enables air to flow straight through the compute blade, increasing volume and enabled the utilization of larger, more efficient, and less noisy blowers. The resulting thermal design permits more efficient and consistent cooling across all components, increasing reliability and overall efficiency.

The Altix ICE compute nodes employ Fully Buffered DDR2 DIMM (FB-DIMM) memory, which enhances reliability and performance. Memory data reliability is ensured with enhanced error-correcting codes to allow every node to independently detect and correct errors.

The Altix ICE platform uses a dual-plane InfiniBand backplane that increases overall MPI bandwidth by aggregating bandwidth over two InfiniBand networks, and leverages InfiniBand features such as data re-transmission to overcome packet drops and further enhance overall reliability.

Along with reliability, serviceability is a key SGI differentiator in the high performance computing marketplace. The advanced, modular blade design of Altix ICE servers enables administrators to access and replace components easily. The diskless blades are hot-swappable, maximizing serviceability and system availability in case of component failure. To quicken resolution of service issues, all Altix systems ship with the SGI Embedded Support Partner – an integrated suite of services that work together to monitor and manage systems and protect against problems. In addition, the SGI customer service organization offers a broad range of support offerings, up to and including mission-critical 24x7 system support. Dedicated to excellence, the SGI support team consistently ranks among the top in the industry, according to the SatMetrix™ third-party evaluation.

3.3 Simplified Management and Scalability

Altix ICE, with its emphasis on component and software integration, sets a new standard for simplicity in the world of scale-out environments. On the hardware side, the clean design of the blade enclosure, with its integrated blades, switches, and interconnect, stands in welcome contrast to the ad hoc maze of many cluster-based systems. This integrated approach continues on the software side. Altix ICE ships with an integrated, complete software solution stack. The standards-based stack, supplemented by SGI tools to simplify system management and enhance performance, ensures fast ramp-up and deployment.

For enhanced scalability and simplified management, Altix ICE is based on a hierarchical management design. This hierarchical management architecture provides a high degree of modularity, enabling Altix ICE installations to scale to very large sizes while maintaining management granularity at every level of the system: node, blade, blade enclosure, rack, and system. This means that administrators can scale the management resources that they need, when they need it – and can also provision, monitor, and service resources at any of these levels.

The entire Altix ICE system undergoes factory integration and testing. SGI Altix ICE arrives at the customer site fully integrated and ready for out-of-the-box deployment. SGI's more than 25 years of experience in delivering "power-up-and-go" systems ensures immediate productivity.

The streamlined system design also simplifies the process of scaling the platform. Component integration, minimal cabling, high performance InfiniBand interconnect, and hierarchical management nodes, supported by a comprehensive suite of software management tools, translates into easy scalability for even the most complex CFD application environments.

3.4 Efficiency in the Data Center: Power/Cooling/Space

The design of the Altix ICE platform takes into account the environmental constraints of today's data centers and offers high efficiency solutions to meet the challenges.

Today's data centers are in a state of crisis. AFCOM's Data Center Institute predicts power failures and power availability will halt IT operations at more than 90% of companies over the next 5-years (AFCOM, 2006). Built years ago for a very different computing environment, many data centers today suffer from limited power, cooling, and space capacity. The environmental inefficiencies of traditional clusters (low density, combined with high power and cooling requirements), barely noticeable on a small scale, become prohibitive when scaling larger installations.

SGI has long been a technological leader in solutions optimizing power and cooling efficiency, mostly recently with its SGI Altix 4700 server platform, where it introduced a power architecture featuring 90% efficiency power supplies and a field-proven water-based cooling system. These innovations have been further optimized and applied to Altix ICE. Together, they represent a major advance in overcoming the constraints of the data center.

Altix ICE utilizes 90% efficiency redundant power supplies that transform AC voltage directly to 12VDC. These high efficiency power supplies are combined with other high efficiency components to minimize losses throughout the entire power architecture. This high level of efficiency results in average electrical savings of 33%, or $21k annually per 10 teraflops of compute power (based on an electricity cost of $0.092/kWh), compared to more typical cluster implementations. If data center facility infrastructure efficiency is also considered, the annual electrical savings doubles to $42k per 10 teraflops of compute power. Data center infrastructure efficiency, commonly described by Power Usage Effectiveness (PUE) = {Total Facilities Power / IT Equipment Power}, is typically 2.0 but ranges from 1.6 to 3.0 or higher (The Green Grid, 2007).

Altix ICE employs a combination of high efficiency redundant blowers and optional water-cooled rear doors to deliver impressive cooling efficiency results. With the water-cooled option, Altix ICE has minimal effect on ambient data center temperature, because up to 95% of the rack heat is dissipated to chilled water. While actual performance depends on many site and geographic variables, the Altix ICE water-cooled option significantly reduces cooling equipment power consumption. Electrical operating cost can be reduced by 17% or more, amounting to $11k annually per 10 teraflops of compute power. Use of the water-cooled option also increases overall system reliability by mitigating the common problems of hot-aisle/cold-aisle recirculation and hot spots within the data center.

Altix ICE addresses the third major constraint of the data center – space – with its breakthrough performance density. Each 42U (30" W x 40" D) rack holds four blade enclosures with 16 two-socket nodes each, achieving a density of up to 512 Intel Xeon cores, or 6 teraflops per rack. This results in up to 70% higher compute power density per floor tile (based on gigaflops per square foot) compared to other blade systems. Despite this performance density, the fully loaded Altix ICE rack stays within data center flooring constraints, with a footprint of 246 lb/ft^2.

Altix ICE performance density, combined with its innovative and highly efficient approaches to power and cooling, ensures maximum utilization of scarce data center resources.

Operating System	SUSE® Linux® Enterprise Server 10 and above or Red Hat® Enterprise Linux® 5 and above
Performance Optimization	SGI ProPack 5
Platform Management	SGI® Tempo or Platform™ Scali Manage
Workload Manager	Altair® PBS Professional™ 8.0 and others
MPI	Multiple options available, including SGI MPT, Intel MPI Library, Scali MPIConnect, MVAPICH-2, and OpenMPI.
IB Fabric and Subnet Management	SGI InfiniBand Fabric Subnet Management (based on OFED and OpenSM)
Development Tools	Intel C++ and Intel Fortran compilers, Intel VTune, Intel Math Kernel Library, Intel Trace Analyzer and Collector, Intel Thread Checker, and more.

Table 2. SGI Altix ICE Software Solution Stack

4.0 SGI Altix ICE Software Solution Stack

Altix ICE ships with a complete, integrated software solution stack, consisting of both standard and customizable components. The software is standards-based, with SGI-engineered extensions to maximize performance and manageability and ease development efforts. The result is a powerful and cost-effective solution, designed to ensure that Altix ICE users become productive immediately. Table 2 lists the main components of the Altix ICE software solution stack.

4.1 A Complete HPC Software Solution Stack

Altix ICE runs on the SUSE Linux Enterprise Server or Red Hat Enterprise Linux Server operating systems. The platform builds on SGI's leadership position in the Linux community. SGI has been, and continues to be, a major contributor to the Linux standard, and brings a wealth of experience and expertise to resolve customers' kernel-level issues quickly and efficiently. With the combination of SGI and Linux, Altix ICE offers a scalable, robust, and standards-based software platform.

SGI ProPack 5, SGI's optimization software package, extends the Linux standard with tools to enhance system administration, development, and performance. These tools include linkless FFIO to accelerate I/O calls, resulting in dramatic performance enhancement for I/O intensive applications.

Altix ICE ships with its own cluster management tool, SGI Tempo. Tempo has been designed to optimize Altix ICE management, enabling full and effective control over Altix ICE's unique advantages, including its hierarchical management framework and diskless booting capability. Where possible, Tempo leverages the power of open source products, while incorporating key innovations to realize the unique capabilities of Altix ICE. As an alternative to Tempo, Altix ICE can run Platform Scali Manage as its cluster management tool. For workload management, Altair PBS Professional allows scheduling and management of jobs and resources, resulting in a higher total utilization of the cluster.

4.2 SGI Collaboration with CFD Software Vendors

Altix ICE offers an ideal platform for running CFD modeling software. SGI collaborates directly with most commercial CFD software providers, as well as with designers of many independent open-source and corporate-specific solutions, to provide an optimized platform for their CFD modeling tools. SGI is a long-time partner with vendors of all the major CFD platforms, such as Fluent® and CFX® from ANSYS®, CFD++™ from Metacomp, Exa PowerFLOW®, and CD-adapco's STAR-CD and StarCCM+. Their engineering teams work together on performance and validation matters, as well as testing and development of new physics and numerical techniques.

5.0 Integrated Storage

Altix ICE is based on a "diskless node" architecture that removes storage from the compute blades, a design that decreases cost and power/cooling requirements while at the same time increasing overall system reliability. In addition, by moving the storage off the compute blades, Altix ICE allows customers to choose the storage option that best fits their computing environment. Leveraging the comprehensive SGI® InfiniteStorage product line, the storage for Altix ICE can be tailored to meet specific application requirements. Another advantage of moving the storage "off-blade" is the centralization of storage resources, promoting better capacity balancing, easier management, and on-line scaling of capacity.

SGI offers storage solutions designed to optimize Altix ICE performance, including the SGI® InfiniteStorage NEXIS 9000 high performance NAS appliance and offerings such as Lustre that can be implemented by SGI's industry-leading Professional Services group.

SGI Altix ICE Features	Benefit
Integrated Interconnect	Reduced cost and complexity and simplified scalability, with cable-free blade enclosures and integrated switches.
HPC-Optimized Compute Blades	Top performance density for optimal data center space utilization. Based on ultra-dense SGI/Intel designed board and Dual or Quad-Core Intel Xeon processors – 512 processor cores per rack.
SGI Patented Power Design	Enhanced power efficiency for reduced overall cost of deployment, with +75% power efficiency at rack level.
SGI Water-Chilled Doors	Optional feature for larger systems – maintains optimal operational environmental temperature to reduce overheating and potential system outage.
Hierarchical Management Infrastructure	Simplified scalability and easier management, with ability to manage, monitor, and provision at blade, blade enclosure, rack, and system level.
Complete Software Solution Stack	Immediate productivity, with a fully integrated solution that includes the SGI Tempo management tool, SGI ProPack, and Altair PBS Professional workload manager.
Based on Industry-Standards	Fully satisfies IT OS, application, and security compliancy requirements, while delivering all of the benefits of industry-standard open software, with SUSE Linux Enterprise Server or Red Hat Enterprise Linux.
Off-Blade Storage	Reduces cost and power/cooling requirements while increasing overall system reliability.
SGI 25+ Years' HPC Expertise	Reduced risk, optimal TCO. SGI Professional Services team, rated best by SatMetrix, brings years of industry and technical expertise to help customers with development and deployment, ensuring an optimal solution to precisely meet customer needs, budget, and timeline.
Single-Source Support	Simplified administration. All system hardware and software components backed by SGI world-class Customer Service organization.

Table 3. SGI Altix ICE Benefits

6.0 Summary: An Ideal Platform for CFD

SGI Altix ICE, with its highly scalable and efficient design, offers an ideal platform for CFD computing. Its innovative design provides a highly manageable, efficient, and reliable platform with unbeatable price/performance value. Backed by SGI's extensive experience supporting CFD application needs, Altix ICE vastly expands the capability for organizations to perform the analyses necessary to solve today's complex problems in fluid dynamics. Altix ICE speeds time-to-solution and overall productivity by freeing your staff to focus on solving engineering problems, rather than resolving IT issues.

7.0 About SGI

SGI is a leader in Linux high-performance computing, with over 25 years of experience in solving the most demanding compute and data-intensive problems. SGI delivers a complete range of high-performance server and storage solutions along with industry-leading Professional Services and Support, enabling its customers to overcome the challenges of complex data-intensive workflows and accelerate breakthrough discoveries, innovation, and information transformation.

SGI helps customers solve their computing challenges, whether it's enhancing the quality of life through drug research, designing and manufacturing safer and more efficient cars and airplanes, studying global climate, providing technologies for homeland security and defense, or helping enterprises manage large quantities of data. With offices worldwide, the company is headquartered in Sunnyvale, California, and can be found on the Web at www.sgi.com.

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