More Innovation Using SC/Tetra, the Innovative CFD Software

Yuya Ando
General Manager at Cradle North America, Inc.
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   - How CRADLE software contributes in innovation

2. Introduction to Cradle CFD software
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Corporate Profile

Establishment: 1984

Offices:
- Headquarters: Osaka, Japan
- Branch Office: Tokyo, Japan
- Subsidiary: Dayton, OH USA

Worldwide Distributors:
- 4 main distributors:
  - Taiwan, China, Korea, France
- Other resellers

Headquarters Osaka, Japan
Cradle North America, Inc.
Dayton, OH
Tokyo, Japan
Software Development
- CFD
- Structural Analysis (FEA) to aid FSI
- Data cleaning and modification software
- Optimization

Trainings and seminars

Technical Support

Engineering Services
- Simulation service
- Consultation
- Customization
- Automation
Cradle’s concept is to provide a tool which aids a company to market a better product in a shorter lead time.
Awards

- 2002: Won JSME award (The Japan Society of Mechanical Engineering)
- 2005: Awarded by METI (Ministry of Economy, Trade and Industry of Japan)
- 2006: Won AEI 2006 Tech Awards (Automotive Engineering International)
- 2007: Certification of Visualization Award (APCOM 2007)
- 2009: Best CFD Graphics Award (The Japan Society of Fluid Mechanics)
Products

CFD

Multi-purpose CFD
Unstructured Mesh

SC/Tetra

* SCTSstruct Option: Steady State Linear structure analysis

MAIN INDUSTRIES:

Automotive / Aerospace
Marine/ Machinery/
Energy/ Electrical Appliances
Oil & Gas/ Bio-medicals

Buildings & Architectures/
Civil & Oceanic engineering/
Electronics Applications

Products

Multi-purpose CFD
Structured Mesh

scSTREAM

HEAT Designer

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Products

**Advanced Data Cleaning Tool**

*CADthru*

- Data Cleaning
- Data Modification

**Optimization**

*Optimization Option*

- Multi Objective
- Genetic Algorithm
Customers

**Automotive**

- TOYOTA group
- Mitsubishi Motors - DENSO
- DAIHATSU group
- YAMAHA group
- HINO Motors Ltd.
- NISSAN group
- HONDA group
- ISUZU Motors
- Mazda Motor
- AISIN group
- COPELAND

**Electronics & Electrical Appliances**

- Panasonic group
- SANYO group
- SHARP Corporation
- SONY group
- IBM Japan Inc.
- NEC group
- Hitachi group
- Mitsubishi group
- Toshiba group
- Fujitsu group
- Oki Electric group

**Industrial Equipments & Machinery**

- Ishikawajima-shibaura machinery Co.,Ltd.
- Hitachi Zosen Corporation
- Hitachi Plant Engineering & Construction Co.,Ltd.
- Kawasaki Heavy Industries, Ltd.
- Komatsu Ltd.
- Murata Machinery, Ltd.
- Nidec Corporation
- Hitachi Koki Co., Ltd.
- Nakashima Propeller Co., Ltd.
- NTN Corporation
- Mitsubishi Heavy Industries
- SEIKO Industry Co., Ltd.
- Mitsui Engineering & Shipbuilding Company, Limited
- Nippon Koei Co., Ltd.
- Schlumberger Limited

More than 800 companies & organizations worldwide
Technical Sponsorship

- DOME
- Toda Racing
- M-TEC
- Dandelion Racing
1. Introduction to SOFTWARE CRADLE
   - How CRADLE software contributes in innovation

2. Introduction to Cradle CFD software
   2-1. SC/Tetra
General:
All-in-one package CFD software consisted of:
- **Preprocessor**
- **Solver**
  - pressure based FVM
  - density based FVM
- **Postprocessor**
- **Data mapping Tool to FEA meshes**
- **Linear structural analysis FEM solver (Option)**
- **Direct coupling I/F with Abaqus for transient FSI (Option)**
Introduction to SC/Tetra

Multi-Purpose CFD Software with Unstructured Mesh

**SC/Tetra**

Mesh Related Technology
- Overset mesh
- Arbitrary Lagrangian-Eulerian (ALE)
- Passive motion control
- Adaptive mesh refinement

Physical Model:
- Compressible / Incompressible flow
- Newtonian and Non-Newtonian fluid
- Heat radiation / Solar radiation
- Multi-phase / Free surface flow / Particle tracking
- Humidity / Condensation / Solidification / Melting
- Diffusion / Chemical reaction / Combustion
- LES / Porous media / Cavitation
- Thermoregulatory model
- DES / VLES / 12 more turbulence models
- Fan model / Thermal conduction panel
- Joule Heating / Aero Acoustic
- Simple Linear Structural Analysis
- 2-way Fluid Structure Interaction with Abaqus
**Introduction of SC/Tetra**

**Outstanding Features of SC/Tetra**

<table>
<thead>
<tr>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Friendly Interface and Usability</td>
</tr>
<tr>
<td>Fast-Robust-Intuitive Mesher</td>
</tr>
<tr>
<td>Low Memory Consumption</td>
</tr>
<tr>
<td>Outstanding Computation Speed and Accuracy</td>
</tr>
<tr>
<td>State of the art Postprocessor</td>
</tr>
<tr>
<td>Parallel Pre/Solve(CFD &amp; Structure)/Post</td>
</tr>
</tbody>
</table>
Characteristics of SC/Tetra

- User Friendly Interface and Usability -- **Navigation**

Navigation that guides a user from importing a geometry to executing calculation.
In addition to various surface cleaning functions, wrapping function is available to remove unwanted features and geometrical error. The octree is used for the resolution of wrapping, therefore, the size of the octant determine the small feature will be kept or removed.
Mesh resolution can be flexibly controlled using octree.

Selection methods:
- Rubber box
- Rubber circle
- Rubber arbitrary shape
- Octant size (level)
- Octants adjacent to specified surface
- Octants adjacent to specified edges
- Closed volume
- Material
- Registered surface

Better Accuracy!
Fast-Robust-Intuitive Meshing

Automatic Mesh Resolution Arrangement

Mesh resolution can be automatically arranged according to the geometry by detecting the narrow shape compared to the octants and refining relatively large octants.

Default

Automatic Mesh Resolution Arrangement
The 3rd and 4th results are almost the same. This shows that about 420,000 mesh with mesh resolution like the 3rd one is required for certain accuracy.
FAST and ROBUST:
Less than 15 min. is required to generate 15 million elements including prism layers.

Windows XP x64 edition / 4GB memory
Intel Xeon 5580

Additional functions:
- Smoothing
- Prism layer adjustment (thickness, the # of layers)
- Internal hexa-mesh
- Sweep mesh
Characteristics of SC/Tetra

- **Low Memory Consumption**

About 5 million elements/1GB!

- With 2GB: 10 million elements
- With 8GB: 40 million elements
- With 32GB: 160 million elements
- With 64GB: 320 million elements

- **More complicated geometry**
- **Better accuracy**

Comparison of the # of mesh per 2GB RAM memory.
## Comparison of Commercial CFD software (2001)

(1) Verification of Aerodynamics  
(2) Engine Intake Port Flow  
(3) Air-Conditioning Analysis  
(4) Air Conditioning Analysis from Defroster Nozzle

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SC/Tetra</strong></td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>FLUENT</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
<td>★★★</td>
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<tr>
<td>CFD Design</td>
<td>★</td>
<td>★</td>
<td>NE</td>
<td>★</td>
</tr>
<tr>
<td>Fire,SWIFT,FAME</td>
<td>★★</td>
<td>★★</td>
<td>★★</td>
<td>★★</td>
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<tr>
<td>FIDAP,ICEM CFD</td>
<td>★★★</td>
<td>★</td>
<td>★★</td>
<td>NE</td>
</tr>
<tr>
<td>CFD++</td>
<td>★★★</td>
<td>★★</td>
<td>NE</td>
<td>NE</td>
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<tr>
<td>Esperanza</td>
<td>NE</td>
<td>★★</td>
<td>★★</td>
<td>NE</td>
</tr>
<tr>
<td>sSTAR-CD,Pro*am</td>
<td>NE</td>
<td>★★</td>
<td>NE</td>
<td>NE</td>
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<tr>
<td>Vectis</td>
<td>NE</td>
<td>★★★</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>PAM-FLOW</td>
<td>★</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
</tbody>
</table>

**NE:** No Entry /  * Bad - Good *** /

Paper Engine Number: 2002-01-1297
Characteristics of SC/Tetra

- Outstanding Computation Speed and Accuracy

Comparison of Commercial CFD software (2006)

* JSAE symposium on Recent Activities in CFD toward Higher Quality, No. 08-06 (2006)
## Characteristics of SC/Tetra

### Outstanding Computation Speed and Accuracy

<table>
<thead>
<tr>
<th></th>
<th>$C_D$</th>
<th>$C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiments</td>
<td>0.245</td>
<td>-0.273</td>
</tr>
<tr>
<td>Simulation</td>
<td>0.247</td>
<td>-0.275</td>
</tr>
<tr>
<td>Difference</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>


3. Propeller Cavitation Analysis (1)

Cavitation analysis of PPTC using CFD

*PPTC: Potsdam Propeller Test Case

- Model propeller (Experimental conditions)
  
  Diameter: 250 mm  
  Rotation speed: 25 rps  
  Velocity: 6.365・7.927・8.805 m/s

- Cavitation model
  
  • Full cavitation model (Singhal et al, 2002)
Comparison of analysis and experimental results

\[ J = 1.019 \text{ (Velocity} = 6.365 \text{ m/s) } \sigma = 2.024 \]

\[ K_T \text{ (Thrust coefficient)} \]

Exp : 0.3725
Cal : 0.3750 (+0.67%)

Sketch (Experimental)  Void fraction: 20%  Void fraction: 50%

Outstanding Computation Accuracy

Propeller simulation including cavitation

Formation of Cavitation Experiments

Simulation Results (Isosurface with Void Coefficient of 20%)

Case 1

Analysis Conditions: \( J = 1.019 \) (Velocity = 6.365 m/s), \( \sigma = 2.024 \)

Simulation results sufficiently show that cavitation occurs on the surfaces and the tip of the blades.

Experiment by SVA Potsdam
Characteristics of SC/Tetra

- State of the art Postprocessor
Introduction to SC/Tetra

- All Parallel Compatible (Pre/Solve/Post)

Meshing with Preprocessor

Drawing with Postprocessor

Calculation with Solver

Formula car
(30 mil. elements, flow only)

CPU: Xeon 5130(2GHz, 2core) x 2 x 32nodes
OS: Red Hat 5.2
Interconnect: Infiniband (DDR/SDR)
Unique and Advanced Features of SC/Tetra
Features of SC/Tetra

Advanced Motion Handling

ALE / Passive Motion / Overset Mesh
Advanced Motion Handling

ALE / Passive Motion / Overset Mesh
Outstanding Features of SC/Tetra

Advanced motion handling

**VOF method with ALE and induced motion**
The temperature and the amount of perspiration of human body can be simulated with **MOST ADVANCED THERMOREGULATORY MODEL**.

Heat transfer by detailed vascular system and heat generation by physiological factors of human body can be predicted with the consideration of morphological characteristics of an individual.

The human body is divided by segments and the heat balance equations of those segments are solved to predict the body temperature and the amount of perspiration.
Density-Based Solver

**Numerical analysis method**

- Time marching method
  - 1\textsuperscript{st}-order Euler method,
  - 2\textsuperscript{nd}-order Runge-Kutta method,
  - Dual time stepping method (BDF2)

- Approximate Riemann solver
  - Roe method,
  - HLL method,
  - Rotated-RHLL Flux method \(^{*1}\)

- Advection term
  - 2\textsuperscript{nd}-order (Limiter function of Venkatakrishnan is applied)

- Diffusion term
  - Alpha-damping scheme \(^{*2}\)

**Reference**


Density-Based Solver

Computational example of inviscid flow analysis

– Validation example 15: “Shock Wave Diffraction”
– Analysis overview
  • Supersonic flow analysis considering shock wave propagation (Ms=5.09)
– Simulation results: Compared to the visible image of experiment
  • Experiment, Schlieren photograph[1] • Computational results, density gradient (animation)

Reference
Computational example of a viscous, turbulent flow analysis

Validation example 16: “Simulation of Flow with a Shock Wave around a Two-Dimensional Airfoil”

- Analysis overview
  - Transonic flow analysis: Main stream Mach number of 0.729 is flowing over RAE2822 airfoil at 2.31° angle of attack. Reynolds number is $6.5 \times 10^6$.
  - Turbulent flow with SST k-ω model
- Simulation results: Pressure distribution
  - Pressure-based solver
  - Density-based solver
Computational example of viscous and turbulent flow analysis

Validation example 16: “Simulation of Flow with a Shock Wave around a Two-Dimensional Airfoil”

- Simulation results: Comparison of pressure coefficient with experiment[1]

Reference
Data Import
Data Import

Model file formats
- Parasolid XT *.x_t
- STEP *.stp, .step
- STL *.stl
- NASTRAN *.nas
- DXF *.dxf
- IGES *.iges, .igs
- ACIS(SAT) *.sat
- VDAFS *.vda
- UNIVERSAL *.unv
- ABAQUS *.inp

Native file formats
- CATIA V4 * .model, .session, .exp
- CATIA V5 * .catpart, .catproduct
- PRO/E, Creo *.asm, .prt
- Inventor *.ipt, .iam
- SolidWorks * .sldprt, .sldasm
- NX *.prt
- SolidEdge *.par

Mesh file formats
- NASTRAN * .nas
- ANSYS *.cdb
- UNIVERSAL *.unv
- ABAQUS *.inp
- Design Space *.dat

Drag & Drop
Coupling Analysis
Coupling/Automation/Optimization

Coupling Analysis

- Structural Analysis
  - **SCT Structure**, ANSYS(.cdb), ABAQUS(.inp), NASTRAN(.nas), I-DEAS(.unv)
  - *2-way FSI: Direct coupling with Abaqus*

- Acoustic Analysis
  - LMS SYSNOISE / Virtual.Lab
  - Actran

- Optimization
  - HyperStudy, Optimus, iSIGHT, modeFrontier

- Morphing
  - HyperMesh, Sculptor, MeshWorks Morpher

- 1D Simulation
  - Flowmaster, KULI
3 Kinds of FSI approaches

- Motion of a rigid body driven by fluid force
  - SC/Tetra alone can simulate it using Dynamical ALE

- 1-Way FSI: Stress in an object can be simulated by using pressure load or thermal values from CFD simulation
  - SC/Tetra Structure can be coupled
  - 3rd Party structural analysis can be coupled using Cradle’s mapping tool

- 2-Way FSI: Transient
  - Abaqus can be coupled
FSI Coupling Analysis: Direct coupling with Abaqus
Automation
Customization & automation with VBA* & VBS*

- Microsoft COM (Component Object Model) technology
  - Enables software components to communicate one another
  - Cradle products are all complied with COM technology

- Automation with VBA* & VBS* (thereafter, called VBI)
  - *VBA: Visual Basic for Applications, Microsoft’s event-driven programming language to enhance functions of MS Office products.
  - *VBS: Visual Basic Script, Microsoft’s active scripting language used in Microsoft Windows and Internet Information Server. (WSH, IE)
Fully Automated System

COM driven

CAD

Meshing

Solving

Post process

VBA

User

Application

COM driven

Excel spreadsheet with columns for Case, Lift [mm], Angle [degree], and Pressure drop [Pa].

- Case 1: Lift = 6.5 mm, Angle = 45°, Pressure drop = 45
- Case 2: Lift = 7 mm, Angle = 50°
- Case 3: Lift = 7.5 mm, Angle = 55°
Fully Automated System

An user defines:

- **LIFT**
- **ANGLE**

Automatically modifies models according the parameters, executes computations, obtains pressure drop, and creates a report.

- **Excel**
- **SolidWorks**
- **CADthru**
- **SC/Tetra**
- **Report**
Fully Automated System

User: EXCEL

Application: CAD

Constraint (Angle)

VBA

original

new design

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Fully Automated System

**User:** EXCEL

**Application:** CADthru

- **Blue:** Inlet
- **Yellow:** Wall
- **Red:** Valve

Color-Region Table

<table>
<thead>
<tr>
<th>Case</th>
<th>Lift [mm]</th>
<th>Angle [degree]</th>
<th>Pressure drop [Pa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.5</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>
Fully Automated System

User: EXCEL

Application: SC/Tetra

- 1. Fine mesh near Valve
- 2. Boundary layer on Wall
- 3. Intet:Flux Wall:No slip
Fully Automated System

User: **EXCEL**

**Application: SC/Tetra**

<table>
<thead>
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<tr>
<td>1</td>
<td>6.5</td>
<td>45</td>
<td>4127</td>
</tr>
</tbody>
</table>

1. Execution
2. Get Pi-Po

![Diagram showing the automated system](image)

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Thank you!