**State-of-the-Art CFD Technology**

Particleworks is a CFD software based on an advanced numerical method known as the Moving Particle Simulation (MPS) method. The mesh-free nature of MPS allows for robust simulation of free-surface flows at high resolutions, saving the need to generate meshes for the fluid domain. Since its first release in 2009, Particleworks has been introduced to a wide range of industries.

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**Highlights**

18.0 [sec]

**Splashing and Free-Surface Flow**

Since fluid is divided into a set of discrete elements, or particles that are allowed to move freely, large deformation, coalescence and segmentation of fluid, and rapid change of flow are simulated without complicated preparation or meshing in advance.

**Flexible fluid-powder/fluid-rigid body Integration**

No complicated settings are required for simulating interactions between fluids and powders, or fluids and rigid bodies.

**Multi-core CPU and GPU computing supported**

Particleworks supports multi-core CPU computing (OpenMP and MPI), GPU computing using GPU boards, and multi-GPU computing, taking advantage of parallelization to shorten calculations and handle large-scale computing. Particleworks can run on NVIDIA CUDA-based GPUs, giving it overwhelming performance gains in all simulation environments, from desktop PCs to large-scale servers.

**Simplified Handling of Moving Boundary**

Particleworks provides excellent performance in the simulation of moving boundary problems, a time-consuming and complicated task with conventional methods. Complicated structures like gears and impellers can be translated to polygon models first, and fine movement settings can then be applied to the model.

**Software reflects latest research results**

Particleworks’ design and development are based on the latest research results by Dr. Seishi Koshizuka—professor at the Graduate School of Engineering, The University of Tokyo, developer of the MPS method, and founder/director of Prometech Software, Inc. Particleworks is continually gaining new simulation analysis skills throughout development from companies and university laboratories across Japan.
Release Overview

Particleworks 5 is focused on extending basic solver capabilities including flexible boundary conditions, improved distance function generation, and automatic simplification of complex shapes. The redesigned user interface, along with accelerated graphics processing, allows for an intuitive user experience.

In addition to the new enhancements, coupled simulation with RecurDyn(Function Bay, Inc.) offers a variety of inflow boundaries, and complex motion configurations.

**Rotational motion on arbitrary axis, and combined movements**
Complex movements such as tilted axis rotation and planetary motion based on combined movements, are now supported.

**Larger variety of inflow boundary shapes**
In addition to circles and rectangles, oval, torus, and arbitrarily-shaped inflow boundaries are available for assorted uses.

**Surface shapes supported**
Particleworks can now model surface shapes directly as polygon walls. Since the solver automatically calculates the thickness, it is not necessary to create a solid from a surface manually in advance.

**Faster pre-processing (multi-core support)**
Preprocessing now utilizes multi-core acceleration. With a 4-core CPU, preprocessing time was cut in half on our tested models compared with the previous version.

**Improved handling of particles across boundary walls**
Particles separated by a thin polygon wall no longer interact with each other, improving simulation accuracy for high-viscosity fluid and heat-conduction analysis.

**Improved handling of complex shapes**
Improvement in the algorithm for generating distance function, along with the new functionality that automatically simplifies the complex shapes of polygon walls, results in more stable simulation. Previously, particles rebonding off a wall after being caught in a gap or hole would lead to unstable computation. To avoid this, users needed to manually simplify the shape. However, thanks to this new function, simplification takes considerably less time.

**Coupled simulation with RecurDyn**
In addition to defining forced movement of solid bodies, more realistic fluid behaviors are also realized by coupling Particleworks with RecurDyn.

The behavior of the mechanics model is first computed by RecurDyn. Particleworks then computes fluid behavior while taking previously-computed mechanical behavior into account, giving the fluid behavior back to RecurDyn. This allows interaction between mechanics and fluids to be computed.

The results provide more suitable computing on simulations like lubricant behavior inside the housing of a transmission chain mechanism. Degrees of lubricant splashing and dripping associated with loosening and shaking of the chain can be calculated more appropriately.

**Redesigned user interface for ease of use**
Particleworks 5 offers a new user interface to make simulation work more efficiently. In addition to basic function and design improvements, the interface provides accelerated rendering and visual manipulation. Users experienced with CAD and CFD software can use it intuitively without a long learning curve.

**Enhanced graphics and I/O**
Improved file loading and caching with enhanced graphics processing enable users to build and visualize large-scale models.

**Undo / Redo**
Input parameters, camera angles and object movements can be undone and reapplied.

**Project management with efficiency**
Multiple related cases are stored in one project.

**Direct manipulation of objects**
Objects are visually editable thanks to picking and other enhanced mouse operations.

**Quick access to commands and animation controls from the right-click menu.**

**Accelerated graphics and I/O**
Improved file loading and caching with enhanced graphics processing enable users to build and visualize large-scale models.
**Key Features**

Particleworks is a CFD software package based on particle method. Engineers can model and analyze free surface flow, large deformation, and coupled phenomena including fluid, powder and rigid body without complication. Non-Newtonian flow and heat transfer can be combined as well. Preprocessing is straightforward without the need for mesh generation along with direct file import form CAD software, making it easy for users to simulate complex systems.

With the enhanced support for multi-core CPUs and GPUs, Particleworks shows competitive scalability from desktop PCs to large-scale servers. The integrated, easy-to-use interface of Particleworks enhances productivity throughout modeling, simulation and postprocessing.

**Simulation Flow**

Just four steps from modelling to postprocessing

1. **Modeling**
   - Import CAD data and define the resolution for preprocessing. Now, you are about to complete modeling. STL, OBJ and Nastran formats are supported.

2. **Condition settings**
   - Apply physical property and movement to the model. No need to define any boundary conditions. Choose physics model and calculation scheme for appropriate simulation.

3. **Simulation**
   - Speed up calculation utilizing multi-core parallel computing and GPU computing. You can check the result as far as current time step while the calculation is not completely done.

4. **Post-processing**
   - Visualize and evaluate the simulation result by using various post-processing tools such as animation, surface mesh generator, color mapping and so on.

**Pressure calculation**

- **Implicit / explicit methods**
  The explicit method speeds up calculation by giving a suitable speed of sound for the calculation.
- **Suppression of pressure oscillation**
  Using the function suppresses spatial pressure oscillation specific to the MPS method, increasing calculation accuracy.
- **Negative pressure model**
  It is said that MPS method has difficulty for handling the effect of negative pressure. With Particleworks, however, you can simulate negative pressure by defining the outside pressure, which is usually set to atmospheric pressure.

**Viscosity calculation**

- **Implicit / explicit methods**
  Implicit method speeds up calculation because of constant time increment in a case like high-viscosity fluid calculation which end up with a small time increment caused by diffusion coefficient-based numerical stability conditions.
- **Newtonian / Non-Newtonian fluids**
  You can handle non-Newtonian fluids like power law and Bingham fluid as well as Newtonian fluids. Defining data tables and user functions also allows you to conduct more flexible viscosity calculation.

**Surface tension models**

- **CSF model / potential model**
  There are two models available for calculating surface tension in Particleworks.
  In CSF (continuous surface force) model, surface tension will be calculated from the geometric shape of the object. In the potential model, meanwhile, inter-facial energy between objects will be taken into account.
  With potential model, it is possible for you to consider the contact angle between two different kinds of physical properties, such as wall fluid and fluid fluid. By providing the magnitude of attractive force as a parameter you can simulate multiple non-miscible fluids like water and oil.

**Rigid bodies**

- **With Particleworks, you can handle non-deforming rigid bodies. Coupled simulation of fluid and rigid bodies makes you to evaluate the interaction between rigid bodies and complex flow.**

**Turbulence models**

- **With Particleworks, you can simulate turbulence flows. The turbulence model adopted here is a hybrid model of pure LES (Large Eddy Simulation) and wall model which enhances the resolution near wall.**

**Boundary conditions**

- **Wall boundaries**
  Wall boundaries can be either “particle” wall or “polygon” wall. Particle wall allows you to calculate internal temperature distributions, while polygon walls are more efficient in terms of memory usage and computation speed. Complex wall (object) movements can be simulated by setting motion to the objects.

- **Inflow boundaries**
  Inflow boundaries allow you to express the phenomena of fluid and/or powder flowing into the region. You can set time-dependent flow velocity or flow rate to the inflow, as well as movement to inflow.
Optional features

High-performance GPU computation

With optional GPU computing module, simulations can be run on NVIDIA CUDA-based GPUs. This dramatically reduces computation time, allowing low-end desktop PCs to perform as fast as supercomputers or HPC servers. Using NVIDIA’s Tesla K40c with 12 GB of GPU memory allows for the simulation of up to 2 million particles at once, and more particles could be handled by using multi-GPU computing.

Working with 3rd party software

NASTRAN data import

The NASTRAN data format, widely used in structural analysis, can be directly imported into Partliceworks. Modeling and simulation can be performed directly without data conversion.

Visualization with EnSight

Partliceworks provides a free data converter into a format readable by EnSight, a general-purpose post-processing package from CYBERNET SYSTEMS Co., Ltd. This allows EnSight to visualize Partliceworks’ simulation results.

2D simulation

The 2D simulation option significantly reduces the number of particles used, consequently allowing for high-speed computation. 2D simulation is useful for the cases like tsunami simulations which requires extensive analysis domains, as well as other periodic phenomena that can be evaluated in a cross section.

High-performance pre/postprocessing

User interface

Partliceworks GUI supports both Windows and Linux. All the operations including preprocessing, simulation and post-processing can be performed intuitively.

Redesigned easy-to-use interface makes it easier to create simulation model including time/condition settings and evaluate simulation results through post-processing without a long learning time.

The view window, the core of the GUI, offers OpenGL-based rendering with high-quality shading, displaying large-scale simulation results smoothly. Window configurations can be freely customized, allowing users to display multiple windows side by side to compare results.

Various visualization for simulation results

Surface mesh generator

Surface meshes can be generated based on particle information from the simulation results. Generating mesh allows you to evaluate fluid surface behavior and calculate surface area. Surface mesh data can be output in STL or OBJ formats.

Mapping

By using this function, virtual orthogonal grid with equal interval will be generated and then mapped physical quantities onto grid point. This function offers a variety of visualization, including contour, vector, isosurface, solid and streamline.

Mapping physical quantities to polygon walls

The physical quantities of near-wall particles can be mapped to the element points of polygon walls, which has no physical quantities in order to display simulation results and output text data.

CSV output for simulation results

Simulation results can be converted and output into CSV format. Output files can be imported into any spreadsheet software for plotting various physical quantities, such as position, velocity, pressure, number density, shear velocity, and the force and moment acted upon by polygon walls.

Animation and screenshots

Animations can be played and saved to movie files or sequential image files based on simulation results. Supported formats are PNG, JPEG, AVI and MPEG. Screenshots can be also output as PNG images.

Other features

There are many other features for detailed settings adjustments and post-processing. Colormap, particle information attributes, probe at designated point or box, and particle extraction in designated areas.
**Analysis of fluid pressure loaded to tank due to sloshing**

### Fluid-structure coupling simulation

Through a one-way coupling from fluid to structure, Particleworks provides highly accurate computation, allowing general structural analysis software to integrate the result of fluid flow with either dynamic or static calculations. To model the stress on the structure, given the structural deformation is not extensive, the fluid pressure applied to the structure can first be computed by Particleworks, and then passed to the structural analysis software such as LS-DYNA.

![Vortex in stirring tank](Image courtesy of Mitsubishi Chemical Corporation)

![Water flow in continuous casting rolls](Image courtesy of Nippon Steel & Sumitomo Metal Corporation)

![Oil flow in HF transformer](Image courtesy of Toyota Motor Corporation)

![Crucible sloshing](Image courtesy of Fuji Heavy Industries Ltd.)

![High viscosity mixing](Image courtesy of Toei Company, Ltd.)

![Smoothing analysis](Image courtesy of Aichi Information System, Co., Ltd.)

![River flooding associated with a 3D map construction](Image courtesy of Otsuka Business Systems Co., Ltd.)

![Cooling down analysis](Image courtesy of Aichi Information System, Co., Ltd.)

The above images show the time-serous pressure distribution loaded to the tank due to sloshing.

**Case Examples**

**Particleworks’ capability in sloshing simulation and its applications**

- **3rd party software** (e.g., LS-DYNA)
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### Capabilities Chart

**Server**

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**Post-processing, Visualization**

- Image/Video output
- Animation/represent vision of physical properties
- Particle properties
- Streamline
- Isosurface/Isobole
- Extraction of particles in a specified region and calculation of minimum, maximum and average physical quantities of the particles (iso-probe)
- Estimation of physical quantities in arbitrary coordinate (point probe)
- Surface mesh generation from particle data
- Flow rate measurement
- Interpolation from particle data to geometry data (Mapping)
- Interpolation from particle data to grid data (Grid)
- ASCII conversion of results (formerly "ProfinAcu")

**Operation requirements**

- Operating System: Windows Vista, Windows 7, Windows 8, RedHat Enterprise Linux 5/6 (64 bit), SUSE Linux Enterprise Desktop 10 (64 bit)
- CPU: Intel AMD, x86 compatible, 2 GHz
- GPU: NVIDIA Quadro FX 5800/6800 (S8) / Titan (S8)
- Memory: 2 GB
- Free 4 GB RAM

**Particleworks’ LS-DYNA solver**

- Supported
- Not supported

*Particulate system is recommended.*

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**CSM (Computational Science Module)**

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**References**

- Particleworks’ Application in the Automotive Industry: "Sloshing Simulations in the Automotive Industry: High-precision Calculation of Fluid Pressure"