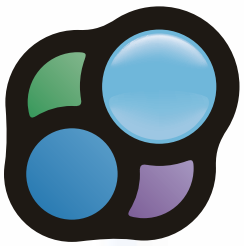
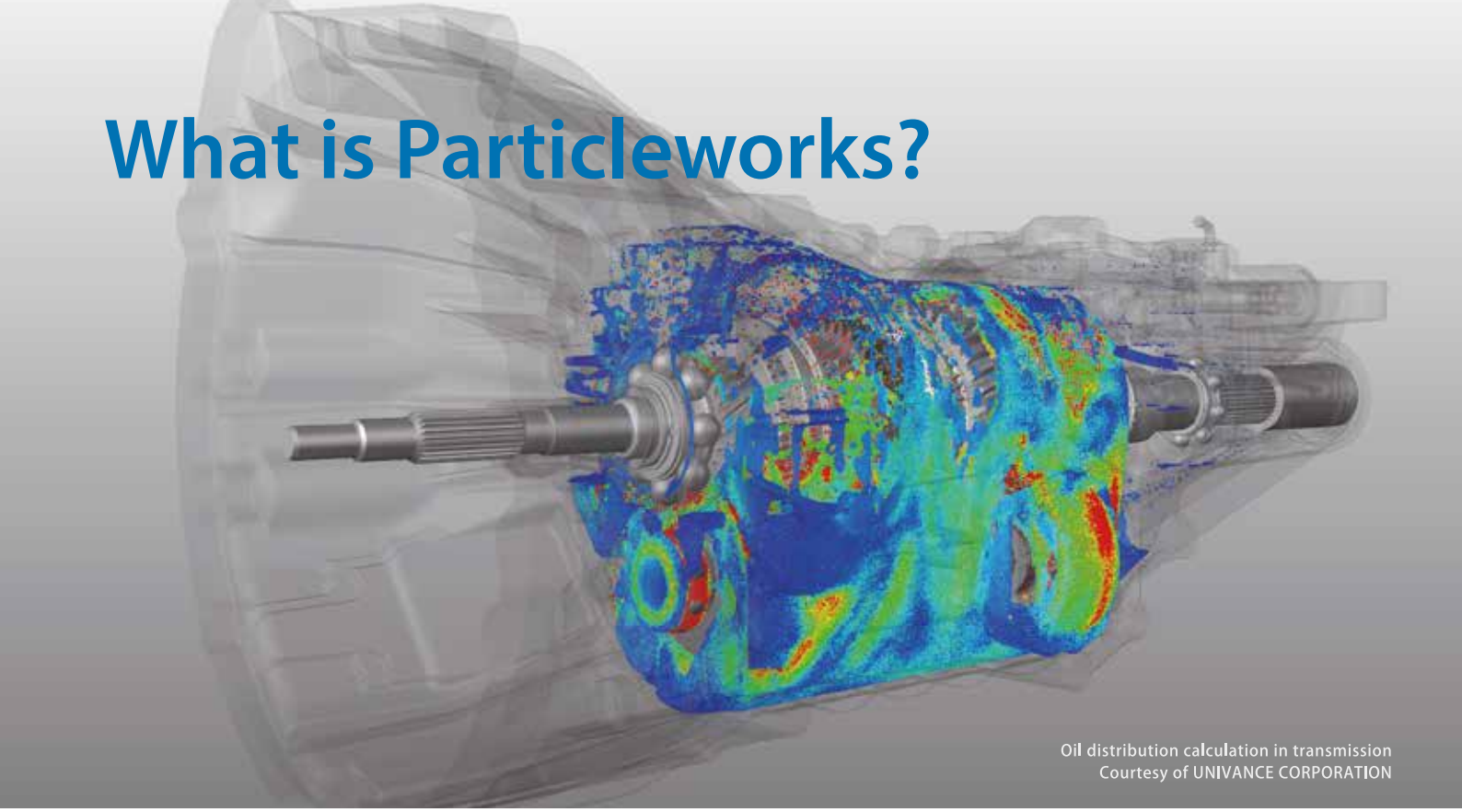


Particleworks™

Particle-based simulation software for CAE

What is Particleworks?



Oil distribution calculation in transmission
Courtesy of UNIVANCE CORPORATION

Fast, Flexible Motion Analysis – with No Need for Meshing

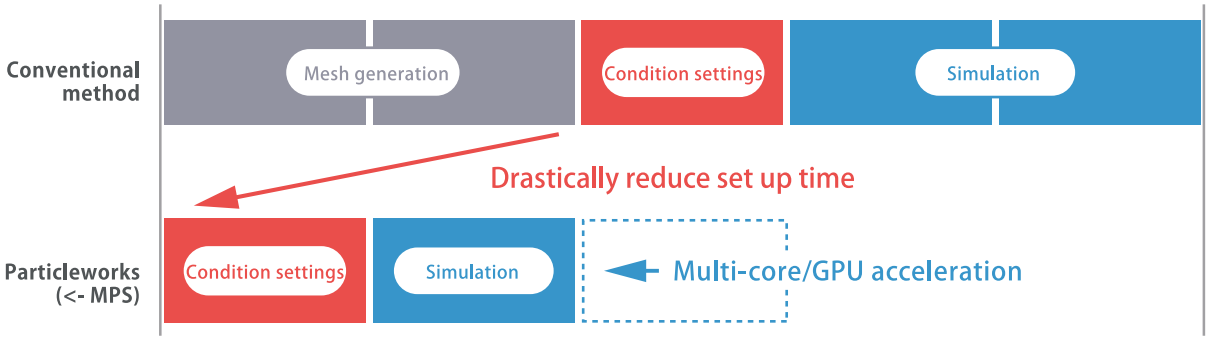
Particleworks is the leading software for simulating the movement of fluids. Our cutting-edge, particle-based simulator makes it easy to create and analyze 3D models in a variety of industrial contexts – from oil sloshing and cooling for the automotive industry to mixing and kneading for medicine and plastics.

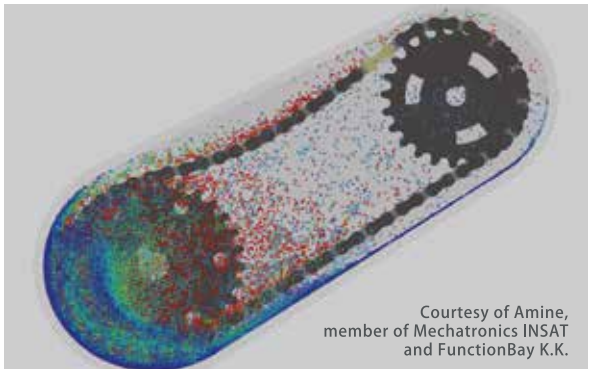
With an intuitive interface, an ultra-fast solver, and powerful visualization tools, Particleworks gives you all the tools you need to analyze motion in order to optimize your engineering process.

No Meshing Needed

Particleworks lets you import files directly from CAD software, so you can avoid the expensive mesh generation needed for conventional CFD software.

No need to do complicated and repetitive mesh generation, you can set up calculation intuitively.





Courtesy of Amine, member of Mechatronics INSAT and FunctionBay K.K.

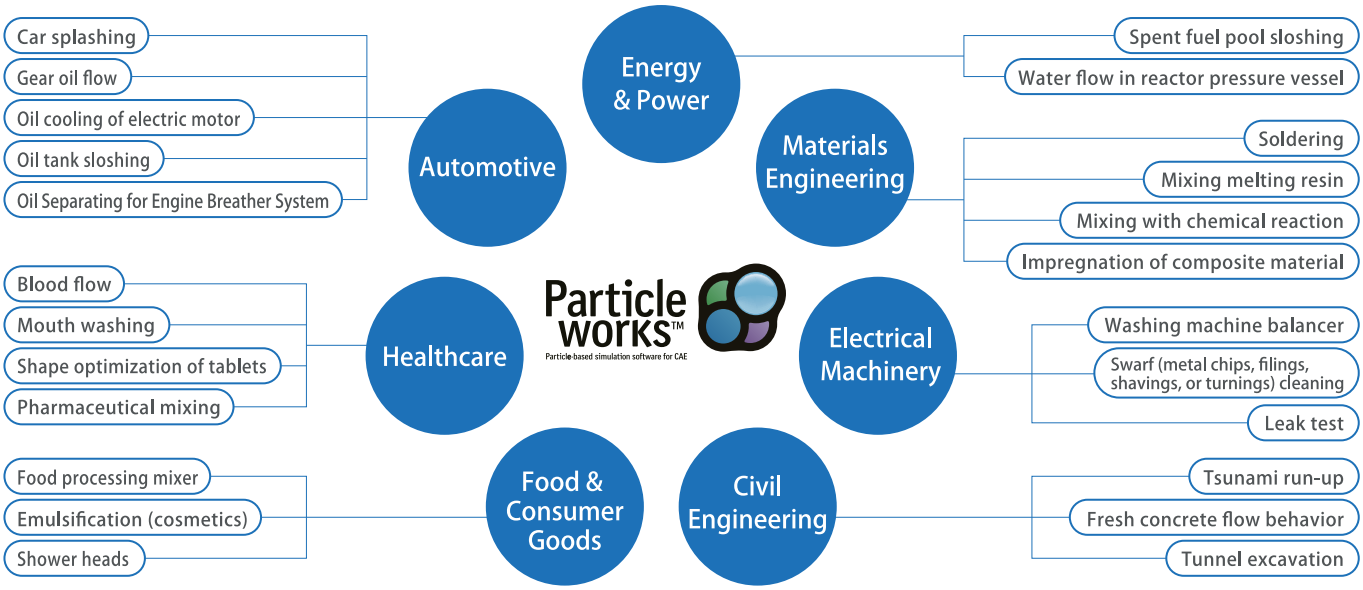
Splash and Free-Surface Flow

Particleworks analyzes the motion of fluids by dividing them into sets of discrete elements or particles, which are allowed to move freely. This approach lets you simulate large deformation, coalescence and segmentation of fluid, and rapid change of flow – without requiring any complicated preparation or meshing in advance.

Particleworks provides excellent performance in the simulation of moving boundary problems, which can be a time-consuming task with conventional methods. When dealing with complex structures such as gears and impellers, the software first translates these structures to polygon models, making it simple to apply detailed movement settings.

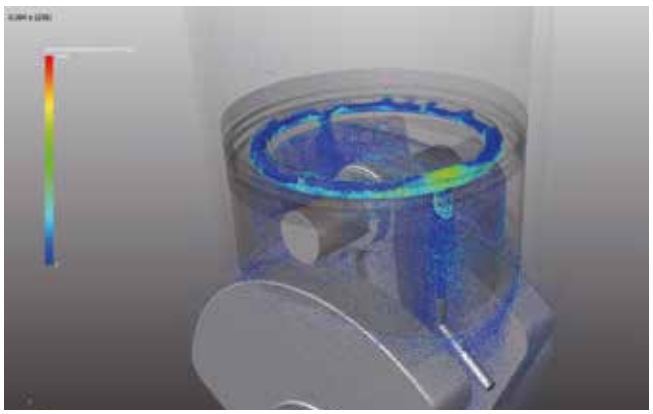
Cutting-Edge Research

Particleworks utilizes the latest research by Dr. Seiichi Koshizuka of the University of Tokyo's Graduate School of Engineering, developer of the MPS method and founder of Prometech Software. Since 2009, it has offered engineers innovative solutions to a wide range of industrial problems. Today, Particleworks continues to gain new simulation capabilities through research conducted within companies and university laboratories across Japan.



Flexible Multi-Body Integration

Particleworks makes it easy to simulate interactions between fluids and powders, or between fluids and rigid bodies, with no complicated settings required. You can even carry out coupled simulations with Particleworks and third-party software, with no need for meshing.

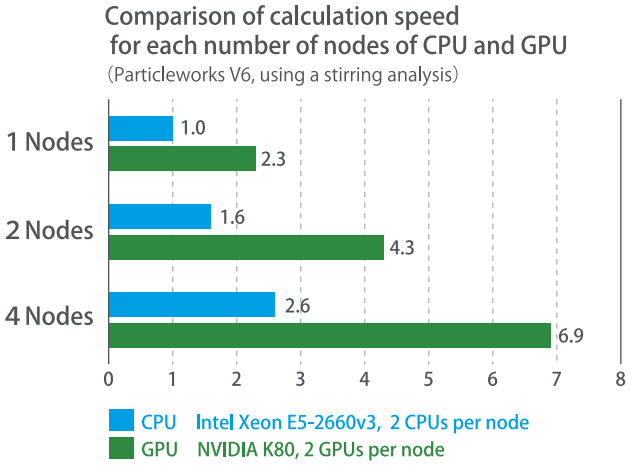


Accelerated Simulation Supporting Today's Latest Hardware

Particleworks makes the most of the latest hardware environments, supporting multithreading (OpenMP) and multiprocessing (MPI), in addition to SSE/AVX instructions on CPUs.

NVIDIA CUDA Support

Particleworks has been recognized by NVIDIA as a program that harnesses the power of NVIDIA's CUDA, a GPU parallel-computing platform and application-programming model that offers overwhelming performance gains in parallel computing.



Features

New Features

New Features in Version 6

Particleworks Version 6 comes with dozens of new features and enhancements, including improvements and accelerations of numerical methods and integration with third-party programs.

Solver

- Support for single-precision floating-point format
- Improved performance for CPU/GPU
- Optimized parallelization for SMP/MPP
- Reduced file size
- Smaller memory footprint

Physics

- More accurate calculation of: Pressure, Surface tension, Air resistance
- Exporting heat convection coefficients
- Aeration
- Support for rigid-body simulations on GPUs

GUI

- Custom scene templates
- Tools for running multiple simulations simultaneously
- Shorter load time for results
- Accelerated video processing
- Improved filter
- Enhanced charts for post-processing

Enhanced Performance

Supports NVIDIA's Latest Technologies

Particleworks supports NVIDIA's Pascal™ architecture, which can run up to three times faster than NVIDIA's earlier Maxwell™ architecture. Leveraging the latest GPU technology, Version 6 runs significantly faster than earlier versions of Particleworks, enabling large-scale simulation with tens of millions of particles.

Improved CPU/GPU Performance

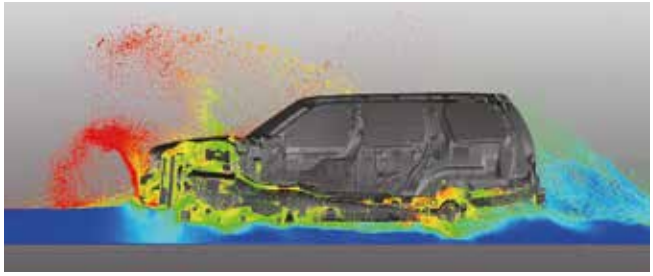
Particleworks Version 6 comes with a brand-new solver, rewritten and optimized for the latest CPU/GPU architectures.

Single-Precision Solver

With the new single-precision mode, you can now run a simplified simulation, saving computation time and memory consumption.

Enhanced Support for External Tools

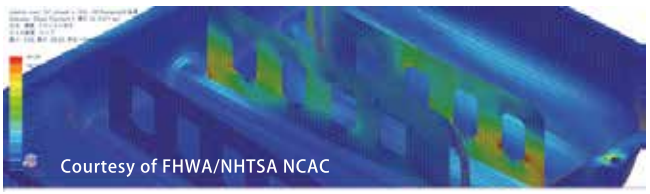
Supports RecurDyn V9R1 (Multi-Body Dynamics Software)



This model has been developed by The National Crash Analysis Center (NCAC) of The George Washington University under a contract with the FHWA and NHTSA of the US DOT

Export to NX Nastran, ANSYS, and Abaqus

Particleworks can now export result data to external tools such as NX Nastran and ANSYS/Abaqus. Time-series data regarding physical quantities on each particle can be exported to CSV files, and then converted to various data formats such as NX Nastran PLOAD4.



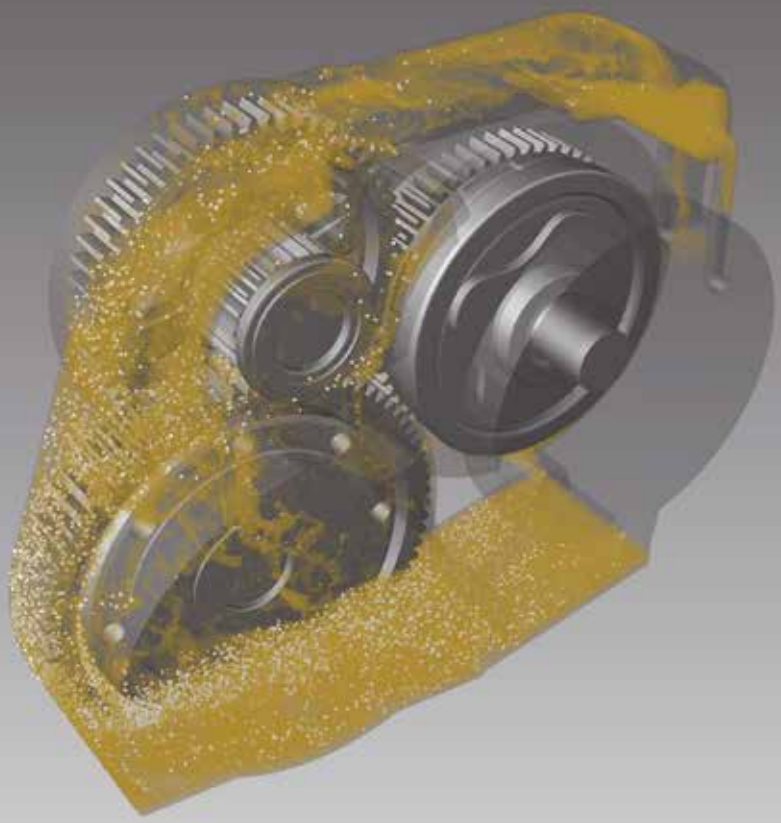
New Features

Aeration

Particleworks version 6.1 introduces aeration, letting it analyze bubble behavior to predict engine oil behavior and chemical processes in stirring tanks. This feature comes in handy when examining design issues related to bubbles. You can:

- Choose the size of simulated bubbles
- Calculate buoyancy force, wall force, drag force, bubble extinction, bubble coalescence, and bubble breakage
- View statistics for spatial distributions of bubbles based on size
- Visualize and spot issues related to bubble behavior

*This function requires co-simulation with Granuleworks.



Exporting Heat Convection Coefficients

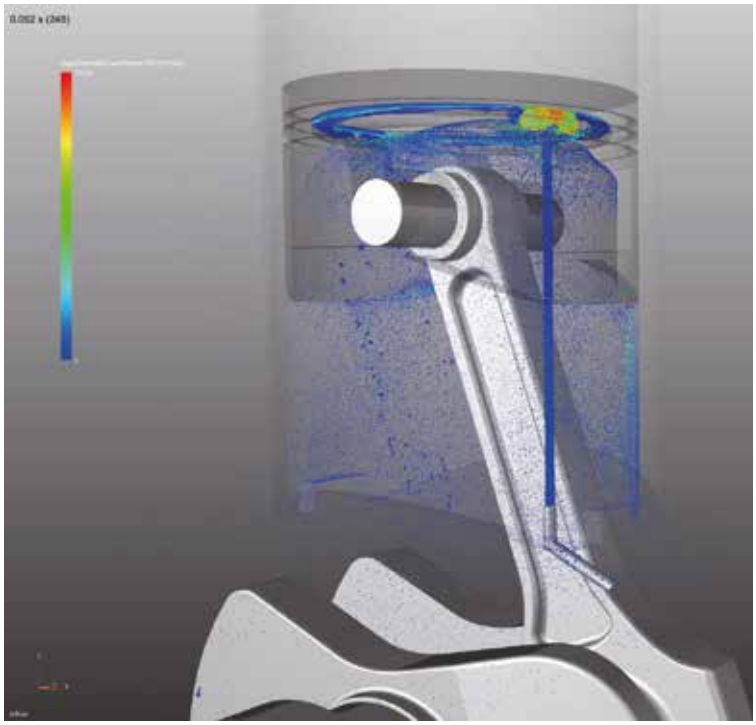
Using flow data of particles, Particleworks can now export heat convection coefficients, which can be applied to analyze the cooling of cylinder heads, motors, or sheet steel.
This function uses the heat transfer coefficient to model the heat flux to the wall, and then it estimates the heat removal (heating) amount of the polygon wall surface. You can simulate cases where the temperature of the fluid is constant and a boundary layer exists. You can:

- Simulate and analyze the cooling of engine oil by a piston
- Simulate and analyze the cooling of steel
- Calculate heat convection coefficients using velocities
- Analyze oil flow with heat transfer

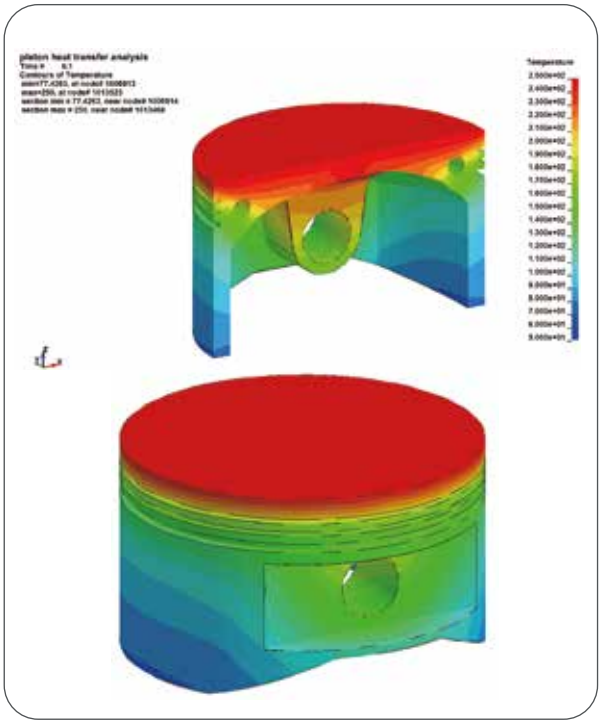
Improved Air Resistance

Version 6.1 also offers increased compatibility with external airflow-analysis programs, offering improved analysis of droplet behaviors such as mist and spray. You can:

- Simulate gas-liquid separations for breather systems
- Create simulations in which each particle represents a group of droplets
- Calculate drag coefficients based on a wide variety of applications
- Analyze filtered particles and pathlines
- Predict oil-separation processes



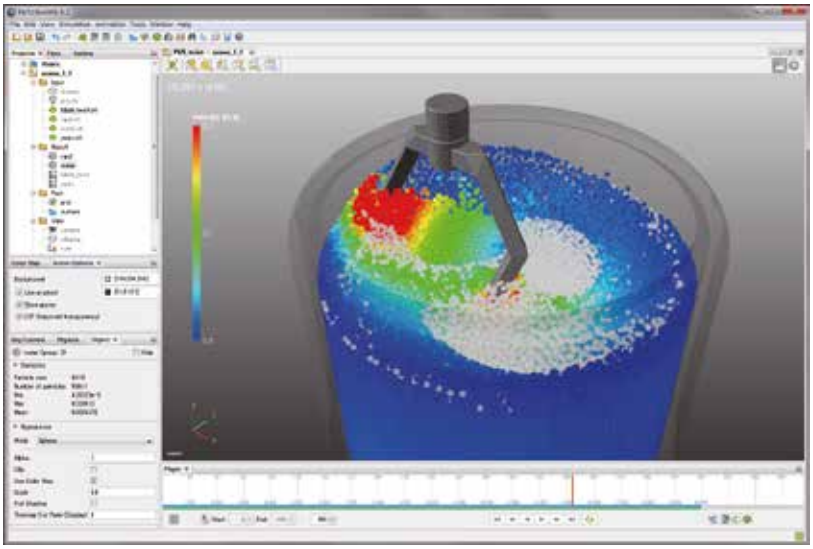
Analyzing heat convection and oil jet behavior inside a piston



Third-party programs such as LS-DYNA® can perform heat analysis using heat convection coefficients exported from Particleworks.

Features

Basic Features

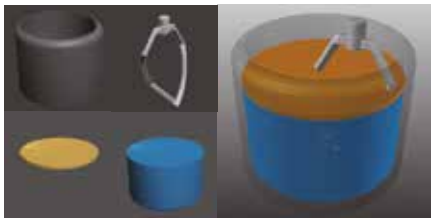


Simulation Flow

Just four steps modeling to postprocessing

Step1
Modeling

Import CAD data and define the resolution for pre-processing. The STL, OBJ, and NASTRAN formats are supported.

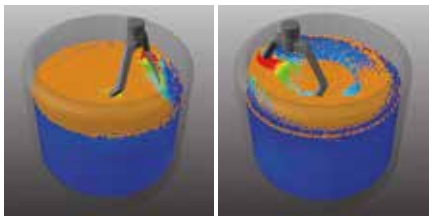


Step2
Condition Settings

Simply apply physical properties and movements to the model. No tedious adjustments are needed for boundary conditions.

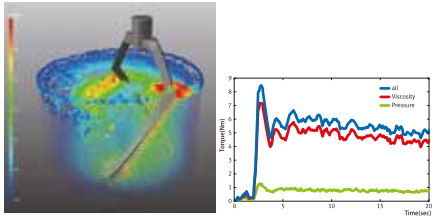
Step3
Simulation

You can accelerate the calculation using multiple CPU cores or GPUs. Additionally, you can view the results of a simulation while it is still in progress.



Step4
Post-Processing

Visualize and evaluate the simulation results using various post-processing tools. For example, you can create surface meshes and export CSV and video files.



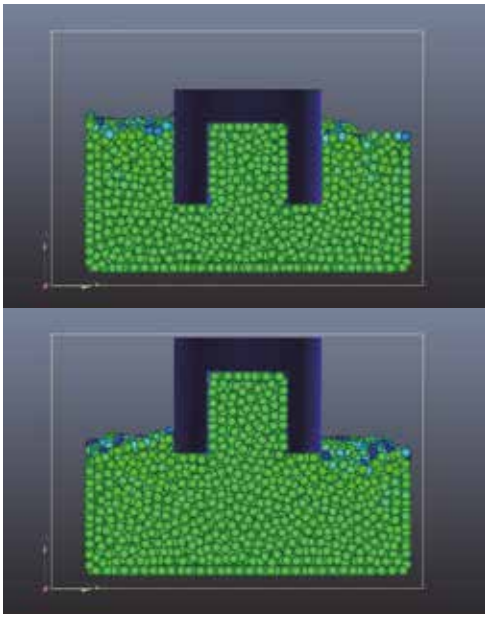
Physics

Pressure

●Implicit/Explicit Methods
The explicit method speeds up calculation by giving a suitable speed of sound.

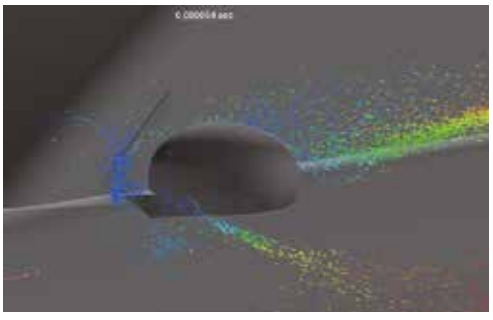
●Suppression of Pressure Oscillation
Spatial pressure oscillation can be suppressed using this function, resulting in higher accuracy.

●Negative Pressure Model
Unlike other particle-based methods, Particleworks can handle negative pressure with ease. Define the outside pressure or atmospheric pressure.



Air Resistance

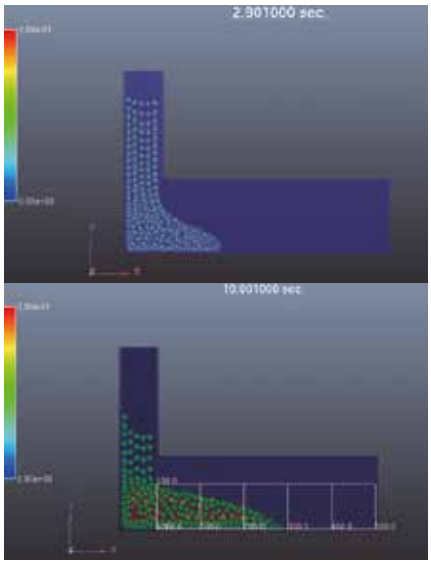
Particleworks can import data points calculated by external CFD programs (in CSV format), such as airflow field around a car body. This function is useful when analyzing the behavior of droplets with air resistance.



Viscosity

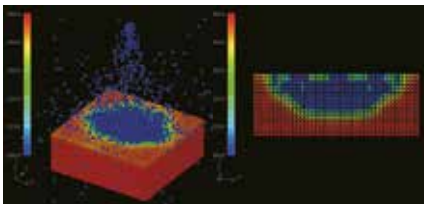
●Newtonian/Non-Newtonian Fluids
Particleworks can simulate non-Newtonian fluids – such as power-law or Bingham fluid – as well as Newtonian fluids. For more detailed control over viscosity, you can specify custom functions or data tables.

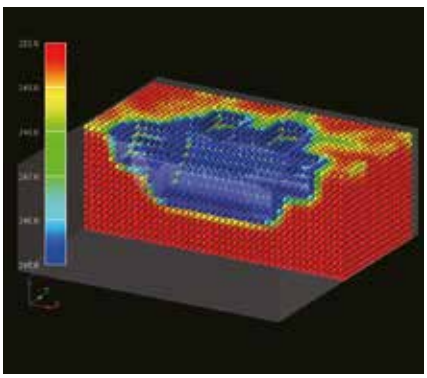
●High-Viscosity Fluids
When simulating high-viscosity fluids, the explicit method tends to give a smaller time step, resulting in a longer calculation. In contrast, Particleworks' implicit method maintains a constant time step, making it an ideal solution for such simulations.



Heat Transfer

Particleworks can analyze heat transfer between solids and fluids, and you can set temperature-dependent viscosity for fluids and shear heating.

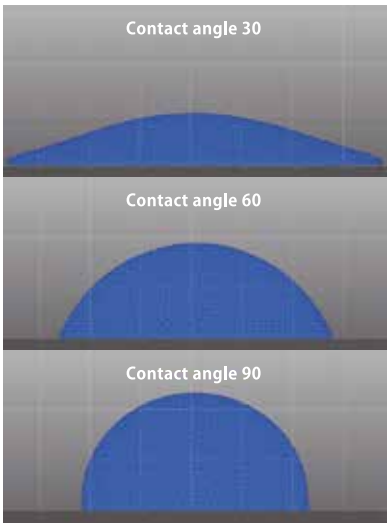




Surface Tension

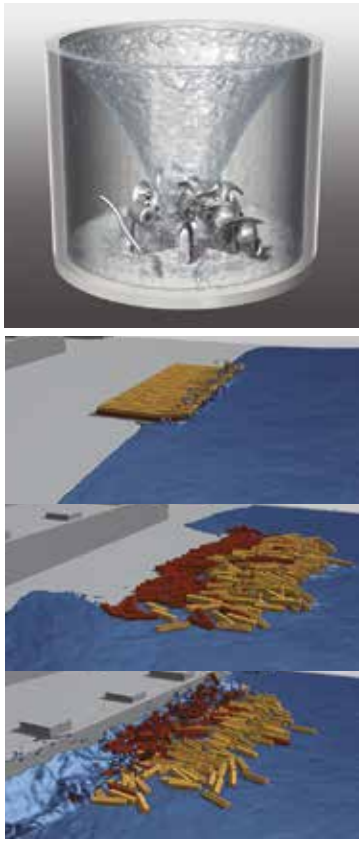
Particleworks offers two models: The CSF model calculates surface tension from the geometric shape of the object, whereas the Potential model uses interfacial energy between objects.

One of the advantages of the Potential model is contact angle. You can set contact angles between two different states of matter, such as wall-fluid and fluid-fluid. By specifying the magnitude of the attractive force, you can simulate multiple fluids that don't mix, such as oil and water.



Rigid Bodies

The interaction between complex flow and non-deforming objects or rigid bodies can be analyzed straightforwardly.



Boundary Conditions

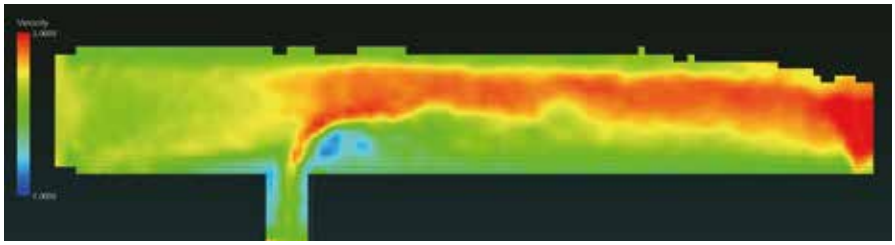
●**Wall Boundaries**
Walls can be either particles or polygons. Particle walls allow you to calculate internal temperature distributions, while polygon walls generally create a smaller memory footprint and allow for faster calculation. You can set movements for both types of walls.

●**Inflow Boundaries**
Inflow boundaries allow you to generate fluid or powder over time. You can specify the flow by its velocity or flow rate (volume). Inflows are movable.

●**Moving/Periodic Boundaries**
The mesh-free method allows the simulation region to be moved. This saves computational resources when simulating a large region, such as a waterway driving test. Periodic boundaries are also supported.

Turbulence

To simulate turbulence flows, Particleworks uses a hybrid model in which LES (Large Eddy Simulation) is combined with resolution enhancement near walls.



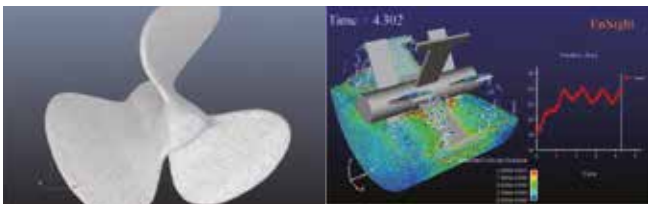
Features

Basic Features

Support for Third-Party Tools

Particleworks allows you to import CAD data in STL or NASTRAN format created by external CAD tools. Post-processing using EnSight (CEI Software) is also supported.

You can use airflow data from mesh-based CFD software such as OpenFOAM, the open-source CFD toolbox, to control fluid behavior in Particleworks.

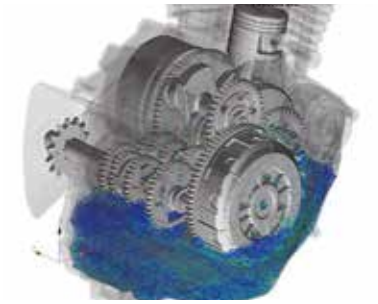


NASTRAN data import　　Visualization using EnSight

Coupled Simulation with RecurDyn

With RecurDyn, you can simulate dynamic interactions between fluid and solid bodies, rather than pre-defined movements. RecurDyn computes mechanics and movements of solid bodies, while Particleworks calculates fluid behavior accordingly.

RECURDYN

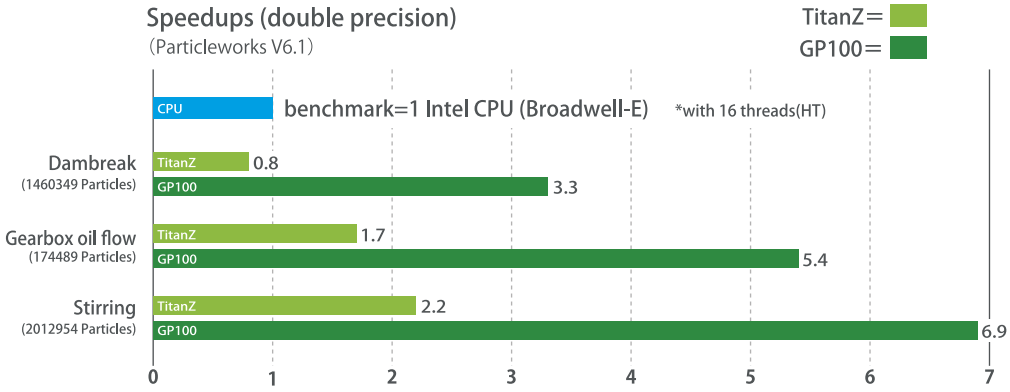


Courtesy of Thomas Freviller and FunctionBay K.K.

Optional Features

GPU

With the optional GPU module, solvers can now run on NVIDIA CUDA-based GPUs, drastically reducing computation time. Using NVIDIA® Tesla® P100 with its 16 GB GPU memory, you can simulate up to 3 million particles (and even more with multiple GPUs).



2D Simulation

The 2D simulation option significantly reduces the number of particles used, resulting in quick computation. This feature is useful for simulating periodic phenomena such as a large tsunami, or for analyzing a cross-section of a domain.

2D simulation of tsunami

Coupled Simulation with Granuleworks

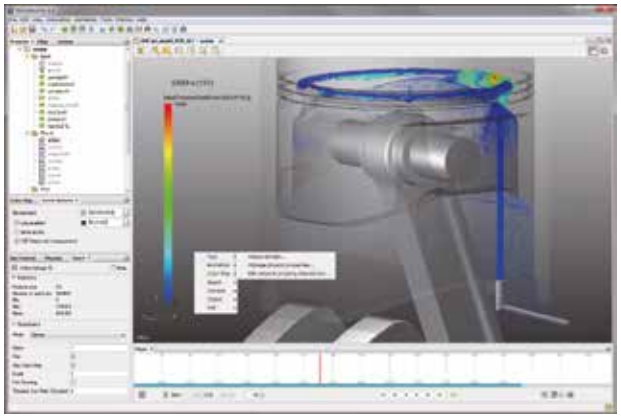
Granuleworks™
Advanced Simulator for Granular Materials

Prometech's Granuleworks enables you to simulate complex phenomena such as mixing and stirring, in addition to mechanical conveying processes. By combining Granuleworks' DEM (Discrete Element Method) and Particleworks' MPS, you can simulate the motion of powder particles in fluids.

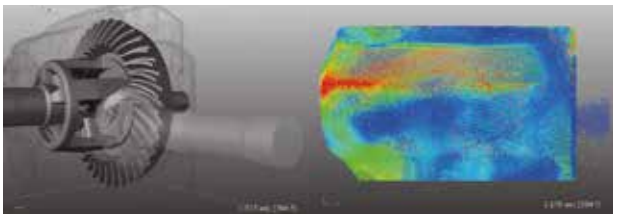
Pre- and Post-Processing

User Interface

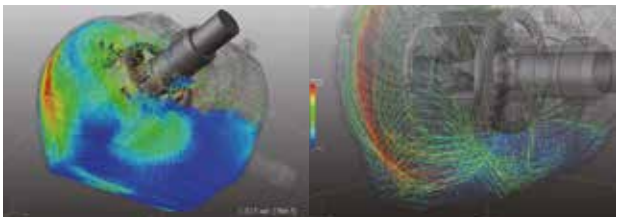
Particleworks' intuitive user interface lets you handle an entire simulation, from pre-processing through post-processing. You don't have to be an expert to edit simulation parameters or keep track of multiple projects.
The 3D view window features ultra-fast, high-quality OpenGL rendering optimized for large-scale simulation with millions of particles. The window system is highly customizable, letting you compare multiple results side by side. Both Windows and Linux are supported.



Visualization



Solid, wire, and transparent views　　Cross-section display



Color mapping of pressure, velocity, and temperature　　Streamline

Vector view　　Pathlines

Surface Mesh Generator

Surface meshes can be generated using particle locations, letting you evaluate the behavior of a fluid surface or calculate the area of a surface. Mesh data can be exported in the STL and OBJ formats.

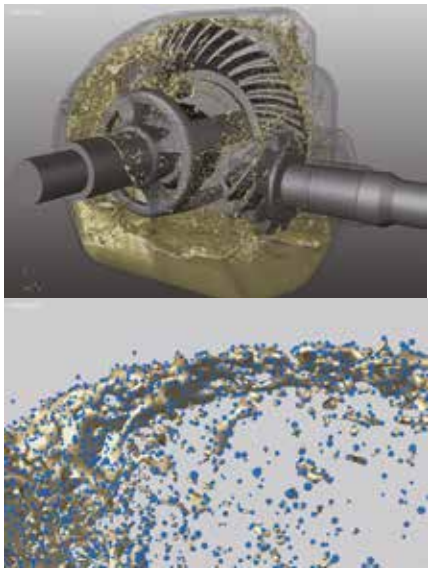
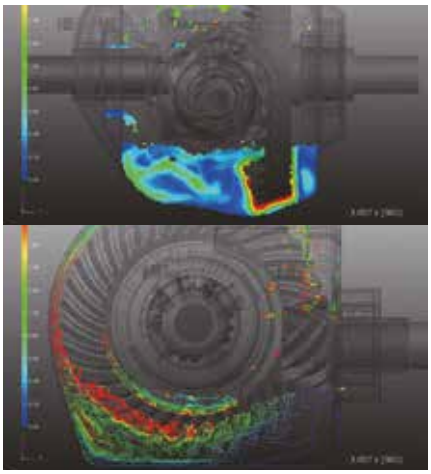


Image and Video Export

You can export simulation results and motion data to video or sequential image files, as well as still images (screenshots). The PNG, JPEG, AVI, and MPEG formats are supported.

Grid Data Generator

You can project the physical quantities each particle carries onto grid points. With the grid data, you can perform further visualization including contour, vector, isosurface, isoline and streamline.

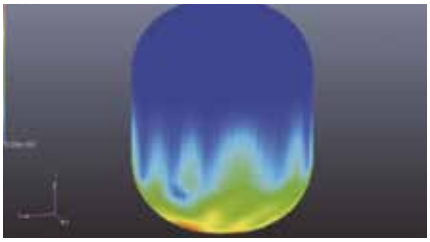


Probing Particles, and Other Tools

You can pick and probe a particle with a single click. With probe and particle filters, you can calculate statistics over particles that exist in a certain range (of any quantity), or near a probe point.
Other tools including the color bar, rulers, and time code will guide you through every step of post-processing.

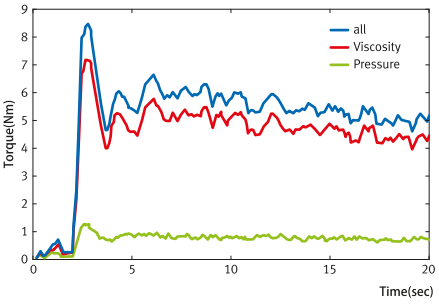
Data Mapping to Polygons

You can also project particle data onto vertices of a polygon mesh, which can be exported as CSV or binary files. You can use the files as input to third-party mesh-based programs.

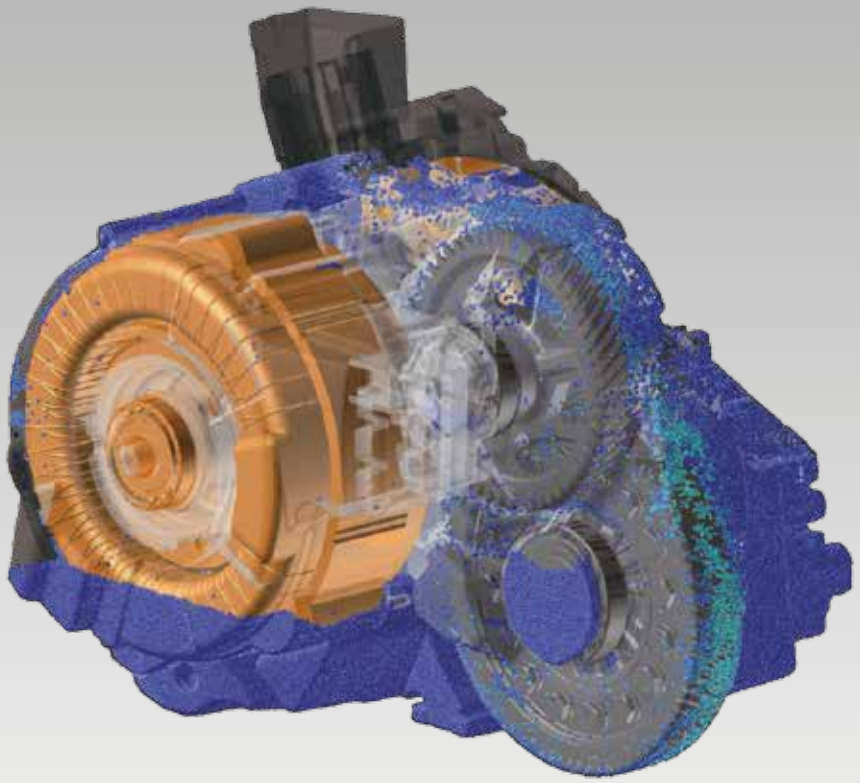


CSV Export

You can export particle data to CSV files, allowing for further data processing on quantities including coordinates, velocity, pressure, number density, and sheer velocity. Force and torque against polygon walls can also be exported.

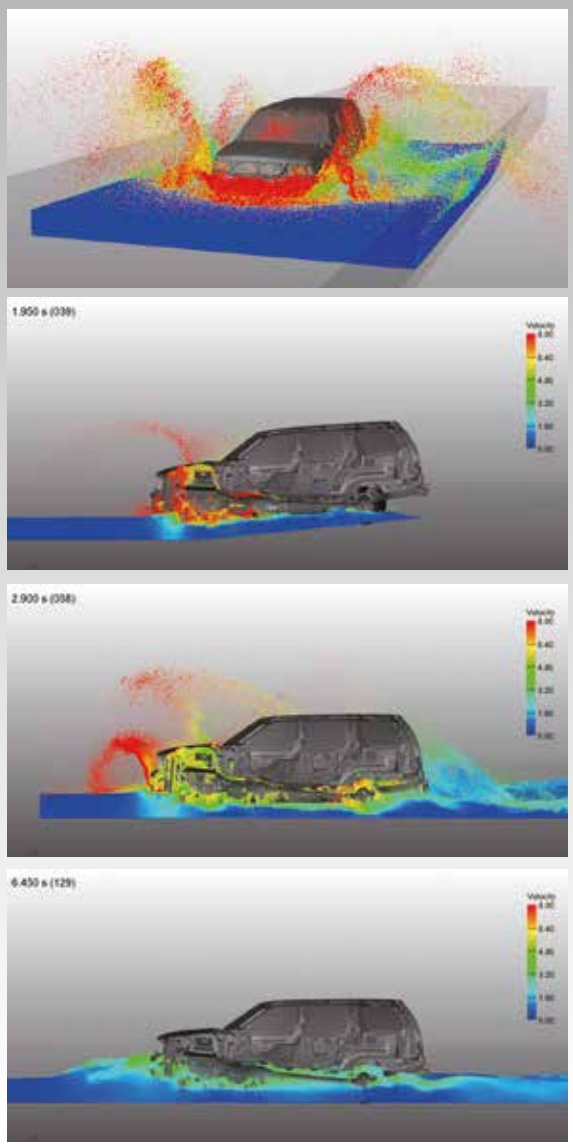


Particleworks Case Examples

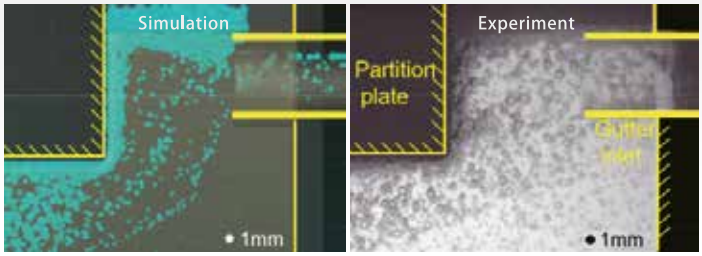


Oil flow in HV transaxle, Image courtesy of Toyota Motor Corporation

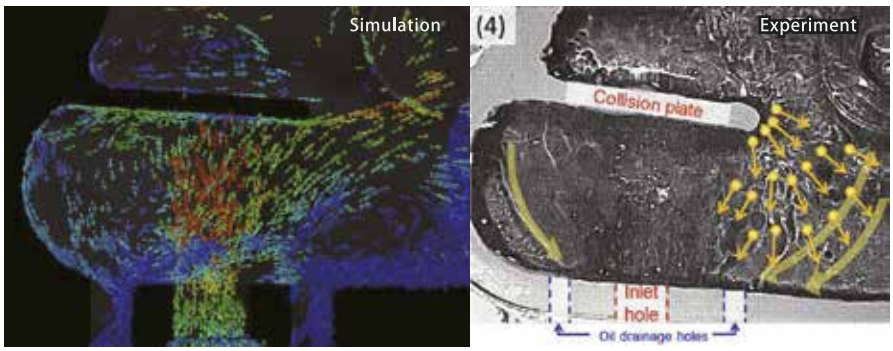
Simulation of vehicle running on flooded road
by using coupled multibody and fluid dynamics



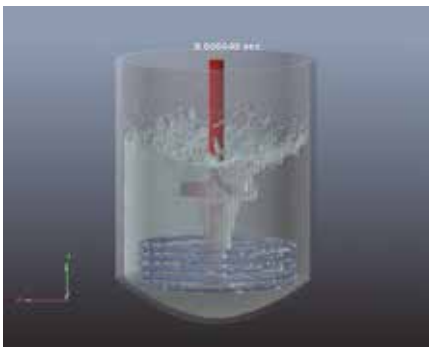
This model has been developed by The National
Crash Analysis Center (NCAC) of The George
Washington University under a contract with the
FHWA and NHTSA of the US DOT



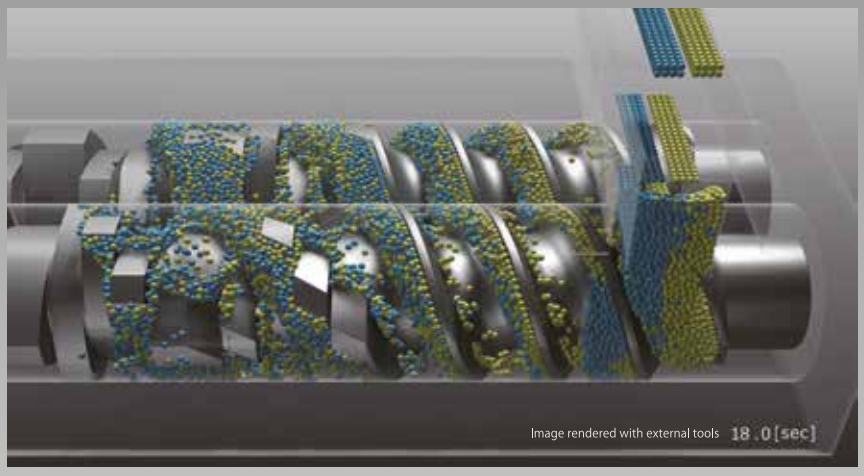
Studies on Particle Method Simulation of Bubble Behavior in Engine Lubricating Oil (First Report),
Courtesy of Honda R&D, Koji Matsui, Koichiro Matsushita et al. JSAE16 Spring season



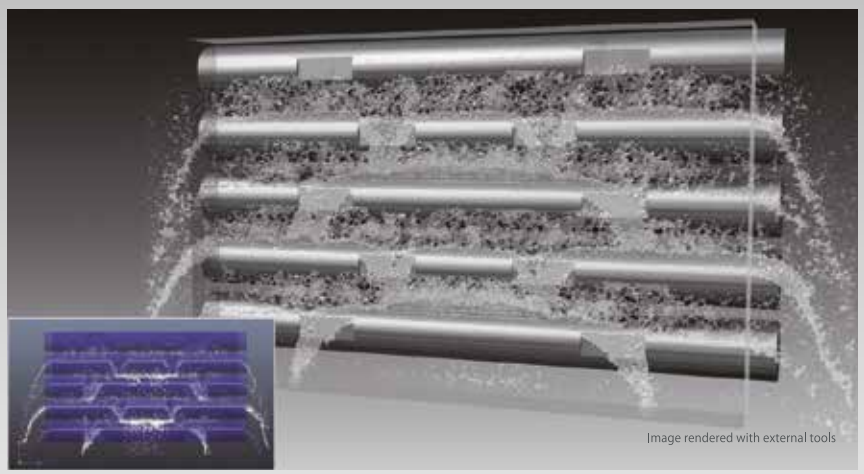
Simulation of Oil Separating Behavior for Engine Breather System, Courtesy of Honda R&D
Makoto HAGA et al. Honda R&D Technical Review Vol.26 No.2



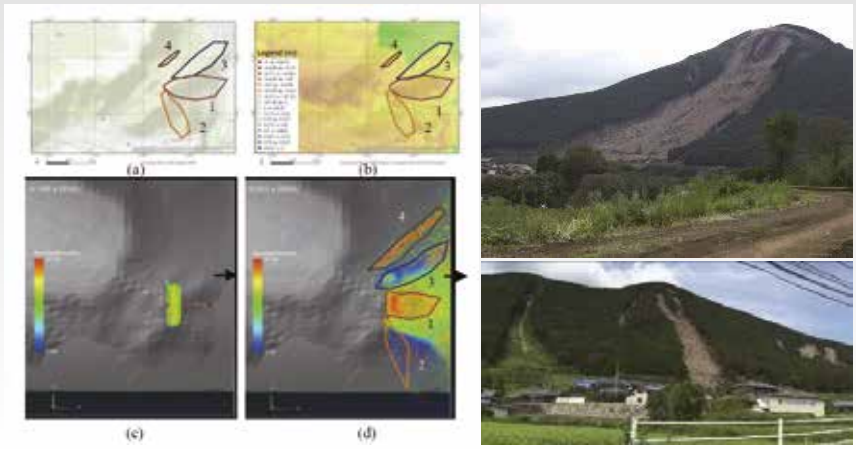
Vortex in stirring tank,
Image courtesy of Mitsubishi Chemical Corporation



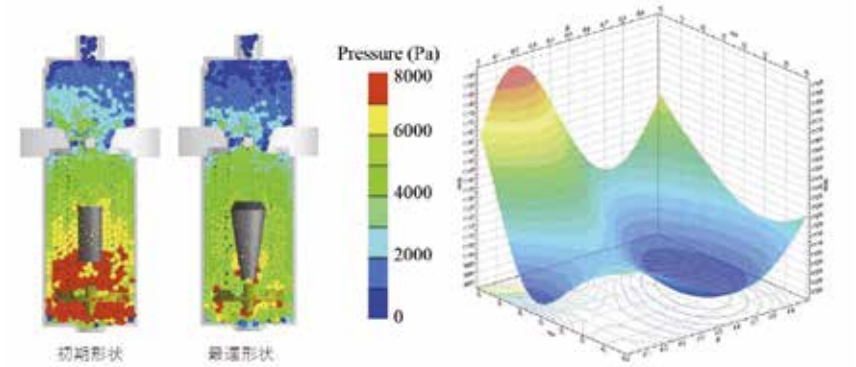
Twin axis screw extrusion molding analysis JAPAN STEEL WORKS, LTD.



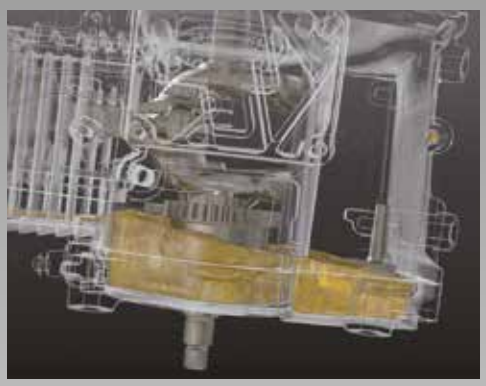
Analysis of the spray behavior between continuous casting rollers. NIPPON STEEL & SUMITOMO METAL CORPORATION



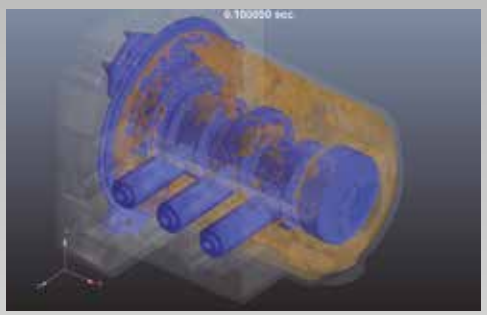
The Application of Interferometry SAR Data Analysis and Particle-based
Simulation for Landslide Disaster Observation (Study Case in Kumamoto Prefecture)
The 61st Autumn Conference of the Remote Sensing Society of Japan
Civil Engineering & Eco-Technology Consultants, Yessy Arvelyna et al.



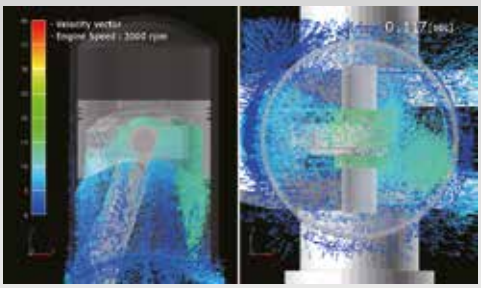
CEEM CO., LTD.
Shape Optimization of Filter System using Fluid Analysis
Based on MPS Particle Method, The Japan Society of Mechanical Engineers (OPTIS2016)



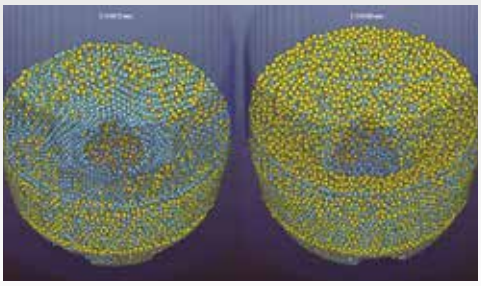
Crankcase slosh, Fuji Heavy Industries Ltd.



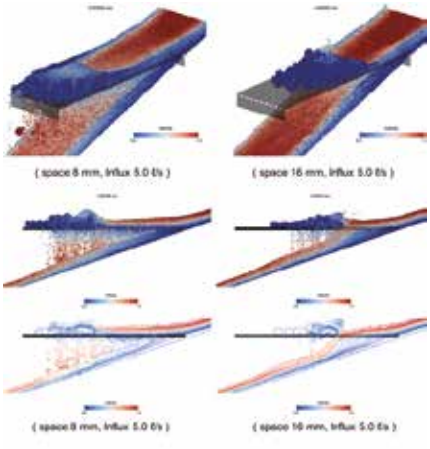
Crankcase oil splash, Company M



Connecting rod oil injection



Vortex barrel, TIPTON Corp.



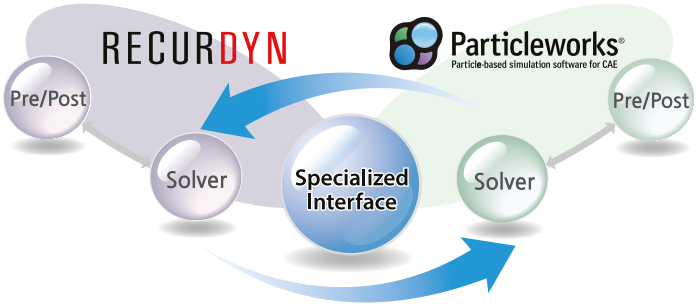
Debris flow simulation on the debris flow breaker
by coupled analysis of rigid body and fluid
Disaster risk reduction Planning Workshop, NPO,
Tokyo, Japan, Hajime Ikeda, Takanori Ito

RECURDYN x Particleworks™

Particle-based simulation software for CAE

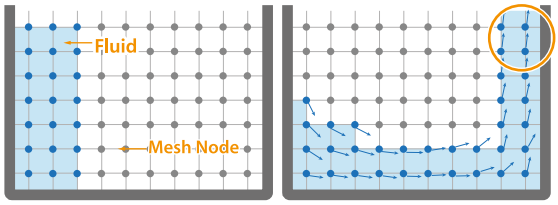
World's First CFD-Specific Multibody and Fluid Dynamics Co-Simulation Interface

RecurDyn has an interface specially designed for Co-Simulation of dynamics of rigid bodies and fluids. RecurDyn is the world's first commercial Multi-Body Dynamics software to offer such an interface. This interface allows you to simulate complicated fluid-solid interactions that were very difficult to simulate in the past.
You can now simulate the coupled interaction between the two easily, so that the solid bodies and the fluids affect each others' behaviors.

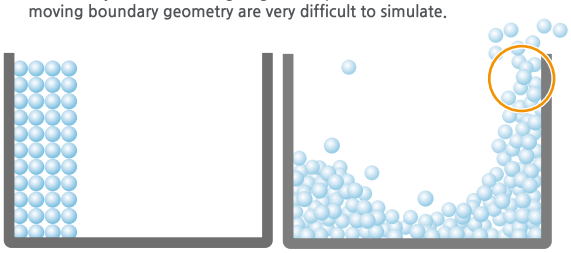


The MPS Method vs Conventional Methods

The Moving Particle Simulation (MPS) method is a formulation for modeling fluid dynamics for uncompressible fluids. In contrast with conventional CFD methods that require meshes, the MPS method models fluids directly using particles to represent the fluid. This allows for easily modeling the free surfaces of fluids and for modeling multiple fluid types together, along with the boundaries between these fluids.
In conventional CFD methods that use meshes, it is very time consuming to generate an optimal mesh, and it is very difficult to simulate free surface flows or complex boundary geometries.
As a result, the MPS method allows you to model and simulate your target system easily and provides a remarkable advantage in simulation of free surface flows and complex boundary geometries.



▲ In conventional CFD methods, which require meshes, optimal meshes can be very time consuming to generate, and free surfaces and moving boundary geometry are very difficult to simulate.



▲ Particle-based CFD methods easily handle free surfaces and moving boundary geometry, and no mesh is used.

Benefits of using the MPS Method

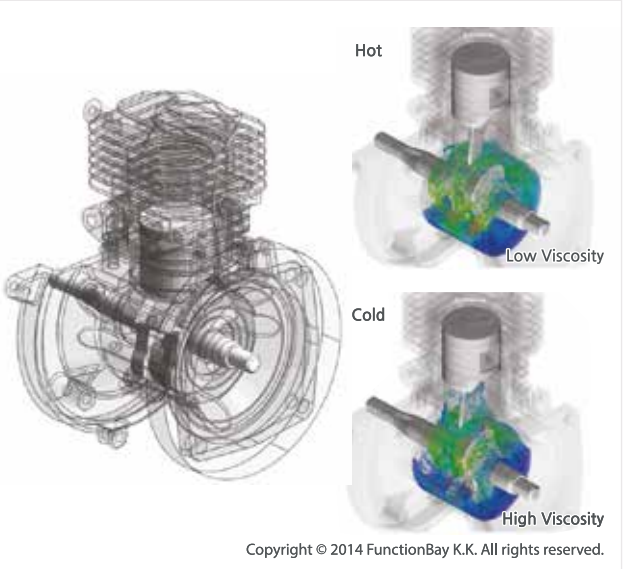
- Captures the effects of the motion of the mechanical system on the fluid.
- Captures the effects of fluid behavior on the mechanical system.
- The effect of the behavior of the mechanical system can be seen in the surfaces and turbulence of the fluid.

▶ Benefits for RecurDyn of Co-Simulation with Particleworks

	Analysis using RecurDyn Alone	RecurDyn-Particleworks Co-Simulation
Resistive Fluid Force (Gear oil splash)	Use simplified analytical or empirical force model	Use realistic fluid force directly on the mechanical system parts
Fluid Momentum (Washing machine balancer)	Use small number of rigid spheres	
Propulsive Fluid Force (Hydraulic torque converter)	Use simplified analytical or empirical force model	
Buoyant Fluid Force (Boat, buoy)	Use simplified analytical or empirical force model	

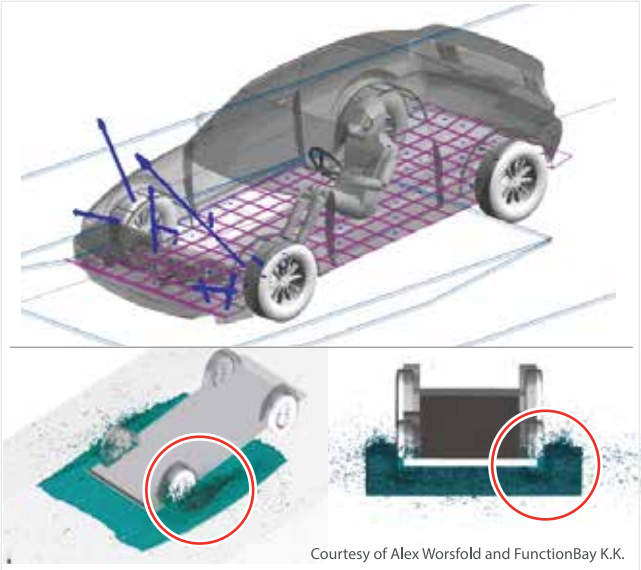
Co-Simulation Case Examples

Reaction torque from lubrication oil on a single cylinder engine at various temperatures



- Demonstrates the relation between the viscosity and reaction torque caused by the lubricating oil at various temperatures.
- Predicts the differences in deceleration at different lubrication oil viscosities caused by variations in temperature.

Fluid impact on the underbody of a vehicle when driving through a puddle



- Simulates the fluid impact on the underbody of a vehicle.
- Shows the flow of the splashed water around parts accessible from the underside of the car, which is especially important for electric and hybrid cars.

Oil sloshing in a vehicle's fuel tank

Predicts realistic fluid behavior during severe tank sloshing and the influence of the fluid dynamics of the fuel on the vehicle.

- The fluid slosh can be visualized in the GUI of Particleworks.
- Allows for the analysis of the interaction between the vehicle and the fuel tank.

▶ Benefits for Paricleworks of Co-Simulation with RecurDyn

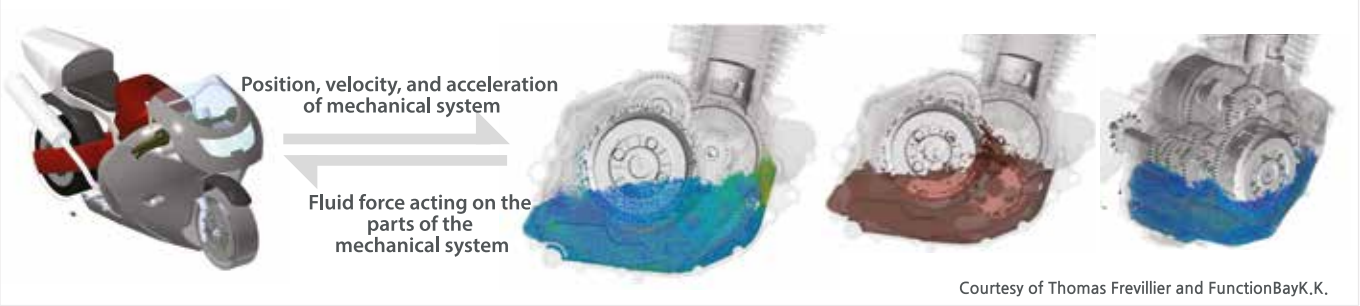
	Analysis using Particleworks alone	RecurDyn-Particleworks Co-Simulation
Buoyancy forces	Simplified body of floating object	Realistic mechanical system bodies
Fluid forces	Output is simple color-based, contour plot	Output is vector-based display of output, x-y plots Fluid load can dynamically affect the motion of the mechanical system
Moving boundaries	Scripted motion of boundaries only	Boundaries dynamically driven by fluids and the mechanical system The bodies of mechanical system can interact using joints and contact forces Can also be used to design controllers for the mechanical system
Flexible bodies	Not possible	Pseudo-flexible bodies approximated as collections of rigid bodies Flexible parts not in contact with fluids can be represented as flexible bodies

Co-Simulation Process

RecurDyn - Particleworks Interface

This software covers various industry problems such as analysis of oil churning inside powertrain, flow of chemical fluid and mixing mechanism, and cooling process between engine oil and related system components, and eventually it will be a strong and efficient assistant tool for product design.

With very intuitive graphic user interface and much faster pre-post processing even without meshing procedure, it can provide highly reliable and persuasive evidence for designers and CAE engineers to decide the most optimal parameters in design process.

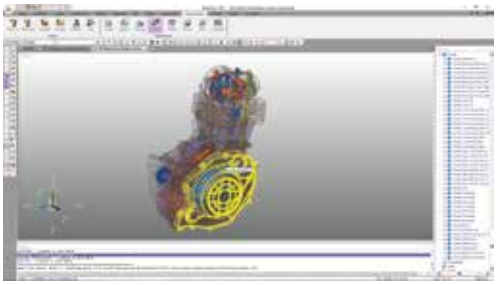


Courtesy of Thomas Frevillier and FunctionBayK.K.

RecurDyn - Particleworks Co-Simulation Process

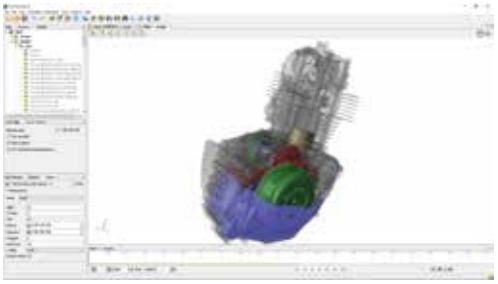
Step 1
RecurDyn Modeling

Export the geometry of a RecurDyn body that will act as a fluid 'vessel' in Particleworks during Co-Simulation.



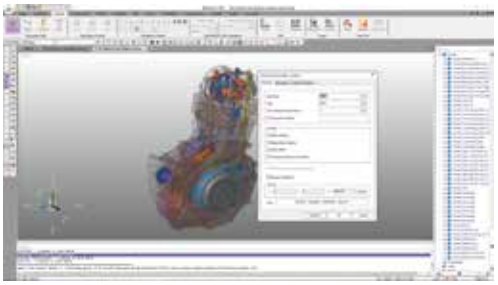
Step 2
Particleworks Modeling

Import the vessel body geometry into Particleworks, generate particles, and set the fluid parameters.



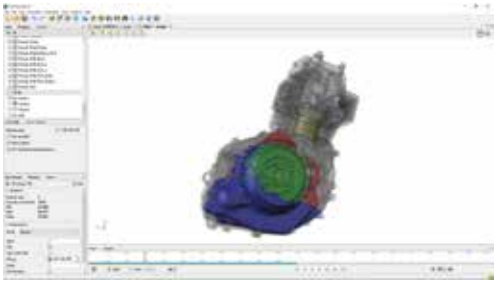
Step 3
Co-Simulation

Co-Simulation using RecurDyn to control the Co-Simulation.



Step 4
Result analysis

Examine the results in both RecurDyn and Particleworks.



Capabilities Chart

○Supported ×Not supported

				CPU		GPU
				3D	2D	3D
Solver	Features	Viscosity model	Newtonian fluid	○	○	○
			Non-Newtonian fluid (Bingham, power law, Cross-Arrhenius, data table input, user function)	○	○	○
		Pressure term solution	Implicit / explicit method Pressure oscillation suppression	○	○	○
			Negative pressure model	○	×	○
		Viscosity term solution	Implicit / explicit method	○	○	○
		Turbulence model	LES model + wall function model	○	×	○
		Airflow		○	×	○
		Surface tension model	Potential model	○	○	○
			CSF model	○	○	○
		Rigid body	Rigid-body motion Fluid-rigid body coupling simulation	○	○	○
		Thermal properties	Thermal conduction, thermal viscosity, shear heat, thermal heat coefficient output	○	○	○
		External force	Constant acceleration (gravity) Time-series data input	○	○	○
		Aeration	Generation, rupture, wall force, coalescence, and drag force of bubbles with size distribution	○	×	○
	Boundary conditions	Particle wall	Forced motion (sloshing and mixing) Adiabatic boundary, isothermal boundary, thermal calculation	○	○	○
		Polygon wall	Forced motion (sloshing and mixing) Force & torque output Adiabatic boundary, isothermal boundary	○	○	○
		Inflow boundary	Velocity input, flow rate input Time-series input	○	○	○
		Outflow boundary	Shape specified or region specified	○	○	○
		Simulation domain	Periodic and moving boundary in orthogonal coordinate system Deletion of outflow particles from simulation domain	○	○	○
		Pump	Region and velocity specified			
	Parallel processing		Inside-node parallel processing (OpenMP)	○	○	—
			Inter-node parallel processing (MPI)	○	○	—
			OpenMP and MPI hybrid parallel processing	○	○	—
			Inside-node parallel processing (multi-GPUs)	—	—	○
			Inter-node parallel processing (GPU cluster)	—	—	○
	Co-simulation		RecurDyn	○	—	○
Pre / Postprocessing	Preprocessing	Generator	Particle generation from geometry file (OBJ / STL)			
			Particle generation from defined liquid level			
			Boundary (distance function) generation from geometry file (OBJ / STL)			
		Geometry file format	STL (both ASCII and binary)			
			OBJ			
			Nastran file format			
		Other	Deletion of overlapping generation particles			
			Adjustment of the number of fluid particles to specified volume			
	Postprocessing, Visualization	Multiple scene views				
		Color map to particles (by group or physical quantities)				
		Image / video output				
		Arrow (vector) representation of physical quantities				
		Particle pathline				
		Examine physical quantities of an arbitrary particle				
		Extraction of particles in specified region (Box probe)				
		Transformation of coordinates to make results easily visible (Coordinate transformation)				
		Interpolation from particle data to geometry data (Mapping)				
		Estimation of physical quantities in an arbitrary coordinate (Point probe)				
		Interpolation from particle data to grid data (Grid)				
		Stream line				
		Isosurface / Isoline				
		Surface mesh generation from particle data				
		ASCII conversion of results				
		Flow rate measurement				
		EnSight support				

※GPU computing is optional. GPU license required. ※2D computing is optional. 2D license required. ※Aeration function requires DEM optional license and MPS-DEM interface optional license.

System Requirements	
OS	Windows 7, Windows 8, Windows 10, RedHat Enterprise Linux WS 6.x
OpenGL	4.0 or later
CPU	Intel, AMD, x86 compatible ≥ 2 GHz
GPU (for GPU computing)	NVIDIA Tesla C2050, C2070, C2075, M2090 / K20, K40, K80 / P100, GP100
Memory	≥ 4GB
HDD	≥ 5GB

※Installation of CUDA 8.0 is required to use GPU computing. ※Particleworks requires 64-bit operating system.

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5F, Pangyo Seven Venture Valley 1 danji 2 dong, 625, Sampyeong-dong, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13487, South Koreahttp://www.functionbay.co.kr
TEL. +82-31-622-3700 E-mail. inform@functionbay.co.kr

Developer
PROMETECH

Prometech Software, Inc.