Moving Particle Semi-implicit Method

MPS-RYUjIN

Features of MPS-RYUJIN

Pre and post functions

- **File read**
  - Particle file (.pcl)
    - … Particle coordinate, speed, pressure, and numerical density of molecules
  - Configuration file (.pos)
    - … Configuration information including viewpoints and color schemes
  - Profile file (.ply)
    - … Unique polygon file, triangular elements, and property ID Supports the import of both STL format (.stl) and Nastran format (.nas) files
  - Calculation conditions file (.slv)
    - … Calculation parameters, options, and physical properties
- **Drawing functions**
  - ◎ Particles
    - Name… Naming of each type of particle
    - Color… Fixed, mixed, or contour (flow rate and pressure)
    - Style… Point display, spherical display (specify particle diameter), and show / hide
    - Properties… Specify Apply / Do Not Apply for cut or slice display
  - ◎ Polygons
    - Name… Naming of each type of model
    - Style… Solid and wire frame,
    - Permeation display (specify permeability), and show / hide
    - Properties… Specify Apply / Do Not Apply for cut or slice display
  - ◎ Path line
    - Color… Fixed, mixed, or contour (flow rate)
    - Style… Specify line thickness and display area, and show / hide
  - ◎ Graph
    - Function that creates a graph based on chronological data (.csv)
  - ◎ Other
    - Contour bar and text (specify an arbitrary string and font style)
- **Viewing function**
  - Basic operation… Rotation, translation, and scaling
  - Cut display… Transfer cut surfaces by dragging them with the mouse (translation and rotation),Supports multiple (up to three) cut surfaces
  - Slice display… Transfer slices surfaces by dragging them with the mouse (translation),Specify slice thickness

Solver function

- **Analysis functions**
  - Incompressible viscous fluids analysis (3D unsteady)
  - Free surface: Supports the examination of surface tension, contact angle, and atmospheric pressure (New!)
  - Thermal analysis: Heat conduction of fluids and of structures (particle models only)
    - Heat transfer between solids and fluids, and buoyancy (caused by temperature changes in mass density)
    - Resulting viscosity from a temperature change
  - Fluid-rigid coupled analysis (polygonal models supported (New))
  - Inflow conditions (transfer and inflow conditions and shower condition (New!))
  - Internal pressure calculation that takes internal pressure into account (New!)
  - Calculation of surface flows and surface velocity (New!)
  - Calculation of stirring torque
- **Analysis conditions**
  - Fluid calculation parameters (e.g. influence radius, Courant condition, and calculation area)
  - Moving boundary conditions (rotation of particles and polygonal walls, vibrations, translation, and multi-axial rotation)
  - Constraint conditions for rigid bodies (axis / spring constraint, and rotary torque input)
  - Load conditions (given inertial force subject to gravitational and time changes)
  - Thermal boundary conditions (heat insulation, temperature fixing, heating, and heat transfer coefficient at the boundary)
  - Property conditions (density, kinematic viscosity, surface tension coefficient, heat capacity, and heat transfer coefficient)
  - Pressure oscillation reduction function (New!)
- **Parallel computing functions**
  - Thread parallel computing function using OpenMP
  - Process parallel computing function using MPI2
  - Hybrid parallel computing function (New!)
  - (Supports simultaneous execution of process parallel computing between nodes and thread parallel computing in a node)
- **Recommended hardware specifications, etc.**
  - Hardware
    - CPU: AMD Opteron or better
      Intel Core2 2GHz or better
    - RAM: 2GB or more (or 8GB or more if 64bit)
    - Disk drive: At least 10GB of free HDD space
  - Software
    - OS Windows XP SP3 (32bit / 64bit)
      Windows 7 / Vista (32bit / 64bit)
  - Red Hat Enterprise Linux Release 4 or later (32bit / 64bit)

* Other distributions also supported if the kernel version is 2.4 or later, although some operations may not be available

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MPS RYUjIN™

Fluid Analysis Software utilizing Particle Method

MPS-RYUjIN

www.ftr.co.jp

Larger, More Detailed Fluid Analysis

MPS-RYUJIN incorporates our unique proprietary method into the particle method wherein fluid flow is substituted with the motion of particles. The software suits the analysis of complicated flows with significantly changing fluid levels, such as stirring with gears, cleaning, and sloshing.

The particle method, unlike conventional software, has resulted in the modeling no longer requiring the preparation of solid meshes, which has achieved more efficient and easy-to-use software that enables very timely fluid analysis.

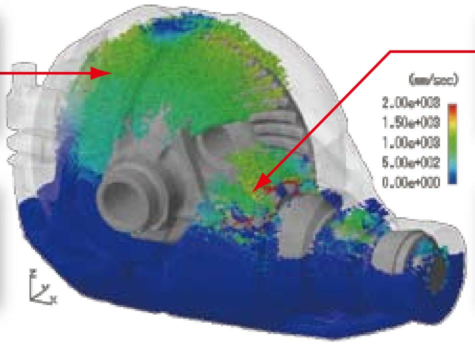
The later version utilizes our unique dynamic load distribution technology that enables faster and larger-scale calculations.

Features of MPS-RYUJIN

Does not require solid mesh models

⇩

Significantly reduces the man-hours needed for the modeling
A few weeks⇨within a few days



Represents large deformations, splashes, or broken waves at the liquid level

⇩

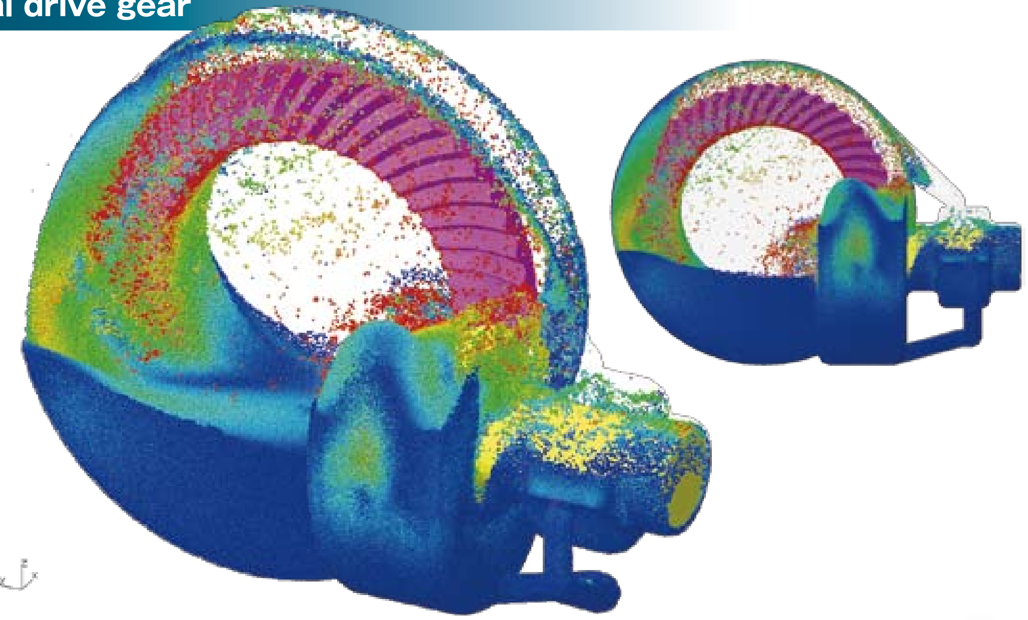
Suits the analysis of stirring, sloshing, or cleaning, which were difficult with the conventional method

Analysis of stirring with final drive gear

This is an analysis example of oil lubrication when a gear is represented using polygons and then rotated.

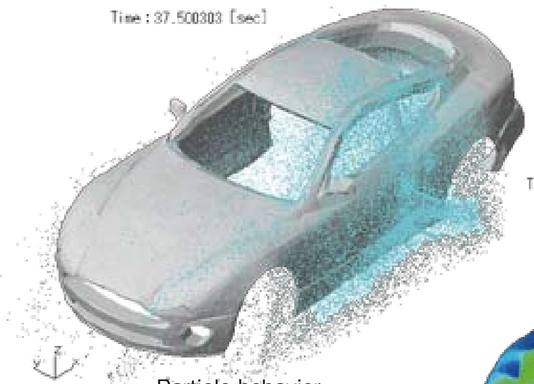
The MPS-RYUJIN best suits calculating swift flows where the liquid level is constantly and significantly changing, and which includes a large amount of droplets.

The latest version enables changes in the external pressure to be calculated.

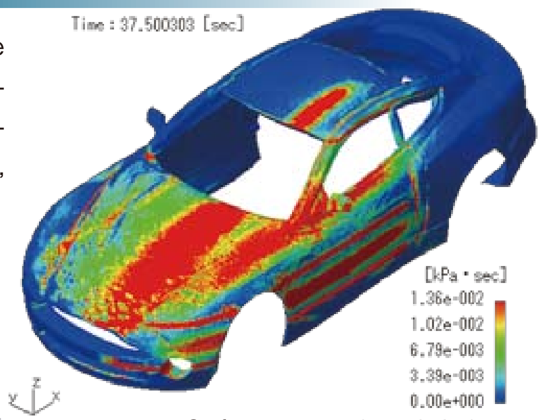


Analysis of shower cleaning

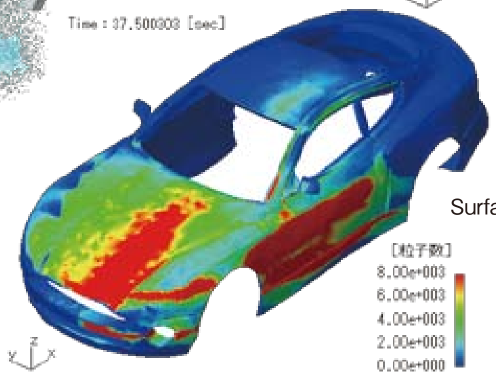
This is an example of the analysis of the cleaning of a full vehicle body using liquid blown out of a shower nozzle. The effect of the cleaning can be evaluated by calculating not only the product surface pressure but the flow rate and velocity of the liquid running over the surface, and then calculating the stress based on those calculations.



Particle behavior



Surface pressure (cumulative)

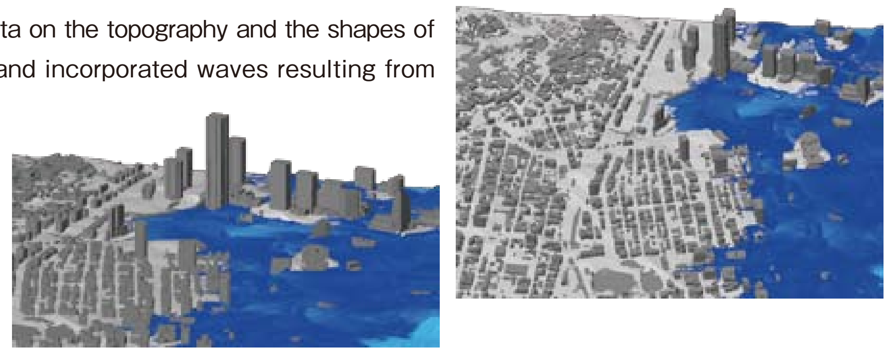


Surface flow (cumulative)

Tsunami analysis

This is an example of tsunami analysis using data on the topography and the shapes of buildings. The RYUJIN analysis allows broken and incorporated waves resulting from breaking waves, the speed and height of waves, or the pressure on structures to be calculated.

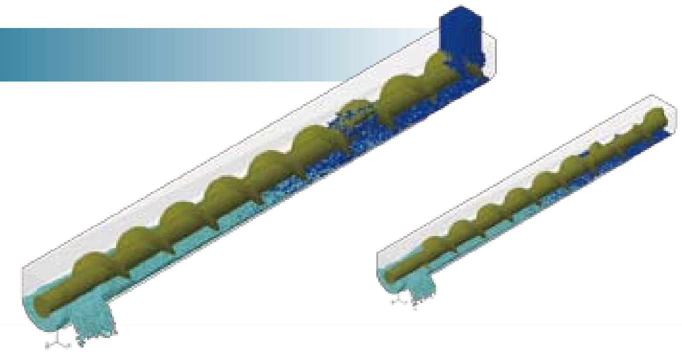
The analysis can be used to evaluate not only tsunamis, wave pressure, overtopping waves and the movement of structures but other types of impact on structures.



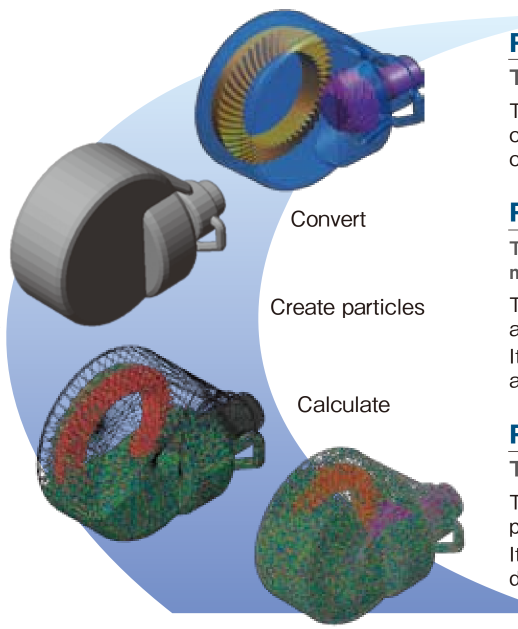
Transport analysis with screw conveyer

MPS-RYUJIN does not need to create a mesh model and therefore allows complicated movements to be set.

It also enables transport analysis of different materials as it can be used to configure several particle models and different property values.



Analysis procedure with MPS-RYUJIN



RYUJIN Pre: Prepares data

This reads the data file of a model to create the data for analysis using MPS-RYUJIN.

This software is used to import STL or NASTRAN data converted from CAD data and then to create analysis data for use with RYUJIN.This step only requires a particle model corresponding to liquid be created and the analysis conditions configured.

RYUJIN Solver: Performs analysis

This reads analysis data created via RYUJIN Pre before executing fluid analysis using the particle method.

This software is used to execute fluid analysis with the particle method, and is based on analysis data created using RYUJIN Pre.

It can calculate the position, speed, and pressure of a particle in time steps in thereby analyzing the flow according to the particle movement.

RYUJIN Post: Visualize results

This visualizes the analysis results calculated using RYUJIN Solver.

This software uses various visualization technologies to represent the correct flow of particles.

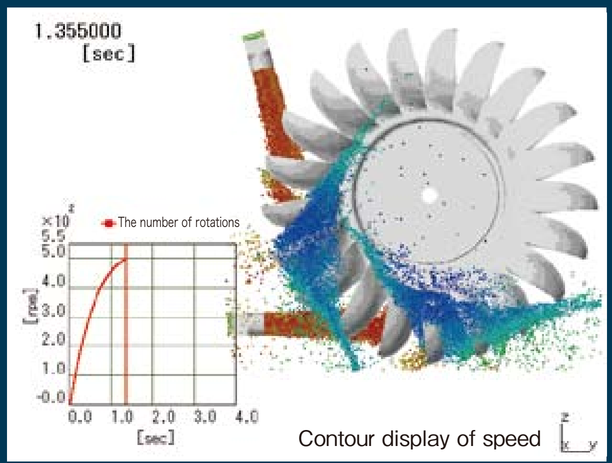
It creates video data on the flows using a cross-sectional view, contour display, path line display, and various other drawing functions.

Example Applications of RYUJIN's Features

Rigid-fluid coupled analysis function

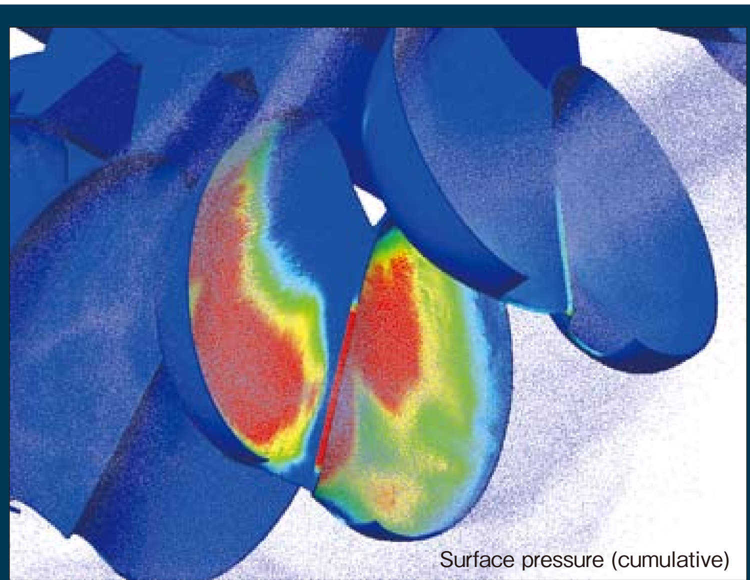
Analysis of the rotation behavior of Pelton wheel runners

This is an example of rigid-fluid coupled analysis with a rotating Pelton wheel via the modeling of the wheel using polygons and water injected from the nozzle. The RYUJIN analysis allows the pressure applied to the turbine surface, the number of rotations, torque, and other values to be calculated. It also enables analysis of how running water interferes through analysis of the rotation behavior using several nozzles, which was difficult with the conventional method.



Contour display of speed

Analysis of rotation behavior of Pelton wheels

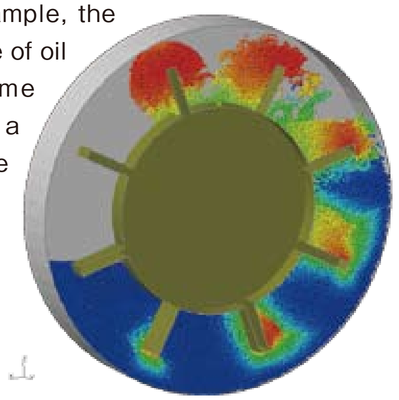

Surface pressure (cumulative)

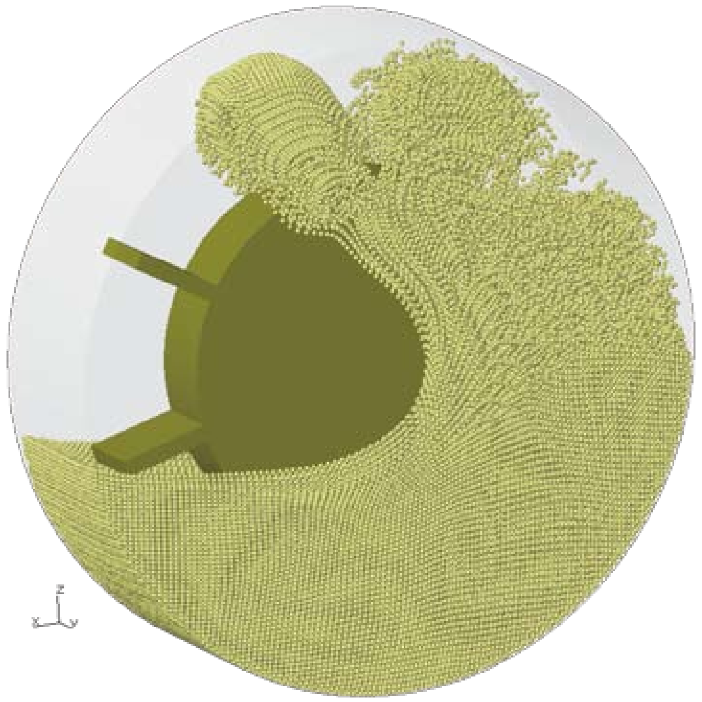
Highly viscous solver function

Analysis of gear stirring using highly viscous oil

With the conventional MPS method any increase in viscosity resulted in smaller hourly intervals, which then required a remarkably long time for the calculation.

MPS-RYUJIN has considerably reduced the time required for analyzing highly-viscous fluids by calculating the viscosity using the implicit method. This enables, for example, the stirring resistance of oil that has become more viscous in a cold area to be calculated.


Contour display of speed

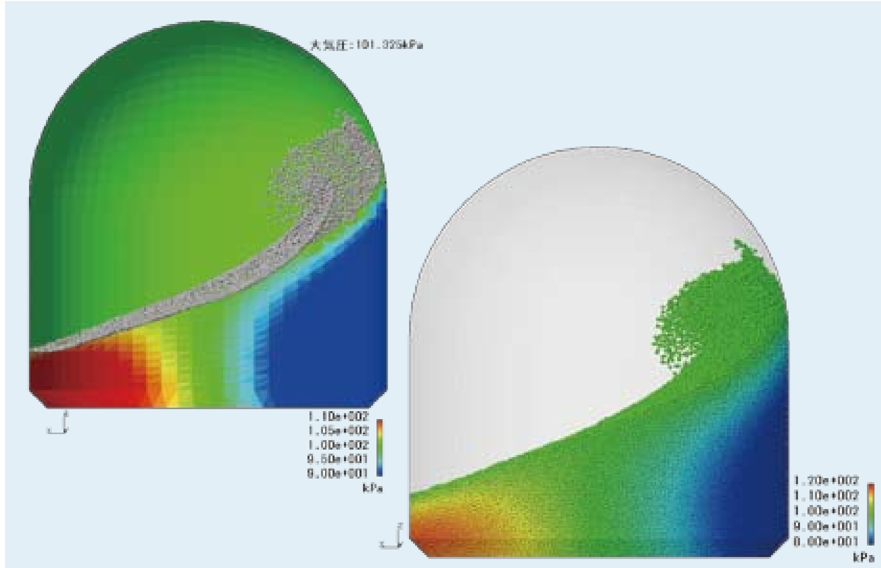

Particle display (monochromatic)

Function that examine atmospheric and negative pressures

Tank sloshing analysis through examining atmospheric and negative pressures

The conventional MPS method could not examine negative pressure as the calculations defined the pressure on the liquid level as 0. MPS-RYUJIN supports fluid analysis that examines both atmospheric and negative pressures through the development of a unique proprietary pressure calculation algorithm.

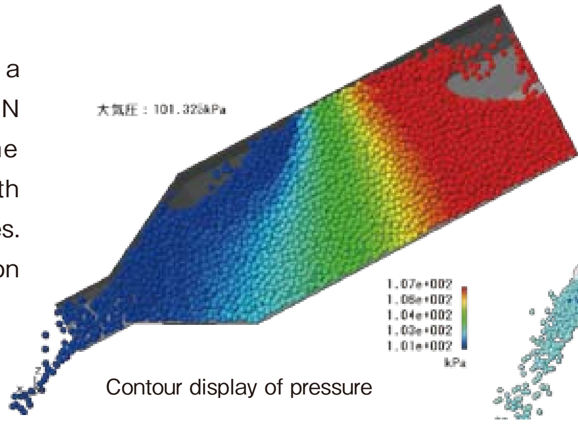
This has then enabled sloshing analysis that analyzes the structural loads caused by not only positive pressure but also negative pressure.

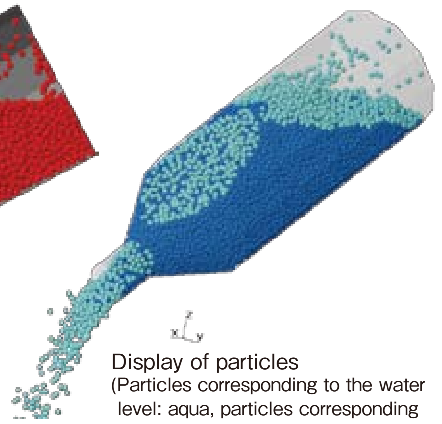


Pressure calculation function with volume changes taken into account

Runoff analysis from bottles

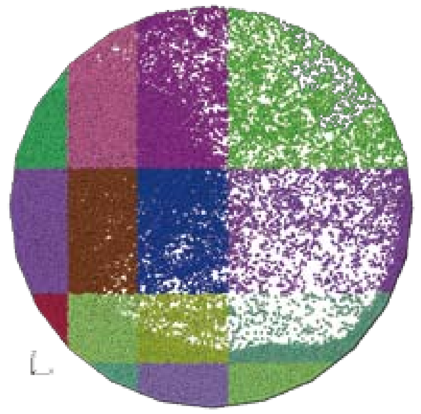
The conventional particle method defined a particle-free space as a vacuum. MPS-RYUJIN enables pressure changes due to volume changes to be taken into consideration with spaces enclosed by structural walls or particles. Applying the pressure of the closed space on the liquid level can represented bubbles.

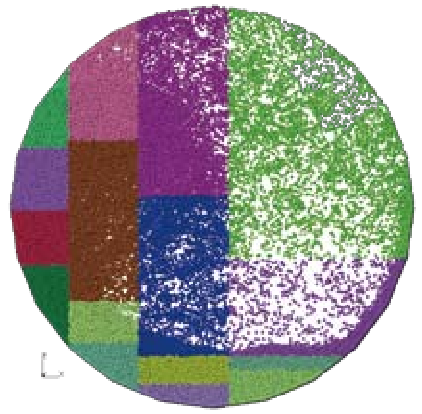

Contour display of pressure


Display of particles
(Particles corresponding to the water level: aqua, particles corresponding to underwater area: blue)

Dynamic load balancing function

Parallel computing with the conventional particle method did not support changes in the computational load with each area associated with changes in flow rate. The latest version utilizes more flexible region segmentation and dynamic load balancing that can handle changes in the computational load associated with swift flows, thus resulting in its parallel performance having been spectacularly improved.


Conventional region segmentation


New region segmentation

MPS (Moving Particle Simulation) method

■ Summary

MPS-RYUJIN Solver uses the particle method, which represents the continuum by means of a finite number of particles. The motion of fluid particles gets updated in accordance with a motion equation, while the discretization of the equation utilizes inter-particle interaction and the MPS method. This method is mainly intended for incompressible fluids, with the calculations using semi-explicit and semi-implicit algorithms.

■ Governing equation of incompressible flows

$$\frac{D\rho}{Dt} = 0$$ … Equation of continuity

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} + \vec{f}$$ … Navier-Stokes equation

Pressure gradient term, Viscosity term, External force term

■ Calculation procedure

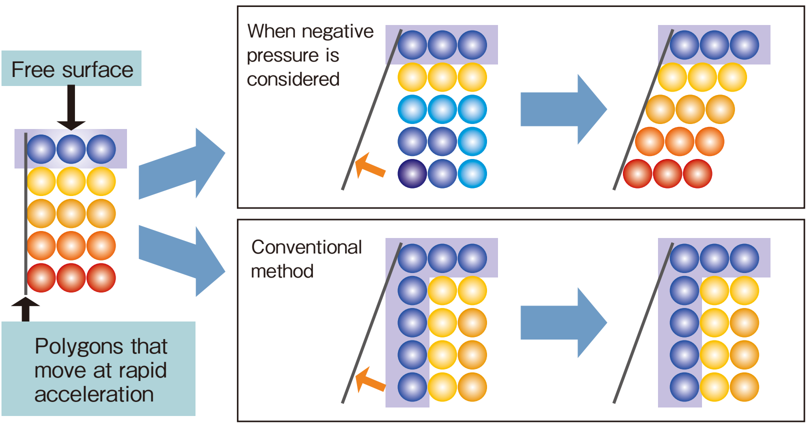
(1) Calculate the viscosity and external force terms utilizing previously acquired values, and obtain the tentative speed and position of particles (explicit calculation). A Laplacian model and the MPS method are used for calculating the viscosity term.

(2) Write a Poisson's equation based on the conditions of a consistent density, and then solve the equation to acquire the particle pressure (implicit calculation).

(3) Calculate the pressure gradient term using the pressure obtained in (2), and then modify the speed and position of the particles. Use a gradient model and the MPS method to calculate the gradient.

(4) Output the calculation result, and then return to (1) if it does not satisfy the termination condition.

Consideration of negative pressure in RYUJIN



Negative pressure denotes any pressure that is lower than standard, or in terms of MPS-RYUJIN, basically refers to any pressure that is lower than that on the free surface (atmospheric pressure).

Consider the case where polygons in liquid rapidly accelerate as an example. Negative pressure not being taken into consideration results in the space generated between the polygons and particles being determined to be a free surface, and hence the difference in pressure that fills that space does not get generated. In contrast to this if the negative pressure taken into consideration it then gets generated for the space, and subsequently the difference in pressure that fills the space between the polygons and particles is generated.

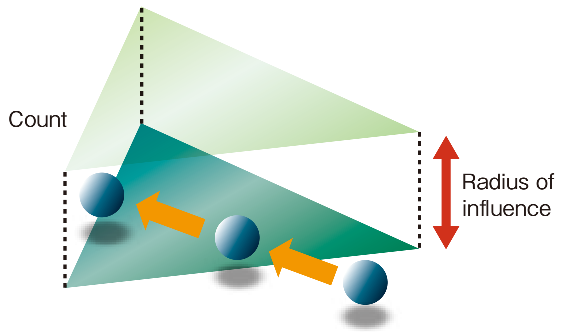
Calculation of surface flow and flow velocity

MPS-RYUJIN is equipped with a function that measures the number of particles flowing over the surface of polygons.

The measurement uses the method indicated in the figure on the right.

A virtual triangle (Default height = Particle diameter × Radius of influence) is set up in the normal direction of a polygon. Particles enter the space, and are then counted at the moment when they exit the space. They are not weighted according to distance or differentiated by the location of their entrance (upper or side).

With calculation of flow velocity the average velocity of the particles within the space shown in the figure is calculated.



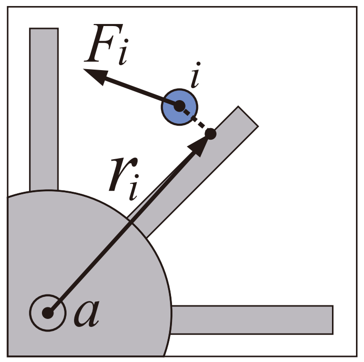
Calculation of torque values via the particle method

MPS-RYUJIN calculates torque values as the reaction to the force that gears exert on fluids:

$$\tau = \sum\{a\cdot(r_i \times F_i)\}$$

τ : Torque (rotational load)	a : Unit vector in the direction of the axis of rotation
$\sum i$: Total of all particles within a specific distance from the walls	r : Vector that connects a point on the axis of rotation with the active point
i : Index of fluid particles	F : Force exerted by a gear on particles

The value obtained after calculating the viscosity and pressure gradient terms with a Navier-Stokes equation is used for the force that a gear exerts on particles. In addition, the inertial force of the gear is taken into consideration and reflected in the flow when required.



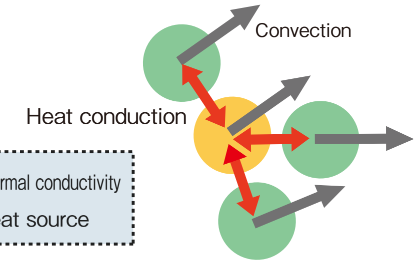
Heat calculation in particle method

Heat generally transfers through fluid migration and heat conduction in fluids. With the particle method, which utilizes the Lagrangian method, however, particles as used calculation points are considered to migrate, thus meaning that the heat conduction between particles should be the only factor to be taken into consideration. The calculations retain the temperature of each particle as a variable. The calculated heat conductions then takes into account the heat sources associated with the boundary conditions as well as any internal heat generated by the viscosity dissipating. The particle motion is then calculated for use in the analysis.

The influence of changes in volume associated with changes in temperature is then taken into approximate consideration by adding the buoyancy term to the right side of the Navier-Stokes equation (Boussinesq approximation). The buoyancy term is finally calculated using the temperature and thermal expansion coefficient.

$$C_v\frac{DT}{Dt} = \lambda\nabla^2 T + Q_s$$

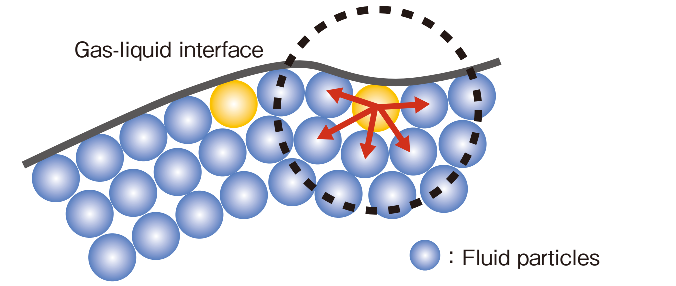
C_v : Thermal capacity λ : Thermal conductivity
T : Temperature Q_s : Heat source



$$\rho\frac{Du}{Dt} =$$ (Pressure gradient term) + (Viscosity term) + (Gravitional term) + (Buoyancy term)

Surface tension

Apply external force similar to the intermolecular force between the particles



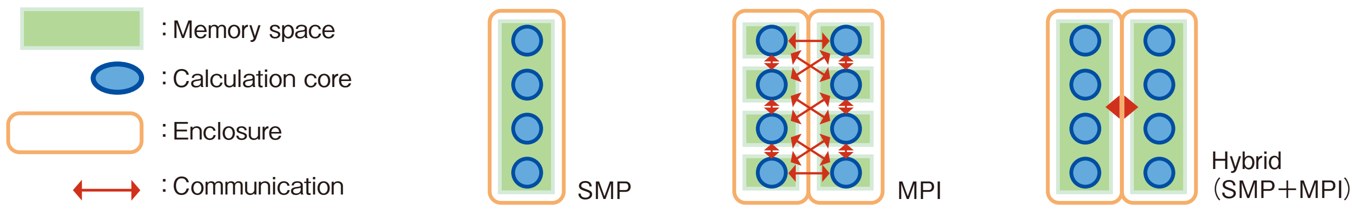
The MPS-RYUJIN utilizes a surface tension model generated using the inter-particle attraction to represent the wettability. The model utilizes an attraction that is similar to the intermolecular force between particles (fluid-fluid or fluid-wall) to consequently show the behavior to be like surface tension.

This also enables the integrated consideration of the wettability of walls, and which can be used to control the scale of the attraction between fluid particles and wall particles that are depend on the contact angle.

Parallel computing of MPS-RYUJIN Solver

MPS-RYUJIN executes parallel computing that combines SMP with MPI, thereby achieving more efficient and faster parallel computing, although depending on the user environment and the details of the analysis. The differences in the parallel methods are listed below:

Parallel method	SMP	MPI	Hybrid
Memory space	Shared in enclosure	Segmented for each calculation core	Shared in the same process
Communication	NA	Communication between all calculation cores	Communication between memory spaces



Moving Particle Semi-implicit Method

MPS-RYUJIN