FLOW-3D Developments

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FLOW-3D CAST

FLOW-3D®

FLOW-3D MP

FlowSight™

FLOW-3D Releases

FLOW-3D Cast v5.0

SMP workstation solver for metal casting applications

Hybrid SMP/MPI version for clusters

FLOW-3D v11.3

SMP workstation solver for general purpose CFD

Hybrid SMP/MPI version for clusters

FlowSight™

FlowSight™

FLOW-3D CLOUD

On-demand simulation service

Solver Developments

Temperature Units

What's New?

- **Use *absolute* temperature units in the solver**
- **Motivation**
  - when a model that requires absolute temperatures is activated, the user needs to change *all temperature inputs*, including temperature-dependent properties

Models that require absolute temperatures:

- radiation heat transfer
- phase change
- void and gas particles
- compressible fluids
- thermal bubbles
- air entrainment with pressure effects

Advantages of Using Absolute Temperatures

- **No need to convert input when activating a model that requires absolute temperatures**
- **Negative temperatures in degrees *C* or *F* can now be used as input**
- **Convergence of the implicit heat transfer solver is independent of the input temperature units**

How Does It Work?

- **User *must* choose temperature units: degrees *C*, *K*, *F* or *R***
  - ***'Unspecified'* is no longer allowed**
  - **required regardless of whether heat transfer is on or off**
- **Input values are automatically converted to *absolute* units by the preprocessor**
- **Graphical output to *flsgrf* is written in the *original* units**
- **The transformations are invisible to the user**

Note of Caution to Developers

When customizing or debugging the solver, the user must be aware of the difference between the *input* temperature units and temperature units *actually* used in the code.

Pressure Units

- **A similar approach for pressure in *FLOW-3D* v11.3**
  - **pressure units:** **'absolute' or 'gauge'**
  - **reference pressure:** **for conversion between absolute and gauge pressures (defaults to 1 atm.)**
  - **input values are converted to absolute pressure**
  - **output in original units**

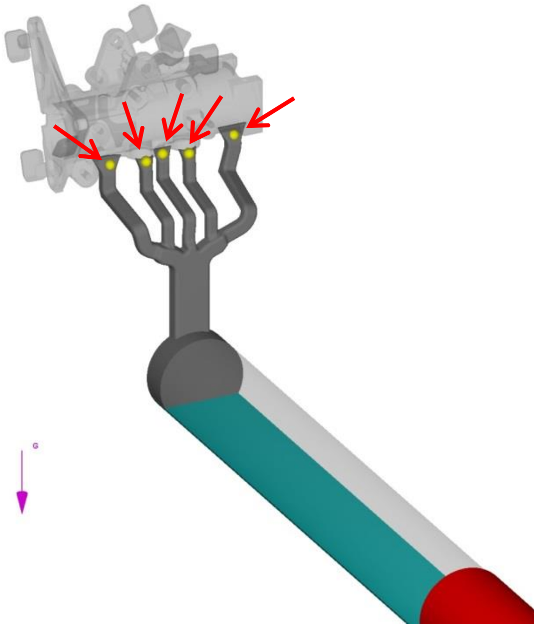
Global Conditions for Active Simulation Control (ASC)

Background

- **ASC allows users to define an object's behavior as a function of the solution**
- **Based on the concept of *conditions, events* and *actions***
  - **history probes capture flow conditions**
  - **events are linked to conditions**
  - **events are associated with actions for time-dependent objects, *e.g.*, GMO, boundary conditions, mass sources, data output frequency**
  - **when conditions are met, then an event is triggered and an action is activated for the object**
- **Limitations:**
  - **when a group of conditions controls multiple objects, modifying those conditions needs to be done for each object**

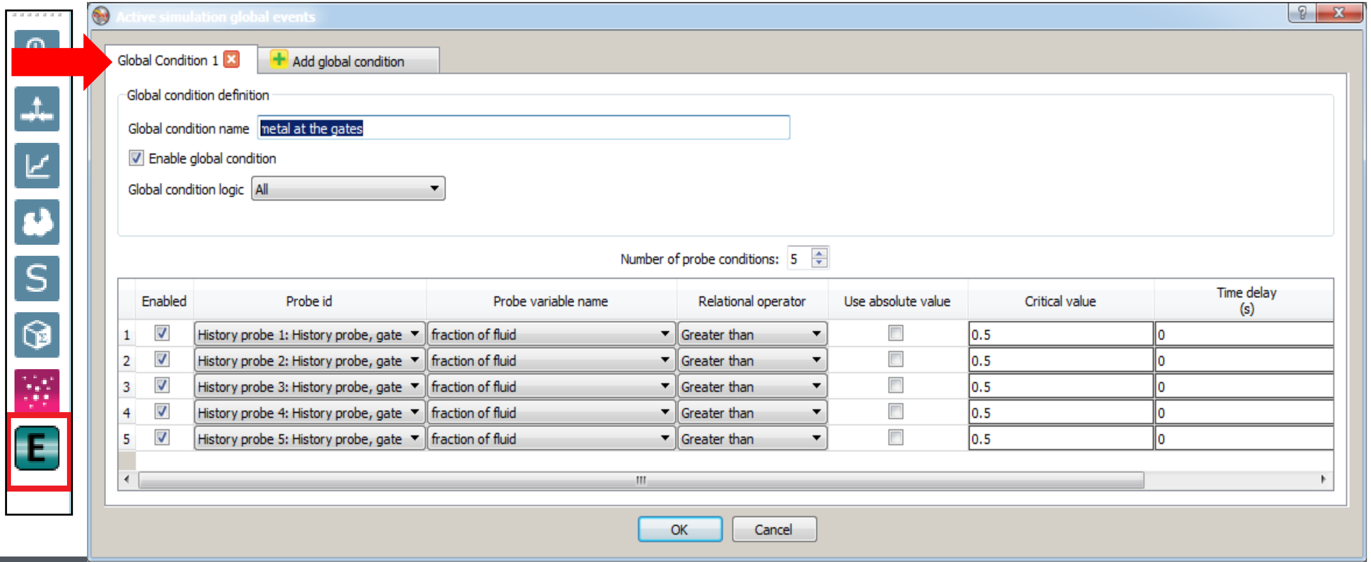
Limitations

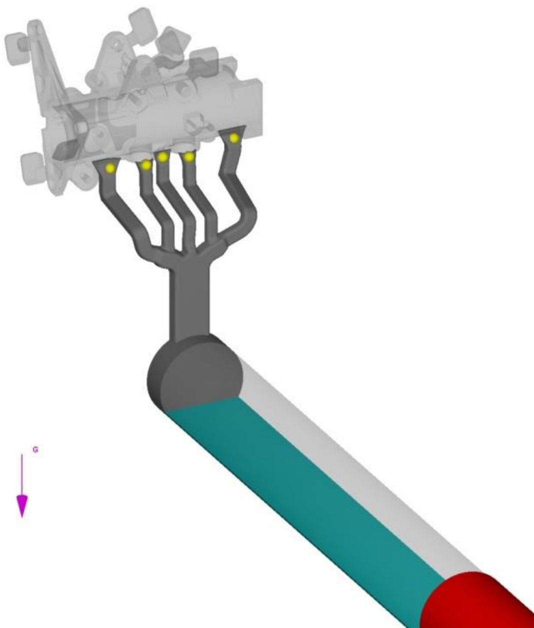
- **Actions when metal reaches *all* gates during HPDC filling:**
  - switch from slow shot to fast shot
  - increase restart data output frequency
  - increase selected data output frequency
- **Define five probes at the gates**
  - five conditions: $F > 0.5$
- **Three objects ➔ three events**
  - *each* event needs the same five conditions defined
    - 3 x 5 = 15 conditions
- **Time consuming, error prone, hard to maintain**



Global Conditions

- **A global condition is defined once**
- **Accessible by all objects**





Geometry Component Transformations

Background

- **Geometry components are made of subcomponents**
- **Transformations apply only to subcomponents**
  - **magnifications, rotations, translations**
- **To translate a component, *all* its subcomponents need to be moved in the *same* way**

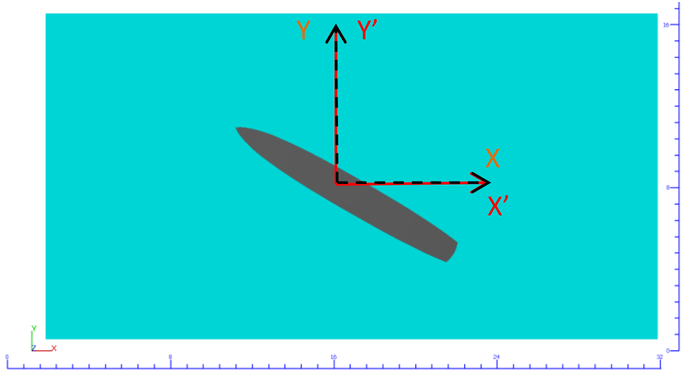
What's New?

- **Transformations that apply to *components***
  - magnifications, rotations, translations
  - apply to all subcomponents at once
- **Applied *after* subcomponent transformations**

GMO Component Transformations

Options for GMO's body-fixed coordinate system during transformation:

- **stays with the space system**
  - current behavior
- **moves with the *component* transformation**
  - simplifies the definition of the inertia tensor
  - more intuitive output for the movement in the body-fixed system

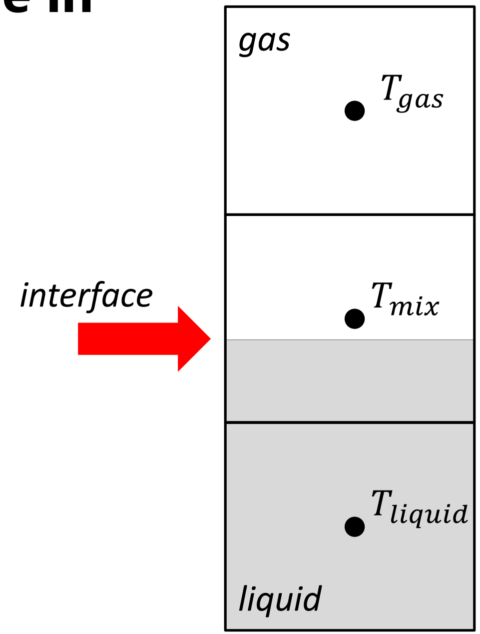


Two-temperature Two-fluid Model

Background

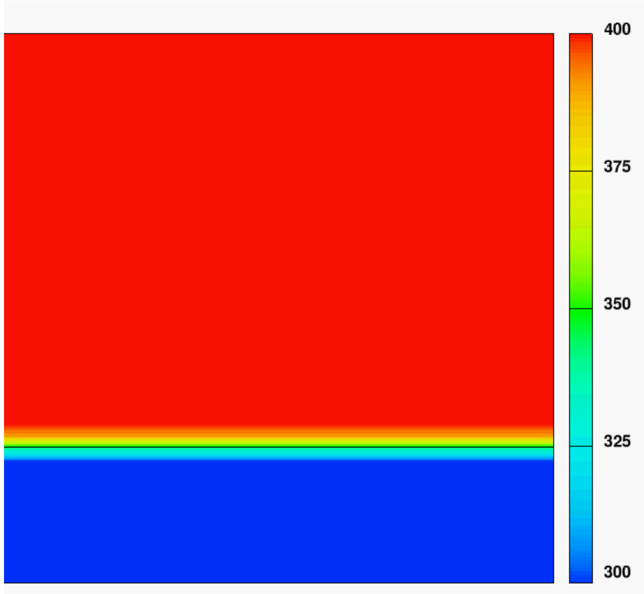
Current two-fluid model uses *average* temperature in the gas-liquid mixture

- **equivalent to *infinite* heat transfer rate between fluids**
- ***no control* on heat transfer between fluids**
- **limited control on mass transfer due to phase change (evaporation/condensation)**

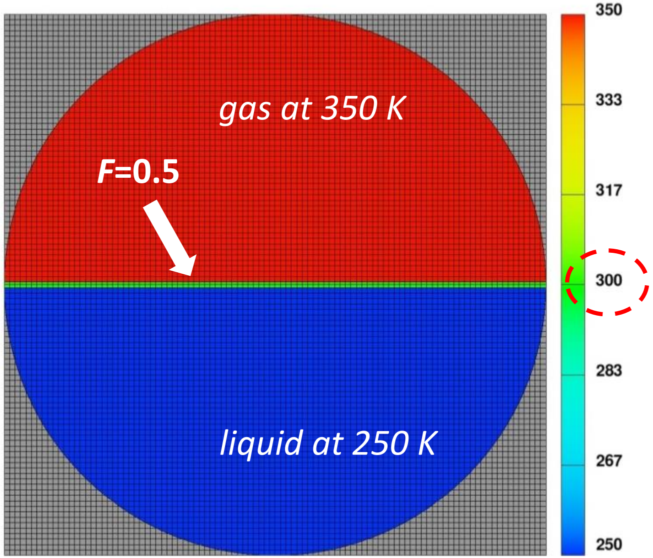


Issues with One-temperature Approach

Heat diffusion during sloshing



Temperature initialization at the interface



What's New?

- **Separate energy transport equation for each fluid**
- **Separate temperatures**
- **Interface boundary condition based on heat transfer coefficient**

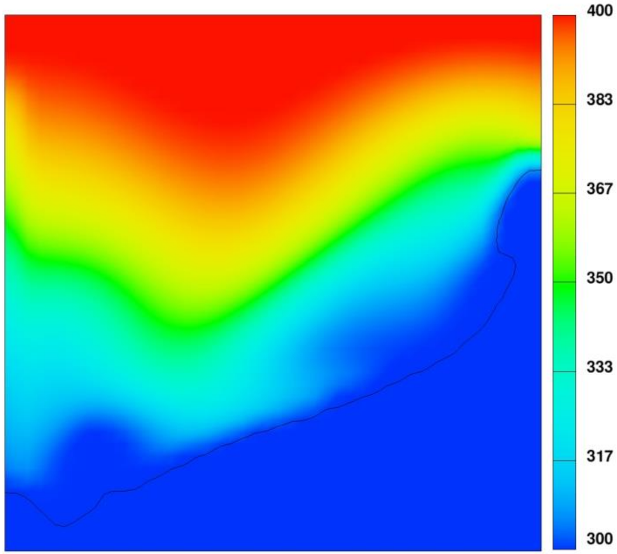
$$\frac{\partial(\rho_1 I_1)}{\partial t} + \nabla(\boldsymbol{u}\rho_1 I_1) = \nabla \cdot (k_1 \nabla T_1) + q + q_{12}$$

$$\frac{\partial(\rho_2 I_2)}{\partial t} + \nabla(\boldsymbol{u}\rho_2 I_2) = \nabla \cdot (k_2 \nabla T_2) + q - q_{12}$$

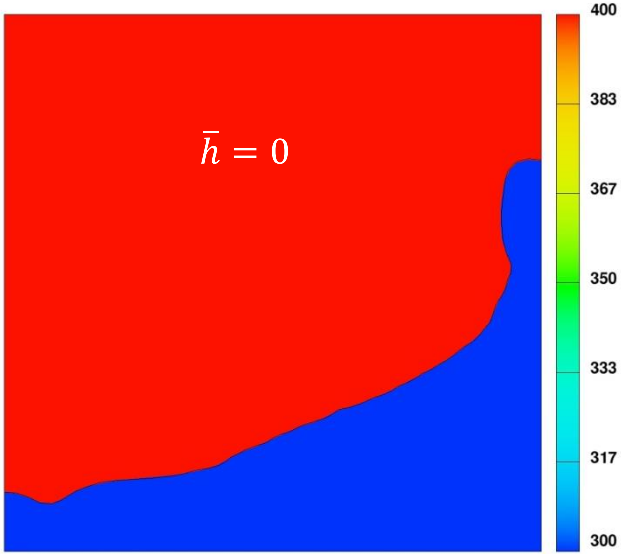
$$q_{12} = \bar{h}(T_1 - T_2)$$

Liquid/Gas Sloshing

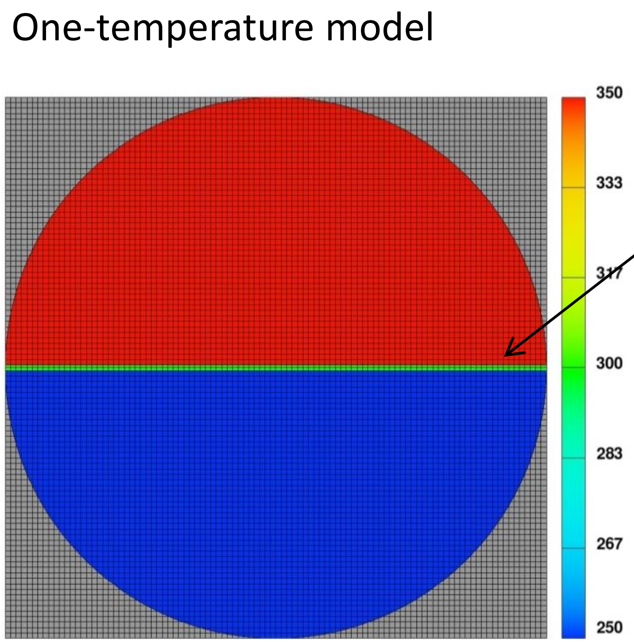
One-temperature model

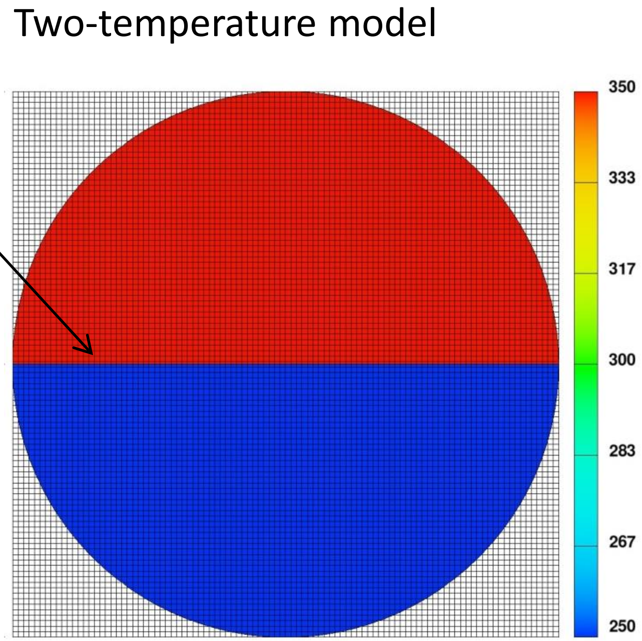


Two-temperature model



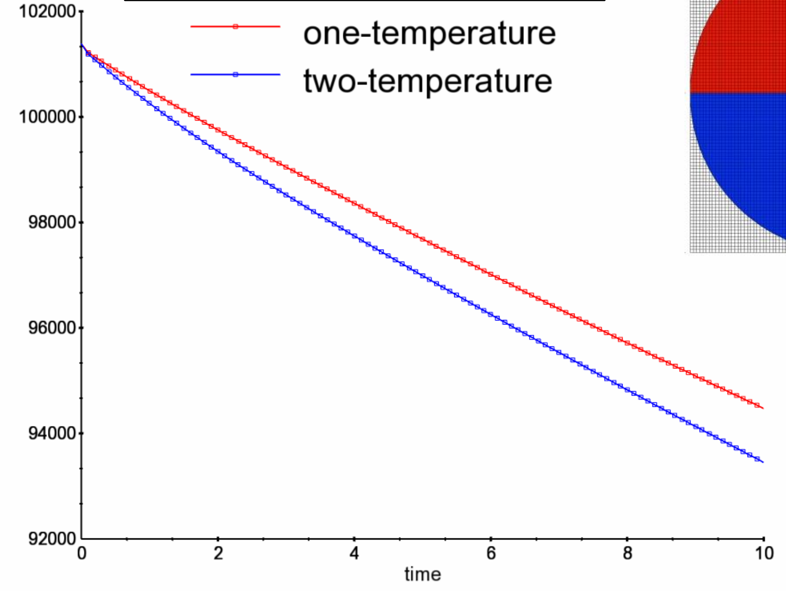
Liquid/Gas Tank: Initial Temperature

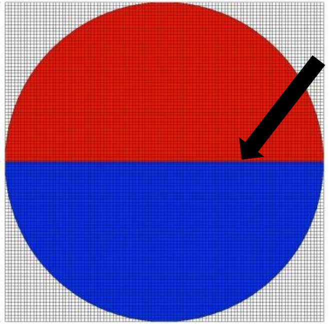




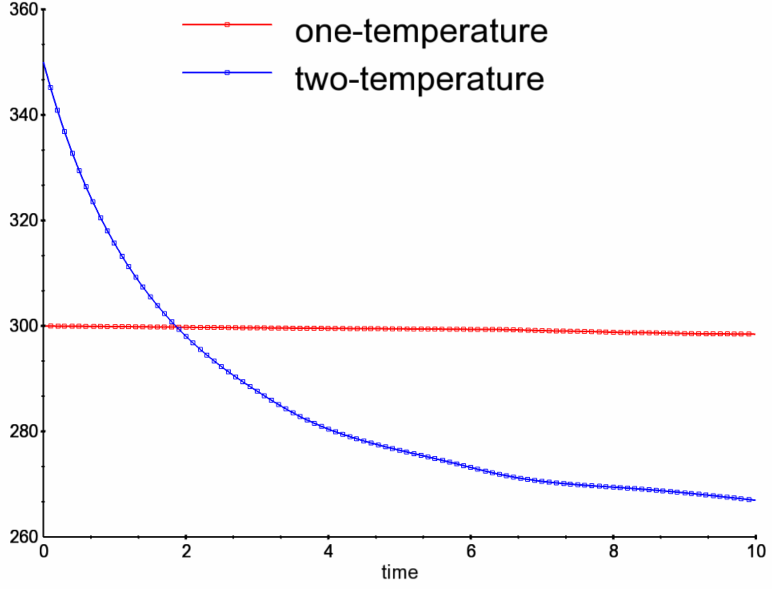
Liquid/Gas Tank

Gas pressure in the tank





Gas temperature at the interface



FLOW-3D

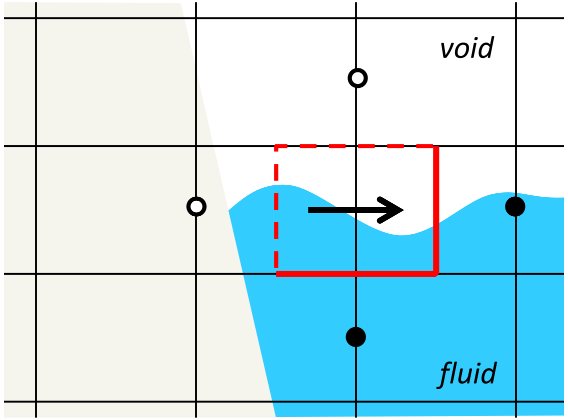
Two-temperature Model Summary

- **Modeling control of the heat and mass transfer at the interface**
- **Precise initialization of temperature**
- **More accurate two-fluid solution**

Back to Basics

Background

TruVOF® and FAVOR™ approximate interfaces in terms of *volume fractions* of fluid and solid: *F* and *VF*.



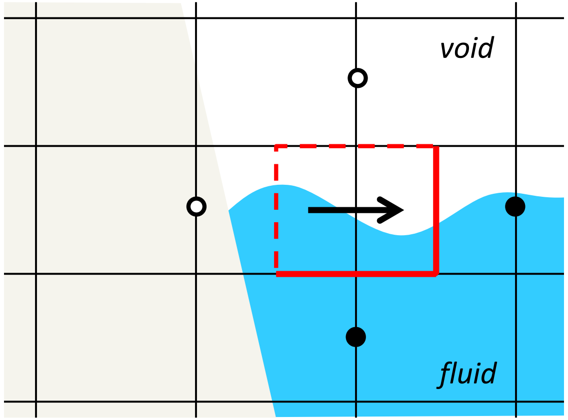
- ● - values available
- ○ - no legitimate values

Fluxes are set to <u>zero</u> at blocked and empty nodes.

Incomplete flux approximations may result in low-level (secular) numerical instabilities.

Background

TruVOF® and FAVOR™ approximate interfaces in terms of *volume fractions* of fluid and solid: *F* and *VF*.



- ● - values available
- ○ - no legitimate values

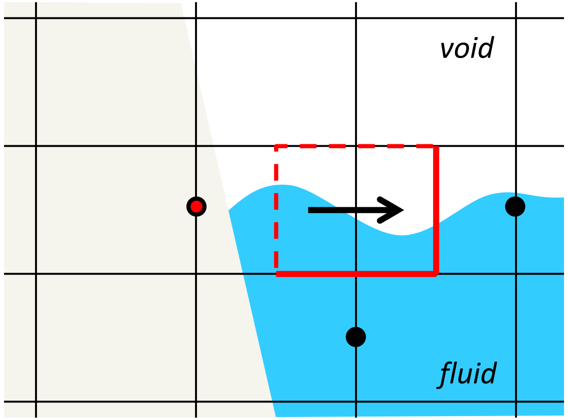
Currently, *a preventive* approach to instabilities:

1. identify truncated control volumes
2. reset velocities using neighbors

Problem: <u>may be too intrusive</u>, potentially resulting in inaccuracies and pressure oscillations

What's New?

Immersed boundary method (IBM)



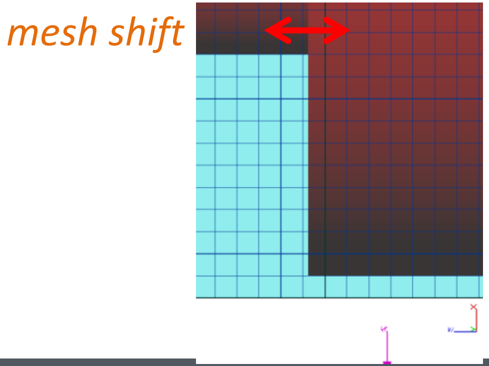
- Calculate velocity values and fluxes at blocked (ghost) nodes using:
  - wall boundary condition: $\boldsymbol{n} \cdot \boldsymbol{u} = 0$
  - solution at valid nodes

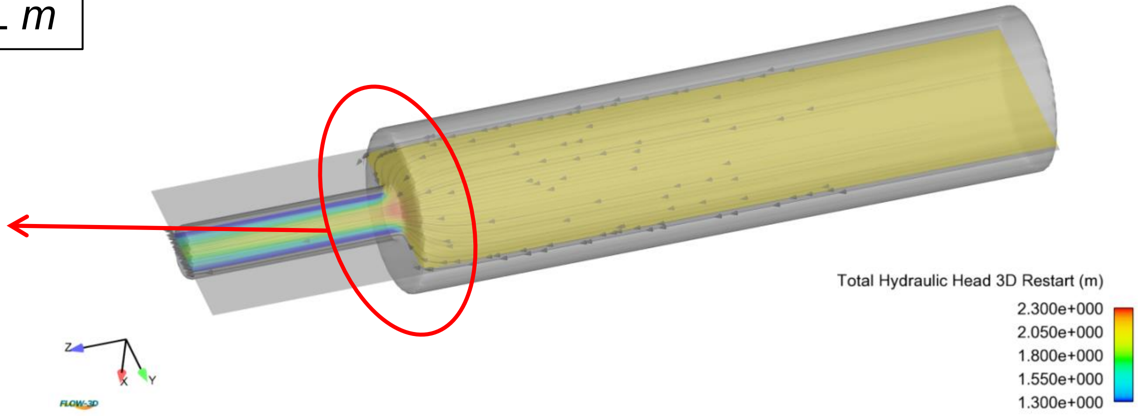
Works with stationary and moving components

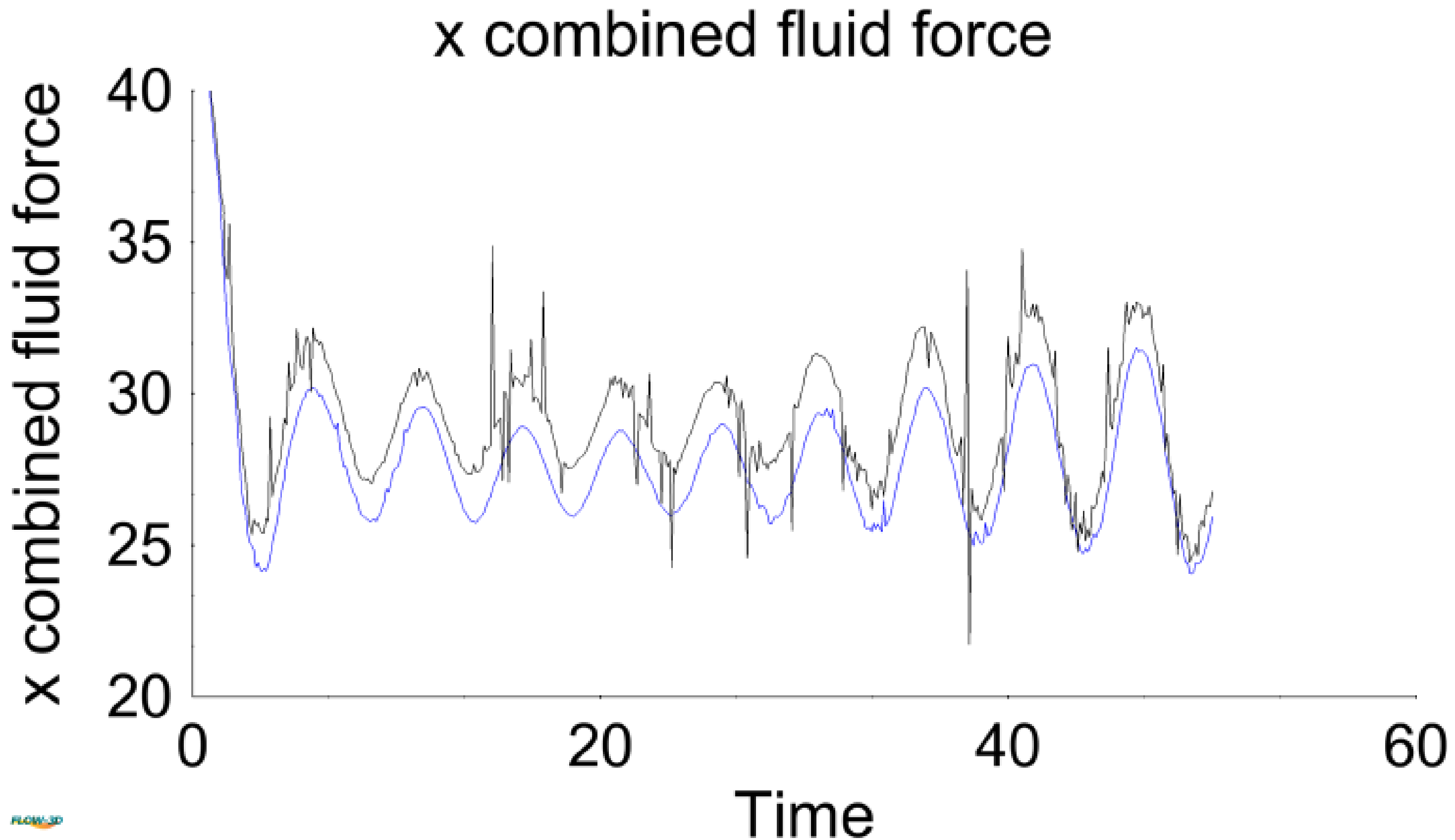
Flow Losses in a Contracted Pipe

	Aligned		Shifted-25%		Shifted-50%		Shifted-75%	
	Standard	IBM=1	Standard	IBM=1	Standard	IBM=1	Standard	IBM=1
Head loss	0.246	0.648	0.335	0.664	0.442	0.648	0.583	0.662

Analytical range: 0.494 - 0.711 *m*



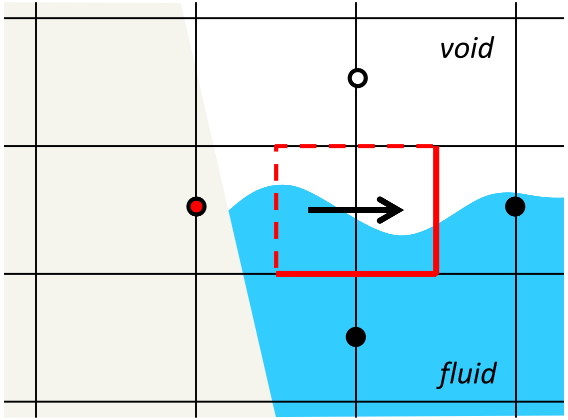



x combined fluid force
x combined fluid force
40
35
30
25
20
0
20
40
60
Time

IBM and IFLOSS

Immersed boundary **method is an *option* in v11.3:**

- **IBM=0, - off, default**
- **IBM=1, - on**



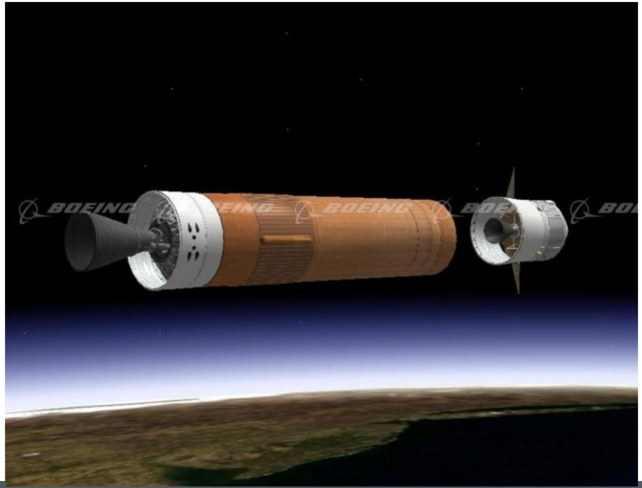
Reactive approach to secular instabilities:

- *detect* an onset of secular instability
- *apply* corrective action as a *flow loss* term
- works on a need-to-do basis: less intrusive

- *option* in **v11.3**:
  - IFLOSS=0, - off
  - IFLOSS=1, - on, default

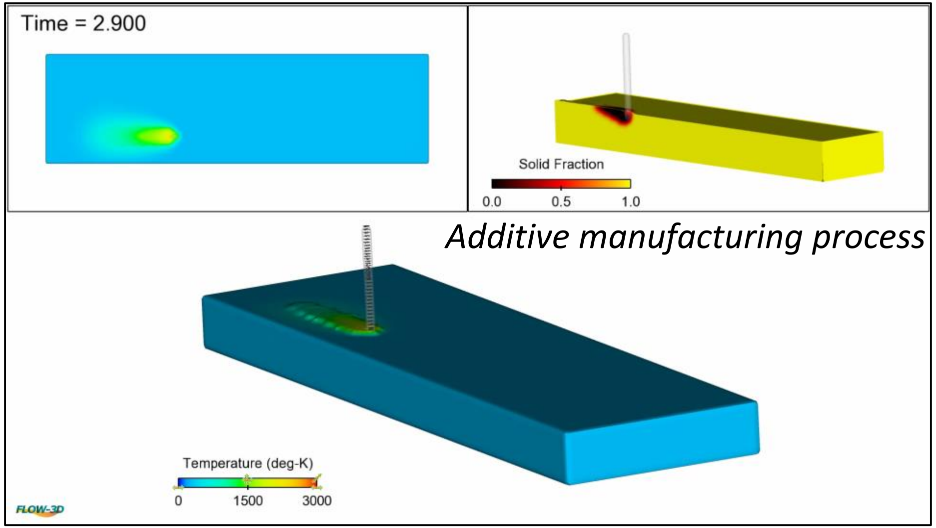
Varying Center of Gravity for NIRF Motion

- **Fuel expenditure**
- **Stage separation**
- **Center of Gravity defined as a tabular function of time**



Moving Particle Sources

- **Time-dependent translational and rotational movement**
- **Mass, gas, fluid, marker particles**



Additive manufacturing process

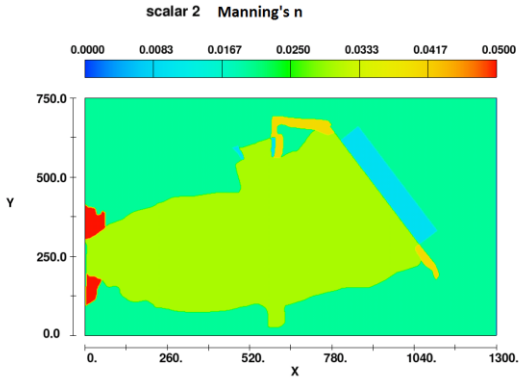
Shallow Water Model Extensions

1. Gauckler-Manning roughness coefficient n:

$$V = \frac{\alpha\, R^{2/3}\, S^{1/2}}{n}$$

V – flow velocity
R – hydraulic radius
S – slope
α – conversion coefficient

– input through raster data interface
– legend file defines the conversion of raster data to roughness
– can be combined with standard roughness



Raster file example

```
ncols         12
nrows          8
xllcorner   -100
yllcorner   -100
cellsize     200
nodata_value  -9999
1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 2 2 2 2 2 2 2 2 2
1 1 2 3 3 3 3 3 3 4 4 4
1 1 2 2 3 3 4 4 5 5 6 6
1 1 2 2 3 3 4 4 5 5 6 6
1 1 2 2 3 3 4 4 5 5 6 6
1 1 1 2 3 3 4 4 5 5 6 6
1 1 4 4 4 3 4 4 5 5 6 6
```

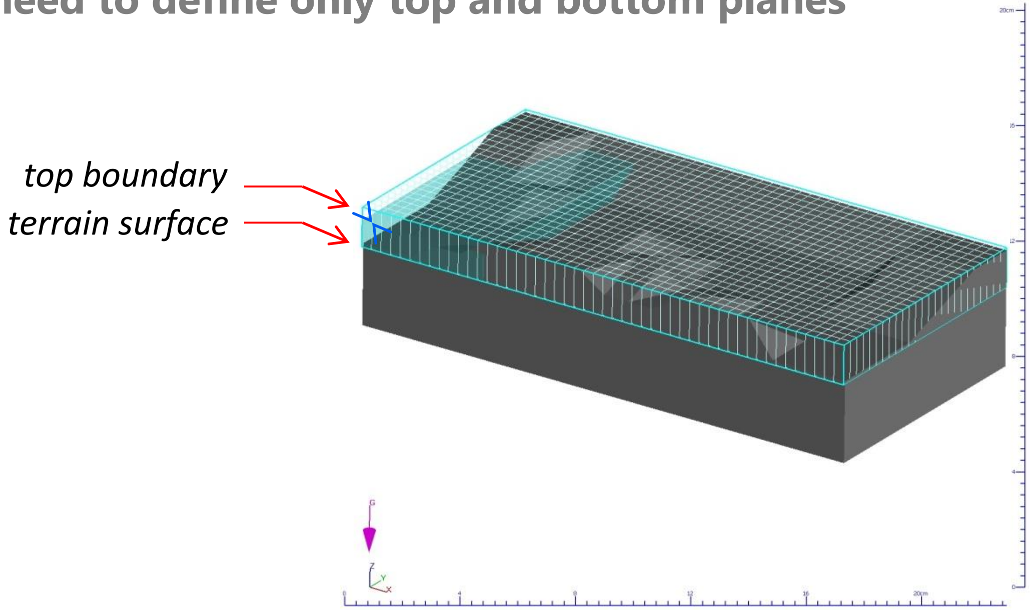
Legend file example

```
Code,    Manning's n value
1,       0.01
2,       0.012
3,       0.014
4,       0.016
5,       0.018
6,       0.02
```

Shallow Water Model Extensions

2. Simplified *z*-direction mesh generation

– **need to define only top and bottom planes**



Sludge Settlement Model

Simulate sludge transport and settlement in septic tanks and clarifiers

Sludge Settlement Model

- **Sludge transport equation**

$$\frac{\partial C}{\partial t} + \nabla \cdot (C\boldsymbol{u}_s) = \nabla(D\nabla C)$$

- ***C*: sludge mass concentration**
- ***D*: diffusion coefficient**
- u_s: **sludge net velocity**

$$\boldsymbol{u}_s = \overline{\boldsymbol{u}} + \boldsymbol{u}_{settle}$$

- $\overline{u}$: **fluid-sludge mixture velocity**
- u_{settle}: **sludge settling velocity**

Sludge Settling Velocity

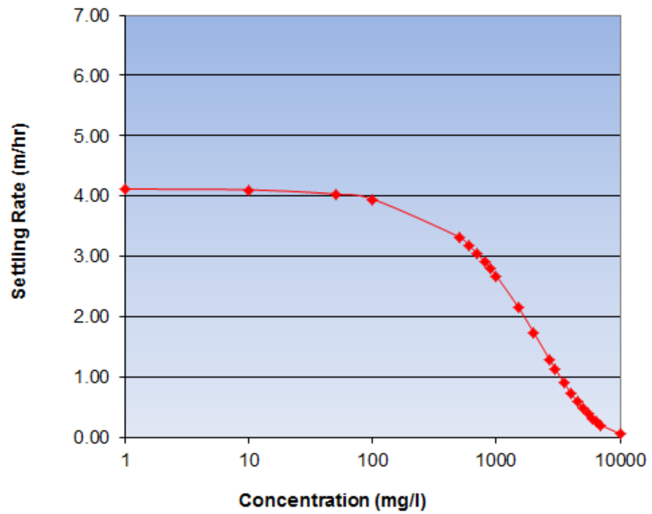
- **Function of sludge mass concentration C**
- ***Vesilind* equation (1968)**

$$u_{settle} = U_0 \, e^{-nC}$$

U_0 **: Vesilind maximum sludge velocity**

n**: Vesilind parameter**

- **Alternatively, u_{settle} can be defined as a table**



- **Main input parameters**
  - U_0 and n for Vesilind equation
    or, u_{settle} v.s. C tabulated in GUI or an external file
  - Maximum settled concentration C_{Max}
    - **Sludge settles until $C=C_{Max}$**
  - Net density of sludge solids ρ_s
  - Initial sludge concentration
  - Sludge concentration at mesh block boundaries

- **Output data**
  - Restart and selected data
    - **Sludge concentration**
    - **Mixture (macroscopic) density**
    - **Sludge velocity**
    - **Sludge mass flux**
  - History data
    - **Sludge mass**

Septic Tank

- Vesilind settling velocity equation

  $V_0=1.144\times10^{-3}$ *m/s*

  $n=0.4317$ *m*^{3}*/kg*
- Net density of sludge solid

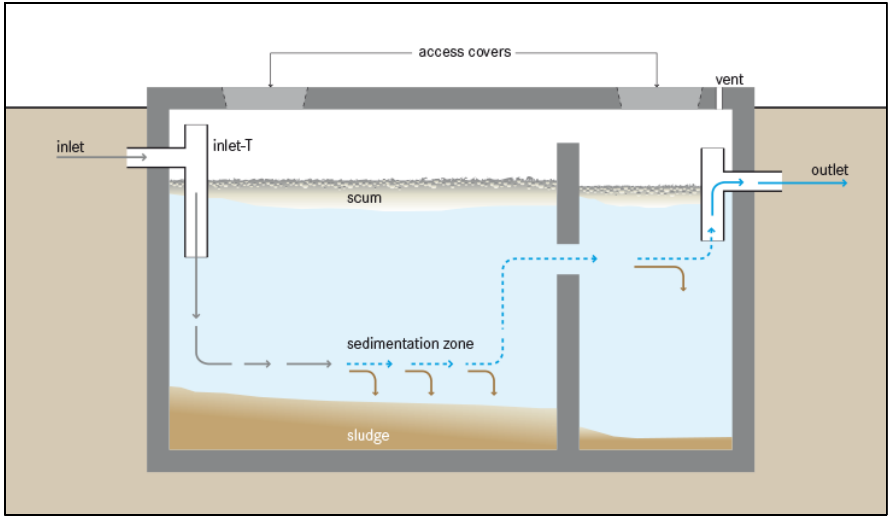
  $\rho_s=1400$ *kg/m*^{3}
- Tank size

  length=3 m

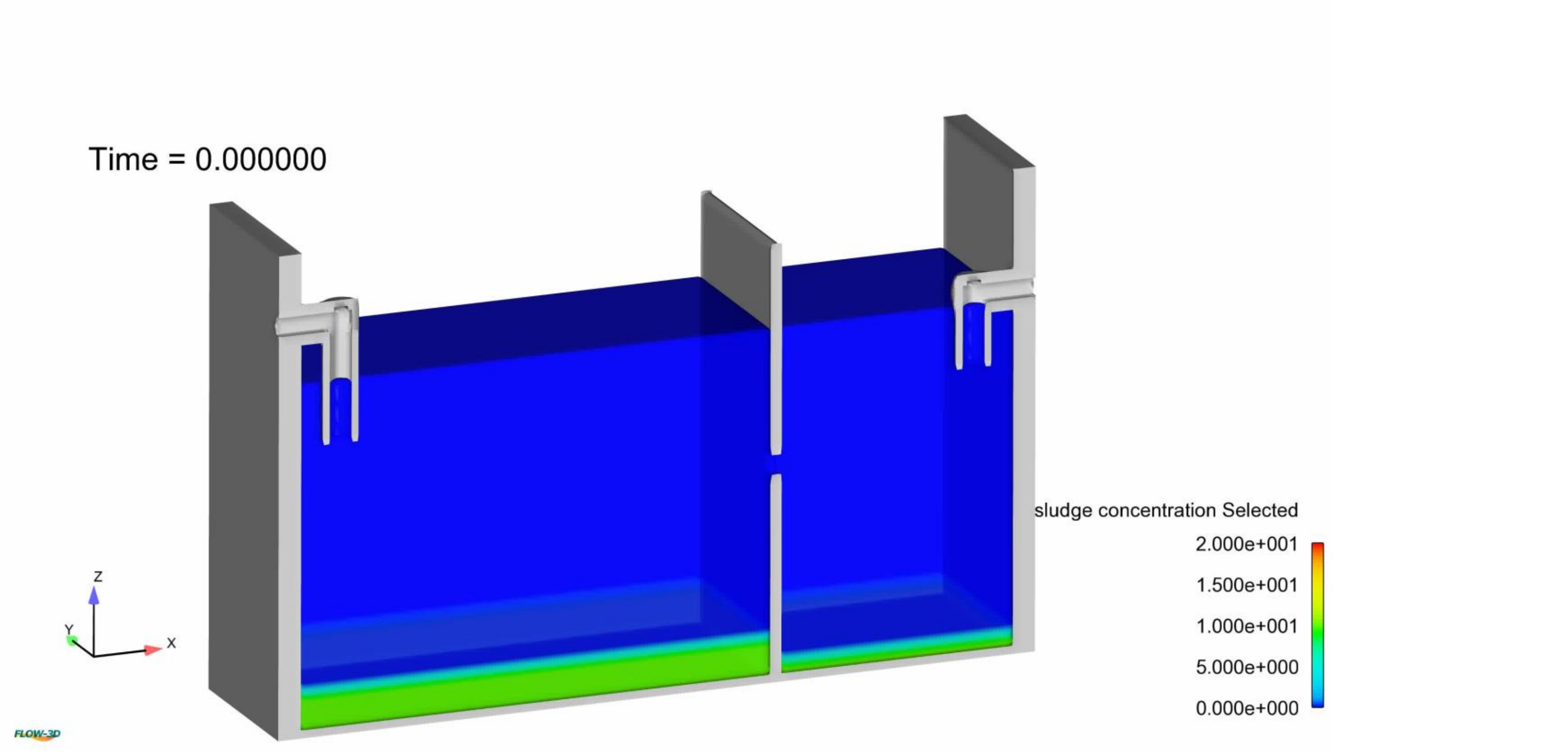
  depth=1.5 m

  height=2 m
- Inlet: 8 sec pulse flow rate

  $C_{inlet}=20$ *kg/m*^{3}



Sep



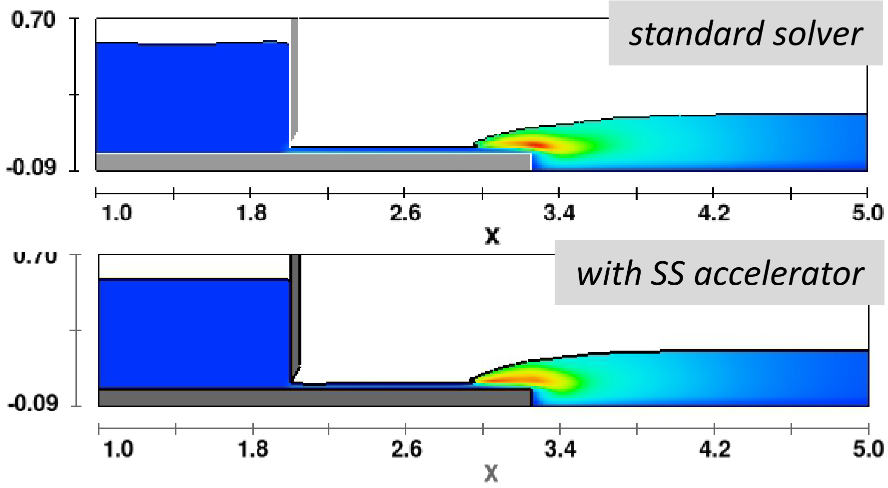
Time = 0.000000
sludge concentration Selected
2.000e+001
1.500e+001
1.000e+001
5.000e+000
0.000e+000
Z
Y
X
FLOW-3D

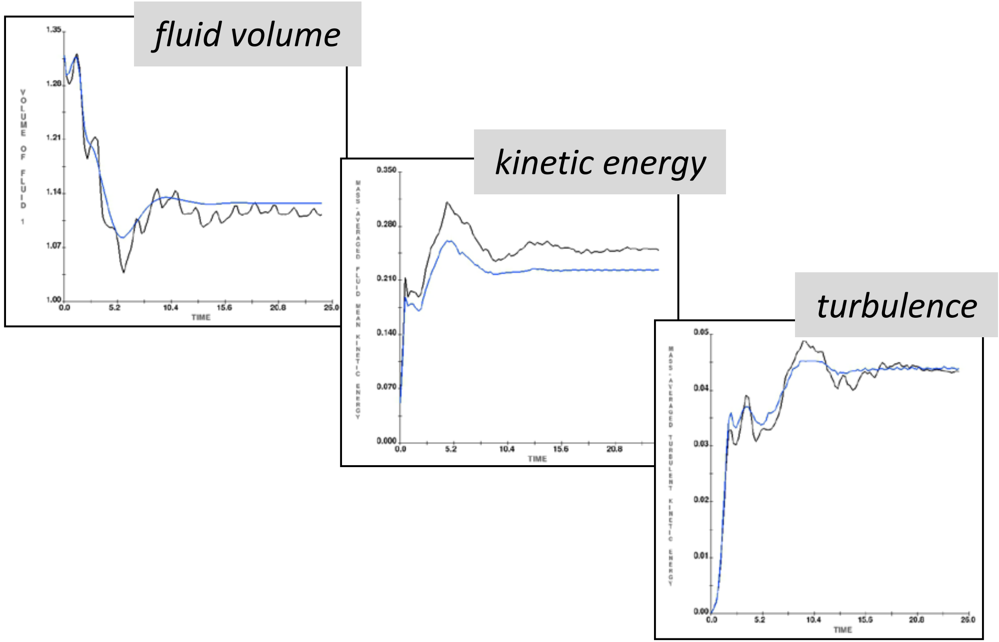
Final Remarks on ***FLOW-3D*** *v*11.3

- **Implicit viscous solver**
  - **more robust solver for highly viscous flows**
- **Revised surface tension stability algorithm**
- **Steady-state accelerator for free surface flows**
  - **faster approach to steady state for flows with free surface**
  - **capture general motion**
  - **dampen out short waves**

“*Steady-State Solver for Free-Surface Flows*,” C.W. Hirt, Flow Science Technical Note, May 2017

Steady-state Accelerator: Hydraulic Jump



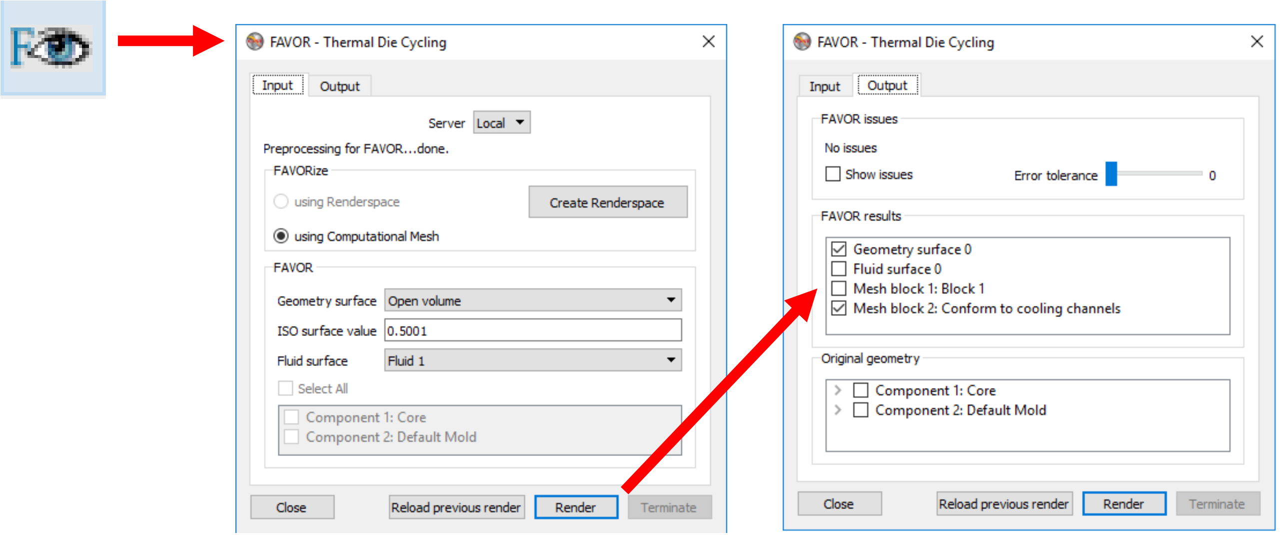


FLOW-3D

User Interface Engineering

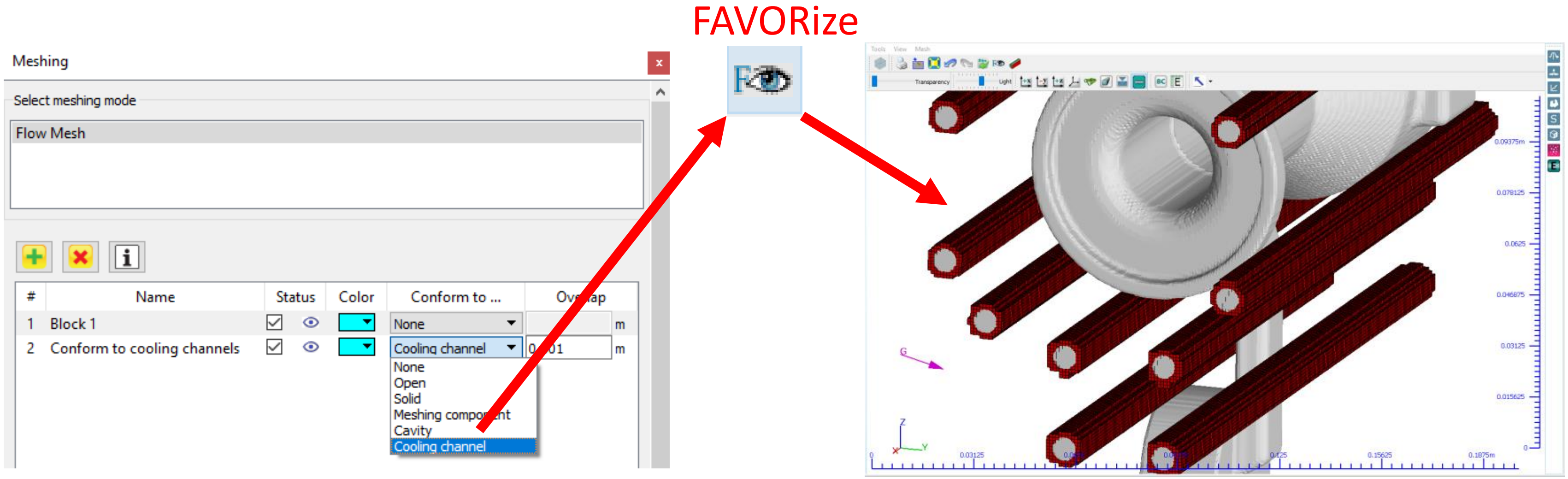
Visualization of Conforming Meshes

- **Conforming meshes are generated on the FAVORize dialog**
- **FAVORize  icon in toolbar in M&G window**



Visualization of Conforming Meshes

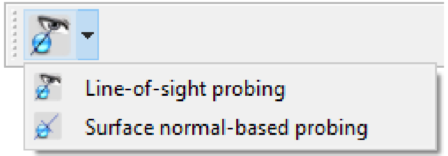
Conforming meshes can conform to open volume, solid, individual components, cavity, and cooling channels



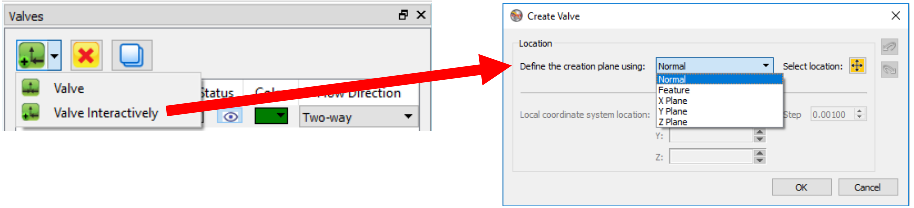
Shown: Mesh conforming to cooling channels

Interactive Geometry Creation

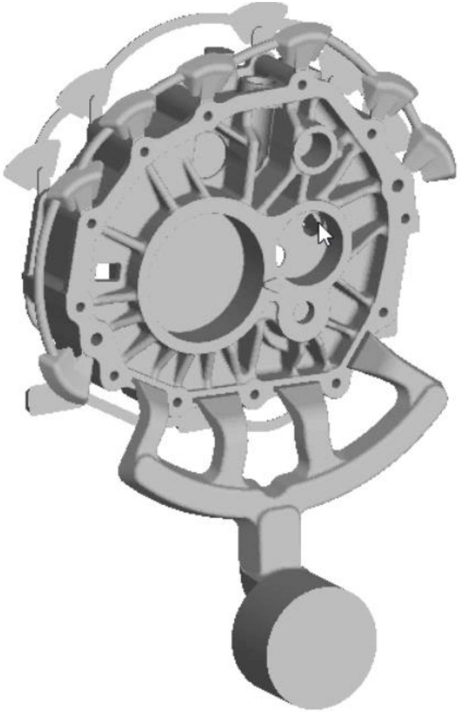
- **Valves, Baffles, Probes, Metal/Gas pointers, Geometry primitives**
- **Line-of-Sight and Surface Normal-based methods**
- **Available for probing on Quick Create toolbar. Select:**



  - **From toolbar**
  - **From shift-right click**
- **Surface Normal-based probing also available via each geometry widget:**



Interactive Geometry Creation



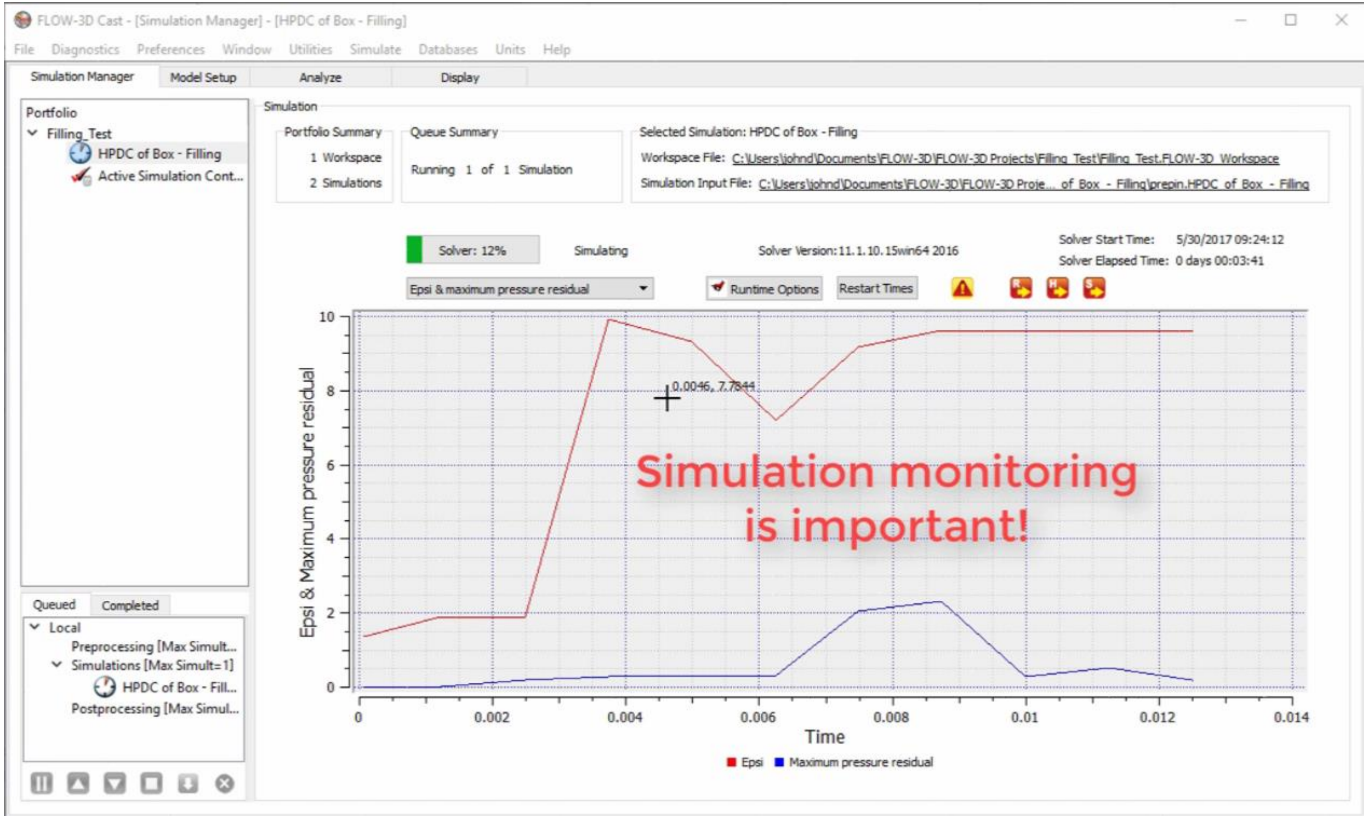
Simulation Monitoring

- **Why monitor simulations? Everything cost money…**
  - **Is the simulation running correctly (Conserving fluid, reasonable results)**
  - **Is the simulation instrumented adequately (Probes outputting correct info)**
  - **Should I keep running my simulation?**
- **Approaches to monitoring simulations**
  - **Simulation Manager – very limited data available**
  - **Analyze/Display or FlowSight – tedious…**

Customizable Simulation Monitor (CSM)

Goals of CSM

- Allow users to select any history data for plotting during run time
- Functions for both local and remote simulations
- Implement searching/filtering functions
- Provide ability to configure plots
- Save/Load plot configuration for each simulation
- Save/Load configurations for use across other simulations

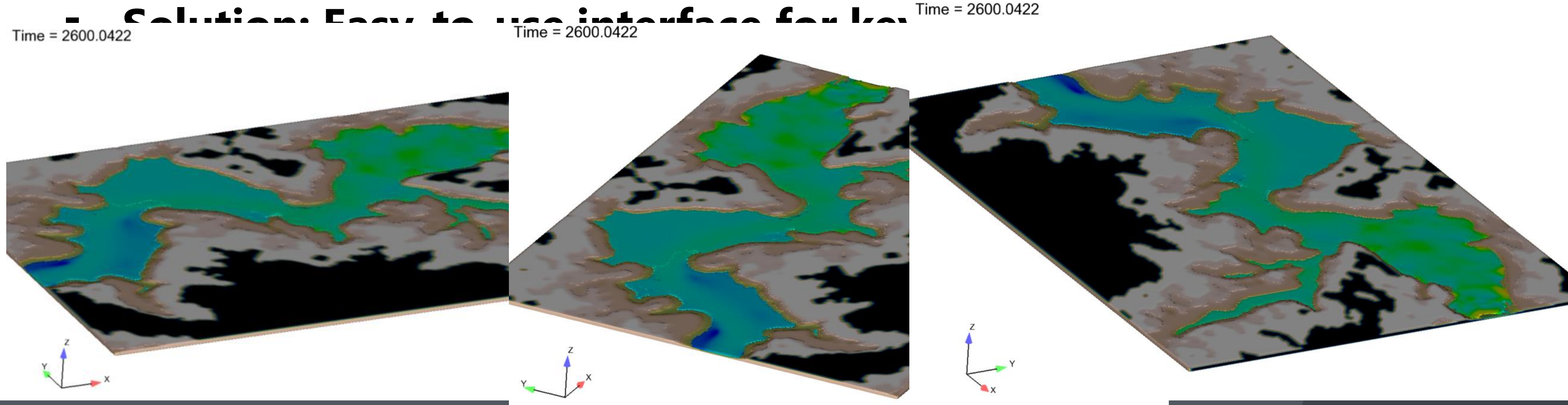

FLOW-3D Cast - [Simulation Manager] - [HPDC of Box - Filling]
File Diagnostics Preferences Window Utilities Simulate Databases Units Help
Simulation Manager
Model Setup
Analyze
Display
Portfolio
Filling_Test
HPDC of Box - Filling
Active Simulation Cont...
Simulation
Portfolio Summary
1 Workspace
2 Simulations
Queue Summary
Running 1 of 1 Simulation
Selected Simulation: HPDC of Box - Filling
Workspace File: C:\Users\johnd\Documents\FLOW-3D\FLOW-3D Projects\Filling_Test\Filling_Test.FLOW-3D_Workspace
Simulation Input File: C:\Users\johnd\Documents\FLOW-3D\FLOW-3D Proje... of_Box_-_Filling\prepin.HPDC_of_Box_-_Filling
Solver: 12%
Simulating
Solver Version: 11.1.10.15win64 2016
Solver Start Time: 5/30/2017 09:24:12
Solver Elapsed Time: 0 days 00:03:41
Epsi & maximum pressure residual
Runtime Options
Restart Times
Epsi & Maximum pressure residual
Time
0.0046, 7.7844
Epsi
Maximum pressure residual
Queued
Completed
Local
Preprocessing [Max Simult...
Simulations [Max Simult=1]
HPDC of Box - Fill...
Postprocessing [Max Simul...
Simulation monitoring is important!

FlowSight Improvements: ***FLOW-3D* Cast** v5.0 & ***FLOW-3D*** v11.3

- **"Cleaner" variable names w/o timeline suffix (*e.g.* ___Restart)**
- **Interface for keyframing tool**
- **Expanded volume rendering controls**
- **Load external STL files to specified viewport**
- **Load views from any location (*e.g.* simulation folder)**

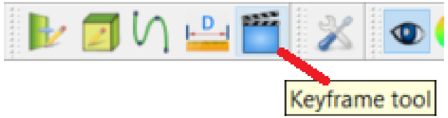
Keyframing Interface

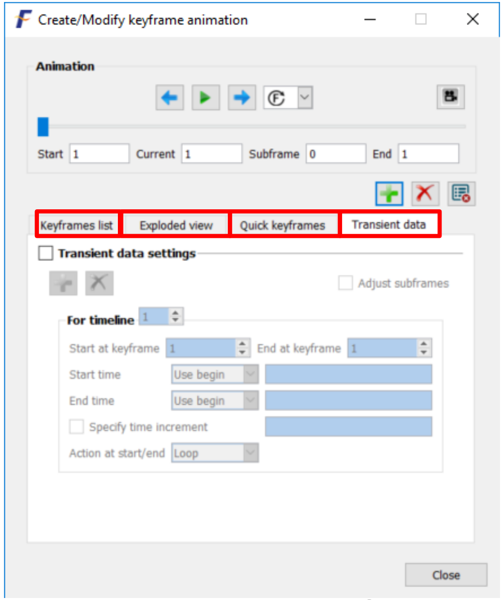
- **What are keyframes:**
  - Keyframes define eye locations in an animation sequence
  - Best eye location may change throughout simulation
  - Keyframing allows eye location to move in space and time
- **Problem: Keyframing is very useful but complicated and challenging!**
- **Solution: Easy-to-use interface for key**



Keyframing Interface

- **New Keyframing icon in FlowSight toolbar**

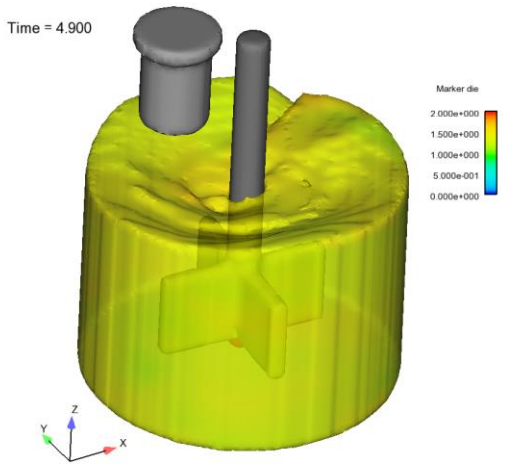




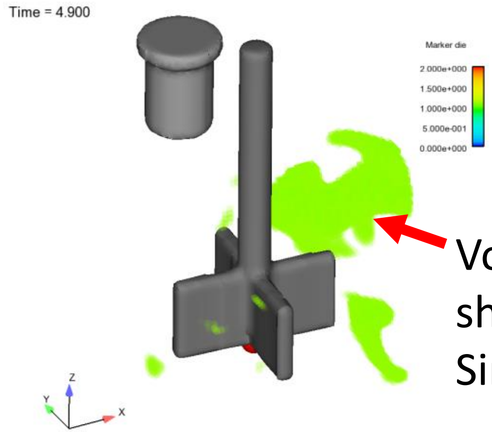
- **Demo: Keyframes in a hydraulics animation**

FlowSight Improvements: *FLOW-3D* Cast v5.0 & *FLOW-3D* v11.3

- **Expanded volume rendering controls**
- **What's the advantage of a volume render over an iso-surface?**



Iso-surface of fluid colored by die concentration

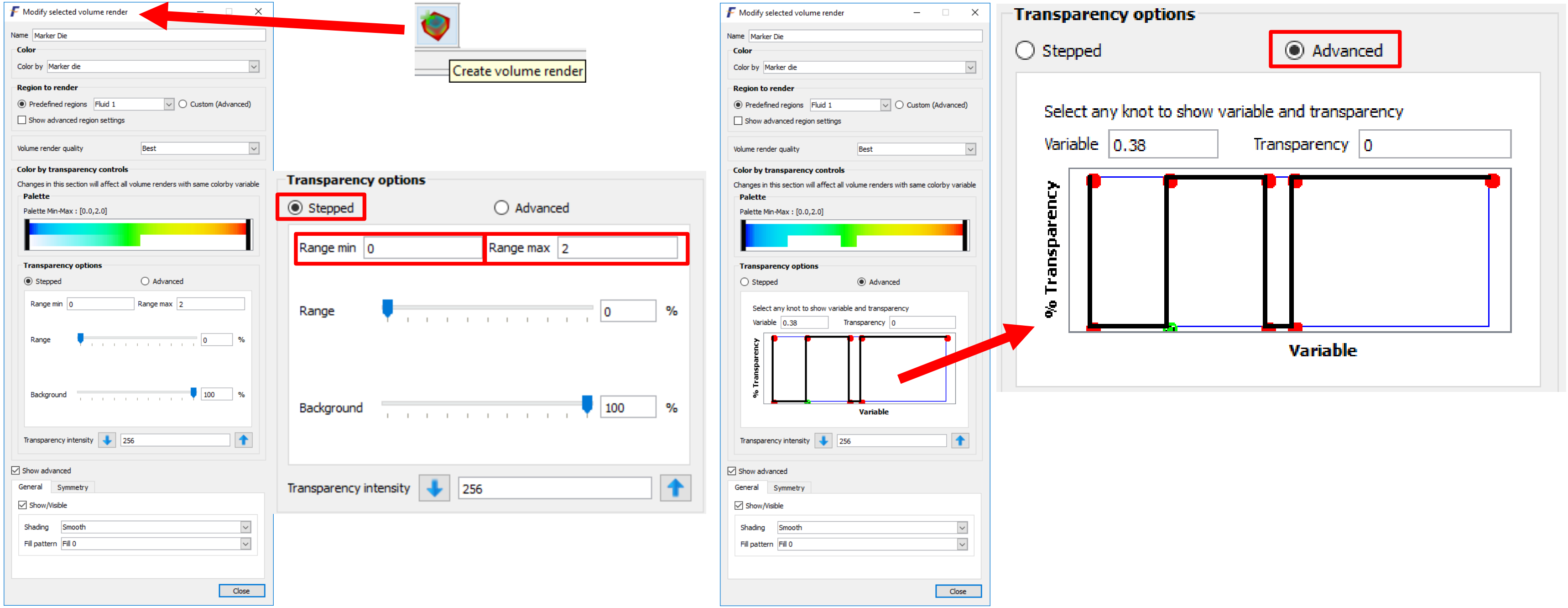


Volume render shows internal Simulation details

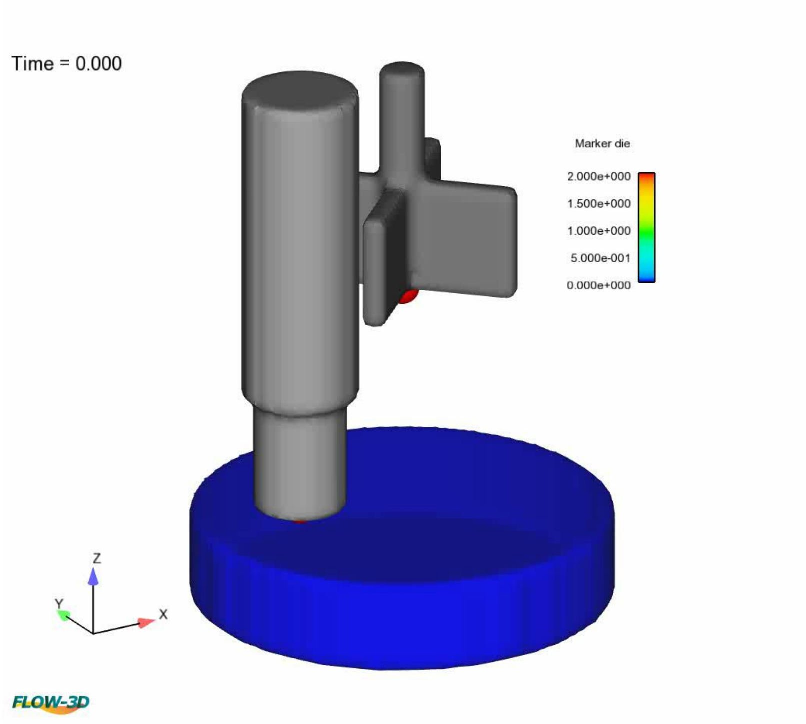
Volume render of die concentration

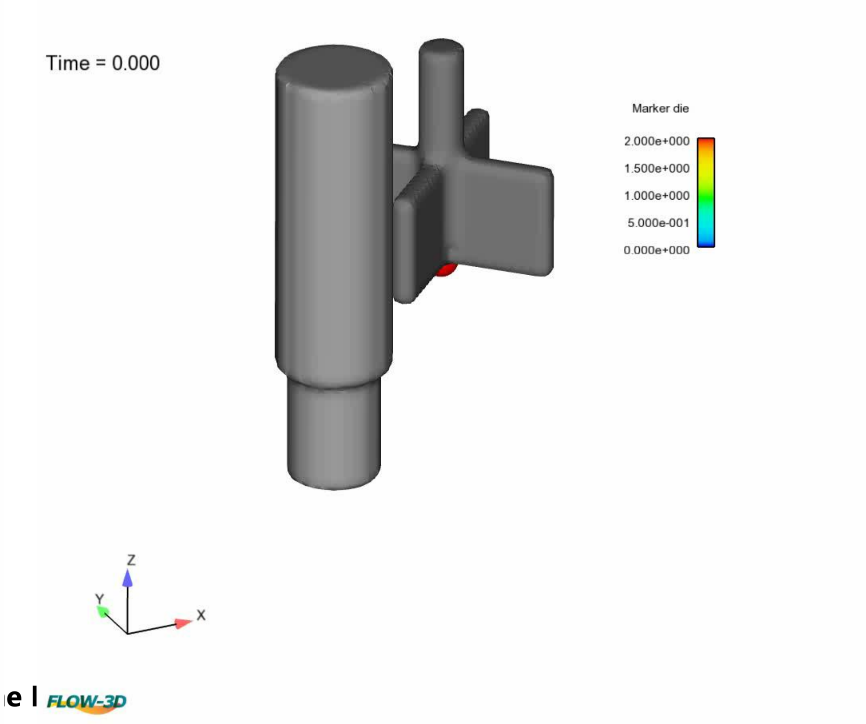
FlowSight Improvements:
***FLOW-3D* Cast v5.0 & *FLOW-3D* v11.3**

- **Expanded volume rendering controls**



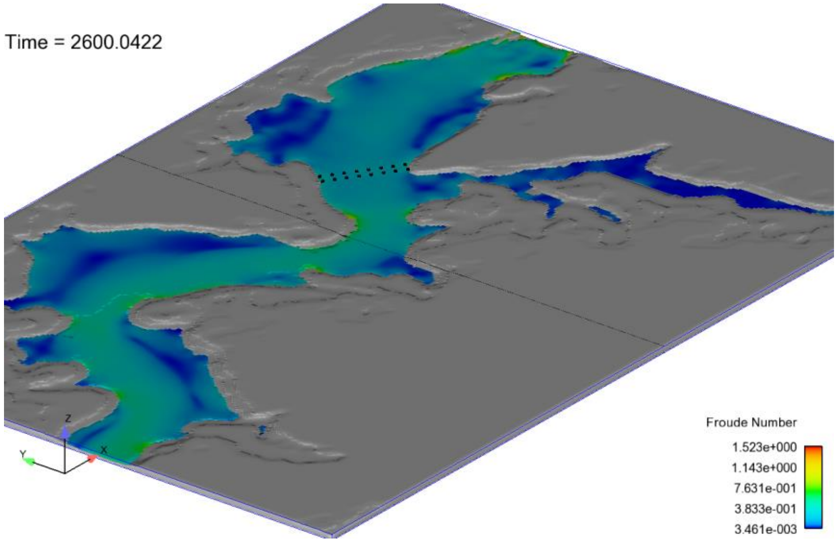
Analysis of Dye Concentration



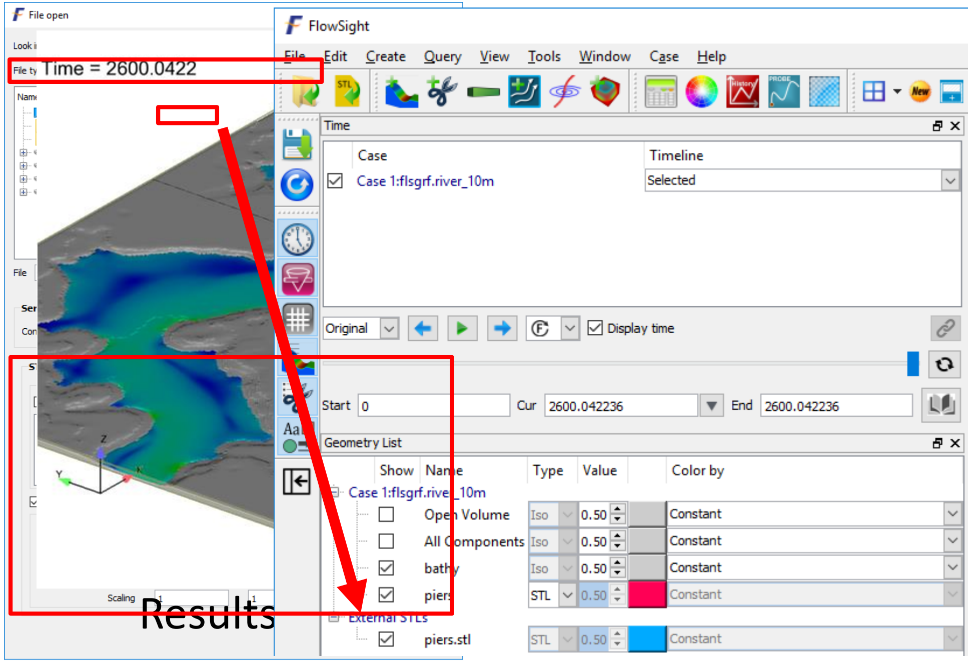


FlowSight – STL Import to Viewport

- **Auxiliary STL geometry can improve clarity of results interpretation**



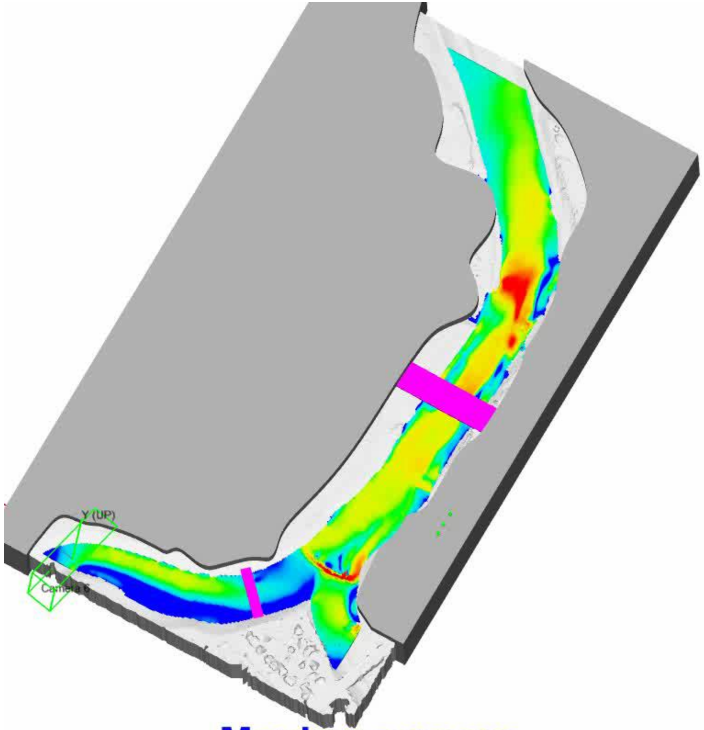
Simulation Results



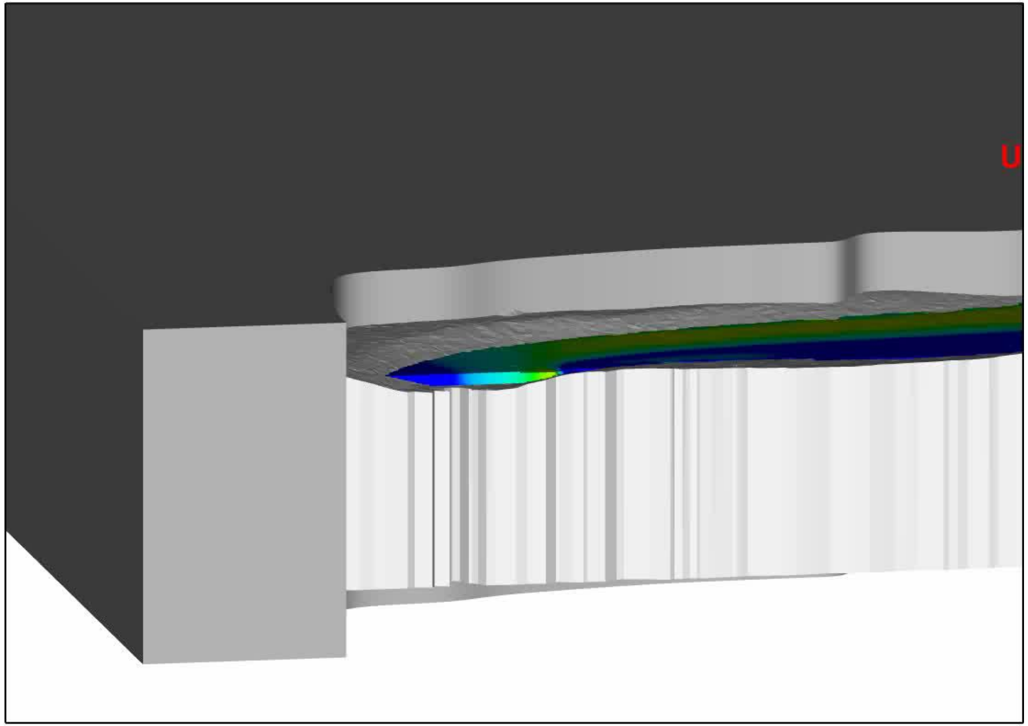
FlowSight for ***FLOW-3D*** v11.3

- **Based on EnSight® 10.2**
- **Reworked/improved graphics engine**
- **New scenario file and viewer**
- **Temporal SOS server (SMP results)**
- **Spatial SOS server (MP results)**
- **Camera along splines**

FlowSight for ***FLOW-3D*** v11.3



Moving camera



Viewport viewed from camera

FlowSight for ***FLOW-3D*** v11.3

- **Extend key-framing capabilities to include rotations**
- **More intelligent case linking**
- **Results file (FLSGRF) editor**
- **Ability to extract text and neutral file output**
- **Display valves**

FLOW-3D v11.3

New Features

- **Interface for chemistry model**
- **Smarter shallow water mesh blocks**
- **Immersed Boundary Method**
- **Component-level transformations**

FLOW-3D v11.3: HPC Version

- **HPC version of *FLOW-3D* → *FLOW-3D*/MP**
  – **Runs on Linux clusters**
  – **Uses mesh decomposition to significantly reduce runtimes**
- **Goal of Cast HPC version - Improve ease-of-use of HPC simulation**
  – **Hide complexity of mesh decomposition**
  – **Eliminate need for new simulation for each mesh decomposition**
- **Windows client (Linux solver only)**
- **Release scheduled for 1-2 months after *FLOW-3D* v11.3**

Questions?

Thank you.