SPLASH SIMULATIONS USING SPH

NORDIC LS-DYNA USERS' CONFERENCE 2022

2022-OCT-18 ERIK ENGDAHL

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BACKGROUND

Products in the cabin of vehicles can be exposed to fluids by splashing.

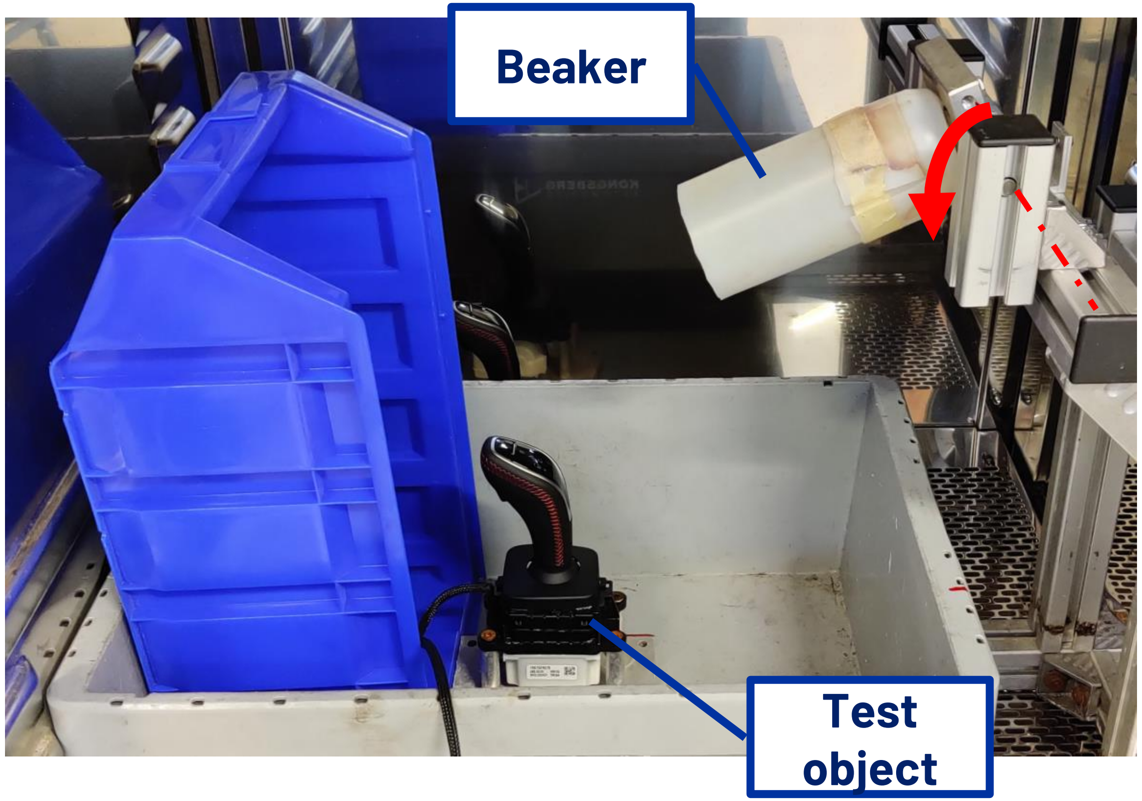
The scenario is that an occupant has an open container with drinking fluid (water, coffee, soft-drink etc) and by accident spills the content in the cabin onto a product.

Fluid entering inside products can cause issues like electrical short-cuts and sticky mechanics. Gaps between parts, seals, drainage holes and run-off paths for fluid needs to be designed in order to manage the fluid.

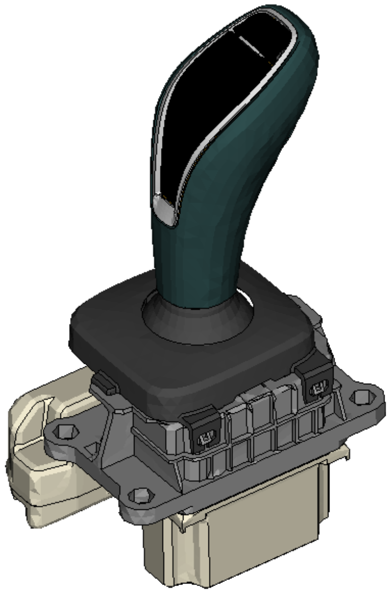
This presentation focus on a dynamic splash-test to see if simulations can contribute to knowledge about product performance in this context.

TEST SET-UP AND PERFORMANCE

- Test object placed at specified distance from beaker
- Beaker mounted on a base-plate with a hinge passing through centerline of beaker base.
- An end-stop restricts base-plate rotation.
- Beaker starting position is tilted towards test-object and contains fluid
- Beaker released – rotates down and “releases” fluid
- Fluid splashes onto the test object

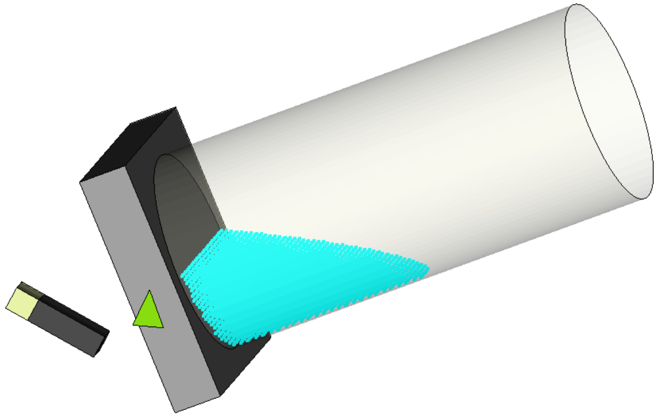


FEA MODELLING



- Structural parts modelled with Shell & Solid Finite Elements
  - Beaker and test rig are modelled as elastic
  - Test object assumed to be rigid (stiffness fluid << test object)

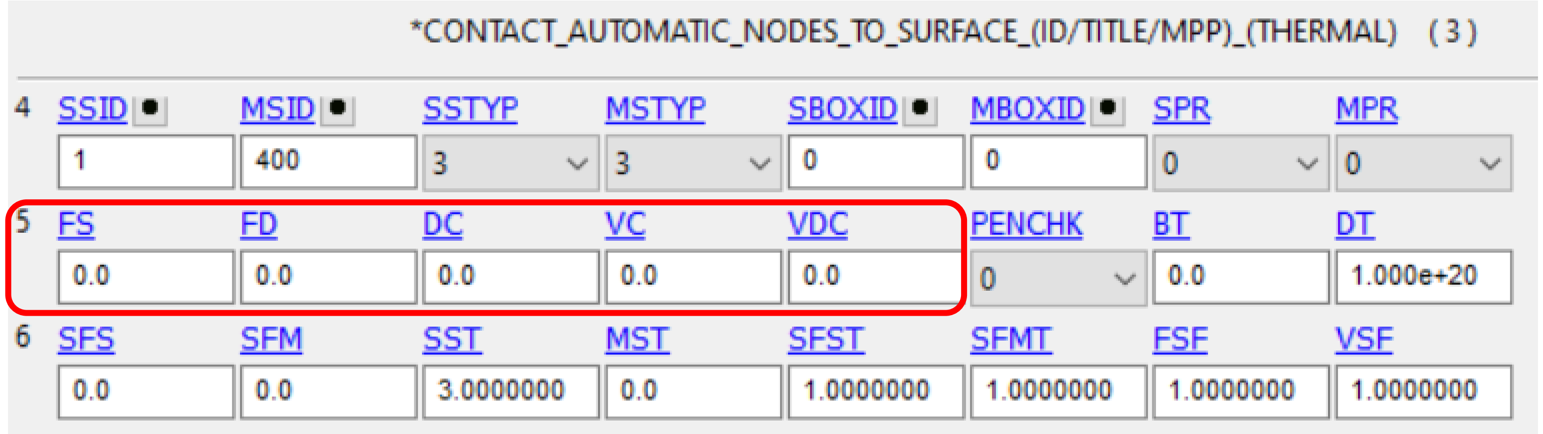
- Fluid modelled with SPH
  - Incompressible
  - Form 15 – enhanced fluid formulation
  - Use EOS_GRUNEISEN (or EOS_MURNAGHAN)



- Fluid Structure Interface (FSI) by using Node to Surface Contact
  - Part with SPH elements as slave
  - Use SOFT = 1
  - Set SST to correspond to particle size

FSI - CONTACT SETTINGS

Contact parameters are important to get realistic interaction between fluid and structure



*CONTACT_AUTOMATIC_NODES_TO_SURFACE_(ID/TITLE/MPP)_(THERMAL) (3)

Card								
4	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR
	1	400	3	3	0	0	0	0
5	FS	FD	DC	VC	VDC	PENCHK	BT	DT
	0.0	0.0	0.0	0.0	0.0	0	0.0	1.000e+20
6	SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF
	0.0	0.0	3.0000000	0.0	1.0000000	1.0000000	1.0000000	1.0000000

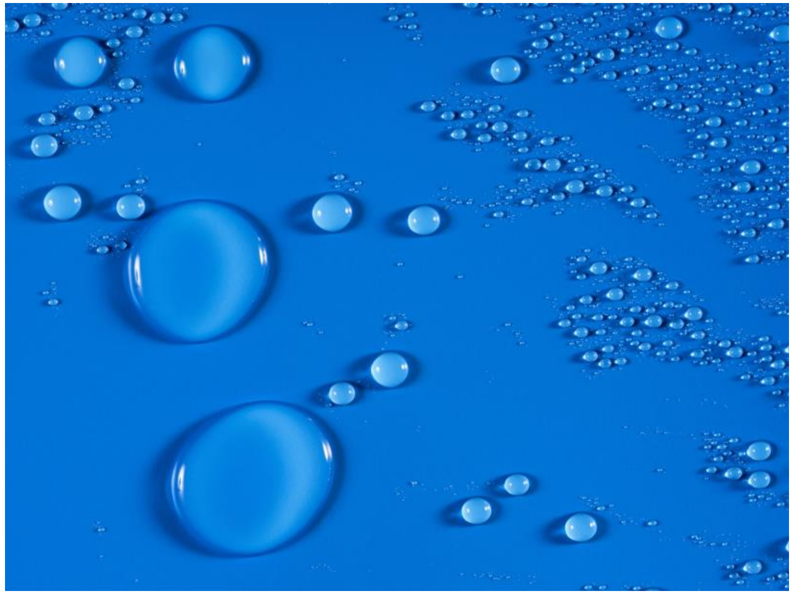
"Tunable" parameters: Friction (lateral adhesion) and damping

DROPLET SIZE

- The droplet size for water mist systems can vary between 1000 µm and 10 µm

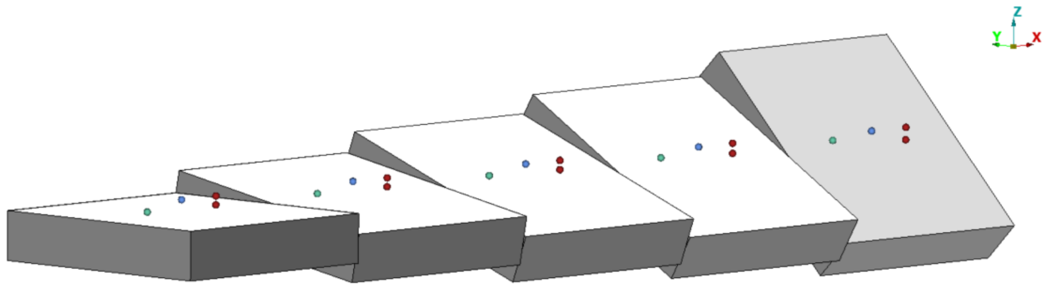
- Raindrop sizes typically range from 0.5 mm to 4 mm [2], with size distributions quickly decreasing past diameters larger than 2-2.5 mm.

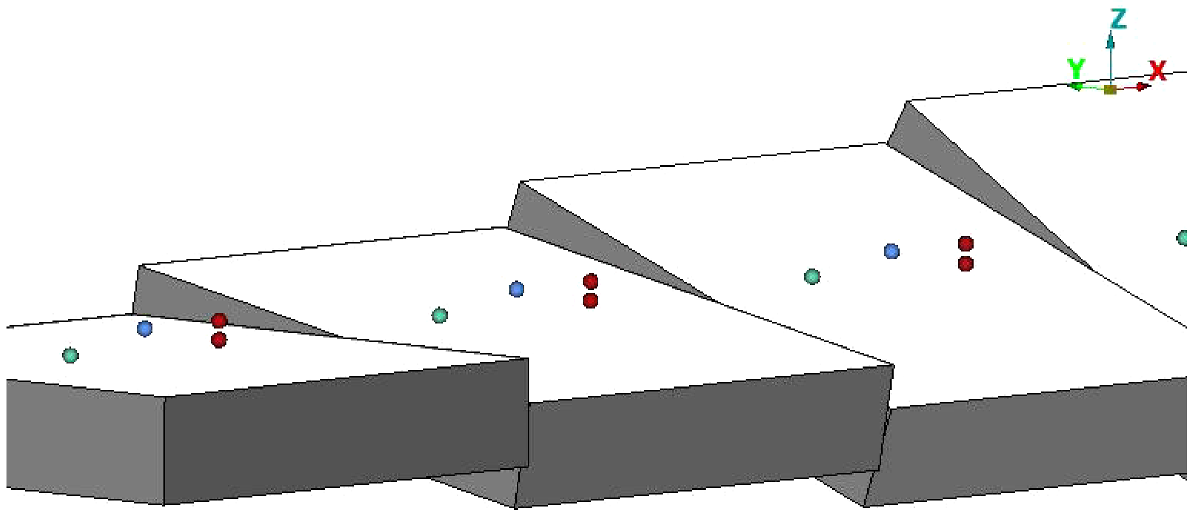
- As a starting point particle around ∅**2mm** can be used (Sphere volume ~4µL)



SMALL MODEL

- SPH particles (water) contacting planes at different angles (Left) 0° to (Right) 45°
- Particles at rest on surface (green) or initial velocity with a travel distance (blue)
- Gravity field
- Defaults on friction and damping (i.e. 0)





Particles (droplets) behaves like an elastic impact, i.e. blue particles bouncing at constant amplitude

Stationary particles slides of at low tilt angles

HYDROPHOBIC / HYDROPHILIC

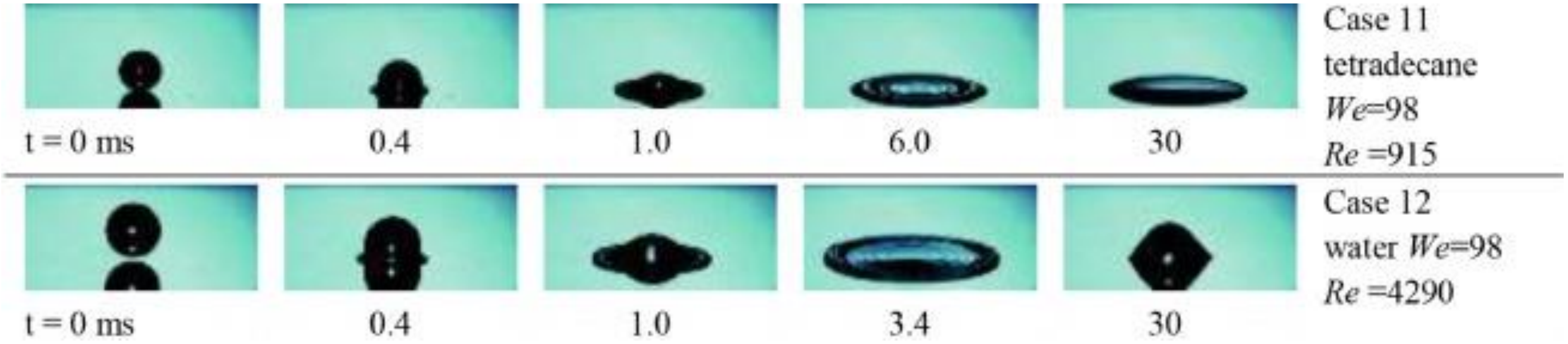
- The wettability between a fluid and a solid depends on the difference in surface energy
- Water has a surface tension of 72mN/m
- Polymers, without any special treatment, the surface energy is typically in range 20-50mN/m

Polymers are (mostly) hydrophobic, i.e. water tend to form drops on the surface

DROP IMPACT ON SOLID SURFACE

- When a drop is impacting a surface, it will not bounce like a perfect elastic impact.
- Specifically, the drop will deposit on the (dry) surface if the impact energy is relatively small [5]

Picture sequence shows fluid drop onto a flat stainless-steel surface with smooth surface [5]



~1.6m/s

No splashing observed for water drop on smooth surface up to 5m/s

DROP ON A TILTED PLANE

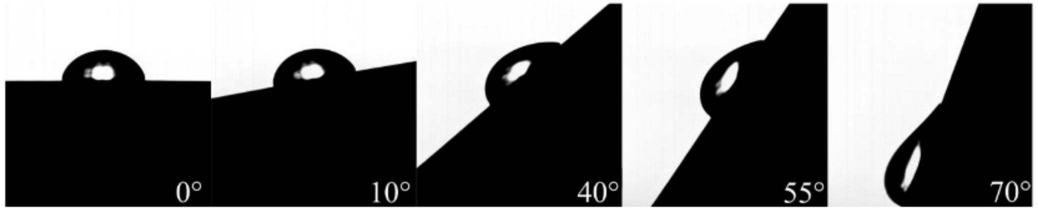


Fig. 5: Different droplet regimes for a 30µl droplet.

- A drop can stay stationary on a tilted plane if the angle is low
- Larger drops slide off at a smaller angle of inclination
- Critical surface inclination for drop sizes of 4 µl of de-ionized water on Teflon-coated glass was 18.8° [3]
- On an acrylic surface the transition from stationary to moving ranges from ~35° to ~10° [4]

Friction can be assumed to be in the range 0.18 to 0.70

Use FS=FD=0.4 for simulations

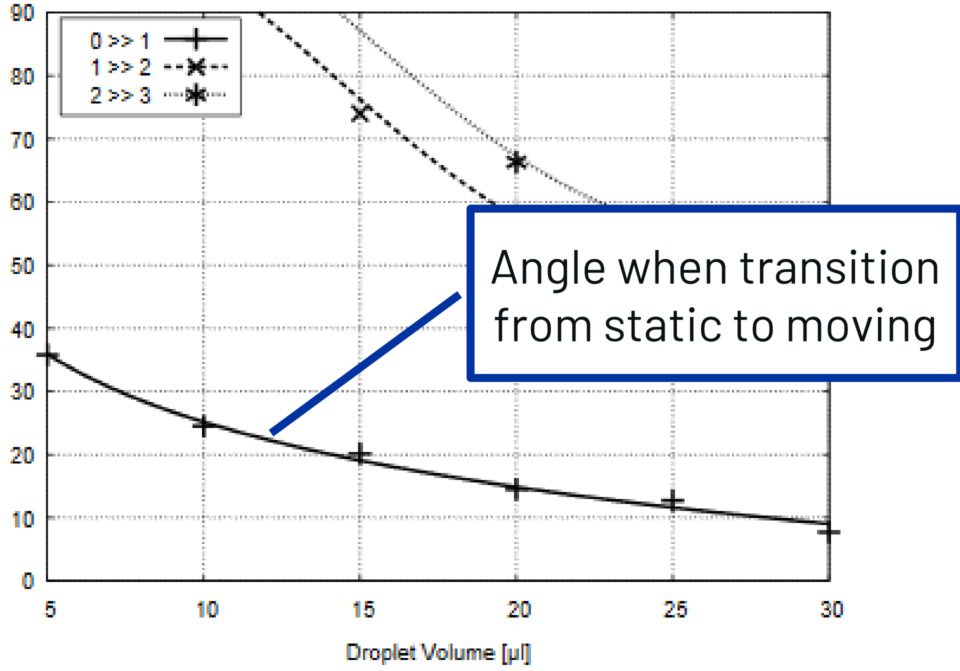


Fig. 6: Flow map for an angular velocity of 10°/s.

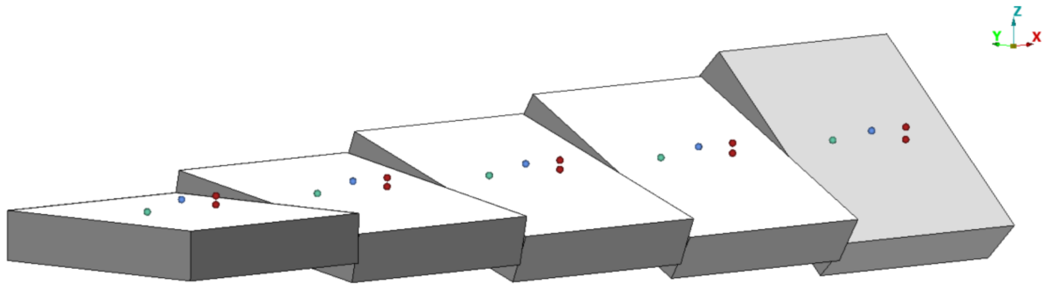
SMALL MODEL UPDATED

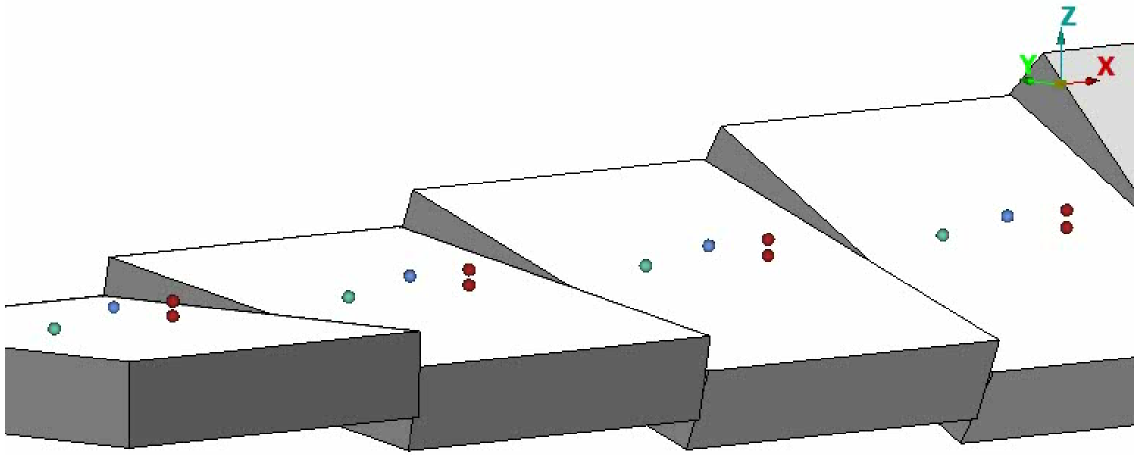
Contact settings

- Friction FS=FD=0.4
- VDC = 99.0 to damp out bouncing of SPH particles

Behavior more realistic

- Stationary particles stay on lower slopes
- Less bouncy



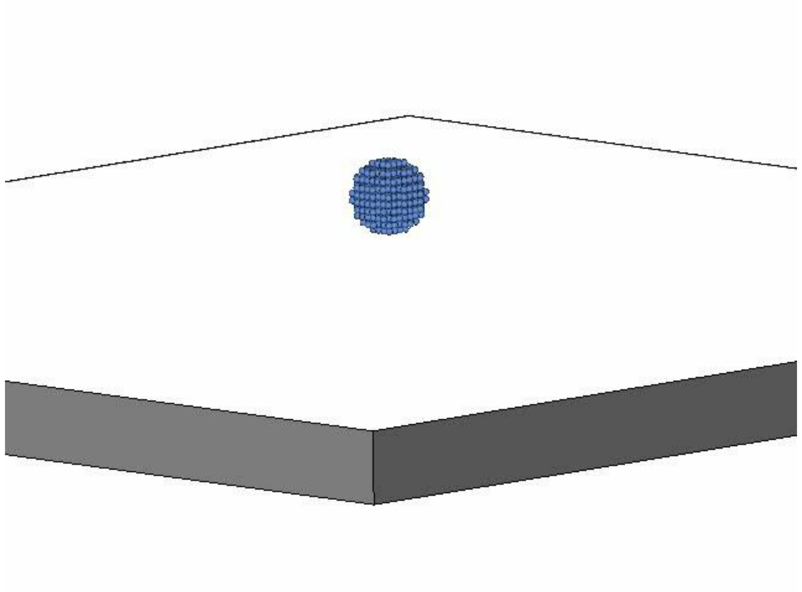


DETAILED DROP

Water drop ∅2mm modelled with 552 SPH elements

Low impact velocity ~0.15m/s (Drop height ~1mm) on a flat plate

Gravity field

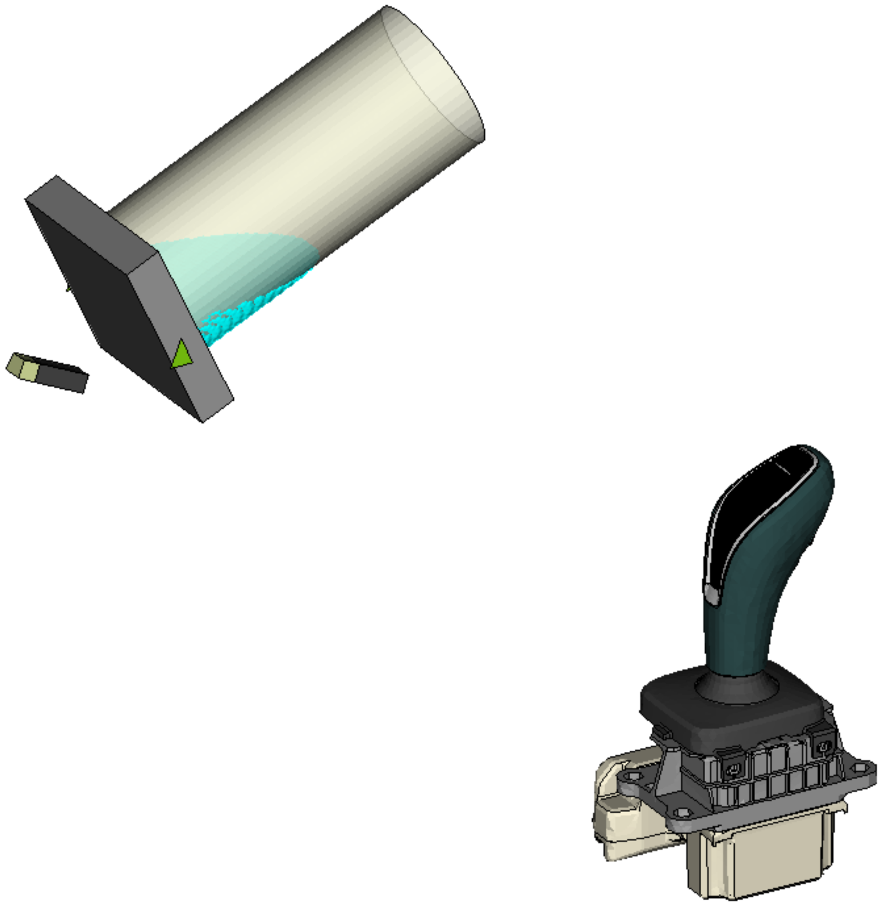


Drop breaks up and particles bounce

Break up of drop is not expected at such low impact velocity

MODEL OF TEST-SETUP

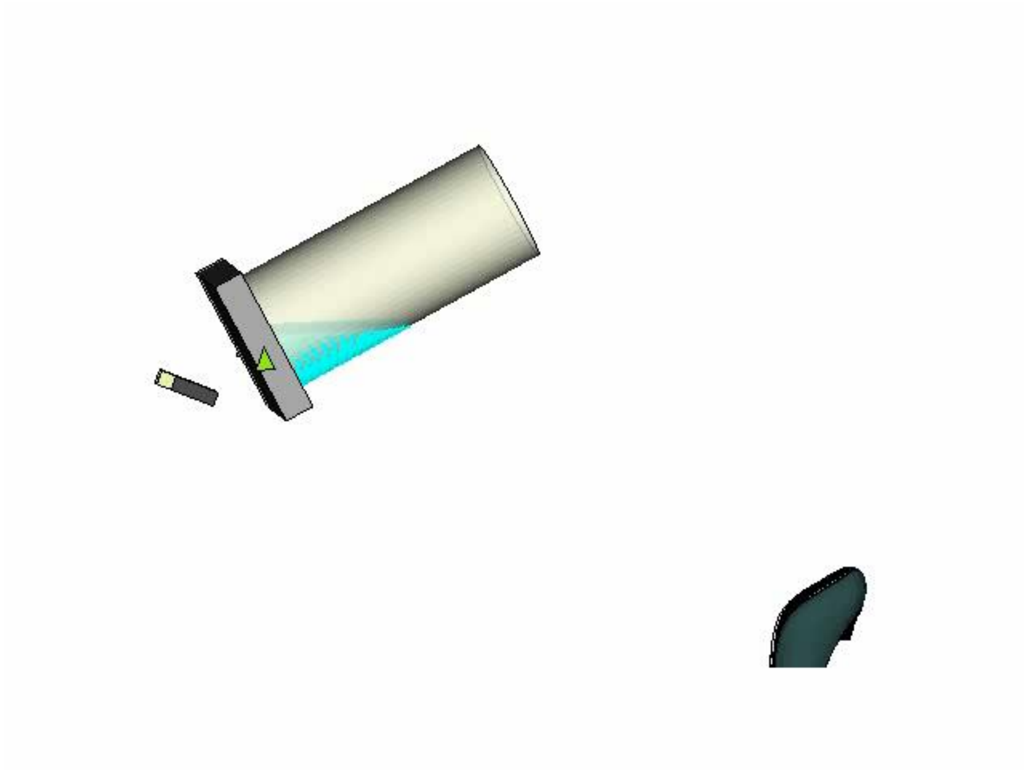
Starting position



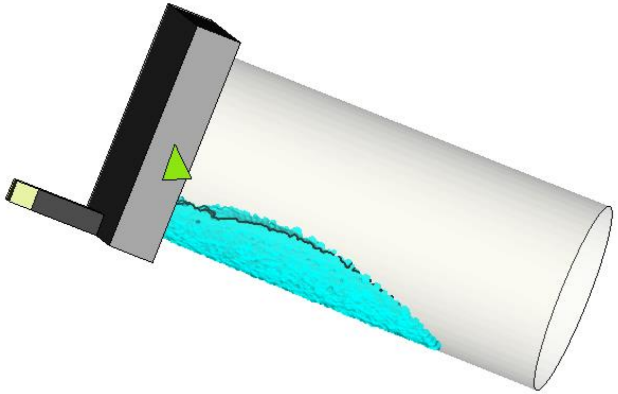
- Zero initial velocity on all parts
- Gravity is the only load
- Fluid will need a “travel time” to reach test-object

BEAKER TIPPING PHASE

Beaker tipping due to gravity and bouncing on end-stop

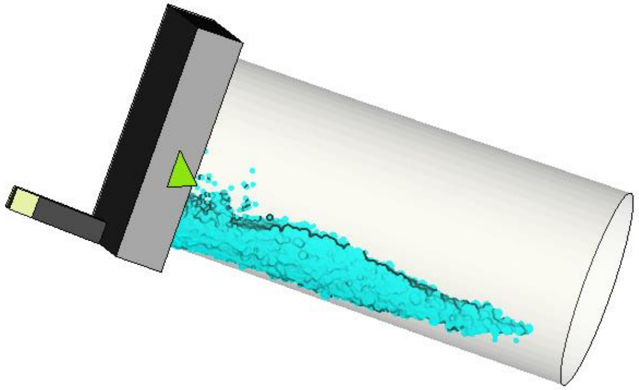


BEAKER END-STOP



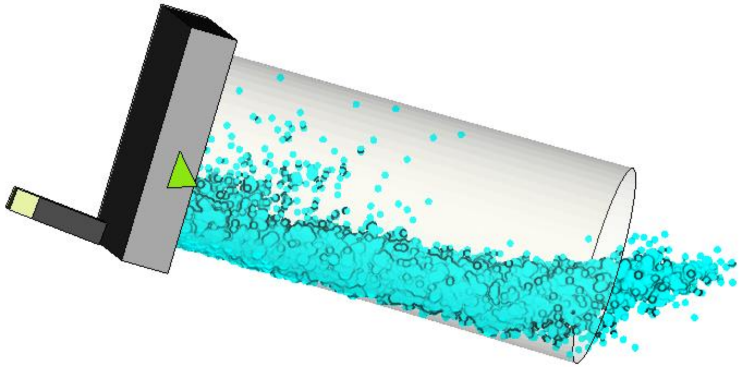
t~0.17s

Before hitting end-stop



t~0.18s

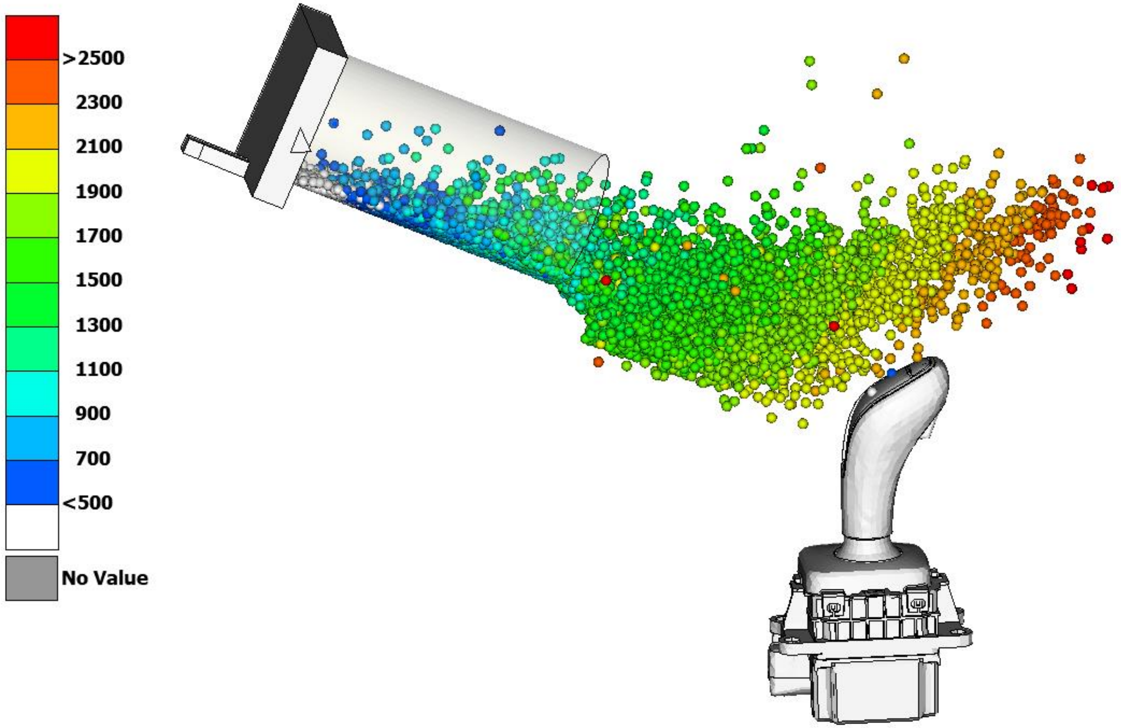
After hitting end-stop



t~0.22s

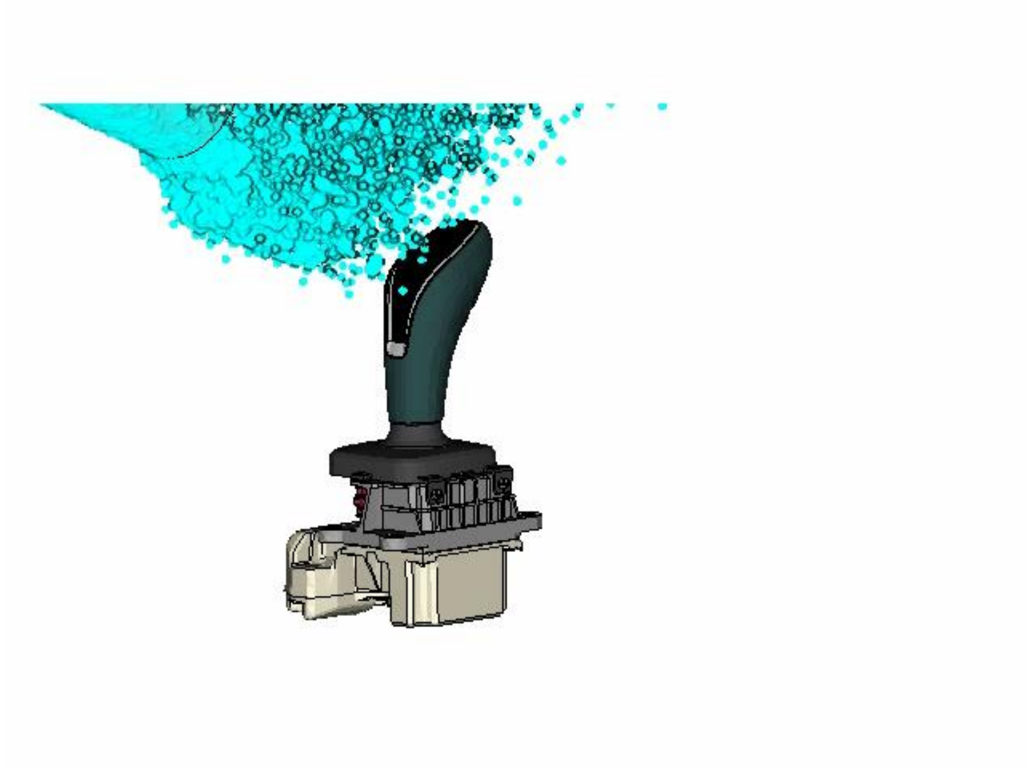
FLUID VELOCITY

Velocity in mm/s

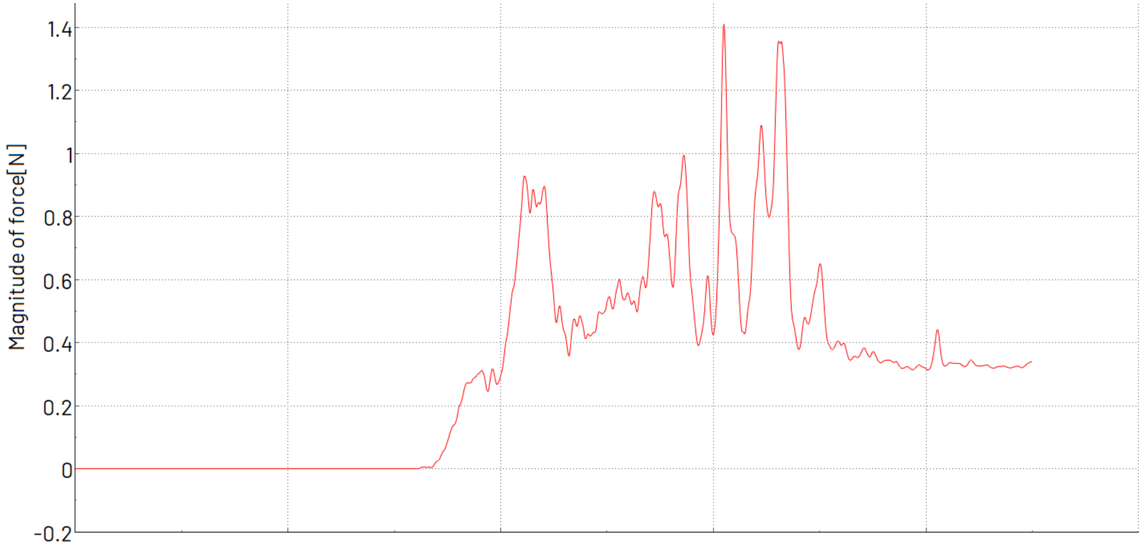


Compare to the terminal velocity of ∅2mm rain drops which is 6 - 7m/s

SPLASHING ON TEST-OBJECT



Force on test-object from fluid



Fluid splashes from top to bottom

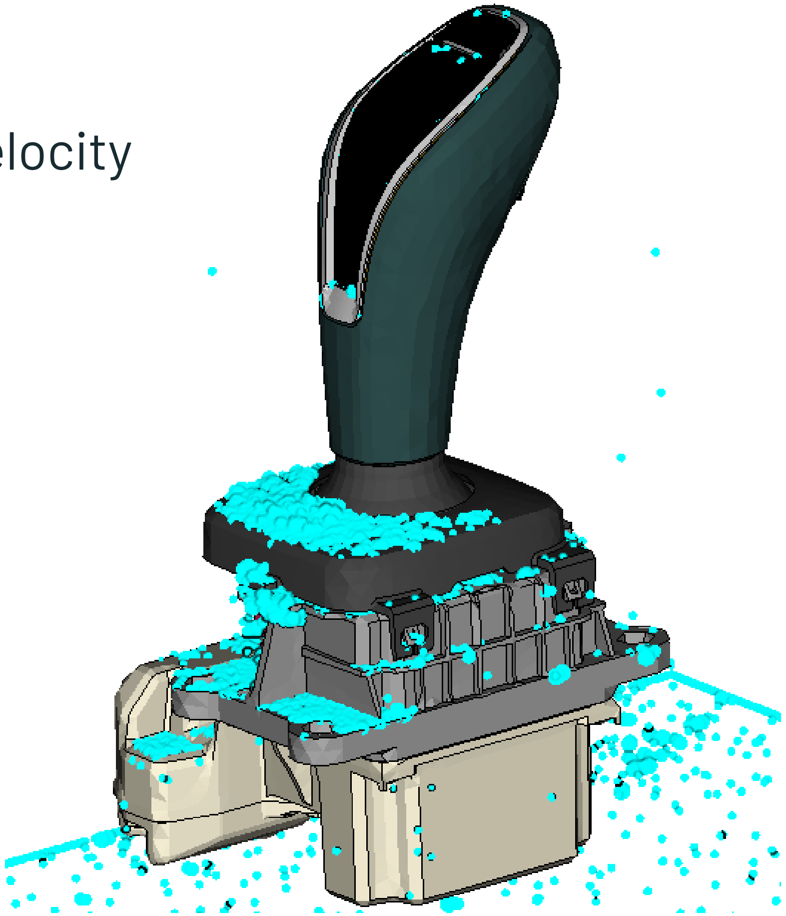
Low forces – assumption on structure modelled as rigid valid

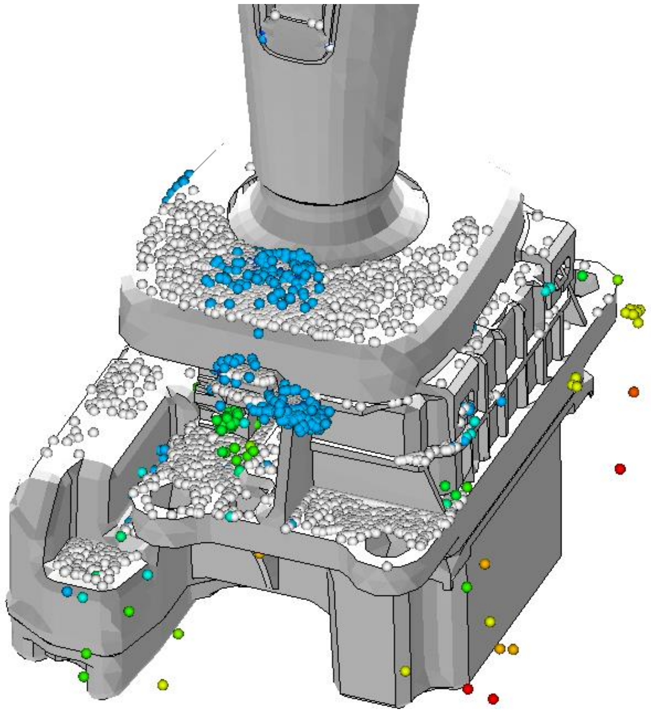
SPLASHING ON TEST-OBJECT

Fluid passing on the sides is one reason for low forces on test-object

RESIDUAL FLUID

Fluid at end of simulation
Note: Not all particles have zero velocity



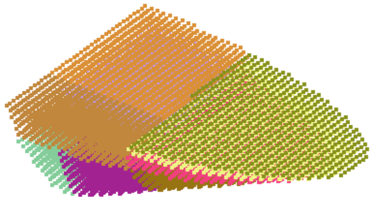


MPP DECOMPOSITION STUDY

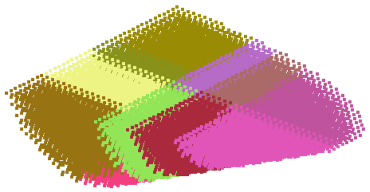
A small MPP decomposition study was performed to find the potential speed increase by using keywords:

*CONTROL_MPP_DECOMPOSITION_DISTRIBUTE_SPH_ELEMENTS

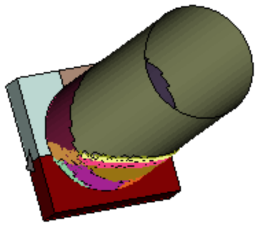
*CONTROL_MPP_DECOMPOSITION_TRANSFORMATION



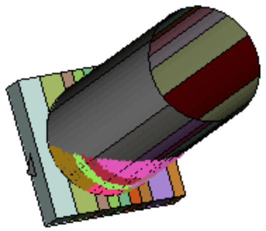
Baseline



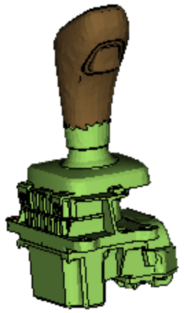
DISTRIBUTE_SPH_ELEMENTS



Baseline

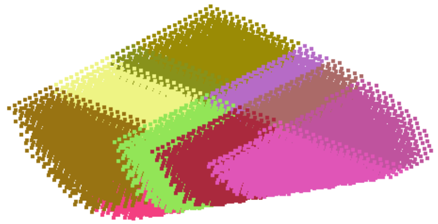


TRANSFORMATION



MPP DECOMPOSITION STUDY RESULTS

Distribute SPH	Transformation	Solution time
N	-	100%
Y	-	63%
Y	SZ 0.0, SY 50.0	59%
N	SZ 0.0, SY 50.0	68%



Using *CONTROL_MPP_DECOMPOSITION_DISTRIBUTE_SPH_ELEMENTS was the biggest contributor to reducing the solution time.

REMARKS

- Capillary effect and surface tension not accounted for
- Impact on surfaces and between particles seems to be elastic

"***All models are wrong, but some are useful“*** - George Box

REFERENCES

[1] Livermore software technology, “LS-DYNA Keyword User's Manual”, 2021

[2] https://www.baranidesign.com/faq-articles/2020/1/19/rain-drop-size-and-speed-of-a-falling-rain-drop

[3] Annapragada, S. R.; Murthy, J. Y.; and Garimella, S V., "Droplet Retention on an Incline" (2012). CTRC Research Publications. Paper 160.

[4] T. Maurer, A. Mebus, U. Janoske, ”Water Droplet Motion on an Inclining Surface“, Proceedings of the 3rd International Conference on Fluid Flow, Heat and Mass Transfer, Ottawa, 2016

[5] C. Tang, M. Qui,et al, Dynamics of droplet impact on solid surface with different roughness, International Journal of Multiphase Flow, Volume 96, November 2017

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