Study of Liquid Dispersal from a Missile Impacting a Wall

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Introduction

- Liquid release and spread phenomena are of interest for the determination of fire risk following an airplane crash on a structure.
- At the beginning of the project, very little representative information was available in the literature.
- Liquid spread has been studied in some IMPACT tests using different missiles and targets.
- Liquid spread study is funded by the Finnish Research Programme on Nuclear Power Plant Safety (SAFIR).

Objectives

- Measure, analyze and document liquid release and spread phenomena in the wet missile IMPACT tests.
- Increase knowledge of liquid spread in a high-speed impact.
- Choose and validate a numerical simulation tool to support the experimental work, and for simulation on liquid spread and, ultimately, resulting fires in the case of flammable liquid.
- Concentrate on the major parameters needed for validation and definition of the boundary conditions for the liquid phase simulation: droplet size, speed and spreading angle.

Status

- So far, 21 wet missile IMPACT tests have been analysed:
  - 17 tests with a cylindrical (aluminium or steel pipe) missile (water mass 15 … 68 kg)
  - 4 tests with an aluminium 3D missile (water mass 8 kg in the wings)
  - Impact velocity 70 ... 177 m/s
  - Impact against a steel force plate or a concrete wall
- Numerical liquid phase simulations have been performed using the Fire Dynamics Simulator (FDS) software.

Missiles

Aluminium pipe missile

3-D missile including wings

Characteristics of liquid (water) spread in a high-speed impact

- Deceleration of missile is very high
  ---> liquid spurts out from ruptured missile due to inertial and gravitational forces.
- Primary and secondary breakup and atomization of liquid stream due to instabilites and aerodynamic forces
  ---> formation of liquid spray
- Spread of spray droplets and the rest of liquid stream forming a spread/splash pattern around the target.
- Accumulation/impact of droplets and liquid stream on the ground and surrounding structures.

Liquid measurements of IMPACT tests

- discharge speed of liquid
- propagation speed and direction of liquid spray
- shape of spread/splash pattern
- pooling on the floor
- size of deposited and flying droplets

IMPACT test results:
liquid spread/splash pattern

General:

- Liquid release takes place mainly to the directions of wall tangent.
- Spreading angle less than 10 ^{o} from the wall tangent.
- The missile geometry and rupture mode have a great influence on the liquid spread pattern in the vicinity of missile.

Characteristics of aluminium/steel pipe tests:

- Spread pattern around the target is relatively symmetrical and uniform.

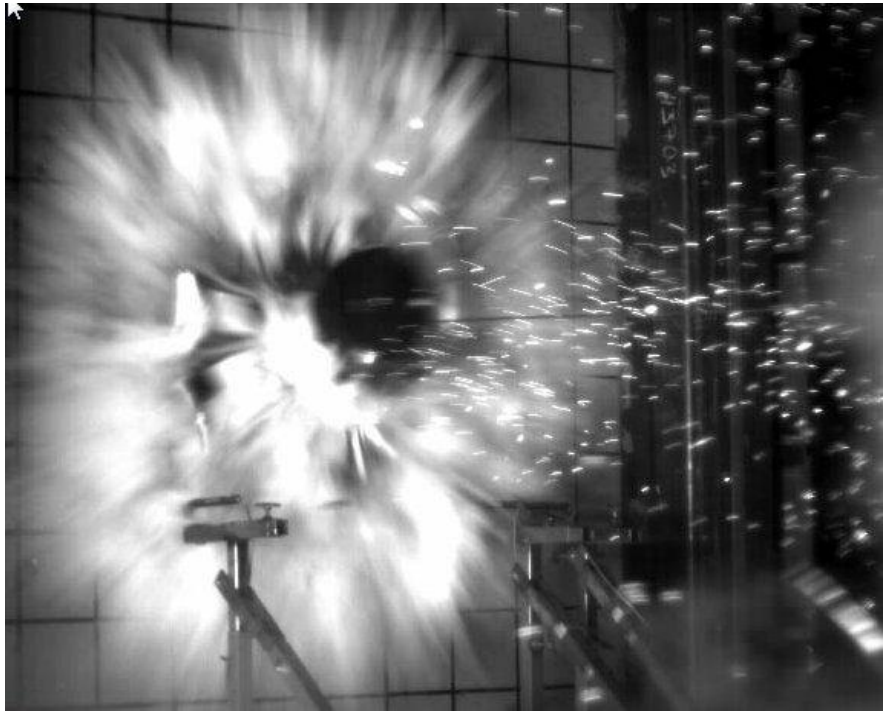
Characteristics of 3-D missile tests:

- Asymmetric and non-uniform spread pattern.
- Because the liquid is located inside the wings, the vertical spread directions are more pronounced than horizontal.

IMPACT test fotos:

Liquid spread from cylindrical and 3-D missiles

- Aluminium pipe missile
  105 m/s



3-D missile
137 m/s

IMPACT test video

Liquid spread from a aluminium pipe missile

Front view

- Water mass 28 kg
- Impact velocity 104 m/s

IMPACT test video

Liquid spread from a 3-D missile

Front view

- Water mass 8 kg
- Impact velocity 167 m/s

IMPACT test video

Liquid spread from a 3-D missile

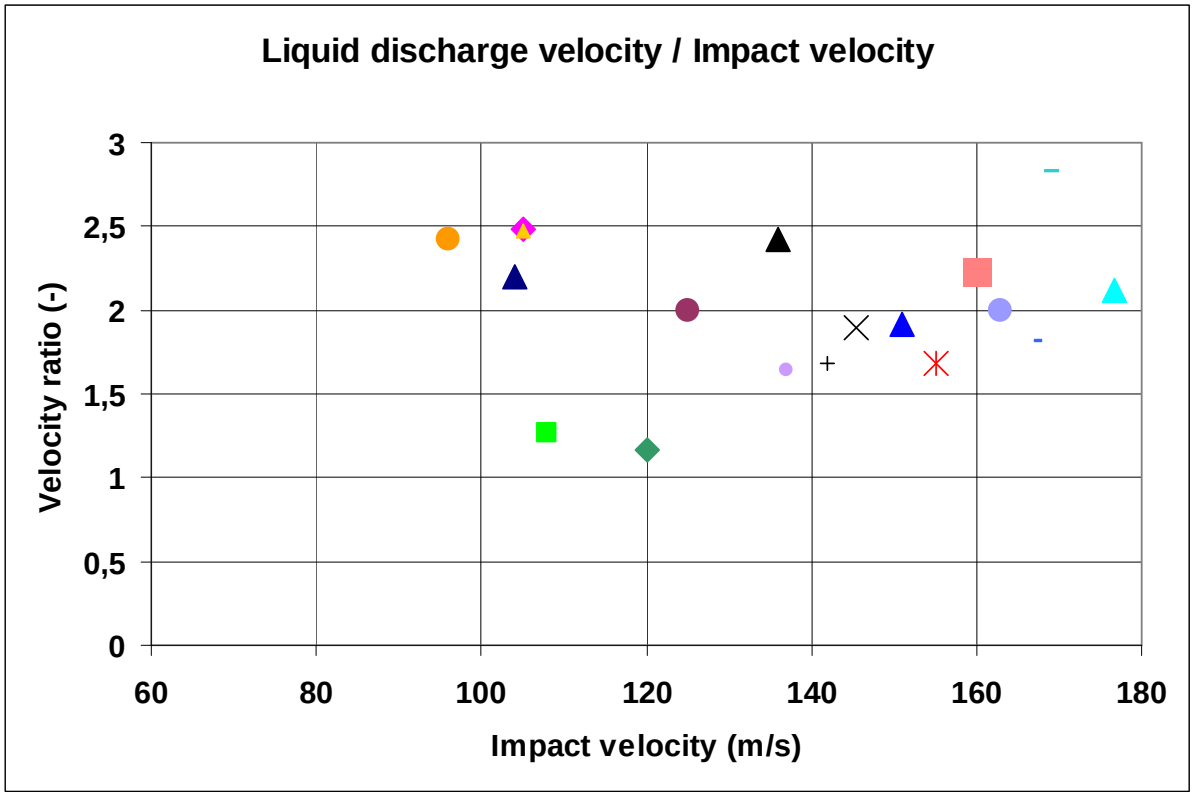
Side view

- Water mass 8 kg
- Impact velocity 169 m/s

IMPACT test results:
liquid velocity

- Initial liquid discharge speed as high as 2.5 times the missile impact velocity.
- The stable droplet size of high-speed liquid spray is small, and the speed of spray front slows down soon after the impact.
- Representative liquid speed from 3-D missiles difficult to measure using the current methods due to strong folding and instabilities of the liquid front.

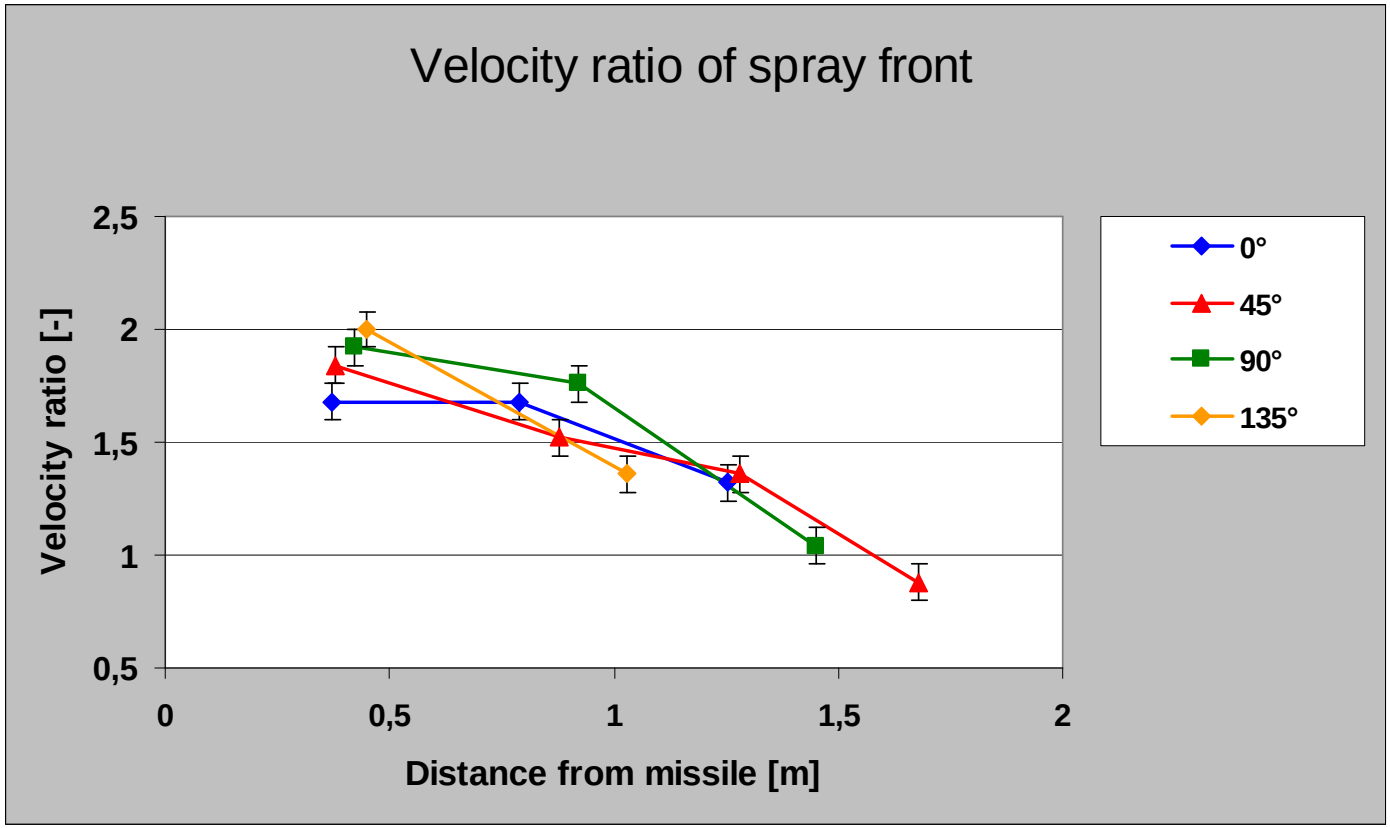
Test results:
liquid discharge velocity



IMPACT test results:

typical liquid velocity from a aluminium pipe missile

- Impact velocity 125 m/s
- Water mass 37 kg

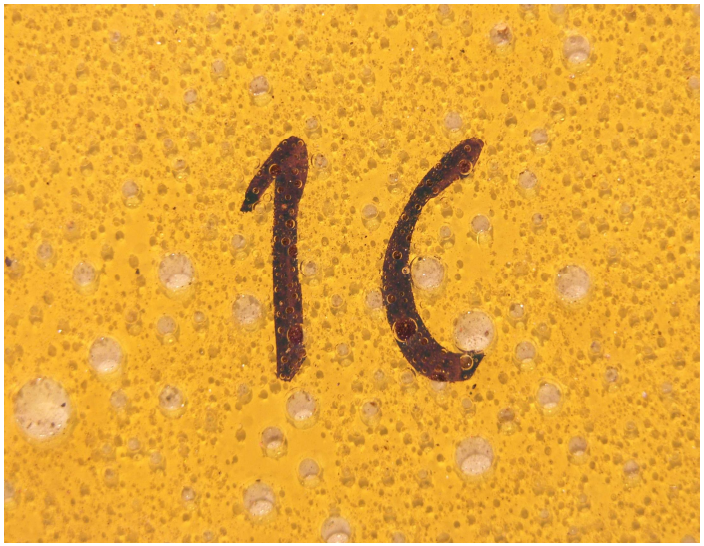


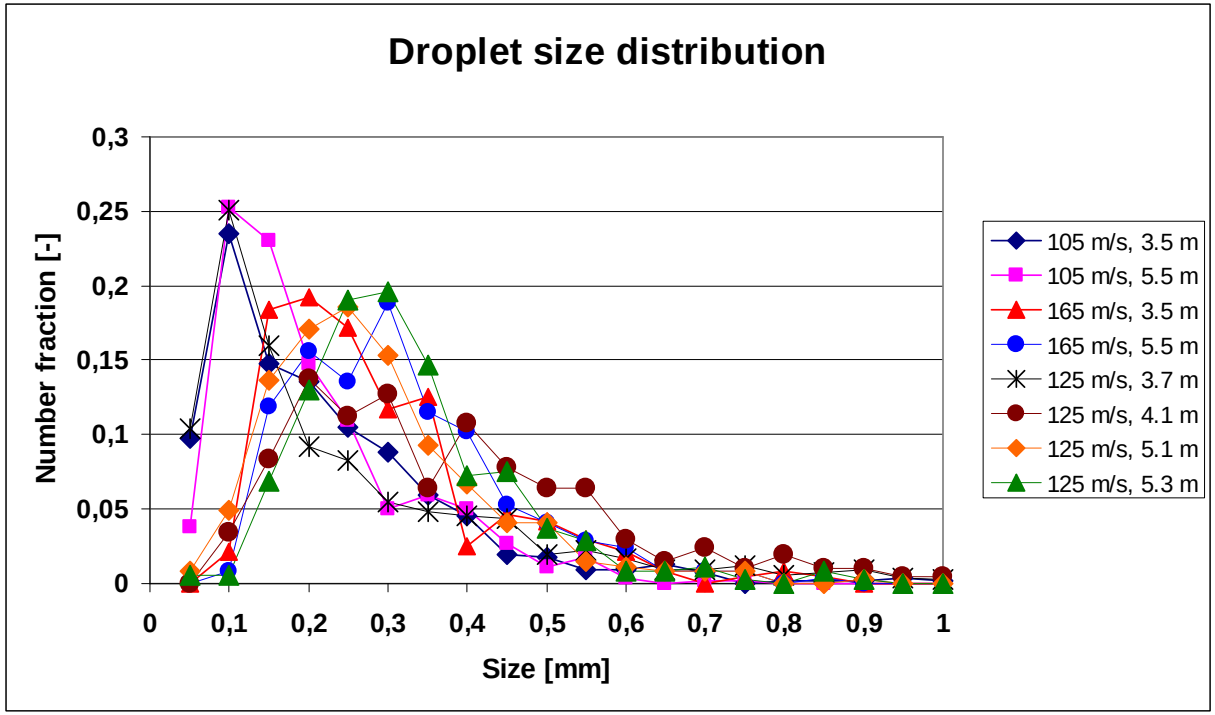
IMPACT test results:

size of deposited droplets on the floor

- Measurements in pipe-missile tests using the oil-coated plates on the floor
- The plates were photographed and the fotos were analysed using a specific image analysis software.
- The smallest droplet diameter that can be detected using this method is around 15 μm.
- Measured arithmetic mean diameter mostly of the order of 200 - 300 μm, in some tests slightly less.
- Droplet size not measured in the 3-D missile tests.

IMPACT test results:
size of deposited droplets on floor

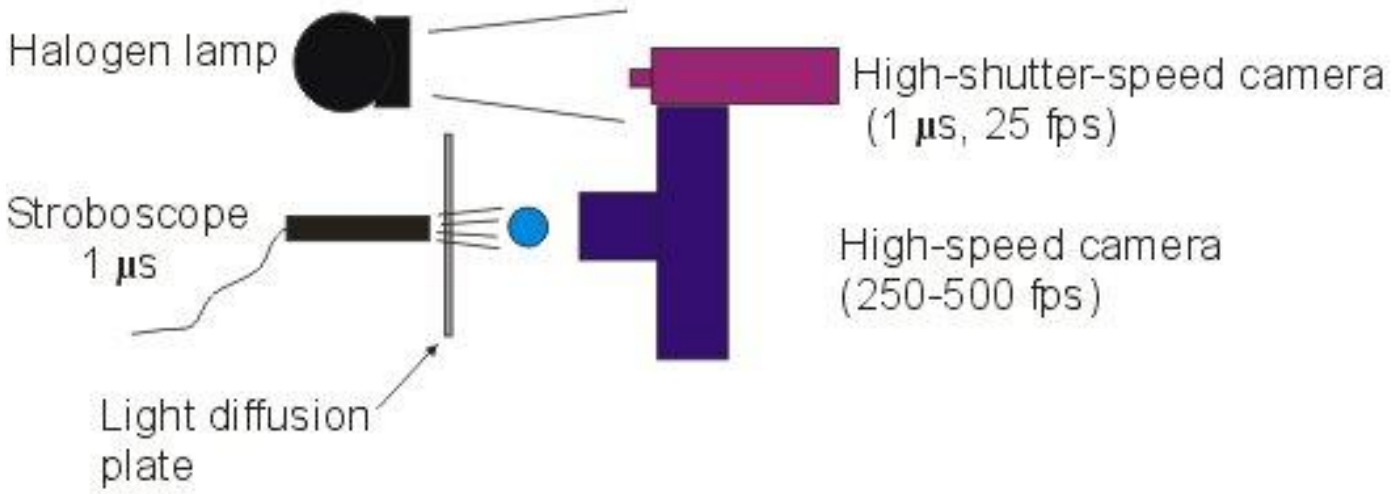




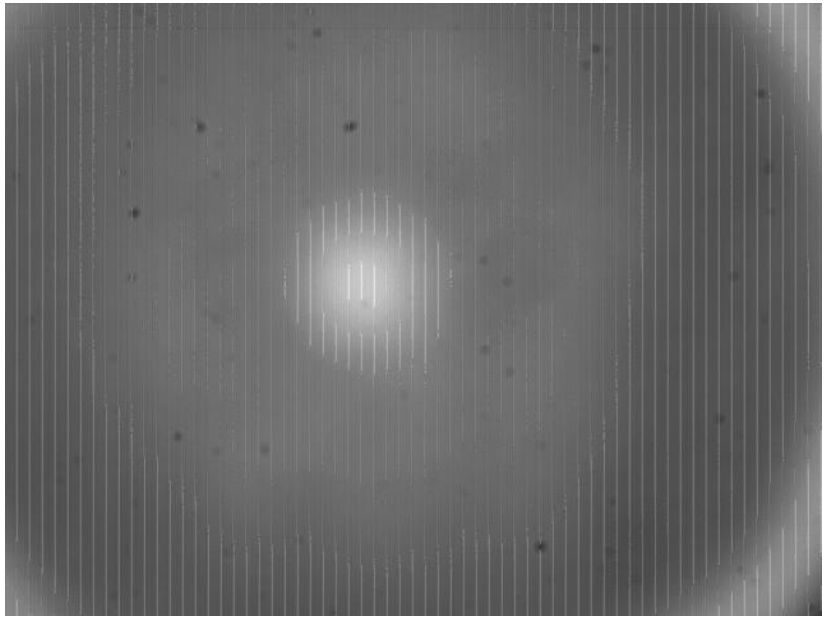
IMPACT test results:
size of flying droplets

- So far, measurements only in one pipe-missile tests
- Recorded with a high-speed video camera (250-500 fpd) using a stroboscope with 1 µs flash time for backlighting illumination.
- Analysis of the still figures using a specific image analysis software.
- Analysing work of the first test results under way.
- The illumination and sharpness of the images need still optimization, but the results so far are already good enough to get quantitative information about droplet size.

IMPACT test results:
size of flying droplets



IMPACT test video:
Flying droplets



Conclusions

- Wet missile IMPACT tests have provided useful and new information on the liquid release and spread in a high-speed impact.
- Important parameters needed for the boundary conditions of simulations, like droplet size, speed and spreading angle, have been measured, and related measuring systems /procedures have been further developed.
- The liquid splash/spread pattern from pipe and 3-D missiles behaves qualitatively differently in the impact.
- The initial discharge velocity of liquid stream may be much higher than the impact velocity, and consequently, the stable drop size of liquid spray is small resulting in fast deceleration of spray front.
- Liquid spreading sector is mostly less than 10 ^{o} from the wall tangent.
- The FDS code will be applied and validated in the future for simulatation of the liquid spread and resulting fires in the case of flammable liquid.