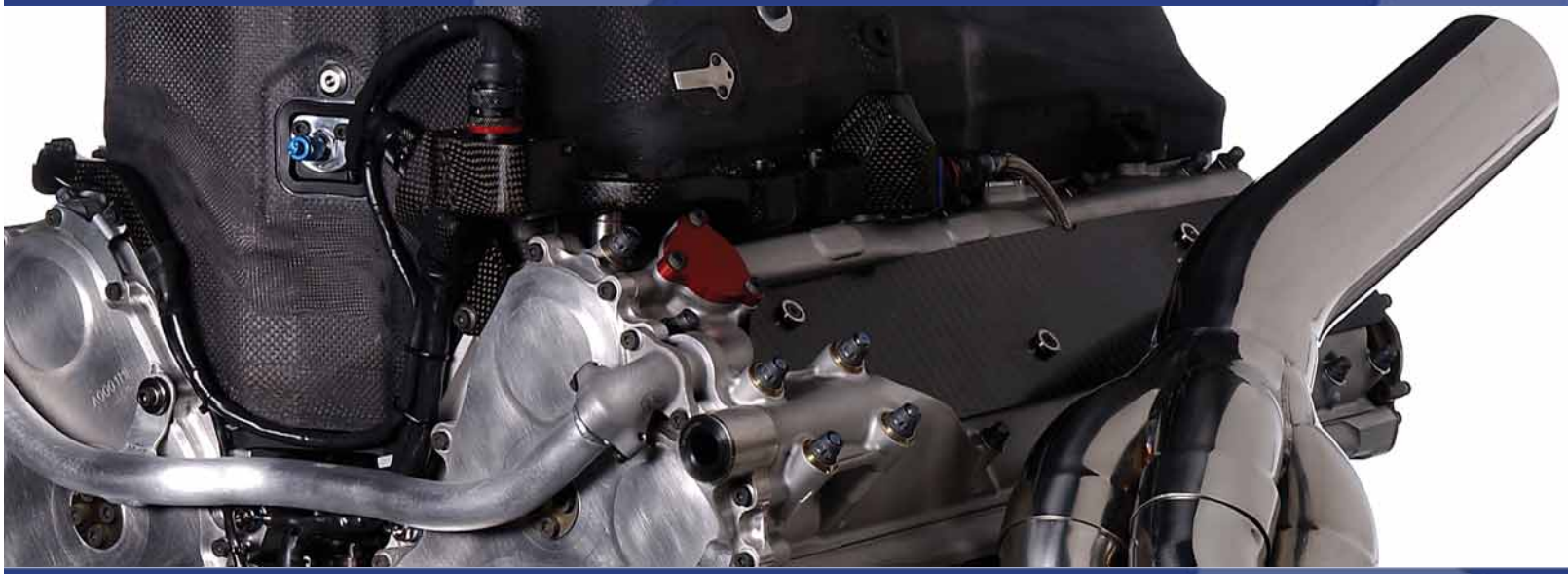

Integration of CAE into Engine and Vehicle Design

Richard Johns

Contents

- The RESEARCH –to ROUTINE CAE Pipeline
- An Example: Engine Spray Modelling
- Diesel Validation and Applications
- Gasoline Validation and Applications
- RENEWAL – refreshing the pipeline
- Modelling Atomisation – Renewal for Engine Spray Calculations?
- Summary

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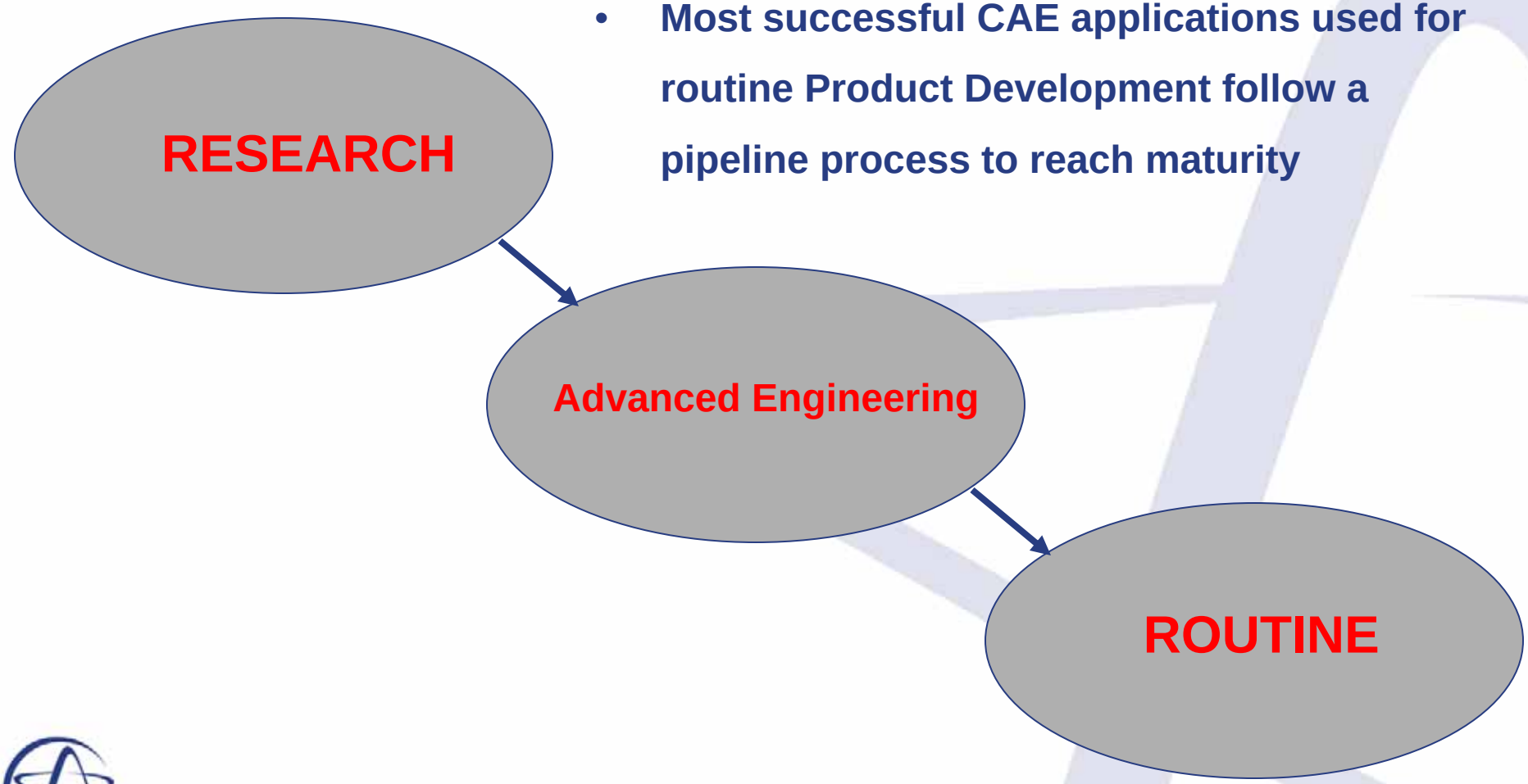
The RESEARCH – to – ROUTINE CAE Pipeline

- **Most successful CAE applications used for routine Product Development follow a pipeline process to reach maturity**



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The RESEARCH – to – ROUTINE CAE Pipeline

RESEARCH

- Opportunities through new engine technology
- Opportunities through modeling or computing developments

- Initial Feasibility Explorations

ADV. ENGINEERING

- Fundamental and Application-based measurements
- Modeling & Numerical Studies

- Assessment & Validation

- Process Development

ROUTINE

- Process roll-out & Initial Usage
- Development of Design Assessment Criteria

- Routine Usage

QUANTIFIABLE PAYBACK

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The RESEARCH – to – ROUTINE CAE Pipeline

- **The really clever bit…..**
  - Identifying the opportunity that a technology change has changed the *status-quo* and the impossible has become possible
- **The really fun bit…**
  - Understanding & modeling the fundamental physics – the first plausible demonstration calculations
- **The really tough bit…..**
  - Combined experimental and theoretical program to develop the modeling – identify and improve weaknesses, validation, quantify accuracy
- **The really valuable bit…..**
  - Developing a process that can be used routinely and “Rolling it out”

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An Example: Engine Spray Modelling

- First calculations of engine sprays using the Lagrangian Discrete-Droplet model appeared in 1980
- Following 25 years has been in refining that model :-
  - Droplet Dynamics – breakup, coalescence, dense sprays, turbulence interactions
  - Impingement & wall film dynamics
  - Advanced heat & mass transfer models
- Rig measurements may be required to set up model with confidence
- Calculations have been performed successfully by many OEMs and there are tangible results on production engines

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Current Approach to Engine Spray Modelling

- **The approach currently for spray simulation in engines is:**
  - Build fuel injection hardware
  - Detailed rig measurements to determine spray structure
  - Match CFD spray model results for spray structure in simple rig geometry
  - Build and run engine CFD model to understand how engine would perform
- **This has become routine in many Automotive OEMs:**

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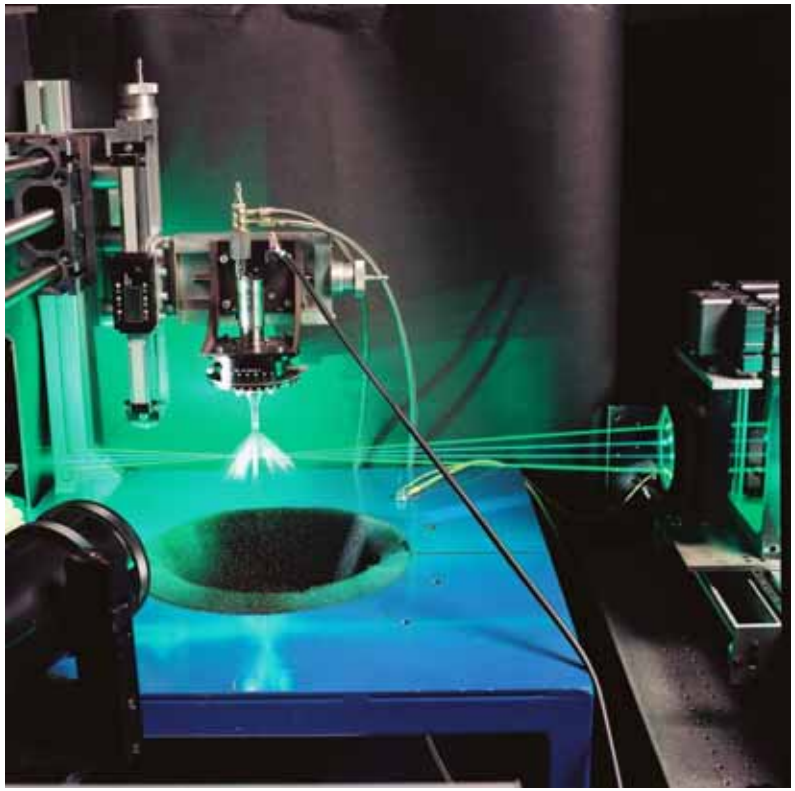
Engine Spray Modelling: Setup & Validation

Build Hardware & Measure on Rig

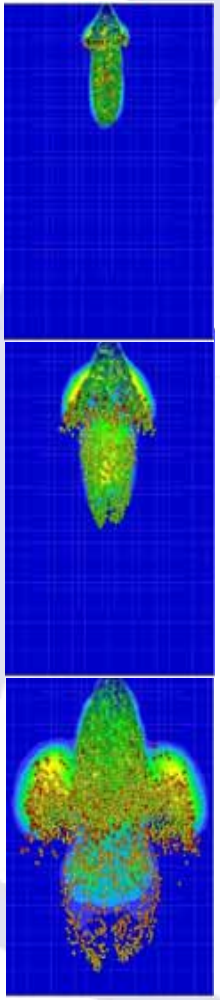


Courtesy of CD-adapco

Loughborough University

Measurement

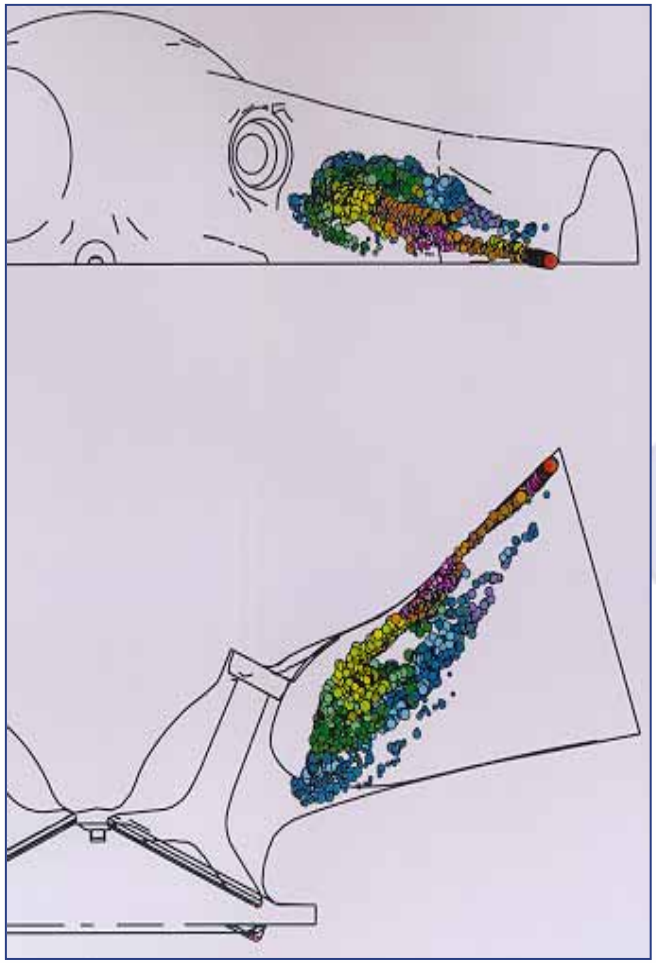
Computations



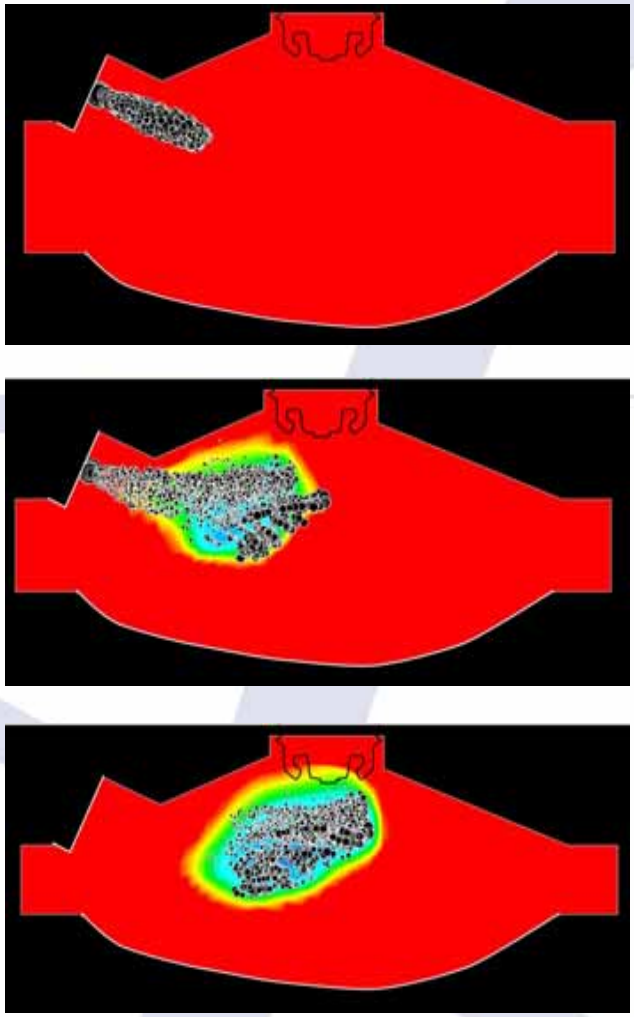
Courtesy of FEV

Gasoline Engine Applications

PFI



GDI



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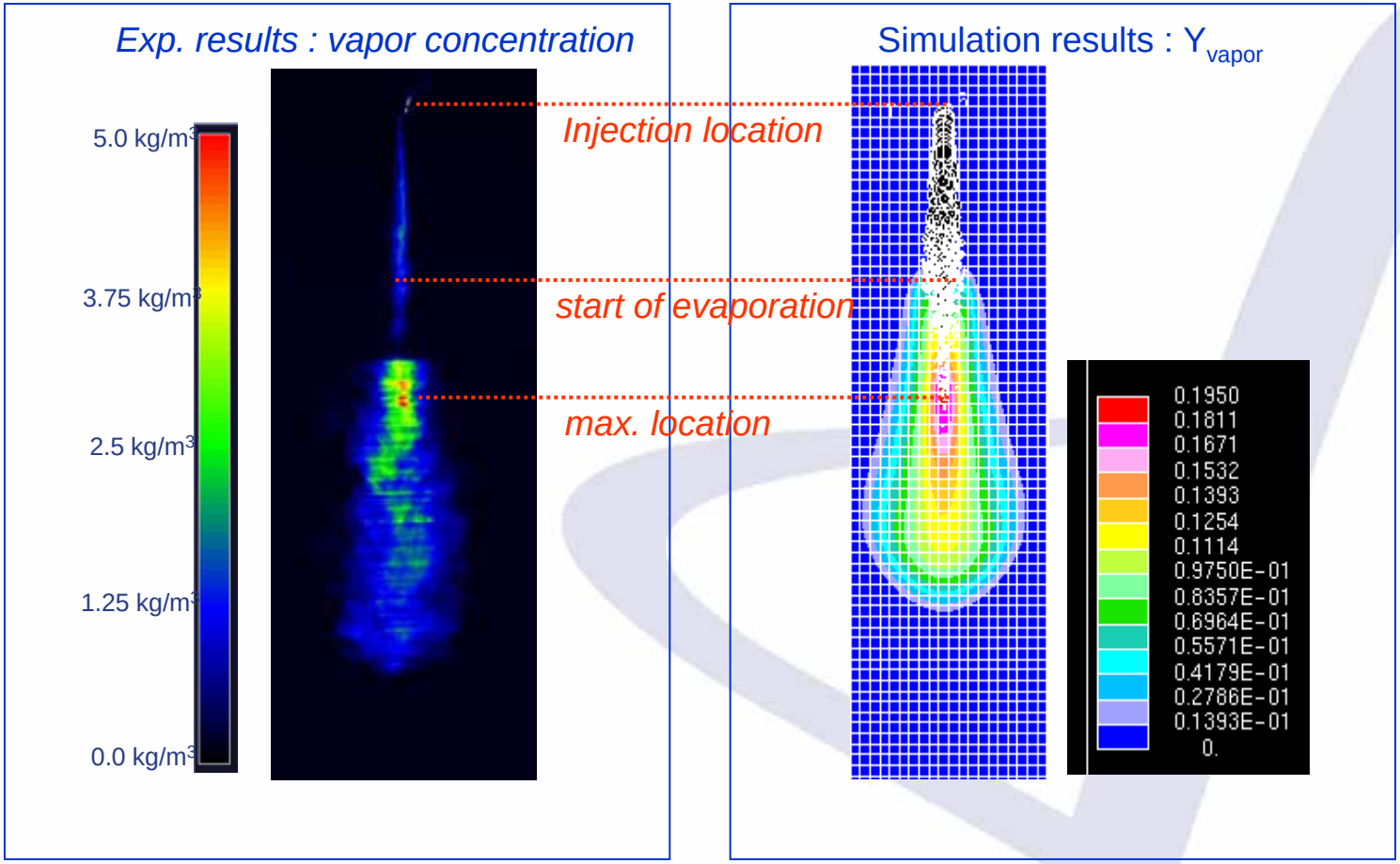
Courtesy of FEV

Diesel Spray Modelling Validation



LIF Technique for the Fuel Vapour penetration

Mie Diffraction for Liquid penetration

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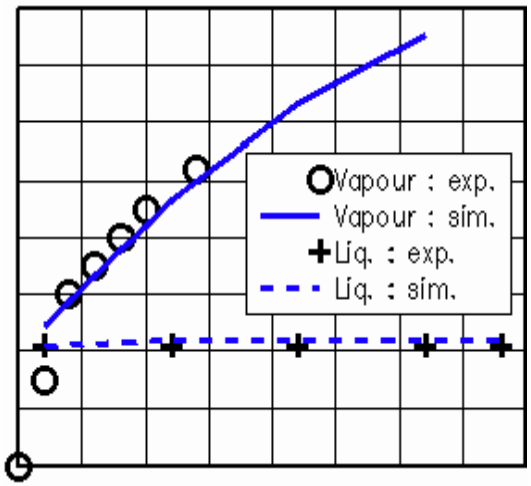
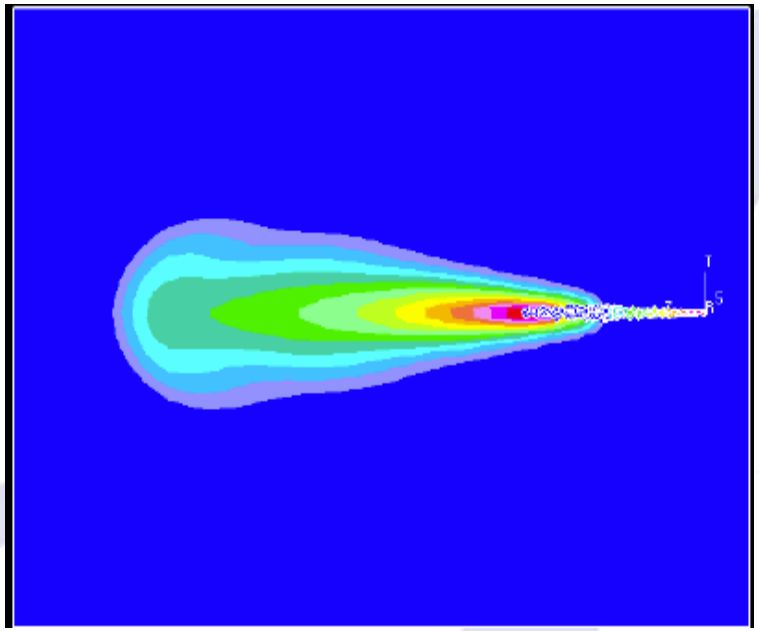
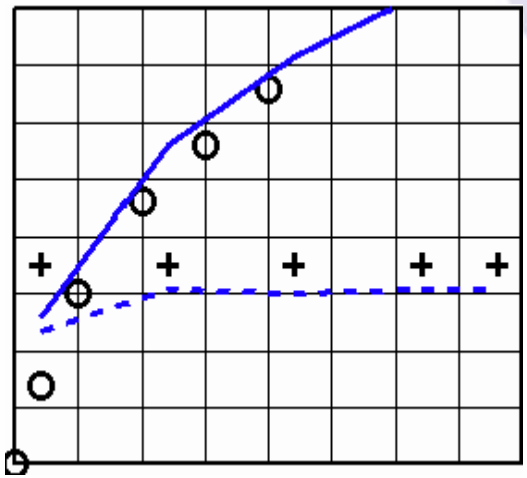
Courtesy of RENAULT

Diesel Spray Modelling Validation



Pinj = 800 Bar





Standard Nozzle model
HUH Atomization model
Reitz&al Break-up model

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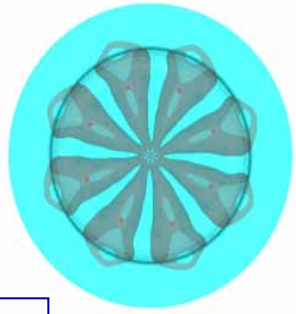
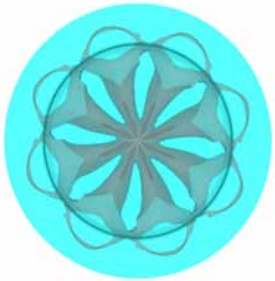
Courtesy of RENAULT

Diesel Engine Applications

Comparison with Combustion Photographs (flame luminescence)
Case 1 - 50 % Load - SOI = 3 deg BTDC



6.5 CA ATDC

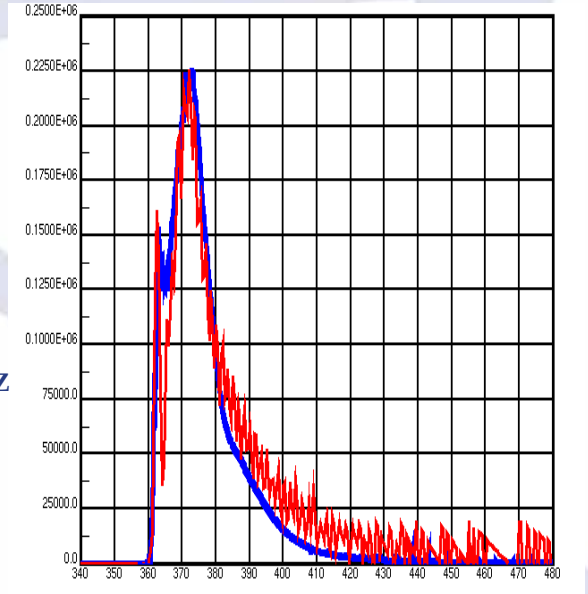


10 CA ATDC

experiments

STAR-CD/ECFM-3Z

ROHR (Watt)



C.A (deg)

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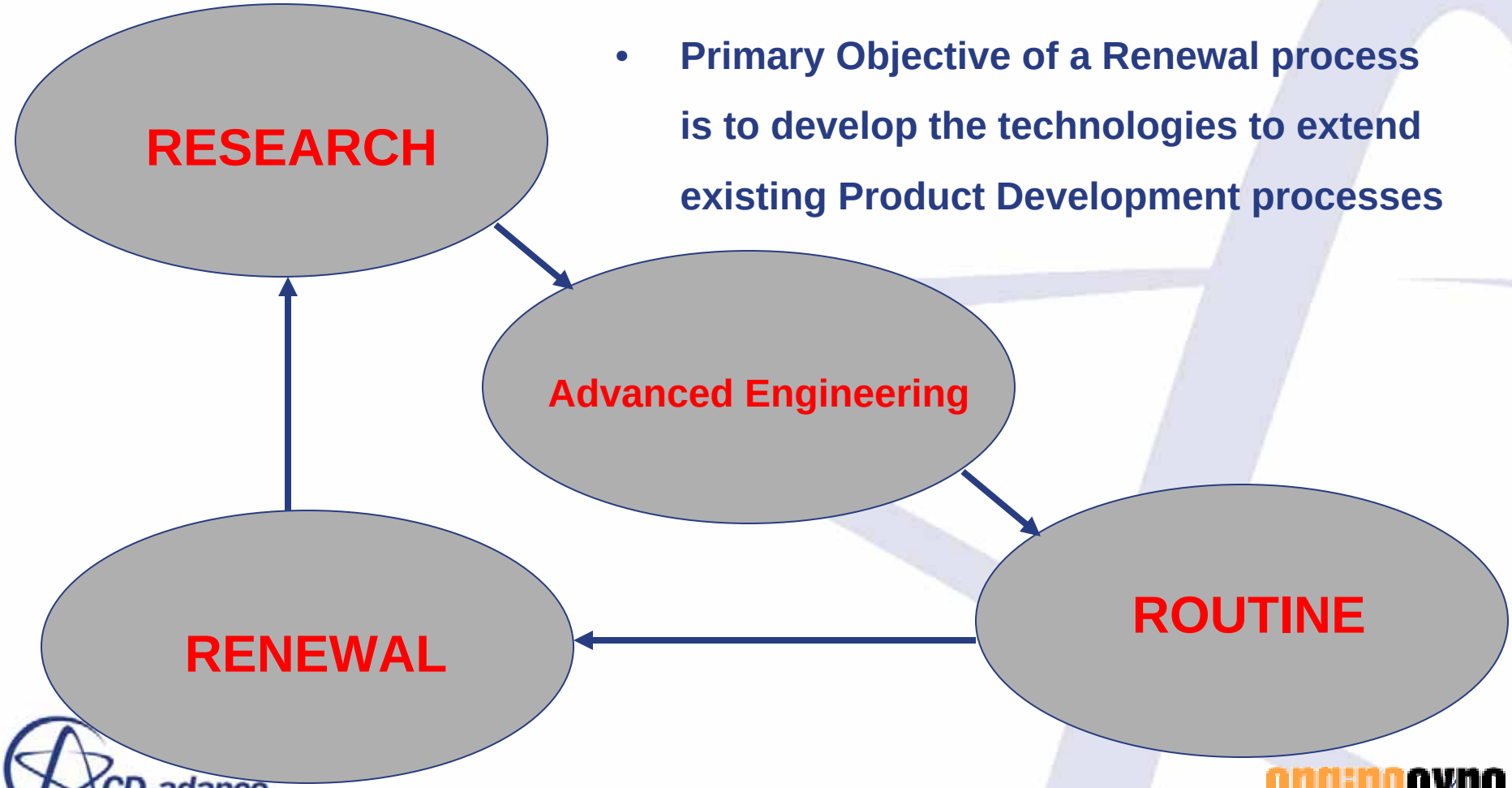
New Technology Challenges

- Developments in FIE – hardware & control - are stretching the current capabilities of CFD
  - Common Rail: multiple injections, very small injection quantities possible, high injection pressures
  - Gasoline injectors: new designs are challenging the accepted simple primary breakup models
- It is increasingly evident that the current generation of spray primary breakup models – the atomization process – is inadequate for the future
  - Time: - significant to make and test hardware and match analysis model data
  - Cost: - expensive rig, PDA and other laser-based systems
  - Design iterations too time consuming to be effective
  - No fundamental understanding of, and no predictive capability for the atomisation process

The RENEWAL process

RENEWAL: a key component of structured technology development



- **Primary Objective of a Renewal process is to develop the technologies to extend existing Product Development processes**

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Renewal: Prospects for Modelling Atomisation

- **A wholly analytical approach is desirable, however there are some difficulties!**
  - Underlying physics of high speed atomisation has been largely hypothesised as measurements at the small time and length scales of injectors is very challenging
  - Modelling and numerics are not trivial
  - Computing requirements are significant to resolve detail at micron and nanosecond level

- **However**
  - Measurements of spray structure (size and velocity pdfs, mass flux) a few diameters downstream of injector can be made with confidence for validation
  - 2-phase flow modelling – cavitation & free-surface and turbulence modelling – LES - have made significant advances
  - Low-cost clusters provide a cost-effective computing solution

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Prospects for Modelling Atomisation

- **Internal Research at CD-adapco has demonstrated:**
  - Calculations of primary breakup of a diesel spray (Buonfiglioli & Mendonca, Peric) are feasible using STAR-CD
  - This is achieved through a combination of Large Eddy Simulation (LES), 2-phase Volume-of-Fluid (VOF), sophisticated fluid/air interface tracking and efficient parallel scalability
  - Reasonable agreement with spray breakup length and angle have been obtained
  - More recently, initial calculations of a GDI gasoline injector have also been demonstrated
  - These calculations exhibit many of the known characteristics that occur during primary breakup, including the growth of surface waves

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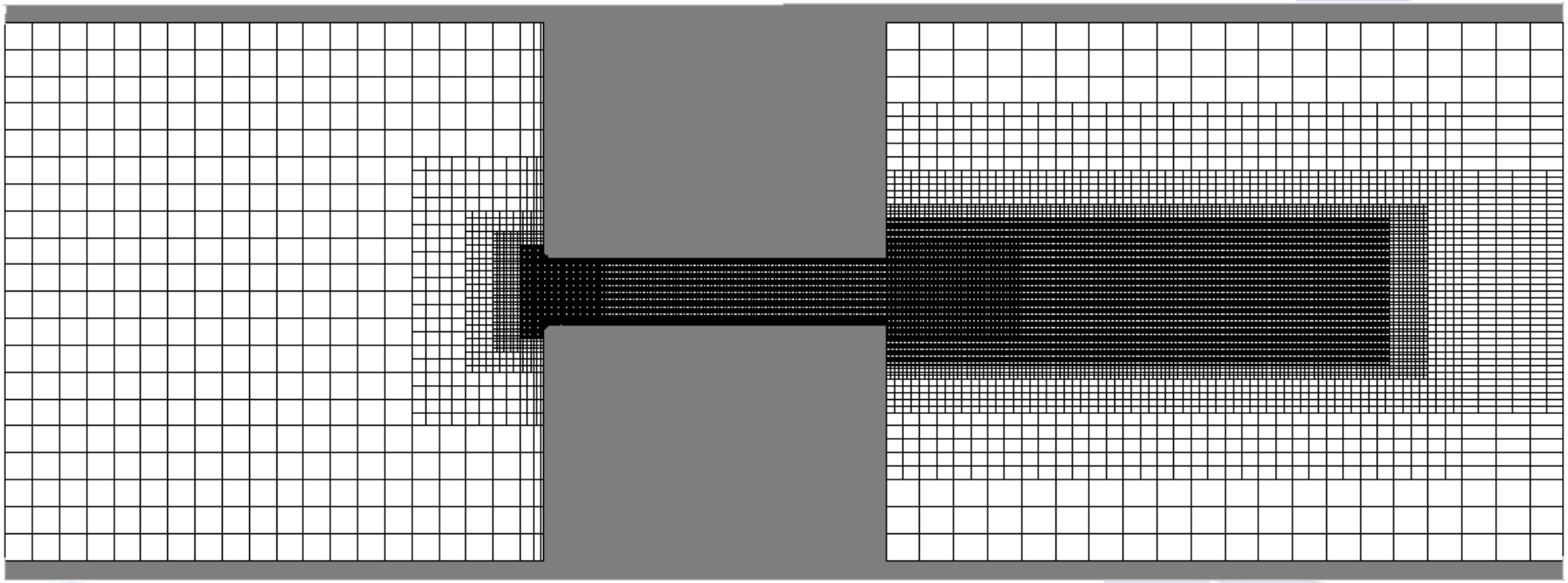
Diesel: Geometry and Boundary Conditions

The mesh has about 1.5 million cells

Nozzle diameter is 0.1 mm = 100 µm

Cavitation & Surface Roughness included

- Inlet pressure: 800 bar
- Outlet pressure: 10 bar
- Time step: 1.e-9 s (1 ns)



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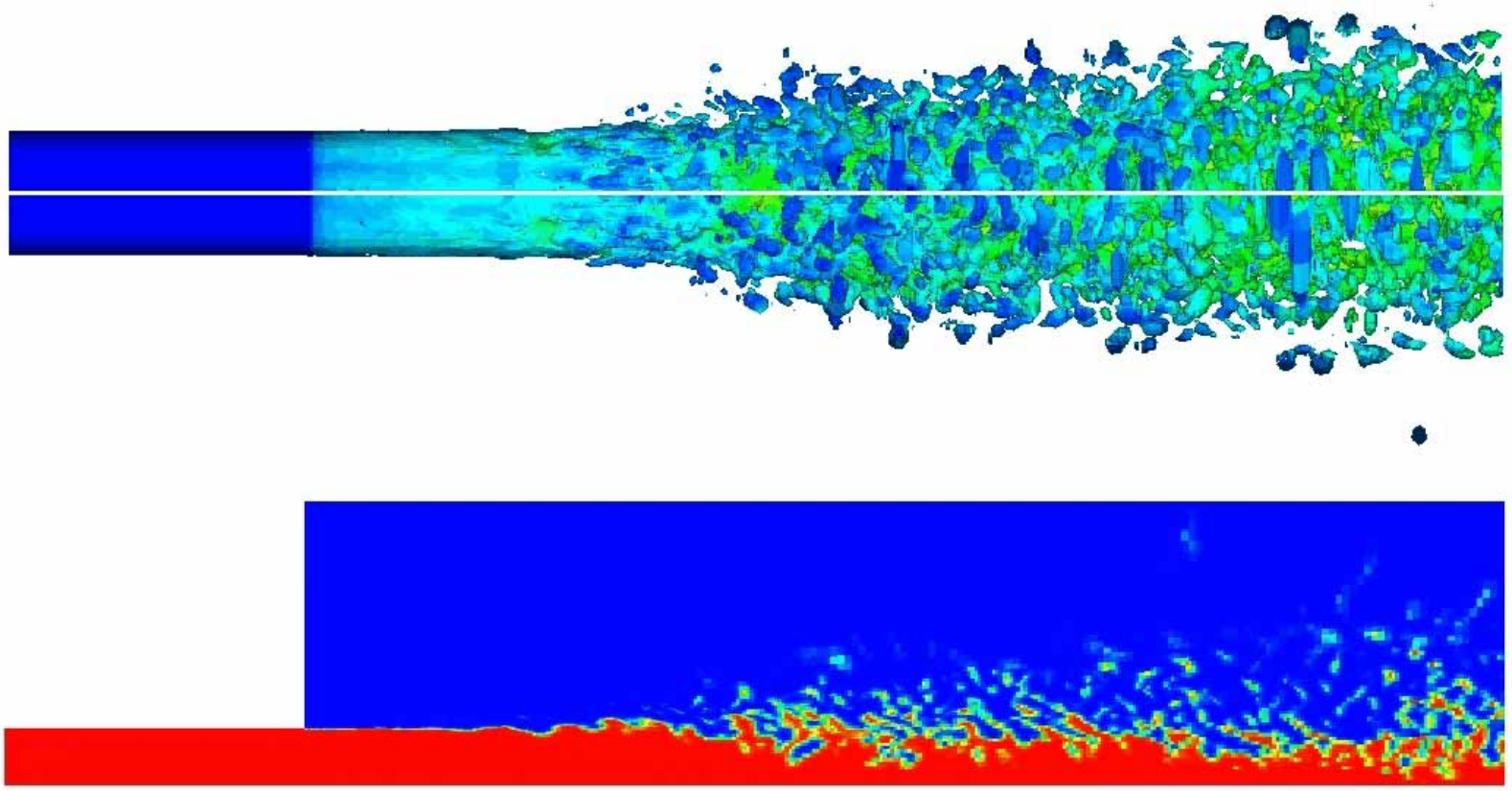
Free Surface and Centre-plane – diesel spray



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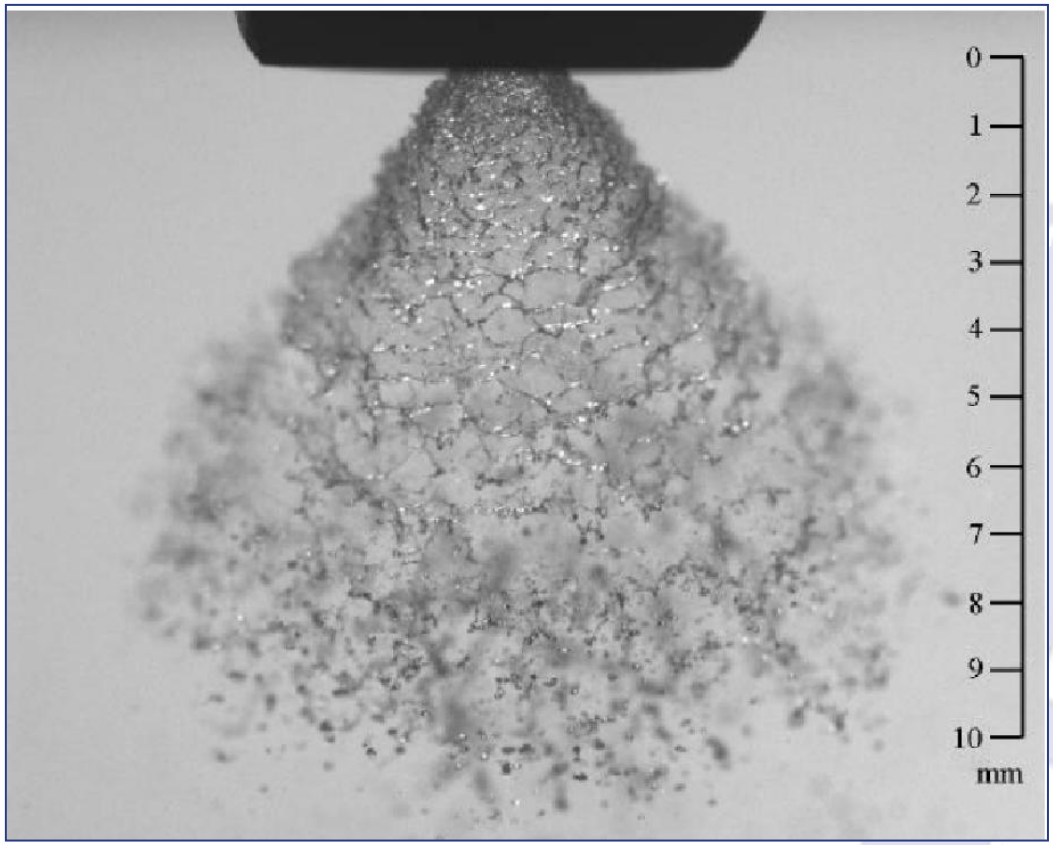
Gasoline Injection: the original GDI injector

- **Two Stages**
  - Formation of Ligaments
  - Breakup of ligaments into droplets
- **Clearly defined startup transient**
- **Air-core formation inside the injector as the swirl develops**



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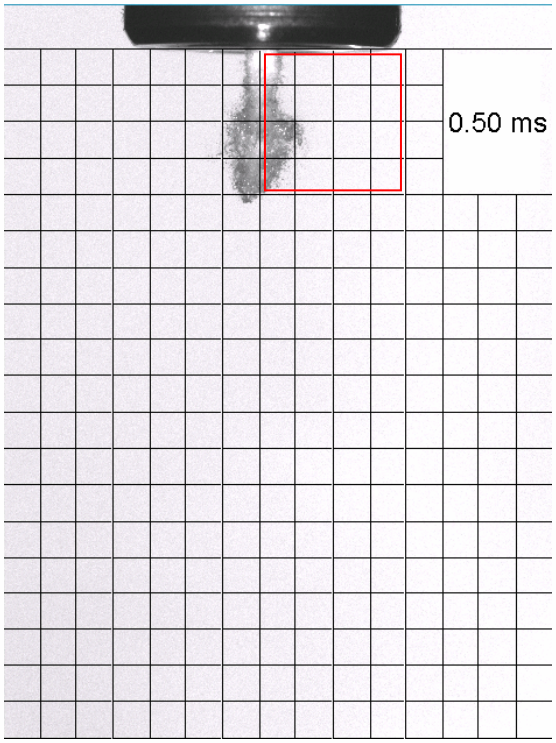
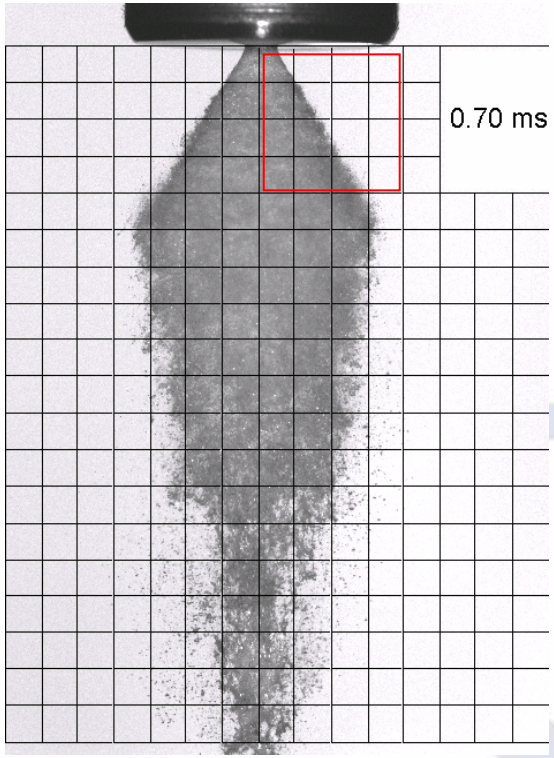
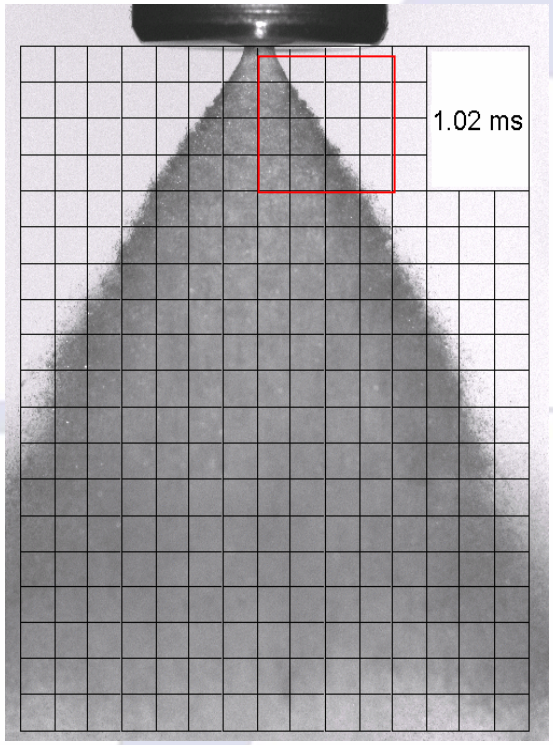
Spray development – experimental results



Startup Transient



Formation of Hollow Cone Spray



Full-developed Spray

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Courtesy of Loughborough University

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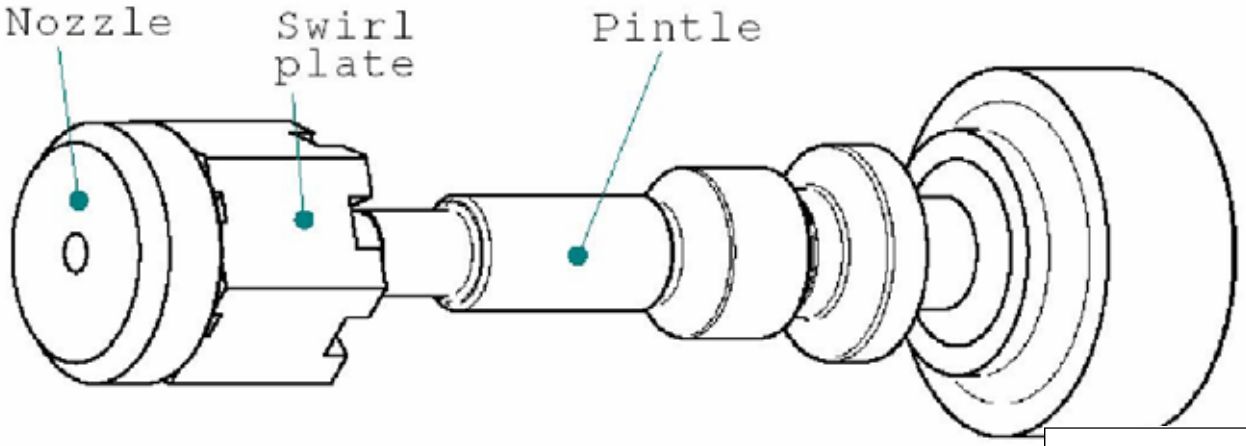
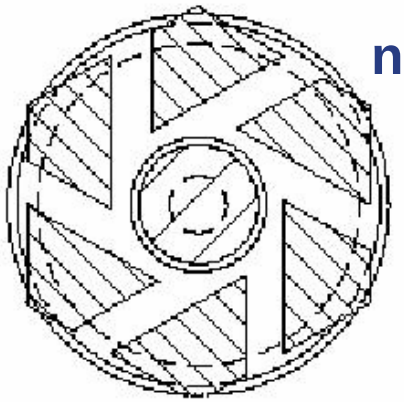
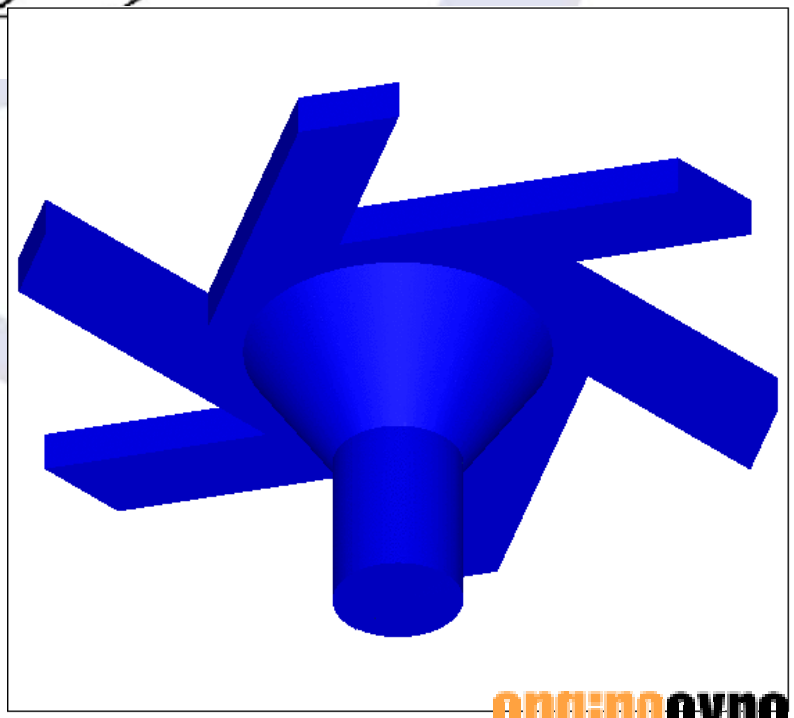
CFD Calculation: Injector model



Swirl ports : 60°

nozzle diameter : 0.9 mm





Computational Model

(60° sector run)

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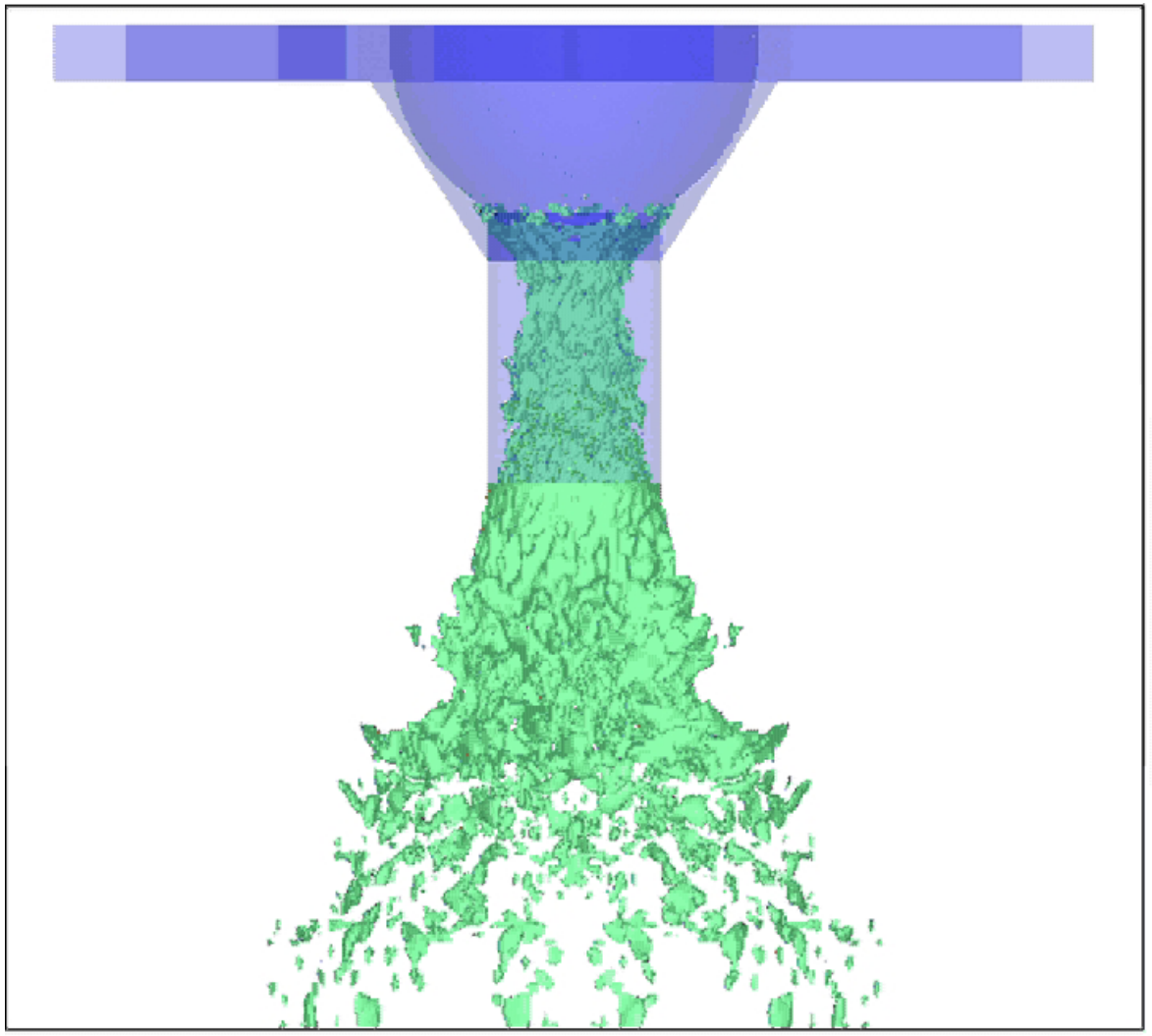
Gasoline Engine Hollow-Cone Spray



pro-STAR 3.2

17-MAR-06
SC 1-VOF

TIME = 0.365000E-03
LOCAL MX= 1.000
LOCAL MN= 1.000

1.001
0.9295
0.8580
0.7865
0.7150
0.6435
0.5720
0.5005
0.4290
0.3575
0.2860
0.2145
0.1431
0.7156E-01
0.6104E-04

Z
Y
X

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Summary

- There is an established process for modelling fuel sprays in engines that places reliance on experimental data
- The developments in FIE hardware and control now require a better understanding and predictive capability for atomisation
- Is the time right for Renewal of the Engine Fuel Injection CFD process?
- The capabilities for modelling atomisation already exist and have been demonstrated in a commercial CFD code – STAR-CD
- CD-adapco plan to establish a consortium project to develop the "*really tough bit*" of this technology to reduce the dependence on experiments

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