Coolant Behavior Consideration

Problem Definition

Question:
What impact does the release of coolant have on the mitigation of refrigerant ignitions?

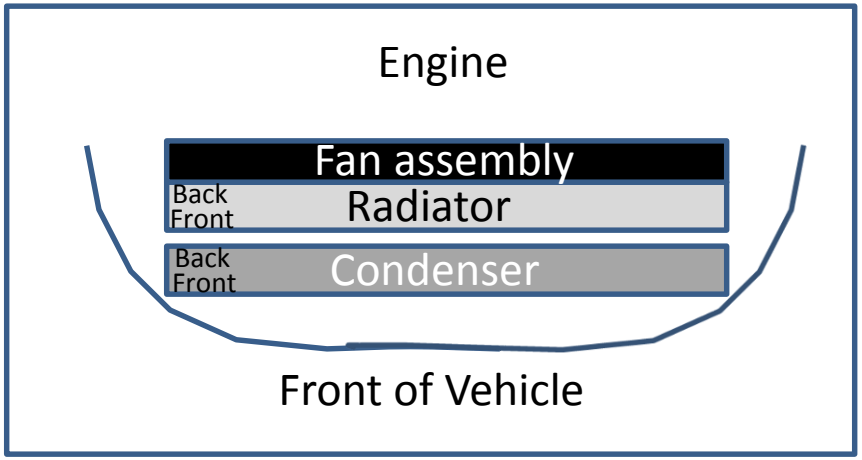
Hypothesis:
Releasing coolant will generate steam and aerosolized water particles that will drive out oxygen and quench ignition

Methodology:

1) Rate of occurrence of radiator breach through CAE & crashed vehicles
2) Impact of steam during actual vehicle testing
3) Relevance of timing: steam generation vs presence of refrigerant
4) Conclusions

Rate of Occurrence of Coolant Breach

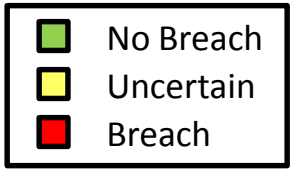
- CAE and Crashed Vehicles -



Radiator Breach Behavior

Question:

Coolant expected to have significant mitigating impact, but how often radiator breach occur during collision?



CAE Analysis – frontal collision

Vehicle	Component	Speed (kph)							
		20	25	30	35	40	45	50	55
Vehicle #1	Condenser	n/a	n/a						
	Radiator	n/a	n/a						
Vehicle #2	Condenser								
	Radiator								
Vehicle #3	Condenser								
	Radiator								

CAE analysis indicates that radiator will always breach
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system

Radiator Breach Behavior (2)

How often radiator breach during a collision?

<u>Vehicle Data</u>– frontal collision

Vehicle	Speed (kph)	Radiator	Condenser
Vehicle #1	56		
Vehicle #2	42.5		
Vehicle #3	45		
	45		
	45		
	50		
	50		
KBA #1	40		
KBA #2			
KBA #3			
KBA #4			

No Breach
Breach

Vehicle data from actual crash tests validate CAE analysis → radiator always breached
- at lower speeds than that required to breach the A/C system or
- during a collision severe enough to breach A/C system

Impact of steam during actual vehicle testing

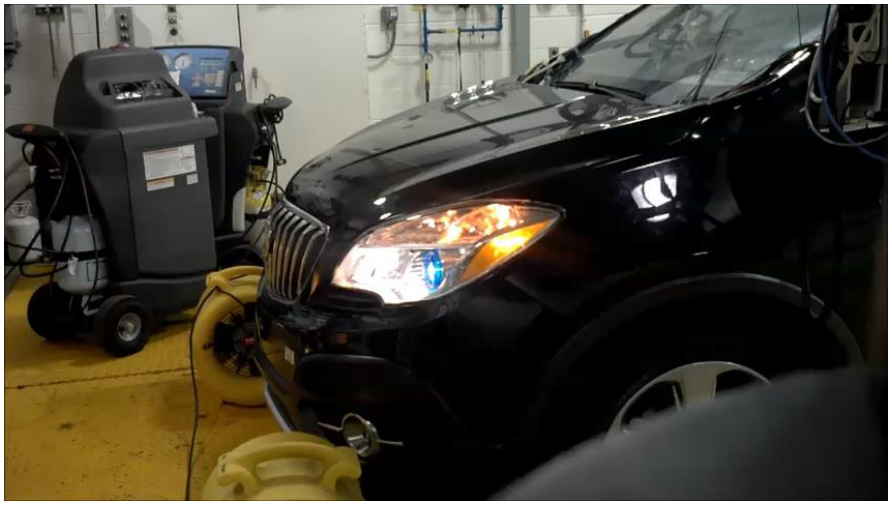
Steam Impact – Release Testing

Test Setup:

- Modified nozzle, fully tuned system for ignition, > 790°C surface temps, fan off

Configuration	# tests	Result
No coolant release	5	Ignition (5/5)
Coolant Release	5	No Ignitions (0/5)

Sample of release test showing steam impact:



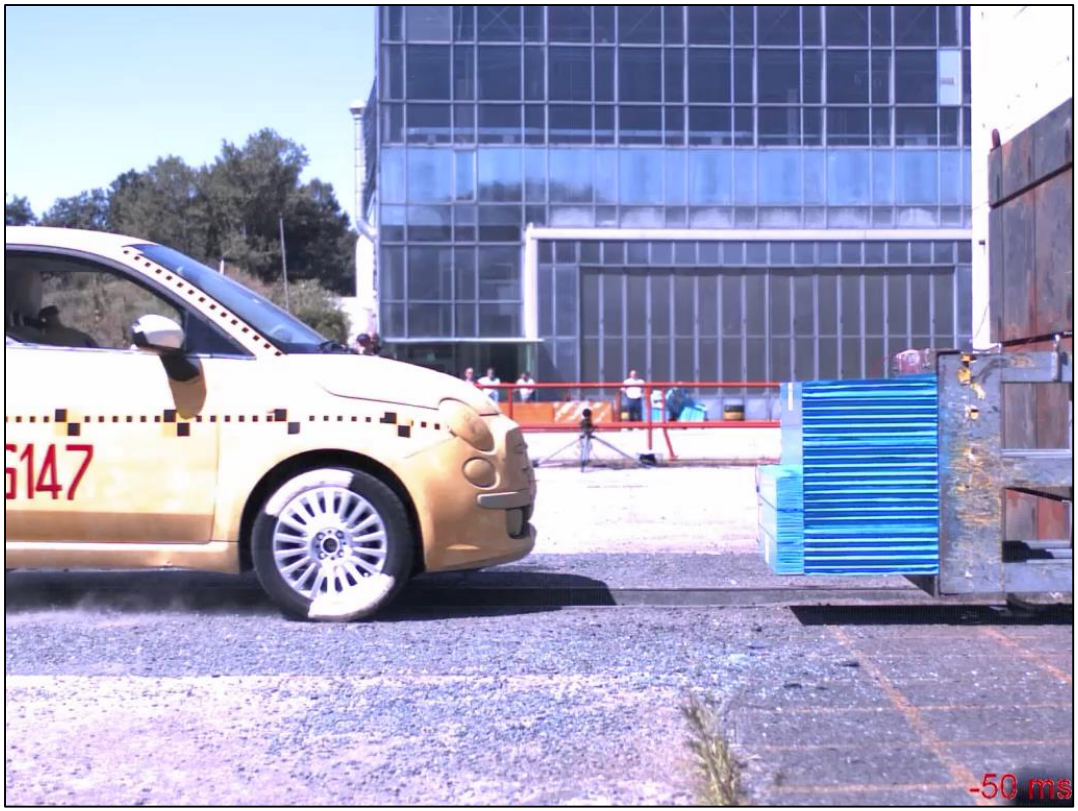
Coolant release always mitigated ignition of refrigerant

Steam Impact – full hot/wet crash tests

Test Setup:

- Production level vehicle, all fluids, >350°C surface temp, 64kph, ODB

Sample of release test showing steam impact:



Slow motion

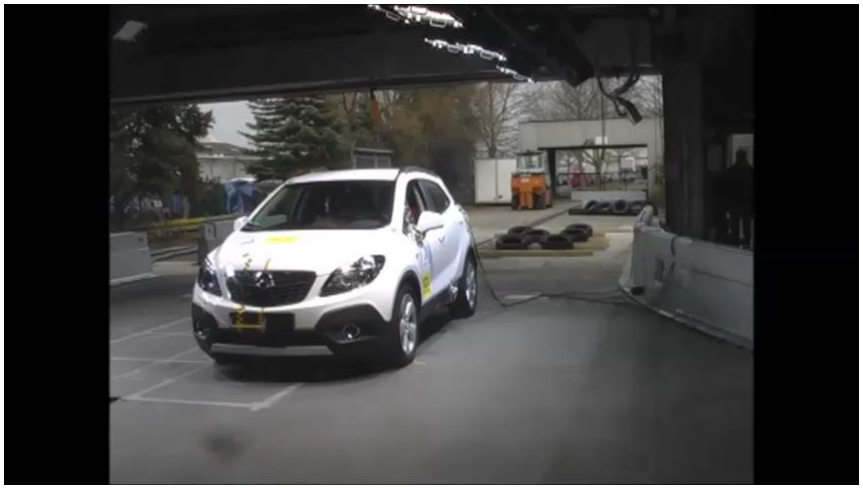
- **Coolant release occurred, steam observed**
- **Refrigerant ignition did not occur**

Steam Impact – full hot/wet crash tests

Test Setup:

- Production level vehicle, all fluids, 750 - 790°C surface temps, 45kph - 50kph

Sample of release test showing steam impact:



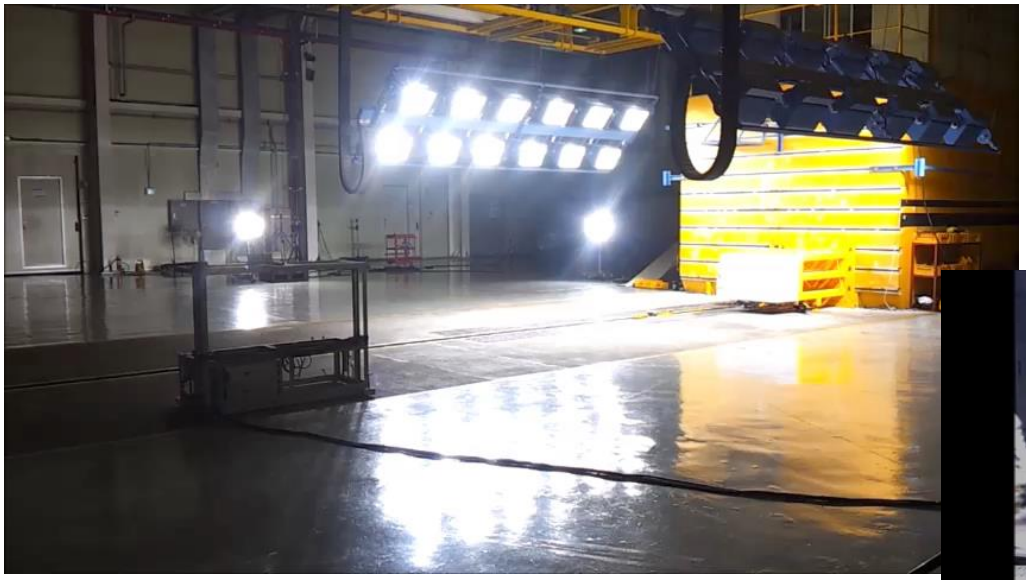
Coolant release always occurred. Refrigerant ignition never occurred

Steam Impact – full hot/wet crash tests

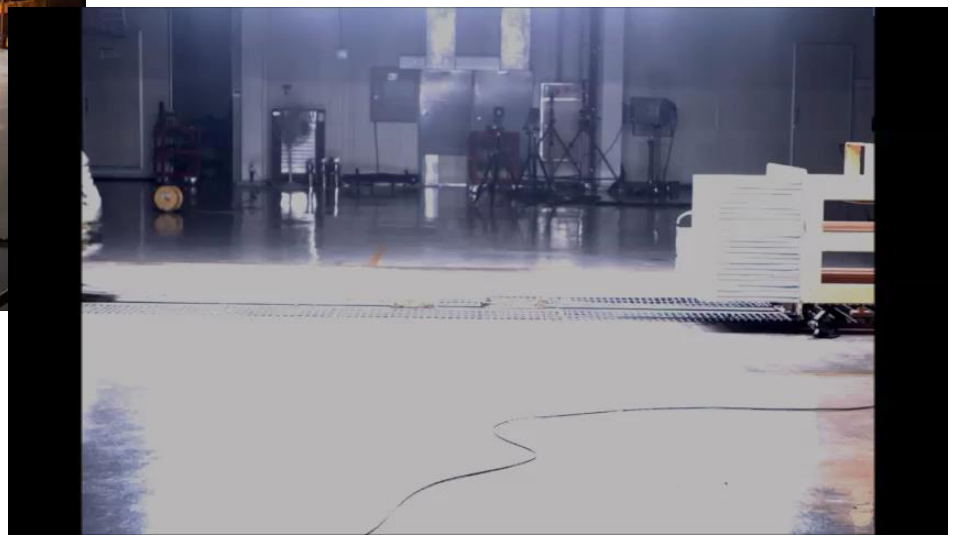
Test Setup:

- Production level vehicle, all fluids, 540°C surface temp, 64kph, ODB

Sample of release test showing steam impact:



Real time



Slow motion

- **Coolant release occurred, steam continued for > 1 minute after collision**
- **Refrigerant ignition did not occur**

R1234yf implementation progress

New C4-Picasso (**June 2013**)

- New Efficient Modular Platform with reduced weight and very low CO2 emission → environmental reference
- First PSA vehicle with R1234yf
- 1.6 turbocharged gasoline versions available → focus on this version in the next slides
- Base for C4 Picasso and New 308 programs

Safety measures to address the flamability risk

- In the case of a crash :
  - A/C system component damage leading to a refrigerant leak : **Location and materials used to mitigate the risk (high bending ability before a leak)**
  - In a severe temperature situation : **specific design of the air intakes, fan strategies, specific design of the heat shields to lower the skin temperatures of the critical components)**
  - Critical concentration : **specific design of the heat shields to**
    - **Either limit the fluid trapping around hot surfaces (e.g. exhaust manifold)**
    - **Or insure a good thermal insulation to avoid contact with hot surfaces (e.g. catalysis system)**

Event Tree Analysis discussion

- Qualitative ETA constructed simultaneously with the CRP
- Quantification evaluated with public databases, and in-house statistical surveys of the customer usage (including german customer)

- Target : no significant increase of the fire risk in the case of a crash, compared with a preexisting vehicle
  - Pre-existing risk in the field : 8.10^{-9} per hour
  - Derived from fleet crashes statistics, French Police database, all brands
  - Target per hour of 10^{-9} as used in the SAE CRP and similar Functional Safety Standard such as ISO26262
    - ISO26262 is applicable for E/E systems
    - Nevertheless it provides figure for proven-in-use validation of E/E systems that could lead to a vehicle fire (e.g. EV Battery charging systems)
    - Most stringent target is 10^{-9} for an ASIL D system

ETA validation : Crash tests - Test protocol

- Selection of worst-case crash test parameters
  - Sufficient collision speed to break the AC system while limiting the hood opening
  - Reach a critical thermal level in the engine compartment (known as able to ignite the refrigerant from previous studies) → (>700°C)
- Conditions actually used for the tests
  - Engine warm-up at 4000 rpm with specific calibration, 0 km/h, T° reaches a level well above the treshold (>730°) : worst temperature reachable on the crash test rig (much lower probability than the 1% of the ETA)
  - Front right-side crash, 35 km/h, 40% overlap, rigid barrier : worst-case scenario selected (much lower than the probability in the ETA)
- Vidéo : New C4 Picasso turbocharged gasoline engine front crash
  - A/C system breaks with refrigerant leak
  - Engine Cooling system leaks
  - Hood stays in place mostly untouched

Good representation of worst-case collision scenario
→ No ignition

PSA Crash Test Protocol

Relevance of Timing

- steam generation vs presence of refrigerant -

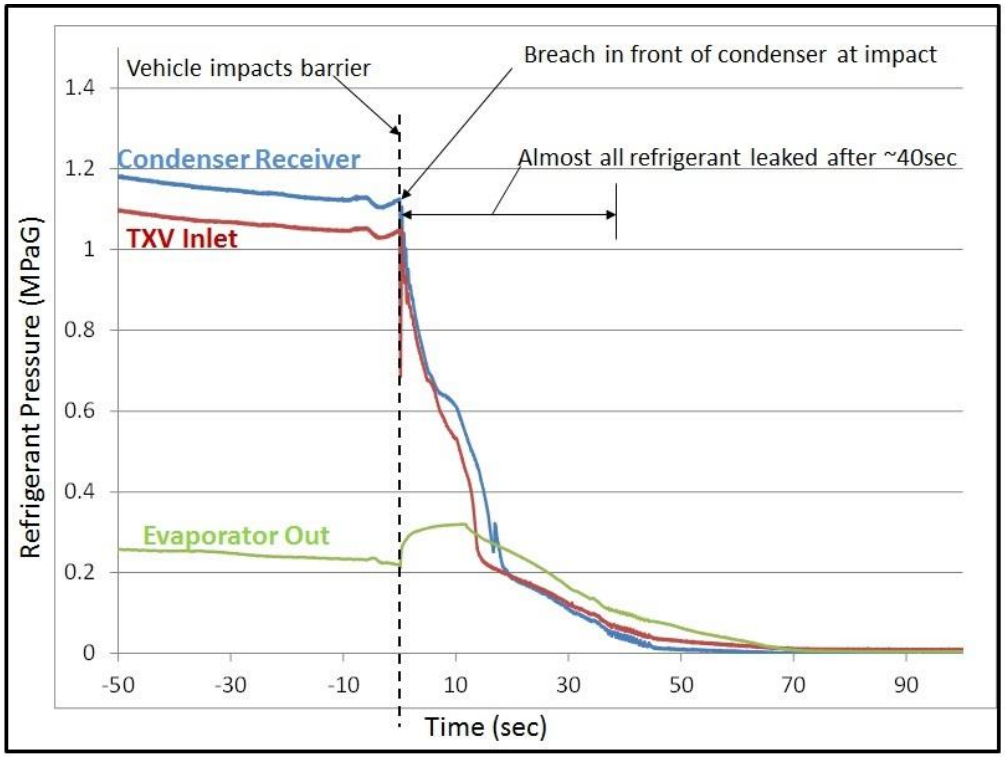
Timing of Steam Generation vs Refrigerant Release

Question:

Calculations may show that coolant has a mitigating effect, but do the 2 occur at the same time and in the same location?

Evidence:

Refrigerant often leaks out < 60sec



Steam generated for minutes

This picture is 125 sec after collision (continues for many more minutes)

Steam generated in same location and for longer time than refrigerant concentration

Conclusions

- **Coolant release significantly mitigate refrigerant ignitions**
  - CAE simulations indicate radiator will always breach
    - At lower speeds than A/C system breach occur or
    - During collision severe enough to damage A/C system
  - Real crash data validate CAE simulations
  - Release tests demonstrated coolant significantly mitigates refrigerant ignition
  - Crash testing showed
    - Coolant released during testing
    - No ignitions observed

All data collected demonstrates that coolant release significantly mitigates refrigerant ignition/propagation