

Analysis of Damage Caused to Vehicle Body Panels by Impacting Hail and Various Tools and Objects

Nikola Josevski, Andreas Sandvik, Chris Jones, Tandy Pok, Tia Orton and Shane Richardson
Delta-V Experts

ABSTRACT

On the 25th December 2011 there was a hail storm in the state of Victoria, Australia, which caused approximately AU \$712 million worth of damage. Some of this damage was caused to passenger vehicles. The authors conducted a number of inspections of hail damaged vehicles as a result of insurance claims being disputed or rejected on the basis that some, or all, of the alleged hail damage was not created by hail but instead created intentionally by the vehicles' owners with the use of different tools and/or objects. As a result of the inspections and investigations of potentially fraudulent claims, the authors conducted a total of 119 tests designed to replicate damage caused to vehicle body panels by impacting hail and to recreate claimed hail damage by using tools and other objects. To do so, the authors created two sizes of hail: Ø20mm and Ø40mm hail. A total of 15 impact tests were conducted with Ø20mm hail. The impact speed for the Ø20mm hail varied between 75km/h and 144km/h, with the average being 113km/h. A total of 50 impact tests were conducted with Ø40mm hail. The impact speed for the Ø40mm hail varied between 66km/h and 133km/h, with the average being 101km/h.

The testing impact speeds were generally higher than the terminal velocities of the corresponding hail, so the damage observed is expected to be an over estimation of the actual damage caused by hail.

The hail was projected at the test vehicle using a purpose built projectile launching device that used a sling-like mechanism to project hail in a horizontal direction at a test vehicle. The test vehicle was a white coloured 2001 model Holden Commodore with non-metallic paint. The body panels tested were: bonnet, roof, boot, all four doors, the vehicle pillars and cant rail. High speed cameras were used to determine the impact speed of the hail. Damage was photographed and recorded. In addition to impacting the vehicle with hail, a number of different tools and objects were used to recreate man-made damage. Tools and objects used were: claw hammer (conventional), welding hammer, ball-peen hammer, mason hammer, lead ball sink in a sock, golf ball in a sock, ratchet, breaker bar, crowbar and centre punch. The conducted tests revealed the following findings:

1. hail impacting the vehicle body panels will not scratch or mark the paint but the paint may chip if hail impacts the vehicle near a fold or edge of a panel;
2. dents caused by hail will cause the light to move smoothly and continuously across the dent and the light will not 'break' or crease;
3. where dents were caused by tools and objects the light will crease into multiple (two or more) distinct areas as it passes over the dent;
4. scratches and/or markings in the paint were identified on dents caused by tools and objects;
5. folds and curves on the panels did not affect the size of the dent caused to the panel; using the same tool and force to impact two different body panels (A-pillar and roof) resulted in dents that were very similar in physical appearance;
6. for the same impact speed the larger Ø40mm hail caused more damage than the Ø20mm hail;
7. For the same size hail the higher impact speed hail caused more damage.

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INTRODUCTION

On the 25th December 2011, a hail storm struck Melbourne and the surrounding areas, which caused approximately AU\$712 million worth of damage [1]. Some of this damage was caused to passenger vehicles.

The authors conducted a number of inspections of hail damaged vehicles across Victoria, Australia, as a result of insurance claims being disputed or rejected on the basis that some, or all, of the alleged hail damage was not created by hail but instead created intentionally by the vehicles' owners with the use of different tools and/or objects.

As a result of these inspection, the authors conducted testing intended to provide means for objectively analysing damage caused by hail striking a vehicle and assessing the probability of non-hail damage to the vehicle, which includes man-made damage.

A series of repeatable tests, including launching ice projectiles designed to replicate hail at a test vehicle, were conducted to recreate damage normally caused by hail striking a vehicle. The damage caused by these ice projectiles was compared to the damage caused by using different tools to intentionally cause 'man-made' damage.

The aim of the testing was to provide an objective method that allows for an assessment of the damage caused to vehicle body panels by hail impacting the vehicle and identification of any damage that was not caused by hail impacting the vehicle but instead was caused by other means (man-made damage using tools and/or other objects, environmental damage such as branches falling on vehicle, normal wear and tear, etc.).

Economic Damage

The Historical Disaster Statistics available from the Insurance Council of Australia for hail events in the past 10 years (Table 1). There were at least 11 events across Australia classified as hail events. The normalised cost of the 11 events is approximately AU\$3.20 billion, or approximately AU\$291 million per event.

It is important to note that this cost includes the total cost of the events, which includes building damage, contents damage, vehicle damage and other. Even if it is assumed that only 20% of all damage caused was to vehicles, then the normalised cost of vehicle damage per event would be approximately AU\$58 million.

Formation of Hail and Graupel

Field et al [2] identified hail are lumps of ice/water/air mixture with sizes greater than Ø5mm that are generally opaque with layered structure. For hail sizes between Ø5mm and Ø10mm they generally appear spherical or conical. For hail sizes between Ø10mm and Ø20mm they tend to be ellipsoidal or conical. Larger than Ø10mm and up to Ø50mm hail may take on ellipsoidal shapes with lobes, while still larger hail between Ø40mm and Ø100mm appear irregular (including disk shapes) with protuberances.

Hail and graupel form in the updrafts of convective storms at temperatures colder than the freezing point of water (0°C). There are two main routes to the formation of hail, but both proceed through the accretion of supercooled liquid droplets. It is easier to understand the growth of hail by considering the evolution in an air-relative frame. In this frame the cloud droplets are essentially stationary and collectors fall through the field of droplets.

One route is for an ice crystal or aggregate of ice crystals to act as the collector and fall through the droplet field and rime by collecting droplets that freeze, increasing the mass of the particle, its fall speed and the rate of droplet collection. The latent heating effect of the droplets freezing determine if the growth will be 'dry' or 'wet'.

Dry growth hail

If the growing particle is able to lose heat to the atmosphere faster through diffusion than latent heat is released from the droplet freezing then the surface will be ice, colder than 0°C and the layers will build up containing many air bubbles. Another way to think about dry growth is like this: Dry growth hailstones grow when the air temperature is well below freezing and the water droplet freezes immediately as it collides with the ice particle. The air bubbles are 'frozen' in place, leaving cloudy ice [3].

Wet growth hail

If the latent heat is released faster than it can be diffused away from the particle then the liquid water will exist on the surface, air can escape and ice will build up with few air bubbles included. Another way to think about wet growth is like this: In wet growth, a tiny piece of ice is in an area where the air temperature is below freezing, but not super cold. When the tiny piece of ice collides with a supercooled drop, the water does not freeze on ice immediately. Instead, liquid water spreads across tumbling hailstones and slowly freezes. Since the process is slow, air bubbles can escape resulting in a layer of clear ice [3].

Graupel

Graupel is soft hail or snow pellets, but very soft compared to hail. Early in the accretion process the accretion is generally through the dry growth mode leading to the formation of graupel.

Graupel appears as white, opaque and conical (sometimes irregular) pellets with sizes up to 5mm. If the graupel is exposed to more supercooled liquid it will continue to grow into a hailstone. The formation of a graupel can be thought of as the generation of a hailstone embryo. The other common embryo for hailstone formation is a frozen rain drop which acts as the collector falling through the supercooled droplets. The creation of embryos either through graupel formation or raindrop formation followed by freezing takes about 15 minutes. Growth of the hail then proceeds by further accretion of supercooled liquid droplets. The alternation of different growth modes can give rise to a layered shell

Table 1. Historical Disaster Statistics from the Insurance Council of Australia concentrating only on hail events in the past 10 years.

Event	Catastrophe Number if declared	Date (dd/mm/yy)	Location	State	Original Cost (AUS million)	2011 Normalised Cost (AUS)
VIC Christmas Day Storms*	CAT 118	25/12/11	Melbourne	VIC	712	N/A
Melbourne Storm*	CAT 102	06/03/10	Melbourne	VIC	1,044	1,160
Severe Hailstorms	CAT NSW 07/6	09/12/07	Western Sydney, Blacktown	NSW	415	486
Hail Storm	CAT NSW 07/4	09/10/07	Lismore Region	NSW/QLD	97	109
Hail	CAT NSW 06/1	31/10/06	Newcastle & Lower Hunter Valley	NSW	51	60
Hail	CAT QLD 05/2	12/10/05	Gold Coast	QLD	61	89
Hail	Not available	19/05/05	Brisbane	QLD	17.6	28
Hail, Storm	CAT VIC 05/1	20/02/05	Eastern Seaboard	NSW/ TAS/ VIC	216.7	304
Hail, Storm	CAT NSW 04/1	13/12/04	Sydney & Lismore	NSW	32.3	46
Hail	CAT QLD 04/1	24/01/04	Brisbane, SE, SW	QLD	28.5	54
Hail	Not available	31/12/03	Melbourne	VIC	100,	156
				Total	2,780	3,200

* indicates events that are known to have contained hail

structure. This used to be thought to indicate that hail forms by undergoing several excursions between warm and cold temperatures, but hailstone trajectories are now thought to be mainly simple up-down arcs with most of the mass growth taking place between -10°C and -20°C and the layering represents differences in icing conditions encountered: supercooled liquid water content, temperature and relative speed of the collector.

Hail formation

Growth from $\varnothing 1\text{mm}$ to $\varnothing 20\text{mm}$ takes approximately 30 minutes.

Figure 1 illustrates the formation of hail and also indicated feedback processes that can lead to the development of further hail embryos. During wet growth liquid water can be shed from the surface of the hail producing raindrops that can subsequently freeze. Collisions between hail/graupel with supercooled droplets can lead to freeze-splintering that generates more ice crystals.

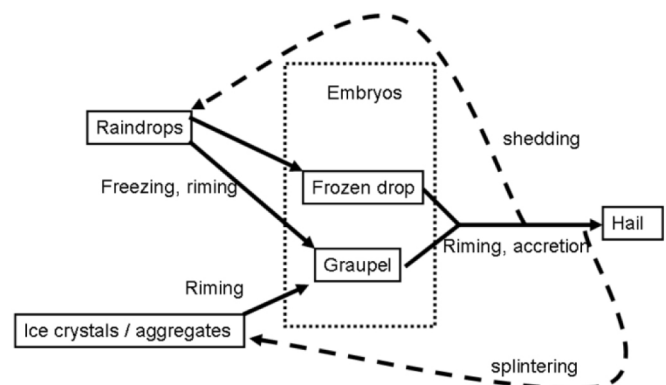


Figure 1. Schematic representation of the production of hail. Boxes represent hydrometeor types. Arrows represent con version processes. Dashed arrows represent processes that can feed back on the production of hail (Figure 4.1 front Field et al. [2]).

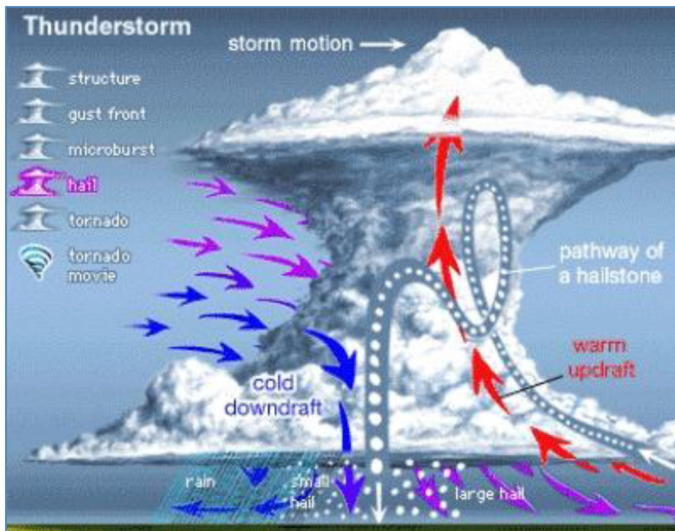


Figure 2. A side profile diagram showing how graupel and hail are formed. In this case, the storm is moving from left to right [4].

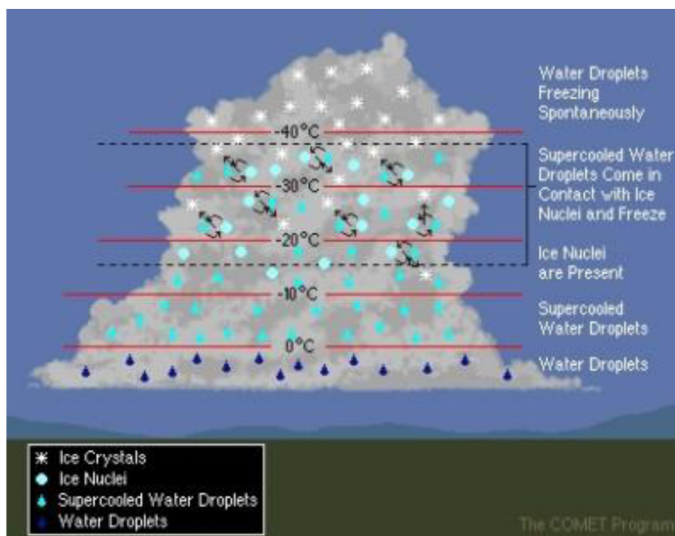


Figure 3. A side profile diagram showing a storm and the temperatures of air within the storm. The formation and the growth of hail take place in the supercooled part of the cloud [4].

A profile view of the formation of graupel and hail is shown in Figure 2. In this case the storm is moving from left to right. The warm air is to the right of the storm and it travels upwards into the storm as the storm moves over the warm air. The formation and the growth of hail take place in the supercooled part of the cloud (seen in Figure 3). As the equilibrium vapour pressure over the water is greater than the saturation vapour pressure over the ice at the same temperature, the liquid water evaporates and the vapour diffuses onto the ice crystals and they grow more rapidly than droplets. The further growth of ice crystals to hail is a result

of the collision and amalgamation of ice particles and water droplets. The strong updrafts ensure long lifetime of the hail in the cloud, which reach to large sizes. When the hail becomes too large, they overcome the updrafts and fall to the ground [3].

Density

Actual measurements of graupel and hail density can vary considerably. For sizes smaller than Ø20mm there is a considerable range of densities from 50kg/m³ to 890kg/m³. For larger sizes the density measurements tend to indicate high densities of 810kg/m³ to 915kg/m³. By comparison, the density of solid ice is 917kg/m³. The lower density particles are likely to be quite fragile (Field et al. [2]).

Fall speed of graupel and hail

The terminal fall speed of a sphere is:

$$V = \sqrt{\frac{4g\rho_{\text{hail}}D}{3C_d\rho_{\text{air}}}}$$

Equation 1

Where:

V = Terminal fall speed of a sphere (m/s)

g = Acceleration due to gravity (9.81m/s²)

ρ_{hail} = Density of the graupel or hail (kg/m³)

D = Size of the hail or graupel (m)

C_d = Drag coefficient

ρ_{air} = Density of air (kg/m³)

As shown by Equation 1, the fall speed increases with the hail/graupel density and size, but decreases with increasing drag coefficient and air density. Figure 4 shows the terminal fall speeds for a range of drag coefficients ranging from 0.5 to 1.5, for ice density of 917kg/m³ and for a temperature of -4.5°C.

Figure 4 shows that that:

1. Ø10mm particles have fall speeds in the range of 9m/s to 17m/s (32km/h to 61km/h);

2. Ø50mm particles have fall speeds in the range of 20m/s to 35m/s (72km/h to 126km/h).

Figure 4 (extracted from Field et al. [2]) shows that the terminal velocity of a falling sphere without taking into consideration the density of air at a temperature of approximately -4.5°C, which is approximately 1.301kg/m³ [7], or if it did take the air density into consideration it was approximated at 1kg/m³.

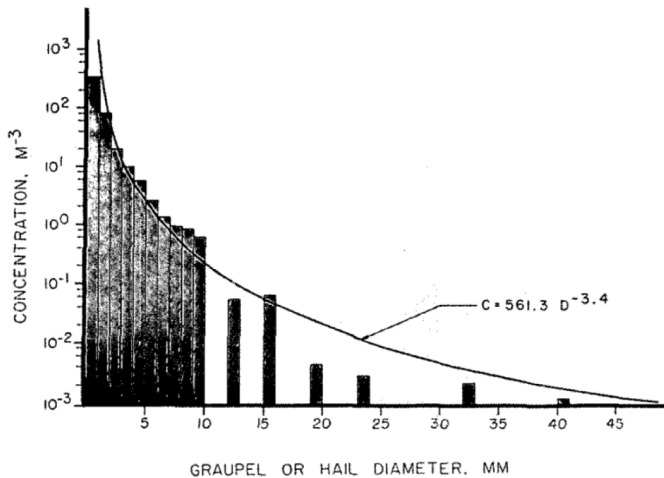


Figure 6. The average graupel and hail size distribution observed from convective cloud systems over the High Plains. (Figure 2 from August [5]).

That is, as the diameter of the graupel or a hailstone is doubled, the concentration drops approximately 1,000 times. Or if the diameter of the graupel or a hailstone is halved the concentration increases approximately 1,000 times.

Hail damage

The damage potential of hail depends on its size, velocity and direction of impact. The surfaces of any object in the path of a hail may be damaged, including vehicle body panels and glass surfaces. Such damage may be observed as a readily visible indentation. When such denting occurs, the aesthetic appeal of the vehicle exterior is reduced. Even when the depth of indentation is exceedingly small, paint damage can be noticeable. Dust, dirt and paint oxidation may be driven below the outer surface. Considerable polishing and buffing may be needed to restore the original look and quality of the paint (Niemeier and Burley [6]).

The current trend towards lighter weight vehicles has resulted in lighter weight exterior panels, including aluminium components and even thinner body panels made from steel. There is also a rise in the use of carbon fibre panels in the push towards the use of more exotic materials in order to lower the weight of a vehicle to increase its performance.

Thin and dynamically stiff surfaces are viewed as more prone to localised indents. Flexible and strong zones are needed to return the momentum of the impact to the indenter (the hail). Energy absorbed by the zone surrounding the impact should, ideally, not produce the stresses required for plastic deformation. However, use of such criteria to resist localised permanent indentation may not be permitted by other general design considerations. Then the chance situation of unavoidable damage due to hail and other impactors must be acknowledged.

Laboratory tests

For freely falling hailstones, the car bonnet, roof and boot are the prime targets during a hailstorm. Wind-driven hailstones can also find points of impact on side panels, fenders and doors.

Niemeier and Burley [6] performed laboratory tests using eight vehicle bonnets; four made of steel and four made of aluminium. Round Ø25.4mm aluminium indentors were projected at bonnets using air cannon. These indentors were of the same mass as larger size hailstones. Accordingly these aluminium indentors possessed the energy and momentum comparable to hailstones. The energy comparison is shown in Figure 7.

The right side of the complete hood unit was selected for impacting and the left side was cut apart to measure thickness, mechanical properties and alloy composition.

Four rows were marked out on each hood, and along each row indentations were developed using impact velocities in the range from 20mph to 60mph (32km/h and 97km/h respectively).

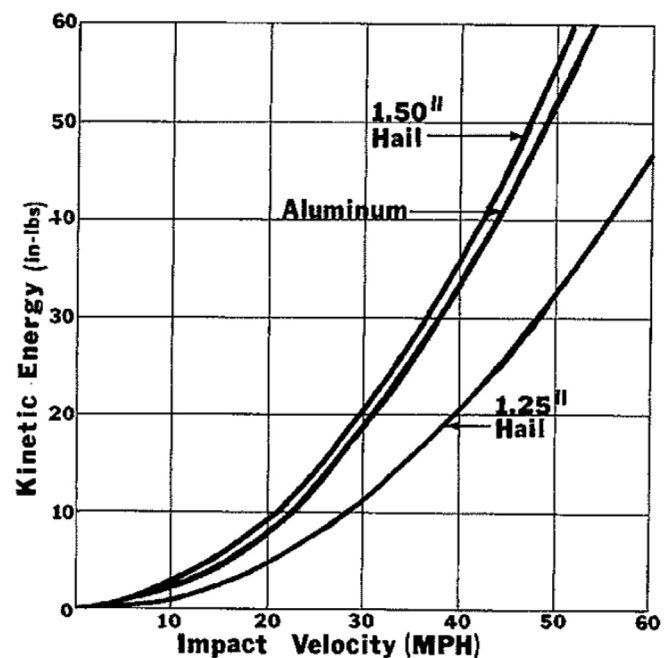


Figure 7. Energy comparison of hailstones and aluminium laboratory indenter (Niemeier and Burley [6]).

It should be noted that the general surface geometry along each row is constant. Row A is along a sharp wind split line. Rows B and D are on generally flat areas. Row C lies along a character and stiffener line. The different rows are seen in Figure 8.

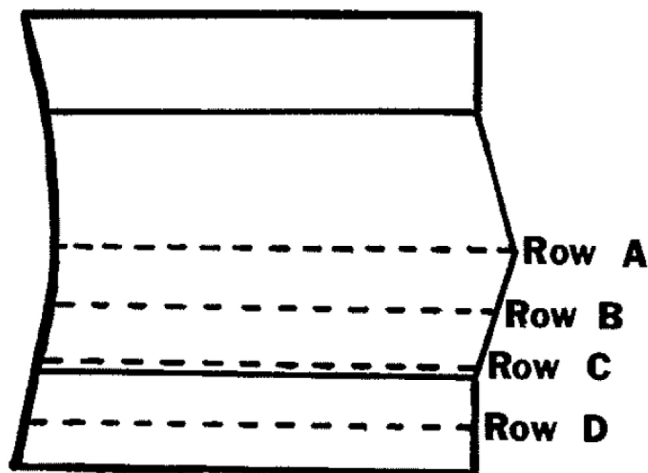


Figure 8. Impact location rows on hoods as tested by Niemeier and Burley [6].

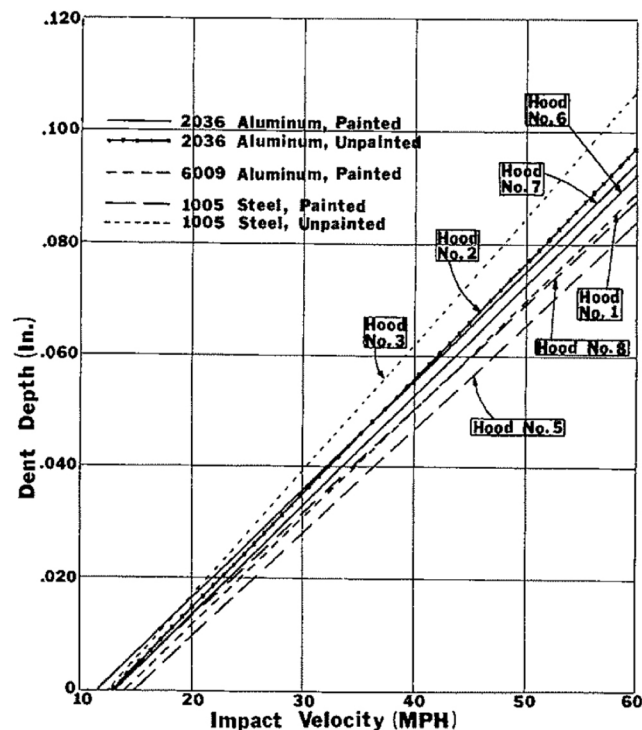


Figure 10. Dent depth versus impact velocity for seven hoods, as tested by Niemeier and Burley [6].

Niemeier and Burley conclude that “statistical analysis shows that the velocity of impact required to initiate denting (i.e. the threshold velocity) is primarily a function of the mass of the impactor and the geometry and thickness of the impacted component.”

TESTING

The testing conducted is intended to provide means for objectively analysing damage caused by hail striking a vehicle and assessing the probability of non-hail (including man-made) damage to the vehicle.

The objective was to conduct a series of repeatable tests which involve launching an ice projectile, designed to replicate hail, at a test vehicle. The damage caused by the ice projectile will be compared to ‘man-made’ damage caused by striking the vehicle body panels with different tools. The intention of the ‘man-made’ damage is to replicate the appearance of real hail damage.

The similarities and differences between two types of damage will be analysed and discussed. The aim of the testing is to provide an objective and evidence based methodology that allows for the assessment of damage caused to vehicle body panels by hail impacting the vehicle and identification of any damage that was not caused by hail impacting the vehicle but instead was caused by other means (man-made damage using different tools and/or objects, environmental damage such as branches falling on vehicle, normal wear and tear, etc.).

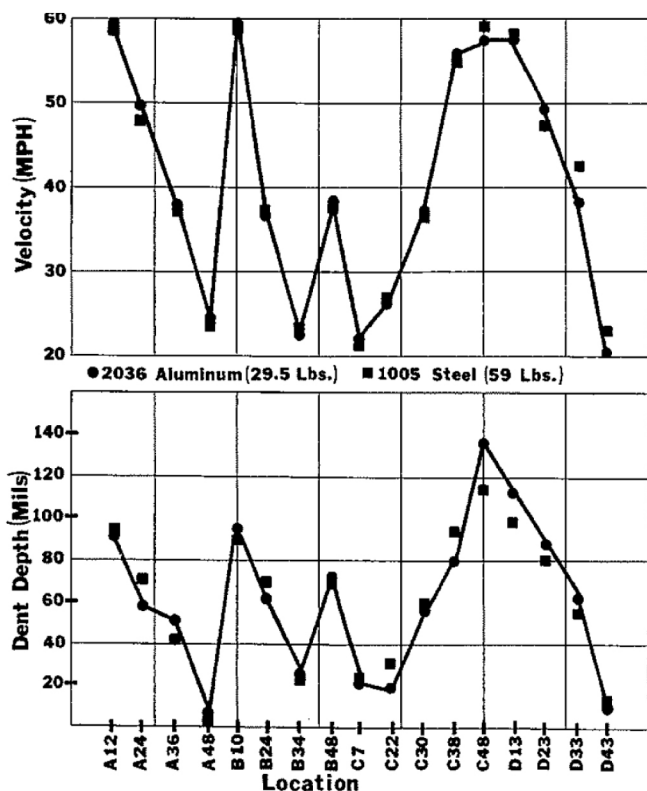


Figure 9. Velocity and dent depth spectra as tested by Niemeier and Burley [6].



Figure 11. Test vehicle.

The Test Vehicle

A white coloured 2001 model Holden Commodore sedan was provided to the authors by CGU Insurance for the purpose of the testing. The following are the details of the vehicle provided:

1. The vehicle is a 2001 Holden Commodore VX sedan, with build date June 2001 identified and bears Victorian registration QXY 530;
2. The colour of the vehicle is white, with colour code J073, also known as "Heron White". This is a solid colour and not metallic;
3. The VIN is 6H8VXK69A1L743678;
4. The Model number is VX8VK69-011-1BB.

Figure 11 and Figure 12 show the test vehicle prior to commencing tests.

The vehicle was inspected for damage on the metal body panels which would be impacted as a part of the hail damage tests. Any damage identified was recorded on an inspection sheet and marked out on the vehicle. The existing damage was also photographed for reference.

The bonnet, both front quarter panels and the boot lid were removed from the vehicle for the purpose of the testing. The bonnet and boot lid were impacted by hail when they were not fixed to the vehicle to allow the hail to impact the panels at a more representative angle (i.e. hail striking the panels at a 90°).

The Hail

Two sizes of hail were created for the purpose of this test; Ø20mm and Ø40mm ice balls. The ice was left in a freezer

overnight to ensure that it was completely frozen before the tests were conducted. The hail was taken out of the freezer progressively as needed just prior to individual tests being conducted. The created hail was solid ice with a density of approximately 917kg/m³.

The size of actual hail can vary from Ø10mm to Ø100mm, with densities varying from 50kg/m³ for smaller hail stones to 915kg/m³ for large hail stones.

The speed at which hail stones were projected at the test vehicle varied:

1. Ø20mm hail stones were projected at speeds between 75km/h and 144km/h. A total of 15 impact tests were conducted with Ø20mm hail. The average impact speed for the Ø20mm hail was 113km/h;

2. Ø40mm hail was projected at speeds between 66km/h and 133km/h. A total of 50 impact tests were conducted with Ø40mm hail stones. The average impact speed for the Ø40mm hail was 101km/h.

Note the difference in speeds when compared to terminal velocities presented in Table 2. Ø20mm hail stone is expected to fall at between 41km/h and 71km/h. Ø40mm hail stone is expected to fall at a speed of between 58km/h and 101km/h. The speeds at which the hail stones were projected at the test vehicle were higher to illustrate the worst case scenario (combined with the high density of ice of 917kg/m³).

In addition, six impact tests were conducted with very large and irregular hail stones (oval shaped hail +Ø70mm). The hail was projected at speeds between 36km/h and 56km/h, with the average impact speed being 45km/h.



Figure 12. Test vehicle when dismantled for testing.



Figure 13. A view of the projectile launching device (yellow). Tape measure on the ground under the table. High speed camera indicated with arrow. In this test, the target body panel was the vehicle's bonnet.

Testing Equipment

The hail was projected at the test vehicle using a purpose built projectile launching device. A sling-like mechanism was

developed to project hail stones in a horizontal direction (Figure 13 and Figure 14).