

CRASH PROTECTION OFFERED TO SMALL OCCUPANTS IN AN OFFSET FRONTAL CRASH

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ABSTRACT

ANCAP crash tests are conducted to well-established protocols and use driver and front passenger anthropomorphic test devices (ATDs) that represent 50 percentile (%ile) adult males. Most modern vehicles do well in these crash tests. However, concerns have been raised about the protection provided to smaller occupants.

In 2013 ANCAP conducted a 64km/h frontal offset crash test of a Holden Commodore VF Ute (single-cab pick-up) with two Hybrid III 50%ile male ATDs (AM50). In 2014 the opportunity arose to conduct a further research crash test of a Commodore VF Ute using a small adult female driver ATD (5%ile adult female) and a 6 year old child ATD (Hybrid III 6) in a booster seat in the front passenger seating position.

The purpose of the research test was to determine whether the two occupants had an increased risk of injury, compared with the adult male ATDs.

The occupant injury measures for the smaller occupants were compared to the results of the previous vehicle crash test (with 50%ile adult male front occupants) in order to make comparisons between the level of protection offered to occupants of different sizes for this type of crash. Furthermore, the authors examined whether the restraint and airbag systems that perform well for 50%ile adult male occupants provide comparable protection for smaller occupants and whether there are any additional hazards for smaller occupants.

The outcome of the research was that for the case examined, with the available methods for assessing injury risk, smaller occupants appear to be offered comparative protection in a frontal offset impact for this particular vehicle model. It is apparent that the test vehicle manufacturer included consideration of smaller occupants in the design and development of this vehicle model.

INTRODUCTION AND BACKGROUND

In accordance with long-established protocols, ANCAP crash tests focus on average sized male occupants for the front seating positions (EuroNCAP 2011). Since 1993 Hybrid III 50th %ile adult male (AM50) ATDs have been used as driver and front passenger occupants for the ANCAP frontal offset crash test.

In 2014 a research test was conducted to examine the injury risk and occupant dynamics in a 64 km/h offset frontal crash, tested with a Hybrid III 5th %ile adult female driver (AF5) and a Hybrid III 6 year old (H6) child ATD restrained in a high back booster seat with a top-tether.

Front seat positions do not normally have an anchorage point for CRS because they are provided for rear seats, where available. This test was feasible because the Commodore Ute has an upper anchorage for the child restraint system (CRS) top-tether in this seat position and many Australian booster seats are provided with top-tethers. Where a top-tether anchorage is provided for a front passenger seat in a vehicle with one row of seats, a

child in a forward facing CRS or booster seat may occupy this position, even if a passenger frontal airbag is fitted. The Commodore Ute does not have provision for disabling the frontal passenger airbag when a CRS is installed in the front seat.



Figure 1. Research test vehicle impact with deformable barrier.

The *possible* safety concerns with a small driver are:

- a) that they are close to the deploying airbag and might be at risk of injury from the airbag
- b) that because they are closer to the steering wheel there might be an increased risk of contact with the steering wheel
- c) that the restraint system (seat belt, airbag and seat) is not optimised for this size occupant and so does not provide the same protection as the 50thile male occupant (in particular the potential for an increased risk of chest injury)
- d) that with the seat fully forward the knees are more likely to contact the instrument panel and/or steering column, with consequent extra risk of injury

In the case of a child in a booster seat, the *possible* concerns are:

- e) interaction with the airbag might pose an injury risk
- f) the lap portion of the seat belt might ride up and penetrate into the abdomen, increasing injury risk - seat belt pretensioners have been observed contributing to this effect (in rear seats - Tylko 2012)
- g) the child starts to slide under the seat belt, particularly if there is excessive movement of the booster seat
- h) the sash portion of the belt may not retained on the ATD shoulder up to the peak of the crash

SELECTION OF TEST VEHICLE

A fairly unique feature of the Australian vehicle population is the utility, or "ute" - a small pick-up with a single row of seats. Many Australian pick-ups are based on popular sedan models where the rear row of seats and luggage area of the sedan are replaced by a utility tray. Over the years the Holden Commodore Ute and Ford Falcon Ute have been popular vehicles. To meet a demand from families both Holden and Ford have provided a top tether anchorage for the front passenger seat of these models. Manufacturers instructions state that this seating position must not be used for a rearward facing CRS (in effect an infant restraint) and to slide the seat back as far as possible for forward facing CRS and booster seats.

A 2014 model year Holden Commodore Ute (VF variant) was chosen for the research test, partly because data from an ANCAP crash test with AM50 ATDs were available for comparison.

SELECTION OF DRIVER (AF5)

Vehicle regulations and NCAP protocols generally use AM50 ATDs as front occupants in frontal crashes tests.

Vehicle manufacturers design vehicles to provide protection to a wide size range of occupants however information about how well smaller occupants are protected is not commonly available.

In 2015 EuroNCAP introduced a 50km/h full-width frontal crash test with AF5 ATDs in the driver and kerbside rear seat. Other crash-test organisations, such as Japan NCAP, and China NCAP, also use the AF5 ATD in some seating positions. It was therefore decided to use the AF5 in the research test.

The injury limits specified in the Euro NCAP adult occupant protection protocol (EuroNCAP, July 2014) were used for assessing the research test outcomes for the AF5.

SELECTION OF FRONT PASSENGER (H6 restrained in booster seat)

Australian Research in the late 1970s led to the development of an Australian Standard (AS/NZS 1754) for child restraints that required dedicated child restraint systems (CRS) to have a top tether to control pitch rotation of the CRS. Since then all Australian CRS with an in-built harness have had the top tether system and (under Australian Design Rule 34/02 - Child Restraint Anchorages and Child Restraint Anchor Fittings) all light passenger vehicles that have two or more rows of seats have to be fitted with top tether anchorages for some rear seats (Paine 2003). In 2004 the standard was updated to encourage all booster seats (that utilise the adult seat belt to restrain the occupant) to have a top tether (AS/NZS 1754:2004).

For more than a decade the Commodore Ute and Falcon Ute have had top tether anchorage available for the front passenger seat. This was mainly to meet a demand from consumers to carry young children in this seating position because no rear seat was available.

Since the 1980s Australian researchers have monitored injuries to children in car crashes and have not come across any cases of injuries to correctly restrained children in this front seating position due to airbag deployment (Brown 2013). Nevertheless there remain concerns within the community due to tragic experiences in the USA with children and airbags - due mainly to children being unrestrained, out of position, and/or early aggressive designs of airbags (Child Passenger Safety Committee on Injury, Violence, and Poison Prevention, 2011).

A Hybrid III 6 year old child ATD was selected to occupy the front passenger seating position using a booster seat with a top tether. Since the ATD is restrained by the adult seat belt and not a dedicated harness this was considered to be a worse case for issues such as restraint geometry, submarining and head excursion. A 6 year old child in a booster seat was considered the most likely configuration to reveal the above problems. A smaller child in a forward facing child seat may not have reveal seat belt-related problems since forward facing restraints for smaller children use an in built harness, rather than the seat belt, to restrain the occupant. An infant in a rearward facing child seat is not recommended for the front passenger seating position, although Suratno and others (Suratno et al, 2009) concluded that there was unlikely to be additional injury risk with this configuration with modern designs of passenger airbags.

The H6 was restrained in a Hipod Boston Booster child seat. This booster performed well in the Australian Child Restraint Evaluation Program (CREP) and had a top tether.

SET UP AND SEAT POSITIONING

The vehicle was set up according to EuroNCAP frontal offset protocol version 5.1 (EuroNCAP, 2011) with the following changes:

- An AF5 replaced the AM50 in the driver position
- A H6 restrained in a booster seat replaced the AM50 in the front passenger position
- Driver seat and steering wheel were set to the following positions
 - The driver's seat was fully forward
 - The driver's seat was set in the mid height setting.
 - The steering wheel was set in the most forward and mid height setting.
 - The driver's head restraint was set in the lowest and fully forward tilt setting.
- The front passenger seat was set in the rearmost locking position
- The front passenger seat head restraint was removed as it obstructed installation of the booster seat.
- In addition to the standard ANCAP camera positions three cameras were mounted within the vehicle cabin. One roof camera was positioned to capture the left side of the driver ATD and another roof camera was positioned to capture the right side of the front passenger ATD. A third camera was mounted on the dashboard and was positioned to capture the right side of the front passenger ATD. These on-board cameras were positioned to capture views that would assist in the assessments, including lap belt performance and frontal airbag interaction. Footage was obtained from both roof mounted cameras but the dashboard mounted camera failed to record usable footage.

OBSERVATIONS AND TEST DATA

Injury scoring scales and limits for the EuroNCAP full-width frontal impact were used for the AF5 driver ATD. The AF5 scales are not necessarily the same as the AM50 scales because they reflect the risk of serious injury for a person of that size.

NHTSA has proposed Hybrid III 6 year old injury limits for US federal regulation FMVSS208 (Kleinberger, et al, 1998) and FMVSS 213 (NHTSA 2002). These injury limits were used for the H6 ATD because injury limits are not defined for this ATD in ANCAP and EuroNCAP protocols.

Injury data for the AF5 and H6 ATDs are shown below in Table 1 and Table 2 respectively.

Driver Outcomes

The calculated points score for the AF5 driver (13.42pts) was similar to the ANCAP points score for the AM50 driver (13.52pts) in the official ANCAP test.

The driver injury readings that exceeded the NCAP lower injury limits were the chest compression and tibia index. The AF5 chest compression of 20.7mm resulted in a score of 3.55 points compared to the official test (AM50) of 26.4mm for a score of 3.37 points indicating an 'acceptable' level of risk to the chest in both tests (using the NCAP injury risk scales - which are different for AM50 and AF5).

The AF5 tibia index of 0.88 returned a points score of 1.87 compared to the official test (AF50) tibia index of 0.82 for a score of 2.15 points. However the Euro NCAP full-width frontal crash test does not make use of the tibia readings for scoring due to uncertainty in the AF5 risk values for tibia and so caution should be exercised in interpreting the lower leg injury risk in the research test.

Although twisting of the driver neck was observed upon rebound from the airbag (a peak neck moment of 28.45Nm at 196ms) the twisting of the AF5 neck in this research test was not sufficient to warrant a modifier under the ANCAP protocols. No estimation of injury risk is carried out after the peak of the impact due to limited biofidelity of the H3 neck for this type of movement.



Figure 2. Twisting of the driver neck.

The driver airbag contacted the driver ATD's face while the airbag was inflating (at approx. $t = 35\text{ms}$) and this may have contributed to the neck twisting. However the estimated airbag deployment speed at the time of contact was below the 90m/s limit used by Euro NCAP to determine whether the airbag deployment is potentially hazardous. It should be noted, however that although the hazardous airbag deployment modifier is used by EuroNCAP it is generally not applied by ANCAP. Airbag contact was judged to be stable and no undesirable interactions between the driver and airbag were observed.

Table 1. AF5 Driver ATD injury data

	Driver ATD (AF5)	Limits for scoring purposes*	Comment on injury outcomes
Head G (Res) (g)	46.8	80	Good
3ms Head G (g)	42.8	80 - 72	Good
HIC (36ms)	243	700 - 500	Good
Neck Shear (kN)	0.30	1.95 - 1.2	Good
Neck Tension (kN)	1.15	2.62 - 1.7	Good
Neck Extension (Nm)	10.0	49 - 36	Good
Chest compression (mm)	20.7	42 - 18	Acceptable
Chest viscous criterion (m/s)	0.07	1 - 0.5	Good
Femur compression (kN) (L/R)	1.51/2.38	6.2 - 2.6	Good
Knee slider (mm) (L/R)	0.0/0.03	15 -6 #	Good
Tibia index, upper (L/R)	0.56/0.47	1.3 - 0.4 #	Acceptable #
Tibia index, lower (L/R)	0.88/0.37	1.3 - 0.4 #	Marginal #
Tibia compression (L/R)	1.69/1.08	8 - 2 #	Good #

* Zero if more than first value, maximum (4) if less than second value (based on Euro NCAP protocol for full frontal crash with AF5 driver)

Not assessed by Euro NCAP for AF5. AM50 limit shown in this table

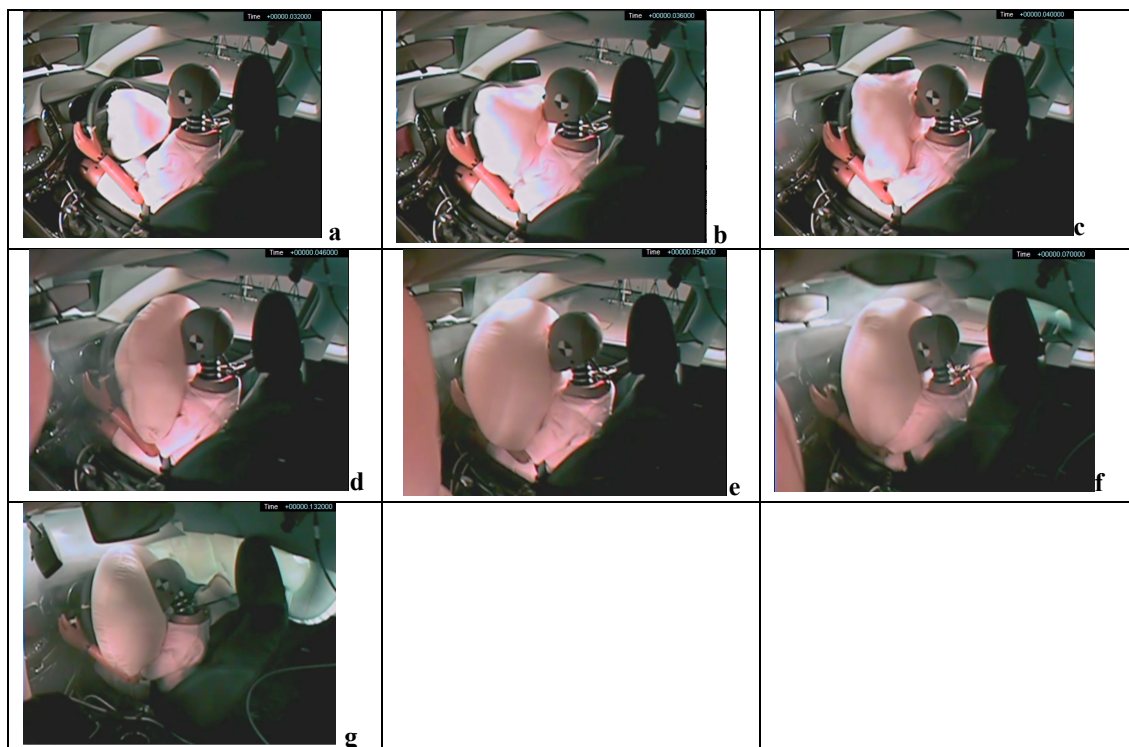


Figure 3 a-g. Sequence of snapshots from on-board camera - driver

Front Passenger Outcomes

The H6 passenger in the booster seat appeared to be well restrained with a relatively low likelihood of serious injury. The measured injury values were well below the limits for scoring purposes. The H6 injury data is provided in Table 2.

The passenger airbag fully inflated prior to contact with the H6 (contact occurs around $t = 74\text{ms}$ when the crown of the ATD head contacts the bag. After contact with the airbag (upon rebound) the top of the H6 head slides across the surface of the airbag.

The child ATD forward head excursion was estimated by analysing the test footage and observing the maximum forward position of the head against reference markings on the vehicle. The maximum forward head excursion for the H6 ATD was estimated to be 300mm and no hard contacts were observed.

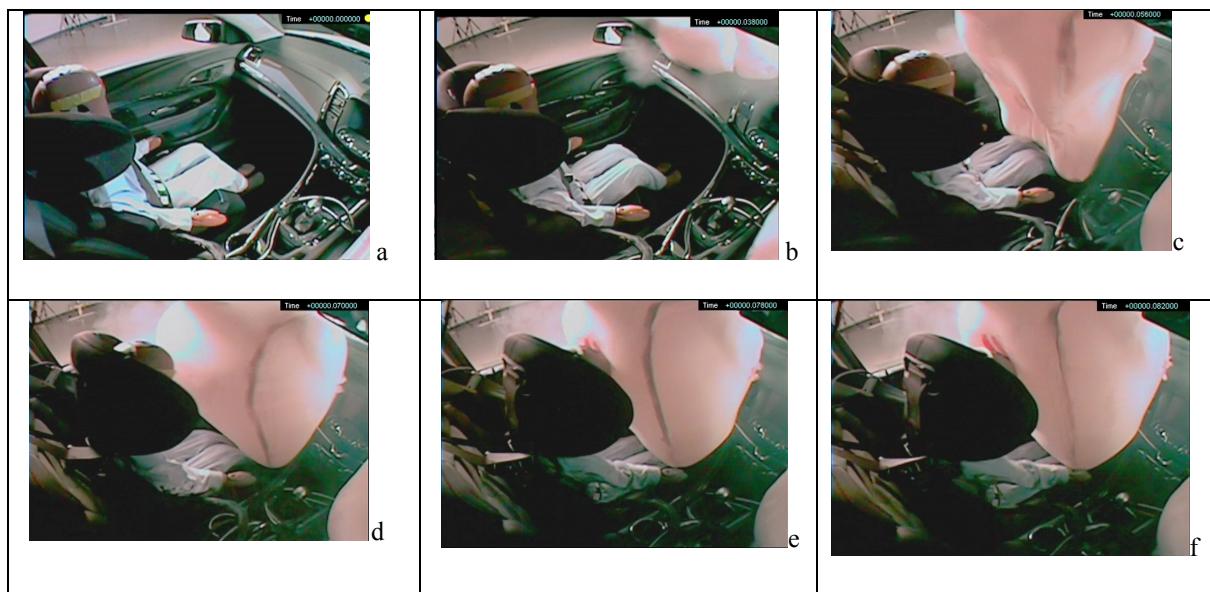


Figure 5 a-f. Sequence of snapshots from on-board camera – H6 ATD

Table 2. H6 Passenger ATD injury data

	Passenger ATD (H6) Injury value	Failure limit for scoring purposes	Comment on injury outcomes
HIC ₃₆	350	>1000*	Pass
HIC ₁₅	191	$\geq 700^{\wedge}$	Pass
Nij	0.61	> 1 [^]	Pass
Chest compression (mm)	20.7	>40 [^]	Pass
Chest acceleration (3ms) (g)	40.8	>60 [^]	Pass
Head excursion (mm)	300	>720 [^]	Pass

* Proposed FMVSS 208 limit (Kleinberger, et al, 1998)

[^] Proposed FMVSS 213 limit (NHTSA, 2002)

Table 3. Comparison between research test vs ANCAP test occupant injury data#

	Research test Driver (AF5)	ANCAP test Driver (AM50)	Research test Passenger (H6)	ANCAP test Passenger (AM50)
Head G (Res) (g)	46.8	35.8	45.0	33.5
3ms Head G (g)	42.8	35.5	44.4	31.6
HIC (36ms)	243	189	350	159
Neck Shear (kN)	0.30	0.46	*	0.50
Neck Tension (kN)	1.15	0.37	*	0.47
Neck Extension (Nm)	10.0	8.2	*	21.40
Chest compression (mm)	20.7	26.4	20.7	17.90
Chest viscous criterion (m/s)	0.07	0.07	*	0.05
Femur compression (kN) (L/R)	1.51/2.38	2.04/0.08	*	0.28/0.27
Knee slider (mm) (L/R)	0.0/0.03	0/46/0.00	*	0.38/0.30
Tibia index, upper (L/R)	0.56/0.47	0.58/0.39	*	0.28/0.16
Tibia index, lower (L/R)	0.88/0.37	0.82/0.31	*	0.39/0.18
Tibia compression (L/R)	1.69/1.08	3.89/1.82	*	1.33/2.12

Note: Different injury scales are applied to each ATD. Direct comparison of injury data between ATDs is not possible.

* Not recorded for this ATD

Restraint System Performance

In addition to injury measurements, the ANCAP/EuroNCAP scoring system provides for "modifiers" that reduce the score if there is a further risk of injury that is not captured by the ATD injury measurements. These modifiers include steering column movement, structural integrity of the cabin, pedal movement, unstable head contact with the airbag, airbag bottoming out (resulting in head or chest contact with the steering column) and facial injury risk due to the manner in which the airbag deploys. The latter assessment is not currently applied by ANCAP.

In addition to these modifier assessments a preliminary assessment of the dynamic performance of the seat belts in accordance with observations by Suzanne Tylko from Transport Canada (Tylko & Bussi res 2012) was carried out:

- a) the sash portion should be retained on the shoulder up to the peak of the crash. It should not fall off the shoulder or load the neck
- b) the lap portion should load the pelvis and not ride up and into the abdomen
- c) there should be no tendency for submarining, where the ATD tends to slide down and forward

From analysis of the video footage there was no evidence of the lap portion of the seat belt riding up and loading the abdomen of the child ATD, nor was there evidence of the child ATD submarining. The sash portion of the seat belt appeared to be retained on the child ATD shoulder until after the peak of the crash (evidence of retention until 150ms) and there was no evidence that the seat belt loaded the neck of the ATD.

Pretensioners deployed for both occupant positions and no evidence of poor belt geometry caused by pretensioner deployment was observed.

LIMITATIONS OF THE RESEARCH TEST

The findings are based on one crash test with two occupants. However, the research draws on experience with a wide range of vehicles and compares directly with a crash test of the same vehicle model.

Due to the different ATDs used, direct comparison between occupant injury readings is not possible but the scaled Euro NCAP scores do relate to the risk of serious injury for both types of adult ATDs.

Although tibia values are not used for the EuroNCAP full-width frontal test the values have been recorded here and compared to AM50 limits. Caution should be exercised in interpreting the lower leg injury risk in the research test. Direct comparison to AM50 values is not possible but the values provide an indication of injury risk for this body region.

The H6 ATD is only instrumented for head acceleration (3 axis), neck shear force and bending moment (3 axis) chest acceleration (3 axis) and displacement (x axis) and pelvis acceleration (3 axis). Injury outcomes for other body regions are not measured.

Child forward head excursion is approximate only, using external cameras and reference marks on the vehicle. This method is susceptible to parallax error. Strategically positioned on-board cameras would provide greater accuracy.

Additional on-board cameras could have provided an improved view of the seat belt buckles, retention of the sash portion of the seat belts on the ATD's shoulders and interaction of the lap portion of the seat belts with occupant abdomens.

CONCLUSIONS

A successful research crash test was conducted to determine the crash protection provided to a small female driver and a 6 year old child restrained in a booster seat in the front seat of a utility style vehicle.

The 5%ile female driver ATD injury measurements indicated that the risk of serious injury was no worse than that of a 50%ile male driver in the same model vehicle and same type of crash test. The restraint system appeared to work well with no sign of submarining or lap-belt penetration into the abdomen. This test was conducted with the driver seat in its most forward position, which is considered to be a worst-case scenario for risk of airbag injury.

The child ATD injury measurements also indicated a low risk of serious injury. The restraint system appeared to work well with no sign of submarining or lap-belt penetration into the abdomen. It is likely that the head contact with the airbag would reduce head, neck and chest loads, compared with no airbag.

This test was conducted with the passenger seat in its rearmost position, as recommended by the manufacturer. Although this is considered to be the best-case scenario there is unlikely to be an elevated risk of serious injury from the airbag when the seat is located further forward.

It is concluded that, for the case examined, with the available methods for assessing injury risk, smaller occupants appear to be offered comparative protection in a frontal offset impact for this particular vehicle model. It is apparent that the vehicle manufacturer included consideration of smaller occupants in the design and development of this vehicle model.

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