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Assessment of Hood Designs for Pedestrian Head Protection: Active Hood Systems

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EXECUTIVE SUMMARY

Pedestrian impact testing of the U.S. vehicle fleet by the National Highway Traffic Safety Administration has provided snapshots of the performance of evolving technologies that protect a pedestrian's head in head-to-hood impacts. One of the recent evolving technologies is the introduction of active hood systems that pop up upon contact with a pedestrian to provide a more "cushioned" impact. Two vehicle models, a 2014 Cadillac ATS and a 2017 Audi A4, were tested with and without an active hood system to examine how active hoods affect pedestrian safety in headform impacts. The effects of the active hood systems were found to vary for both vehicles. For the Cadillac ATS, the active hood had a significant influence as HIC values went from high with the undeployed hood to very low with the active system. For the Audi A4, the undeployed hood produced low-to-moderately high HIC scores with negligible improvement with the active system.

1. Introduction

1.1. Background

The National Highway Traffic Safety Administration has conducted many pedestrian headform-to-hood impacts to investigate protection provided through vehicle front end design. The experimental testing of the U.S. vehicle fleet has provided snapshots of the performance of evolving technologies. One of the recent evolving technologies is the introduction of active hood systems that pop up upon contact with a pedestrian. These deployable hoods are designed to provide more clearance to engine components and, as a result, a more "cushioned" impact.

1.2. Objective

This study examines the components that comprise an active hood system and how active hoods affect pedestrian safety in headform impact tests. Two vehicle models, a 2014 Cadillac ATS and a 2017 Audi A4 (both 4 door sedans), were tested with their European version pop-up mechanisms installed and activated, and the level of safety improvement with the active systems was assessed and compared with the U.S. version that does not contain an active hood system.

2. Methods

All headform tests in this study were performed according to the procedures outlined in the European New Car Assessment Programme (Euro NCAP) Pedestrian Testing Protocol (Version 8.3, December 2016) at NHTSA's Vehicle Research and Test Center (VRTC). Headforms were launched into the hoods of the test vehicles at 11.1 m/s, which simulates a 40 kph (25 mph) vehicle impact into a pedestrian. Certified child and adult headforms that conform to Euro NCAP requirements (mass, diameter, moment of inertia, and instrumentation position) were used in this study.

The Head Injury Criterion over a duration of 15 ms (HIC15), which is derived from the resultant head acceleration and defined in the equation below, is correlated to the risk of skull fracture due to a head impact and is used to assess the head impacts. A HIC15 value of 650 (the full point threshold for Euro NCAP scoring) is associated with a 9% risk of AIS 3+ head injury while a HIC15 value of 1700 (the zero-point threshold for Euro NCAP scoring) is associated with a 49% risk of AIS 3+ injury.

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$$

To evaluate the effectiveness of active hood systems on headform performance, the hoods of a 2014 Cadillac ATS and a 2017 Audi A4 were tested in both non-deployed and deployed-static states. Both vehicles are only available with non-active hood systems in the U.S. market. However, in Europe, they are available for purchase with active hood systems. From conversations with Audi and GM, VRTC was informed that both vehicles can be outfitted with the European active hood systems by swapping out the hinges and hood latch striker and installing a deployment actuator. For non-deployed tests, both vehicles were tested as they are sold in the U.S. For deployed-static tests, the original U.S. parts were replaced with European active hood system parts (i.e., hinges, actuators, latches). The hood designs are the same for European and U.S. models, so the same hood design was used for both non-deployed and deployed-static tests. Photos of the Cadillac and Audi active hood conversion parts are shown in Figure 1 through Figure 5 below.

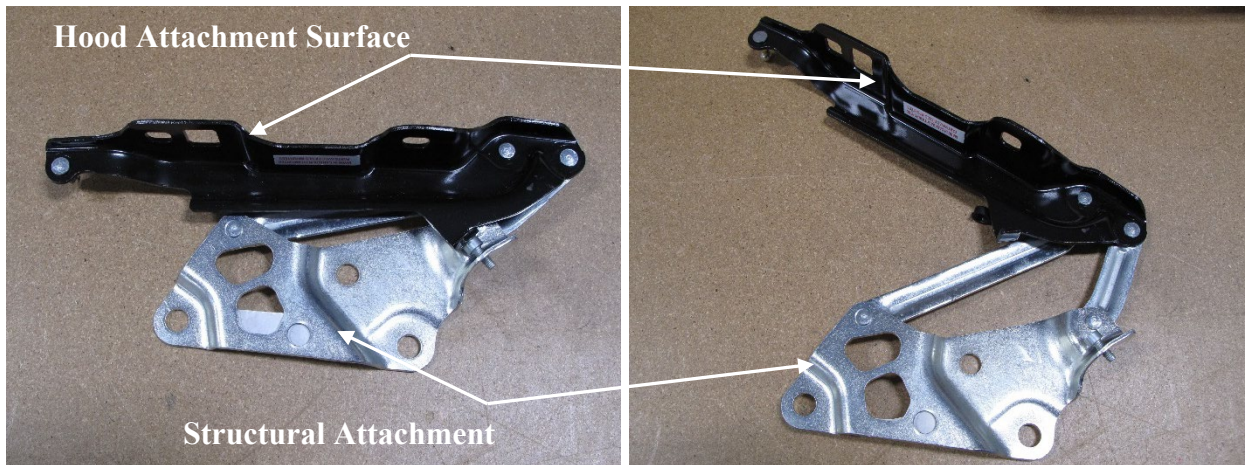


Figure 1. 2014 Cadillac ATS original, non-active hood hinge; closed (left) and open (right)

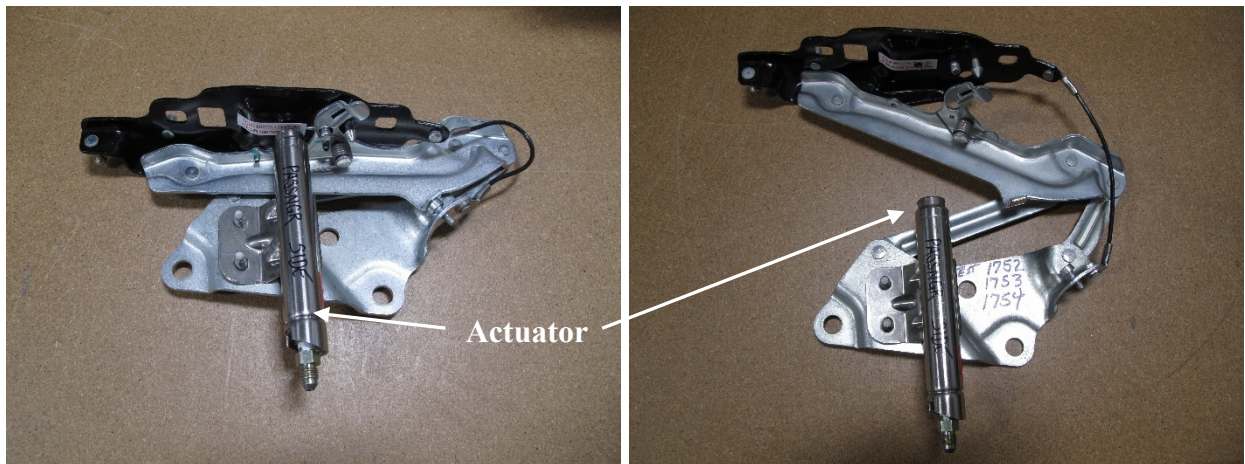


Figure 2. 2014 Cadillac ATS active hood hinge with deployment actuator; closed (left) and deployed (right)

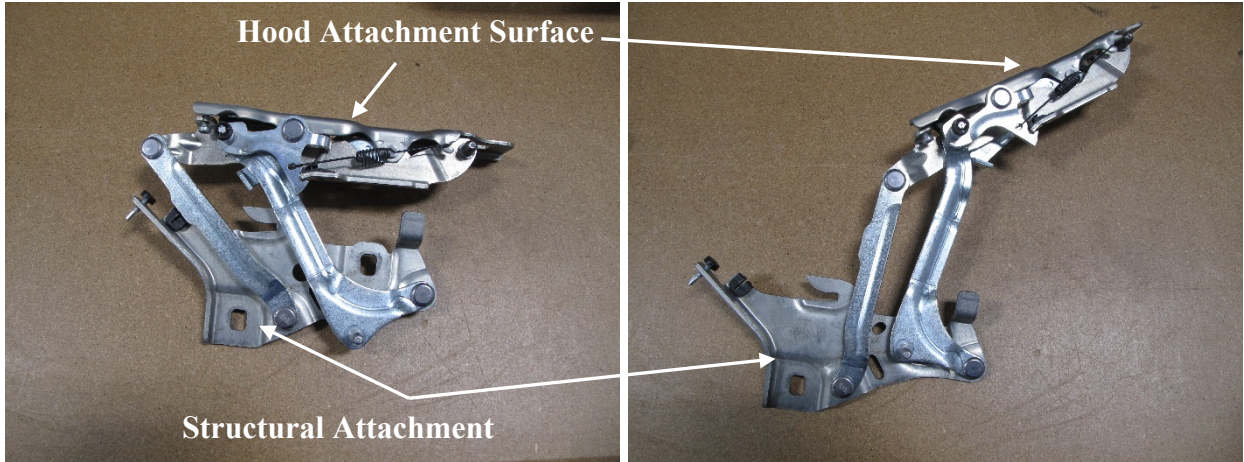


Figure 3. 2017 Audi A4 active hood hinge without deployment actuator; closed (left) and open (right)

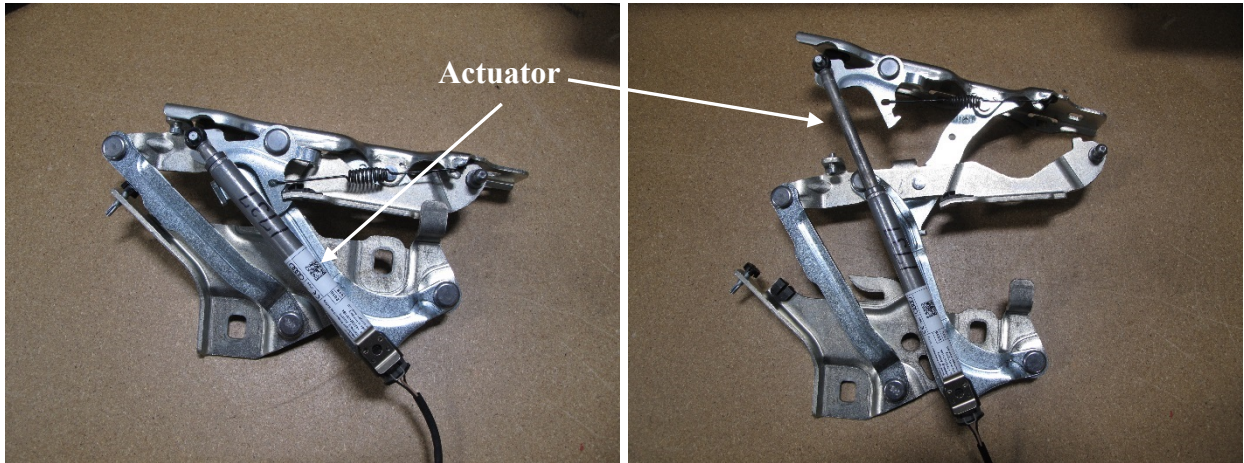


Figure 4. 2017 Audi A4 active hood hinge with deployment actuator; closed (left) and deployed (right)

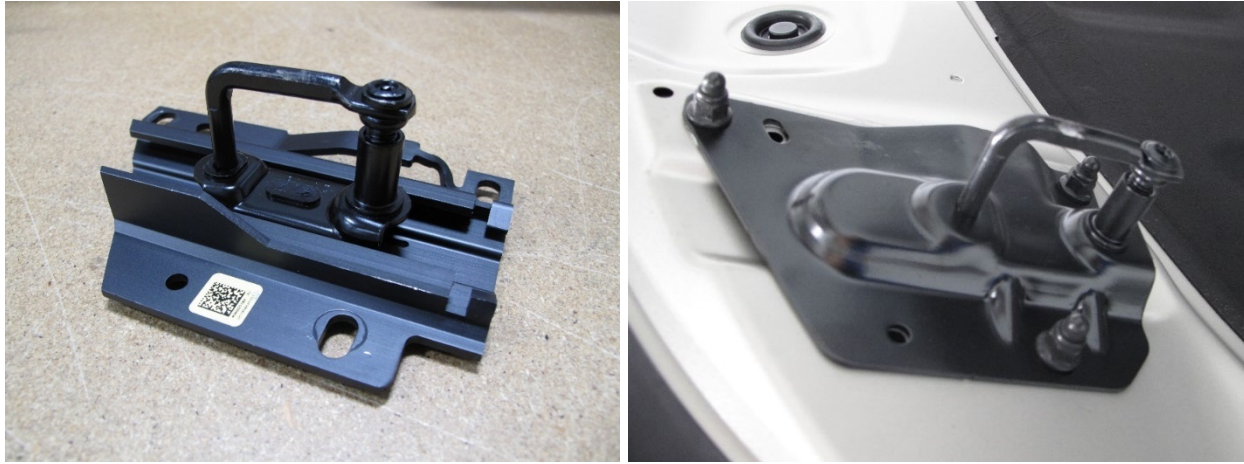


Figure 5. 2017 Audi A4 active hood latch striker (left) is free to slide while the original, non-active striker (right) is fixed

The total response time (TRT) of a hood deployment is the total time from pedestrian contact until full deployment of the hood. Different stature pedestrians (i.e. 6yo, 5th female, 50th male, and 95th male) have different wrap around distances (WADs) when struck by the front end of a given vehicle. Thus, they will also have different head impact times (Figure 6). To be most effective, any active hood system's TRT should be less than the head impact times for pedestrians of all sizes.

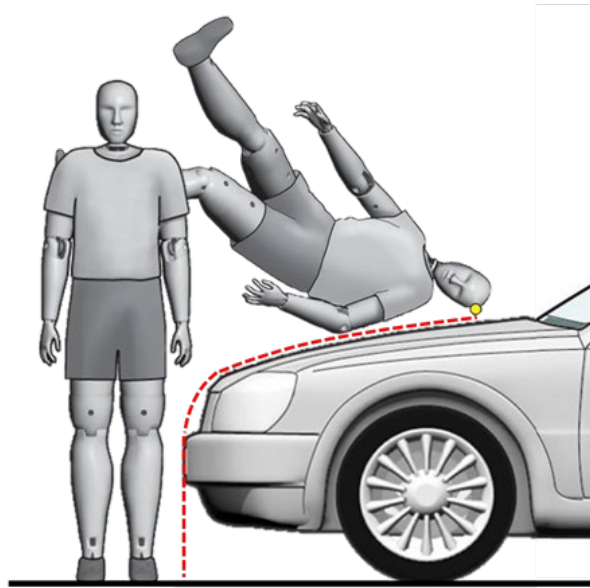


Figure 6. Wrap around distance (WAD) for a given stature shown by the red dotted line

Through simulations, a vehicle manufacturer can determine the head impact time (HIT) for a given stature (i.e. WAD) and how that relates to the total response time of the active hood system. Figure 7 below shows an example plot of head impact time versus stature (WAD) and how that relates to the total response time. If the system is fully deployed and remains in the intended position prior to the head impact time of a given stature pedestrian (i.e. if $TRT < HIT$), then all headform tests shall be performed with the hood in the fully deployed position and there will be no need to trigger any active elements during the test. If the system is not fully deployed before the head impact time of a given stature (i.e. $TRT > HIT$), then all grid points forward of the corresponding WAD are tested dynamically. In Figure 7, for example, the 6yo should be tested dynamically while the 5th female, 50th male, and 95th male should be tested in the fully deployed position. For systems that do not remain in a permanently deployed position and descend back down immediately after deployment, dynamic tests are required for all grid points.

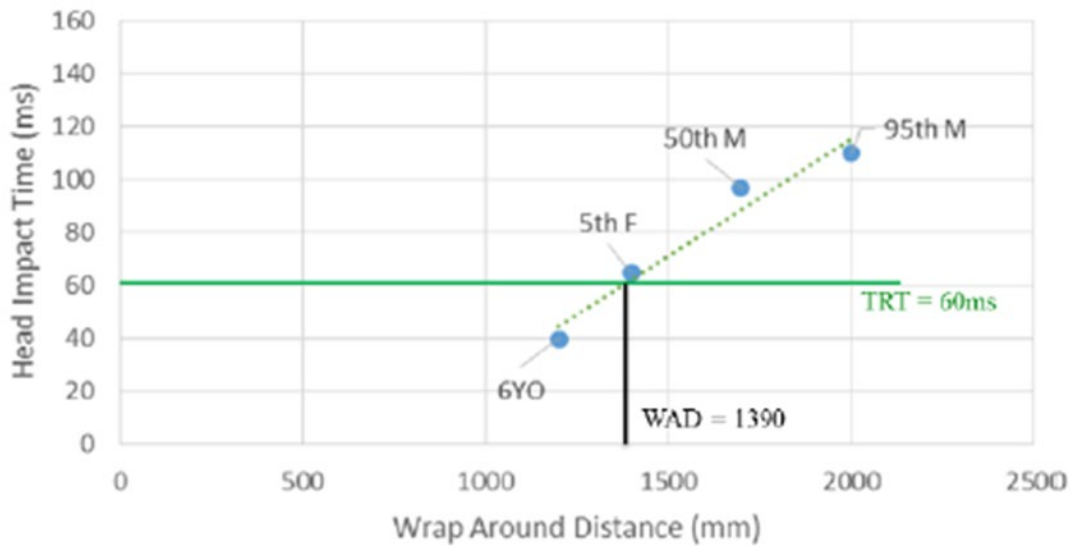


Figure 7. Head impact time (HIT) versus wrap around distance (WAD) and the relationship with the active hood total response time (TRT)

Both the Audi and the Cadillac are sold in Europe with an active hood system, and both have undergone the type approval process in which HIT vs. TRT was examined. Additionally, the Audi has been tested by Euro NCAP, prior to which Audi was required to produce a dossier containing simulation results and a plot similar to Figure 7.

According to both Audi and GM, the total response time of both hood deployments are less than the head impact time for all statures. Additionally, both hoods remain in a permanently deployed state. Therefore, head impacts to the active hood systems of both vehicles were performed in the fully deployed state (aka. deployed-static).

Grid points were chosen at locations where HIC values were predicted to be influenced the most by an active hood system based on their proximity to hard underlying structures. Grid points were marked and tested on the 2014 Cadillac ATS and 2017 Audi A4 undeployed hood following Euro NCAP test procedures. The same grid points were tested on deployed-static hoods. The same procedures were followed for targeting the grid points in both undeployed and deployed-static scenarios. In both cases, the headform is aligned with the selected grid point while the hood is in an undeployed condition. In the undeployed test, the headform is launched into the hood as usual. In the deployed-static test, the hood is deployed and allowed to settle before the headform is launched. Undeployed and deployed-static vehicle test setups for the Cadillac ATS are shown in Figure 8 and Figure 9, respectively. Undeployed and deployed-static vehicle test setups for the Audi A4 are shown in Figure 10 and Figure 11, respectively.

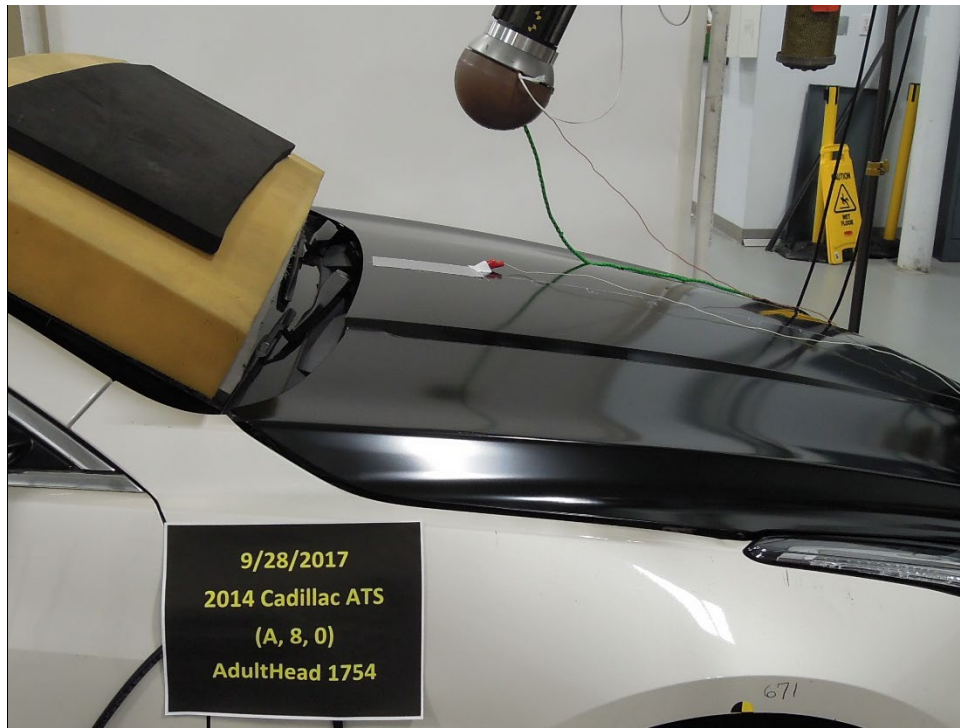


Figure 8. 2014 Cadillac ATS undeployed hood

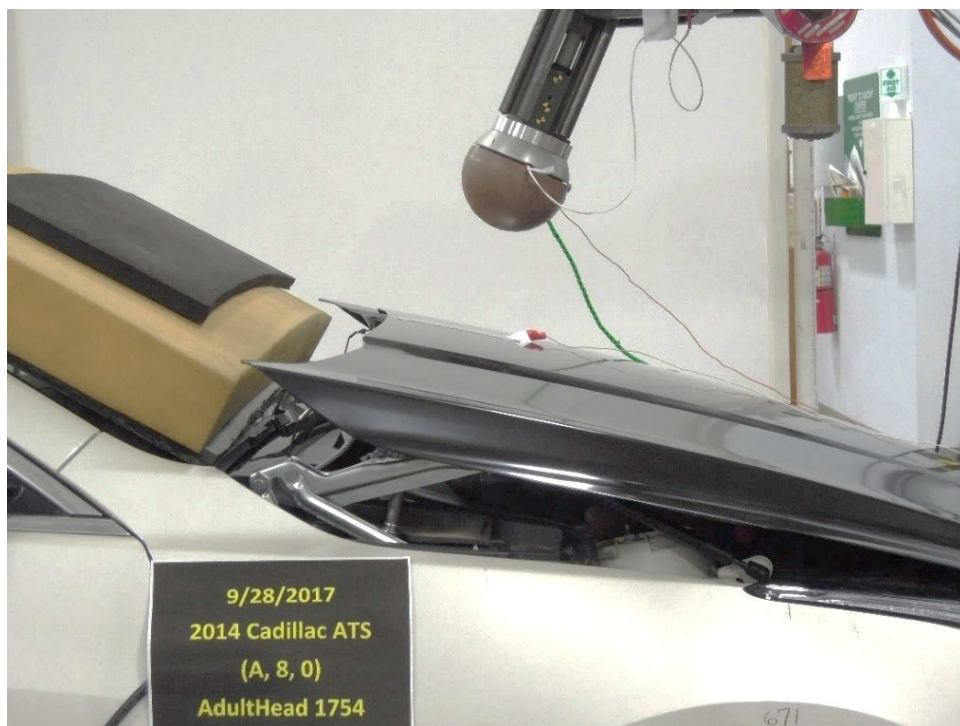


Figure 9. 2014 Cadillac ATS deployed-static hood. The rear of the hood moves upwards during deployment.



Figure 10. 2017 Audi A4 undeployed hood



Figure 11. 2017 Audi A4 deployed-static hood. Upon deployment, the hood slides rearward and extends upward.

3. Results

3.1. 2014 Cadillac ATS

Three grid points, which were predicted to be severe impacts based on the underlying structures, were chosen and tested on the 2014 Cadillac ATS undeployed and deployed-static hoods and are shown in Figure 12 below. Headform velocities and HIC15 results are summarized in Table 1.



Figure 12. 2014 Cadillac ATS headform impact points

Table 1. 2014 Cadillac ATS headform impact results

Impact Location	U.S. Version Undeployed Hood		European Version Static Deployed Hood	
	Impact Velocity (m/s)	HIC15	Impact Velocity (m/s)	HIC15
C,6,+6	11.27	1923	11.19	400
C,5,0	11.25	2753	11.21	299
A,8,0	11.18	1793	11.11	232

3.2. 2017 Audi A4

Six grid points were chosen and tested on the 2017 Audi A4 undeployed and deployed-static hoods and are shown in Figure 13 below. Headform velocities and HIC results are summarized in Table 2. Additionally, Table 2 shows HIC15 data provided by Euro NCAP, which tested the same generation of the Audi in 2015 (the A4 was introduced in Europe before it was introduced in the U.S.). Of the six grid points that we tested, Euro NCAP only tested one of them. However, as part of the evaluation process, Audi provided Euro NCAP with predicted HIC15 ranges for all grid points. The ranges for the six points that were tested are included in Table 2.

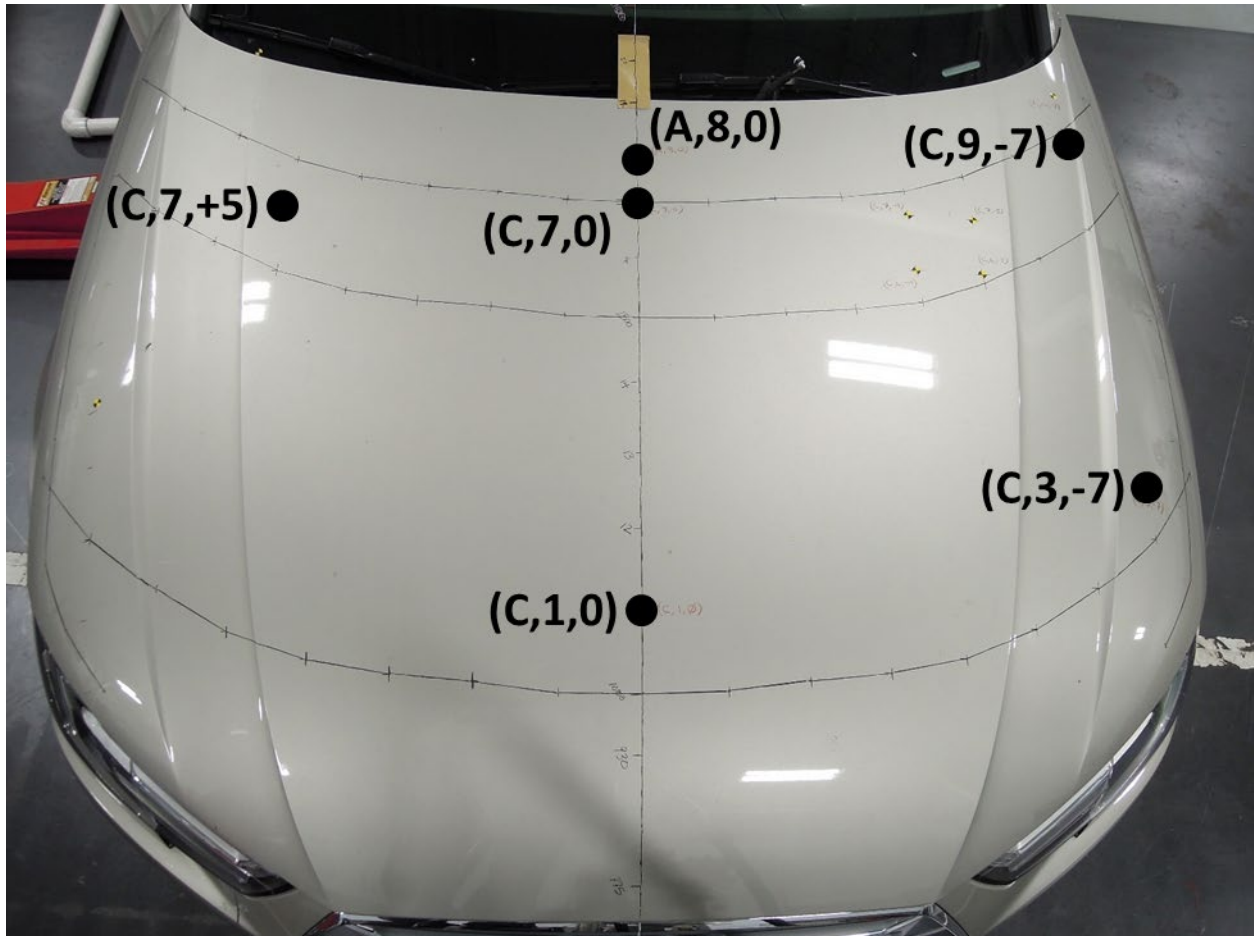


Figure 13. 2017 Audi A4 headform impact points

Table 2. 2017 Audi A4 headform impact results

Grid Point	NHTSA Tested (U.S. undeployed hood)		NHTSA Tested (deployed hood)		Euro NCAP Tested (deployed hood)	Audi Predicted (deployed hood)
	Impact Velocity (m/s)	HIC15 Score	Impact Velocity (m/s)	HIC15 score	HIC15 Score	HIC15 Range
C,1,0	11.14	945	11.12	795	---	1000 - 1350
C,7,0	11.16	621	11.15	698	---	< 650
C,9,-7	11.10	1053	11.25	1153	---	1000 - 1350
C,7,5	11.13	703	11.18	556	568	< 650
C,3,-7	11.12	1085	11.27	766	---	650 - 1000
A,8,0	11.05	875	11.19	450	---	< 650

3.3. Summary

As shown in Table 1, HIC15 values for the 2014 Cadillac ATS’s undeployed hood were around 2000 and greater. The HIC15 results were greatly reduced during the deployed-static impacts. In the deployed-static impacts, HIC15 values were reduced to values below 500. On the other hand, as shown in Table 2, the Audi A4 did not show as dramatic of a reduction in HIC15 values in the deployed-static impact hood. Only three of the six tests resulted in lower HIC15 values that affected the score (i.e., the HIC15 reduction was enough to move into a higher point category). In two tests, the HIC15 values actually increased (but not enough to affect the scoring).

For the case of the Audi A4, the results of the NHTSA tests for the deployed condition match very closely to the data provided by Euro NCAP. This indicates that the front-end and hood structures that influence pedestrian head impact performance are nearly the same for the U.S. and European variants of the Audi. However, the U.S. variant available to consumers does not include the active hood feature.

4. Discussion

The large HIC15 values for the Cadillac ATS in the undeployed impacts may be due to the low hood height and the hood’s proximity to the underlying components within the engine compartment. When laid on a flat surface, the rear edge of the Cadillac ATS hood has a height of approximately 95 mm (Figure 14).

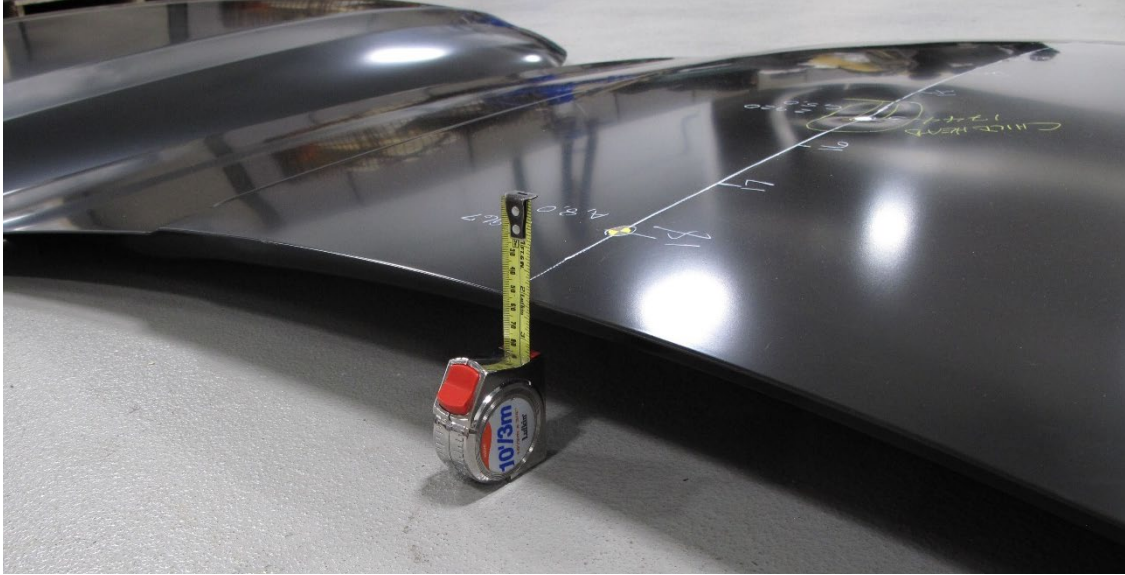


Figure 14. 2014 Cadillac ATS rear hood height measurement

In fact, in the undeployed impact at location (C,6,+6), the headform penetrates the hood with enough depth to contact the bolts of the strut tower as shown in Figure 15 below, creating a very harsh impact environment and large HIC15 value. Additionally, at impact location (C,5,0), the headform is believed to have penetrated the hood with enough depth to contact the top of the engine, again creating a very harsh impact and large HIC15 value.



Figure 15. Strut tower bolt intrusion (circled in red) in the Cadillac ATS at impact location (C,6,+6)

In the Cadillac ATS deployed-static impacts, the deployed hood created more space between the hood surface and underlying engine components. The increased space cushioned the impacts, greatly reducing their HIC15 values.

The low to moderate HIC15 values for the Audi A4 in the undeployed impacts are likely due to the greater hood height and the hood's greater distance to the underlying components within the engine compartment. When laid on a flat surface, the rear edge of the Audi A4 hood has a height of approximately 145 mm (Figure 16).

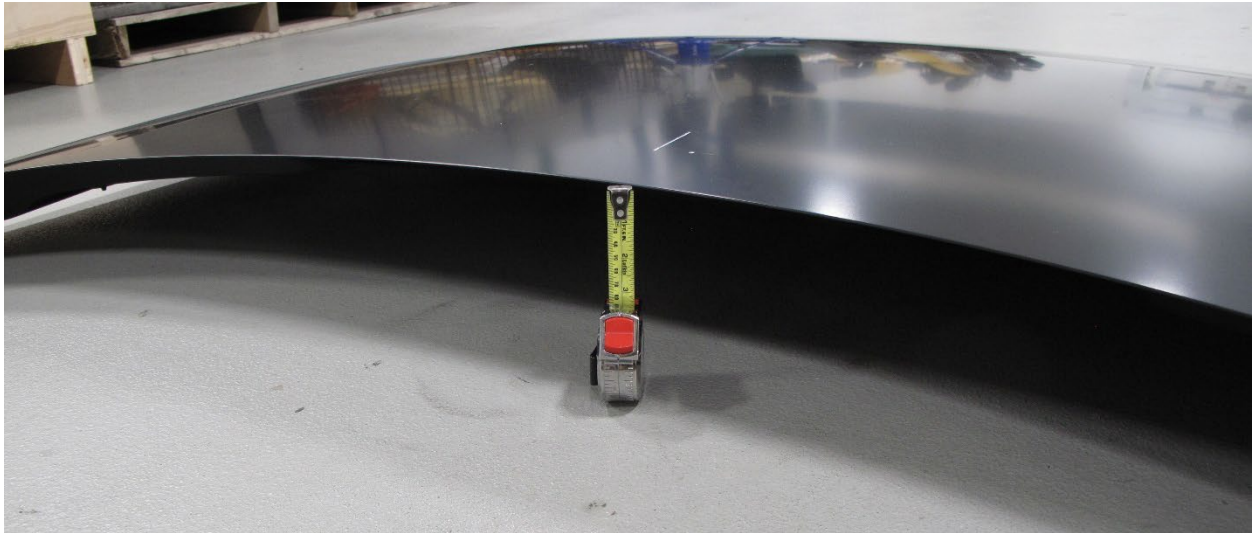


Figure 16. 2017 Audi A4 rear hood height measurement

Since there is already a good amount of space to soften a head impact in the Audi A4 undeployed hood, the addition of more space in the deployed-static hood did not greatly affect the impact results. As observed previously, only three of the six tests resulted in HIC15 values that were reduced enough to affect the overall score.

VRTC discovered that for some vehicle makes and models that exist in both European and U.S. markets, it is possible to install active hood system components with no structural modifications to the vehicle. VRTC successfully implemented European active hood systems into two U.S. vehicles, the 2014 Cadillac ATS and 2017 Audi A4. Headform impacts were performed on both vehicles with the hoods in an undeployed state and a deployed-static state following Euro NCAP procedures. In conclusion, it was found that active hoods generally reduce HIC15 values, but the amount of reduction depends greatly on the vehicle design.

The 2017 Audi A4 represents a vehicle with sufficient space between the hood and underlying components of the engine compartment such that it will generally perform well in undeployed hood impacts and will only benefit slightly with the installation of an active hood system. On the other hand, a vehicle with very little space between the hood and underlying engine components, such as the 2014 Cadillac ATS, performs poorly in undeployed hood impacts. When fitted with an active hood system, the headform impact performance improves dramatically.

Therefore, U.S. vehicles with low-profile front-end styling and small under hood clearances can be made to be pedestrian friendly with an active hood system. However, just because a vehicle model exists in both EU and U.S. markets, it should not be assumed that active hood components can be simply installed into U.S. models. VRTC looked at a third vehicle, a 2014 Nissan Q50, and discovered that a simple install was not possible as the original hinge designs and clearances did not allow for the installation of a deployment actuator. For this vehicle, cutting through, modifying, and re-welding of major structures would have been necessary. Because this vehicle was also being used for other NHTSA studies, it was decided to not pursue these extensive modifications.

5. Conclusion

- Two vehicles were identified where active hood systems could be installed in the U.S. version with little/no change to the vehicle: the 2014 Cadillac ATS and the 2017 Audi A4. Both were tested with and without the active system in place.
- For the Cadillac, the active hood had a very significant influence; HIC15 values went from very high with the standard, undeployed hood (i.e., over the zero-point threshold of 1700) to very low with the active system (i.e., under the full point threshold of 650) due to the additional clearance between the hood and underlying structures.
- For the Audi, since a large amount of clearance between the hood and underlying structures was already present, the standard, undeployed hood produced low-to-moderately high HIC15 scores. The active hood showed only a negligible improvement in HIC15 scores.

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