JAGUAR 'F' TYPE DEPLOYABLE BONNET - CONFLICTS BETWEEN BONNET FUNCTIONALITY AND PEDESTRIAN HEAD IMPACT PROTECTION

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ABSTRACT:

European pedestrian legislation includes simulated head impacts with vehicle bonnets. Acceleration based injury criteria require energy absorption zones with depths between 65-85mm.

If this energy absorption zone is unavailable and cannot be created due to package/styling constraints, technology such as a deployable bonnet will be required.

A high performance car like the Jaguar 'F' type is such a vehicle with restricted under bonnet clearance.

This paper investigates the feasibility of raising the 'F' type bonnet to create an energy-absorbing zone. Conflicts between the bonnet stiffness required for normal bonnet functionality, deployment and pedestrian head protection are identified and discussed.

1. INTRODUCTION TO PEDESTRIAN SAFETY

1.1. Background

Pedestrian fatalities are the second largest category of motor vehicle deaths. In 2000, in the EU there were 6045 fatalities, equating to 15% of all road deaths, and in Japan 2955 equating to 28% of all road deaths (1).

Serious and fatal injuries are often caused by head impacts to the bonnet (2). Under bonnet components prevent the bonnet from deforming sufficiently to absorb the impact. Serious injuries to the pedestrian's pelvis and legs are also common (2).

Euro NCAP introduced testing in 1996 to assess levels of pedestrian protection (3). This led to increased consumer awareness and car manufacturers have been criticised for concentrating on improving driver safety while doing little to protect pedestrians. European pedestrian protection legislation is being introduced in two phases, step 1 in 2005 and a more stringent step 2 circa 2010 (4). Japanese legislation is also being introduced in 2005. Although differences exist between these legislative and public domain test modes, they all follow similar principals of head, lower leg, and upper leg impact test procedures and injury assessment protocols.

However, adult and child head impacts are of particular interest in high performance sports cars as under bonnet space is restricted by physical engine size and low sleek vehicle styles.

1.2. The head impact test

1.2.1. European legislation step 1(4)

A small adult headform is impacted into the bonnet top. The test is performed at an impact speed of 35 km/h using a 3.5 kg test impactor. The head performance criterion (HPC) shall not exceed 1000 over 2/3 of the bonnet test area and 2000 for the remaining 1/3 of the bonnet test area. The HPC is a calculation, over a specified time period, of the maximum resultant acceleration experienced during the impact.

1.2.2. European legislation step 2(4)

A child headform is impacted into the bonnet top. The test is performed at an impact speed of 40 km/h using a 2.5 kg test impactor. The HPC shall not exceed 1000 for the bonnet test area between the 1000mm and 1500mm wrap around lines. These lines are marked on a vehicle by placing one end of a flexible tape in contact with the ground, vertically below the front face of the bumper and the other end held in contact with the bonnet.

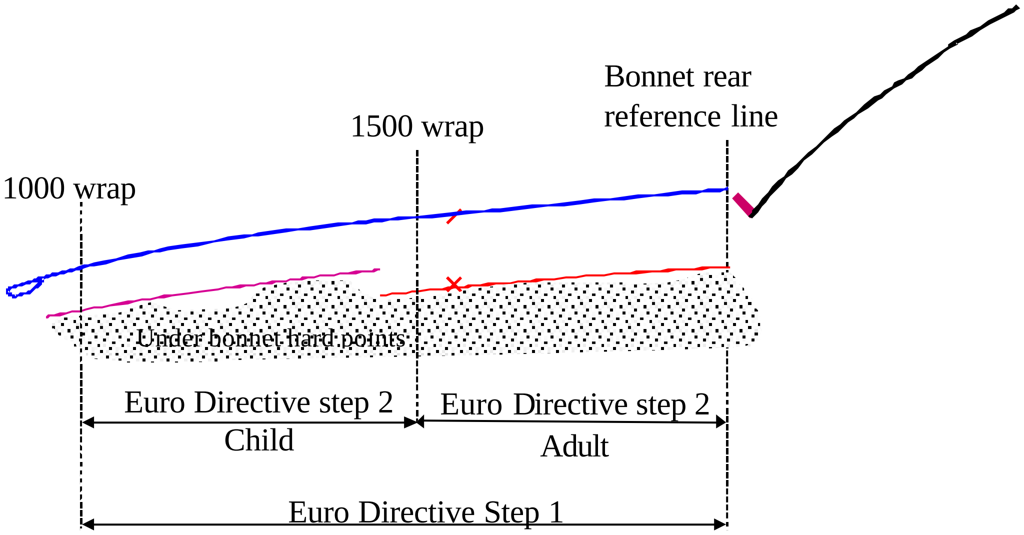
An adult headform is impacted into the bonnet top. The test is performed at an impact speed of 40 km/h using a 4.8 kg test impactor. The HPC shall not exceed 1000 for the bonnet test area between the 1500mm and 2100mm wrap around lines or alternatively the 1500mm line and bonnet rear reference line. The bonnet rear reference line is used if the 2100mm line falls on the windscreen and is obtained by rolling a 165mm diameter sphere around the rear of the bonnet while maintaining contact with the windscreen. For the Jaguar 'F' type the test area is between the 1500mm wrap around line and the rear reference line.

1.3. Necessity for under bonnet clearance

Acceleration based injury criteria require energy absorption zones between the bonnet 'A' surface and under bonnet hard points to absorb the impact of the head. The main means of dissipating the energy is by bending and crushing of the bonnet (deformation). The amount of under bonnet crush space required varies between European legislation step 1 and step 2 due to the different headforms and test protocols being used.

Some original work was undertaken to estimate the minimum crush distance required to produce a HPC not exceeding 1000 (5) assuming a constant deceleration of the impactor. The distance calculated, for a 'square wave' (very efficient) deceleration was 56mm. Normal impacts unfortunately do not produce this type of optimum crush behaviour, therefore the crush efficiency is severely reduced leading to an increased package requirement.

Figure 1 identifies the automotive industry accepted clearances required from the bonnet 'A' surface to the under bonnet hard points.



Headform	Required Clearance
Euro Directive step 1	~ 60mm
Euro Directive step 2 Child	~ 65mm
Euro Directive step 2 Adult	~ 85mm

Figure 1. Underbonnet clearance requirements

1.4. Scope

This paper investigates the head impact to bonnet requirements of European legislation step 1 and step 2 and the effects of the requirements on bonnet design of performance sports cars using Jaguar 'F' type concept car as a representative model (Figure 2).

Figure 2. Jaguar 'F' type

2. BONNET DESIGN AND CHALLENGES

2.1. Styling away from impact zones (5)

During the research work on the Jaguar ‘F’ type some care has been taken to style the vehicle adequately to maximise pedestrian protection. For this study other injurious zones such as wiper spindles, fenders, & headlights have been packaged and styled in order to avoid head impacts with these components.

For example, the plenum area that houses the wiper spindles has been styled and engineered such that a pedestrian head would contact the bonnet only (Figure 3).

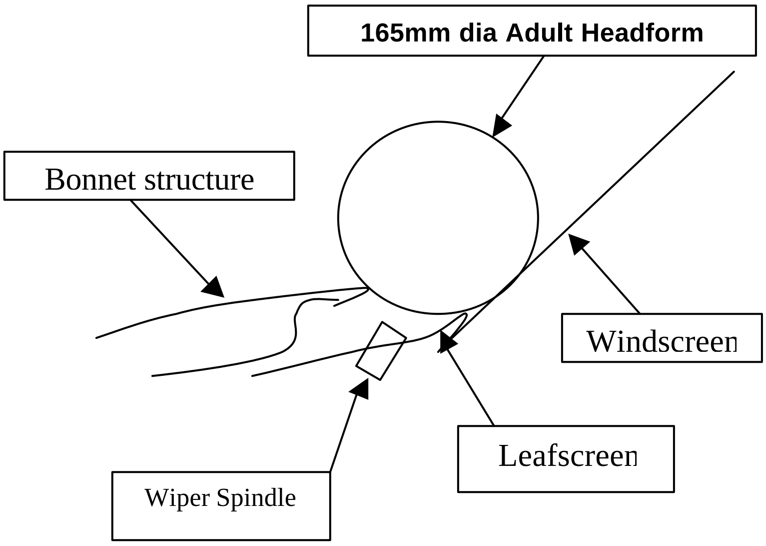


Figure 3. Section of 'F' type bonnet and windscreen

The bonnet shutlines were positioned outside the head impact area ensuring that all the head impacts were to the bonnet top and no impacts were necessary on the fenders. The headlamps, being heavy components and rigidly fixed to the vehicle, were positioned outside the head impact zone.

2.2. Jaguar 'F' type challenges

With its iconic styling and high performance engine, the Jaguar ‘F’ Type concept car (Figure 2) does not have the necessary under bonnet crush space to meet pedestrian head requirements. Moving or modifying under bonnet components is not feasible due to limited package space and the bonnet cannot be permanently raised without affecting forward vision requirements and the low sleek vehicle style. However, pedestrian requirements could be achieved by introducing a deployable bonnet to generate the necessary crush space just prior to pedestrian head impact.

In addition to the pedestrian head impact requirements, the bonnet must still be able to fulfil normal bonnet functionality requirements that have practical importance for the vehicle owner. The owner does not want a flimsy feel when opening and closing the bonnet and wants the bonnet to operate as intended for the life of the vehicle. It would also be an annoyance if there were excessive wind noise and vibration. Therefore, numerous functional requirements exist such as bonnet torsional rigidity, noise, vibration, and harshness (NVH), and bonnet system durability. These requirements and many others are needed to ensure there is no customer dissatisfaction.

A further challenge when using a deployable hood to meet pedestrian requirements is managing the deployment loads. An acceptable level of bonnet stiffness is required to counteract the deployment loads that are generated by the actuators. If an acceptable level is not reached, this can result in a bonnet that is not stable after the full deployment height is reached.

2.3. 'F' type test buck

The Jaguar research project on the deployable bonnet was centred around a test buck, which represented the 'F' type vehicle.

The bonnet inner has been engineered to provide a substantially uniform stiffness across the entire surface of the bonnet (Figure 4).

A cross member was also added to the rear of the bonnet structure to strengthen the bonnet under deployment.

The bonnet specification was aluminium with an inner panel thickness of 1mm and outer panel thickness of 0.9mm. The mass of the bonnet was 18kg.

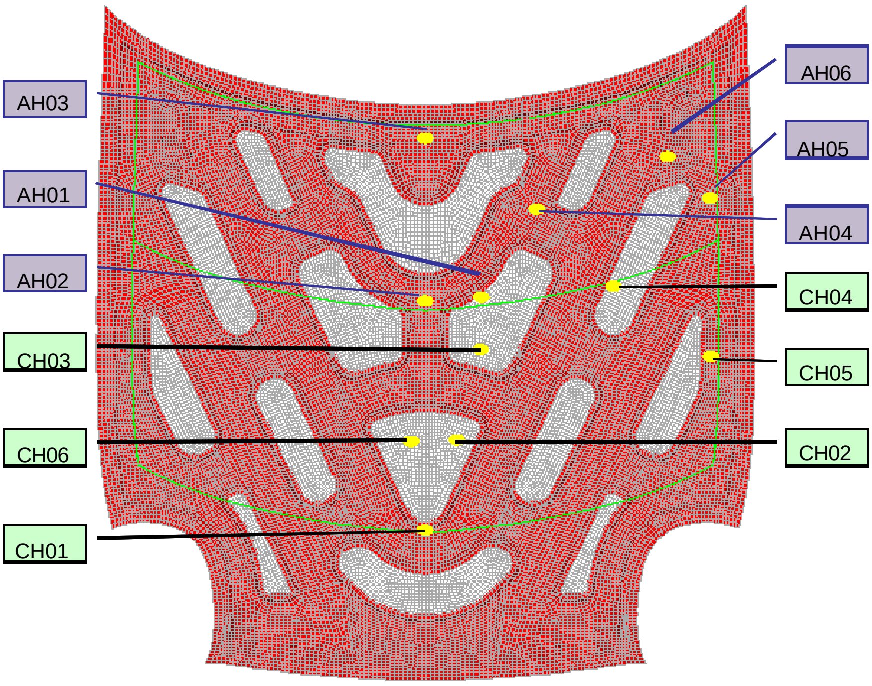
Two actuators were positioned at the rear of the bonnet at the left hand and right hand rear corners. The actuators raise the bonnet approximately 100mm rotating around the front hinges to give the necessary under bonnet clearance. A contact sensor located in the front bumper of the vehicle is used to trigger the actuators on recognition of a pedestrian impact. The time between first contact of the vehicle with the pedestrian and the pedestrian's head contact on the bonnet was found to be 65ms. This time was established by running a 50th percentile pedestrian MADYMO model. Based on the MADYMO results and sensing time needed to make a robust decision, the deployment timing required was 25ms to ensure the bonnet was in place prior to pedestrian head impact.

2.4. Initial development

Child and adult head impacts as per European directive step 2 protocols were conducted on the 'F' type buck with the bonnet in a pre-deployed condition. The impact locations are shown in figure 4.

'Live' firing of the deployable bonnet was conducted to assess deployment stiffness.

The bonnet was assessed against a selection of the bonnet functional requirements.



Key:

AH = Adult

CH = Child

Figure 4. Uniform stiffness 'F' type inner bonnet showing impact locations

2.5. Further development

The bonnet from the initial development phase was modified to improve normal functionality requirements and maintain head impact performance. The bonnet inner was again engineered to provide a constant stiffness across its entire surface. The pattern used was a further iteration of the initial bonnet design that had been developed. Reinforcements were also added along the sides to increase deployment stiffness. The hood inner gauge was increased to 1.5mm and hood outer to 1.1mm. This bonnet design is shown in figure 5.

CAE was used to evaluate this bonnet design (pre-deployed) against European directive step 1 and step 2 protocols, and also to assess deployment stiffness. The bonnet was also assessed against all of the necessary bonnet functional requirements.

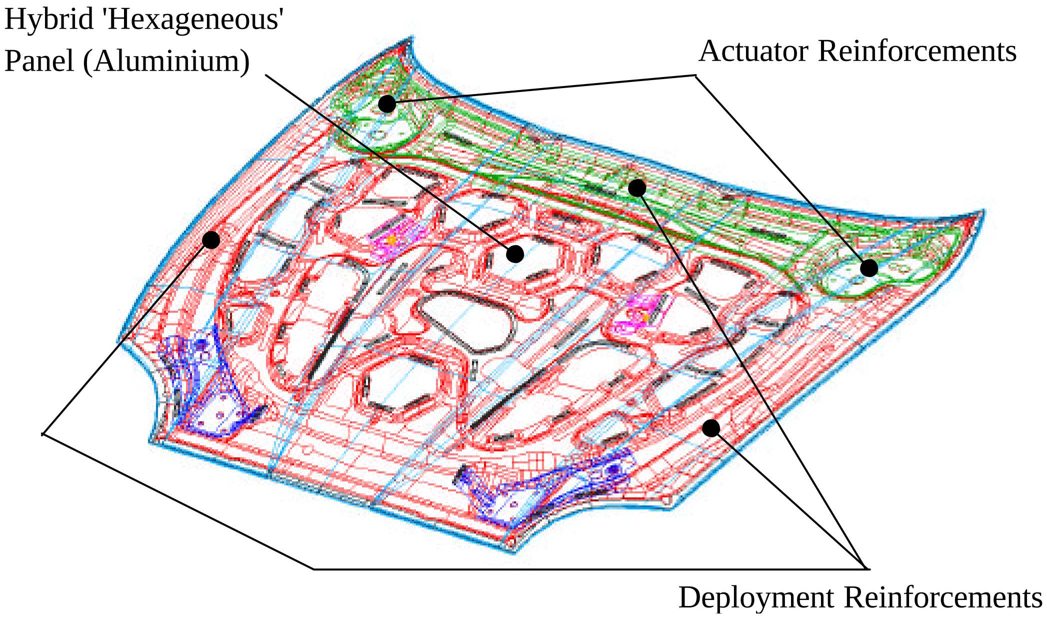


Figure 5. Next bonnet iteration

3. RESULTS

3.1. Initial development

The results obtained for child and adult head impacts on the pre-deployed bonnet met the requirements of European legislation step 2 (<1000 HIC) as highlighted in figure 6.

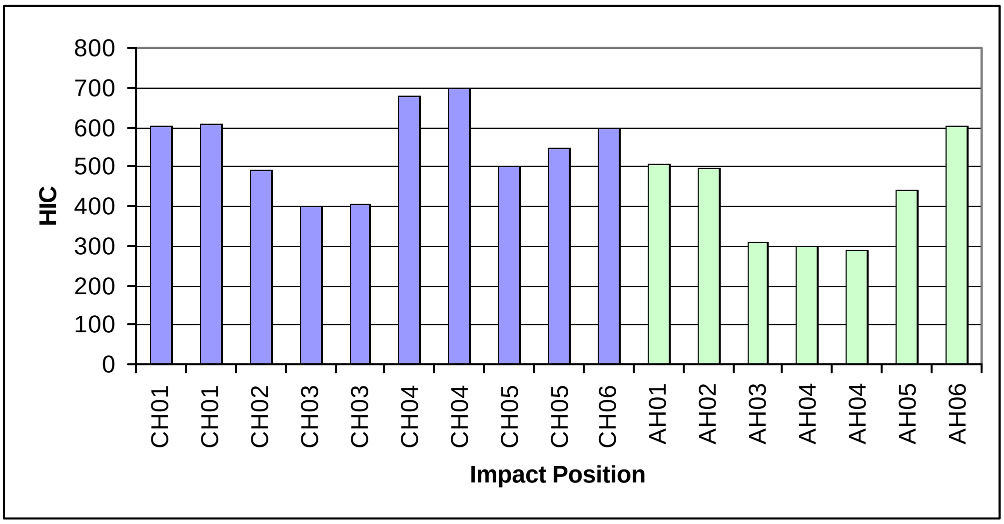


Figure 6. Child & adult head impact results

From these initial results it can be seen that in general the child head injury values are greater than the adult results (for a bonnet of constant stiffness). From film analysis and observations of the vehicle post-test, it was apparent that the child head displacement was less than the adult for the same impact speed.

However, from film analysis of the 'live' fire testing, it was observed that when the actuators had achieved full lift, the bonnet continued to oscillate and appeared unstable.

Also the bonnet did not meet the normal functional requirements it was assessed against e.g. torsional rigidity, lateral and vertical stability and bonnet system durability.

3.2 Further Development (Bonnet modified to improve stability and functional performance)

3.2.1 European directive step 1

The CAE results obtained for small adult head impacts on the pre-deployed bonnet met the requirements of European legislation step 1 as highlighted in figure 7.

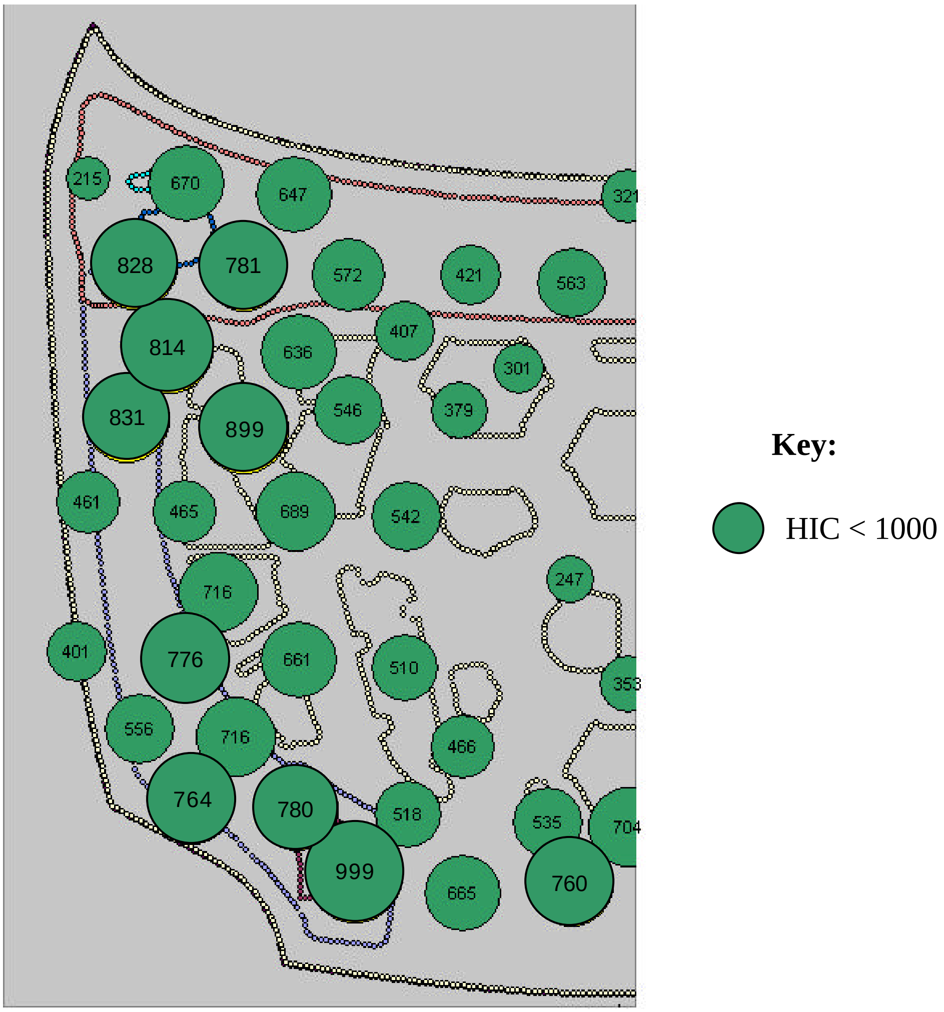
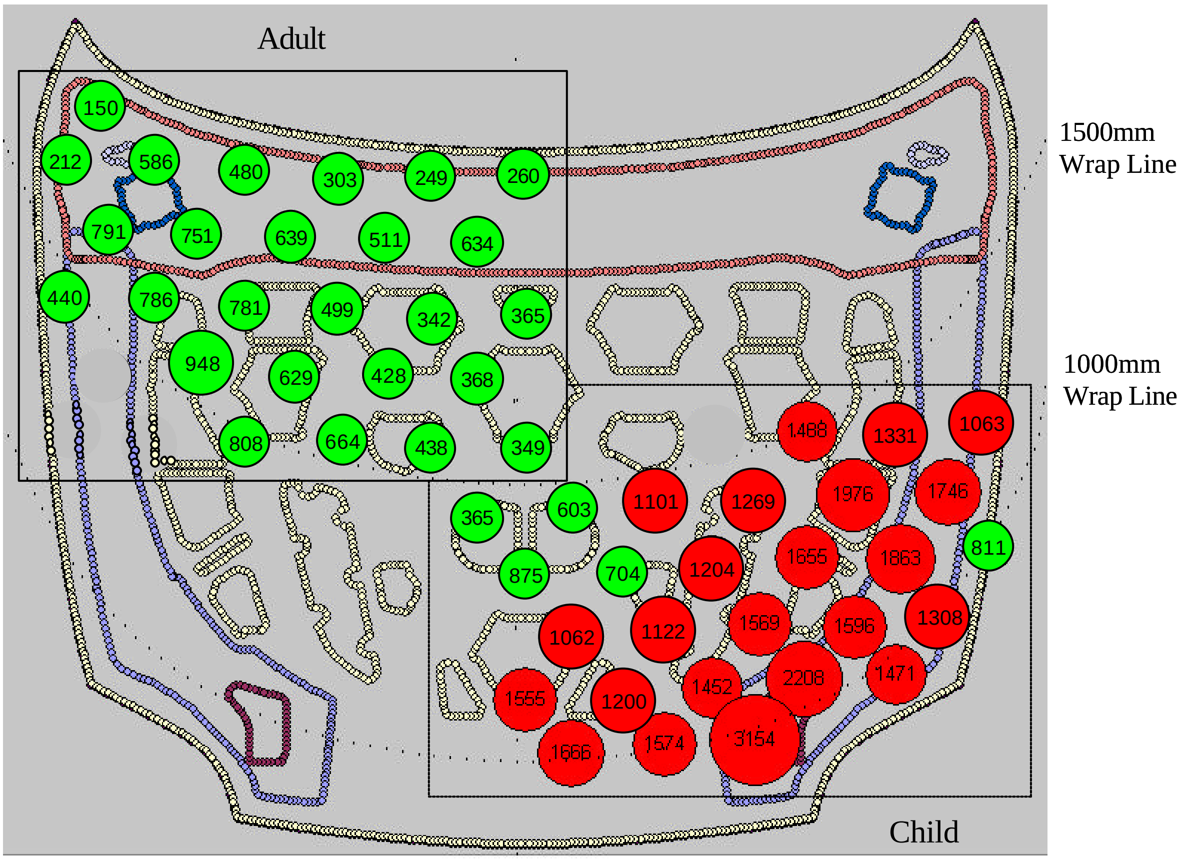


Figure 7. Euro legislation step 1 results for modified bonnets

3.2.2 European directive step 2

The CAE results obtained for adult head impacts on the pre-deployed bonnet met the requirements of step 2. However, the CAE results obtained for the child head impacts exceeded the limits of step 2 (Figure 8).



Key:

🟢 HIC < 1000

🔴 HIC > 1000

Figure 8. European legislation step 2 results

Minimal oscillations were witnessed after the actuators had achieved full lift, and the bonnet appeared stable.

The bonnet met all the normal functional requirements.

The child head injury values are significantly greater than the adult results. From film analysis and observations of the vehicle post-test, it was apparent that the child head displacement was less than the adult for the same impact speed.

4. DISCUSSIONS

The initial development indicated that a bonnet could be engineered to meet European directive step 2 if normal bonnet functionality and deployment stiffness are ignored. A consequence of not meeting bonnet functionality requirements is reduced quality with a high risk of customer dissatisfaction, which potentially could result in lost sales. The consequence of an unstable deployment is that the bonnet may not achieve the necessary under bonnet clearance at the time of head impact. This is a result of the high lifting forces that are applied to the rear edge of the bonnet by the actuators. Further detailed investigations would be necessary to establish the full effect on head injury levels of an unstable deployment.

The development work shows that an optimised bonnet that complies with normal functionality and deployment stiffness requirements can meet European directive step 1. However, for European directive step 2, although adult head performance is still acceptable, child performance has been compromised. By comparing the child head (step 2) and small adult head (step 1) results, even though the impact energy ($\frac{1}{2}mv^2$) between the two headforms is comparable (164.7J vs. 154.0J), the child head results are greater. This can be explained by the fact that the mass of the child head is less than the small adult (2.5kg vs. 3.5kg). Consequently for the same impact force (F), the acceleration (a) on the head is inversely proportional to its mass (m) ($a=F/m$). As the mass of the child head is lower, it can be concluded that its acceleration is more severe, often resulting in an increased HPC.

This implies that to meet child injury criteria, the bonnet stiffness needs to be greatly reduced in order to minimize the acceleration. An obvious route would be to downgauge the bonnet structure. Unfortunately, this would affect the bending and torsional performance of the bonnet system. To compensate, the bonnet inner depth would need to be increased to retain equivalent engineering behaviour. As limited under bonnet clearance is available on the Jaguar 'F' type, this would be an extremely difficult task.

5. CONCLUSIONS

Forthcoming pedestrian legislation will have a major influence on vehicle design and performance, and will present a significant challenge to manufacturers. Although a lot can be done by styling the vehicle and clever package engineering, some vehicles, like the Jaguar 'F' type concept car, do not have the necessary crush distance to absorb the pedestrian head impact energy. Therefore, a potential solution is to deploy the bonnet to generate this package space. This needs to be done without compromising normal bonnet functionality requirements that have practical importance for the vehicle owner, and it needs to be ensured that the desired level of deployment stability is achieved.

The current research based on the ‘F’ Type concept car shows that (with the bonnet deployed) it is possible to meet European directive step 1 requirements simultaneously with normal bonnet functionality targets and necessary deployment stiffness. For step 2 of EU directive it will be very difficult to reconcile the conflicting requirements of higher stiffness required for deployable bonnet stability and bonnet functionality with the lower stiffness necessary to achieve child head impact performance.

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REFERENCES

(1) International comparison of accident statistics 2000 (Source IRTAD Jan 2002).

(2) Paper Number 02P-367 Foresight Vehicle: Using Accident Data to Develop Advanced Protection for Vulnerable Road Users (APVRU) M.G. McCarthy TRL Limited

(3) European new car assessment programme (EuroNCAP) Pedestrian testing protocol

(4) DIRECTIVE 2003/102/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 November 2003 relating to the protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle and amending Council Directive 70/156/EEC

(5) 'Style and Package Requirement to Maximise Pedestrian Protection', TVT2004. C Bastien, Dr K Distin, Dr K L Laing.