MASS-BASED CONSIDERATIONS FOR HEAD INJURY PROTECTION DEVELOPMENT

Brian M. Boggess
Grant G. Foreman
Honda R&D Americas, Inc.
United States of America
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ABSTRACT

The purpose of this research study is to understand the mass limits of typical instrument panel (IP) components given standard design guidelines for head injury risk reduction. The IP components of passenger vehicles are continually changing to increase features and quality. Consequently, these changes increase the mass of the IP components. It was hypothesized that, regardless of the mounting, certain IP components possess significant inertial resistance such that injury risk values may be above accepted risk levels without modification to their internal structures. Using the FMVSS201 test procedure, multiple IP components from several vehicles (n=6) were tested for head injury risk both in-vehicle and as isolated suspended systems. The isolated components were tested using a simple pendulum setup with the component properly oriented and suspended from 2m cables. The component then was impacted with a 6.8kg linear head impactor at a velocity of 19.0km/h. Initial results showed that in an isolated state, the injury values, both peak and 3ms clip deceleration, correspond to as much as 93% of the in-vehicle tested values. From the component and in-vehicle tests, work functions based on the component mass were developed to replicate the impact event and establish mass-based thresholds. Models studied included waveforms comprised of haversine, half-sine, triangular, trapezoidal and square functions. A simple spring-mass model was also used to characterize the impact event. Initial assessment of the model showed the energy associated with an impact to a typical 4.5kg tuner assembly is great enough to potentially exceed the acceptable injury risk values according to Federal regulations. Furthermore, integrated structures such as air bag modules have a lower mass threshold due to their internal stiffness and interaction with the IP. Based on these thresholds, some design guidelines to improve the crush characteristics of structures such as tuners, HVAC controllers, and air bag modules are presented.

INTRODUCTION

Every year in the United States, over 60% of the nearly 40,000 fatalities and 50% of the 2.7 million reported injuries are a result of a front directional crash [1-World Bank]. In these crashes, there is a risk of an occupant's head striking the instrument panel.

In the United States (US), Federal Motor Vehicle Safety Standard (FMVSS) 201 imposes regulations aimed at limiting the rigidity of the instrument panel to provide head impact protection to occupants [2-FMVSS]. Similarly, in Europe (Economic Commission for Europe (ECE) 21.01), Japan (TRIAS34-1975), and Australia (Australian Design Rules (ADR) 21/00), requirements specify maximum injury levels for similar head impact events [3 – ECE, 4-TRIAS, 5- ADR].

All of the requirements specify an upper limit of 80g's for a 3ms continuous time clip. However, the impact speed of the 6.8kg headform varies from 19.0 to 24.1 km/h, depending on the market. The 3ms clip acceleration represents the typical injury assessment reference value (IARV) used for instrument panel impact testing.

Regardless of the specific test conditions and impact zones, the primary technique used to meet the interior impact requirements is to maintain sufficient clearance behind instrument panel components (e.g. tuner assemblies, HVAC controllers, etc.) to reduce head injuries. However, the increased mass of components creates a logical limit where the inertial resistance of a component is too great to overcome and still meet the prescribed injury thresholds. Therefore, these components must be developed to absorb energy internally as opposed to translation of the overall component.

This paper focuses on establishing mass-based thresholds to meet government regulations with conventionally mounted designs. If the thresholds are exceeded, then internally stroking designs must be used to meet the regulations. Specific design criteria are discussed to illustrate options for the construction of these designs.

METHODS

For this study, FMVSS 201 test procedures were used to study the mass-based implications of various components. The basic test parameters involve a 6.8kg headform impacting the IP surface at 19.0km/h. The impactor has a 'rigid' aluminum hemispherical construction with a 165mm diameter and is constrained either linearly or by a radial pendulum [2-FMVSS].

Figure 1. Typical configuration for a FMVSS 201 instrument panel head impact.

Head Injury Risk Assessment

The injury judgment criteria is a 3ms continuous clip of the headform deceleration. For this study, the focus was on the 3ms clip deceleration, but maximum acceleration and loading rates were also investigated. Manufacturers typically target a 20% lower than regulation value for safety margin. For this study, an industry accepted 3ms clip of 64g's was used to establish the mass-based threshold.

The concept of 3ms clip acceleration tolerance stems from the Wayne State Tolerance Curve first published in 1971. In this study head drop tests of forty cadaver subjects were conducted to develop what is now referred to as the Wayne State Tolerance Curve. The curve is a relationship of peak effective acceleration to time and the subsequent injury risk. The curve shows that the skull fracture tolerance of the human head has an inverse relationship between acceleration and time for injury risk. The human skull can sustain equally either a high-acceleration for a short duration or a lower-acceleration for a longer duration [6-Hodgson].

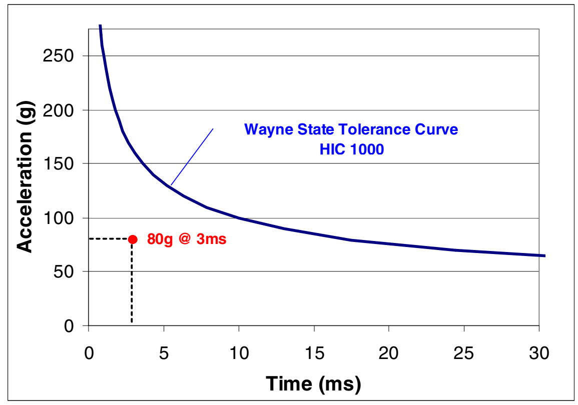

Figure 2: Wayne State Tolerance Curve depicting HIC1000 and the margin the 3ms, 80g IARV entails.

The 3ms clip IARV of 80g is clearly within the HIC1000 curve. Further, for a head contact event in which the head strikes the instrument panel, the time duration is typically below any range in which the HIC1000 tolerance curve would be exceeded.

Vehicle Testing of Tuner Assemblies

A variety of historical tests for impacts to the center of tuner assemblies were compared to establish an average jerk (g/ms) for a basic tuner construction design. Figure 3 shows that the average jerk for the tuner assemblies tested is 56g/ms. These tuners used conventional structures targeting a stroking unit mounted with deformable brackets. The mass of the tuner assemblies varied from 2.20 to 5.15kg.

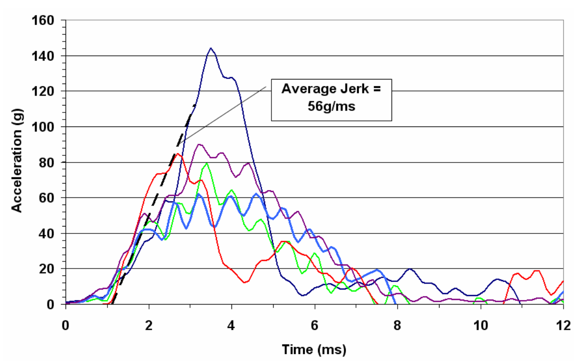

Figure 3. Acceleration versus time for a variety of tuner assembly impacts from various vehicles

Isolated Tuner Tests

A series of five impact tests were performed with the headform striking suspended tuner assemblies of various masses [Figure 4, 5]. The tuners were suspended from a 2m cable and impacted at a velocity of 19.0km/h with a 6.8kg headform impactor. The suspended tuners were impacted normal to the faceplate and in line with the center of gravity of the unit. The target point of the tuners corresponded (<10mm) with the geometric center of the faceplate. Headform acceleration was measured and processed according to SAE J211 [7-SAEJ211].

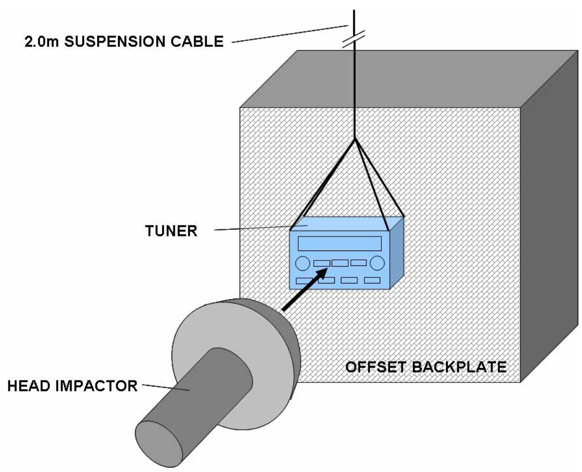

Figure 4. Setup of the isolated tuner test with the tuner suspended forward of a padded backplate to control the event after the initial impact.

Figure 5. Setup of isolated tuner test with the impactor loading through the center of gravity.

The tuners were also tested in-vehicle at the same relative angle and location. The comparison of component and in-vehicle tests showed linear correlation as high as 95%. Figure 6 shows one example comparing the in-vehicle test to isolated tuner test. This example illustrates a correlation of ($R^2 = 0.82$) between the tests.

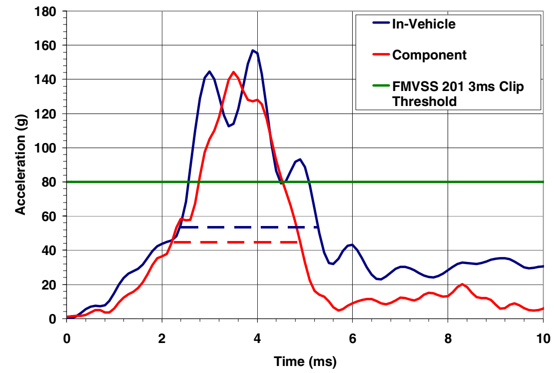

Figure 6. Overlay of tuner acceleration-time trace for the in-vehicle and component level impact test.

A review of the injury risk prediction values reveals that the isolated tuner assembly test represents a significant portion of the in-vehicle test. For the five tuners tested, the component test accounted for an average of 80% of the overall response measured in the vehicle test [Figure 7]. This suggests the tuner assembly inertia and stiffness account for the majority of the deceleration event, regardless of the in-vehicle mounting used for these particular conditions.

	3ms Clip (g)				Peak Accel (g)		
Tuner	Vehicle	Component	Percent		Vehicle	Component	Percent
1	53.4	44.7	84%		157.5	144.2	92%
2	45.6	36.2	79%		96.5	84.0	87%
3	45.6	42.5	93%		96.5	76.1	79%
4	66.1	52.6	80%		141.9	90.2	64%
5	35.3	23.2	66%		112.0	85.1	76%

Figure 7. Comparisons of 3ms clip and peak acceleration for in-vehicle and isolated component level tests.

Various Acceleration-Time Curve Waveforms

Based on the controlled input of the headform and mass of the impacted object, there exists a finite amount of energy available in the system. For this study, several waveforms were examined for their correlation to the measured performance of the head impact to tuner assembly. By examining these various models, it is possible to understand the upper and lower limits of what may be seen in actual vehicle testing. The waveforms studied included the following [Figure 8]:

•Square: Perfect ideal response to impact (infinite jerk to a 3ms peak value). This form represents the maximum 3ms clip for a given energy input.

•Triangular: Isosceles triangle response with ramp up/down rates equal to average onset from previous discussed vehicle tests.

• Trapezoid: Trapezoidal response with ramp up/down rate equal to the average jerk from vehicle tests and plateau 3ms in duration.

• Half Sine: Half period of sine wave with peak acceleration equal to that predicted by the component mass tests of the previous discussed tests.

• Haversine: Full period of shifted cosine wave with peak acceleration equal to that predicted by the component mass tests of the previous discussed tests.

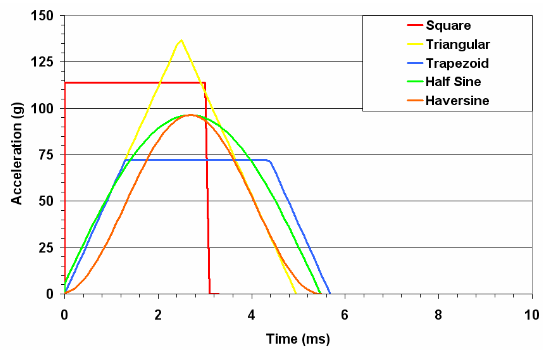

Figure 8: Various wave profiles for the energy transfer associated with a 4.0kg impacted mass given a 19.0km/h head impact.

For all the waveform profiles, the inputs by the headform remained constant for both mass and velocity. Further, the work done on the mass by the impactor was held constant for each mass, and the 3ms clip prediction subsequently calculated. Based on the mathematical models, the mass versus 3ms clip injury prediction was established [Figure 9]. The range of predictions for the various models was significant.

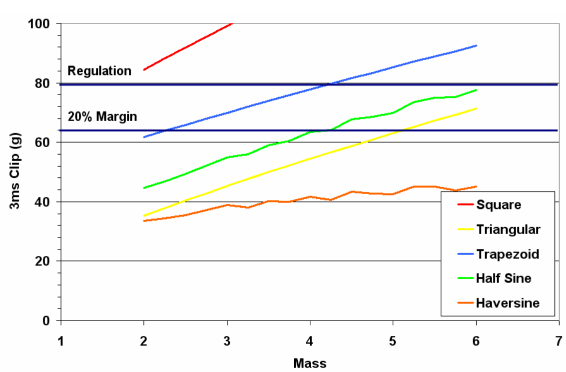

Figure 9: Relationship of component mass and 3ms clip acceleration for various wave profiles.

Dynamic Spring-Mass Model

A simple spring-mass model was used to establish the effects of varying the component mass given a constant input [Figure 10]. Given the input of a 6.8kg, 19.0 km/h headform, the mass of the component was varied from 2.0 to 6.0kg to establish a trend of mass versus injury risk. The spring stiffness was held constant and corresponded to the 56g/ms average jerk in the tuner impacts. In terms of stiffness, this is equivalent to 375N/mm.

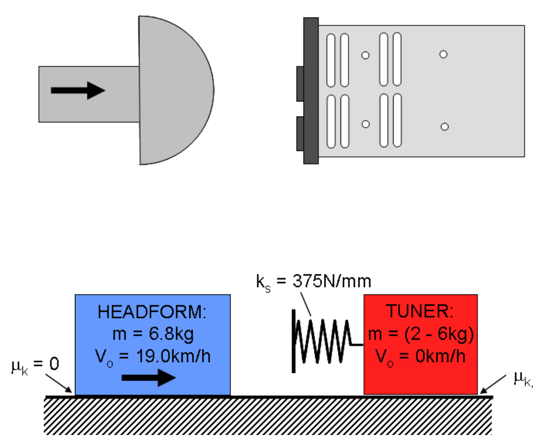

Figure 10. Spring-mass model used to relate the impacting headform to components of varying mass. The spring stiffness was held constant.

Using numerical integration, the dynamics of both the headform and tuner were calculated. Figure 11 shows the acceleration vs. time profiles of various component masses. From these time profiles, the subsequent injury risk potential (3ms clip) of the events for the various masses are presented [Figure 12]. For the mass range of interest, the injury risk prediction increases as the mass of the tuner is increased as originally hypothesized.

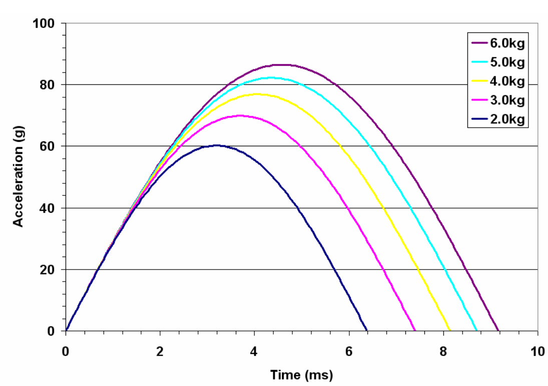

Figure 11. Predicted acceleration-time profile of various component masses.

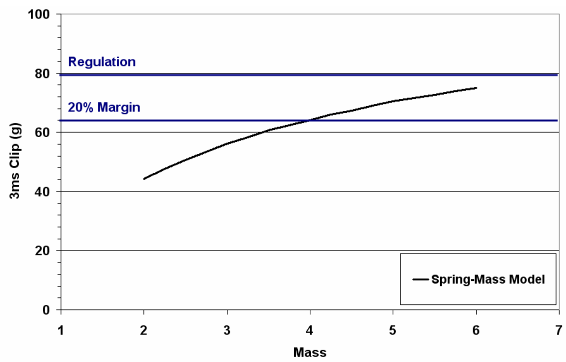

Figure 12. Injury predictive threshold of the spring-mass model used to relate the impacting headform to components of varying mass. The spring stiffness was held constant.

RESULTS / DISCUSSION

Correlation of Predictive Models

The comparison of the tuner impacts to the various waveform models showed the effectiveness of the models to both correlate the acceleration-time profile as well as the overall 3ms clip acceleration. For the five tuners studied, the haversine function correlated the strongest to the measured acceleration for actual tuner impacts [Figure 11]. The example shown in Figure 11 is for one of the 3.15kg tuner assemblies. The correlation varied dramatically between waveform models, but the haversine function had the highest correlation value ($R^2 = 0.93$) [Figure 12].

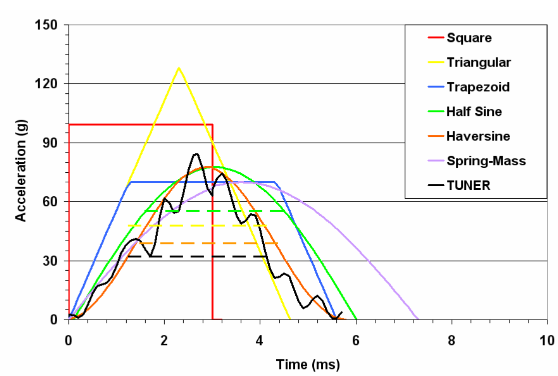

Figure 11: Acceleration-time relation of the waveform prediction models and the actual component tuner impact test.

Model	Correlation (R^2)	3ms Clip Error
Square	0.00	209%
Triangular	0.56	41%
Trapezoidal	0.65	103%
Half Sine	0.87	71%
Haversine	0.93	21%
Spring-Mass Model	0.42	75%

Figure 12: Correlation of the 3.15kg tuner impact to the various waveform prediction models and the error in 3ms clip prediction.

The predictive models and the actual in-vehicle tuner impacts were compared to establish the overall best predictors for the 3ms clip IARV [Figure 13]. The square wave and trapezoidal wave significantly over predicted the 3ms clip injury risk and can be disregarded as unrealistic. The triangular wave was the best model predictor to the in-vehicle tuner impacts in terms of 3ms clip prediction. Based on this model, a 5.0kg threshold is predicted as the mass at which there is inertial resistance to fail the IARV with 20% margin.

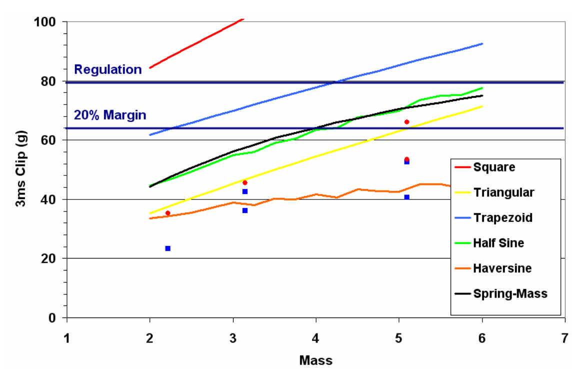

Figure 13: Correlation of tuner impacts compared to the predictive waveform models.

A slightly more conservative model compared to the triangular waveform would be either the half sine or spring-mass model. The mass threshold for these two models is 4.25kg given the 20% margin to the regulation.

Mass Based Threshold Predictions

Center Stack Components

A review of the predictive models used in this study show that the mass threshold of center stack components is between 4.25 – 5.0kg. This assumes a tuner assembly that is mounted to deformable brackets and the components can stroke into the instrument panel during impact At 4.0kg, the 3ms event is completed at 5.5ms according to the spring-mass model, but the headform has displaced 11mm [Figure 14].

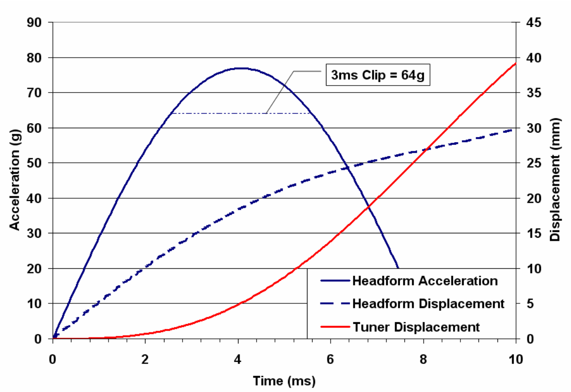

Figure 14: Relation of headform acceleration and displacement and the tuner displacement as a function of time.

As a conservative approach, the mass-based threshold for center stack components can be set as 4.5kg. Below this threshold, the ability to translate an instrument panel component is feasible given a representative stiffness, mounting structure, and clearance within the instrument panel to stroke. However, above this mass, the component must be designed with lower crush stiffness in order to internally displace and absorb the impact energy. At these higher masses, the injury risk portion of the event is over before the component strokes a significant amount.

Air Bag Modules

A similar investigation was carried out using impacts to the instrument panel over the passenger air bag module. Similar requirements exist for this area compared to tuner assemblies.

Typical designs by manufacturers involve either (1) crushable air bag module housings or (2) positioning the air bag below the instrument panel surface with sufficient stroke to absorb the impact before air bag module contact. With the latter design, a chute is applied to guide the air bag up and through the instrument panel surface.

To study the ability to translate the air bag module, CAE was conducted to measure the effects of the mounting brackets for a particular air bag assembly [Figure 15]. In this example, the air bag is mounted directly below the instrument panel surface and weighs 2.2kg. The brackets in the model were deleted to illustrate the inertia versus mounting effects of the system. The results for this study showed, like the tuner, the air bag module's mass is responsible for the majority of the impact event [Figure 16]. The 3ms clip acceleration for the condition with the brackets removed was 93% of the normal construction with brackets attached. Similarly, the peak acceleration was 92% of the normal condition and the overall correlation was $R^2 = 0.95$.

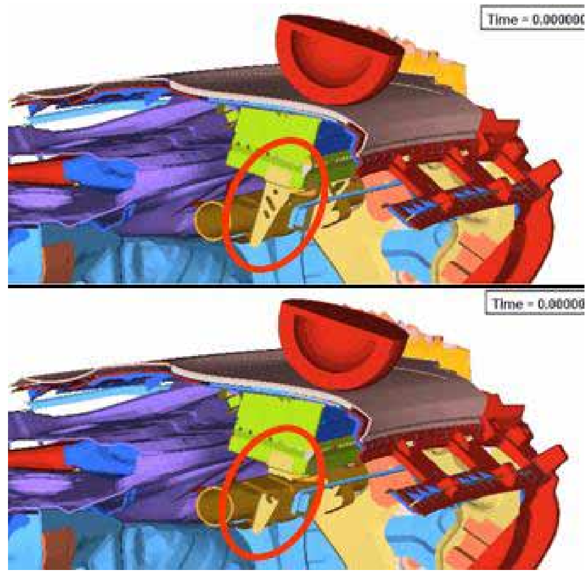

Figure 15: Instrument panel section showing the instrument panel as designed, and the brackets removed to compare the inertial and mounting effects.

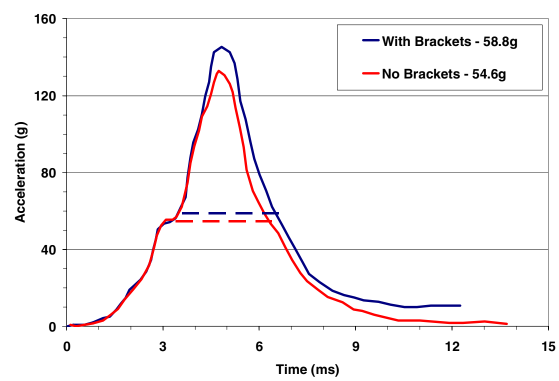

Figure 16: Comparison of the head impact to air bag module with and without mounting brackets.

By conducting an analysis similar to the center stack components predictive tool, a mass threshold of 2.5 kg can be set for airbag modules of comparable stiffness and mounting. The reduced mass threshold for the airbag module is a direct result of both the component stiffness and the interaction with IP substrate, which engages more of the IP mass than the center stack components.

CONCLUSIONS

It was originally hypothesized that regardless of mounting, certain IP components possess significant inertial resistance such that injury risk values may be above accepted risk levels without modification to their typical internal structures. This study has confirmed this belief as well as established mass-based thresholds for typical instrument panel components.

For tuners and other types of center stack components (e.g. HVAC controllers, NAVI screens, etc), the predictive models show a limit at 4.5kg for maintaining a reasonable (20%) margin to the regulation. Above this level, the potential for excessive injury risk is high and the predictive model quickly elevates the 3ms clip estimation. For all the mass-based criteria, the mass of the tuner, brackets, and any other combine parts such as HVAC assemblies must be considered.

Alternatively, structures such as air bags which mesh with the overall IP surface and subsequently acquire more mass and stiffness from the surrounding structure have a considerably lower mass threshold of 2.5kg for the specific module analyzed.

Design Alternatives

The IP components of passenger vehicles are continually changed to increase features and quality, which consequently increases the mass of these components. While continuing to apply additional features and the subsequent mass, new approaches to complying with regulations are necessary. If the ability to remove mass or relocate components without compromising content is not feasible, alternative structures must be developed.

For tuner assemblies, if the mass exceeds 4.5kg, the tuner could be designed with reduced stiffness and compartmentalized into secondary components to avoid overall part translation.

Airbag modules typically can be designed to crush and absorb energy while still meeting deployment requirements. Due to packaging limitations, if the airbag module must be mounted directly beneath the IP skin or near the skin, the housing must be designed to absorb the impact energy in a controlled manner.

Using the aforementioned design techniques, functionality or quality does not need to be sacrificed to meet head impact requirements.

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