

FIREWORTHINESS OF CABIN EXHAUSTER VENTS AND THE EFFECT OF AGEING

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ABSTRACT

In many case studies, post-collision fires originating outside the occupant compartment were found to have propagated into the occupant compartment through the cabin exhaust vents. HVAC systems in modern vehicles include exhaust vents to flow air out of the occupant compartment, while preventing air, moisture and dirt from flowing in. Cabin exhaust vents are typically constructed with a matrix of elastomeric flaps mounted to a rigid plastic grate and attached directly to the sheet metal of the vehicle body. This study evaluates the ability of production and improved exhaust vent designs to resist fire propagation.

INTRODUCTION

Modern vehicles rely on cabin exhaust vents to enable the HVAC system to flow air out of the cabin and to mitigate the shock of doors closing. These vents are typically located at the lower rear corners of the vehicle underneath the bumper fascia. In pickups, the vents are typically placed at the lower portion of the rear bulkhead and are concealed by the forward bulkhead of the bed. Figure 1 shows the location of an exhaust vent under the rear bumper fascia in a 2010s vintage domestic sedan. This vent uses a matrix of 9 elastomeric flaps to control airflow. The flaps are attached along their top edges to a plastic housing in a normally closed position and bend outward to allow air to flow out of the interior of the vehicle. When air pressure is applied from outside the vehicle, the flaps seal against the plastic housing to resist airflow into the interior of the vehicle.

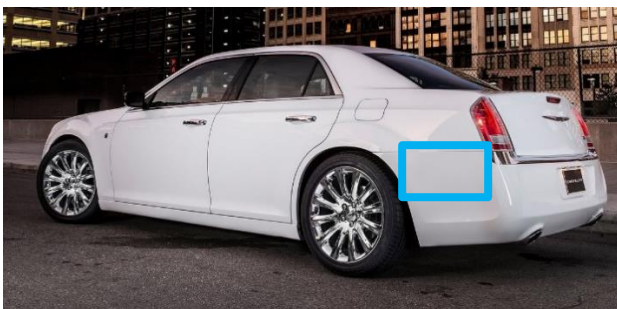


Figure 1: Cabin Exhaust Vent

Numerous real world post-collision fire incidents have been analyzed in which it was determined that fire propagated into the occupant compartment through exhauster vent openings in the body sheet metal. Exhauster vent openings are among the largest openings found in body panels, rivaled only by openings in the cowl for the HVAC air intake. In addition, exhauster vents are typically located low on the vehicle where they are exposed to pool or underbody fire scenarios. Because of their exposed location and construction with combustible materials, exhauster vents are not well suited to protect the large openings they occupy in the body structure.

Nearly 3 out of 4 vehicle fires are caused by mechanical or electrical failures or malfunctions, but these fires only account for 11% of vehicle fire deaths. Collisions and overturns contribute to ignition in only 3% of vehicle fires, however, these fires result in 3 out of 5 vehicle fire deaths.[1] Occupant extrication often requires 15-20 minutes from the time of a crash. However, death can occur in as little as 1-3 minutes once fire enters the occupant compartment.[2],[3] Vehicles must therefore be designed to resist the ingress of fire for a sufficient time to facilitate extrication to protect entrapped or incapacitated occupants. There is no federally mandated testing standard to evaluate how long it takes for fire to penetrate the occupant compartment of a motor vehicle.

EXEMPLAR VENT SURVEY

Exhauster vents are typically positioned behind the vehicle's rear bumper but that does not preclude them from damage and degradation. Throughout their lifetime, exhauster vents are subject to environmental factors, road debris and temperature changes that cause material degradation. Figure 2 below shows an aged exhauster vent obtained from an exemplar 2013 model year sedan compared to a new OEM replacement vent for the same vehicle. The elastomeric flaps in the aged vent have degraded significantly, two of the flaps have become displaced and one of the flaps is missing.

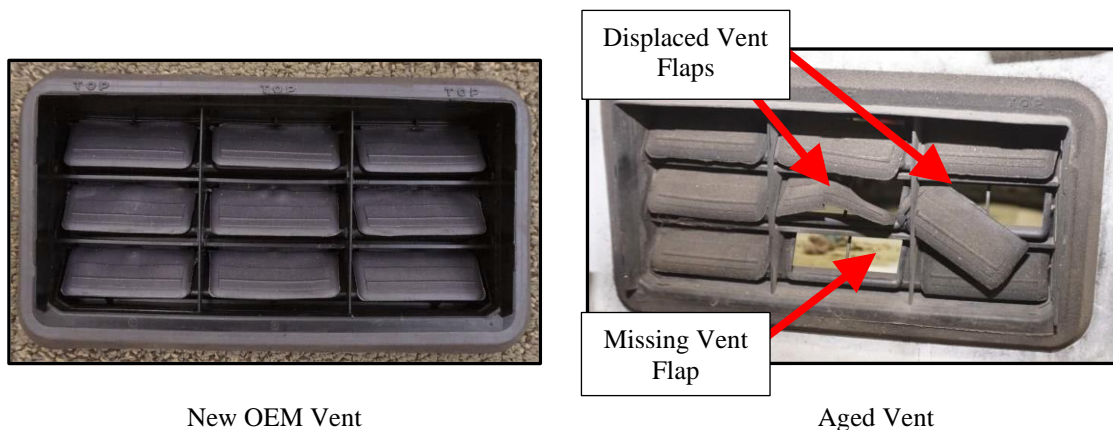


Figure 2: New OEM vs Aged Vent Comparison

Motor vehicles have the potential to last for many decades. According to data from the National Household Travel Survey, or NHTS, nearly half of the vehicles on the road are 10 years old or older. In addition, nearly 1 in 4 vehicles on the road are 15 years old or older, and nearly 1 in 10 vehicles is 20 years old or older.

A survey was conducted on the condition of exhauster vents on 33 vehicles ranging from 8 to 25 years old. Each examined vent was checked for three categories of ageing and deterioration. Degraded material classifies vents that have weak or brittle flaps, or other changes in material properties that impair the functionality or integrity of the vent. Displaced flaps categorizes vents that have flaps that are distorted, partially detached, or otherwise out of position. Finally, missing flaps classify vents that are missing at least one of their flaps. It was observed that 7 of the 33 vehicles exhibited the above signs of ageing, summarized in Table 1 below. Examples of the vents listed in Table 1 are presented in Figure 3 through Figure 6.

Table 1: Summary of Vehicles with Degraded Vents

| Vehicle Number | Model Year | Degraded Material | Displaced Flaps | Missing Flaps |
|----------------|--------------------------|-------------------|-----------------|---------------|
| 4a | 2004 BMW X3* | Yes | No | No |
| 4b | 2004 BMW X3* | Yes | Yes | No |
| 7a | 2003 Chevrolet K1500 | Yes | No | No |
| 7b | 2003 Chevrolet K1500 | Yes | No | No |
| 12 | 2004 Hyundai Elantra | No | No | Yes |
| 15a | 1996 Jeep Grand Cherokee | Yes | No | No |
| 15b | 1996 Jeep Grand Cherokee | Yes | No | No |
| 22 | 1998 Nissan Altima | Yes | Yes | No |
| 25 | 2000 Toyota 4Runner | - | - | Yes |
| 28 | 2000 Toyota Celica | Yes | No | No |

*Flaps inoperable, material disintegrated when touched



Figure 3: Exhauster vent 4a driver's side (Left) and 4b passenger's side (Right)



Figure 4: Exhauster vent 7a driver's side (Left) and 7b passenger's side (Right)



Figure 5: Exhauster vent 12

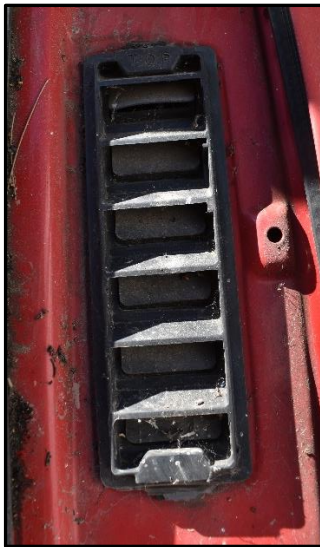


Figure 6: Exhauster vent 15a driver's side (Left) and 15b passenger's side (Right)

It was determined 7 of 33 vents examined in the survey, 21% of the sample size, showed signs of ageing. However, many vents did not have any visible evidence of ageing or degradation despite being found in vehicles that were of similar or older vintage compared to the vehicles with degraded vents. Factors such as design and material selection determine whether a vent deteriorates with age. In addition, the survey found that vehicle 15 had degraded vents while another vehicle of the same make and model and only one model year newer did not have degraded vents. This suggests that environmental factors and differences in usage also influence the degradation of vents. More exposure to the elements and temperature extremes, and more hours of usage of the HVAC system would be expected to hasten the ageing process.

PRODUCTION DESIGN BURN TESTING

Burn testing has been conducted on new OEM replacement and aged vents utilizing fuel sources representative of the fuels identified in real world vehicle fire incidents. This testing has been run utilizing partial vehicle clips obtained from exemplar vehicles to represent the area of fire propagation identified in the case studies, as well as sheet metal bench testing fixtures representing the pass-through openings in the subject vehicles. New OEM replacement exhauster vents and pass-through seals were tested, as well as aged exhauster vents obtained from exemplar vehicles and improved vent and pass-through designs.

Test Series 1

Burn testing was conducted to evaluate the fire resistance of the vent design used on a domestic pickup cab using gasoline in a burn pan positioned underneath the exhauster vent. An exemplar cab was obtained from a vehicle that was approximately 18 years old at the time of the test. The aged vent in this cab was subjected to testing. In addition, a new OEM vent was subjected to burn testing in a sheet metal bench testing fixture configured in a manner consistent with the portion of the cab where the vent is installed. The setup for each test is shown in Figure 7. It was noted that the design of the new OEM replacement vent had changed compared to the vent from the 18 year old exemplar cab. While both vents were designed to fit the same opening, the new OEM vent had fewer flaps.



Aged Vent from 18 Year Old Exemplar Cab

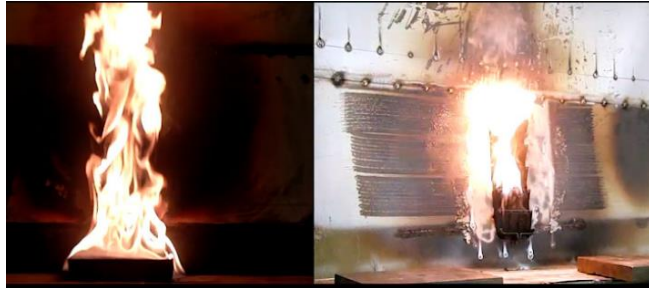


New OEM Vent

Figure 7: Test Setup

In the new OEM vent test, fire broke through and ignited the inside of the vent at approximately 78 seconds after ignition and the vent had fallen completely out of the opening by approximately 99 seconds. In the aged vent test, flames were first visible on the interior side of the exhauster vent at approximately 42 seconds after ignition and the vent had fallen completely out of the opening by approximately 53 seconds after the fire was ignited. Figure 8 shows the point when the fire ignited the inside portion of the vent in each test.

New OEM Vent
~78 seconds



Aged Vent from 18 Year Old
Exemplar Cab
~42 seconds

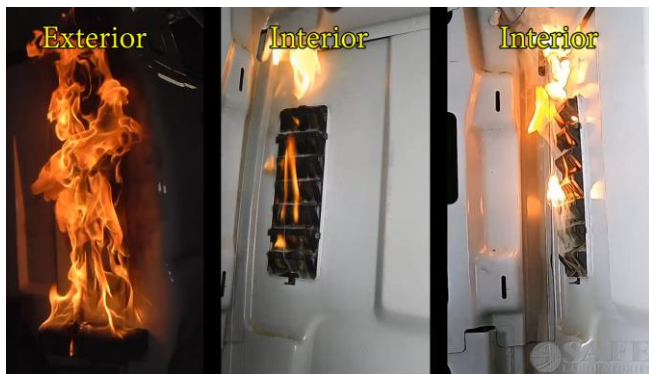


Figure 8: Test Results

Test Series 2

Burn testing was conducted to evaluate the fire resistance of the vent design used on a 2014 import sedan. A rear clip obtained from an approximately 7 year old exemplar vehicle was tested with the aged vent that arrived with it. The test was run using gasoline in a burn pan positioned underneath the exhauster vent and igniting it with an external source. Flames were first visible on the interior side of the exhauster vent at approximately 24 seconds after ignition, shown in Figure 9. The vent was completely engulfed and was melted out of the cut-out by approximately 40 seconds after ignition.

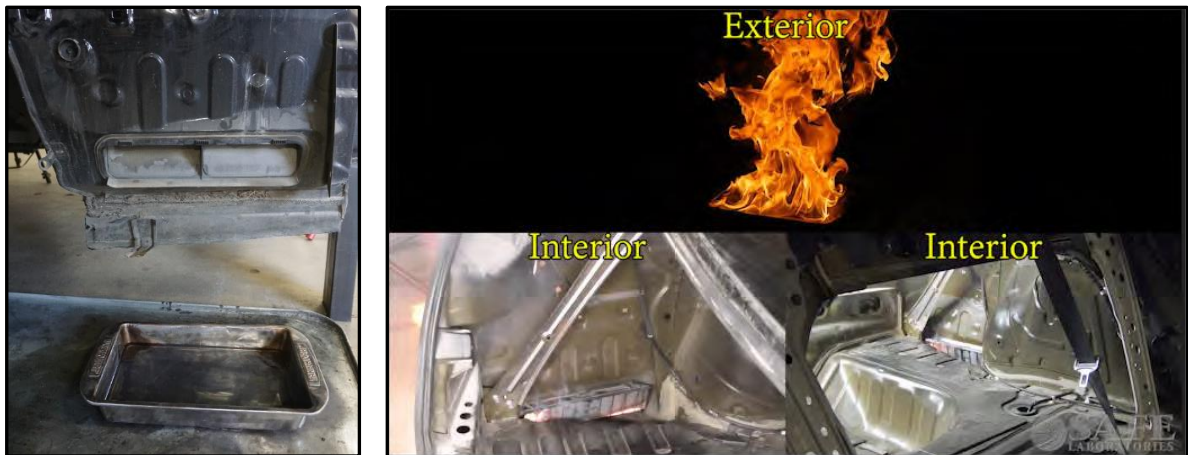


Figure 9: Test Setup and Results

Test Series 3

A pair of burn tests was conducted to evaluate the fire resistance of the vent design used in a 2013 model domestic sedan. The vents were fitted in a steel panel benchtop fixture and straw was positioned underneath each vent and ignited with an external source. The first test evaluated a new OEM replacement vent and the second evaluated an aged vent obtained from an exemplar vehicle that was approximately 8 years old at the time of testing. Flames began coming through the new OEM vent approximately 68 seconds after ignition, and flames were observed coming through the aged vent 15 seconds after ignition. The benchtop testing is shown in Figure 10.

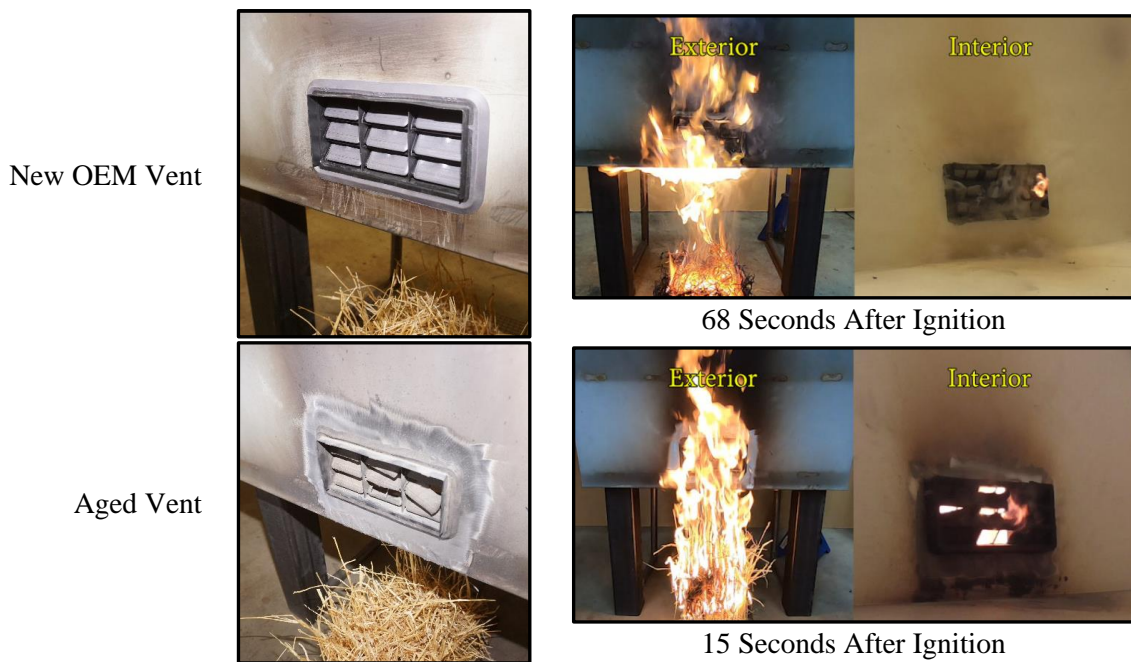


Figure 10: Test Setup and Results

An additional burn test was conducted on a new replacement OEM vent installed in the rear clip of an equivalent vehicle using straw similarly positioned underneath the exhauster vent and ignited with an external source. Flames were first visible on the interior side of the exhauster vent was at approximately 71 seconds after ignition, shown in Figure 11.



Figure 11: Test Setup and Results

IMPROVED DESIGN BURN TESTING

Test Series 1 Flame Arrestor Shield

An improved design flame arrestor type vent was evaluated under burn conditions identical to those of the production test. A steel housing was fitted around the interior of the OEM exhauster vent. A commercially available flame arrestor type fire resistant vent assembly consisting of an aluminum honeycomb core with an intumescent coating encased with perforated sheet metal on one side and a fine stainless-steel mesh on the other was installed in the housing. The improved design exhauster vent was subject to the same test procedure used to evaluate the OEM pass-throughs. The fire burned for approximately 564 seconds and no flames were able to pass through the exhauster vent, shown in Figure 12.

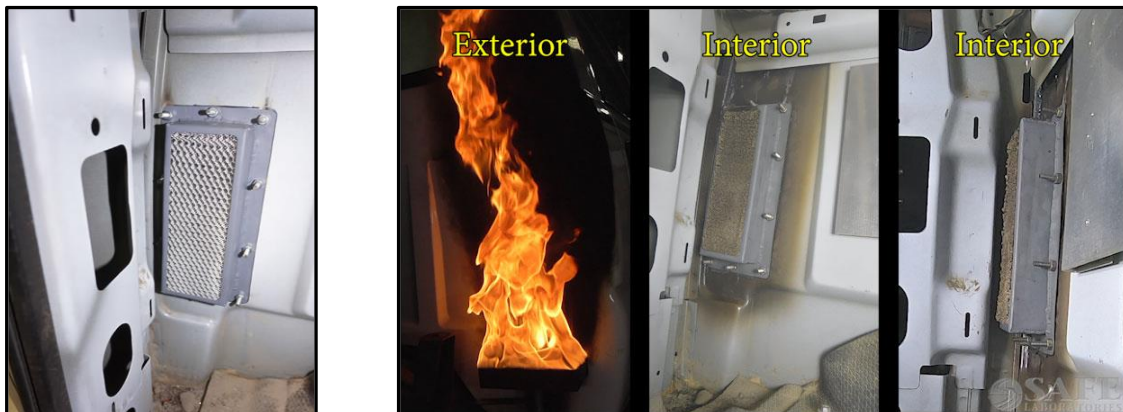


Figure 12. Test Results

In the production vent test, flames were visible in the occupant compartment approximately 42 seconds after the gasoline in the burn pan was ignited. Therefore, the improved vent design resisted the fire for a significantly longer time period than the production design and could likely have continued to resist fire for a longer period of time. The results of test series 1 are summarized in Table 2.

Table 2. Summary of Test Series 1 Results

| Test | Time at Ignition of Interior of Vent | Time when Vent Falls out of Opening |
|----------------------------------|--------------------------------------|-------------------------------------|
| New OEM Bench Test | 78 seconds | 99 seconds |
| Aged Vent Exemplar Cab Test | 42 seconds | 53 seconds |
| Flame Arrestor Exemplar Cab Test | N/A* | N/A* |

*The interior of the vent did not ignite and the vent remained intact until the fuel source was exhausted approximately 564 seconds after ignition.

Test Series 3 Flame Arrestor Shield

An improved design flame arrestor type vent was evaluated under burn conditions identical to those of the production test. The vent design was improved by constructing a housing around the interior of the OEM exhauster vent opening capable of fitting on top of an OEM vent assembly. The housing was fitted with a commercially available flame arrestor type fire resistant vent assembly. The assembly consists of an aluminum honeycomb core with an intumescent coating encased with perforated sheet metal on one side and a fine stainless-steel mesh on the other. The OEM elastomeric vent assembly was not installed for the test in order to evaluate the performance of the flame arrestor alone. The improved design vent was subject to the same test procedure used to evaluate the OEM vent. The fire burned for approximately 221 seconds at which time the fuel source was consumed and no flames were able to pass through the exhauster vent, shown in Figure 13.



Figure 13: Test Results

In the production vent test flames were visible in the occupant compartment approximately 71 seconds after the straw was ignited. Therefore, the improved vent design resisted the fire for a significantly longer time period than the production design and could likely have continued to resist fire for a longer period of time. The results of test series 3 are summarized in Table 3.

Table 3. Summary of Test Series 3 Results

| Test | Time at Ignition of Interior of Vent |
|-----------------------------------|--------------------------------------|
| New OEM Bench Test | 68 seconds |
| New OEM Exemplar Clip Test | 71 seconds |
| Aged Vent Bench Test | 15 seconds |
| Flame Arrestor Exemplar Clip Test | N/A* |

*The interior of the vent did not ignite and the vent remained intact until the fuel source was exhausted approximately 221 seconds after ignition.

Benchtop Testing Series

Improved vent designs were fabricated and subjected to burn testing in a benchtop fixture similar to the one used in Test Series 3. A new OEM replacement vent of the same design evaluated in Test Series 3 was also tested in order to establish a baseline level of fire resistance. For each test, a tray containing a quantity of gasoline sufficient to burn for approximately 20 minutes was ignited underneath the vent.



Figure 14: Test Setup

Baseline Test

A new OEM replacement vent of the same design evaluated in Test Series 3 was subjected to burn testing. Fire was observed to have started on the inside of the vent approximately 57 seconds into the test. This time was approximately 10 seconds shorter than observed in Test Series 3, but the gasoline fuel source ignited more quickly and was located slightly closer to the vent. After approximately 82 seconds the vent was observed to be falling out of the opening. At approximately 95 seconds the vent was observed to be burning on the inside of test fixture. Figure 15 shows the progression of the test.

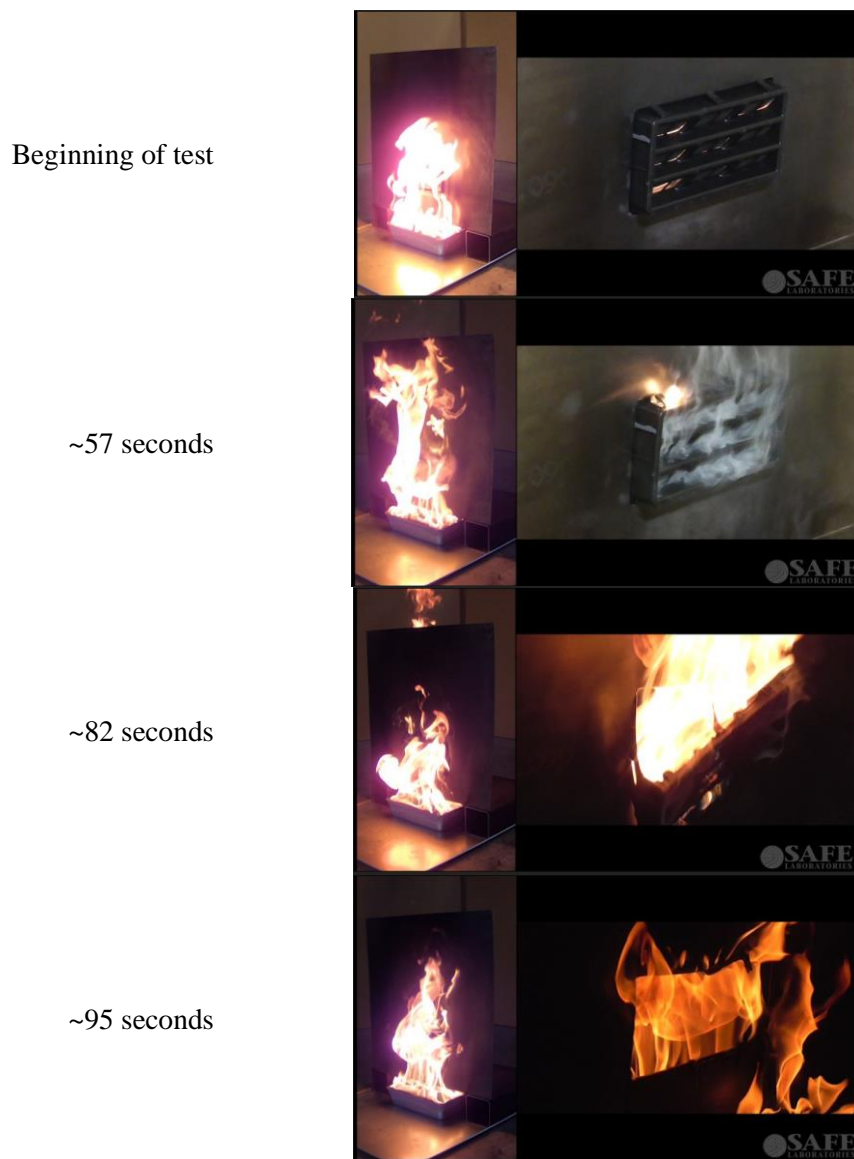


Figure 15: Baseline Test Results

Diverter Shield

A diverter shield was constructed and fitted to the test fixture, shown in Figure 16. The shield was approximately 3 inches wider and 2 inches taller than the OEM vent assembly, and extended from the surface of the test fixture at its base to approximately 3 ½ inches away from the test fixture at its top.



Figure 16: Improved Design – Diverter Shield

A new OEM vent was fitted in the test fixture behind the diverter shield and subjected to burn testing. As the test progressed, some smoke was observed to emanate from the interior side of the vent but it did not ignite. At approximately 285 seconds, the plastic vent assembly had melted to the extent that it fell into the interior side of the test fixture. However, it did not ignite. An elastomeric flange from the exterior side of the vent remained in place, stuck to its original position on the exterior side of the opening in the fixture. This flange eventually caught fire and fell away from the opening, propagating the fire to the inside of the vent opening. At approximately 522 seconds, the body of the vent on the inside of the test fixture was observed to have ignited. Figure 15 shows the progression of the test.

Beginning of test



~ 285 seconds



~ 522 seconds



Figure 17: Test Results

Metal Vent Assembly

An all metal vent assembly was fabricated and subjected to burn testing. The vent was designed to fit the same opening as the production OEM vents tested previously. The vent assembly was constructed with a machined aluminum housing, and a single flap made of thin steel was attached to the top of the housing at two pivot points as shown in Figure 18.

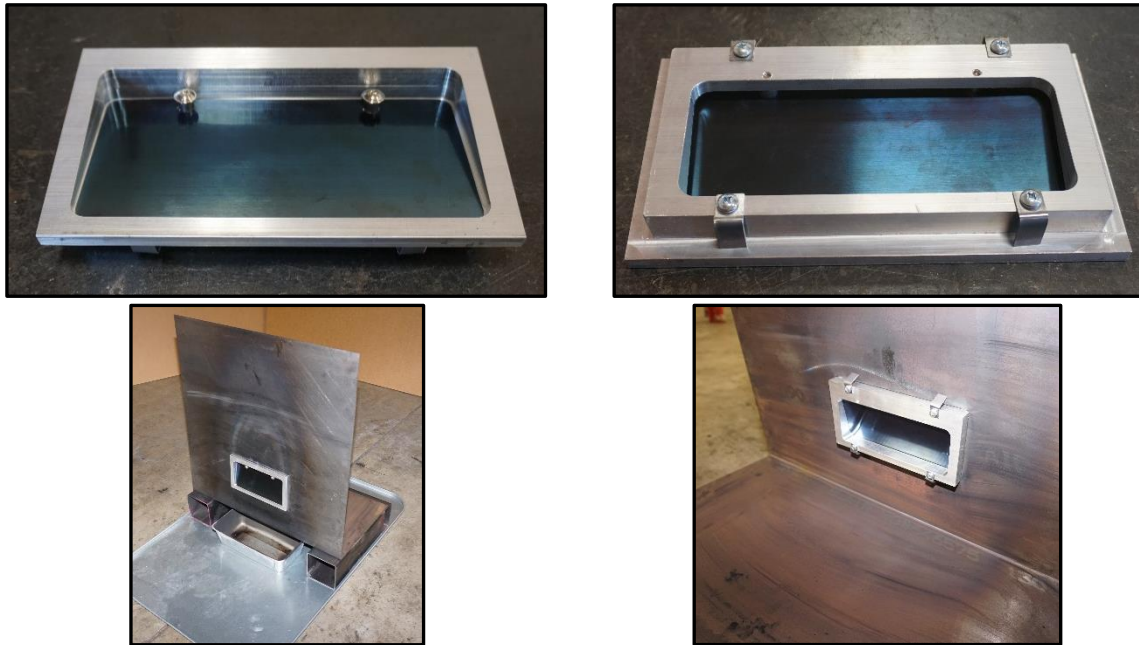


Figure 18: Improved Design – Metal Vent Assembly

The all metal vent assembly was installed in the test fixture and subjected to burn testing. The vent assembly remained intact during the test and did not ignite. Some slight warping of the flap was observed during the test. The gasoline burned out after approximately 20 minutes. Figure 19 shows the beginning of the test and shortly before the gasoline burned out.

Beginning of test

Just before 20 minutes



Figure 19: Test Results

The results of this test series are summarized in Table 4.

Table 4. Summary of Benchtop Testing Results

| Test | Time at Ignition of Interior of Vent | Time when Vent Falls out of Opening |
|-----------------|--------------------------------------|-------------------------------------|
| Baseline | 57 seconds | 82 seconds |
| Diverter Shield | 522 seconds | 285 seconds |
| Metal Vent | N/A* | N/A* |

*The interior of the vent did not ignite and the vent remained intact until fuel source was exhausted approximately 20 minutes after ignition.

DISCUSSION AND CONCLUSIONS

The new OEM replacement vents evaluated were found to resist fire propagation for only 1 to 2 minutes. Aged vents were observed to allow fire to enter the occupant compartment in as little as 15 seconds when subjected to burn testing under the same conditions. When exhauster vents ignite, become a fuel source that facilitates propagation of fire. The aged vents tested ignited very quickly and would be expected to expedite the propagation of fire into the occupant compartment.

No service or replacement intervals are specified by the manufacturers for the vent designs that were evaluated. However, the elastomeric flaps on aged vents obtained from used vehicles were observed to have deteriorated to varying degrees, and in some cases portions of the flaps had become distorted or fallen away. Exhauster vents are typically located in parts of the vehicle that are extremely difficult to access, making replacement burdensome. Many vehicles on the road have been in service for 20 years or more, and the age of the vehicle fleet has been trending higher in recent years. Therefore, vehicle manufacturers should endeavor to design exhauster vents to last the life of the vehicle.

The testing presented in this paper also shows that exhauster vents could serve an important safety function in addition to their role as a part of the HVAC system. In order to ensure occupant protection in crashes, designers must also ensure that vehicles can protect occupants from post-collision fires. Care should be taken in the design of exhauster vents to ensure they provide a suitable level of resistance to fire propagation and to select materials that maintain that level of protection for the life of the vehicle.

Finally, the improved vent design tests demonstrate the potential to substantially increase the fire resistance of exhauster vents. This improvement in fire resistance can be achieved by adding shielding to protect typical production elastomeric vents, and by replacing the elastomeric materials used in typical vent designs with more resilient materials. These improvements not only increase fire resistance, but also increase the service life of the vent. Vehicle manufacturers could apply similar design concepts to improve fire resistance and to ensure that exhauster vent openings maintain a suitable level of fire resistance for the life of the vehicle.

REFERENCES

- [1] Ahrens, Marty, July 2008, 'U.S. Vehicle Fire Trends and Patterns,' NFPA.
- [2] Digges, K.H., Sep. 3-5, 2007, 'Improving Survivability in Motor Vehicle Fires,' in *Interflam 2007 Conference*, Royal Holloway College, University of London, UK, Interscience Communications, London.
- [3] Hirschler, M., 2002, "Rate of Heat Release of Plastic Materials from Car Interiors", Business Communications Company Eleventh Ann. Conference on Recent Advances in Flame Retardancy of Polymeric Materials, Norwalk, CT.