

POST COLLISION VEHICLE FIRE ANALYSIS

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ABSTRACT

Other than the movie industry will have us believe post collision vehicle fires are a very seldom event. Nevertheless they pose an enormous threat to the occupants. Due to the small figure and the inevitable combination with accident damages only little reliable statistical data on post collision vehicle fires is available. The official German accident statistic does not contain the parameter fire. According to an estimate made by the German Federal Highway Research Institute (BASt), about 80 persons are killed by fire or its side effects each year on German roads. The German Insurance Association (GDV) counted about 40,000 vehicle fire claims in 1999. About 6% of these fires were caused by a traffic accident. But also this statistic does not permit a direct transfer to the accident occurrence by different reasons. American data like the FARS data provides a good overview with the limitation of only fatal accidents.

The paper presents the results of different studies concerning the post-collision vehicle fire occurrence. Based on an analysis of own accident reconstructions and fire investigations the most common damage patterns resulting in fires were identified. Own fire tests with damaged cars and a screening of different video clips available through internet portals rounded up the study.

INTRODUCTION

A car is driving on a scenic county road. Suddenly a large truck comes along and crashes into the car. The car, totally smashed, immediately bursts into flames. The truck explodes two seconds later in a breath-taking scene well known from many movies.

However, reality is far removed from such nightmare scenarios. Vehicle fires are a rare occurrence. Most of them are caused by technical defects or improper repair and pimp-up efforts. Post collision vehicle fires account for only a very small proportion of fire events. Nevertheless, the combination of accident

damage and fire damage poses a double threat to the vehicle's occupants.

Several studies have highlighted the burning behaviour of cars, albeit mostly undamaged cars. The results obtained from these tests are highly useful to arson investigators, insurance companies, architects planning garages or tunnels, and to the automotive and parts supply industries. However, they are only of limited value with regard to the potential risk to the occupants as a result of a vehicle fire. As long as a car is not damaged, there will normally be enough time for the occupants to escape and seek shelter. A very different situation arises when a severely damaged vehicle catches fire. One aspect is that the occupants may be injured and trapped, and thus unable to free themselves. Another aspect is that fire spread can be promoted by damaged vehicle components, such as parts of the electrical system, devices containing combustible liquids, and thermal shields. Rapid fire spread and immobilized occupants make for a dangerous combination.

To find out more about post collision vehicle fires and the attendant risks for occupants and rescue personnel, DEKRA Accident Research initiated a post collision vehicle fire study in 1999. Based on the analysis of accidents involving fire, as well as a literature study and knowledge acquired from independent fire tests, the DEKRA Technology Center crashed two current models of car for fire testing purposes. The damage patterns found in the study were reproduced in the Crash Test Center. The two crashed cars and a third, rolled over car were ignited in accordance to the ignition scenarios investigated in the study.

STATISTICS

The German National Traffic Accident Statistics [1] do not include the category vehicle fire. The statistic is based on accident reports by the police. The official form used by the police all over Germany does not contain a query regarding fire.

Extensive databases, such as GIDAS, are representative of traffic accident occurrence, but do not provide reliable data on vehicle fires. Post collision fires are so rare that projecting data from the collection area to the entire country would be subject to too great an error [2].

More reliable data is provided by the statistics of the Association of the German Insurance Companies (GDV). Round about 21,000 vehicle fires were reported to German insurance companies in 2006 [3] (compared to about 40,000 in 1999). The weak point of that statistic is that most fire cases are only registered if the cars had fully comprehensive collision insurances. An older estimation of the GDV resulted in a post collision fire risk of less than 1% in all accidents.

The German Automobile Club ADAC cited 40,000 vehicle fires per year in Germany in a 2002 publication [4], while the Swiss Automobile Club TCS and the Austrian ÖAMTC club each cited 3,000 vehicle fires per year in their respective countries [5][6]. In all three countries, it is estimated that a total of about 100 people are killed per year as a result of post collision vehicle fires.

Up-to-date data is available from the Austrian Federal Fire Service Association. In 2004 it counted 1,844 vehicle fires, out of which 1,621 were car fires. No details are given as to the proportion of post collision fires [7].

A study conducted by the Büro für Kfz-Technik in Munich in 1974 investigated 28,936 car accidents involving at least one injured occupant. A fire occurred in 68 of these cases (0.24%) [8].

The same institute continued the study in 1990 with an investigation of 15,000 accidents. Those involved 44 post collision fires (0.25%) [9].

Comparatively extensive data is provided by the NFPA in the USA. According to this data, there were 258,000 reported vehicle fires in 2007 resulting in 385 civilian deaths, 1,675 civilian fire injuries and property damage of \$1.4 billion [10]. Compared to the 2006 data, with 278,000 reported vehicle fires, 490 civilian deaths, 1,200 civilian injuries and property damage of \$1.3 billion, there were fewer fires but property damage was higher [11]. Post collision vehicle fires account for approximately 1% of all motor vehicle crash fatalities each year [12].

Impact Configuration

An important factor in the post collision vehicle fire research is the impact configuration. Knowledge about the main impacted areas and the resulting

damages shed light on those vehicle components destroyed or displaced. In particular, the comparison of damage patterns of cars involved in fire accidents with those involved in non-fire accidents can provide information about the risk factors.

The main results of the DEKRA study was a disproportionately high percentage of frontal damage among those vehicles which caught fire [13]. The results corresponded very well to those of an NHTSA study [14]. 30 fire accidents involving at least two vehicles [15] were analyzed as part of a 2008 DEKRA study [16]. In this case, too, frontal impacts were the most frequent, Figure 1.

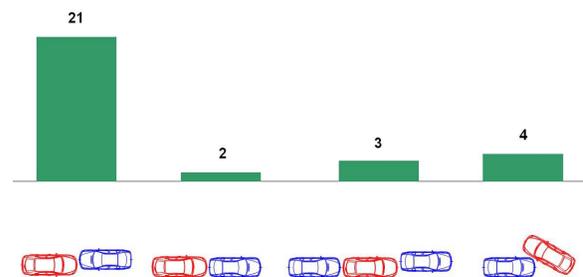


Figure 1. Distribution of main impacts in 30 crashes resulting in a fire, DEKRA 2008 [15]

The large percentage of single vehicle accidents resulting in a post collision fire is worth noting. These accidents accounted for about one third of the accidents investigated in all DEKRA studies. There was a high incidence of tree impacts, but only a small number of rollover accidents.

In Other Studies the Institut für Fahrzeugsicherheit and the Bavarian Ministry of State investigated 204 accidents on Autobahns in 1994. 29 of these accidents resulted in fire. According to an in-depth analysis, frontal impacts accounted for 63%, side impacts for 11% and rear impacts for 22% [17].

Another 43 post collision vehicle fires were analyzed by the Institut für Fahrzeugsicherheit in 2002. They used their FS90 and FS2000 databases. Here 72% of the fire relevant impacts were in the front, 21% in the side and just one (2.5%) in the rear. Two vehicles were involved in rollovers [17].

Another 16 expert opinions regarding post collision vehicle fires were provided by the German Insurance Association (GDV) [18]. In ten of these cases, one relevant impact was frontal, another was side-on and two were rear impacts. Two cars were involved in a rollover and one car impacted sideways with a tree.

According to an analysis of FARS data from the years 2000 to 2002, 64% of fatal crashes involving fire were frontal impacts. Side impacts accounted for

18% and rear impacts for 8%. Rollover accidents accounted for 10% [19].

A study published by Exponent in 2006 analyzed data of the Fatality Analysis Reporting System, the National Automotive Sampling System's Crashworthiness Data System and General Estimates System, and combined state data from three states. The results correspond very well to those found in other studies. A striking aspect of this study is the high rate of rollover fire accidents [20].

Crash Severity and Ignition

In several studies, most of those vehicles which caught fire were severely damaged. Electrical parts, fluid reservoirs and fuel tanks have regularly been affected. Again, however, the exception proves the rule. The first DEKRA study included a post collision vehicle fire which started after a low-energy front-to-front collision. Experience gathered by the DEKRA Crash Test Center also shows that unfavorable crash configuration can result in fire even if little damage occurs during the crash.

14 out of 30 fires reconstructed in the first DEKRA study were ignited at a thermal source, 9 fires were caused by mechanical ignition (e.g. friction between vehicle components and the road surface), 6 could be ascribed to an electric ignition source, and one ignition could not be reconstructed. In 6 of these cases the fire encroached upon another vehicle [21].

Two examples are shown in Figure 2 and Figure 3.



Figure 2. Severely damaged Mini Cooper after a frontal crash against a truck's side [16]



Figure 3. Passenger car after a car-on-car impact resulting in fire due to a bursting fuel tank [16]

Internet Video Analysis

A new but usually very efficient way to get information about real live accidents is the analysis of videos presented on websites like youtube®, google videos® and so on. Many videos showing accidents and vehicle fires can be found there.

The videos are often cut, only show sequences or even are fakes. Analyzed with a realistic eye, however, they provide very good information about burning behavior, occupant and eye witness reactions and rescue services work. Many videos taken before the arrival of the firefighters provide good information about the most interesting, early phase of fires. By combining this information with information obtained from in-depth accident analysis and fire testing, we can fill in the gaps in our knowledge.

FIRE TESTING

Several vehicle fire tests have been carried out in recent decades. These tests were aimed at gathering information about fire propagation, the effectiveness of preventive fire protection measurements, heat release rates and gaseous emissions, as well as educating fire fighters and arson investigators and validating the results of arson investigations. Most vehicles tested so far were not damaged.

The burning behaviour of vehicles severely damaged by an accident is clearly different to that of undamaged vehicles. Structural features designed for ignition and fire protection can be destroyed and thus not work effectively. Broken windows do not hold back smoke and radiated heat. Splashed combustibles like brake fluid, oils, or windshield cleaner promote rapid fire spread, and damaged components of the electrical system are liable to short circuit.

Within the study several sources have been analysed. Especially in America various publications are available.

Very broad and interesting projects on the topic of post collision vehicle fires were carried out within the context of GM fire safety research sponsoring. This was a part of the March 7, 1995 Settlement Agreement between General Motors and the U.S. Department of Transportation. The analyses were performed to 1) evaluate possible causes and effects of vehicle fire events; 2) assess the adequacy of existing databases for studying these events; and 3) recommend possible enhancements to these data files to assist safety researchers in studies of motor vehicle fires [22]. The resulting reports are available through the Motor Vehicle Fire Research Institute's website [23]. A final report was presented at the 2009 ESV Conference in Stuttgart [24].

Extensive literature can also be found on the sites of the National Institute of Standards and Technology (NIST) [25].

GM and Kidde presented a paper at the 2005 SAE World Congress describing two crash tests for testing an automatic fire suppression system. In both high speed tests a fire started [29].

In Germany, due to insurance terms and conditions used in the 1980s and 1990s, the original price of vehicles with an age of up to two years was paid by insurers after a car fire. With car leasing becoming more and more popular during that period, arson became a real problem. For example, lessees who could no longer pay their leasing rates, had exceeded the maximum lease mileage, or had crashed were setting their vehicles on fire to make the insurance pay. To counter this trend, the German Insurance Association initiated a campaign to educate arson investigators, sensitize police officers and show the public how "easy" arson can be detected. Therefore they commissioned several fire tests [26]. For some of these tests, the vehicles were damaged in order to have case examples for investigating vehicles involved in an accident and then intentionally ignited at a later point of time.

The German Automobile Association ADAC is a member of the Euro NCAP consortium. In an Euro NCAP crash test carried out in 2000 an Audi A2 caught fire about two minutes after the crash occurred. The fire was caused by a contact in the air conditioning unit and in the starter. The components were relocated by the manufacturer after the crash test.[27][28].

The Japan Automobile Research Institute cooperated with different Japanese police organizations for a

series of four fire tests with sedan cars. The cars were undamaged but the test procedure was very complex. The cars were ignited either at the splashguard of the right rear wheel or at the left front seat in the passenger compartment with a gasoline spill. The temperature inside the burning car and the mass loss rate were measured [30].

To support the DEKRA vehicle fire and arson investigation unit fire tests are regularly carried out. With the accident research unit working active in the field of developing methods for fire protection and fire fighting different tests are carried out here, too.

With the topics of crash and fire safety of alternative propulsion vehicles getting more and more important [31][32] and the numbers of fire fighters getting hurt during extinguishing vehicle fires [33] the DEKRA Accident Research unit decided to crash modern vehicles in accordance to the findings from studies explained in the statistics chapter. Thus the knowledge base is broadened for studies to come. An additional focus was laid on extracting information for the fire investigators and on the test of different extinguishing methods and agents.

Aims and Purposes of the Fire Tests

The main purpose of the tests was to provide teaching material for fire investigators, accident reconstruction experts, employees of insurance companies, and for information of the public about "vehicle explosions". The tests became necessary because the material won from fire tests for customers is subject to secrecy.

The DEKRA Accident Research Unit additionally wanted to find out more about the influence of different degrees of damage, ventilation, the source of ignition, and about risks for fire fighters. Also different extinguishing methods and extinguishing agents were tested.

The tests were neither intended to compare different brands or types of automobile nor to collect data on the burning behaviour of selected materials or components.

Selection of Vehicles

The vehicles used for the test were in accordance with the average vehicle population on German roads. They had a high safety level and were equipped with the standard safety features and comfort components. Furthermore, the cars were not conspicuous in studies in respect of fire frequency. The choice was made in favour of two Audi A4 (8E) models and one Opel Astra G.

Selection of the Crash Test Configurations

According to the frequency of frontal vehicle impacts in overall accident statistics, the frontal impact is also the most common constellation leading to fires. As shown in the statistics section, this has been proven by many international studies.

Actual accident statistics also show that severe crashes present the highest risk of fire, arguing in favour of a high collision speed. Keeping in mind that the risk to the occupants as a consequence of fire requires a survivable collision speed, the chosen test speed was not excessively high. Based on DEKRA analyses, a collision speed slightly above the frontal impact speed as per the EuroNCAP test procedure represents a good compromise. With fires ignited by an electrical circuit already occurring at lower speeds, a collision speed between the speeds required for type approval and EuroNCAP is realistic.

The DEKRA accident pool contained different cases, which were used for defining the test configuration. Two examples of an electrical ignition are given here.

An Audi was travelling on a country road. When overtaking a truck it collided with an oncoming car, resulting in a fire in the engine compartment due to an electrical short circuit. The fire was extinguished soon after ignition with a fire extinguisher, Figure 4.



Figure 4. Engine fire after short circuit

A new Mercedes GL went off the road while speeding and rolled over in the neighbouring field when its wheels became stuck. Even though there were only minor deformations, an edge of the hood pinched the wiring harness, producing a short circuit. When the fire department arrived on the scene about 10 to 12 minutes after the accident, the vehicle was completely ablaze, Figure 5.



Figure 5. Rollover with only little deformations of the vehicle followed by a fire

Crash Test 1

The first Audi was crashed against a deformable barrier at a speed of 58.1km/h (36.1mph) and with 40% overlap. The crash weight was measured at 1,610kg (3,542lbs). The 40% overlap was chosen so the results could be compared with those obtained in Euro NCAP and ECE-R 94 tests, Figure 6.





Figure 6. Crash test with a collision speed of 58.1km/h and the resulting deformations

Crash Test 2

The second Audi was crashed against a deformable barrier at a speed of 68.9km/h (42.8mph) and with 40% overlap. The crash weight was measured at 1,620kg (3,564lbs), Figure 7.



Figure 7. Crash test with a collision speed of 68.9km/h and the resulting deformations

Crash Test 3

Rollover accidents are a very rare event on German roads, as compared to U.S. accident statistics. This can be attributed to the different composition of the vehicle population in Germany (SUVs and pickups account for only a small proportion of vehicles), a large proportion of ESP-equipped vehicles, and different roadside infrastructure. Nevertheless, these accidents do occur. Against the background of the NASS/CDS data [35] and limited knowledge of rollover-induced fires within the DEKRA cases, it was decided to test an upturned vehicle, Figure 8. Being aware that the missing damages of the vehicle would lead to deviations to a real rollover fire accident, the results are nevertheless quiet useful for the schooling and information purpose.

This constellation had one big advantage over the other two tests in that it was possible to drive the vehicle before rolling it over at the fire test facility, thereby ensuring that the engine and exhaust system were at working temperature.



Figure 8. Test vehicle for the third test

Crash Test Results

The test results were as expected. While the first test resulted in severe damage to the engine compartment, the passenger compartment retained its stability. In the second test, the driver would have been trapped inside the vehicle and unable to open the driver's door. The risk of receiving severe injuries was high, as the Hybrid III dummy loads showed. In both tests, several fluid reservoirs were destroyed. Oil, brake fluid, gas and windshield cleaner leaked out. The only damage incurred by the Astra in the third test was a broken driver's window.

Fire Test 1

The car was electrically ignited on the right side of the engine compartment. A 12V starter battery was used for that. In accordance with a real-life accident, the area around a battery-connected wire near the air intake was chosen for the short circuit. The course of fire is displayed in Table 1 and Figure 9.

**Table 1.
Time analysis of the fire test 1**

Time [s]	Course of Action
000	Ignition
030	White smoke in the passenger compartment
068	Disconnection of power source
136	Flames visible in the engine compartment nearby the ignition source Dark smoke color
300	Dark smoke in the passenger compartment
316	“Flashover” in the engine compartment, large flames, intense production of smoke, flame impingement of the windscreen
440	Two explosive flames at the vehicles right front end by components of the AC
470	One explosive flame in the same region, nearly no smoke in the passenger compartment due to natural ventilation through the front windows
499	One explosive flame at the right front region
500	Passenger compartment totally filled with smoke
520	Burn-through of the windscreen
540	Fully developed fire of the dashboard
620	Front seats on fire
650	Fully developed fire of the engine and passenger compartment
680	Start of fire-fighting

Subjective findings: immediately after energizing the wire, white smoke was emitted. The ventilation system was still working and transporting the smoke into the passenger compartment. About 30 seconds after t_0 , white smoke was visible at the driver's seat. The smoke density in the passenger compartment depended on the wind direction (both front windows were open). The compartment was filled with smoke at a very early point in time. Fire-fighting was complicated by burning light metals in the passenger compartment.



t = 50s



t = 384s



t = 238s



t = 478s



t = 300s



t = 608s



t = 628s



t = 714s

Figure 9. Sequence of fire test 1

Fire Test 2

To start the car fire, the ignition of spilled combustible liquids was simulated. After reconstructing the spillages and combustible accumulations similar to the situation after the crash test, a flare was used for ignition. Figure 10.

Table 2. Time analysis of the fire test 2

Time [s]	Course of Action
000	Ignition
020	White smoke above the engine compartment
042	Nearly no visible smoke, no visible flames
166	Restarting development of white smoke
260	Explosive flame between engine and bonnet
272	Increased smoke development, only little flames

317	Flashover in the engine compartment, excessive smoke development
457	Smoke in the passenger compartment
460	Ignition of the dashboard and of the roofliner on the driver's side
467	Fire in the driver's and co-driver's area
518	Fully developed fire of the engine and passenger compartment
607	Start of fire-fighting

Subjective findings: immediately after ignition, white smoke was emitted. 30 seconds later, nearly no smoke was visible any more. A vehicle fire was not perceptible before second 166. Starting at that point, it took only a little more than 5 minutes to a fully developed fire in the engine and passenger compartment.

Due to the compression of the components in the engine compartment, fire damage was limited to the top of the engine. Fire did not spread to the lower parts of the engine.

In this case, too, fire-fighting was complicated by burning light metals in the passenger compartment.



T₀ = 0s



t = 274s



t = 310s



t = 456s



t = 352s



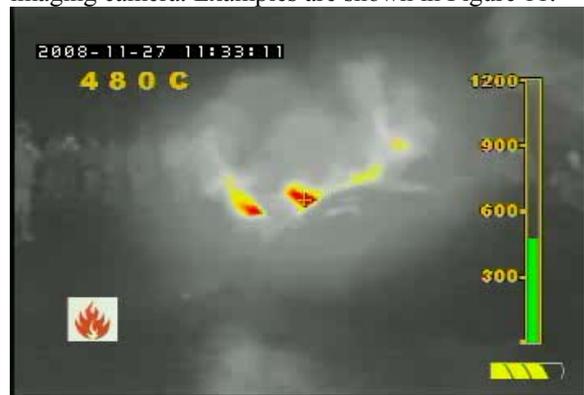
t = 616s

Figure 10. Sequence of fire test 2

The test was additionally monitored with a thermal imaging camera. Examples are shown in Figure 11.



t = 448s



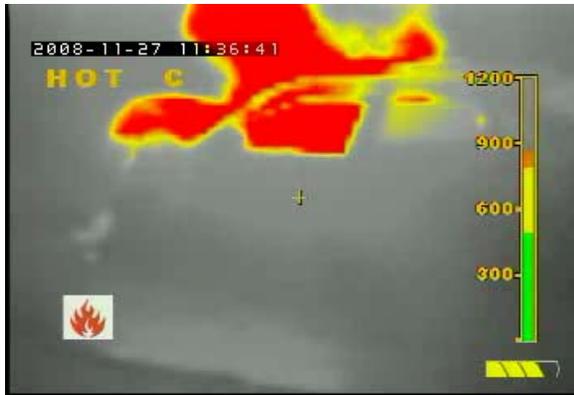


Figure 11. Thermal images of the engine fire and the moment before the flashover in the passenger compartment

Fire Test 3

The car was electrically ignited at the front of the engine compartment by simulating a stuck radiator fan motor, which had been found to be the cause of fire in a rollover accident. The course of fire is displayed in Table 3 and Figure 12.

**Table 3.
Time analysis of the fire test 3**

Time [s]	Course of Action
000	Ignition
058	Disconnection of power source
133	Few white smoke above the engine compartment
216	Little flames in the engine compartment
239	Larger flames, intensified production of darker smoke
289	Fuel line on fire
308	Rupture of the fuel line, large explosive flame
410	Thick brown smoke in the passenger compartment
529	Fully developed fire of the engine compartment
553	Explosion of a gas-pressure shock absorber
609	Right side of underbody on fire from front to back
659	Burning components dropping down in the passenger compartment
689	Driver's side of passenger compartment on fire
692	Burning smoke on passenger's side
796	Fully developed fire in the passenger compartment

860	Explosive flame nearby the left front wheel
1058	Explosive flame nearby the right front wheel
1220	Rupture of the fuel tank, explosive flame
1318	Start of fire-fighting

Subjective findings: nearly no smoke was visible during the first 216 seconds. With the fire burning along the fuel line, the fire spread along the vehicle's underbody towards the rear axle and fuel tank. Only a few seconds elapsed from when smoke first entered the passenger compartment until it was completely filled with thick smoke. Fire-fighting was complicated by burning light metals in the engine compartment.



$T_0 = 0s$



$t = 160s$



t = 220s



t = 486s



t = 290s



t = 586s



t = 446s



t = 660s



t = 734s



t = 1050s

Figure 12. Sequence of fire test 3

CONCLUSIONS

Post collision vehicle fires are the type of fire which poses the greatest risk to vehicle occupants. Most research and testing done in the field of vehicle fire protection is based on undamaged vehicles and new components, enabling results to be compared and reproduced. However, the scope for acquiring knowledge about post collision fires is very limited. Very valuable post-crash fire tests have been carried out in the USA within the last years.

Due to a lack of statistical information regarding the frequency of post collision vehicle fires and only limited availability of data on fatalities and injuries, exact risk assessments cannot be made concerning European roads. The cumulative figure of about 100 vehicle fire deaths per year in Germany, Austria and Switzerland is based on rough estimates by the regional automobile clubs.

To gain further knowledge of vehicle fires, analyses of the real-life accident events by DEKRA were supplemented by three fire tests on crashed vehicles. The results can be used as a basis for determining the arrival times of rescue services, informing the public that burning vehicles do not explode and that it is possible to rescue trapped occupants, and finally as educational material for accident reconstruction by legal experts, arson and fire investigators.

The following findings and results were won in comparison with former fire tests:

- The intrusion of smoke in the passenger compartment occurred a lot faster than in previous fire tests on undamaged vehicles.
- Several minutes can elapse between ignition and the first visible signs of a fire.
- Fire spreads a great deal more quickly in an engine compartment at working temperature than in cold engine compartments.
- The ventilation system can accelerate the rate of smoke intrusion into the passenger compartment.
- Exploding struts or gas-pressure shock absorbers can result in a very loud bang, causing blast trauma in persons near the car. No pressurized components were discharged during the DEKRA tests.
- The kind of accident and the accident severity have an important influence on the fire spread.
- The fire side effects like smoke and its toxic contents pose a higher risk for the occupants than the direct flames. That has to be considered in defining fire department response times.

Recommendations:

- The public needs to be taught that burning vehicles do not explode and that only quick evacuation of the car can help to save lives.
- Automatic shut-down of the ventilation system in an accident would be advantageous.
- It would be useful to carry out crash tests on actual fuel with the engines running, and the engines and exhaust systems at working temperature. In practice, at least, the last point is hardly feasible.
- Pressurized systems like struts should - where possible - be equipped with pressure relief devices.

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