



ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)
INGENIERO INDUSTRIAL SUPERIOR

**“STUDY THE INTRODUCTION OF NEW
TECHNOLOGIES TO DEVELOP SAFETY
COMPONENTS IN CASE OF A LATERAL IMPACT IN
THE AUTOMOTIVE INDUSTRY”**

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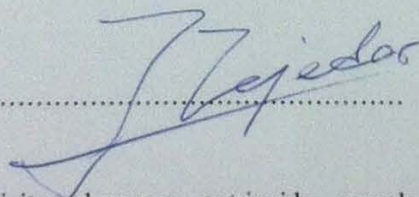
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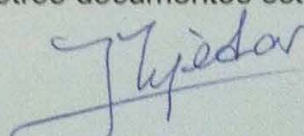
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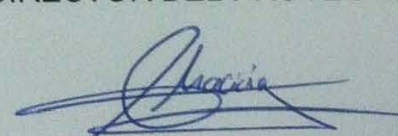
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-Resumen

En la actualidad, los accidentes de tráfico son una de las causas principales de fallecimiento sobretodo en la población más joven. Con el objetivo de reducir estas cifras y las lesiones derivadas de dichos accidentes, los fabricantes de automóviles están focalizando todos sus esfuerzos en mejorar los sistemas de retención y en desarrollar nuevos elementos capaces de proteger al ocupante ante diferentes accidentes posibles.

Para que un vehículo salga al mercado, tiene que cumplir una serie de normativas y regulaciones que le permitan circular por las vías públicas. Dichas normativas y regulaciones son propias de cada país o continente y son cada vez más estrictas con los fabricantes en relación a la seguridad del pasajero.

Además de las normativas y regulaciones, existen una serie de programas privados que también evalúan la seguridad de los vehículos. Son los llamados programas NCAP (EuroNCAP, U.S.NCAP) y que no son obligatorios.

Como parte del proceso de desarrollo de los sistemas de seguridad de los vehículos hay unos ensayos denominados “Crash simulations” o más comúnmente ensayos de trineo. Consisten en una plataforma metálica (trineo) donde se montan los elementos más característicos de cada tipo de ensayo (frontal, lateral poste, lateral barrera, etc.) y a la que se le da un pulso de aceleración por medio de un actuador hidráulico de altas prestaciones. El objetivo de estos ensayos es simular las aceleraciones de diversos tipos de accidentes en distintos elementos fundamentales del vehículo. En el caso de este proyecto, se centrará en ensayos laterales y por tanto estos elementos fundamentales son: asiento, puerta (varias zonas) y dummy.

Para realizar estos ensayos, Cidaut dispone de un actuador hidráulico que da un pulso de aceleración de modo que el resto de elementos involucrados se adecuan a la aceleración objetivo por medio de sistemas pasivos (rotación, honeycombs...).

El objetivo fundamental de este proyecto es buscar y analizar la tecnología óptima para añadir a nuestro sistema de ensayo de modo que podamos representar aceleraciones en diversos elementos de forma más precisa y sin sobrecargar el cilindro principal que dispone la empresa en estos momentos ya que, como se ha dicho, las regulaciones y normativas son cada vez más estrictas y por tanto se deben alcanzar valores más altos de aceleración, velocidad, etc.

Una vez seleccionada la tecnología óptima, se procederá a analizar datos de ensayos de trineo reales para ver que características técnicas deben cumplir dichos actuadores y de ese modo se buscará el proveedor que cumpla con ellas.

Una vez definido el actuador y encontrado el proveedor, se dará un primer diseño que podría cumplir con las necesidades del sistema analizando el número de actuadores necesarios así como su posición óptima y el modo en que diferentes aéreas de la puerta lograrían alcanzar su aceleración objetivo.

Una vez hecho un primer diseño del sistema, se procederá a hacer un estudio de fiabilidad para ver la evolución de la probabilidad de fallo del sistema con respecto al tiempo y se propondrán una serie de modificaciones y mejoras de modo que se reduzca dicha probabilidad de fallo.

Con todo esto el último paso será un estudio económico donde se analizaran los costes directos e indirectos de la implementación de este sistema en nuestras instalaciones, de modo que en un futuro no muy lejano se puedan utilizar para decidir si introducir esta mejora o no.

Abstract

Nowadays, road accidents are one of the main causes of death moreover among the young population. With the objective of reducing these figures and injuries, car manufacturers are focusing all their efforts on improving the restraint systems and on developing new elements capable to protect the occupants against different type of accidents.

In order to get into the market, a car has to accomplish a list of rules and regulations that allow them to circulate on the public roads. Those rules and regulations are different for each country or continent and are getting stricter each year with car manufacturers in terms of passenger safety.

In addition to these rules and regulations, there are also some private assessment programs that evaluate car safety and are commonly known as NCAP Programs (New Car Assessment Program), which are not compulsory.

As part of the restraint systems development process for vehicles, there are a type of tests called “crash simulations” or more commonly sled-tests. They consist on a metal platform (sled) to which the most relevant components from a type of crash (frontal, side post, side barrier, etc.) are mounted. A high performance hydraulic actuator propels this sled in order to reproduce the accelerations from a real crash. The main accelerations that the system has to be able to reproduce in case of a lateral test (focus tests of this thesis) are: seat, door (several areas) and dummy.

To carry out these tests, Cidaut has a big hydraulic actuator that gives an acceleration pulse to the sled while the other relevant components adjust to their acceleration pulses by means of passive systems (hinges and rotation, honeycomb, etc.).

The main objective of this thesis is to search and analyze the different technologies available at the market in order to decide which one is the optimal to add it to the actual facilities in order to better represent these accelerations with more precision and without overloading the principal hydraulic cylinder. In addition to this and looking to the future, it is a fact that the rules and regulations are getting stricter and therefore it is essential to have a testing system to reach the high accelerations required.

Once the optimal technology has been selected, the thesis will proceed to analyze data and information from real sled tests carried out at Cidaut in order to define the technical specifications for the actuators needed and once the specifications are defined, a supplier of this technology will be proposed.

Once the technology and the supplier have been selected, it will be given a first design of how the testing system could be: number of actuators, position, guiding system... This first sketch of the system is just a first idea of the future testing facility.

With this first design, the next part will include a reliability study to analyze the probability of failure of the system and a will provide some modifications and improvements in order to reduce it.

The last step of this thesis will be an economical study with real information of all the direct and indirect costs that the project implementation will carry. This study will be very useful in order to decide whether to carry out the project or not.

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1-Introduction

1.1-Background

Nowadays it is well known that road accidents are one of the most important topics related to the population's health and safety worldwide. Annually, 1.24 million people are killed on the world's roads and up to 50 million are severely injured, having a huge impact on health and development [WHO_15]. Specifically, global accident statistics show that side impacts account for approximately 30% of all impacts and 35% of the total fatalities [GIDA15].

They are the leading cause of death among young people aged between 15 and 29 years (*Figure 1.1*), and cost governments approximately 3% of GDP [WHO_15]. Despite this massive –and largely preventable– human and economic toll, action to combat this global challenge has been insufficient.

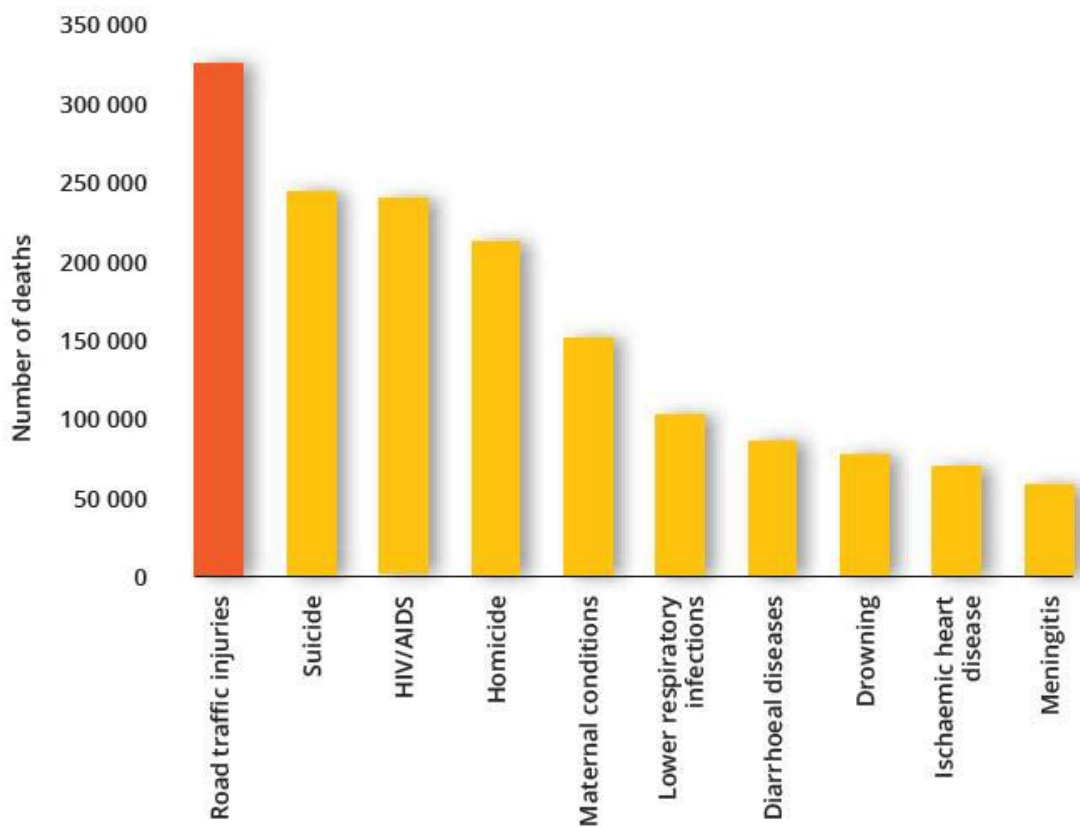


Figure 1.1: Top 10 causes of death among people aged 15-29 years old

In the past three years there has been a 16% increase on the number of vehicles on the world's roads and in 2014 alone, a record 67 million passenger cars came into circulation. However, road traffic deaths globally have stabilized at 1.25 million a year [WHO_15].

In the face of rapid motorization, notably in low –and middle- income countries, these are good news as it reflects the efforts of a number of countries to put in place measures known to make roads safer and especially car manufacturers are developing more and better vehicle safety improvements (*Figures 1.2 and 1.3*). While stabilization in numbers is a welcome first step in the fight to reduce road traffic deaths, it is insufficient.

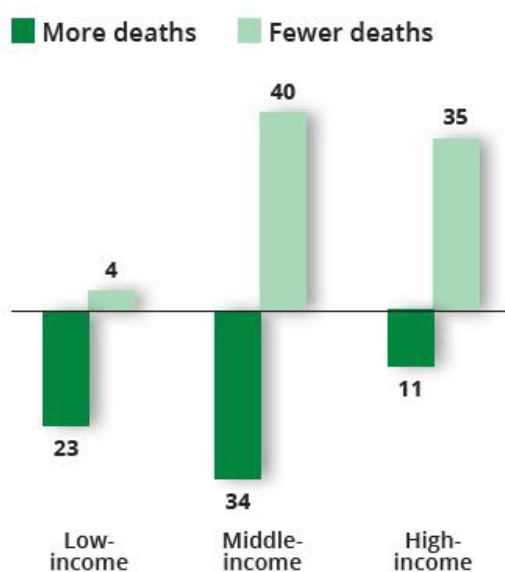


Figure 1.2: Countries showing changes in the number of road traffic deaths, by country income status

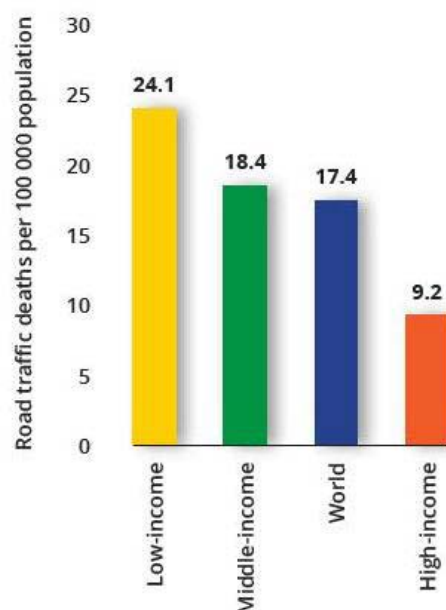


Figure 1.3: Road traffic deaths per 100,000 population, by country income status

Governments and nongovernmental organizations are implementing measures known to be effective, such as improving road safety legislation; managing speeds around schools; harmonizing data collection relating to road traffic deaths; and rolling out minimum standards on vehicle safety. These commendable national efforts have taken place against the backdrop of the Decade of Action for Road Safety 2011-2020, a global framework guiding national-level action across a number of areas relevant to road safety.

In addition to the Decade of Action, international attention to the urgency of road safety has increased recently with the adoption of the 2030 Agenda for Sustainable Development. Setting a goal of reducing road traffic deaths and injuries by 50% by 2020 as part of this agenda is a reflection of the growing recognition of the

contribution of road safety to health, development and broader environmental objectives, and the potential for action [UNNA14].

1.2- Safety designations

To prevent and reduce all these road fatalities and injuries, there are plenty of elements and systems available for vehicles. Some of them are compulsory and others optional. These systems are classified as follows:

1.2.1-Active safety

In the automotive sector the term active safety (or primary safety) refers to safety systems that are active prior to an accident. This has traditionally referred to non-complex systems such as good visibility from the vehicle and low interior noise levels. Nowadays, however, this area contains highly advanced systems that use an understanding of the state of the vehicle to try to avoid any kind of accident. Some of these elements are:

- Good driver's visibility
- Brakes
- Suspension
- Tires
- Anti-lock Braking System (ABS)
- Electronic Stability Control (ESP)
- Traction control

1.2.2-Passive Safety

Also known as secondary safety, this term involves every system and component used to reduce injuries and damages to driver and passengers once the accident occurred. Advancement in passive safety systems has progressed very far over the years and it's the main focus topic on safety development nowadays. Some of these components are:

- Airbags: frontal, lateral, curtain, interaction...

- Seat belt
- Chassis and structure
- Retractable steering column
- Headrests

1.2.3-Integral Safety

Nowadays, active and passive safety terms are more difficult to differentiate. While active safety refers to all the systems that try to avoid a car accident, the target of passive safety components is to reduce the occupant's injuries once the accident has occurred. It could be said that the border between both of them is the instant when the accident occurs.

However, at present they're developing more and more systems that anticipate to the car accident and act to reduce the passenger injuries at a moment where is no longer possible to avoid the crash. That means that they are acting before the crash but in order to minimize passenger injuries after the accident.

These systems should be included under the category of integral safety systems. One example of these systems is the belt pretensioner, that receives the signal just before the crash and its mission is to adjust the seat belt to the passenger's abdomen so it can retain the body in a better way during the accident.

1.2- Problem Definition

The strong competition between car manufacturers is forcing them to search ways for reducing costs and time for the development of new products which are supposed to be new, reliable and as economic as possible while fulfilling more and more stringent requirements. One of the most important car developments in the past years has been in terms of safety devices.

To fulfill the regulations and other optional assessment programs, vehicles have to accomplish different tests. The aim of these tests is to prove the good performance of all the safety systems as well as the general structural behavior of the car. There are several assessment areas: Adult Occupant Protection, Child Occupant Protection, Pedestrian Protection and Safety Assist; and each of these areas will have their own different tests. The main thesis topic will be related to Adult Occupant Protection.

The predefined tests for the Adult Occupant Protection assessment are the following (Figure 1.4):

-Full Width Frontal Impact Test: the target of this test is to evaluate a direct full width frontal impact against a solid wall. There are no additional absorption-elements involved in this crash.

-Offset Deformable Barrier Frontal Impact Test: the goal of this test is to see what happen during an offset frontal crash against another car. In this case some absorption elements are involved in order to simulate the energy absorption capacity of the other car involved.

-Moving Deformable Barrier Side Impact Test: the aim of this test is to assess the car structural and restraint systems performance during a crash against another car in a road crossing. A carriage with a determined speed and weight will impact against the side of the assessed car with a relative impact angle of 90° .

-Pole Side Impact Test: the main objective of this test is to see the behavior of the car structure and restraint systems during a crash against a narrow object such as a tree or a street lamp post. The car will be launched sideways against a solid and static pole with a determined relative angle.

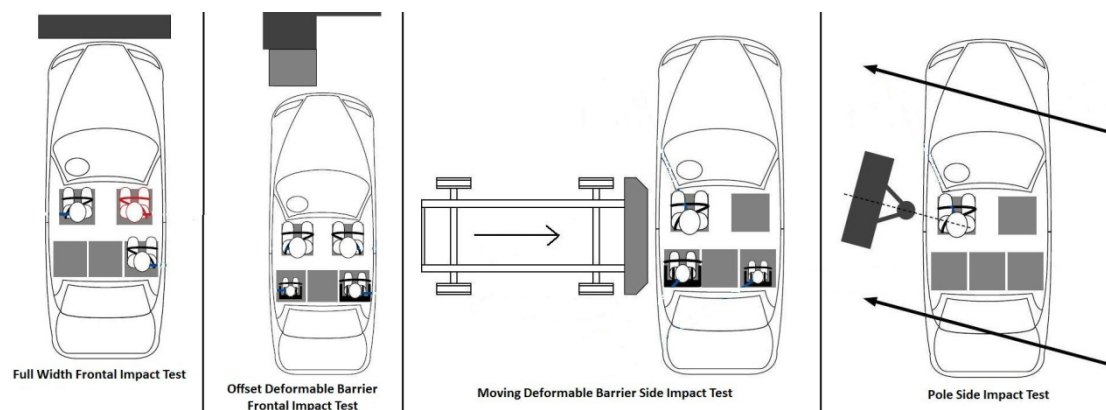


Figure 1.4: Adult Occupant Protection Crash Tests

Needless to say, a crash test with a complete car is very expensive. We have to understand that these cars are in development process and all the elements aren't still mass-production parts. That's why it's necessary to find an alternative to study and reproduce the behavior of the car during one of these crash tests before carrying out the official assessments.

Since the introduction of airbags as a complement to seat belts in user protection, different trial systems and software programs have been developed to simulate and predict automotive crashes in a more accurate way and its effect on the bodywork, passengers and other variables. In case of a lateral crash, the severity of the impact received by the passengers is much higher in comparison with a frontal one due to less energy absorption from the vehicle. This situation makes the development of side protection systems especially complex. This thesis will be focused on side impact crashes.

At this time, the development of any component involved in the security (seat belt, door, airbag, seat and B-Pillar) has the same phases: development and trial of components, subsystem trials and trials of the complete system, which are the assessment tests to pass the rules, regulations or optional programs.

With the experimental subsystem trials –also known as crash simulations- the aim is to reproduce the car's accelerations and components' kinematics during a real crash in the most accurate manner. In this case, Cidaut GmbH is using an Inverse Crash Simulator (HYGE) with an engaged sled in which all the components will be fitted to reproduce their exact position in a vehicle (*Figure 1.5*). The main purposes of these trials are to simulate different crash conditions in order to define several restraint system characteristics such as airbags deploy time, seat belt pretensioners activation time, number of airbag leveling valves..., and predict the car systems behavior in order to fulfill the rules, regulations and optional assessment programs.

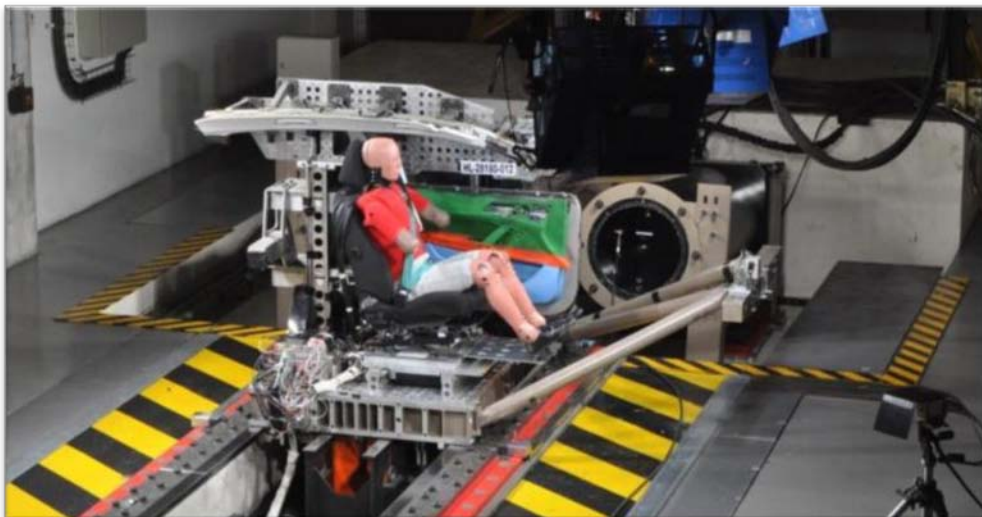


Figure 1.5: Cidaut GmbH lateral sled test configuration

To achieve these objectives, each supplier should design, develop and test their own trial methods, adjusting their available equipment and technologies. However, the strict test regulations, the new protection tendencies (far side, new dummies, etc.) and the increasingly cost pressure, makes this an area of constant evolution.

Each methodology and technologies used by the different companies have their own advantages and disadvantages that make them more or less adequate depending on the various situations that can be proposed in the trials. Available technologies also get better each year and for these reasons companies such as Cidaut GmbH should be aware of these new and better technologies in order to always have an adequate test system that can fulfill all the specifications required for the tests.

The topic of this thesis will be focused on studying the introduction of new available technologies to upgrade the trial systems and therefore to contribute to the development of new and better passive safety components and hence to reduce road accident fatalities.

1.3-Main thesis objectives

The main thesis objectives are to research which available technologies and upgrades could be introduced in the actual testing systems in order to improve the reproduction of accidents for the experimental trials. For this purpose this thesis will be focused on the study of different types of high speed actuators that will simulate the accelerations and kinematics in different components involved in a lateral impact.

In a real side crash there are different accelerations and in these tests they should be reproduced in an exact manner.

The main area's kinematics and accelerations that should be simulated are:

-Car's main structure: it is where the rest of elements are attached to. The door and seat accelerations will be relative to this one.

-Seat: it is where the dummy is placed and consequently it's one of the principal accelerations. The dummy sensors are the ones that will tell us whether a restraint system works properly or not and if it's going to help us to reduce the injuries in a real crash. When the car receives the lateral impact, the seat moves to the door due to the inertia involved.

-Door: it is the area that receives the direct impact in a side crash. It will deform in different ways depending on if it is a pole crash or a barrier one and in the tests it's essential to reproduce these kinematic conditions in an accurate way. It is the most important area in these tests as its deformation will determine the way all the airbags

involved deploy and distribute along the available cabin space and therefore the information related to injuries taken by the dummy sensors.

The problem remains in the door kinematics. As already explained this car area is the most important during a side crash and therefore has to be represented in the best way. There isn't one acceleration or intrusion for the whole door; there are different ones depending on the area (*Figure 1.6*). It's necessary to search the way to reproduce the different area's kinematics with the available technologies, in this case actuators.

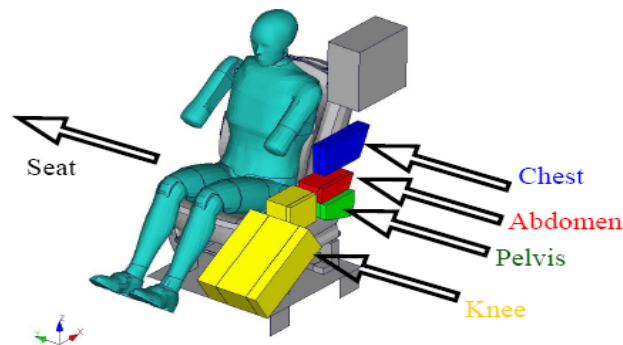


Figure 1.6: Main accelerations in a side crash test (Source SAE 11-0072)

Other point that is also very important is the repeatability of the test. This means that it is possible to reproduce the exact same crash several times in order to introduce design changes in the restraint systems and test them again under the same conditions to see the new behavior.

It should be taken into account that these tests are expensive and a lot of preparation is needed. Each of these tests last just a couple of milliseconds and that's why everything has to work perfectly and on time.

For all these reasons above, the actuators needed are very specific and difficult to find. The actuator selection will be based on a research into the market to see the available actuator technologies and also it will be evaluated the possibility of design and build them up in our headquarters facilities. And once the information of the supplier is put together, it will be studied whether the technical specifications are suitable for the requirements or not.

1.4-Procedure

First of all, the actual system will be presented with its working principle. It will contain an explanation about the different parts and how control several accelerations are controlled for different car regions. Then it's necessary to analyze the system strengths

and weaknesses to explain why it's a good idea to study the introduction of new actuator technologies in order to have a best-in-class testing system and to keep up with the current needs.

At this point all the information available about the different actuator technologies will be gathered: working principles, specifications... The information will be taken from a research through internet, specialized magazines, testing expositions, other final degree thesis, articles, and documentation available at the company.

The main technologies that will be studied are the following:

- Electric Actuators
- Hydraulic Actuators
- Pneumatic Actuators
- Pyrotechnic Actuators

With all this information about each of the technologies, the next point is to conduct a study to see if the specifications are suitable for these requirements depending on several important parameters and a list of advantages and disadvantages will be extracted. With this study it will be possible to select the best technology for the application then the study will be focused on this type of actuator.

Once is selected the actuator technology that could match the needs, it's necessary to determine the specifications required for the actuator. For that purpose, relative information from real sled tests will be used in order to define the most important parameters and characteristics for the actuator.

With the actuator requirements defined, the thesis can proceed to see which possible designs and configurations would work to achieve the objectives and whether the results are better or worse than with the actual system.

The next part will be a reliability study to have more information about the system probability of success, the frequency of failures and availability. Reliability engineering deals with the estimation, prevention and management of high levels of "lifetime" engineering uncertainty and risks of failure.

As mentioned above, the last part will be an economical study that will include everything related to earnings and costs to see if it could fit with the budgets and predictions. Some of the costs of this new system could be: pieces, software implementation, building hours, stop time for services...

Finally it's essential to write a conclusion to summarize all the information obtained in the previous studies and to decide whether to introduce this new technology or to stay

with the actual system. It will also include some future workflow tendencies in order to have an idea on how could this project be extended.

1.5-Important Parameters to take into account

The most important parameters to take into account for this thesis are related to dimensions and technical specifications. Some of them are listed and briefly explained below:

-Weight: it is especially important when we talk about on-sled actuators. This term means that the actuators are mounted and fixed on a rigid sled that will receive the main movement in the system. As it is going to be propelled, the weight has to be taken into account in order to not exceed the limits of the system that gives the impulse.

-Speed: depending on which type of crash and for which rule, regulation or assessment program the tests are being carried out, we will need one speed or another. These speeds represent those involved during a real car accident and therefore they are very high and violent. Each component on the car will have a different speed and even in the same component we can find several speeds for different areas as it happens on the door.

-Acceleration: not only the speeds are important but also the time needed to obtain them. The acceleration is the derivative of the speed and of course it's also very important. In these crashes we can even have accelerations of 120g, where a 'g' represents the gravity acceleration (9.81m/s^2).

-Jerk: possibly the most unknown of the parameters, but in fact one of the most important ones if not the most one. The jerk is the derivative of the acceleration and it could informally be explained as the "acceleration of the acceleration". The tests to which this thesis is referring last just around 100 milliseconds. During this short time, there are high accelerations and high speeds, and as said before, the accelerations can even be higher than 120g. For this reason and in order to reach these acceleration ranges in such a short time, a high jerk is needed. In a graphic, the jerk represents the slope of the acceleration curve.

-Force/Pressure: these two terms are related. The pressure is the amount of force applied per unit area. These parameters will determine the weight that these actuators can move and also the dimensions of the door area that is going to move.

These parameters will be even more important when talking about on-sled actuators due to the inertia with which they have to deal. As an explanation, the on-sled actuators are attached to a rigid sled with an acceleration given. These actuators have

to give a determined movement to the door area and to achieve it they have to overcome the inertia forces that push the cylinders backwards. And this results in force and pressure requirements.

-Length: the sled, to which these actuators will be fixed to, has a determined available surface. On this surface, several car components have to be fitted: door, panel, seat, dummy, etc. and this limits the available space for the actuators. For this reason, the dimensions of the actuators are so important.

-Maximum cylinder extension: in order to have an accurate crash reproduction, it is indispensable to simulate the real door intrusions. For this reason, the cylinder extension has to be long enough to reach the intrusion requirements of the crash.

-Double/Single effect: these terms refers to whether the cylinder has the capacity to work in both ways or just in one: extension and retraction or just extension or retraction. This will be explained in a deeper way in the next chapter.

2-State of the Art

2.1-Restraint systems development

Car development processes need to be shorter and cheaper each year at the time that better and more complex systems are developed. It should be understood that this makes the development process very controversial and difficult. Especially in the restraint systems area where regulations are getting stricter, companies should develop easier ways to test them in order to obtain the goals proposed by means of virtual and cheaper tools to avoid real car crashes which are very expensive due to its prototype condition.

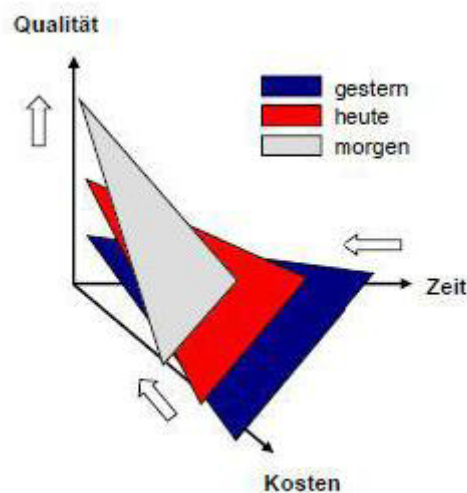


Figure 2.1: Magic Triangle of Product Development.

Competitive products are characterized by a high level of innovativeness, quality and dynamics. Due to the pressures of a competitive market, companies have to deal with the quality, cost and time dimensions which are depicted in the magic triangle (*Figure 2.1*).

In this phase both the customer's and legal requirements and the market and environment conditions have to be taken into account.

Nowadays there are three main parts in which restraint systems development could be divided. These parts are: CAE design, subsystem trials and final validation.

2.1.1-CAD and CAE design

For the car development process first of all an initial design is needed. This design is done thanks to CAD (Computer Aided Design) software which allows companies to

obtain a representative virtual 3D model. In this CAD software, you can give the models information about materials, geometry, functional information...

Each part and component is made individually and separately to obtain a fully detailed realistic piece. Once all these parts are designed, they are assembled together in order to study the packaging objectives so that all parts fit in their correct position without any conflict or interference with any other element from their surroundings.

CAD tools started during the late 1980's and the beginning of the 90's decade where a full car model used to be composed by 80000 elements. Nowadays, a normal full car CAD model can be formed by more than 2000000 parts even smaller than 4mm while the biggest ever model size was made out of 12000000 elements [SAUP14].

Once that the full-car 3D CAD model is developed and in order to study the general structural and kinematics behavior, a CAE (Computer Aided Engineering) tool is needed. The goal of the CAE software is to study the structural behavior during different critical load cases, particularly for the restraint systems development it represents possible crashes in order to see the functionality of these components.

This CAE software is based on the Finite Element Method (FEM) which divides all the pieces in thousands of smaller parts and each of these small parts are studied individually in order to obtain the global deformation in an accurate manner (*Figure 2.2*). For the restraint systems development process all the legislation's and assessment program's crash tests are represented with all the elements involved such as the dummies (with all the corresponding sensors and accelerometers), the post or barrier (depending on the crash type), airbags, seat belts (with their pretensioners...), etc. so that the simulation is as realistic as possible.

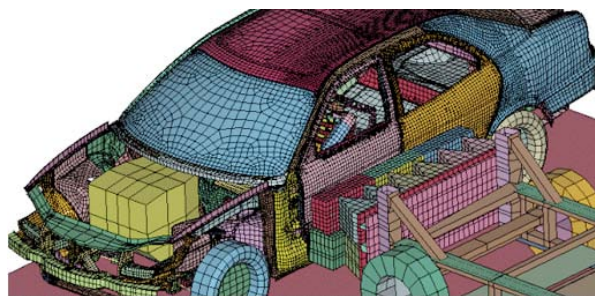


Figure 2.2: CAE model with FEM Meshing

CAE tools have enabled the automakers to reduce product development cost and time (*Figure 2.3*) while improving the safety, comfort, and durability of the vehicles they produce. The predictive capability of CAE tools has progressed to the point where

much of the design verification is now done using computer simulations rather than physical prototype testing.

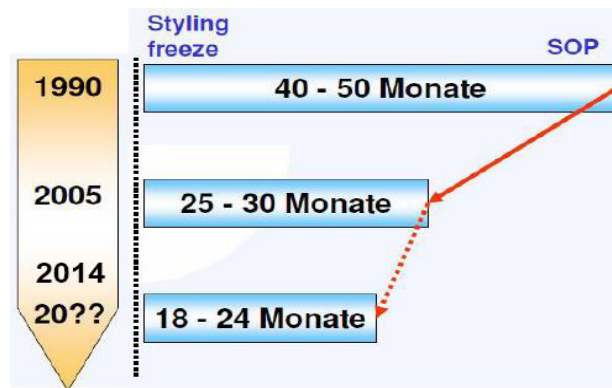


Figure 2.3: Time reduction due to CAD & CAE tools

2.1.2-Subsystem trials

These trials consist of several different tests to see the components real behavior. These tests are different depending on the area where the component will be fitted, because they will be tested for different load cases and these load cases depend on the type of crash. There are also specific and customized tests due to specific requirements during the development process. One of the main objectives of these trials is to compare the virtual tests from CAE software with the real ones in order to improve the CAD and CAE simulations so that they can have better correlation for further requirements. Some examples of tests related with safety against side crashes could be:

-Linear Impactor Test (LIP): a determined mass is launched against the component you want to test. This impactor can have several weights and shapes and is launched with a determined speed. To give some examples this impactor could have a spherical shape or even a pelvis shape to simulate the impact of this body region against a door panel (Figure 2.4).

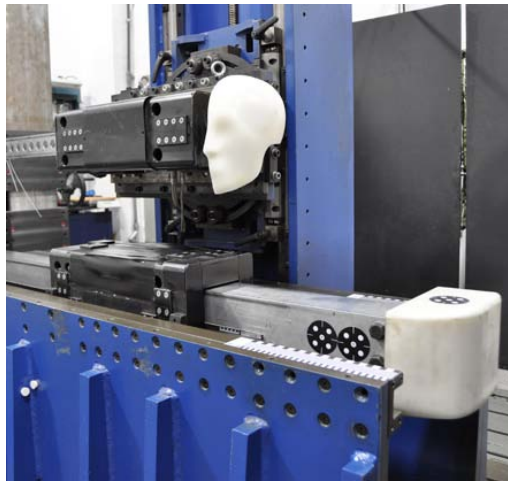


Figure 2.4: Cidaut's Linear Impactor System with two shapes for different regions.

-**Bending Test:** to see the behavior of components under bending conditions. This test can be done with just a component, for example a door trim to see breaking limit or a subsystem, for example a door panel with trim to see how clips and subsections behave.

-**Static Test:** for this test the dummy is placed in the predetermined sitting position and the airbag is activated without giving any acceleration to the system. Some objectives of this test are to check that the airbag deploys at the correct time, that the airbag unfolds properly, and that the hit received by the dummy is under the limit values. A type of static test could be the Out Of Position Test (OOP), where the dummy is placed in a dangerous position instead of the normal sitting position. In this test the goal is to evaluate the damages suffered by the dummy under abnormal situations.

-**Dynamic Test:** this test is commonly known as Sled Test or crash simulation. This is the test where the thesis will focus. The goal of this test is to reproduce a real crash without the need of destroying a real full-car and to introduce modifications to the restraint systems in order to obtain the best safety levels possible. For this test only the most important components involved in the type of crash are needed. In the case of a lateral crash, the main elements involved are: car structure (B-Pillar, sills), seats, door (door panel and trims), steering wheel (when front airbag is assessed), and restraint systems (Airbags, seat belt...) (Figure 2.5). All these parts are fitted together in a structure that reproduces the car main structure so that all the pieces are placed in the same exact position as in the real car model.

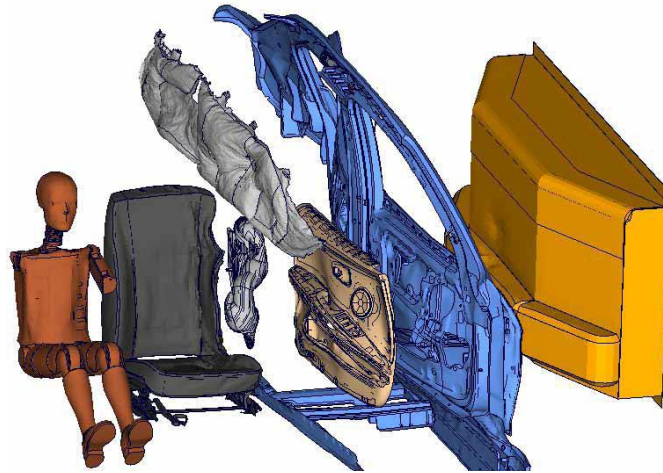


Figure 2.5: Common elements for a Side Sled Test, in this case a Barrier.

Once all the system is assembled and the dummies have been seated in their correct position, the system is given an acceleration that simulates the same conditions as in a real car crash (*Figure 2.6*). As already explained in the introduction, there are several accelerations depending on the different elements involved that will be controlled thanks to active or passive systems. These different acceleration pulses are obtained thanks to the virtual simulations and are introduced in the system that will give the signal to the mechanism that transmits the acceleration to the car structure.



Figure 2.6: Frontal sled test.

2.1.3-Final validation

The final validation tests are the last step in the restraint systems development process. For these last tests, full-car models are used and the main objective is to verify that as checked before thanks to the other real and virtual tests, everything

work as expected. All the restraint systems have to work properly in order to fulfill the regulations and to obtain the best safety rating from several private assessment programs (*Figure 2.7*). It's one of the last matters before bringing the new car model on to the market.



Figure 2.7: Audi Q7 MDB Side Impact Test for EuroNCAP

Car safety will normally be evaluated among these different areas: Adult Occupant Protection, Child Occupant Protection, Pedestrian Protection, and Safety Assist systems.

2.2-Crash dummies

During the 1940's decade, they started to investigate and test with human cadavers to determine the human body capacity under the crushing and tearing forces involved in a collision.

However these tests fell into disuse due to the old age of the cadavers that made the tests not representative of the population that could have a road crash. Due to the not representative condition of the sample and the moral conflict of using human cadavers, they started to test with animal bodies such as pigs, which have a similar intern structure.

A crash test dummy is a full-scale anthropomorphic test device (ATD) that simulates the dimensions, weight proportions and articulation of the human body, and is usually instrumented to record data about the dynamic behavior of the ATD in simulated vehicle impacts. This data can include variables such as velocity of impact, crushing force, bending, folding, or torque of the body, and deceleration rates during

a collision for use in crash tests. The more advanced dummies are sophisticated machines designed to behave as a human body and with many sensors to record the forces of an impact; they may cost over US\$400,000 [HUMA15] (Figure 2.8).



Figure 2.8: EuroSID-2 Dummy. Real model (left) and CAE model (right).

The first dummy was introduced in 1971 [HUMA15]. Called “Hybrid I”, was developed by General Motors. It was the first time that they simulated the effects of a car crash in a person representative of the population in a realistic way and it made possible the use of the same dummy model for many tests so that they could compare the results in order to obtain conclusions.

Nowadays, there are several different dummy models that are used for different assessment programs and regulations. They can be differentiated by model, sex, age, and percentile (percentage of population it represents).

The main dummies used for lateral impact tests are the following:

-EuroSID-2 (ES-2)

The ES-2 side impact dummy is the next generation of the EuroSID1 dummy. The EuroSID-2re, also used for some tests, differs from the first one because it incorporates a rib extension system which provides a more realistic interaction with vehicle seatbacks.

-SID-11s

It's a new generation crash test dummy to specifically evaluate advanced automotive side impact protection systems, particularly side airbags. Anthropometry reproduces a 5th percentile female dummy and also closely matches size and weight of the 12-13 year old child.

-Q-Dummies

The Q-Dummies were developed to represent children from several ages. They are very important for the development of protective measures for children in vehicles. Right now, for the side crash tests the following Q-Dummies are been used: Q1.5, Q3, Q6 and Q10.

-WorldSID

The one used for the tests is the 50th percentile, which represents an average mid-size adult male. This is one of the best and most important dummies nowadays due to its great biofidelity. The WorldSID's biofidelity, a measure of how well the dummy simulates the forces and motions of a human, is the best of any side impact crash dummy to date and far exceeds that of its closest rival.

ISO/TR 9790 specifies procedures for evaluating side impact dummy biofidelity performance using a series of 33 laboratory tests [SAUP15]. Based on the ISO/TR9790 rating scale, the WorldSID rating is 7.6 out of 10 (*Figure 2.9*).

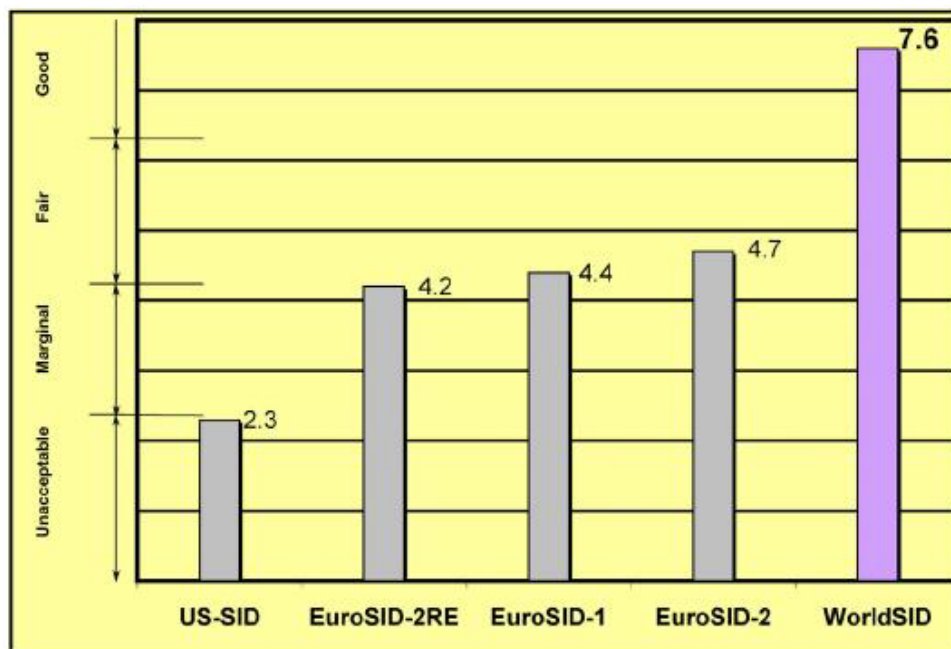


Figure 2.9: ISO TR9790 Biofidelity Rating Summary

To define all the measures collected by the dummy such as accelerations, forces and torque, a reference system is needed. From now on, every time that one of these measures is mentioned will always be referred to the axis shown in *Figure 2.10*.

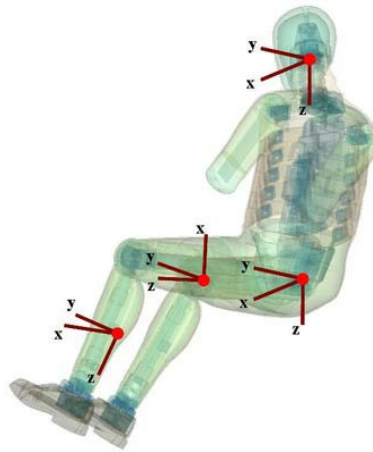


Figure 2.10: *Dummy referral axis*

2.3-Rules, regulations and private assessment programs

Once a new car model has been developed, it has to pass some final validation tests that will decide whether the car can get into the market or not. The rules and regulations establish the minimum standards among several aspects as they can be active safety, passive safety, emissions, and noise level. There are different rules and regulations depending on the region where the car is going to be commercialized but there are not big differences between them. (*Annex I*)

Relative to passive safety rules and regulations, there is a common one for the European region while countries such as U.S.A., Japan, China or Australia have their own one.

The centers that can carry out these final tests have to be an accredited laboratory. There, car manufacturers can test their models according to different region's rules and regulations so that they can obtain the approval for commercializing the model in several markets in just one laboratory.

However, apart from these rules and regulations, which are compulsory, there are also some private assessment programs, which are optional (*Annex II*). These private programs assess the active and passive safety of the newest car models and publish the results. Specifically, the main private programs are done by the NCAP organizations, abbreviation of New Car Assessment Program. As an example, in Europe this assessment is done by the EuroNCAP.

These NCAP assessment programs are organized and integrated by different associations and organizations, such as several governments, motorists clubs, foundations, etc. For this reason it can be said that the private assessment programs are independent from any car manufacturer and that provide objective results.

The aim of these private programs is to encourage manufacturers to develop higher safety levels than just the minimum ones stated by the rules and regulations to get cars into circulation. In other words, the aim of safety development is not just to accomplish the rules and regulations in order to sell cars, the aim is to protect and save lives.

In this way, NCAP assessment programs let car manufacturers show to the potential customers their capabilities, having the opportunity to stand out from their competitors.

Obviously, it's impossible to assess all the new car models that go into circulation each year and that is why NCAP organizations select just a couple of them. However, car manufacturers have also the opportunity to voluntarily get their models assessed whenever they want.

For the evaluation process they usually award 'star ratings' based on the performance of the vehicles in a variety of crash tests among several areas. The top overall rating is five stars but these ratings are only comparable between vehicles within the same category because weight and dimensions have influence on the tests results.

The main assessment areas are the following:

- Adult Occupant Protection (AO)
- Child Occupant Protection (CH)
- Pedestrian Protection (Pe)
- Safety Assist Protection (SA)

The Adult Occupant Protection assessment area has frontal, lateral and rear crash tests. However, this thesis will just be focused on lateral ones, which are usually crash tests against pole and against a moving barrier.

2.3.1-Oblique Pole Side Impact Test

This test simulates a side car crash against a pole with a determined relative angle, as it could happen with a tree or a streetlight. To carry out the test we will need the vehicle that we want to evaluate, a sled, the pole and the dummy.

The car will be placed on a sled so that it will be launched laterally against the rigid and static pole with a determined target speed at the moment of contact that depends on the rule, regulation or private assessment program for which is being done (*Figure 2.11*).

The diameter of the rigid pole is specified and at the moment of impact needs to have a specific alignment so that, when the vehicle-to-pole contact occurs, the direction of vehicle motion forms the specific angle required with the vehicle longitudinal centerline.

The test against rigid pole is not as common as others along the several rules, regulations and private programs, but in fact it should be one of the most important assessment points due to the severe hit received by passengers in this crash type. It has to be said that in lateral impacts, the free space between the occupant and the point where the impact occurs is almost inexistent so that the passenger absorbs most of the energy from the crash.

To get all the information relative to the impact parameters (Forces, Accelerations, Torque...) many acquisition channels, for the dummy, vehicle and carriage are needed.

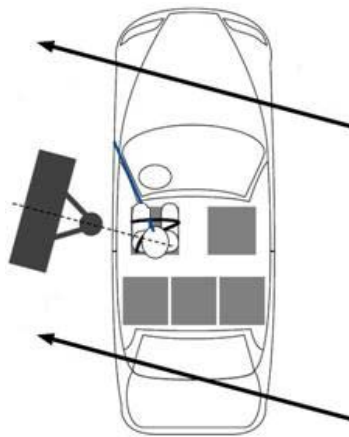


Figure 2.11: *Oblique Pole Side Impact Test Diagram*

2.3.2- Moving Deformable Barrier Side Impact Test

This test simulates a side crash between two cars with a determined relative angle, as it could happen in a road crossing for example. To carry out this test, it's needed the main vehicle to evaluate, a carriage and the dummies.

The car to be tested will be placed in the crashing track and it will have no initial speed. The carriage will act as the second car involved and it will crash against the car with a specific target speed at the moment of impact and a relative angle. The carriage area that receives the direct impact is made of honeycomb material which simulates the energy absorption capacity of a real car in order to reproduce in an exact way the damages caused to the tested vehicle (*Figure 2.12*).

The carriage weight is specified and the alignment between carriage and car has to be in that way that the center line of the barrier is at a determined distance from plane of R-point, where the R-point is a reference point given by the car manufacturer.

This test is done for all rules, regulations and private assessment programs, each of them with their own parameters and crash conditions.

In this case it's also necessary to get all the information relative to the impact. For it there are many acquisition channels distributed between the dummies, the car and the carriage.

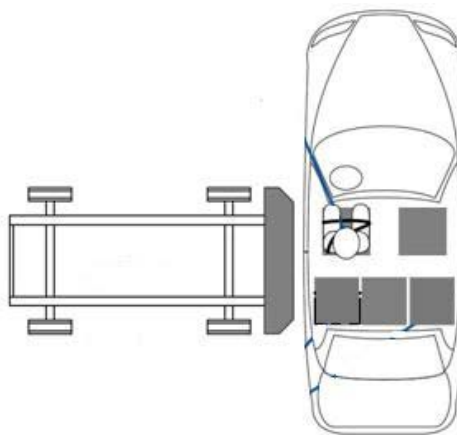


Figure 2.12: *Moving Deformable Barrier Side Test Diagram*

2.4-Actuator's technologies

An actuator is a type of motor that is responsible for moving or controlling a mechanism or system.

It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion.

An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.

There are two types of actuators depending on the movement they transmit: linear and rotatory. This thesis will be focused on linear actuators in order to obtain the door intrusions.

2.4.1-Electric Actuator

Electro-mechanical linear actuators are similar to mechanical actuators except that the control knob or handle is replaced with an electric motor. Rotary motion of the motor is converted to linear displacement.

Most electromechanical designs incorporate a lead screw and lead nut, while some use a ball screw and ball nut to convert rotation into linear displacement. In either case, the screw may be connected to a motor or manual control knob either directly or through a series of gears (*Figure 2.13*). Gears are typically used to allow a smaller, weaker motor, rotating at a higher RPM to be geared down to provide the torque necessary to rotate the screw under a heavier load than the motor would otherwise be capable of driving directly. Generally speaking, this approach effectively sacrifices linear actuator speed in favor of increased actuator thrust.

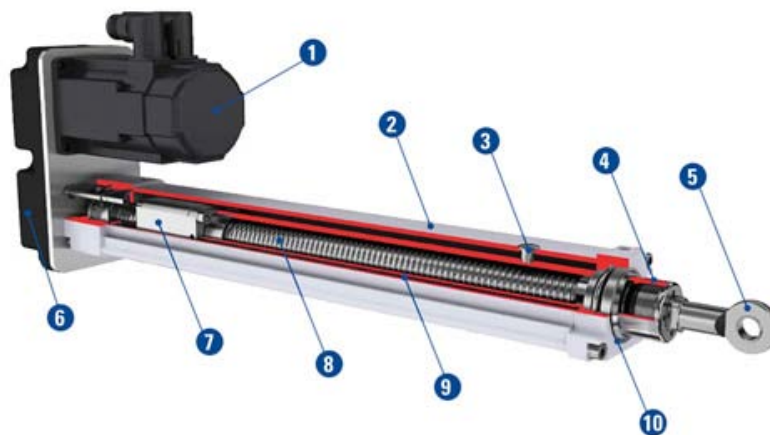


Figure 2.13: Thomson Electric Actuator

- | | |
|------------------------|--------------------------------------|
| 1. A.C. or D.C. motor. | 8. Ball screw drive. |
| 2. Outer tube. | 9. Internally guided extension tube. |
| 3. Lubrication point. | 10. Sealing. |
| 4. Outer tube. | |
| 5. Extension cylinder. | |
| 6. Set of gears. | |
| 7. Safety ball nut. | |

-Working Principle

In recent years, a range of linear electric actuators have been developed to perform functions similar to hydraulic and pneumatic cylinders. These are based on a motor driven lead screw. The motors may be AC or DC. The speed of the motor is reduced with a compact gear box before driving the lead screw.

D.C. Motors

They are based on a piece of wire bent into a rectangular loop, which is suspended between the poles of a magnet. When you hook up a wire like this to a battery, a direct current (DC) flows through it, producing a temporary magnetic field all around it. This temporary field repels the original field from the permanent magnet, causing the wire to flip over. Normally the wire would stop at that point and then flip back again, but if we use an ingenious, rotating connection called a commutator, we can make the current reverse every time the wire flips over, and that means the wire will keep rotating in the same direction for as long as the current keeps flowing. That's the essence of the simple DC electric motor, which was conceived in the 1820s by Michael Faraday [FARA44] and turned into a practical invention about a decade later by William Sturgeon.

In a DC motor, the magnet (and its magnetic field) is fixed in place and forms the outside, static part of the motor (the stator), while a coil of wire carrying the electric current forms the rotating part of the motor (the rotor). The magnetic field comes from the stator, which is a permanent magnet, while you feed the electric power to the coil that makes up the rotor. The interaction between the permanent magnetic field of the stator and the temporary magnetic field produced by the rotor is what makes the motor spin (*Figure 2.14*).

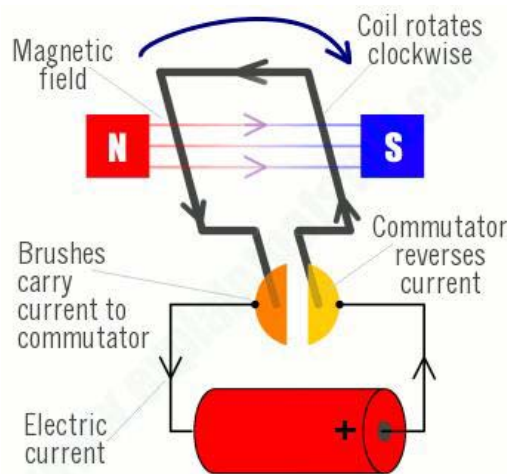


Figure 2.14: D.C. Motor working diagram.

A.C. Motors

In an AC motor, there's a ring of electromagnets arranged around the outside (making up the stator), which are designed to produce a rotating magnetic field. Inside the stator, there's a solid metal axle, a loop of wire, a coil, a squirrel cage made of metal bars and interconnections or some other freely rotating metal part that can conduct electricity. Unlike in a DC motor, where you send power to the inner rotor, in an AC motor you send power to the outer coils that make up the stator. The coils are energized in pairs, in sequence, producing a magnetic field that rotates around the outside of the motor (*Figure 2.15*).

In order to make the motor move, the rotor, suspended inside the magnetic field, is an electrical conductor. The magnetic field is constantly changing (because it's rotating) so, according to Faraday's law of electromagnetism, the magnetic field induces an electric current inside the rotor. If the conductor is a ring or a wire, the current flows around it in a loop. The induced current produces its own magnetic field and, according to Lenz's law tries to stop whatever it is that causes it by rotating as well. (You can think of the rotor frantically trying to "catch up" with the rotating magnetic field in an effort to eliminate the difference in motion between them.) Electromagnetic induction is the key to why a motor like this spins—and that's why it's called an induction motor.

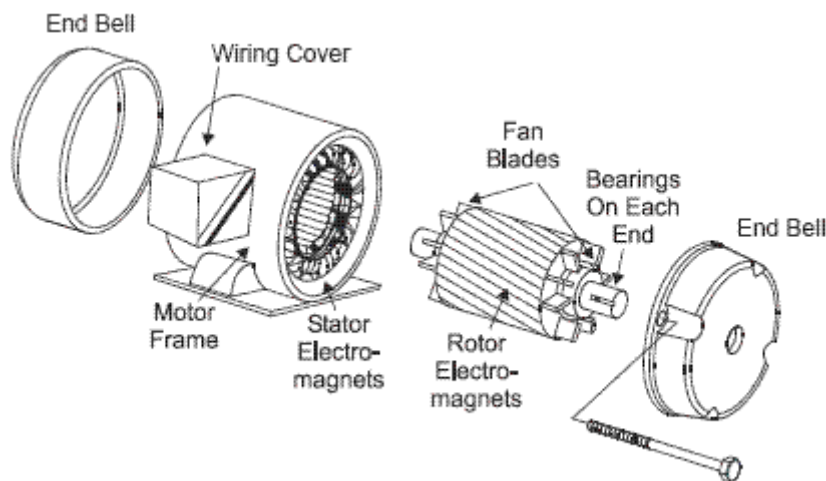


Figure 2.15: A.C. Motor construction

2.4.2-Hydraulic Actuator

A hydraulic actuator consists of a cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation. The mechanical motion gives an output in terms of linear, rotary or oscillatory motion. The fluid used in hydraulic actuators is highly incompressible so that pressure applied can be transmitted instantaneously to the member attached to it.

The hydraulic cylinder consists of a hollow cylindrical tube along which a piston can slide. There are two main types of linear actuators:

-Single acting: is used when the fluid pressure is applied to just one side of the piston. The piston can move in only one direction, a spring is being frequently used to give the piston a return stroke.

-Double acting: is used when pressure is applied on each side of the piston; any difference in pressure between the two sides of the piston moves the piston to one side or the other.

-Working Principle

The energy transmission between fluid and mechanical movement is based on the Pascal's Law that dictates: "Pressure applied to a confined fluid at any point is transmitted undiminished and equally throughout the fluid in all directions and acts upon every part of the confining vessel at right angles to its interior surfaces."

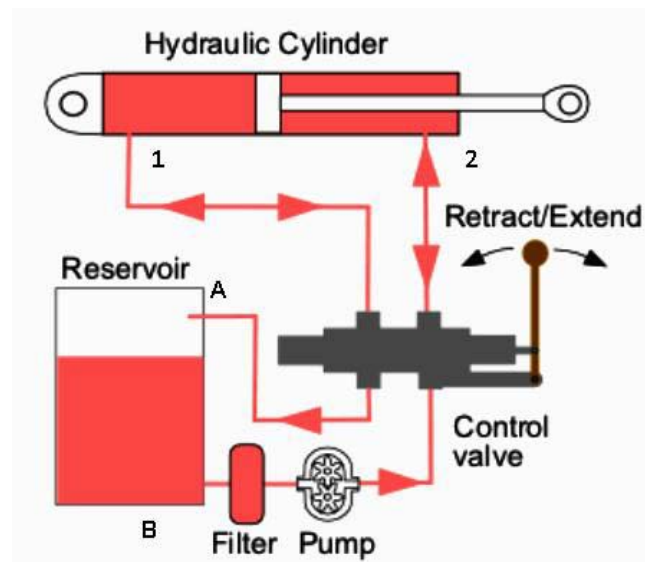


Figure 2.16: Hydraulic cylinder working diagram and main components.

The working principle of a hydraulic cylinder is as seen in *Figure 2.16*. There are two main movements depending on the control valve position:

-Retract: in this position the control valve lets the fluid go from the reservoir (B) through a filter to take out all the solid particles and then is driven by a pump to finally get into the cylinder right chamber (2). At the same time, the fluid from the left chamber (1) is pushed by the piston to the reservoir (A) resulting on the cylinder going backwards (*Figure 2.16*).

-Extend: in this position the control valve lets the fluid go from the reservoir (B) through a filter to take out all the solid particles and then is driven by a pump to finally get into the cylinder left chamber (1). At the same time, the fluid from the right chamber (2) is pushed by the piston to the reservoir (A) resulting on the cylinder going forward (*Figure 2.16*).

2.4.3-Hydraulic Accumulator

Accumulators usually are installed in hydraulic systems to store energy and to smooth out pulsations. Typically, a hydraulic system with an accumulator can use a smaller pump because the accumulator stores energy from the pump during periods of low demand. This energy is available for instantaneous use, released upon demand at a rate many times greater than what could be supplied by the pump alone (*Figure 2.17*).

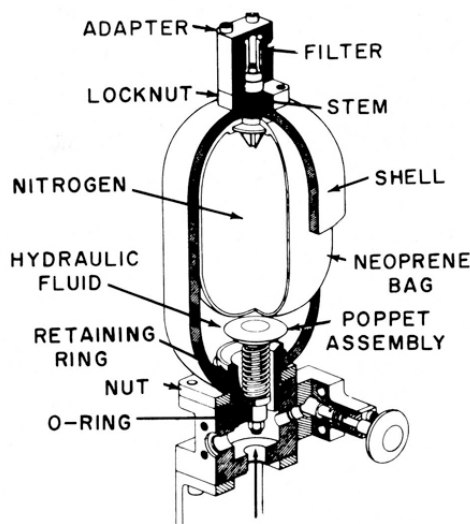


Figure 2.17: Hydraulic accumulator main parts.

Accumulators also can act as surge or pulsation absorbers, much as an air dome is used on pulsating piston or rotary pumps. Accumulators will cushion hydraulic hammer,

reducing shocks caused by rapid operation or sudden starting and stopping of power cylinders in a hydraulic circuit.

There are four principal types of accumulators: the weight-loaded piston type, diaphragm (or bladder) type, spring type, and the hydro-pneumatic piston type. The weight-loaded type was the first used, but is much larger and heavier for its capacity than the modern piston and bladder types. Both weighted and spring types are infrequently found today. Hydro-pneumatic accumulators are the most commonly type used in industry.

-Operation

When sized and precharged properly, accumulators normally cycle between stages (d) and (f), as shown in *Figure 2.18*. The piston will not contact either cap in a piston accumulator, and the bladder will not contact the poppet or be compressed so that it becomes destructively folded into the top of its body.

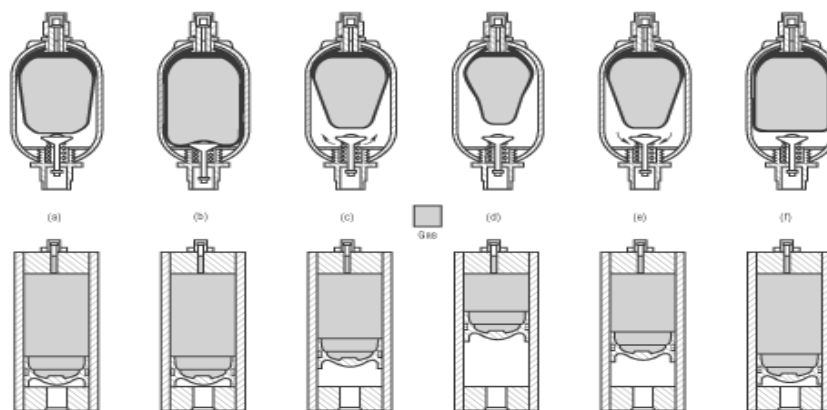


Figure 2.18: Hydraulic accumulator working phases. Bladder type up and piston type down

Manufacturers specify recommended precharge pressure for their accumulators. In energy-storage applications, a bladder accumulator typically is precharged to 80% of minimum hydraulic system pressure and a piston accumulator to 100 psi below minimum system pressure. Precharge pressure determines how much fluid will remain in the accumulator at minimum system pressure.

Correct precharge involves accurately filling an accumulator's gas side with a dry inert gas, such as nitrogen, while no hydraulic fluid is in the fluid side. Accumulator charging then begins when hydraulic fluid is admitted into the fluid side, and occurs only at a pressure greater than the precharge pressure. During charging, the gas is compressed to store energy.

A correct precharge pressure is the most important factor in prolonging accumulator life. The care with which precharging must be accomplished and maintained is an important consideration when choosing the type of accumulator for an application, all else being equal. If the user tends to be careless about gas pressure and relief valve settings, or adjusts system pressures without making corresponding adjustments to precharge pressure, service life may be shortened, even if the correct type of accumulator was selected. If the wrong accumulator was selected, premature failure is almost certain.

2.4.4-Pneumatic Actuator

Air or pneumatic cylinders are devices that convert power of compressed air into mechanical energy. This mechanical energy produces linear or rotary motion. In this way, the air cylinder functions as the actuator in the pneumatic system, so it is also known as a pneumatic linear actuator. In the following explanations I will focus on linear actuators.

As happened with hydraulic actuators, there are two main types of pneumatic linear actuators:

-Single acting: is used when the gas pressure is applied to just one side of the piston. The piston can move in only one direction, a spring being frequently used to give the piston a return stroke.

-Double acting: is used when pressure is applied on each side of the piston; any difference in pressure between the two side of the piston moves the piston to one side or the other.

-Working principle

Physical processes proceeding in pneumatic drives are submitted to the gas laws. The gas laws are a set of laws that describe the relationship between thermodynamic temperature (T), pressure (P) and volume (V) of gases. Three of these laws, Boyle's law, Charles's law, and Gay-Lussac's law, may be combined to form the combined gas law:

$$\frac{P_1 \cdot V_1}{T_1} = \frac{P_2 \cdot V_2}{T_2}$$

With the addition of Avogadro's law later gave way to the ideal gas law. Other important gas laws include Dalton's law of partial pressures. The kinetic theory of gases, Graham's law of effusion and root mean square velocity explains how individual molecules act in a gas and their relation to pressure, volume, and temperature.

A gas that obeys these gas laws is known as an ideal gas (or perfect gas). An ideal gas does not exist; however, some gases follow the laws more closely than the others in given standard conditions.

The most important gas law is the ideal gas law, which states that: $P \cdot V = n \cdot R \cdot T$

The gas commonly used for pneumatic actuators is Nitrogen and it's considered an ideal gas.

In the following picture it is explained the working principle of a pneumatic single-acting linear actuator.

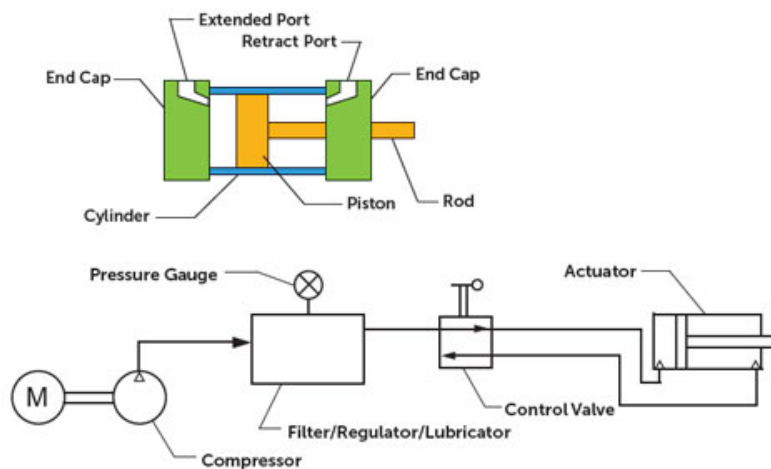


Figure 2.19: Pneumatic actuator working diagram and main components.

The motor (M) moves the compressor in order to inject the compressed air into the system. The air passes through a filter and goes directly to the control valve which will be the one that conducts the pressurized air into the cylinder chambers.

In the position shown on the *Figure 2.19* the control valve is in the expanding position: the compressed air goes to the left chamber while the right chamber's air goes out, resulting in the expanding cylinder.

2.4.5-Pyrotechnic Actuator

Pyrotechnic actuators are widely used in the automotive industry due to the fact that such a construction provides very short time of reaction. Furthermore, they are able to produce large amount of energy not requiring much space to store. Mostly such devices are used in pyrotechnic seat belts pretensioners, in pop-up hood systems for pedestrian protection, systems which open doors of a crashed vehicle in order to provide easier access to the injured occupants etc. These actuators can be made with several dimensions: from the micro actuators for the aerospace industry to the actuators whose cylinder have 20 cm diameter [GORN12]. Although these actuators can also be customized depending on the specifications required.

-Working principle

The piston of the pyrotechnic actuator is trusted forward upon the ignition of the pyrotechnic charge. This charge produces a large amount of gases as combustion products in the time of milliseconds and therefore generates a wave which acts on the piston forcing it to advance forward. The shock wave in terms of pyrotechnics is defined as a pressure wave of high intensity characterized by a very rapid initial increase in pressure followed by a slow falling off.

In appearance this type of actuator could be like any other: a sealed cylinder which moves from inside to the outside. However, the main differences are inside, where instead of having valves for letting the gas or oil get in and out, there is a pyrotechnic charge which is activated by means of an igniter (*Figure 2.20*).

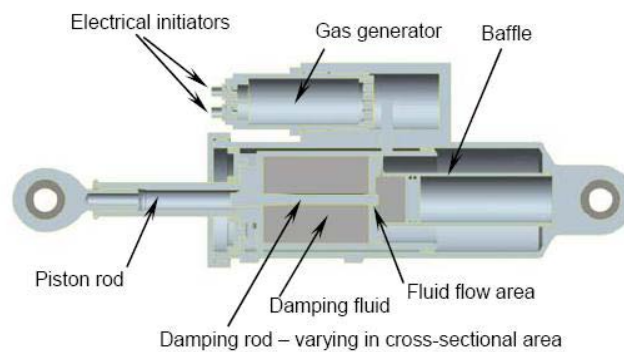


Figure 2.20: *Pyrotechnic actuator main parts.*

2.6-Honeycomb structures

Honeycomb structures are natural or man-made structures that have the geometry of a honeycomb to allow the minimization of the amount of used material to reach minimal weight and minimal material cost. The geometry of honeycomb structures can vary widely but the common feature of all such structures is an array of hollow cells formed between thin vertical walls. The cells are often columnar and hexagonal in shape. A honeycomb shaped structure provides a material with minimal density and relative high out-of-plane compression properties and out-of-plane shear properties.

Man-made honeycomb structural materials are commonly made by layering a honeycomb material between two thin layers that provide strength in tension. This forms a plate-like assembly. Honeycomb materials are widely used where flat or slightly curved surfaces are needed and their high specific strength is valuable. They are widely used in the aerospace industry for this reason, and honeycomb materials in aluminum, fiberglass and advanced composite materials have been featured in aircraft and rockets since the 1950s. For this thesis I will focus on aluminum honeycombs (*Figure 2.21*).

Honeycombs from metals (like aluminum) are today produced by the expansion process. Continuous processes of folding honeycombs from a single aluminum sheet after cutting slits had been developed already around 1920 [DEAN19]. Continuous in-line production of metal honeycomb can be done from metal rolls by cutting and bending.

There are several honeycomb strengths depending on the density of spaces (hexagons) of the material and they are used for different applications where the requirements are varied.

This structure is also used in the automotive testing area, and especially for the crash-test dynamic simulations. These materials are used when different movable parts are involved in the tests to simulate the real deformations and in order to adjust the accelerations and velocity curves of these elements some honeycomb energy absorption elements are introduced. Depending on the geometry (length, cross-section area, density of free spaces...) we will obtain different energy absorption specifications.



Figure 2.21: Honeycomb structure.

2.7-The actual system

The company's headquarters are located in Valladolid, Spain. There are plenty of industrial buildings there for different purposes related to the industrial sector for which it works.

One of these plants is dedicated entirely for the sled tests. For carrying out these tests enough space is needed for all the offices, storing areas, the test track, etc.

The testing facilities are mainly composed by a 30m long test track (*Figure 2.22*) along which the sled will be driven and with the purpose also of reducing its speed until it's stopped, and the HYGE which is in charge of transmitting the pulse to the sled.



Figure 2.22: Cidaut's crash-test track

To carry out these tests, you can use a direct crash system (from initial speed until zero) or an inverse crash system (from steady state until a determined speed). Both systems will provide the same information about the crashes and about injuries taken by the dummy channels.

In this case, the HYGE is an inverse crash simulator. In order to give the sled pulse, it has a big cylinder that works thanks to the pressure given by a hydraulic and pneumatic system.

The mixture of these two technologies is due to the necessity of reaching higher acceleration values, as it happened with smaller actuators that use accumulators. In this case, these accumulators are two and are big enough to give 345bars of pressure (*Figure 2.23*).

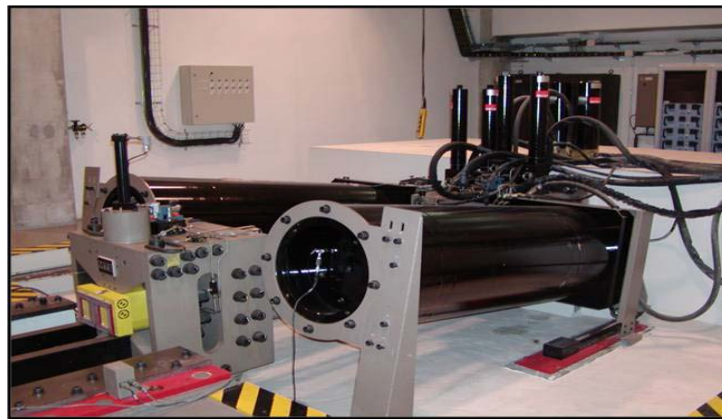


Figure 2.23: *HYGE nitrogen accumulators*

The working principle of these accumulators is the same as in the smaller ones for the hydraulic actuators. There is a cylinder separated into two chambers by a piston. One of these chambers is filled with gas (in our case nitrogen) and the system introduces pressurized oil on the second chamber compressing in that way the nitrogen from the first chamber.

Once the nitrogen has reached the working compression values, a valve is opened to release the oil from the accumulators and in order to propel the cylinder that pushes the sled.

On *Figure 2.24* it can be seen a scheme of how this system works.

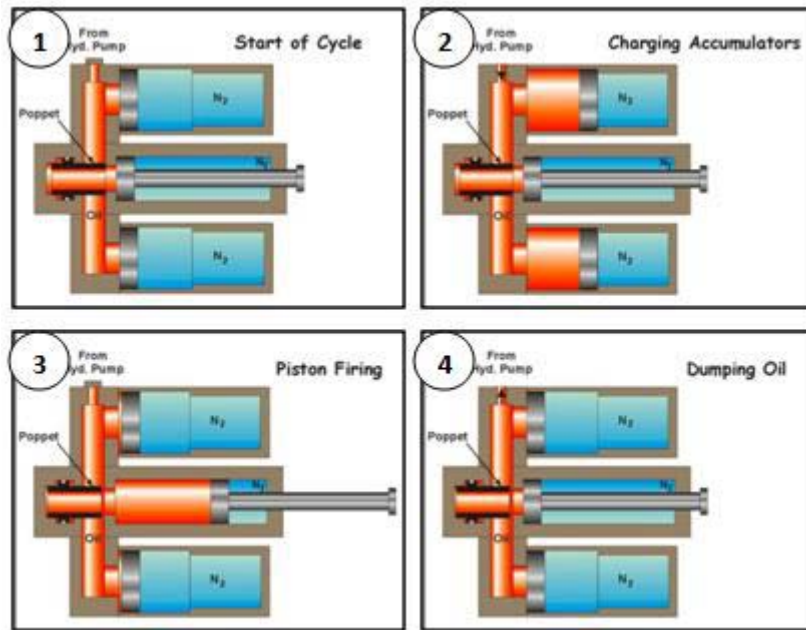


Figure 2.24: The system's working sequence

Once that the test has been carried out, the cylinder goes back to its initial position thanks to a valve that the system opens and due to the oil pressure remaining in the circuit.

3-The Project

3.1-Study of the actual system

As already explained, each testing company has to develop their own system and methodology. For this reason, there are several options and characteristics to obtain a representative crash reproduction.

In this case, Cidaut GmbH uses a mixture between active and passive systems that at this time is obtaining very good correlations between the input specifications and the output got.

The HYGE propels the sled where all the system is fixed to (active system), while all the other elements adjust to their specifications values thanks to the use of honeycomb materials (passive system). Specifically, door segments I and II and the seat move backwards (relative to the sled) due to the inertia, which means that they have a relative deceleration to the sled.

A scheme of the actual system used for a MDB Test at the company is shown on *Figure 3.1*, while the scheme for a Pole Test is shown on *Figure 3.2*.

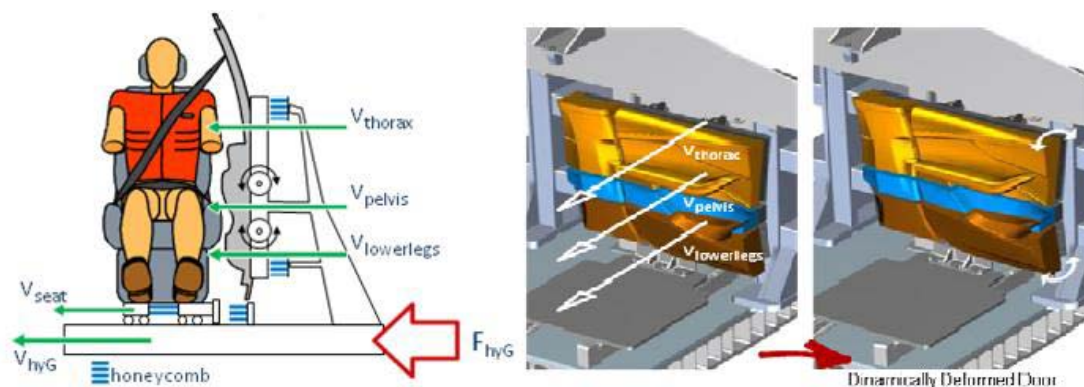


Figure 3.1: Scheme of the actual configuration for a MDB test.

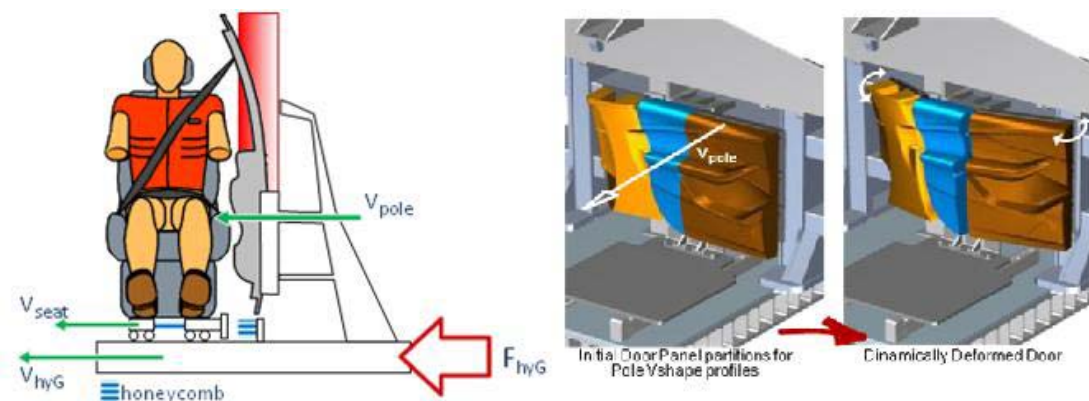


Figure 3.2: Scheme of the actual configuration for a Pole test.

In other words, we are requiring high accelerations from the HYGE in order to obtain relative decelerations for some elements such as the seat and the door segments, which force to pay special attention to the structural design of the test bench and supports of all the elements since they are subjected to very high forces during the tests.

However, due to the high specifications required to the HYGE, high oil flow is needed, which means a large volume of fluid per time unit. To achieve this condition, a big fast valve is needed and the bigger the valve, the bigger the inertia it has.

With the door division into segments (two for post and three for barrier tests), and thanks to the relative seat movement to the door, it is represented in an accurate manner what is commonly called the closing gap. This term refers to the available space between the door and the dummy along the crash and it is really important because it will determine the way an airbag deploys and expands, and therefore the values received by the dummy. The point that makes the closing gaps from Cidaut GmbH so representative is that with the system they have real movement of the door segments with respect to each other making it as realistic as possible; while other systems focus just on the acceleration pulses and therefore they don't need real movement of the door.

The use of passive technologies in order to obtain the requisites makes the system really simple despite having great specifications. The simplicity of the system helps to reduce the rate of failure and the problems related to technology and reduce the area of attention whenever an error occurs. When too much technology is involved, it is difficult to find where the problem occurred, because everything tends to be isolated and difficult to reach.

In addition to the good correlations between the input given (desired curve) to the system and the output obtained (achieved curve), the system also has great repeatability. This means that you can launch the exact same test with same conditions and specifications several times. This is really important during the development phases because it allows introducing improvements and corrections to any of the elements involved such as airbags, seats or seat belts, and carrying out the test again under the same conditions to see if they obtain better results and if they work properly.

It has to be said that these problems explained above aren't serious and doesn't make the system better or worse than the others available at other companies. Each system has its own advantages and disadvantages.

Actually, the main problematic and limits of the actual system are explained below. These are the main pillars of this thesis.

- I. As explained above, in the testing facilities the HYGE gives the highest acceleration of all the elements involved in the sled system, and then the other components reduce and adjust their accelerations by means of inertia and honeycomb materials until they reach their specification objectives. The problem related to this configuration is that the safety rules, regulations and other private assessment programs are getting stricter each year obtaining higher accelerations in the car crashes which need to be also reached in this sled tests. For this reason and due to the requirement that the HYGE has to give the highest acceleration of all the system, for some rules, regulations and assessment programs our system couldn't reach the specifications needed in certain cases.
- II. The second weakness of the system could be the way the door segments get fixed when moved due to the inertia. The door segments are joined one to other by means of a hinge having one or two free-moving segments (depending on the test). The system by which the free-moving segments get fixed in a specific position at the end of the test, consist of a fixed metal rack guide and a pin attached to each of the door segments that prevent the movement to the original position. The problem with this is that it cannot represent accelerations and decelerations of the door segments in an exact way because once the pin has passed one of the rack teeth it cannot go backwards again. This can be seen in the *Figure 3.3* highlighted by a black circle on the curves.

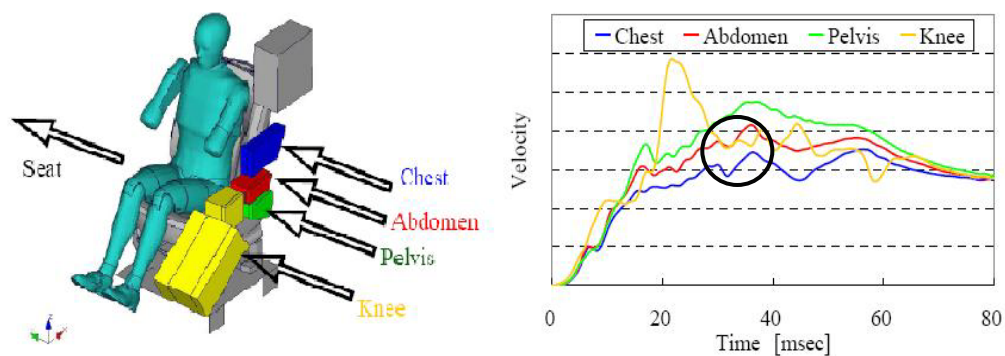


Figure 3.3: Example of velocity peaks highlighted under a black circle.

3.2-Study of the available technologies

In this section it will be analyzed all the advantages and disadvantages of each of the actuator's technologies proposed and focused on this specific application.

3.2.1-Electric actuators

Advantages

Electric actuators are one of the most extended technologies nowadays. The use of electricity as the main power source makes them versatile and safe. You can simply configure the system and connect them to the electric network.

They are clean and you don't have to be worried about liquid leakages and sealing systems which can produce a loss of pressure and therefore to produce a failure or not to accomplish the desired results.

Thanks to the use of electricity as power source this technology is easy to control by a control system such as a computer. Actuators are usually controlled by electric systems which work with electricity as this type of actuators, and for this reason the control system and the actuators are 100% compatible making it simple to control everything without the need of any mix of energy sources.

Disadvantages

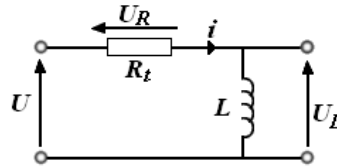
However, for this thesis a very specific type of actuators are needed due to the high requirements. And that's why electric actuators have a lot of disadvantages.

First of all there are some general disadvantages that are not unique just for this thesis. For example, the electric motors involve lot of problematic such as the following:

- A. The electric motors suffer severe damages in case of stagnation or overload due to the magnetic and electric fields that would lead the motor to a peak of temperature that could infringe irreparable problems to the system. Overload or blockage is very common in this type of testing due to the high accelerations and heavy components involved. In other type of technology it could exist a release valve for this type of situations that would protect the system.
- B. The working principle of A.C. and D.C. motors need coils to produce and conduct the magnetic and electric fields. The problem with these coils is that they have inertia; this means that they need a certain time until they are able

to produce the current needed for the system. For example for a RL circuit, the current through the coil would be defined as follows:

$$I_{Bobina} = \frac{U}{R_t} \cdot (1 - e^{-\frac{t}{\tau}})$$



Where R_t is the total resistance of the circuit and τ is the circuit time constant. This equation is valid for the transient period, which last for approximately 5τ and after it can be said that it already has the permanent current through the coil.

To control this it could be defined a time lag between the trigger signal of the system and the one for the electric motor in order to let the coil time enough to be ready. This could sound easy but in fact it's almost impossible for the kind of use needed due to the small time margin of milliseconds that the tests last. The coils delay time depends on a lot of factors such as temperature, humidity, attrition of the material, etc.

- C. The magnetic saturation is a phenomenon by which in some magnetic materials an increase of the external magnetic field doesn't increase the magnetization of the material further. Saturation puts a practical limit on the maximum magnetic fields achievable in ferromagnetic-core electromagnets and transformers of around 2T (Figure 3.4), which puts a limit on the minimum size of their cores.

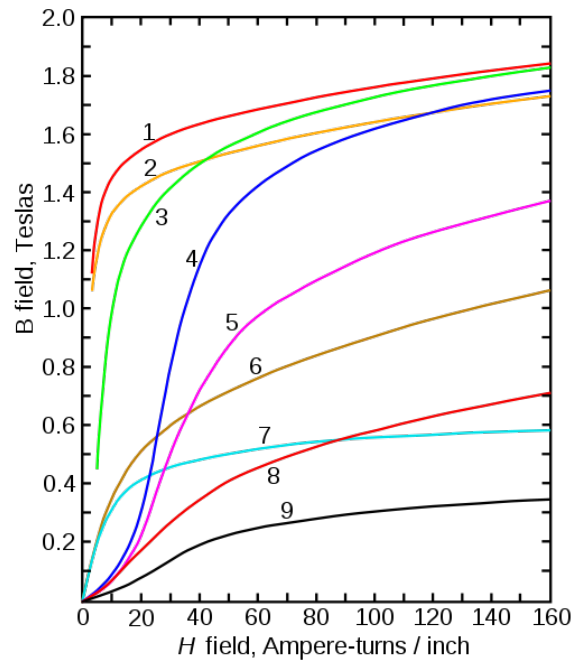


Figure 3.4: Magnetization curves of 9 ferromagnetic materials, showing saturation. 1.Sheet steel, 2.Silicon steel, 3.Cast steel, 4.Tungsten steel, 5.Magnet steel, 6.Cast iron, 7.Nickel, 8.Cobalt, 9.Magnetite

Other problem existent is that these actuators will be fixed on a movable sled. It could be selected to have a D.C. motor and a battery mounted on the sled, but apart from the weight it adds to the system, for the specifications required an A.C. motor would be needed due to the higher capacities and for this it will need to be wired to a fixed position.

However, for the system the main problems this technology has are:

- I. The capacity to tolerate overloads or blockage conditions as explained above on the motors problematic.
- II. The low speed is one of the biggest problems to define the system with this type of technology. Electric actuators usually transform the rotating motion from the motor into linear motion thanks to a helical guide in the inner surface of the cylinder cover and due to a screw shape cylinder that moves through the guide (Figure 3.5). The problem remains on the equivalence between the revolutions per minute of the motor and the linear speed of the screw. To relate these parameters a thread's pitch is needed, which represents the linear movement per revolution of the electric motor and it's usually too small.



Figure 3.5: Nook Industries electric actuator

- III. The rate of power per unit weight is low for this type of technology, and for this case is needed the highest specifications with the minimum weight possible. Don't forget that the cylinders will be fitted on the sled and the HYGE has to move all that system.

3.2.2-Hydraulic actuators

The hydraulic technology is one of the best and more used technology for testing applications nowadays. In fact it is the technology of the company's facilities at this moment. It is capable of obtaining high speeds which is essential for this application.

Advantages

The speed of this type of actuators is variable and in case of having a double-effect actuator, the direction will also be variable due to the possibility of introducing the fluid pressure in both sides of the cylinder. This is very interesting, although for changing the direction the cylinder has lot of inertia due to the high speed and the short time ranges that has to accomplish.

For this reason it would be even better to work with a single-effect cylinder and a hydraulic brake that controls the accelerations and decelerations of the cylinder in an accurate way, obtaining better results than with a double-effect one.

It also has a good power to weight ratio, which as explained before is very important for this case because the actuators will be fixed on the movable sled. The more weight added to the sled, the more the specifications that will be requested to the HYGE.

For security reasons, this technology has protection against overload and blockage, which could happen in this case due to the high specifications involved during the tests such as accelerations, forces, intrusions and weights. This system consists of a pressure release valve that makes the pump conduct the fluid back to the tank whenever the pressure exceeds a determined limit. Once the pressure has been released, the system can keep on working without problems.

Other good and interesting point that could be introduced into the advantages is the possibility of adding a hydraulic accumulator. The working principle of this technology is explained in the State of the Art section of this thesis and allows the system to precharge the oil with a higher pressure by means of compressed gas. Thanks to this, it can obtain even higher accelerations and speeds. An example of how an actuator with a hydraulic accumulator looks like is shown on *Figure 3.6*.



Figure 3.6: Hydraulic actuator with accumulator.

Disadvantages

It has to be said that this technology doesn't have many or too important disadvantages for the needs. However, everything has to be taken into account in order to have the best testing system possible.

The first disadvantage that could be said about it is that depending on the severity of the acceleration changes needed, the cylinder cannot reach them due to the time that the valves need to open and close.

Other of the main disadvantages of this technology is the necessity to store the oil. This means that the fluid has to go from and to a tank, and this tank has to be big enough to store all the fluid required. For this reason there are two options:

- A. Fix the tank to the floor. This requires piping lines going from and to the tank to move the fluid when the cylinder is moving. The problem remains on the fact that these piping lines have to be long enough not to be torn away during the test. At least they have to be longer than the testing track. This could sound like an option but the longer the piping lines, the more the loss of pressure you have.
- B. Fix the tank to the sled. This involves attaching the tank and all the piping lines and pumps to the movable sled. It has to be understood that this will add a lot

more of weight, which the HYGE would have to propel. For this reason the HYGE requisites would be much more demanding.

Other important limitation of this technology is the possibility of fluid leakage due to the high pressure involved. This disadvantage would lead to safety problems due to the fire risk (oil is inflammable) and to a loss of pressure of the system. This last fact, will involve obtaining a lower output than specified because there is some fluid that leaks without transmitting the energy that carries, resulting on less acceleration, speed, etc.

For this specific application, there would be great problems in order to synchronize the actuator with the main hydraulic cylinder (HYGE). The reason for this is that you need a brake system for the actuator to achieve a determined curve needed and for that purpose you also need a fast response servovalve to allow the quick movement of fluid. The biggest acceptable time mismatch between the HYGE and the actuator is smaller than one millisecond.

The last disadvantage that should be taken into account is the possibility of cavitation. Each time that fluid and pressure are involved, the appearance of cavitation is always a possibility. The cavitation occurs when a fluid changes rapidly its speed, changing consequently its pressure. Sometimes this pressure reaches the vapor pressure value of the fluid, changing from liquid state to vapor and therefore appearing bubbles along the fluid. When these bubbles implode, they erode the material that surrounds the fluid producing a deterioration of the system (*Figure 3.7*).

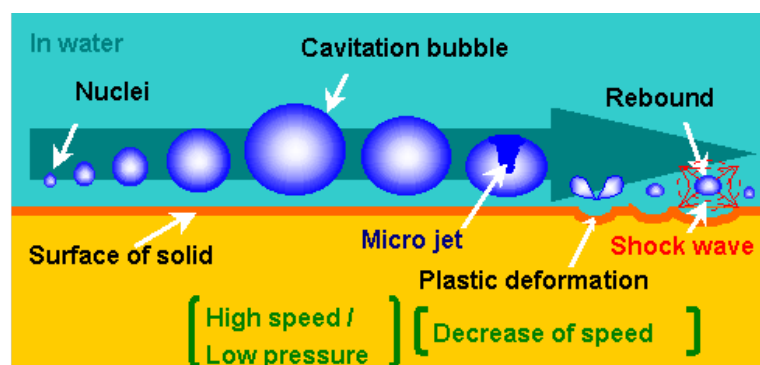


Figure 3.7: Cavitation's process

The damage produced by the implosion of a small bubble could seem harmless, but in fact when there are a lot of bubbles and with a high rate of production, they cause big damages to the material (*Figure 3.8*).

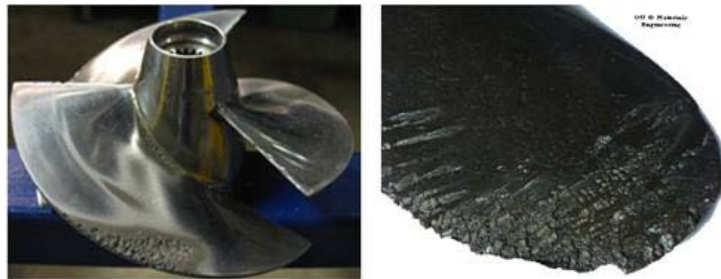


Figure 3.8: Damaged propeller due to cavitation.

3.2.3-Pneumatic Actuators

As happened with hydraulic actuators, pneumatic technology is also considerably common for testing purposes. They have many advantages and just a couple of disadvantages that are summarized below.

Advantages

Through this technology, it's possible to obtain high speeds with a relatively simple design, which is very interesting for this application. It is relatively simple mainly because unlike hydraulic actuators, this system doesn't need a reservoir or tank to store the fluid.

The fluid used by these actuators is compressed air, which is really cheap and easy to obtain. The means by which this air is created is as easy as a simple compressor that takes air from the atmosphere, pressurizes it and introduce it in the cylinder through piping lines.

You could think that it is not that different from a hydraulic actuator. It could seem that from one technology to the other it just changes the tank for a compressor but the piping lines are still there for both. However, there is an important difference from one to the other.

This main difference is that unlike the oil used in hydraulic actuators, air is compressible. This means that the air can be introduced in the cylinder's chamber and be compressed until the working values while the cylinder movement is blocked by a hydraulic brake.

As the cylinder movement is being released, the air from one of the cylinder chambers has to go out, and this is other of the advantages, that air can be released to the atmosphere without contamination or security issues as happen with the hydraulic technology.

This allows to dispense with the tank and the piping lines, leaving a simple and cleaner system (no leakage of pollutants), and reducing considerably the loss of pressure at the same time that costs are reduced (these machinery is usually composed by high quality systems and therefore are very expensive). The absence of tank and piping lines let having a more independent and lighter system to mount on the sled, which is the intention.

It could be better seen as a cylinder launched by compressed air and a hydraulic brake that controls the movement rather than an actuator which movement is controlled by an inlet and outlet valve.

Other option that this type of technology allows is that the use of hydraulic brakes let engage as many as needed one before the other in order to reach higher specifications.

To conclude, the last advantage that could be mentioned is the tolerance against overload and blockage, which in this case is interesting due to the high accelerations and speeds used, making the appearance of these cases possible.

Disadvantages

The main disadvantage for this type of technology is the difficulty of working at low speeds due to the need of low air pressure to accomplish it. The problem resides on the decrease of specifications whenever the air pressure is reduced.

However, as happened before, it can be solved with a hydraulic brake that allows having high pressure and low speeds whenever it's needed.

But this hydraulic brake has not only benefits; there are also some problems related to it. The two main problems are:

- A. The attrition of the brake pads. For this reason attention is needed to the general condition of them and must be changed when needed. This leads on maintenance times. However, the biggest problem related to brake pads attrition is the fact that between tests, there isn't the same braking capacity and therefore the performance that the cylinder is able to give is reduced.
- B. The hydraulic circuit. Using a hydraulic brake, you can dispense with the cylinder's air pressure circuit. However, these brakes need also a hydraulic system with piping lines and a reservoir. This system adds weight to the system, but it's not too big due to the small gap between the brake pads and the

cylinder, which requires just a low oil flow. In conclusion, by eliminating the cylinder air pressure circuit and adding the brake hydraulic circuit, you get a lighter and more accurate system.

An example of this type of pneumatic actuator with hydraulic brake can be seen on *Figure 3.9*.

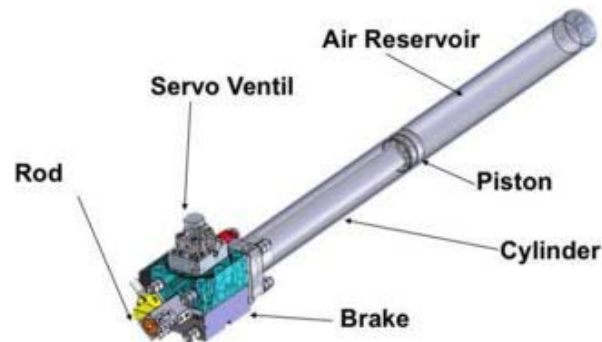


Figure 3.9: Pneumatic actuator from DSD

3.2.4-Pyrotechnic Actuators

Possibly this is the less known actuation technology, but actually, these actuators are really common in the aeronautic industry and for some automotive purposes such as the seat belt pretensioners (*Figure 3.10*). The ones that we can find in the market are not as big as what is needed for this application but they could also be ordered custom made.

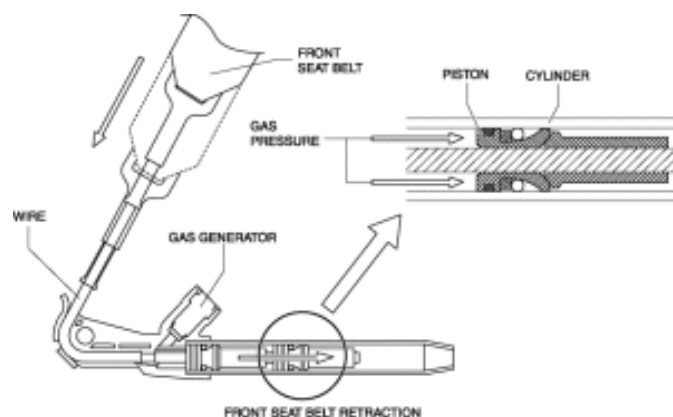


Figure 3.10: Scheme of a pyrotechnic actuator for a seat belt pretensioner

Advantages

The main advantage of these systems is the high performance they are able to reach. You can obtain high speeds, accelerations and forces which is exactly what is needed for these tests.

These actuators are simple and therefore they don't need complex technology to make them work which makes them cheap which is also really interesting for the purpose.

Other good point they have is that they are light. These systems consist on just a cylinder, a chamber and a pyrotechnic charge which is responsible of producing the explosion that will move the cylinder forward.

Disadvantages

The disadvantages of this technology are many, but these actuators had to be studied as well.

The technology uses as the main power source explosives. Explosives are a critical and difficult item to have and to maintain:

- I. Manipulation. Not everyone has license to manipulate this kind of material and it should be a specialist the one with the right to move and use them. For this reason the company should contract a specific profile for this purpose or give the formation required, which costs money and time.
- II. Storage. Explosives have to be stored in a determined way. The grade of humidity has to be very precise because if not, the performance of the pyrotechnic charges changes. The temperature also has to be extremely controlled because if it reaches certain high values the charges can even explode, which in Spain can be quite common especially during the summer.
- III. Protection. To protect the storeroom against thieves or people which could use this material for bad purposes, the explosives have to be guarded twenty-four hours a day and three-hundred and sixty-five days a year. This involves a lot of money for the company.
- IV. Security. Not only are easy to explode with high temperatures or any spark, but there are also dangerous to the ones who breath the particles from the explosion that hang on the air. For this reason, every time that one of these tests is carried out, a specific time is needed to evacuate these harmful particles. This means time and maybe an upgrade for the ventilation system.

Other problem with pyrotechnic actuators is the difficulties to control the output they give. It doesn't matter that they are able to give high speeds, accelerations and forces that if you cannot control them, they are useless.

This uncontrolled situation is the main disadvantage of this technology and is due to the way the energy from the explosion is transmitted to the cylinder. Once the explosion takes place, the energy is transferred to the cylinder by means of a pressure wave. This pressure wave hits the cylinder base (pushing it forwards), rebounds, goes to the end of the cylinder housing, and rebounds again backwards, hitting the cylinder base; and does it again and again until the pressure wave loses its energy. The problem with this way to transmit the energy is that it's almost impossible to predict and control the behavior of the actuator, making it not appropriate for these needs.

3.2.5-Conclusion and selection of the adequate technology

The first part of this thesis consists on the selection of the most adequate technology from the available at the market. Above is explained the main advantages and disadvantages of these technologies. However, for these specific purposes, some of them are more important than others.

Electric actuators are the ones with more disadvantages for this application. The low speeds and power obtained with this technology are the main reason for which it has to be discarded. As explained before, for the crash tests high specifications are required such as accelerations, speeds and power; which are in most ways correlated.

However, other characteristics such as the difficulty to resist overloads or blockages make them unsecure and fragile for this case. For these reasons the electric technology has to be totally discarded.

The second technology with more disadvantages for these needs is the pyrotechnical. The problems associated to the manipulation of explosives such as maintenance, surveillance and security, make them difficult to use and despite of using a simple actuation system, they are expensive altogether.

To continue, this technology is able to reach high specifications, however is almost impossible to control it in an accurate way due to the pressure wave in charge of transmitting the energy. As a reminder, this pressure wave rebounds from one side to the opposite of the cylinder housing resulting on the cylinder giving uncontrolled movement impulses. For these reasons, the pyrotechnic technology is also discarded.

Finally we have just the hydraulic and pneumatic technologies left. Both of them are capable of reaching high speeds, accelerations and forces in a controlled way. However, there are some characteristics that make the pneumatic technology better than the hydraulic for these specific purposes. The main ones are explained below:

- I. Hydraulic actuators use fast valves to control the oil flow and therefore the cylinder movement. For some specific tests and regulations, these valves are not able to cope with the flow needed due to the high speeds or accelerations required.
- II. The necessity of storing the oil makes the use of a reservoir and piping lines mandatory for the hydraulic technology, adding weight and complexity to the system. On the other side, pneumatic actuators are more independent due to the absence of a fluid circuit and due to the possibility of releasing the air to the atmosphere. However, the pneumatic technology needs a circuit for the hydraulic brake, but much smaller and compact than the one used to drive a cylinder.

In conclusion, the pneumatic technology should be selected over the hydraulic one due to the advantages listed above that makes this technology more adequate for the requirements.

3.3-Worst case determination

To define the specifications required for the actuator, first of all the worst case between the possible crash tests that can be carried out has to be selected. As explained before, there are two types of side crash tests: moving deformable barrier side impact test and pole side impact test.

These two tests are quite different and it's difficult to understand which of these two would be more critical in order to define the actuator specifications. The main reasons are listed below:

- I. The moving deformable barrier is a heavy carriage launched with a high speed to the lateral of the tested car; however this barrier is made out of honeycomb material which absorbs part of the initial energy.
- II. The pole side test is carried out with a much lower speed, but it's against a rigid pole (without honeycomb material to absorb energy) and the hit is much more critical due to the small area that receives the direct impact (the pole diameter is usually 254mm).

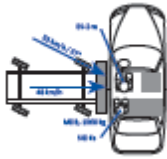
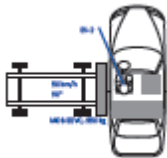
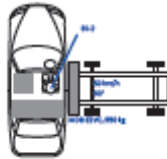
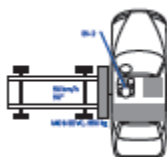
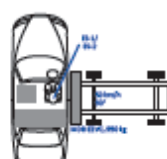
For these reasons, it cannot be compared the severity or the criticality of these two types of tests with just the specifications, it can only be done through a comparison of the results of both tests for the same car model.

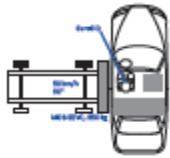
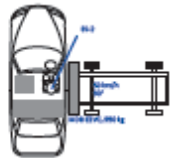
First of all it will selected between all the rules, regulations and private assessment programs the most critical moving deformable barrier and pole tests. To do this, a small study focused on the kinetic energy just before the crash is needed.

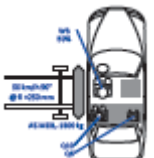
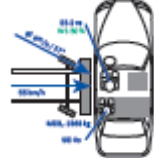
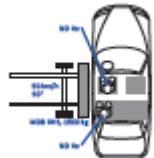
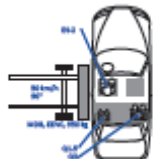
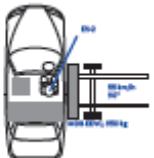
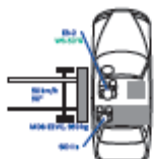
The information from tables have been taken from the several rules, regulations and private assessment programs (*Annexes I and II*).

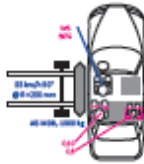
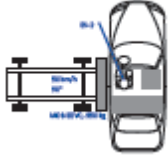
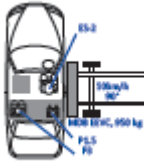
3.3.1-Moving deformable barrier worst case

In the following tables are summarized all the moving deformable barrier crash tests from rules, regulations and private assessment programs worldwide with the information about the carriage weight and initial speed in order to calculate the initial kinetic energy of the system. The speed taken is in the 'Y' component, which will be the one that defines the actuator characteristics.

Rules and Regulations	Country	Diagram	Speed	Carriage Mass
FMVSS 214	U.S.A. 		$V_y=48$ km/h	M=1368 kg
UN R95	Europe 		$V_y=50$ km/h	M=950 kg
Art. 18 & Art. 24	Japan 		$V_y=50$ km/h	M=950 kg
GB 20071-2006	China 		$V_y=50$ km/h	M=950 kg
AIS-099/F	India 		$V_y=50$ km/h	M=950 kg

KMVSS 102	South Korea 		$V_y=50$ km/h	M=950 kg
ADR 72/00	Australia 		$V_y=50$ km/h	M=950 kg

NCAP Program	Country	Diagram	Speed	Carriage Mass
EuroNCAP	Europe 		$V_y=50$ km/h	M=1300 kg
U.S. NCAP	U.S.A. 		$V_y=55$ km/h	M=1368 kg
IIHS	U.S.A. 		$V_y=50$ km/h	M=1500 kg
Latin NCAP	Latin America & Caribbean		$V_y=50$ km/h	M=950 kg
JNCAP	Japan 		$V_y=55$ km/h	M=950 kg
C-NCAP	China 		$V_y=50$ km/h	M=950 kg

KNCAP	South Korea 		$V_y=55 \text{ km/h}$	$M=1300 \text{ kg}$
ASEAN NCAP	Southeast Asia	 For 3,4 or 5 stars: UN R95	UN R95 $V_y=50 \text{ km/h}$	UN R95 $M=950 \text{ kg}$
ANCAP	Australia 		$V_y=50 \text{ km/h}$	$M=950 \text{ kg}$

At this point, there are two tests that could be the most critical ones. Those are the U.S. NCAP and the IIHS, and to see which one is the worst case, the initial kinetic energy of the system will be calculated, which corresponds to the carriage energy:

U.S.NCAP

$$M= 1368 \text{ Kg}$$

$$V_y=55 \text{ Km/h}=15'28 \text{ m/s}$$

$$E_K = \frac{1}{2} \cdot M \cdot V_y^2$$

$$E_k=159'7 \text{ KJ}$$

IIHS

$$M= 1500 \text{ Kg}$$

$$V_y=50 \text{ Km/h}=13'89 \text{ m/s}$$

$$E_K = \frac{1}{2} \cdot M \cdot V_y^2$$

$$E_k=144'7 \text{ KJ}$$

It could seem that the moving deformable barrier worst case test selection is as easy as taking the one with the highest initial kinetic energy. However, the difference is just 15 KJ, which is almost negligible for this kind of trials.

For this reason, a more detailed analysis of both tests is needed in order to understand which one is the most critical one.

One of the most important characteristics that will define the way in which the vehicle deforms (speeds, accelerations, forces...) and therefore the specifications required for the actuators is the shape and design of the deformable barrier.

U.S.NCAP and IIHS Barriers study

Barriers for U.S.NCAP and IIHS crash tests have several similarities (*Figure 3.11 and 3.12*). The main one is that both are divided into two differentiated sections with two honeycomb materials with different strengths to represent the shape and energy absorption capacity of a real vehicle. The lower honeycomb structure is more rigid with a crush-strength of 1690 ± 103 KPa while the higher structure has a crush-strength of 310 ± 17 KPa.

The other similarity they share is the width of the barrier and the height of the lower honeycomb material.

Information about the barrier's dimensions for the IIHS MDB test can be found on *Annex III and Annex IV*, and the barrier's dimensions for the U.S. NCAP on *Annex V*.

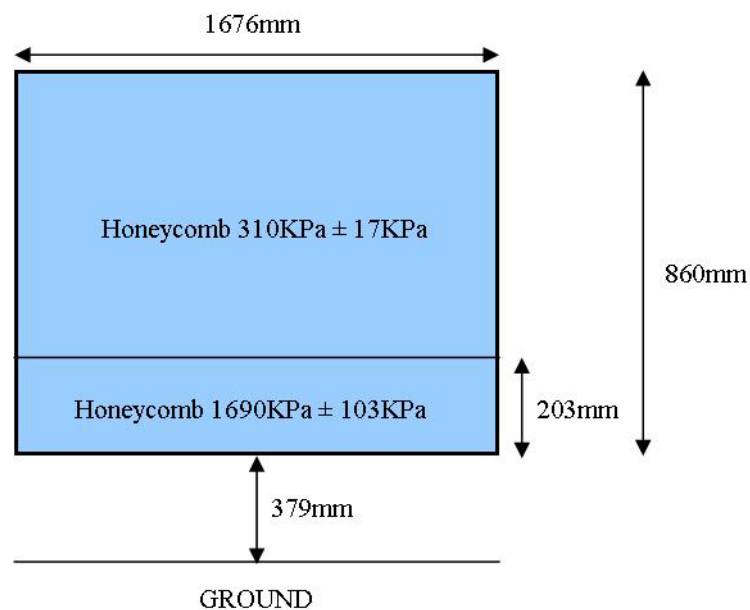


Figure 3.11: IIHS MDB Barrier dimensions

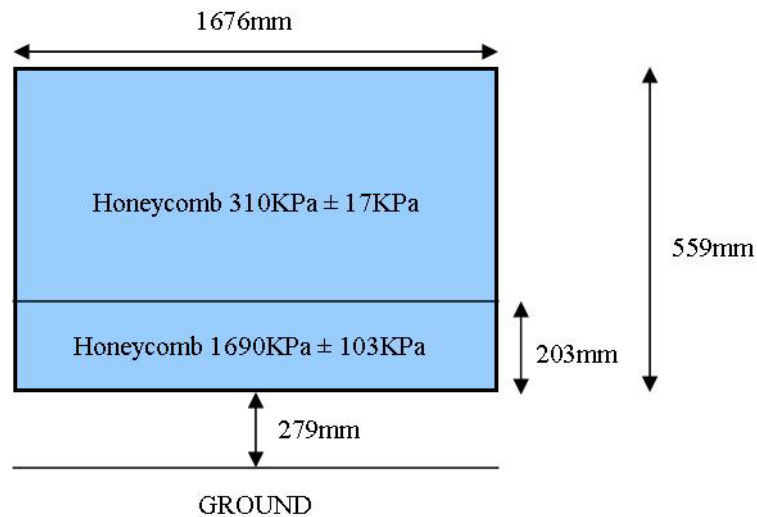


Figure 3.12: U.S. NCAP Barrier dimensions

However, there are two main characteristics that make the difference between both tests:

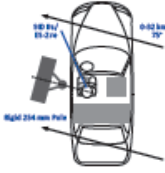
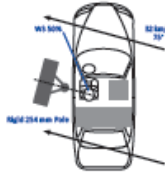
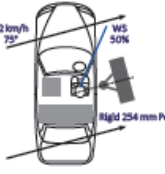
- I. The barrier height. This characteristic is one of the most important ones because it will define the car's side area that will receive direct impact from the barrier. The more separated this area is from the sill, which is a very rigid structural part on the bottom of the door, the more the intrusion and accelerations the door will experiment.
- II. The ground clearance. It is the free space left between the ground and the deformable barrier. This parameter will determine the plane where the lower honeycomb structure from the barrier, which is more rigid, will crush the side of the car. For that reason, the biggest the ground clearance is, the more separated from the car sill the hit will be. And therefore, the side of the car will receive higher accelerations and intrusions.

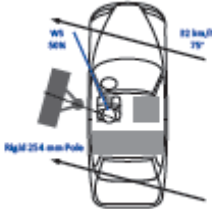
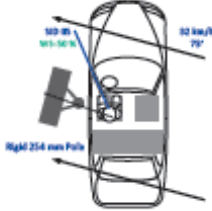
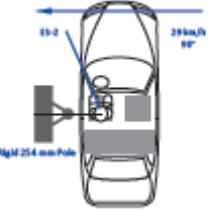
For these two reasons listed above and due to the company's experience with crash tests, it is known that the worst case possible for a moving deformable barrier side test will be the IIHS.

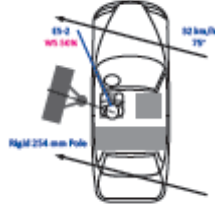
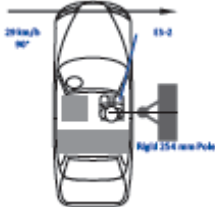
3.3.2-Pole test worst case

As already explained, it is almost impossible to compare both side tests due to the several differences between them. That's why a study about the worst case of the pole

tests is needed and after a comparison will be done thanks to real information about the crashes done at the company's facilities.

Rules and Regulations	Country	Diagram	Speed
FMVSS 208	U.S.A. 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$
UN R135	Europe 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$
ADR 85/00	Australia 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$

NCAP Program	Country	Diagram	Speed
Euro NCAP	Europe 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$
U.S. NCAP	U.S.A. 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$
Latin NCAP	Latin America & Caribbean		$V_y = 29 \text{ Km/h}$

KNCAP	South Korea 		$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$
ANCAP	Australia 		$V_y = 29 \text{ Km/h}$

It can be seen that there are just two main versions of the pole side impact tests along all the rules, regulations and private assessment programs. The first one is launching the car with a 90° angle and 29km/h and the second one is with a 75° angle and 32km/h.

However, for this study it will be taken the 75° Pole Test, as you have to focus on the ‘Y’ component of the velocity and in this case is the highest:

$$V_y = 32 \cdot \cos 15^\circ = 30,9 \text{ Km/h}$$

The value of the weight doesn’t apply in order to get the worst case between the tests, because the structure that carries the kinetic energy is the main vehicle and the pole tests are evaluated for the same vehicle model.

For this reason, and for further studies, it doesn’t matter which 75° Pole test you take between the ones carried out for different rules, regulations and private assessment programs. The specifications obtained to define the actuators required will be similar in all of them due to the same ‘Y’ speed component, which is the direction where the actuator will work.

3.3.3-Conclusion

As explained above, you cannot compare a pole test with a moving barrier test due to the many differences between them. Therefore the worst case of the moving barrier tests and the worst case of the pole tests have been selected and the results of both of them will be compared in order to define the specifications of the actuators.

-Worst case of moving deformable barrier tests: **IIHS**.

-Worst case of pole tests: **75° Pole** side test.

3.4-Definition of the actuator specifications

For this part the results of real sled tests for the IIHS moving deformable barrier and for the 75° Pole test in a real best-in-class family car being developed at the moment.

In this way you get a real representation of the level of specifications required at the moment for the restraint systems development phases in order to dimension the actuators needed.

It should be clarified that after the CAD design and the CAE simulations with complete car, you also need to simulate through CAE tools how the sled test will be. For this purpose, you have to take the main car parts involved and create a simplification of the car that will have similar results as with the complete car. You simulate exactly the same sled model that after will be built in order to do the real sled test; and you also have to represent the segments in which you divide the door.

After all these simulations are done, you carry out the real tests which are the information and data that will be used for the following studies and are based on the sled tests done at the company, being the main focus point of the thesis.

First of all, as the actuators will be mounted on the sled (and therefore will be giving relative speeds, accelerations, etc.) you need to define which values will the main hydraulic cylinder (HYGE) give in order to define which ones will the actuators need to give.

For this purpose, and for further studies, it will be defined as the HYGE values the ones from the driver's seat. The good thing about giving the sled directly the pulse of the driver's seat is that you don't need to have a system to simulate the movement of the seat relative to the sled like is done at the moment with honeycomb material.

The schemes of the actual system for the IIHS MDB test and for the 75° Pole test are shown on *Figures 3.13 and 3.14* respectively. For the IIHS MDB test, segment two is fixed to the sled and therefore has the same parameters' values as it. For the 75° pole test, the sled is oriented to obtain those degrees and segments one and two are fixed together at the time that they don't have relative movement to the sled; for this case just segment three rotates relative to the sled.

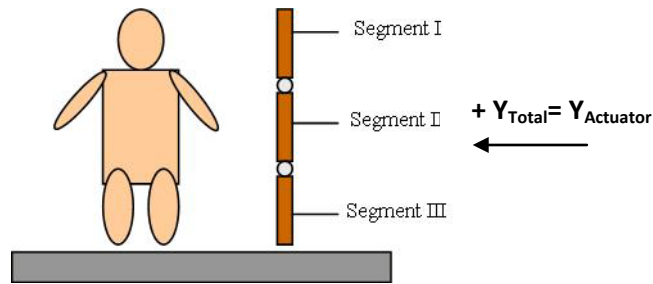


Figure 3.13: MDB sled test scheme

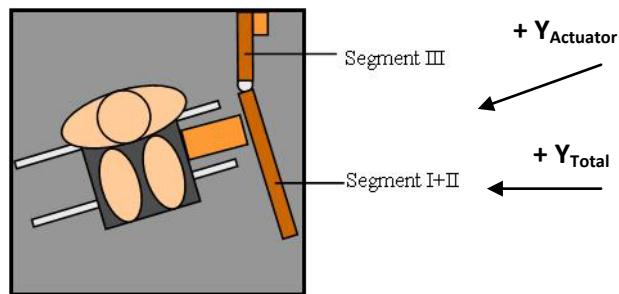


Figure 3.14: 75° Pole sled test scheme

The sensors give information on the global axis (Y_{Total}), and what it's needed is data on the 'Y' axis where the actuator will work (the actuator will act perpendicular to the door; $Y_{Actuator}$). In case of the IIHS MDB test both axis are the same, however for the 75° Pole test you need to project the values through the cosine of 15. As the cosine of 15 is 0.97, it will be considered insignificant to make an important difference. For that reason, it will not be taken into account for further studies, and the information given by the graphics will be directly used for the definition of the actuator's specifications.

The information collected by the sensors cannot be used directly for our purpose because of the misalignment of their measurement axes. This effect occurs with the segments that rotate (one and three for the IIHS and number three for the pole test). The reason is that as long as they start rotating, the referral axes of the accelerometers start to change. In order to obtain accurate data in global axes, data of rotating angle versus time should be known but unfortunately those data were not gathered from the conducted tests. An example of this is shown on *Figure 3.15* for the IIHS MDB test.

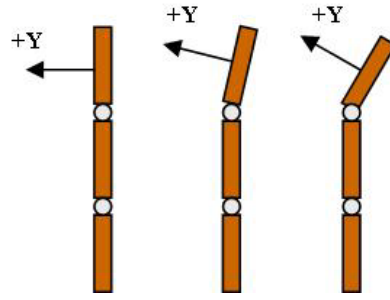


Figure 3.15: Explanation of the axes rotation

However, the good point about this is that the most critical segments are number two for the IIHS MDB test and number one and two (fixed together) for the Pole test. As already explained, these segments are fixed to the sled and the main hydraulic cylinder (HYGE) gives the acceleration pulses of them while the other segments (one and three for the IIHS MDB test and number three for the Pole test) rotate relative to them, having lower accelerations, velocities, jerk and intrusions.

For that reason, the studies will be focused on the parameters' values of segment II for the IIHS MDB test and segment I+II for the 75^o Pole test.

Before proceeding with the data analysis, it has to be said that the values taken by the sensor on segment III in the IIHS MDB Test aren't representative even though its axes are rotating with time. This sensor was broken, but as already said, it doesn't give important information to dimension the actuators.

Now an analysis of the data from the tests will be done to determine the specifications required for the actuators.

3.4.1-Acceleration

The acceleration values of both sled tests simulations filtered by a low-pass filter are given in order to take out the entire signal's noise. The acceleration values are always on the 'Y' axis, which is the axis where the actuator will have to work.

IIHS Moving Deformable Barrier

The values of the total acceleration of the three door segments are shown on *Figure 3.16*. For the next graphics the time unit is [s] and the acceleration units are [m/s²].

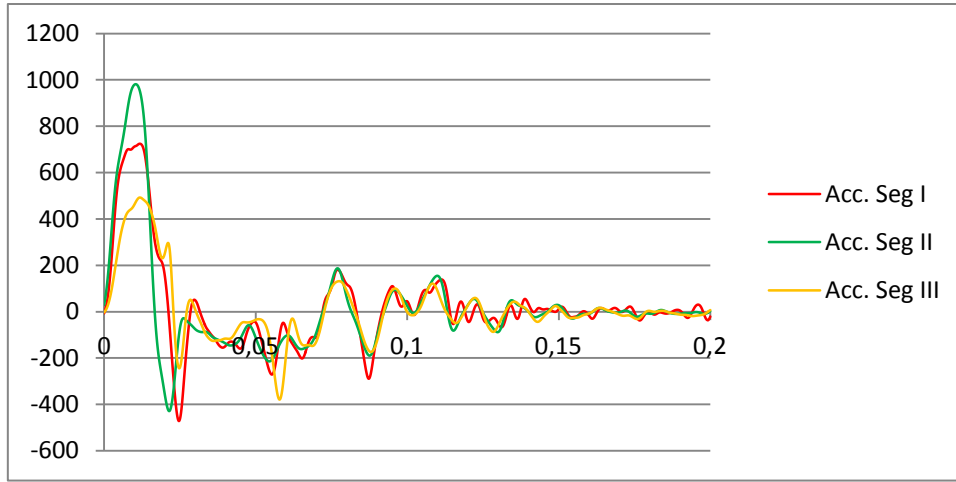


Figure 3.16: Total segments' acceleration from the IIHS MDB test

And the values of the total acceleration of the seat (taken as the sled values) are shown on *Figure 3.17*.

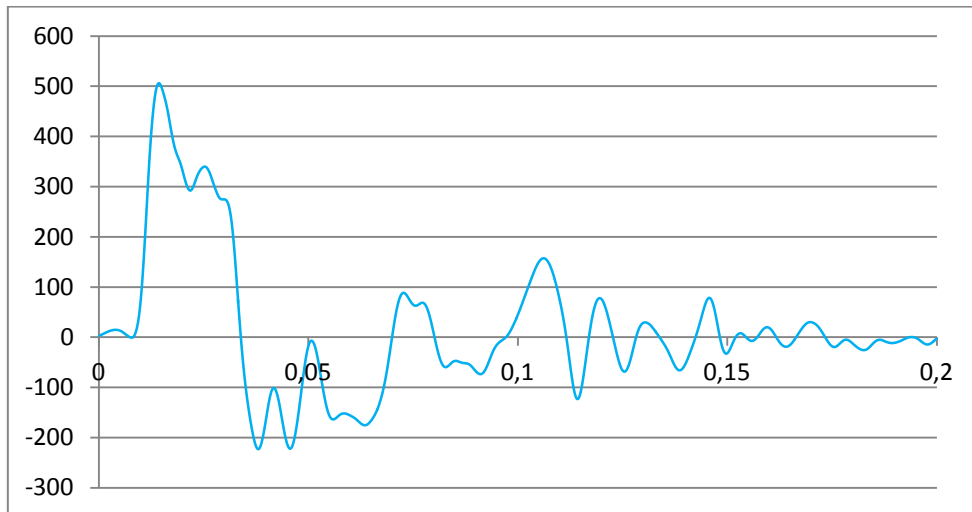


Figure 3.17: Seat's acceleration from the IIHS MDB test

What it's needed to define the actuator's specifications are the door relative values to the sled, which is represented by the seat values (the HYGE gives the sled the acceleration pulse of the driver's seat).

For this reason and in order to obtain the relative acceleration values of the segments to the sled, the following subtraction has to be done:

$$A'_{Seg.i} = A_{Total,i} - A_{Seat}$$

The relative values obtained are shown on *Figure 3.18*.

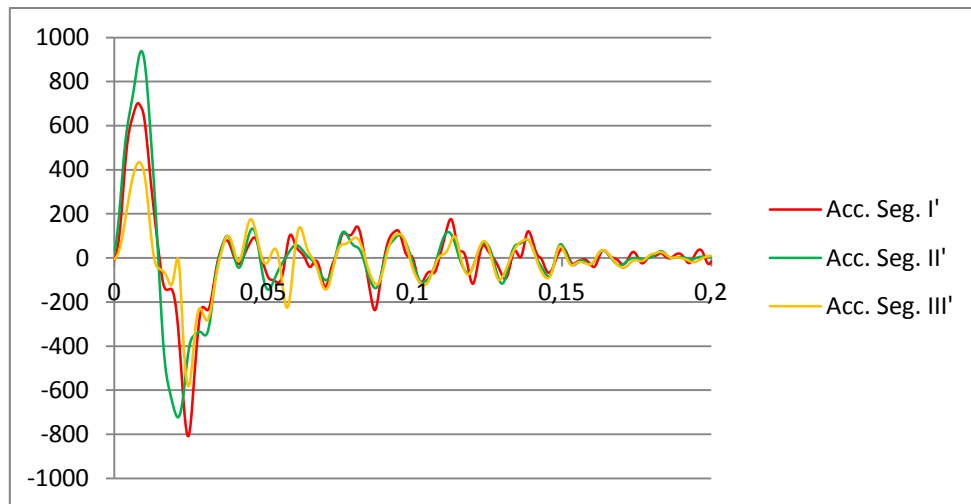


Figure 3.18: Segments' relative accelerations from the IIHS MDB test

It can be seen on the graphic how from a determined time, all the system moves together and therefore the relative accelerations should be zero. However, as explained, information from segments I and III is not very trustful due to their axes rotation.

During the first milliseconds of test you get the highest acceleration peaks. Segment II will have the highest acceleration due to the height and crush strength of the deformable barrier in this area, while segment I will have lower acceleration due to lower crush strength of the barrier than in segment II and finally segment III will have the lowest peak due to the ground clearance of the barrier.

Once it's explained how the relative values are obtained, it is not necessary to do the same for every test and parameter. For further studies, the relative values of the parameters will be used.

75° Pole Test

We usually divide the door into three segments to represent the kinematics and the real movement and deformation. However, for some tests it is preferably to have just two door segments in order to better represent how the door moves during the crash.

For this test, instead of having three segments where two of them have free movement, there are just two segments where just one segment rotates. In the following graphics it can still be seen three segments represented, however, segments one and two are the same as they are fixed one to the other.

The acceleration relative values during the pole tests are represented on *Figure 3.19* and are given in [G].

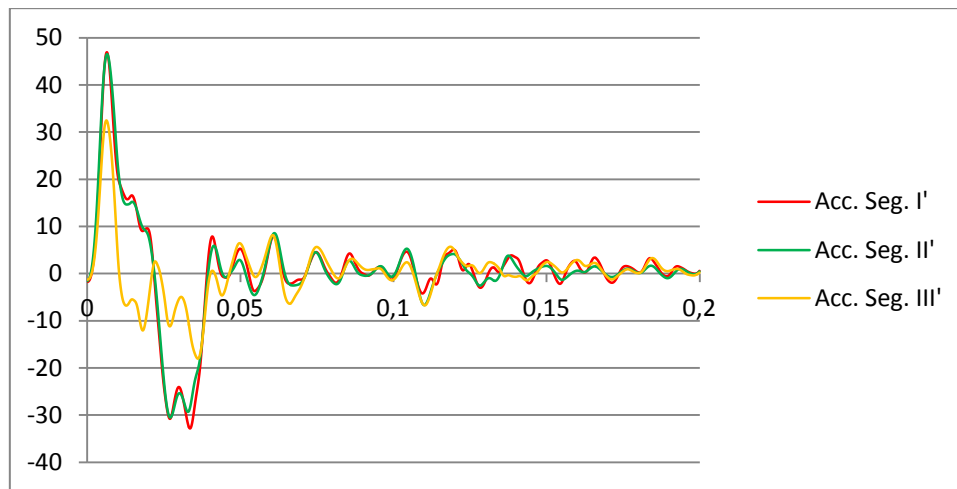


Figure 3.19: Segments' relative accelerations from the 75° Pole test

As said, the values obtained from segment III are not representative due to its axis rotation. Once again, from a determined time the relative acceleration values are zero due to the movement of the system all together.

Conclusion

To conclude, the maximum and the minimum acceleration between both tests will be taken in order to define the maximum and minimum accelerations that the actuators need to be able to give.

	MDB IIHS	75° Pole
Max. Acceleration	96G	47G
Min. Acceleration	-74G	-33G

As it can be seen, the maximum acceleration required for the actuator is 96G, while the maximum brake acceleration is 74G. The minimum acceleration value has been taken from the second segment as well, which is where we have reliable results from the test. However, to take these possible variations into account, a correction factor will be applied later when looking for the optimal actuator. The brake acceleration is easier to reach due to the possibility of attaching a second hydraulic brake one before the other.

3.4.2-Velocity

Now, as done before with the acceleration, in order to study the most demanding of the velocities between the IIHS moving deformable barrier test and the 75° pole one, another small study will be carried out.

First the results obtained on the real tests will be presented and then a conclusion about which is the most restrictive between both lateral tests will be given.

IIHS Moving Deformable Barrier

The total seat velocity is shown on *Figure 3.20*.

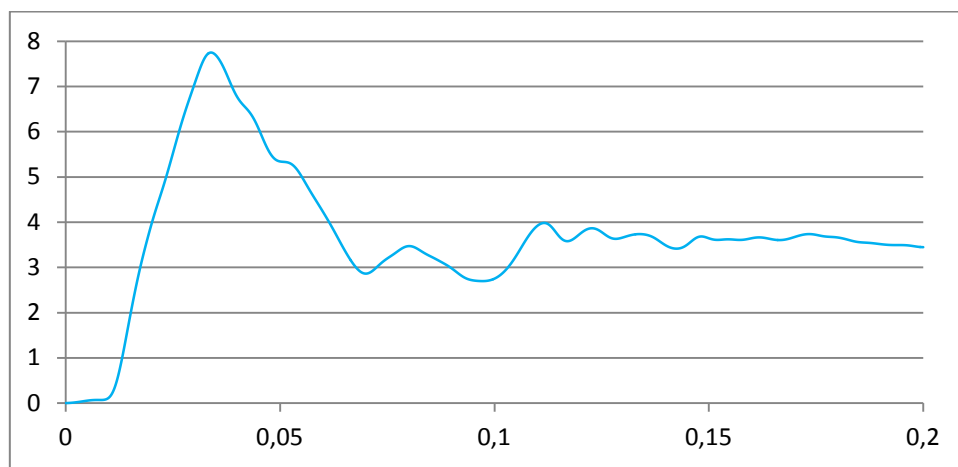


Figure 3.20: Seat's velocity from the IIHS MDB test

The segments' relative velocities are shown on *Figure 3.21*.

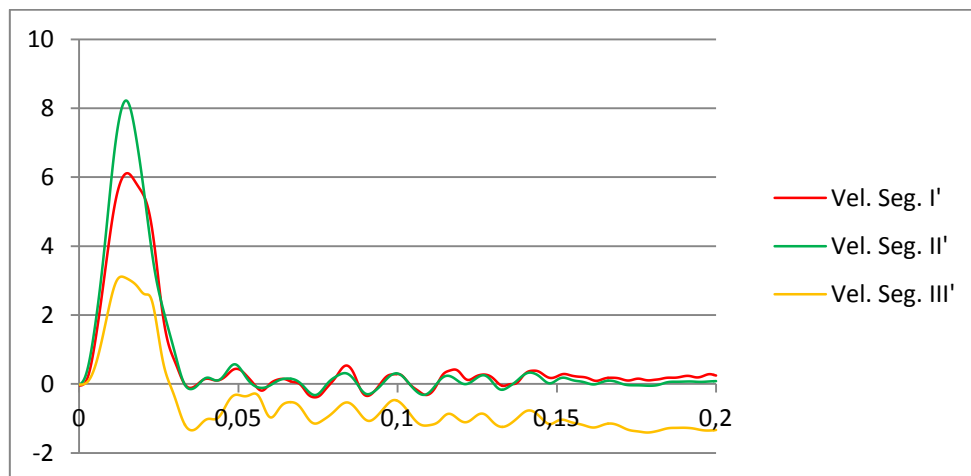


Figure 3.21: Segments' relative velocities from the IIHS MDB test

It can be seen during the first ten milliseconds that the seat velocity is zero. This situation happens in a real crash due to the door's relative movement to the car which is absorbing some initial kinetic energy and is represented on the sled test thanks to the honeycombs deformation.

Once the first milliseconds of crash occurred, the honeycombs are already crushed and the seat doesn't have any movement relative to the door. The door segments and the seat move with the same speed and therefore the relative velocity between all of them is zero as happens from the twentieth millisecond approximately on *Figure 3.19*.

It has to be cleared that from the twentieth millisecond there are still waves due to resonance and vibrations that the sensors take but is just noise. And of course, as already explained the accelerometer on segment I and III doesn't give real information on the global 'Y' axis.

75º Pole Test

The segments' relative velocity values are shown on *Figure 3.22*. Don't forget that segment one and two are fixed together for the simulations used.

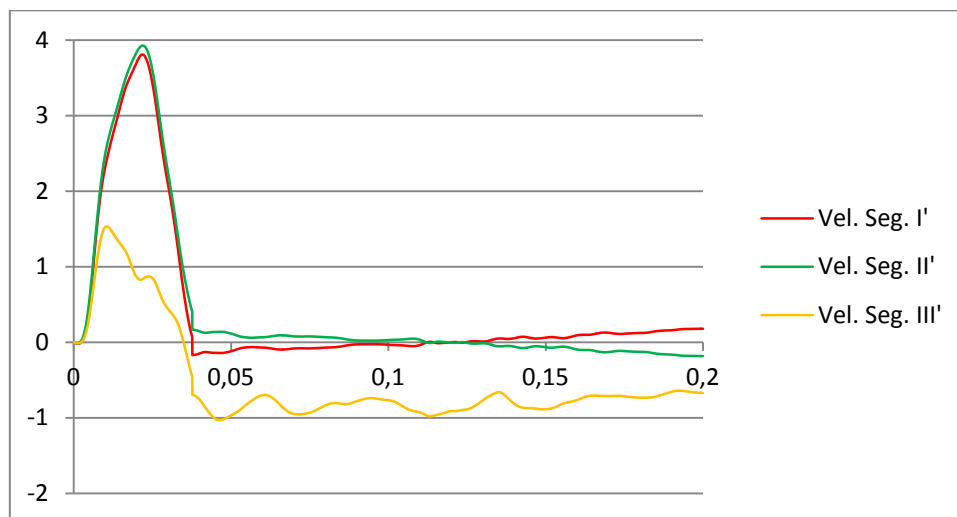


Figure 3.22: Segments' relative velocities from the 75º Pole test

It can be seen once again that from a specific time the relative velocities of the segments are zero because all the honeycombs involved are completely crushed and the system moves all together.

The signal from segment III is again useless due to its axes rotation along the test.

Conclusion

To conclude, the maximum values of the segments' relative velocities for both side tests in order will be taken to compare them.

	MDB IIHS	75º Pole Test
Maximum Velocity	8,22 m/s	3,93 m/s

So the maximum velocity that the actuator should be able to give is 8,22 m/s, which is 29,59 Km/h.

3.4.3-Intrusion

What is needed to represent with the stroke of the actuator is what it's commonly called 'closing gap'. The 'closing gap' is the available space between the seat and the door, and it is very important because it will determine the way in which several airbags deploy and expand, and therefore the performance of the restraint systems reducing the injuries taken by the dummy channels.

The crash channels give information about the total displacement of the segments. For further studies both 'closing gap' and intrusion expressions will be used equally.

IIHS Moving Deformable Barrier

The car's seat total displacement for this test is shown on *Figure 3.23*. For the following graphics the time is given in [s] and the displacement in [m].

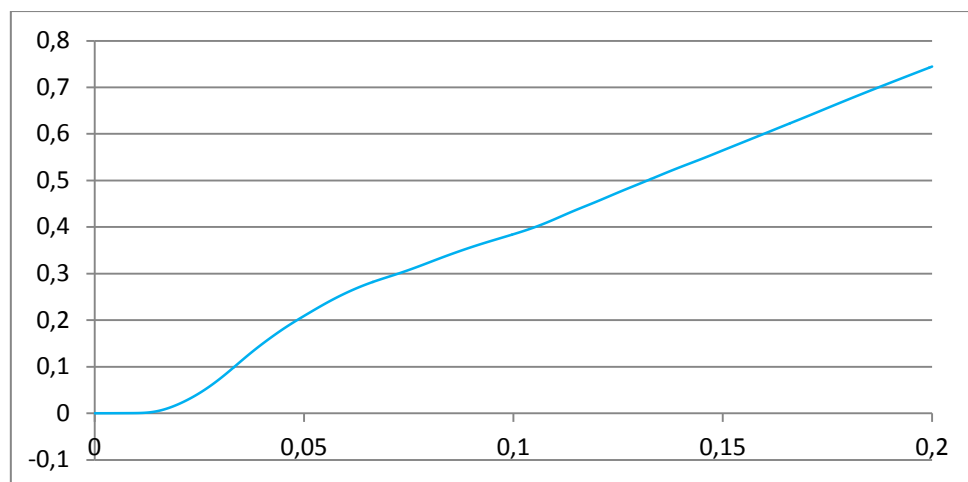


Figure 3.23: Seat's total displacement from the IIHS MDB test

And the door segments total displacement also for this test is as shows *Figure 3.24*

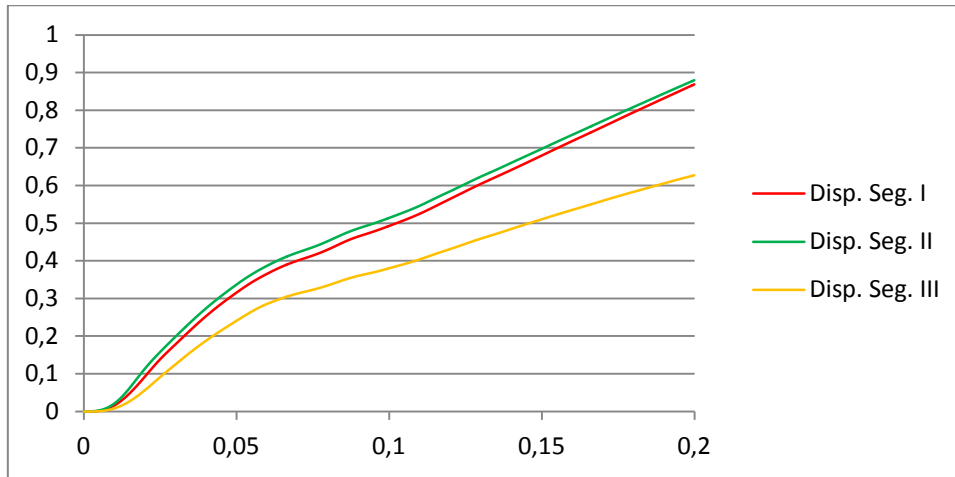


Figure 3.24: Segments' total displacement from the IIHS MDB test

From this last graphic, it has to be said that once all the door segments have reached their rack position, their displacement curves have to move in parallel. But once again the accelerometers from segments I and III give unreal information from the global 'Y' axis displacements.

However, the total displacements don't give us useful information to determine the maximum stroke of the actuator's cylinder.

In order to obtain the maximum stroke of the actuator, we need data about the relative door deformation. For that purpose we will subtract the segments' displacement values minus the seat's displacement. Then I will take the maximum value so I can define the stroke needed for the actuator.

$$Intrusion_{seg.i} = Displacement_{Seat} - Displacement_{Seg.i}$$

Doing the subtraction, the door segments' intrusions are as shows *Figure 3.25*.

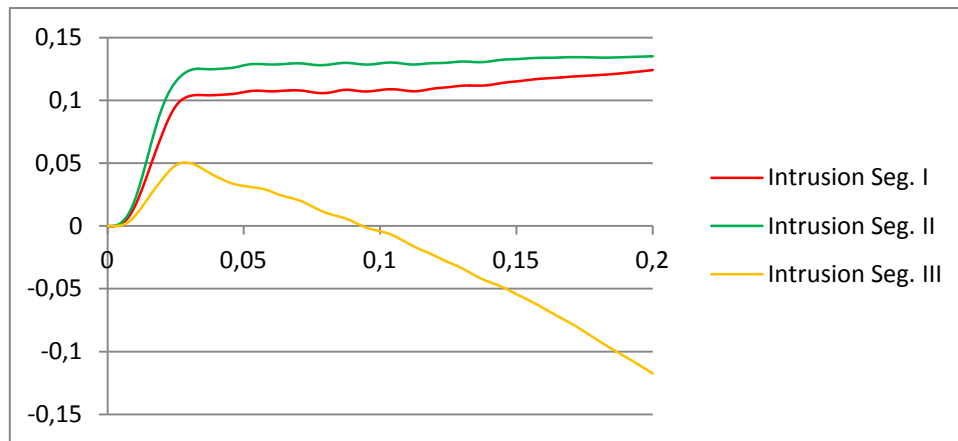


Figure 3.25: Segments' intrusion from the IIHS MDB test

As said, the values given by the sensor on segments I and III are useless for our purposes. Approximately from second twenty-five, all segments are fixed on their rack position and therefore the intrusion should remain constant (curves should go in parallel).

The maximum intrusion will be reached on segment II, which is the one that receives the highest acceleration.

75° Pole Test

The door segments' intrusions for the 75° Pole Test are shown on *Figure 3.26*. Again the door segments one and two are the same for our study case. The displacement is given in [m] and the time in [s].

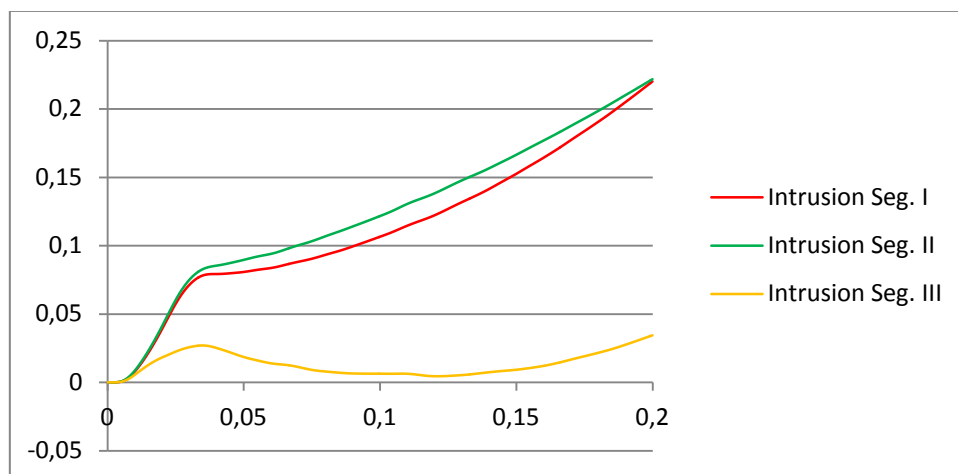


Figure 3.26: Segments' intrusion from the 75° Pole test

As already explained several times, the sensor on segment III doesn't give real information about the displacement on the global 'Y' axis. That's why its curve is so strange. However, the segment with the biggest intrusion will be the one formed by segment I and II, which is the one that receives the highest acceleration.

Conclusion

The following table summarizes the maximum intrusions in both side tests. The biggest value will be taken in order to dimension our actuator.

	MDB IIHS	75° Pole Test
Max. Door Intrusion	135,15 mm	221,79 mm

In this case the 75° Pole test is more aggressive than the IIHS MDB even though it has a lower initial speed.

3.4.4-Jerk

Maybe this parameter is the most uncommon of the ones studied on this thesis; however it is really important for these testing purposes. The jerk, as explained on the introduction, is the derivative of the acceleration and is a measure of the time needed to reach a specific acceleration.

The jerk values obtained from the sled tests have been filtered by a low-pass filter in order to remove the noise and to get clearer information for the study. The values are given in [G/ms] and time in [s].

IIHS Moving Deformable Barrier

Once again and in order to obtain the values that the on-board actuators need to give, the actuator's jerk will be calculated as the subtraction of the total segment's jerk minus the jerk value of the sled, which in this case is represented by the seat values.

In this case I have just taken the information from segment II due to the useless information that segments' sensors I and III give for the study and because it will be the one reaching the highest values.

Segment II relative jerk value is represented on the *Figure 3.27*.

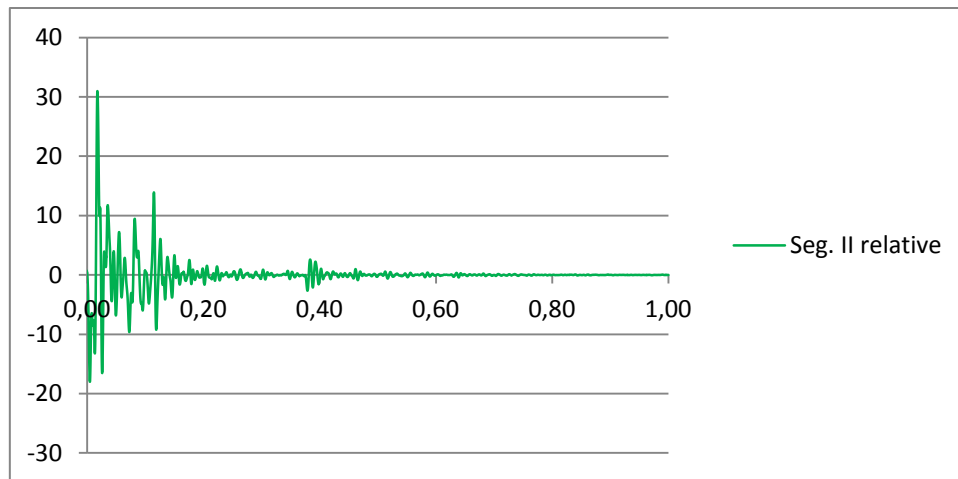


Figure 3.27: Jerk relative values from segment II in the IIHS MDB test

In order to see with more detail what happens during the most important period of time, on *Figure 3.28* there is an enlargement.

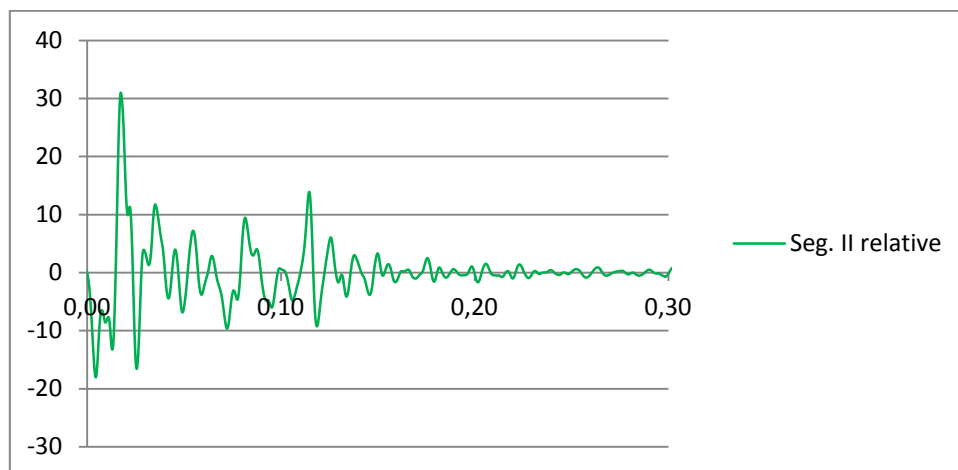


Figure 3.28: Enlargement of the jerk relative values from segment II in the IIHS test.

75º Pole Test

Segments I and II relative jerk value is obtained like in the last point and the results are shown on *Figure 3.29*. As both segments are fixed together, I will just represent one curve and again, I have eliminated curves from segment III which is useless for this study.

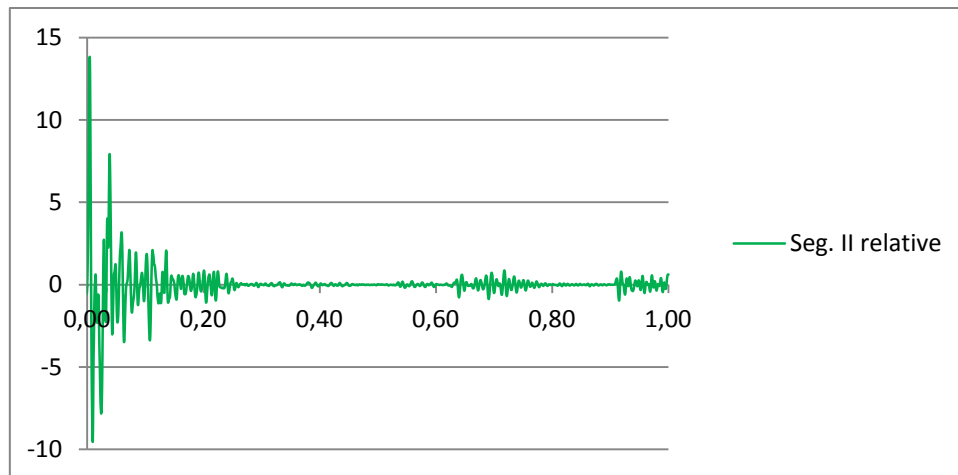


Figure 3.29: Jerk relative values from segment I+II in the 75º Pole test

An enlargement of the main interesting time period is given in the following *Figure 3.30*.

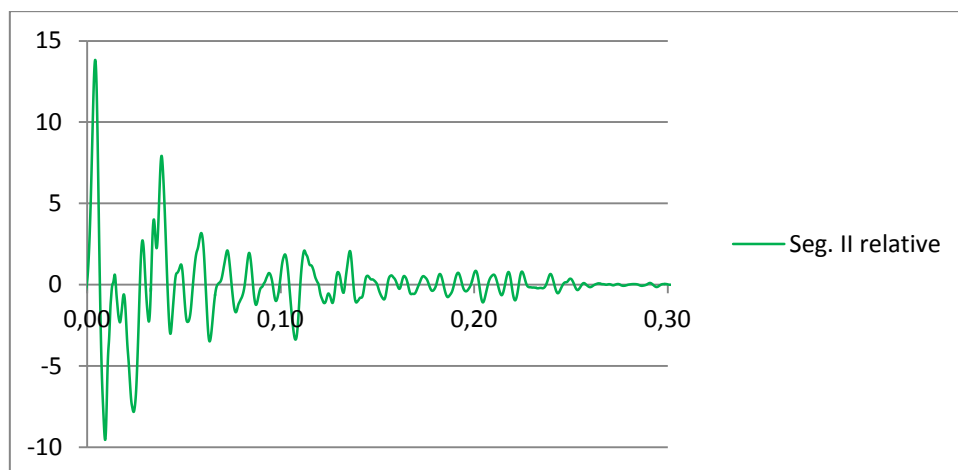


Figure 3.30: Enlargement of the jerk relative values of segments I+II in the 75 Pole test

Conclusion

To conclude, below are summarized the maximum and minimum jerk values for both side tests in order to determine this requirement for the possible actuator.

	IIHS MDB	75º Pole Test
Maximum Jerk	31 G/ms	14 G/ms

3.4.5-Force

The crash results don't give information about the forces involved. To calculate the maximum force that the actuator has to be able to reach, the second Newton's Law will be applied:

$$F = M \cdot A$$

In this case, as the actuator will be fixed on the sled, there is an inertial force that has to be overtaken. This inertial force is the result of the segment's mass trying to stay on its initial state (*Figure 3.31*).

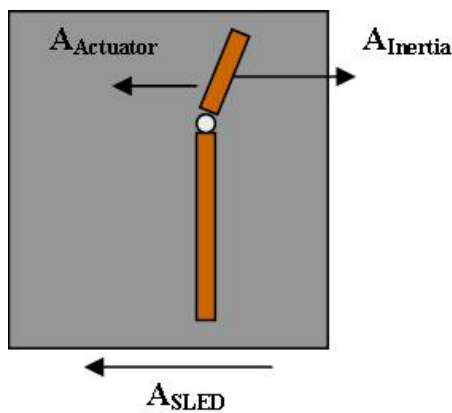


Figure 3.31: Sled's accelerations scheme

As the sled accelerates, the door segment tries to stay where it was at the beginning of the test. For that reason, it will have the same acceleration value as the sled but in the opposite way.

In order to give the door segment the movement needed, the actuator has to be able to overtake the inertial force and give an extra force to reach the acceleration values required.

The inertial force that the actuator has to overtake is:

$$F_{Inertia} = M_{Segment} \cdot A_{Inertia}$$

The force related to the acceleration that the actuator has to give is:

$$F_{Extra} = M_{Segment} \cdot A_{Actuator}$$

In total, the force that the actuator has to be able to transmit is the addition of both forces from above:

$$F_{Total} = M_{Segment} \cdot (A_{Inertia} + A_{Actuator})$$

The $A_{Inertia}$ has the same value as the A_{Sled} , and therefore as the A_{Seat} . In order to find the maximum force value of the actuator, you need to look for the maximum value of the acceleration addition in brackets.

The actuator will apply its force to a door segment and the segment's weight is estimated to be approximately 35Kg.

IIHS Moving Deformable Barrier

As explained above, the maximum value of the following expression is needed:

$$(A_{Seat} + A_{Actuator})$$

The graphic that represent this addition for the IIHS side test is shown on the *Figure 3.32*. Acceleration is given in $[m/s^2]$, while time is in $[s]$.

Once again this maximum occurs on the second segment, which is the one with the highest relative acceleration and knowing that the acceleration peaks happen at the same moment makes sense that this is the segment that need the highest force from the actuator.

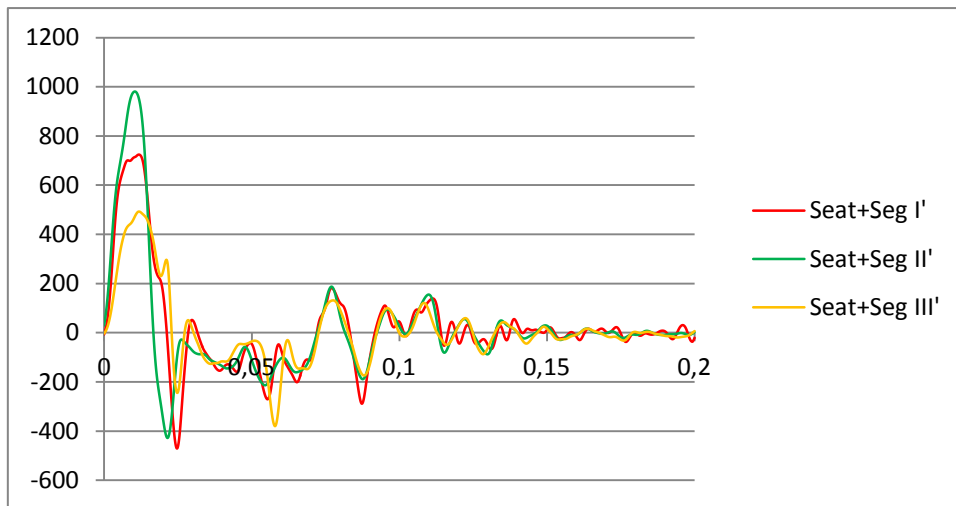


Figure 3.32: Addition of the segments' and the seat's accelerations for the IIHS test

75° Pole Test

In this case, the values of that addition for which the maximum value is needed, are represented on the *Figure 3.33*. Acceleration is given in [G] and time is shown in [s].

As happened with the IIHS MDB test, segments I and II (fixed together) have the highest relative acceleration, and knowing that the acceleration peaks occur at the same time, it is normal that these segments have the highest value of the addition between them and the seat acceleration.

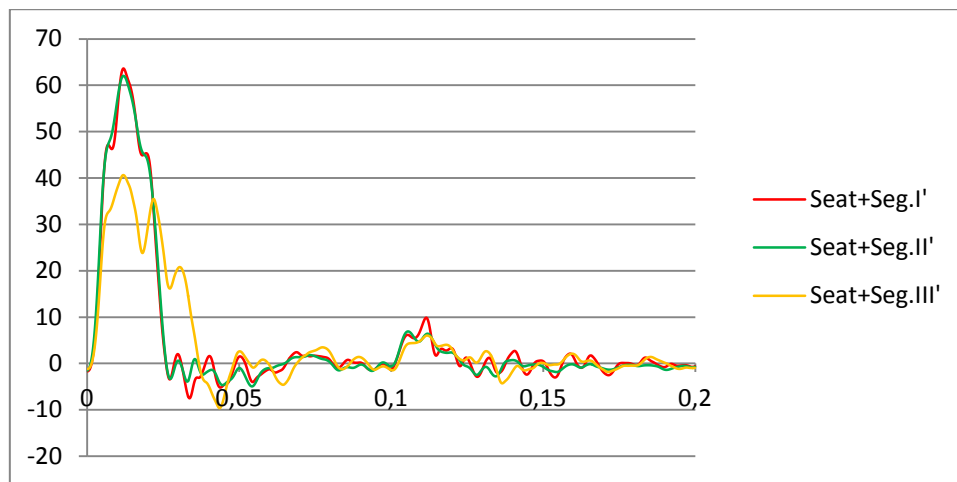


Figure 3.33: Addition of the segments' and the seat's accelerations for the 75 Pole test

Conclusion

In order to define the maximum and minimum forces that the actuator has to be able to give, the next table summarizes the maximum and minimum values of the acceleration needed to calculate those forces:

	IIHS MDB	75° Pole Test
Maximum Acceleration	981,204 m/s ²	624,306 m/s ²
Minimum Acceleration	-471,225 m/s ²	-94,586 m/s ²

The maximum acceleration will be used to calculate the maximum force that the actuator has to give working at compression. In this case, the IIHS Moving Deformable Barrier has the highest acceleration value.

$$F_{Actuator}^{Max} = 35 \cdot 982 = 34370 [N] = \mathbf{34,37 [KN]}$$

The minimum acceleration will be used to calculate the maximum force that the actuator has to give working at traction. Again, the IIHS MDB Test has the minimum value.

$$F_{Actuator}^{Min} = 35 \cdot 472 = 16520 [N] = \mathbf{16,52 [KN]}$$

3.4.6-Summary of the actuator's specifications

Once an individual study of each of the important parameters has been carried out to define the actuator needed, all of them will be summarized in a table. It has to be cleared that some of these values calculated are approximations. For example, the forces have been obtained without adding the forces involved due to the friction of the hinges. In order to take into account these calculation errors and to have more working margin for the future, an extra 20% increase approximately has been added to each of the parameters as a correction factor.

	Value	Units
Max. Acceleration	115	[G]
Min. Acceleration	-88	[G]
Max. Velocity	10	[m/s]
Max. Stroke	266	[mm]
Max. Jerk	37	[G/ms]
Max. Compression Force	41	[KN]
Max. Traction Force	20	[KN]

In this way, a more realistic approximation is obtained and when looking for an actuator supplier it's important that the actuator limits are not too close to the working requirements in order to have some extra margin.

3.5-Study of the HYGE's requirements

Now that the characteristics for the new on-board actuator are defined, it's also necessary to study whether our actual system, the HYGE, can work under the values that it has to transfer to the sled. In this case those values are the ones of the driver's seat, as already done for previous studies.

For this study it's also needed to evaluate both side tests: the IIHS Moving Deformable Barrier and the 75º Pole Test; in order to define the worst case under which the HYGE could need to work.

3.5.1-Acceleration

The acceleration values of the seat for the IIHS Moving Deformable Barrier Side Test and for the 75º Pole Test are summarized in the *Figure 3.34*.

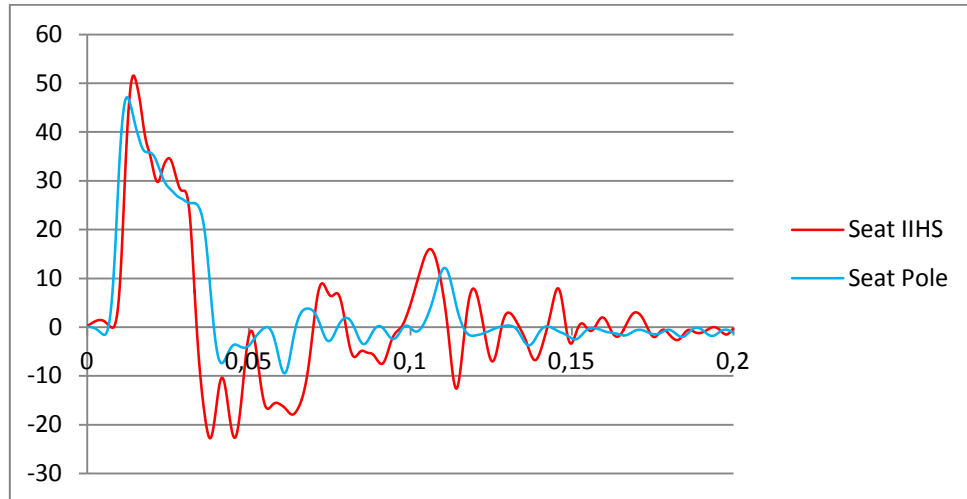


Figure 3.34: Comparison between seat's accelerations from IIHS and Pole tests

In the following table are the approximations of the maximum and minimum acceleration values for both lateral tests:

	IIHS MDB	75º Pole Test
HYGE Max. Acceleration	52G	47G
HYGE Min. Acceleration	-23G	-10G

3.5.2-Velocity

The *Figure 3.35* shows the seats' velocities for both lateral tests.

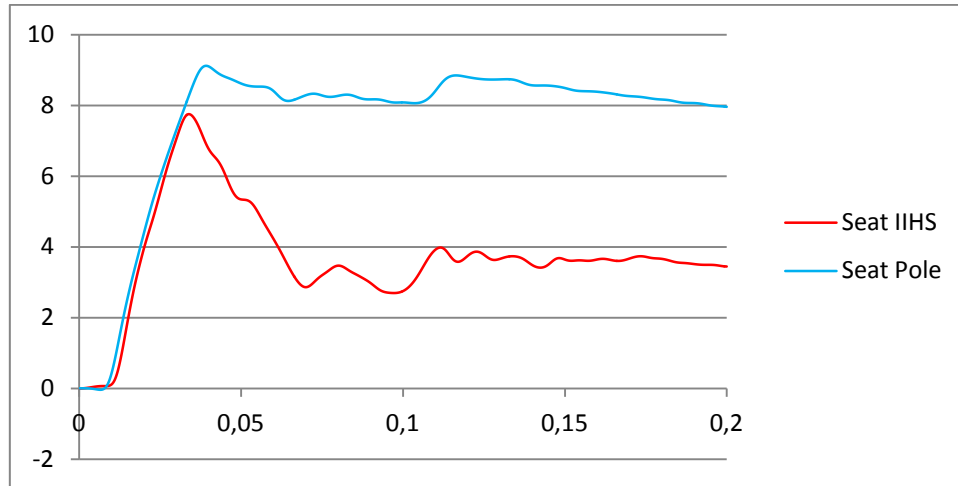


Figure 3.35: Comparison between seat's velocities from IIHS and Pole tests

And the velocity maximum values are:

	IIHS MDB	75º Pole Test
HYGE Max. Velocity	7,75 [m/s]	9,12 [m/s]

3.5.3-Intrusion

This parameter doesn't affect to the HYGE specifications because this cylinder is used to give just accelerations and velocities. It doesn't need to be able to reproduce deformations of any vehicle's part.

However it has to be able to reach the maximum displacement of the driver's seat. But as these data is from real tests, it's already known that it can reach that displacement values.

Just for information, the HYGE's maximum cylinder stroke is 1650 [mm].

3.5.4-Jerk

The *Figure 3.36* shows the seat's jerk for the IIHS Moving Deformable Barrier Side Test and for the 75° Pole test.

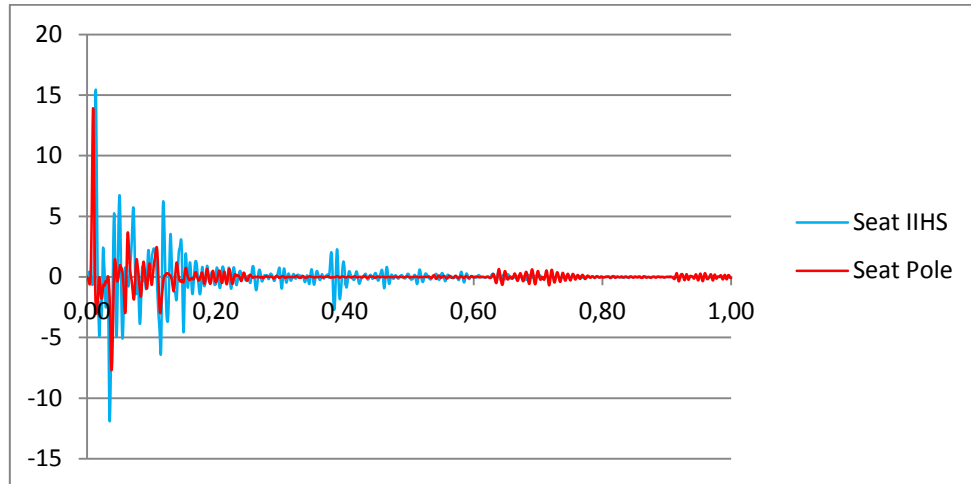


Figure 3.36: Comparison between seat's jerk from IIHS and Pole tests

On the following *Figure 3.37* there is an enlargement to see the most important area of the graphic.

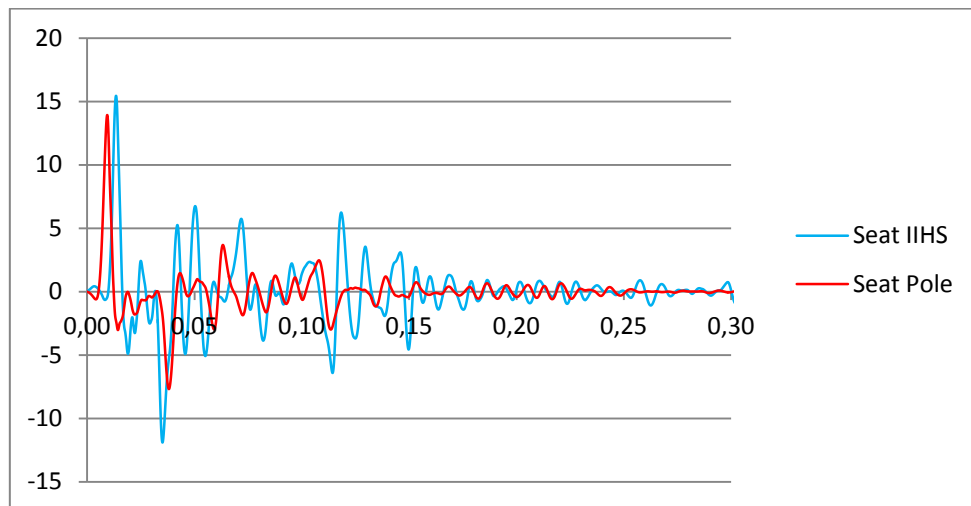


Figure 3.37: Enlargement of the seat's jerk from IIHS and Pole tests

The following table summarizes the maximum jerk value that the jerk has to reach.

	IIHS MDB	75° Pole
MAX. Jerk HYGE	15 [G/ms]	14 [G/ms]

3.5.5-Force

The calculation of the maximum force that the HYGE has to give is probably the most important parameter involved in this study. The reason for this is the fact that the maximum acceleration that our hydraulic cylinder has to give is being reduced, but the weight is being increased considerably. So in conclusion it's not known if the HYGE will be able to put up with it.

To proceed with this study, first of all the elements involved and their weights are needed in order to sum them all and to calculate the maximum force.

At the moment, there are two individual sleds which can be joined together when needed, for example for a frontal crash with both front and rear seats. For the lateral sled tests it's always used just one sled due to the constant vehicle width even when a crash with two seat lines is done.

However, in order to add an actuator on the sled for lateral tests, there is no available space just on a sled due to all the components fixed: seats, dummies, door... For that reason and in order to have enough space to fix the actuator, you need to carry out the lateral tests with two sleds, the front one for the actuators, and the rear for the elements involved in the crash (*Figure 3.38*).

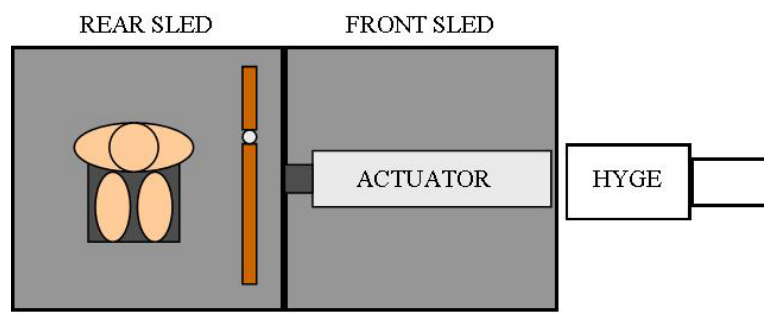


Figure 3.38: Scheme of the possible configuration

The total mass on the rear sled involves: steel guides, interface sheet, dummies, cameras, wings, seats, etc.

The distribution of weights involved is as follows:

- Frontal sled: 600 Kg
- Total mass on frontal sled: 100 Kg (one actuator) or 200 Kg (two actuators)
- Rear sled: 560 Kg
- Total mass on rear sled: 700 Kg
- TOTAL:** Approximately 2000 Kg

And once again, thanks to the second Newton's law:

$$F_{HYGE}^{Max} = M_{Total} \cdot A_{HYGE}^{Max}$$

Replacing the terms from the equation by the parameters' values:

$$F_{HYGE}^{Max} = 2000 \cdot (52 \cdot 9,81) = 1020,24 [KN]$$

Knowing that the HYGE Maximum Force limit is 2000 KN, there is a lot of working margin yet.

3.5.6-Sled's dimensions

In order to fix the actuators on the sled, you also need to know whether these cylinders fit or not. The company's actual sled dimensions are shown on *Figure 3.39*.

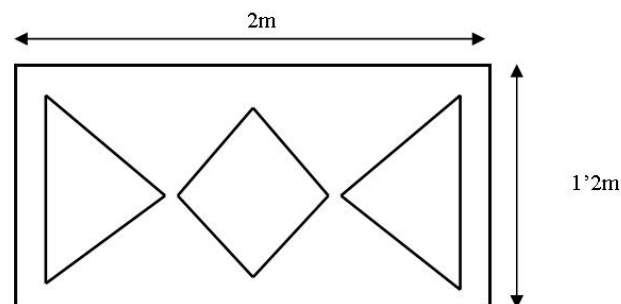


Figure 3.39: Sled's dimensions

The following table summarizes the sled's and actuator's dimensions so a conclusion can be obtained.

	Length	Width
SLED	2000 [mm]	1200 [mm]
ACTUATOR	1800 [mm]	280 [mm]

Therefore there is enough space for one actuator on the sled and even for a second one. The minimum distance between two intrusion areas is 225 [mm], so the total width for two actuators would be 785 [mm] (280+280+225).

3.5.7-Summary of the HYGE's requirements

Once the maximum values that the HYGE will need to reach have been determined, they will be summarized into a table, comparing them with the HYGE design values. As done with the actuator's characteristics, an increase of around 20% will be given for the working values.

The color scheme works as follows:

-[Green]: everything in order.

-[Orange]: with some limit problems that could be solved.

-[Red]: impossible to work with those values.

HYGE	Working Value	Design limit	OK?
Max. Acceleration	62 [G]	120 [G]	
Min. Acceleration	-28 [G]	-45 [G]	
Max. Velocity	11 [m/s]	22,5 [m/s]	
Max. Jerk	15 [G/ms]	12 [G/ms]	
Max. Force	1230 [KN]	2000 [KN]	

As it can be seen on the table above, all the specifications can be achieved unless the jerk value. This parameter is very tricky and it always tends to be as high as possible in order to reach the acceleration values almost instantly.

For the values taken to interpret these tests, every simple vibration, strange movement and the derivation of the acceleration has a repercussion on the jerk value, and that's why we obtain such a high maximum jerk. For that reason, in these cases

the curves reach a maximum of 28 [G/ms] for segment II in the IIHS MDB Test (this segment is only moved by the HYGE), while the system surprisingly has a design limit of 12 [G/ms].

In other words, even though the curves say that we obtained a 15 [G/ms] maximum value, it will probably be lower and it could be reached. If the graphics say it reached a 28 [G/ms] jerk, makes sense that it will be capable of obtaining 15 [G/ms] (it is almost half the value).

3.6-Possible design of the system

Once the technology and the specifications that our system would need have been determined, the next step is to do a scheme for the possible configuration of the system. This first sketch is just an idea of how could the system be designed but under no circumstances this is the definitive system.

To build and design one of these systems takes at least two years and a lot of characteristics and parameters have to be taken into account. For that reason the design's sketch done at this chapter is just a simplification and a general idea of how could the lines of this future design could be.

3.6.1-Supplier election

It has to be said that there are not too many companies that offer this type of actuators with these specific characteristics. At the moment there are two main suppliers for this kind of systems: Encopim and DSD. The first one is still developing them and for that reason there is no data or information about the working characteristics; and the second one is the company that developed them time ago and for which there is plenty of information available.

For that reason, the second company will be chosen as the supplier for the actuators. The main working characteristics are summarized in the next table and compared to the specifications needed for the tests. The right column is a color guide that means:

-[Green]: everything in order.

-[Orange]: with some limit problems that could be solved.

-[Red]: impossible to work with those values.

	Working Value	Design limit	OK?
Max. Acceleration	115 [G]	150 [G]	
Min. Acceleration	-100 [G]	-110 [G]	
Max. Velocity	10 [m/s]	15 [m/s]	
Max. Stroke	266 [mm]	400 [mm]	
Max. Jerk	31 [G/ms]	10 [G/ms]	
Max. Acceleration Force	41 [KN]	60 [KN]	
Max. Brake Force	20 [KN]	100,8 [KN]	

As explained for the HYGE, the high value of the jerk can be due to vibrations or any other undesired event. However, there are always methods to soften these curves peaks, as the values of jerk obtained are almost impossible to reach with the actual technologies. For that reason, it should be studied more deeply whether this parameter could be reached in reality by this actuator or maybe if with a different combination of values given by both the HYGE and the actuators could these jerk levels be achieved.

3.6.2-Determination of the number of actuators needed.

To determine the number of actuators that needed for these testing purposes, you have to focus on the door areas that suffer the main intrusions.

In case of a Moving Deformable Barrier test, the main intrusion area is the corresponding to segment II. While in case of a Pole test, the main intrusion area is the corresponding to segment II if the door is divided into three segments (*Figure 3.40*).

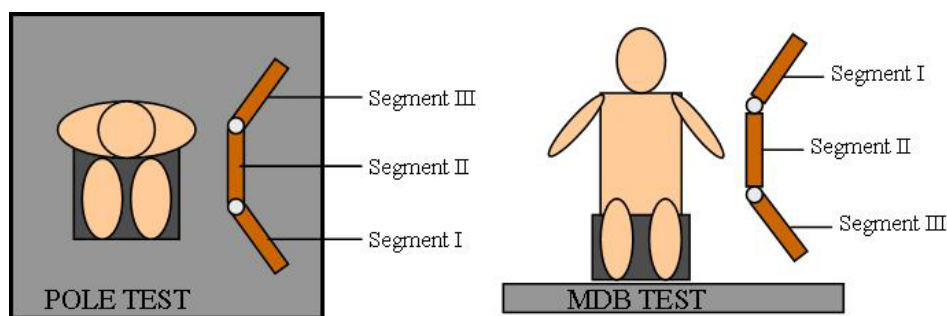


Figure 3.40: Scheme of both sled tests configurations.

Due to budget control and space availability on the sled, a maximum of two actuators has always been considered as a possible optimum.

It can be seen on the Pole test scheme that the door is divided into three segments in order to obtain a better representation of the kinematics and deformation of the door. The more independent areas you have, the better results you will obtain. However, this is just a design idea; it can also be done with just two segments.

In order to define the number of actuators that need, first you have to focus on the specifications required and the actuator's characteristics which are summarized on the previous point. As it can be seen, with just an actuator is enough to reach the working values of the parameters, and therefore this design will use just one actuator.

3.6.3-Sketch for the system design

First of all, it is evident that the actuators will have to act on the segments with the highest parameters' values (acceleration, velocity, intrusion...) and this segment is segment II (see *Figure 3.38*) for both cases.

For that reason, in this system design, segment II will be active and segments I and III will be passive. This means that segment II will receive the direct impact from the actuator and segments I and III will need to adequate their motion.

One of the possible concepts proposed is to fix the outside extremes of segment I and III to the sled, in order to obtain the door deformation when the actuator gives the impulse on the middle segment. However, design is not feasible because some movement in the extremes has to be allowed. When the outside segments rotate upon the middle segment, the point of their extremes obviously vary. This is shown on *Figure 3.41*.

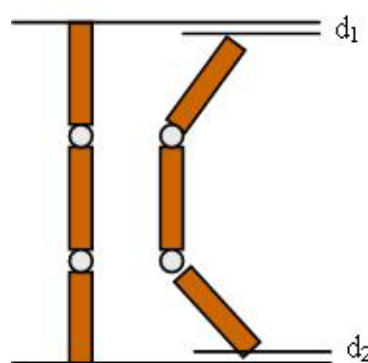


Figure 3.41: Representation of the segments' movement

For this purpose, the extremes of both segments I and III will be fixed to the sled, but with just determined movement allowed that will be enforced thanks to customized

guides made for every different test and based on the information from the simulations.

In this way, it will be able to obtain a good representation of the door deformation. The guide concept is shown on *Figure 3.42* and is valid for both barrier and pole tests as they are both divided into three segments and depending on the point of view they can be simplified with the same scheme.

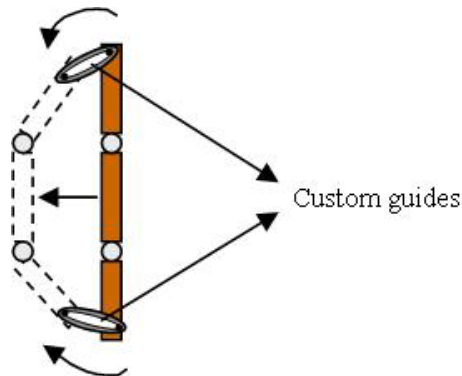


Figure 3.42: Custom guides concept

3.6.4-Conclusion

To conclude, it must be clarified again that this is just a possible configuration and that there are much more configurations that could be done depending on the number of actuators and the disposition available.

However, in this could be quite a simple configuration with better results than now and is not that different to the design being used at the moment.

The complete design's sketch is summarized on *Figure 3.43*.

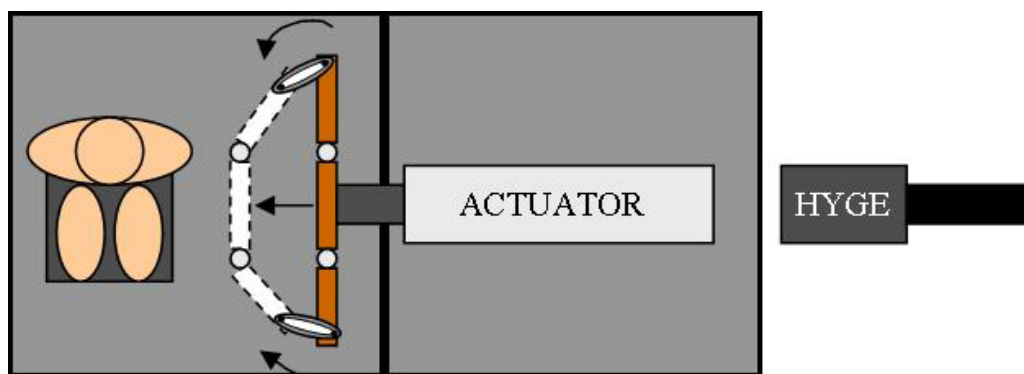


Figure 3. 43: Design scheme

3.7-Reliability study

As explained in the introduction, reliability engineering studies the probability of success and failure of a determined system. It is used to analyze the main factors or elements that have more influence in the probability of failure of the complete system.

This study will analyze the probability of failure through time of the new actuator in order to have an idea of how the system behaves and how it can be improved in order to reduce this failure probability and therefore to increase the probability of success.

3.7.1-Analysis of the actuator system

To carry out this study, first of all you need the system diagram to see which main components are involved in the system and to analyze which problem or failures each of the components could have.

The system scheme is shown on *Figure 3.44*.

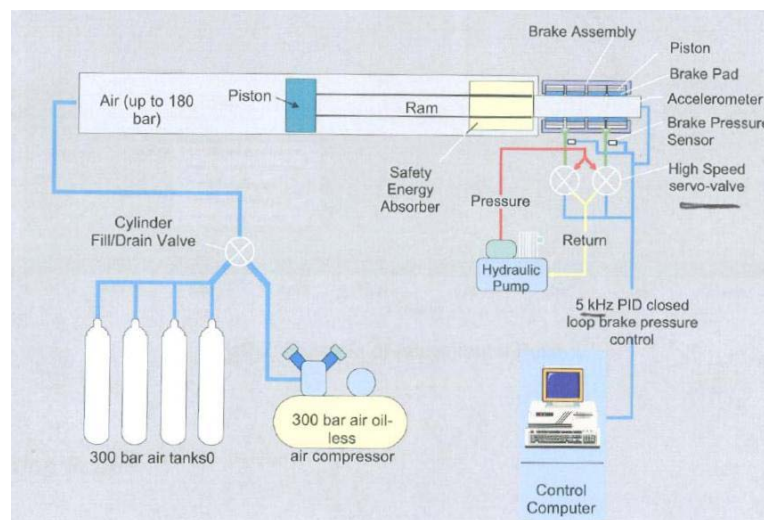


Figure 3.44: Actuator's system representation

It can be seen that there are three main independent circuits or loops: pneumatic, hydraulic and electronic. To those must be added a fourth one, the electric circuit. Each of them is explained below.

- I. **Pneumatic circuit:** it's the one in charge of propelling the cylinder forward by means of pressurized nitrogen. Its main components are:
 - Tanks: it is where the pressurized gas is stored and they must to be ready to fill the cylinder's chamber.

- Compressor: it is the one that compresses the nitrogen until it reach the working pressure values.
 - Valve: it controls the entrance of pressurized gas in the actuator. It opens and closes when needed and has to be capable of maintaining the gas inside the cylinder's chamber without leakage.
- II. **Hydraulic circuit:** it's used to control the brake. The brake controls the forward movement of the cylinder and therefore has to be very precise. The oil pushes a piston that presses the brake pads against the cylinder. Its main components are:
- Pump: is in charge of giving pressure to the fluid and therefore to move it forward.
 - Piping: it's through which the fluid moves along.
 - Reservoir: as already explained, the oil has to be stored in a tank in order to avoid contamination or fire risk. It is a closed loop: the oil goes from and to the reservoir.
 - Servovalve: it is a very special type of valve that allows a quick response to open and close the circuit in order to activate or deactivate the brake. It is one of the main problematic components as it will be seen later.
 - Brake piston: is the one that presses the brake pads to the cylinder.
 - Brake pads: they are in direct contact with the cylinder when braking. Therefore, they will suffer of fast deterioration.
- III. **Electronic circuit:** it's used to control all the components that form the complete system. Its main parts are:
- Accelerometer: it measures the acceleration of the cylinder in order to control the cylinder movement.
 - Pressure sensors (x2): are used to measure the pressure applied to the cylinder.
 - Control PC: it is the one that receives the signals of the accelerometer and the pressure sensors and translates them into actions in every component.
 - Cabling: in charge of moving all the information from one side to other.
- IV. **Electric circuit:** of course any of these systems wouldn't operate without electric current.

3.7.2-Scheme and simulation of the actuator system

In order to do an analysis of the system, specific software will be used. This software is called RiskSpectrum and uses a common scheme to show all the possible failures that could happen in a system. In order to do this scheme, it uses two main logic gates:

- I. Gate OR: it is used to explain that the event just above it can happen when any of the following events (just below it) occur.
- II. Gate AND: it is used to explain that the event just above it can happen when all of the following events (just below it) occur at the same time.

An example of the graphic representation of both gates is shown on *Figure 3.45*.

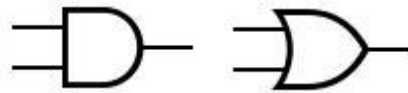
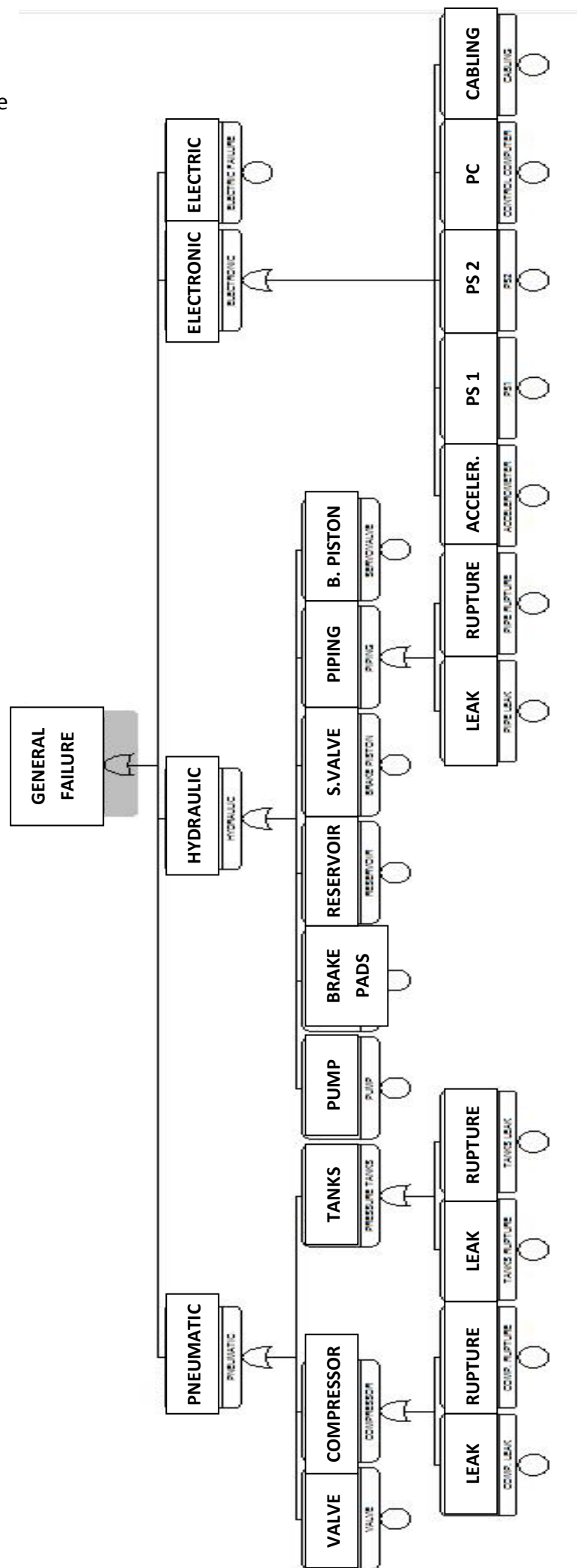


Figure 3.45: Gate AND (left) and Gate OR (right)

The system circuit is represented by means of logic gates and events on *Figure 3.46*. Each of the boxes represent a possible component failure, while for some of them have more detail of which possible failures could make them fail.

Figure 3.46: Scheme



In order to run the simulation of this system in the software, we need to give information about failures of each of the components. The parameter used normally is the failure rate (λ), which represents the frequency with which an engineered system or components fails and the units are failures per unit time. The λ value of each of these failures is summarized in the following table:

POSSIBLE FAILURE	λ
Accelerometer	25E-6
Brake pads	1E-4
Brake piston	76,3E-6
Cabling	1E-6
Compressor leak	4,4E-3
Compressor rupture	1E-4
Control PC	25E-6
Electric outage	80E-6
Pipe leak	14E-6
Pipe rupture	11E-7
Pressure sensor 1 (PS1)	25E-6
Pressure sensor 2 (PS2)	25E-6
Pump	40,4E-6
Reservoir	6,6E-6
Tanks leak	1,1E-6
Tanks rupture	3,2E-7
Valve	5,2E-6
Servo valve	3E-3

These values are obtained by testing each components several times, however for this thesis that's not the focus point so values from other studies and papers have been taken. These are the *Annexes VI, VII and VIII*, which maybe are not for the exact same application but they give an approximation of the value they could have.

The formula that relates this λ values with the probability of failure, $Q(t)$, is:

$$Q(t) = 1 - e^{-\lambda \cdot t}$$

The results of the $Q(t)$ obtained for the system described and for those lambda values are represented on *Figure 3.47*.

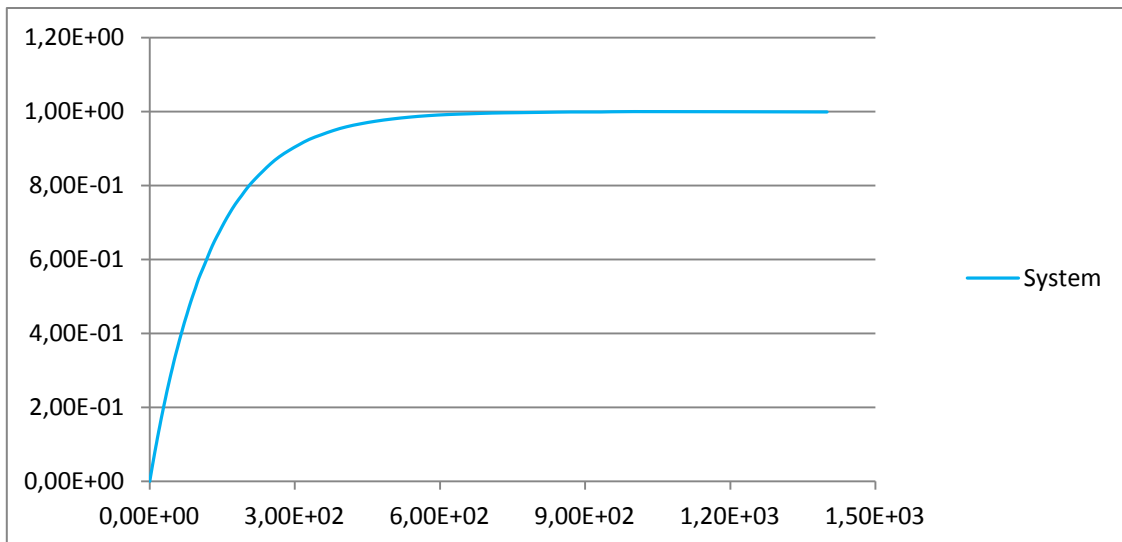


Figure 3.47: System's probability of failure $Q(t)$

Seeing the formula, makes sense that the probability of failure, $Q(t)$, tends asymptotically to 1 when times approaches to infinite.

3.7.3-Presentation of solutions and results

In order to reduce the probability of failure, I have introduced three main ideas:

- Install a second servovalve in parallel to the one existent. In case the original servovalve fails, there is a second one that can work with the same characteristics.
- Introduce a different type of compressor without gaskets in order to reduce the leakage failure rate.
- Put a redundant electronic circuit in parallel that can work whenever the original one fails. This can be done with the electronic circuit which basically includes a PC, some sensors and cabling, but it would be too expensive to do the same with the hydraulic or pneumatic circuit.

The next sections explain the results obtained for the solutions listed above.

-Servovalve in parallel

As explained, this servovalve will work in case the principal one has a problem or fails. The idea is to give solutions to the components with smaller failure rates in order to reduce the global probability of failure of the system. *Figure 3.48* shows how the scheme's part of the servovalves would be.

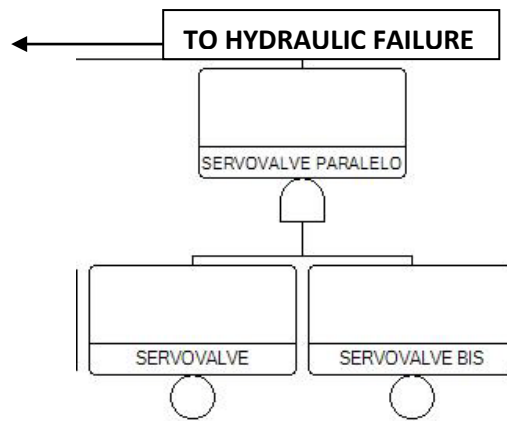


Figure 3.48: Parallel servovalves' scheme

The results obtained are presented on *Figure 3.49*, in comparison with the original system.

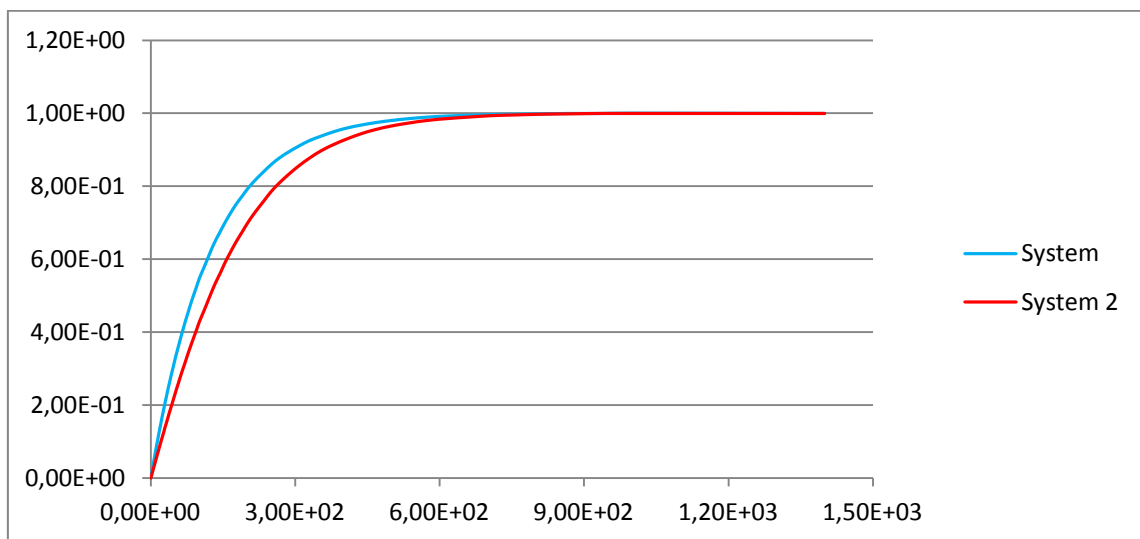


Figure 3.49: Comparison between original system and the one with 2 servovalves

It can be appreciated, that the curve doesn't change too much. The objective is to reduce the slope of the curve in order to reduce the time it takes to reach the 100% of failure probability. For that reason a second modification will be added: the compressor without gaskets.

-Servovalve in parallel and compressor without gaskets

It could seem that a small change on the type of compressor wouldn't have too much influence on the previous curve. However, there is a big change on the failure rate value and therefore it has a strong effect on the global failure probability.

The curve is shown on *Figure 3.50*.

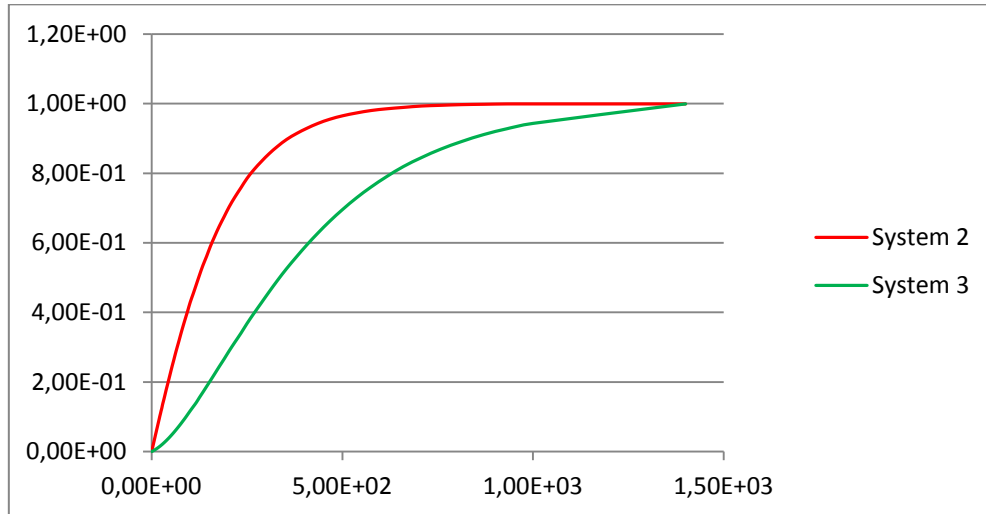


Figure 3.50: Comparison between previous system (2) and the one with compressor without gaskets (3).

It can be seen that indeed it has a big effect on the previous system probability of failure.

-Servovalve in parallel, compressor without gaskets and redundant electronic circuit

As said before, a redundant circuit is possible due to the relatively low costs of the components. However, it would be too expensive to do the same with the hydraulic or pneumatic circuit.

The redundant electronic circuit scheme is presented on *Figure 3.49* and as it is in parallel, it has to come out from an AND logic gate. This means that both circuits would have to fail in order to have an electronic circuit.

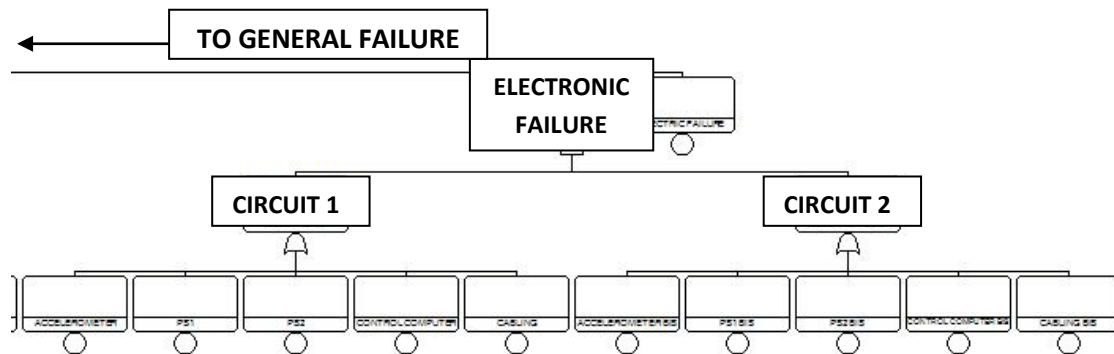


Figure 3.51: Scheme of the redundant electronic circuit

And the results obtained for this configuration are shown on *Figure 3.52*.

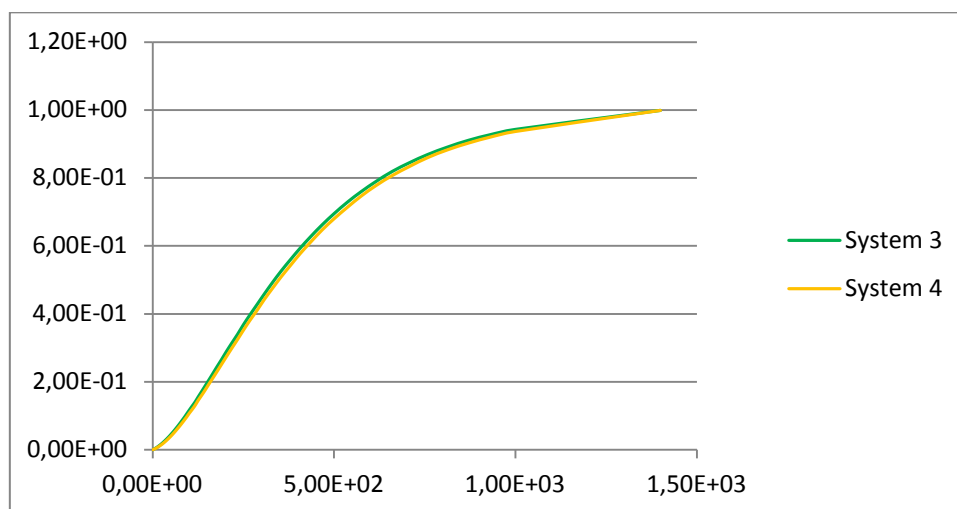


Figure 3.52: Comparison between the previous system (3) and the one with a redundant electronic circuit (4)

It can be seen that there is not much changes from the previous system to this last one. For that reason it wouldn't be too interesting to do it.

3.7.4-Conclusion

Finally, on *Figure 3.53* presents all the curves together in order to see the evolution as soon as the modifications were introduced.

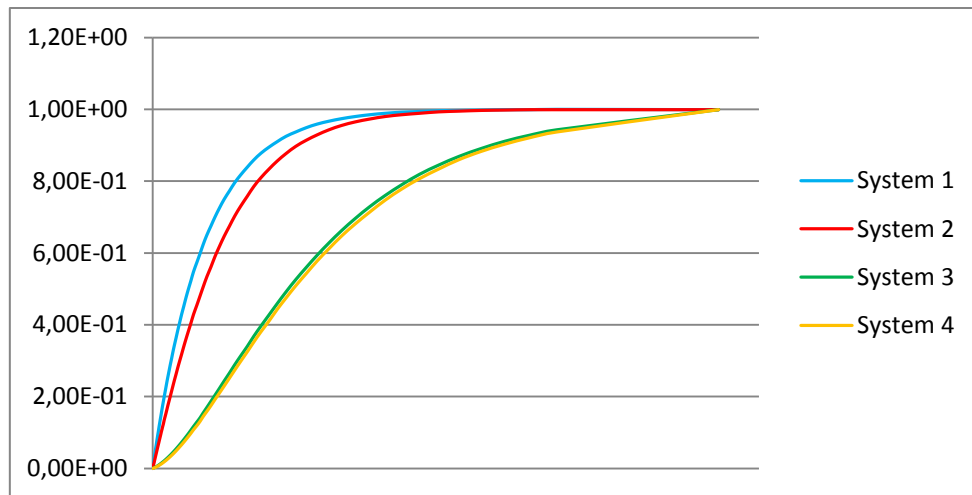


Figure 3.53: Comparison between all the possible modified circuits

This last graphic (*Figure 3.53*) let us understand which of the proposed modifications is worthy. In this specific system the compressor without valves is the one that gives the best results in order to reduce the probability of failure.

3.8-Economical study

One of the main parts in every thesis is the calculation of the economical costs that its implementation carries. This study will help to decide whether to improve the system with this new technology or not.

The main project costs are often divided between two main sections depending on if they affect directly to the product or not. In this way appear the concepts of direct and indirect costs. The first costs are usually the ones with more weight over the total costs because they involve the next aspects:

- **Staff costs**: it evaluates the number of hours that the assigned staff has worked in order to carry out the project and is multiplied by the price per working hour of each of them.
- **Amortization costs of the equipment**: to carry out the project, it's necessary to use several equipment and software. Since this equipment and software are not only used for this specific project, it's required to take into account the proportional part of the amortization of these items.
- **Material's costs**: this includes the costs of raw materials used, documentation, etc. that have influence in the final result of the project.

- Direct expenses: here it's included the expenses related to electricity consumption related directly with the project as could be the consumption of the equipment used during the working hours. There will not be included general expenses as lightning or heating, which will be included in the indirect costs category.

On the other hand, indirect costs are not usually a very important part of the total costs but they have to be considered as well. These costs involve concepts like lightning, telephone, air-conditioning, cleaning services, etc.

3.8.1-Direct costs

-Staff costs

For the implementation of this project, it will be considered the participation of three professional categories:

- Master's Degree Engineer
- Bachelor's Degree Engineer
- Mechanic's specialist

To make the analysis easier, costs per working hour will be used. Therefore, it's necessary to know the hours of work in a year.

Its determination is based on the "Convenio del Metal" (Metal Agreement), which manage the activities of the Cidaut Foundation.

Total days		365
To discount:		
-Saturdays and Sundays	104	
-Free days for holidays	20	
-Public holidays	15	
-Personal days	6	
Total days to discount		145
Resultant working days		220

Assuming that a normal labor day has 8 hours, the total number of working hours per year is calculated through this simple formula:

$$Annual\ working\ hours = 8 \frac{hours}{day} \cdot 220 \frac{days}{year} = 1760 \frac{hours}{year}$$

On the following table, are included the costs for the company that result from the staff payments related with this project. In this quantities are included the payment for the worker as well as the contribution for the social security, which is currently 32% of the net salary but it will be used a 33,33% in order to use round figures.

CATEGORY	GROSS WAGE (€/YEAR)	NET WAGE (€/YEAR)	COST PER HOUR (€/HOUR)
Master's Degree Engineer	40000	30000	17.05
Bachelor's Degree Engineer	32000	24000	13.60
Mechanic's Specialist	24000	18000	10.25

From these costs per hour, several direct staff costs will be determined for this project.

-Costs of the study previous to the tests. Conceptual design

In this category all the costs resulting from the research and development of the project are included.

Concept/Category	Master's Degree Engineer	Bachelor's Degree Engineer	Mechanic's Specialist	Total cost per concept
Coordination	40			682,00 €
Documentation's preparation	30			511,50 €
Study of the positioning of the actuator	40	40		1.226,00 €
Study of the actuator	40	40		1.226,00 €
Study and design of the system	80	80		2.452,00 €
Design of tests	80	80	16	2.616,00 €
Theoretical studies	20			272,00 €
Total	330	240	16	8.985,50 €

The total costs of the staff for the preparation of the study to carry out the tests and for the setup of the equipment for its development amounts to 8985,50€

-Tooling design and manufacturing

Under this category are included all the costs related to the design and manufacturing of the complete structure that will be mounted on the sled: door segments, main structure, guiding system, etc.

Concept/Category	Master's Degree Engineer	Bachelor's Degree Engineer	Mechanic's Specialist	Total cost per concept
Coordination	20			341,00 €
Documentation's preparation	20			341,00 €
Tooling design	40	40		1.226,00 €
Manufacturing	5	40	300	3.704,25 €
Tooling assembly	5	10	80	1.041,25 €
Total	90	90	380	6.653,50 €

The total costs of this category amounts to 6653,50€

-System integration in the HYGE facility

Under this category are included all the staff costs related to the integration of this independent actuator into the actual system, having to synchronize the whole system in order to obtain good results without delays between both cylinders.

Concept/Category	Master's Degree Engineer	Bachelor's Degree Engineer	Mechanic's Specialist	Total cost per concept
Coordination	40			682,00 €
Documentation's preparation	40			682,00 €
Hidraulic system implamentation	20	20	40	1.023,00 €
Pneumatic system implamentation	20	20	40	1.023,00 €
Control signals implementation and sincronization	20	20	40	1.023,00 €
Total	140	60	120	4.433,00 €

The total staff costs of this category amounts to 4433,00€

-Tests for set up and fine tuning

Under this category are included all the staff costs related to the first assembly, one pulse calculation, 2 loops of 3 tests without dummy and environment to check tooling vibrations, integrity, repeatability, robustness, etc, and tooling adjustments for fine tuning between each loop. The pulse calculation is the same for all the loops.

Concept/Category	Master's Degree Engineer	Bachelor's Degree Engineer	Mechanic's Specialist	Total cost per concept
Pulse calculation	16	8	16	545,60 €
1st loop: 3 tests without dummy & environment	12	12	24	613,80 €
1 st loop analysis	8	2	0	163,60 €
Tooling fine tuning	1	4	16	235,45 €
2nd loop: 3 tests without dummy & environment	12	12	24	613,80 €
2 st loop analysis	8	2	0	163,60 €
Total	57	40	80	2.335,85 €

The total staff costs for this category amounts to 2335,85€

-First tests with the complete system

These tests are 3 tests with WS50 (WorldSID dummy 50th percentile) dummy with a real environment for correlation level and repeatability assessment.

Concept/Category	Master's Degree Engineer	Bachelor's Degree Engineer	Mechanic's Specialist	Total cost per concept
3 tests with Word SID50 dummy & environment	18	24	48	1.125,30 €
Tests analysis ad correlation	40	16	0	899,60 €
Total	58	40	48	2.024,90 €

The total costs of the tests and the setup of all the equipments used for the project amounts to 2024,90€

In total, the costs related to the work of the staff rise to **24432,75€**

-Costs of the equipments' amortization

For the analysis of the costs related to the use of equipment, you have to take into account the period of amortization that corresponds to each of them. In this case it's considered that the computer equipment and testing systems such as accelerometers, acquisition systems, dummy, etc. are already amortized.

It will only be considered the new test equipment bought for this specific project and the tooling elaborated for it.

The price of all this equipment will be summarized in just one payment as it is easier to analyze it. The amortization model will be at five years and with a zero residual value.

First of all the price per test will be calculated. The total lateral tests done each year are estimated to be 250 and therefore in five years we get:

$$\text{Tests in five years} = 5 \cdot 250 = 1250 \text{ tests in the amortization period}$$

In order to calculate the costs of these adjustment and configuration tests, it's needed the cost per test during the amortization period. The total cost of the equipment for one actuator and one brake amounts approximately to 150000,00€ and the tooling costs amount to 12000,00€ approximately. The cost of the equipment for each of the test is then:

$$\text{Cost per test} = \frac{150000 + 12000}{1250} = 130,00\text{€ approx.}$$

Having done in total 6 tests for the setup and fine tuning and another 3 tests with dummy and real environment in total are 9 tests. Knowing the price per test and the total number of test we can easily obtain the total costs due to the tests done in this process:

$$\text{Total tests' equipment cost} = 9\text{tests} \cdot 130\text{€ per test} = 1170,00\text{€}$$

-Direct costs of material

In this category are included all those materials that are used for the tests and have a limited period of life time.

Direct costs of materials= 1000€

-Direct expenses

Under this concept are integrated all the expenses related directly with this project. As commented at the beginning of this chapter, only the expenses related to the electricity that the equipments consumed are included here.

These expenses are estimated to be: 800€

3.8.2-Indirect costs

The indirect costs are those which are not directly related to the execution of this project, but they derive from the company's activities overall. Included are the heating costs, electricity consumption due to lightning, telephone, maintenance, etc.

These costs are an estimation of the part of these concepts attributable to this specific project.

The indirect costs are estimated to be 5300€

3.8.3-Total costs

Having explained each of the different costs, the total costs calculation is simple:

DIRECT COSTS	Staff direct costs	24432,75
	Amortization direct costs	1170,00€
	Material direct costs	1000,00€
	Direct expenses	800,00€
INDIRECT COSTS		5300,00€
TOTAL COSTS		32702,75€

The total costs for the implementation of this project would be approximately 32702,75€, which could seem like a lot of money but actually it's relative.

With this inversion the company will have the opportunity to attract new potential customers due to the better results of the tests which will lead to higher incomes for the company.

This testing technology is being used currently by other companies from the same testing sector and despite the big first inversion and time period needed, now they are very happy with the results and the precision obtained.

In this case would have the same repercussion, and the equipment will be rapidly amortized. But not only will be amortized quickly so it will also let the company get to know for other manufacturers and suppliers, securing better and more contracts.

4-Summary and Conclusions

4.1-Summary

The main objective of this thesis was to study the possibility of introducing a new on-board actuator to the actual Cidaut's sled tests facilities. The reason for studying this possibility was mainly in order to do better and more precise lateral tests which will lead to more realistic results. These tests are used during the restraint systems development process for any car model, being one of the main parts of this process.

Another big reason for this study was that the several rules, regulations and private assessment programs that assess the safety levels of the new car models that get into the market in different countries and continents are getting stricter each year. This means that the testing facilities have to reach higher specifications such as accelerations, velocities, etc. and therefore leading to the necessity of having another active system to introduce acceleration pulses to the system.

First of all, a study between all the actuator's technologies available at the market was done. Advantages and disadvantages for this specific application were explained so it was possible to choose which technology would be the best to achieve these specific necessities. For this case, the pneumatic actuator was chosen with a hydraulic brake to control the movement of the cylinder.

Once it's selected the actuator's technology to use, the thesis proceeded to carry out a study focused on obtaining the specifications which the actuator should need to have so it could achieve the testing requirements. To define the actuator's minimum specifications, first of all a study to determine the worst possible case between all the lateral tests was done. The conclusion was to analyze the test's specifications for the IIHS Moving Deformable Barrier Lateral Test and the 75º Pole Test.

With the worst cases defined, information from both real sled tests carried out at the company was gathered. To determine the pulses of the actuator, first it was needed to define the HYGÉ's pulses so the on-board actuator will need to give the relative values to the HYGÉ. The HYGÉ was defined with the seat pulse and it was studied whether the HYGÉ working requirements were under the design limit values. For the HYGÉ the most important parameter was the maximum force. The following table summarizes this information:

HYGÉ	Working Value	Design limit
Max. Acceleration	62 [G]	120 [G]
Min. Acceleration	-28 [G]	-45 [G]
Max. Velocity	11 [m/s]	22,5 [m/s]
Max. Jerk	15 [G/ms]	12 [G/ms]
Max. Force	1230 [KN]	2000 [KN]

Having the actuator's technology and its specifications, a first sketch of the possible design was defined. First of all, it was elected the actuator supplier and the minimum specifications defined were compared to the limit values of the actuator. The results are summarized in the table below:

ACTUATOR	Working Value	Design limit
Max. Acceleration	115 [G]	150 [G]
Min. Acceleration	-100 [G]	-110 [G]
Max. Velocity	10 [m/s]	15 [m/s]
Max. Stroke	266 [mm]	400 [mm]
Max. Jerk	31 [G/ms]	10 [G/ms]
Max. Acceleration Force	41 [KN]	60 [KN]
Max. Brake Force	20 [KN]	100,8 [KN]

The system design proposed in this thesis is represented in the following *Figure 4.1*

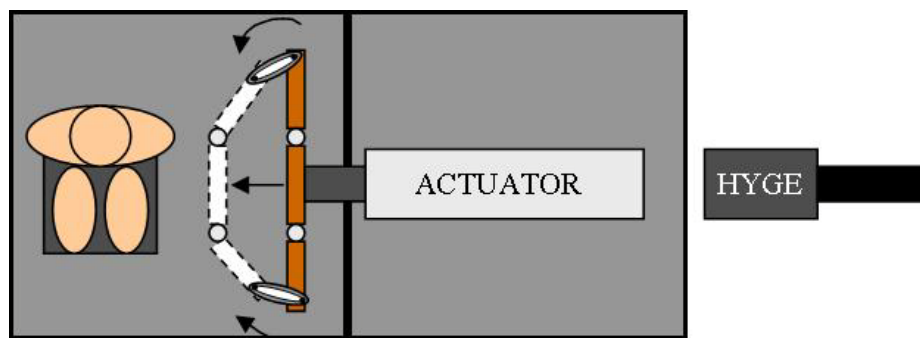


Figure 4.1: Scheme of the system design

In addition to these studies, the actuator's system was also analyzed in terms of reliability in order to get an idea of how to improve the system and to reduce the probability of failure. Several modifications were proposed and their solutions obtained.

Figure 4.2 shows the probability of failure obtained for the following systems:

- *System 1:* the original actuator system.
- *System 2:* the original actuator system with a servovalve in parallel to the one given.
- *System 3:* system 2 with the inclusion of a compressor without gaskets.
- *System 4:* system 3 with a redundant electronic circuit in parallel to the one already existent.

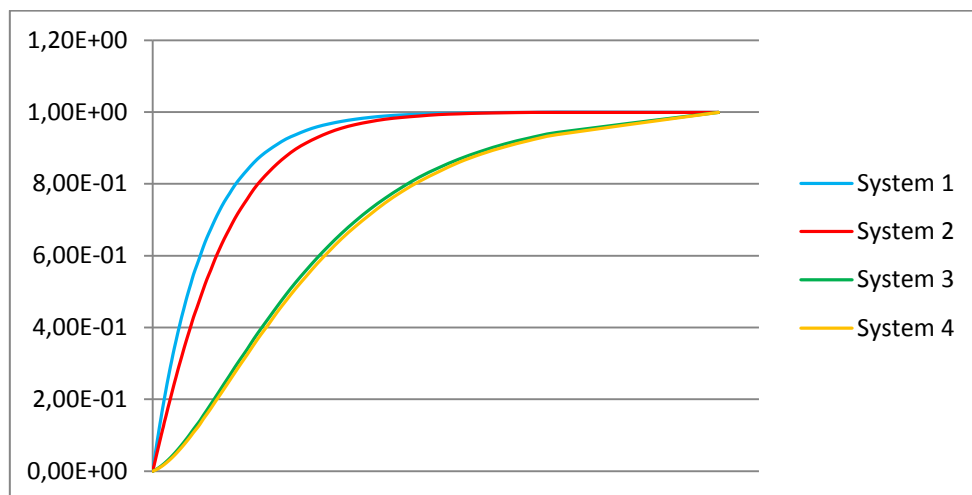


Figure 4.2: Comparison of the system and the modifications proposed

Finally, to conclude the thesis, an economical study was introduced in order to help with the decision of whether to introduce the new system or to stay with the actual one without modifications.

For this study, real information of costs and hours of dedication to several working categories and areas from the company were used.

The total costs for the fine tuning of this project amounts to 32702,75€

4.2-Conclusions

Once the thesis is finished, it is the moment to analyze if the main objectives were achieved.

First of all, the thesis had the important objective of studying the different actuator technologies available at the market and analyzing their main advantages and disadvantages for this specific application.

This study was documented and a deep research was made. Several advantages and disadvantages were explained and a conclusion about the type of technology to be used for the tests was obtained. This is not only useful for this thesis, but also for future applications and studies.

Once the technology was selected, the main objectives for these testing purposes were the following:

- I. Reduce the charge of the main cylinder (HYGE): as it was exposed, the working values of the HYGE for the analyzed tests were under the limit values and with a big margin for variations and modifications. This objective has been achieved.
- II. Improve the reproduction of accidents: at the moment, the company is able to reproduce in an accurate manner several accidents with just one hydraulic cylinder. Makes sense that with the introduction of a second actuator fixed on the sled and independently controlled it could increase the precision of the crash reproduction. This actuator will also introduce real movement to the door segments instead of just giving an acceleration pulse and therefore it will be much more representative.
- III. Update the system for future tests: other of the main reasons for carrying out this study is that the rules, regulations and private assessment programs are getting stricter each year and therefore higher specifications are required for these tests. Parameters such as accelerations, velocities and forces have to reach higher values in order to be representatives and also more independent pulses have to be introduced in the system to reproduce different components movements. Being independent, this actuator could also be used for other applications such as component testing, which could also be interesting for the company.
- IV. Define a first sketch of the system: the objective of this first design was to give a first idea of how the system could be assembled. For this purpose, the number of actuators and position was defined and also how could the door segments be guided in order to obtain the results required. All this study was made and therefore this objective was also achieved.

As explained above, the objectives of the thesis were achieved. However it is difficult to obtain a final conclusion about the introduction or not of this system in the actual facilities. This thesis was just a first step of a much bigger study that should be carried out in order to obtain a more trustful answer about whether to buy this system or not.

For that reason, the final conclusion of this thesis will only be based on the results obtained in these studies.

It must be said that comparing the values which the actuator will have to give against the ones from the HYGE, they are much higher the ones from the on-board actuator. For that reason and in order to compensate, it could be proposed a configuration where the HYGE would give higher values in order to reduce the stress on the actuator.

Focusing on the actuator's specifications required, this technology would reach the values needed for the testing purposes exposed in the project. It has to be taken into account that the studies were based on the values gathered by the accelerometers fixed on the several components and therefore, they took higher values than the real ones due to vibrations and resonance that lead to higher peaks.

Despite being based on higher values and having added a 20% increase to all of the parameters studied, the actuators still reach the requirements needed. This is a great first step in order to take a decision for the introduction of the new system.

Knowing that a much deeper study has to be done in order to be completely sure about the decision, it can be said that the introduction of these actuators and to make them work synchronized with the HYGE in order to obtain a best-in-class testing system is feasible.

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Figure 2.4: Cidaut, <http://www.cidaut.es/en/passive-safety-tests>

Figure 2.5: Current Worldwide Side Impact Activities – Divergence Versus Harmonization and the Possible Effect on Future Car Design, SAE Paper 05-0077

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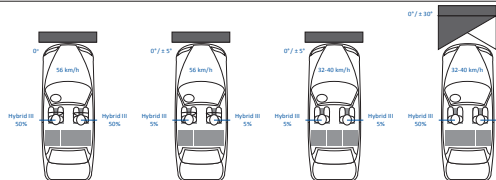
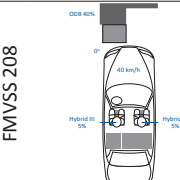
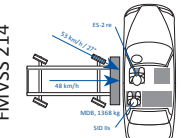
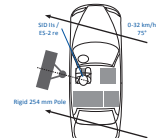
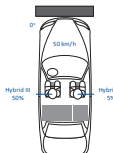
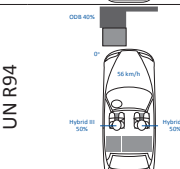
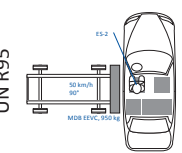
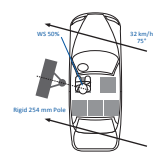
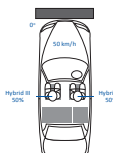
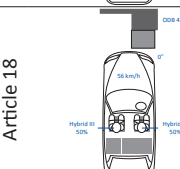
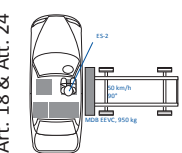
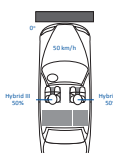
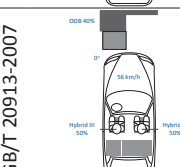
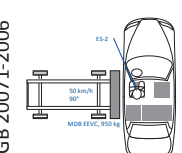
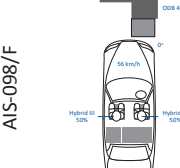
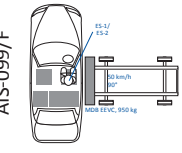
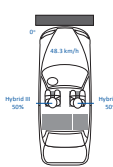
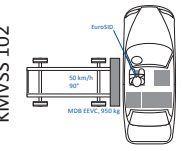
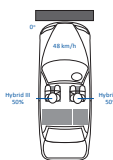
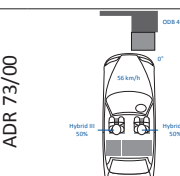
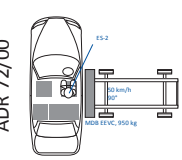
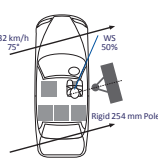
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7-Annexes

Annex I

Rules and Regulations on Occupant Protection

2016 2017

	Full Width Frontal	Offset Frontal	Side Barrier	Side Pole	Pedestrian	Rear	Head Impact	Rollover
USA 	FMVSS 208 	FMVSS 208 	FMVSS 214 	FMVSS 214 		FMVSS 202a FMVSS 301	FMVSS 201U	Tilted Ramp: FMVSS 208 Roof Crush: FMVSS 216a Ejection Mitigation: FMVSS 226
Europe 	UN R137 	UN R94 	UN R95 	UN R135 	R (EC) 78/2009 R (EC) 631/2009 UN R127	UN R32	UN R21	
Japan 	Art. 18 & Att. 23 	Article 18 	Art. 18 & Att. 24 		Article 18 & Attachment 99	Article 18 & Attachment 34		
China 	GB 11551-2014 	GB/T 20913-2007 	GB 20071-2006 		GB/T 24550-2009	GB 20072-2006	GB 11551-2009	Roof Crush: GB26134-2010
India 		AIS-098/F 	AIS-099/F 		AIS-100	AIS-101		
South Korea 	KMVSS 102 		KMVSS 102 		KMVSS 102-2			
Australia 	ADR 69/00 	ADR 73/00 	ADR 72/00 	ADR 85/00 				

Annex II

NCAP-Tests

2016 2017 2018

	Euro NCAP	U.S. NCAP	IIHS	Latin NCAP	JNCAP	C-NCAP	KNCAP	ASEAN NCAP	ANCAP
Full Width									
ODB / SOB									
MDB								■ prerequisite for 3, 4 or 5 star rating: UN R95 criteria ■ planned as 2017	
Pole				prerequisite for 5 star rating 					
Rollover		■ SSF	■ Roof Crush			■ Curtain Airbag	■ SSF		
Pedestrian	■ Flex PLI ■ Upper Legform ■ Headforms ■ AEB VRU Pedestrian ■ AEB VRU Cyclist	■ Flex PLI ■ Upper Legform ■ Headforms ■ AEB Pedestrian ■ Rear Automatic Braking		■ Award	■ Flex PLI ■ Headforms ■ AEBs Pedestrian Daytime ■ AEBs Pedestrian at Night		■ Flex PLI ■ Upper Legform (on Bumper only) ■ Headforms ■ AEBs Pedestrian		■ Flex PLI ■ Upper Legform ■ Headforms
Child Safety	■ Frontal ODB ■ Side MDB ■ CRS- Installation ■ Vehicle based assessment		■ LATCH (Lower Anchoros and Tethers for Children)	■ Frontal ■ CRS-based assessment ■ Vehicle based assessment		■ P3 in Full Width Frontal	■ Q6, Q10 in ODB and MDB	■ Frontal ■ CRS-based assessment ■ Vehicle based ass.	■ ODB, MDB (no assessment)
Whiplash	■ static front / rear ■ dynamic (3 pulses) ■ AEB City		■ static ■ dynamic (1 pulse)		■ dynamic (1 pulse)	■ dynamic (1 pulse)	■ static ■ dynamic (1 Puls) ■ rear seats dynamic	■ Points for head protection tech.	■ static ■ dynamic (1 pulse)
Other	■ Assistance systems: SBR, SAS, AEB, LSS	■ FCW, LDW, Rear View Cameras, AEB, Blind Spot Detection, Headlights	■ AEB, FCW ■ Headlights	■ SBR, (prerequisite for ≥ 3 star ratng) ■ ESC (prereq. for ≥ 4 star)	■ Brakes, SBR, Usability rear belts, LDW, AEB, Around-view Monitor, LKA	■ ESC, SBR ■ AEB, FCW, LDW	■ Brakes, SBR, FCWS, LDWS, AEBs, AEBs City, ACC, LKAS, SLD	■ ESC, SBR (prerequisite for 5 star rating) ■ Safety Assist	■ Assistance systems

Annex III



Side Impact Crashworthiness Evaluation

Crash Test Protocol (Version VII)

May 2014

SIDE IMPACT CRASHWORTHINESS EVALUATION CRASH TEST PROTOCOL (VERSION VI)

Supporting documents for the Insurance Institute for Highway Safety (IIHS) side impact crash test program are available from the technical protocols section of the IIHS website (<http://www.iihs.org/ratings/protocols>).

DOCUMENT REVISION HISTORY

A document revision history is provided in Appendix C.

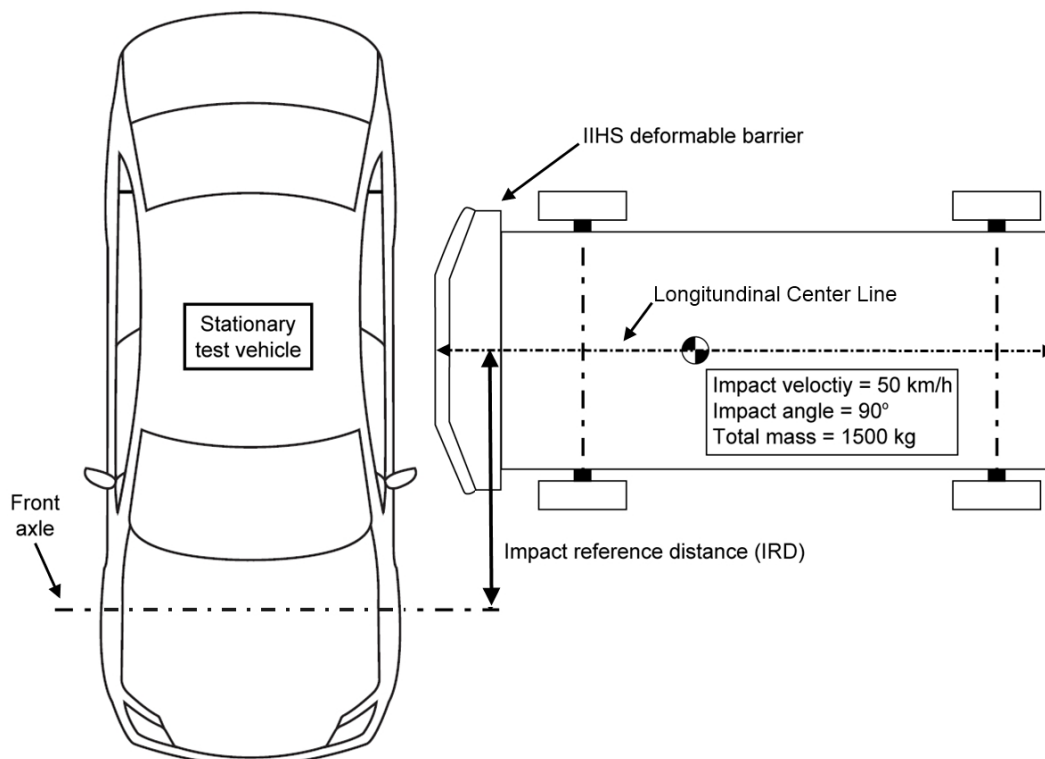
TEST CONDITIONS

Impact Configuration

Side impact crash tests consist of a stationary test vehicle struck on the driver side by a crash cart fitted with an IIHS deformable barrier element. The 1,500 kg moving deformable barrier (MDB) has an impact velocity of 50 km/h (31.1 mi/h) and strikes the vehicle on the driver side at a 90 degree angle. The longitudinal impact point of the barrier on the side of the test vehicle is dependent on the vehicle wheelbase. The impact reference distance (IRD) is defined as the distance rearward from the test vehicle front axle to the centerline of the deformable barrier when it first contacts the vehicle (Figure 1).

The MDB alignment calculation was configured to maximize loading to the occupant compartment and allow alignment of the driver dummy head with the flat portion of the barrier face. For most vehicles, the MDB alignment also aligns the rear dummy head with some portion of the barrier. If the alignment calculation allows the flat portion of the MDB face to overlap either the front or rear tires, the impact

Figure 1
Moving Deformable Barrier Alignment with Test Vehicle



alignment may be modified to prevent direct loading to these structures early in the crash. To date, only one such vehicle has been tested by IIHS, the Smart Fortwo (188 cm wheelbase). Currently, there is no set alignment rule for vehicles that fall into this category, therefore impact alignment will be determined on a case-by-case basis. Manufacturers may contact IIHS for impact point determination and/or confirmation of impact point during the vehicle development process.

IRD calculation:

If wheelbase < 250 cm, then IRD = 144.8 cm

If $250 \text{ cm} \leq \text{wheelbase} \leq 290 \text{ cm}$, then $\text{IRD} = (\text{wheelbase} \div 2) + 19.8 \text{ cm}$

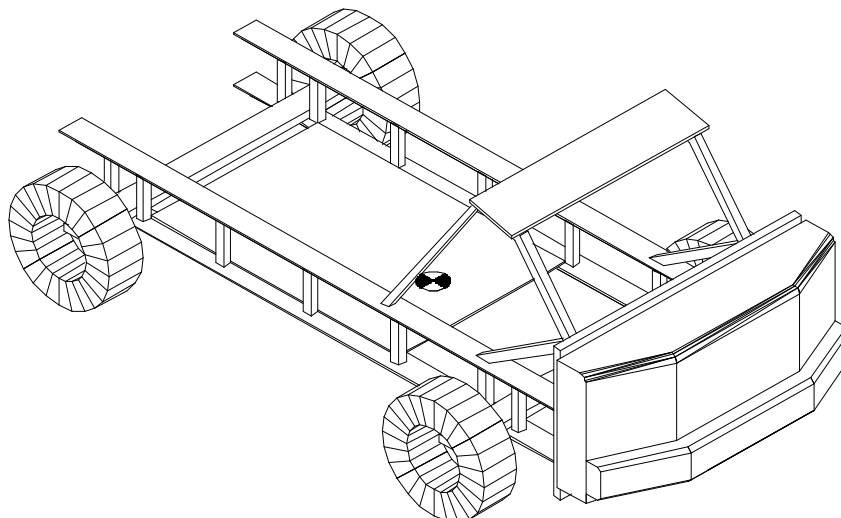
If wheelbase > 290 cm, then IRD = 164.8 cm

The MDB is accelerated by the propulsion system until it reaches the test speed (50 km/h) and then is released from the propulsion system 25 cm before the point of impact with the test vehicle. The impact point tolerance is $\pm 2.5 \text{ cm}$ of the target in the horizontal and vertical axes. The impact speed tolerance is $50 \pm 1 \text{ km/h}$. The MDB braking system, which applies the test cart service brakes on all four wheels, is activated 1.0 second after it is released from the propulsion system. The brakes on the test vehicle are not activated during the crash test.

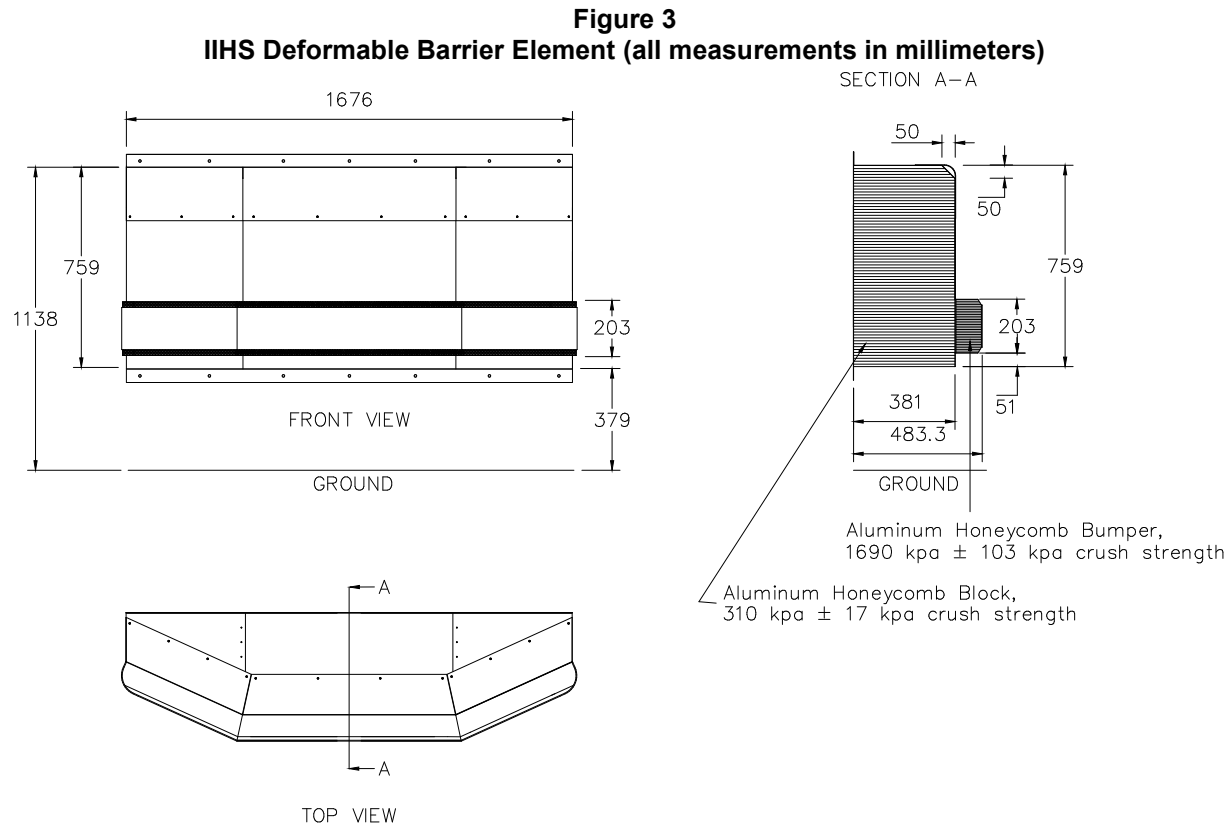
IIHS MDB Properties

The MDB consists of an IIHS deformable aluminum barrier (version 4) and the cart to which it is attached. The crash cart is similar to the one used in Federal Motor Vehicle Safety Standard (FMVSS) 214 side impact testing but has several modifications (Figure 2). The wheels on the cart are aligned with the longitudinal axis of the cart (0 degrees) to allow for perpendicular impact. The front aluminum mounting plate has been raised 100 mm higher off the ground and has been extended 200 mm taller than a standard FMVSS 214 cart to accommodate the IIHS deformable barrier element (making the mounting plate top surface 300 mm higher from the ground than the FMVSS 214 barrier). Steel plates are added as necessary to increase the mass of the cart. The MDB test weight is $1,500 \pm 5 \text{ kg}$ with the deformable element, test instrumentation, camera, and camera mount. The MDB center of gravity in the fully equipped test condition is $990 \pm 25 \text{ mm}$ rearward of the front axle, $0 \pm 25 \text{ mm}$ from the lateral centerline, and $566 \pm 25 \text{ mm}$ from the ground. The MDB roll (I_x), pitch (I_y), and yaw (I_z) moments of inertia are 542 kg-m^2 , $2,471 \text{ kg-m}^2$, and $2,757 \text{ kg-m}^2$, respectively.

Figure 2
IIHS Test Cart with Deformable Barrier Element Attached



The deformable element has a width of 1,676 mm, a height of 759 mm, and a ground clearance of 379 mm when mounted on the test cart (Figure 3). Detailed information on the IIHS barrier development and evaluation testing has been documented previously (Arbelaez et al., 2002). The IIHS deformable barrier design and performance criteria are documented in the *Side Impact Moving Deformable Barrier Specification* (IIHS, 2007).



Test Vehicle Preparation

Test Vehicle Selection and Acquisition

Each vehicle is inspected upon arrival at the research center. Vehicles are examined to verify that they are in satisfactory operating condition and to note defects such as prior collision damage, missing parts, maladjustments, or fluid leaks. If directly relevant to testing, such deficiencies are corrected or a replacement vehicle is procured.

Some of the vehicles evaluated in the side impact test program have been used in the IIHS bumper test program. Such vehicles have been subjected to an impact on the front and/or rear of the vehicle at either 5 km/h (3.1 mi/h) to the corner or 10 km/h (6.2 mi/h) across the full width (IIHS, 2010). Any structural damage pertinent to side impact protection is repaired or replaced before the side impact crash test. Cosmetic damage is repaired at IIHS discretion. Parts are repaired or replaced as appropriate based on the judgment of professional insurance appraisers.

Fluids

Gasoline is removed from the fuel tank and fuel lines. The fuel tank then is filled with Stoddard solvent to 90-95 percent of useable capacity. The fuel pump is run for a short period to ensure the Stoddard solvent has filled the fuel lines. Additional fluids may be drained from the vehicle should the vehicle exceed the maximum allowable test weight.

High-Voltage Batteries

High-voltage batteries in vehicles with hybrid electric and full-electric drivetrains are tested in a charged state as per FMVSS 305, which specifies a maximum state of charge recommended by the manufacturer. If no recommendation is made, the battery is tested at a state of charge of not less than 95 percent of maximum capacity. Maintenance fuses are not removed, but additional precrash and postcrash precautions specified by the vehicle manufacturer are followed. Equipment will be added to the high-voltage system in accordance with manufacturer recommended procedures for monitoring electrical isolation as per FMVSS 305. Thermocouple(s) also will be attached to the high-voltage battery to detect temperature increases that may indicate a thermal runaway condition.

Test Vehicle Instrumentation

An aluminum instrumentation rack, which supports the test equipment, is installed in the cargo area of the vehicle. The carpeting in this area is removed to allow access to the floor. If necessary, the spare tire, accessory jack, tool compartments, and third row seats may be removed. The following test equipment is installed on the instrumentation rack located in the cargo area:

12-volt battery and monitoring system: This system supplies electrical power for the Diversified Technical Systems (DTS) data acquisition system (DAS), and a wireless bridge for DAS communication. The system weighs 35.2 kg. The wireless device for DAS-to-network communication is mounted to the outside of the vehicle and weighs 1.5 kg. A two-conductor cable connects the 12-volt battery in the instrumentation rack to the vehicle battery terminals.

High-speed camera and onboard lighting power supply: This system supplies electrical power to the onboard high-speed video cameras and LED lighting. The weight of the camera/lighting power supply is 26.0 kg.

Two camera mount platforms are installed on the nonstruck side of the vehicle at locations adjacent to the front and rear passenger window sills; the front and rear platforms weigh 22 and 12 kg, respectively. Three digital onboard high-speed cameras (500 frames per second), along with a camera router, are mounted on the platforms to observe dummy kinematics throughout the crash. Additionally, three LED lights are mounted inside the vehicle. The total weight of the three digital cameras, mounting hardware, camera router, cables, and lights is 19.6 kg.

A plastic block containing an array of high-intensity LEDs is attached to the roof of the vehicle with sheet metal screws. Additional LEDs are placed inside the vehicle in view of the onboard high-speed cameras. A pressure-sensitive tape switch is applied to the driver side of the vehicle such that it makes first contact with the barrier during the crash. Pressure applied to this tape completes an electrical circuit that signals the start of the crash (time-zero) for the data acquisition systems and illuminates all the LEDs.

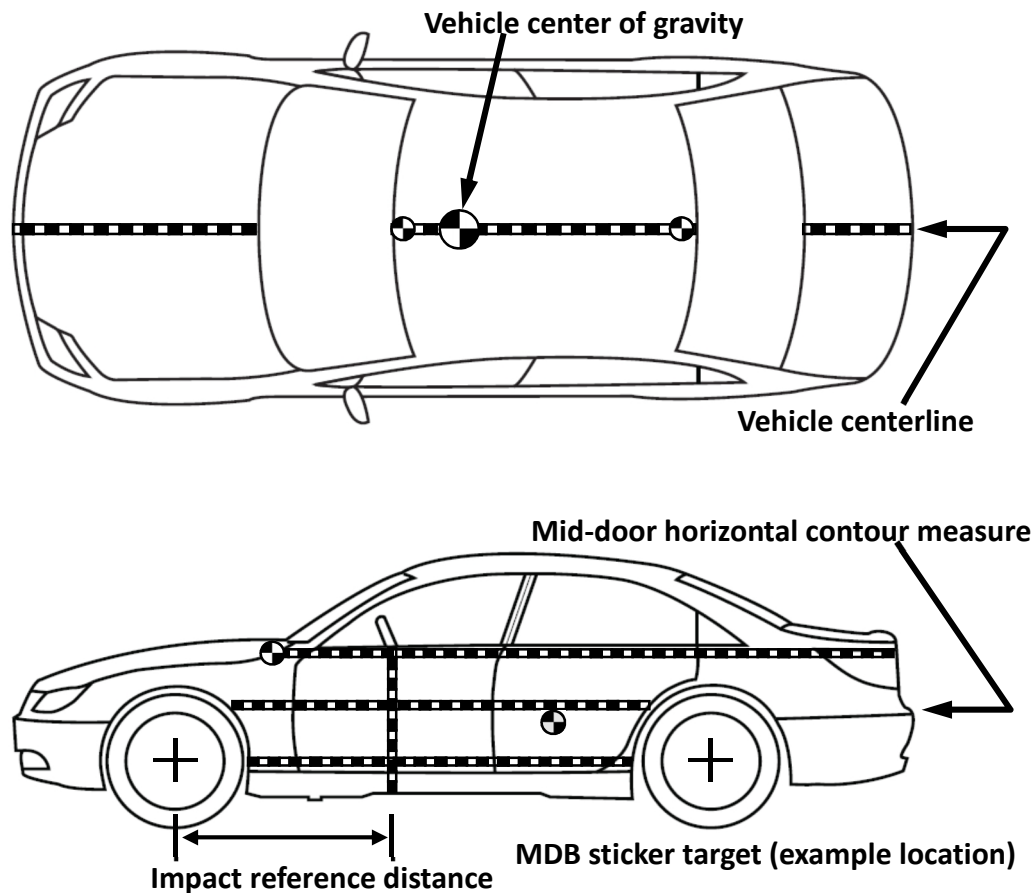
If floor mats are standard or offered as an option through the manufacturer or dealership, they are installed in the driver footwell and left rear passenger floorpan.

The location of the vehicle precrash longitudinal center of gravity is marked with a photographic target applied to the appropriate top surface of the vehicle (Figure 4).

The front passenger head restraint and passenger side windows are removed to prevent possible obstruction of camera views during the test.

If the vehicle is equipped with running boards, they are removed unless they are standard equipment across the entire model line for the specific drive configuration being tested (two-wheel or four-wheel drive).

Figure 4
Exterior Surface Marking



Attachment of Antiroll Device to Vehicles with High Centers of Gravity

To prevent a possible rollover subsequent to the side impact, vehicles with high centers of gravity (those classified by IIHS as SUVs, pickups, or passenger vans) will be tested with an antiroll device attached to the nonstruck side of the vehicle (Figure 5). The antiroll device is made primarily of 4130 Chromoly structural tubing and weighs 42.5 kg. It attaches to the vehicle where the roofrail intersects the B-pillar and at two points on the pinch welds under the door sill. The device is designed to allow the vehicle to rotate up to 5 degrees before further rotation is countered by a spring (14.8 kN/m) in the upper support member, which will allow an additional 5 degrees of rotation before bottoming out. Detailed drawings of the antiroll device are available free of charge from the IIHS website.

Test Vehicle Mass and Weight Distribution

The test weight of the vehicle, which includes the vehicle instrumentation, three cameras, and two SID-IIs dummies, is 150-225 kg greater than the measured curb weight of the vehicle (as delivered from the dealer with full fluid levels). If the vehicle test weight needs to be increased to fall within the range, ballast weight is distributed in a manner that comes closest to replicating the original front/rear and left/right weight distributions of the vehicle. If the vehicle test weight needs to be decreased, nonessential, nonstructural items are removed from the rear of the vehicle.

Figure 5
Antiroll Device for Tests of SUVs, Pickups, and Passenger Vans



Driver Seat and Driving Control Placement

The driver seat and adjustable steering controls are adjusted according to the *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V)* (IIHS, 2004). The outboard upper seat belt anchorage point (if adjustable) is set in the full-down position, unless otherwise specified by the test vehicle manufacturer. After the driver seat has been adjusted, the latching mechanism is examined to note whether all of its components are interlocked. If partial interlocking is observed and normal readjustment of the seat does not correct the problematic misalignment, the condition is noted and the test is conducted without repairing the mechanism. The right front passenger seat is set to match the position of the driver seat.

The driver head restraint (if manually adjustable) is set in the full-down position, unless otherwise specified by the test vehicle manufacturer. The head restraint height adjustment locking mechanism (if equipped) is examined to ensure the mechanism has engaged. All manually adjustable head restraint tilting mechanisms are adjusted to their full-rearward position.

The driver seat manually adjustable inboard armrest (if equipped) is moved to its lowered position. For vehicles equipped with multiple locking armrest positions, the position that results in the top surface of the armrest being closest to parallel with the ground is chosen. When seats have inboard and outboard armrests, both are placed in the lowered position.

Rear Passenger Seat Placement

If applicable, the rear passenger seat is positioned according to the *Dummy Seating Procedure for Rear Outboard Positions* (IIHS, 2005).

If manually adjustable, the rear passenger head restraint is set in the full-down position, unless otherwise specified by the test vehicle manufacturer. In cases where the head restraint can be lowered for stowage or positioned for non-use, it shall be set to the first usable locking position. All manually adjustable head restraint tilting mechanisms are adjusted to their full-rearward position.

The rear seat manually adjustable inboard armrest (if equipped) is moved to its lowered position. For vehicles equipped with multiple locking armrest positions, the position that results in the top surface of the armrest being closest to parallel with the ground is chosen. When seats have inboard and outboard armrests, both are placed in the lowered position.

Side Windows and Door Locks

The nonstruck side doors are fully latched and locked, whereas the struck side doors are fully latched but not locked. However, if the vehicle is equipped with automatic locking doors that cannot be set to remain unlocked when the vehicle is in forward motion, the struck side door locks are kept in their automatic state. The front and rear driver side windows are fully raised.

Transmission and Ignition

The ignition is turned to its on position, and the transmission is shifted into its neutral position prior to the test. The front left tire is chocked to prevent the vehicle from moving prior to the test.

Crash Dummy Preparation and Setup

A 5th percentile female SID-IIs dummy is positioned in the driver seat according to the *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V)* (IIHS, 2004). A second SID-IIs dummy is positioned in the left rear seat according to the *Dummy Seating Procedure for Rear Outboard Positions* (IIHS, 2005).

Standard Build Level D SID-IIs (Humanetics Innovative Solutions, 2011) dummies are used for the IIHS side impact program. The dummy has been modified by removing the upper and lower shoulder rib stops on the spine box (Humanetics Innovative Solutions, Inc., part numbers 180-3369 and 180-3370). Removal of the shoulder rib stops restores the shoulder deflection to the range that was allowable in the Standard Build Level C SID-IIs. The Build Level D shoulder potentiometer (Humanetics Innovative Solutions, Inc., part number 180-3381) has been replaced with a potentiometer (Humanetics Innovative Solutions, Inc., part number 180-3382) that has a longer travel range. Photographic targets are placed on both sides of the head to mark the location of its center of gravity.

The dummies used in these tests are calibrated according to 49 *CFR* 572 (V) after being subjected to no more than five crash tests. Additionally, the shoulder, thorax, and abdomen regions are individually recalibrated if deflections recorded during a test exceed 50 mm or if postcrash inspection reveals damage. All visible damage is repaired before the dummy is used again.

The dummies and vehicle are kept in a climate-controlled area in the crash hall where the temperature is maintained at 20.0-22.2 degrees Celsius and the relative humidity at 10-70 percent for at least 16 hours prior to the test. The driver and rear passenger seat belts are fastened around the dummies. For vehicles with continuous-loop lap/shoulder seat belts, the slack from the lap portion of the driver seat belt is removed, and the webbing is pulled fully out of the retractor and allowed to retract under tension a total of four times. The lap belt slack then is removed again with a small pulling force. For vehicles with separate lap and shoulder seat belt retractors, the webbing from each is pulled fully out of the retractor and allowed to retract under tension a total of four times. Prior to the crash, the heads of both dummies are colored with grease paint to facilitate postcrash identification of impacts with the vehicle interior and/or the striking barrier face.

Photography

Still Photography

The precrash and postcrash conditions of each test vehicle are photographed. Two precrash and two postcrash views show the side and left front quarter of the test vehicle. Additional photographs document the precrash position of the driver and rear passenger dummies.

Three standard views each of the vehicle and MDB together in their postcrash positions, of the struck side of the vehicle, and of the MDB face are recorded. Additional photographs document the postcrash positions of the driver and rear passenger dummies, as well as any paint transfer areas due to dummy contact with the vehicle or MDB. Once the dummies are removed from the vehicle, both seating compartment areas are photographed as a means of illustrating vehicle intrusion. Additional photographs are taken with the struck side doors removed.

High-Speed Motion Picture Photography

Motion picture photography is made of the test with nine high-speed digital imagers along with real-time cameras. The coordinates and lens focal length of each offboard camera are listed in Table 1. The

camera view and focal length of the onboard high-speed cameras are listed in Table 2. All high-speed imagers record at 500 frames per second. The positions of the offboard and onboard cameras are illustrated in Figures 6A and 6B, respectively.

Table 1
Crash Hall High-Speed Phantom Cameras – Coordinates, Focal Points, and Settings

	A	B	C	D	E	F
Camera Position	Overhead	Left Side Oblique	Front High	Front	Front Oblique (driver)	Front Oblique (drv-pass)
Coordinate X (cm)	-16	-536	-33	-18	415*	415*
Coordinate Y (cm)	-33	1350	768	668	740*	740*
Coordinate Z (cm)	910	149	194	250	146	146
Focal length (mm)	35	50	95	100	135	200

*Varies by vehicle size and type

Figure 6A
Offboard and MDB High-Speed Camera Positions in Crash Hall

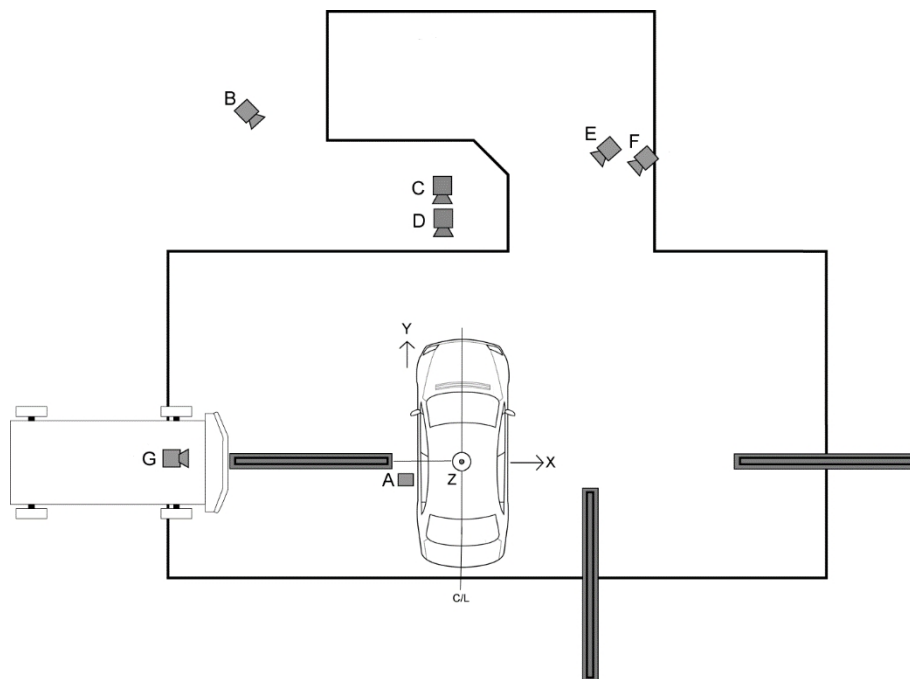
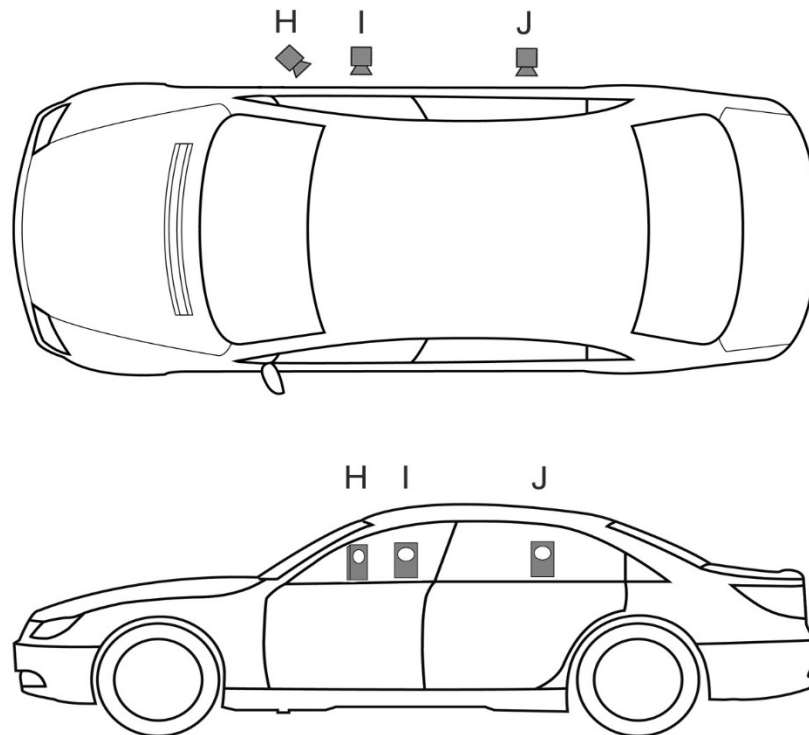


Table 2
Onboard High-Speed IDT Digital Cameras – Focal Points and Settings

	G	H	I	J
Camera Position	Centered On MDB	Front Passenger Window Sill	Front Passenger Window Sill	Rear Passenger Window Sill
Focal point	Impact from perspective of MDB	Oblique view of driver and passenger	Lateral view of driver	Lateral view of passenger
Focal length (mm)	10	10	16	10

Figure 6B
Onboard High-Speed IDT Camera Positions



MEASUREMENTS AND OBSERVATIONS

Test Weight

The test weight of the vehicle is measured at each of the four wheels. The vehicle is weighed with all test equipment installed (ballast weight is added to account for the driver and passenger dummies). In tests of SUVs, pickups, and passenger vans, the test weight is measured without the antiroll device attached. The front and rear axle weights are used to determine the longitudinal position of the center of gravity for the test vehicle.

Impact Speed

The barrier impact speed is determined by averaging two speed trap measurements. Both speed traps measure the average velocity of the barrier between 1.0-1.5 m before impact with the vehicle. The propulsion system also has an optical speed measuring device that serves as a backup to the two speed traps. This device measures the speed of the hardware attaching the barrier to the propulsion system immediately prior to barrier's release from the propulsion system before impact. The speed is clocked over a 1 m length of vehicle travel ending 0.5 m before the barriers's release from the propulsion system.

Impact Point

A threaded 0.125 inch (3 mm) rod with a sharpened tip is attached to a tapped hole in the leading edge of the MDB bumper aluminum cladding. The horizontal location of this impact striker is selected such that it contacts the vehicle structure rearward of the driver door at the point of impact. The impact striker extends 20-30 mm from the front edge of the barrier face, thus it makes first contact between the barrier and the vehicle. A 3 inch (76 mm) diameter photo target is placed on the vehicle (Figure 4) so that the tip of the impact striker is located in the center of the target during precrash vehicle positioning. At the point of impact, the striker punctures the target, thus providing an indication of the initial MDB alignment with respect to the vehicle.

Vehicle Accelerations

The lateral acceleration of the vehicle occupant compartment is measured (Endevco 7264B-2000 or 7264A-2000 accelerometers) at two locations on the floor, just rearward of the A- and B-pillars (nonstruck side), and recorded by the data acquisition system. Positive vehicle accelerations are to the right along the lateral axis. The data are presented filtered according to the channel frequency class (CFC) 60 as defined in SAE J211 – Instrumentation for Impact Tests (Society of Automotive Engineers (SAE), 2000).

Fuel System Integrity

Observations about fuel system integrity are recorded for each test. Any Stoddard fluid leaked from the fuel system within 1 minute after the impact is collected as the first sample. This typically is done by soaking up the fluid with an absorbent pad of known mass. The second sample of leaked Stoddard fluid is collected during the 5 minutes immediately following the collection of the first sample. This sample typically is collected in pans placed under the sources of identified leaks. The third sample is collected during the 25 minutes immediately following the collection of the second. The pans used to collect the second sample are replaced with clean empty pans. The volume of each sample is determined by dividing the weight of the sample by the density of Stoddard fluid (790 g/l). The elapsed time is determined using a stopwatch. The entire process is recorded with a video camera equipped with an internal timer, which displays the time in each frame.

High-Voltage System Integrity

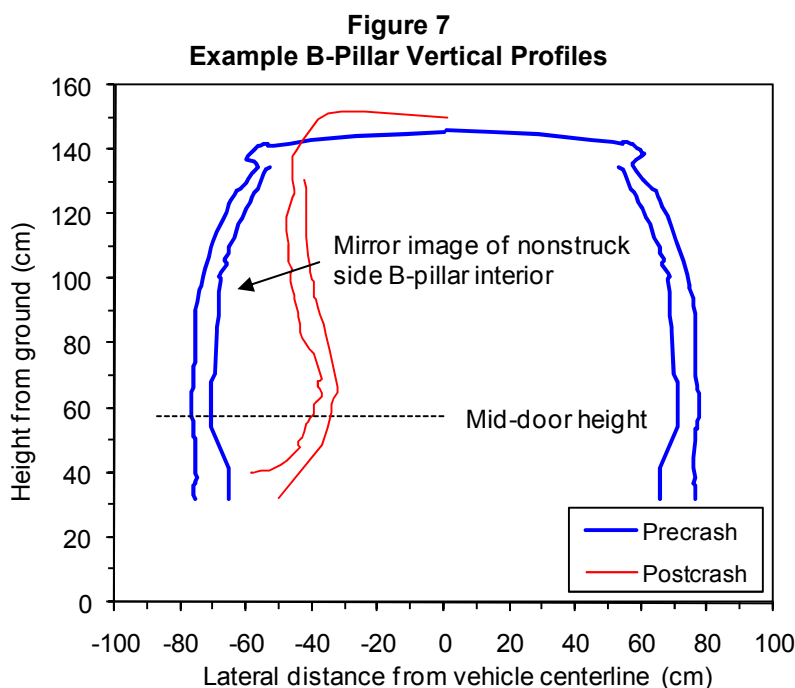
Vehicles with a hybrid or full-electric drivetrain are monitored to ensure the high-voltage electrical system has not been compromised. Postcrash observations include a measure of electrolyte spillage (if any), battery retention, and electrical isolation of the high-voltage system as per FMVSS 305. Additionally, the battery temperature will be monitored to detect a rapid increase in temperature that may indicate a thermal runaway condition. Following the crash, power will be drained from high-voltage systems in a manner specified by the manufacturer.

Vehicle Crush Profile and Compartment Intrusion

The spatial coordinates of the test vehicle B-pillars and profile of the driver side structure are measured before and after the crash. A horizontal contour line is marked on the driver side of the vehicle at the level of the mid-door (Figure 4) and then recorded using a coordinate measuring machine (Romer CimCore Inc.). This contour line is measured after the crash using the same reference coordinate system. Precrash measures are recorded on the struck side B-pillar exterior and the nonstruck side B-pillar exterior and interior (with interior trim removed); postcrash measures are recorded on the struck side B-pillar exterior and interior (with interior trim removed). Precrash measures on the struck side B-pillar interior are not recorded due to the possibility that removal and reattachment of the interior trim could affect the deployment of roofrail-mounted head curtain airbags. A mirror image of the nonstruck side B-pillar interior vertical profile will be used to determine the relative movement of the B-pillar interior. Figure 7 shows an example of precrash and postcrash B-pillar vertical profile measures.

Coordinate System Definition

A right-handed, three-axis orthogonal coordinate system is used for these measures: longitudinal (front to rear is positive), lateral (left to right is positive), and vertical (bottom to top is positive). The precrash coordinate system is defined with the vehicle unloaded (no occupants) on a level floor. The plane of the ground is used to define the X-Y plane, and the two end points on the centerline of the roof are used to define the X-axis (Figure 4). Coordinates of three marked reference points on the nonstruck side vehicle structure are recorded before the crash to establish the postcrash coordinate system.



Dummy Kinematics and Contact Locations

Both dummies are inspected in their undisturbed postcrash positions. Any damage to or unusual final resting position observed for either dummy is documented. The locations of grease paint transferred from the heads of the dummies to the vehicle interior and/or barrier face are noted and photographed. Any entrapment of the lower extremities also is documented when the dummies are extricated from the vehicle.

Review of the high-speed video helps determine dummy kinematics and estimate the time after the start of the crash that various events occur. For each event, the camera that provides the clearest view of the event is used. The start of the crash is considered to be the first frame in the video from each camera in which the LEDs mounted on the roof and inside the vehicle are illuminated. The time recorded for each event is based on the number of frames elapsed from the start of the crash and the nominal operating speed of the camera. For the cameras operating at 500 frames per second, the estimate of the crash start time can be up to 2 ms late, and the event time, as determined from the film, can be early or late by 2 ms. The times of the driver and passenger side airbag deployments, full inflation, and first dummy contacts are recorded as well as any other notable events.

Dummy Responses

Each SID-IIs dummy is equipped with instrumentation for measuring the following:

Head

- Tri-axial accelerations (three Endevco 7264B-2000 or 7264A-2000 accelerometers)
- Triaxial angular rate sensors (three DTS ARS Pro – 18k)

Neck

- A-P shear force
- L-M shear force
- Axial force
- L-M moments
- Twist moments (Humanetics IF-205 or Humanetics 1716A load cell)

Shoulder

- Triaxial forces (Humanetics IF-344 or Humanetics 3167 load cell)
- Lateral shoulder compression (Humanetics 180-3882 0.5 inch linear potentiometer)

Spine

- T1, base of the neck, lateral acceleration (Endevco 7264B-2000* accelerometer)
- T4, first thoracic rib level, lateral acceleration (Endevco 7264B-2000* accelerometer)
- T12, first abdominal rib level, lateral acceleration (Endevco 7264B-2000* accelerometer)

Chest and Abdominal Ribs (three thorax and two abdominal ribs)

- Struck side lateral rib accelerations (Endevco 7264B-2000 or 7264A-2000 accelerometers)
- Lateral rib compressions (Humanetics 180-3881 0.5 inch linear potentiometers)

Pelvis

- Lateral acceleration (Endevco 7264B-2000 or 7264A-2000 accelerometers)
- Lateral acetabulum force (Humanetics IF-520 or Humanetics 3249 load cell)
- Lateral ilium crest force (Humanetics IF-507 or Humanetics 3228 load cell)

Lower Extremities

- Left lower femur L-M force and L-M and A-P moments (Humanetics IF-625 or Humanetics 1914A load cell)

All instruments are regularly calibrated to a known standard. Accelerometers and load cells are calibrated every 12 months. All measurements recorded from these instruments comply with the recommendations of SAE Information Report J1733 – Sign Convention for Vehicle Crash Testing DEC94 (SAE, 2000).

DTS TDAS G5 data acquisition systems are used for all dummy and vehicle data acquisition. All measurements are recorded in the system random access memory with 16-bit resolution at a sample rate of 10 kHz. Signals in all channels convert simultaneously, so the time reference for different channels is not skewed. To ensure digital fidelity, all signals are filtered by an analog low-pass prefilter with a 3 kHz cutoff frequency.

After the data have been downloaded from the data acquisition systems, any initial offset from zero is removed from each channel by computing the mean value for 100 data points preceding the crash event (from 50 to 40 ms before impact) for each channel and subtracting each mean from the respective data channel. With the exception of rib deflection and pelvis acceleration data, which are filtered to SAE CFC 180, all other data are digitally filtered using the frequency response classes recommended in SAE Recommended Practice J211/1 – Instrumentation for Impact Test – Part 1, Electronic Instrumentation MAR95 (SAE, 2000). All filtering and subsequent calculations are executed using DIAdem (National Instruments Corporation, 2010).

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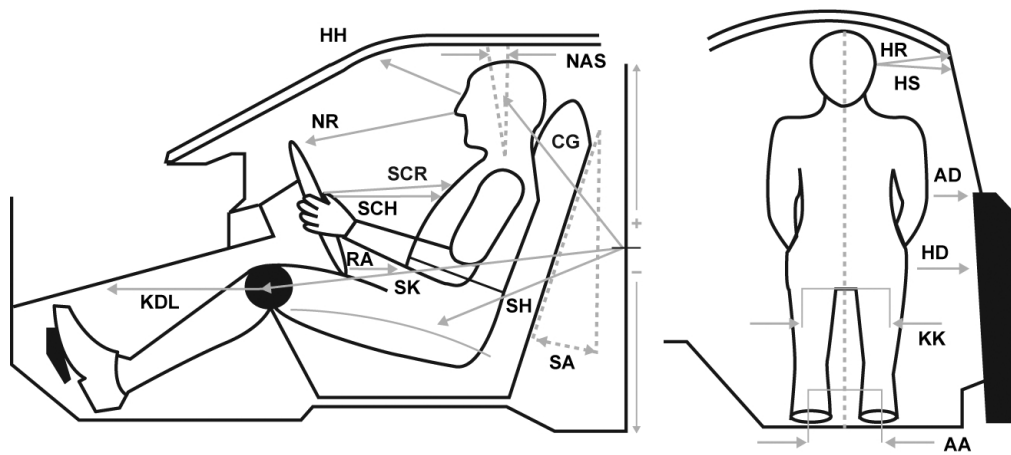
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APPENDIX A

Driver Dummy Clearance Measurement Definitions



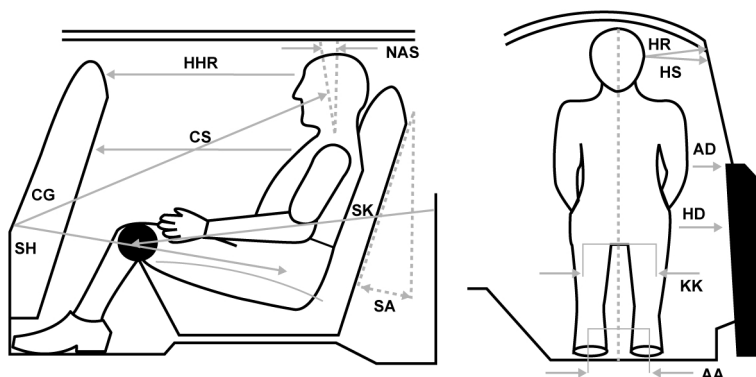
Location	Code	Definition of Measurement
Ankle to ankle	AA	Taken between the center points of both ankles, after the feet are placed per IIHS protocol.
Arm to door	AD	Horizontal measurement taken from the center point of the elbow to the first contact point of the door panel.
Armrest to dummy, minimum	ADM	Minimum horizontal measurement taken from the vehicle armrest to the dummy.
Head to A-pillar	HA	Horizontal measurement taken from the center of the head outboard center of gravity target to the A-pillar (<i>not shown in figure</i>).
Hub to chest, minimum	HCM	Minimum horizontal distance measured from the hub to the dummy chest (<i>not shown in figure</i>).
H-point to door	HD	Horizontal measurement taken from the H-point hole to the first contact point of the door panel.
Head to header	HH	Taken from the center point between the eyes to the header directly in front of dummy.
Head to roof	HR	Taken from the center of the outboard target to the roof edge (not the upper edge of the vehicle door), perpendicular to the longitudinal axis of the vehicle. If a tape measure is held from the target and extends below the roof, the point to measure is at the low edge of the roof line, which will make contact with the tape measure.
Head to side window	HS	Taken from the center of the outboard target to the side window, measured horizontally and perpendicular to the longitudinal axis of the vehicle. In cases where the window is not fully up, a flat bar should be placed across the window opening to simulate the position of the window.
Knee to dash, left	KDL	Taken from the knee pivot point to the point on the dash that is directly level with the center of the knee.

continued

Location	Code	Definition of Measurement
Knee to knee	KK	With the legs in a vertical plane after the feet are placed per IIHS protocol, the measurement is taken from the outside flange to the outside flange of the knees. The minimum distance is 270 mm (10.6 inches).
Neck angle, seated	NAS	Taken from the neck when the dummy is seated across two of the “vertebral disks” of the neck.
Nose to rim	NR	Taken from the tip of the nose to the steering wheel rim at the 12 o'clock position.
Pelvis angle	PA	Taken from the instrumented pelvis sensor (if available) or by placing an inclinometer on the H-point bar, which is used to align the H-point with previous measurements.
Rim to abdomen	RA	Taken from the point where the bottom of the chest jacket and the pelvis structure meet the steering wheel rim at the 6 o'clock position.
Seat back angle	SA	Taken from the lower left corner of the driver seat back unless otherwise directed by the manufacturer, at which time it will be properly noted along with the measurement.
Steering wheel to chest, horizontal	SCH	Horizontal measurement taken from the center of the steering wheel to the dummy chest.
Steering wheel to chest, reference	SCR	Taken from the center of the steering wheel to the top rib guide (SID-IIs dummies).
Striker to head CG, horizontal	CGH	Horizontal measurement taken from the head center of gravity to the driver door striker. Value is negative if the head center of gravity is forward of the striker.
Striker to head CG, lateral	CGL	Lateral measurement taken from the head center of gravity to the driver door striker.
Striker to head CG, vertical	CGV	Vertical measurement taken from the head center of gravity to the driver door striker. Value is negative if the head center of gravity is below the striker.
Striker to H-point, horizontal	SHH	Horizontal measurement taken from the H-point to the driver door striker. Value is negative if the H-point is forward of the striker.
Striker to H-point, lateral	SHL	Lateral measurement taken from the H-point to the driver door striker.
Striker to H-point, vertical	SHV	Vertical measurement taken from the H-point to the driver door striker. Value is negative if the H-point is below the striker.
Striker to knee	SK	Taken from the center point of the knee to the front door striker.
Striker to knee angle	SKA	Calculated using the coordinates of the knee pivot point and the location of the driver door striker.
Torso recline angle	TRA	Taken from the H-point to the head center of gravity.

APPENDIX B

Rear Passenger Dummy Clearance Measurement Definitions



Location	Code	Definition of Measurement
Ankle to ankle	AA	Taken between the center points of both ankles, after the feet are placed per IIHS protocol.
Arm to door	AD	Horizontal measurement taken from the center point of the elbow to the first contact point of the door panel.
Armrest to dummy, minimum	ADM	Minimum horizontal measurement taken from the vehicle armrest to the dummy.
Chest to seat, horizontal	CS	Horizontal measurement taken from the top rib guide in the chest to a point on the back of the driver seat.
Head to B-pillar	HB	Horizontal measurement taken from the center of the head outboard center of gravity target to the B-pillar (<i>not shown in figure</i>).
H-point to door	HD	Horizontal measurement taken from the H-point hole to the first contact point of the door panel.
Head to head restraint	HHR	Horizontal measurement taken from center point between the eyes to the back side of the driver head restraint directly in front of the dummy.
Head to roof	HR	Taken from the center of the outboard target to the roof edge (not the upper edge of the vehicle door), perpendicular to the longitudinal axis of the vehicle. If a tape measure is held from the target and extends below the roof, the point to measure is at the low edge of the roof line, which will make contact with the tape measure.
Head to side window	HS	Taken from the center of the outboard target to the side window, measured horizontally and perpendicular to the longitudinal axis of the vehicle. In cases where the window is not fully up, a flat bar should be placed across the window opening to simulate the position of the window.
Knee to knee	KK	With the legs in a vertical plane after the feet are placed per IIHS protocol, the measurement is taken from the outside flange to the outside flange of the knees. The minimum distance is 270 mm (10.6 inches).

continued

Location	Code	Definition of Measurement
Neck angle, seated	NAS	Taken from the neck when the dummy is seated across two of the “vertebral disks” of the neck.
Pelvis angle	PA	Taken from the instrumented pelvis sensor (if available) or by placing an inclinometer on the H-point bar, which is used to align the H-point with previous measurements.
Seat back angle	SA	Taken from the lower left corner of the rear passenger seat back unless otherwise directed by the manufacturer, at which time it will be properly noted along with the measurement.
Striker to head CG, horizontal	CGH	Horizontal measurement taken from the head center of gravity to the rear door striker. Value is negative if the head center of gravity is forward of the striker.
Striker to head CG, lateral	CGL	Lateral measurement taken from the head center of gravity to the rear door striker.
Striker to head CG, vertical	CGV	Vertical measurement taken from the head center of gravity to the rear door striker. Value is negative if the head center of gravity is below the striker.
Striker to H-point, horizontal	SHH	Horizontal measurement taken from the H-point to the rear door striker. Value is negative if the H-point is forward of the striker.
Striker to H-point, lateral	SHL	Lateral measurement taken from the H-point to the rear door striker.
Striker to H-point, vertical	SHV	Vertical measurement taken from the H-point to the rear door striker. Value is negative if the H-point is below the striker.
Striker to knee	SK	Taken from the center point of the knee to the rear door striker.
Striker to knee angle	SKA	Calculated using the coordinates of the knee pivot point and the location of the rear door striker.
Torso recline angle	TRA	Taken from the H-point to the head center of gravity.

APPENDIX C

Document Revision History

Revisions to Version VII of the protocol compared to Version VI:

- Explanation of dummy injury measure calculations was moved to the Side Impact Guidelines for Rating Injury Measures.
- The removal of the shoulder rib stops from the SID-II's outlined.
- The weight of the onboard test equipment was updated.
- The maximum allowable test weight above measured curb weight was increased from 200 kg to 225 kg.
- The photography section now indicates high-speed digital imagers are now used instead of high-speed film cameras. Crash hall positions of the cameras have also been updated.
- Additional instruction of where to place the rear passenger head restraint in cases where it can be stowed for non-use.

Revisions to Version VI of the protocol compared with Version V:

- IRD is now measured from front axle to barrier centerline.
- High-voltage systems found in vehicles with electric drivetrains are discussed in the Test Conditions and Measurements/Observations sections.
- Denton IDDAS DAS no longer used.
- SID-II'sD dummy is now being used to match the regulated version of the dummy being used by the National Highway Traffic Safety Administration.
- Data processing is now conducted with the DIAdem software program.

Revisions to Version V of the protocol compared with Version IV:

- The method of determining the impact point for vehicles with very short wheelbases may deviate from the impact point defined by the impact reference distance calculation.
- Impact point and impact speed tolerances of ± 2.5 cm and ± 1 km/h have been added.
- The reference to and specifications for the IIHS low-speed bumper test program have been replaced with the IIHS bumper test program.
- Additional detail has been provided for the weight of the on-board cameras, data acquisition units, and the platforms used to support them.
- Clarification has been provided for the treatment of vehicles equipped with running boards.
- If a vehicle is equipped with automatic locking doors that cannot be set to remain unlocked when the vehicle is in motion, the struck side door locks are kept in their automatic state.
- Either Humanetics IDDAS or DTS TDAS G5 data acquisition systems may be used to record all dummy and vehicle data. Both units are being used during an interim period, after which only the TDAS G5 units will be used as part of an in-dummy data acquisition system.

Revisions to Version IV of the protocol compared with Version III:

- The reference list reflects recent updates to the *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V)*.
- Precrash and postcrash vehicle crush profiles measured at the window sill and rocker panel and the door vertical profiles measured at the driver and rear passenger H-point locations have been eliminated.
- Precrash and postcrash crush profile measures of the moving deformable barrier (MDB) deformable element have been eliminated.

Revisions to Version III of the protocol compared with Version II:

- The MDB vertical center of gravity was updated to reflect official measurements taken at an inertial measurement facility.
- Roll, pitch, and yaw moments of inertia also were added to the MDB specifications.

Revisions to Version II of the protocol compared with Version I:

- In addition to postcrash photographs of the vehicle taken with the struck side doors on, photos are taken with the door skins removed, then again with the doors removed.
- Additional structural measures are recorded on the struck and nonstruck side B-pillar interior. In addition, the postcrash coordinate system is now reestablished using reference points that are recorded precrash.
- The pubic force load measurement was eliminated.

Annex IV



Side Impact Crashworthiness Evaluation

Moving Deformable Barrier Specification

October 2007

Side Impact Crashworthiness Evaluation Moving Deformable Barrier Specification

Scope

This specification describes a deformable impact barrier to be used in Insurance Institute for Highway Safety side impact crashworthiness evaluations.

Purpose

The design and performance criteria described in this specification are intended to provide a measurement tool with sufficient precision to ensure repetitive and correlative results under similar test conditions and to reflect adequately the protective performance of a motor vehicle or item of motor vehicle equipment with respect to human occupants.

General Description

The side impact moving deformable barrier consists of two parts: a main honeycomb block and a bumper consisting of three honeycomb elements. Both honeycomb layers are covered with aluminum sheets and adhesively bonded to each other. Barrier construction and assembly drawings (Figures 1-10) are included at the end of the specification.

Barrier Component Dimensions and Specifications

The dimensions of the moving deformable barrier are illustrated in Figure 1. All dimensions allow a tolerance of ± 2.5 mm and ± 0.5 degrees unless otherwise specified.

Main Honeycomb Block Material

The main honeycomb block is manufactured out of aluminum 5052, with a cell size of 9.5 mm, a density of $25.6 \text{ kg/m}^3 \pm 4 \text{ kg/m}^3$, and a crush strength of $310 \text{ kPa} \pm 17 \text{ kPa}$, measured in accordance with the certification procedure described in US Department of Transportation, NHTSA, Lab Test Procedure for FMVSS No. 214 “Dynamic” Side Impact Protection, TP214D Appendix C TP214D-07 C-1.

The main honeycomb block is cut/shaped from one honeycomb block to exhibit the length, width, height, and bevel dimensions shown in Figure 2, with the foil ribbon running parallel to the length dimension and the cell axis running parallel to the height dimension.

Bumper Element Honeycomb Material

The bumper element honeycomb is manufactured out of aluminum 3003, with a cell size of 6.35 mm, a density of $83.0 \text{ kg/m}^3 \pm 4 \text{ kg/m}^3$, and a crush strength of $1690 \text{ kPa} \pm 103 \text{ kPa}$, measured in accordance with the certification procedure described in US Department of Transportation, NHTSA, Lab Test Procedure for FMVSS No. 214 “Dynamic” Side Impact Protection, TP214D Appendix C TP214D-07 C-1.

The bumper section consists of three individual honeycomb elements that are cut from one honeycomb block to exhibit the length, width, height, bevel, and contour dimensions shown in Figure 3, with the foil ribbon running parallel to the width dimension and the cell axis running parallel to the height dimension.

Main Honeycomb Base Plate

Dimensions – The backing sheet has a height of $860 \text{ mm} \pm 1.0 \text{ mm}$ and a width of $1676 \text{ mm} \pm 1.0 \text{ mm}$ as shown in Figure 4.

Material – The main honeycomb backing sheet is manufactured out of aluminum 5251 H22 or 5052 H34, with a thickness of 0.8 mm $\pm$ 0.05mm.

Main Honeycomb Top Cladding

Dimensions – The cladding sheet covers the top and front face of the main honeycomb block. The cladding sheet blank is cut to the dimensions shown in Figure 5 and then bent along the indicated folding lines in Figure 5 to attain a folded shape that matches the top and front surfaces of the main honeycomb block as shown in Figure 6.

Material – The main honeycomb cladding sheet is manufactured out of aluminum 5251 H24 or 5052 H34, with a thickness of 0.7 mm $\pm$ 0.04 mm.

Main Honeycomb Upper Corner Plate

Dimensions – The top corner plate covers the intersection of the top and front face of the main honeycomb. The top corner plate blank is cut to the dimensions shown in Figure 7 and then bent along the indicated folding lines in Figure 7 to attain the contoured shape as shown in Figure 8.

Material – The top corner plate is manufactured out of aluminum 5251 H24 or 5052 H34, with a thickness of 1.6 mm $\pm$ 0.07 mm.

Bumper Element Base Plate

Dimensions – The bumper element backing sheet blank has a height of 203 mm $\pm$ 1.0 mm and is bent to the dimensions shown in Figure 9, matching the final shape of the front surface of the main honeycomb cladding sheet after this cladding sheet has been bonded to the main honeycomb block.

Material – The bumper element backing sheet is manufactured out of aluminum 5251 H22 or 5052 H34, with a thickness of 3.0 mm $\pm$ 0.07 mm.

Bumper Element Profile Sheet

Dimensions – The bumper element cladding sheet blank has a height of 159 mm $\pm$ 1.0 mm and shall be bent to the dimensions shown in Figure 10.

Material – The bumper element backing sheet is manufactured out of aluminum 5251 H22 or 5052 H34, with a thickness of 3.0 mm $\pm$ 0.07 mm.

Adhesive Bonding Procedure

Prior to bonding, all aluminum backing and cladding sheets shall be degreased. The adhesive to be used throughout should be a two-part polyurethane (such as Ciba Geigy XB5090/1 resin with XB5304 hardener) or equivalent.

Bonding Strength Tests

- Flatwise tensile testing is used to measure bond strength of adhesive according to ASTM C 297.
- The test pieces should be 100 mm $\times$ 100 mm, and 15mm deep, bonded to a sample of the back plate material. The honeycomb used should be representative of that in the impactor.
- The minimum bonding strength shall be 0.6 MPa (87 psi).

The adhesive is only applied to the aluminum sheet surfaces when bonding aluminum sheets to honeycomb surfaces. A maximum of 0.5 kg/m² must be applied evenly over the surface, giving a maximum film thickness of 0.5 mm.

Construction

The *main honeycomb block* is centered on and adhesively bonded to its *back plate*. The back plate extends beyond the height of the main honeycomb block at the bottom and top, providing mounting flanges. The front portion of the *top cladding* is bonded to the main honeycomb block. The top portion of the top cladding is not bonded to the cell edges of the honeycomb block. The top cladding sheet flange, integral to the top portion of the main honeycomb cladding sheet, is overlapping, but not bonded to the top flange of the main honeycomb backing sheet.

The *main honeycomb upper corner plate* is positioned over the edge of the top and front portion of the main honeycomb top cladding and attached via bonding and pop-rivets.

The three *bumper honeycomb element* sections are adhesively bonded to the *bumper base plate* and *bumper profile* such that the honeycomb cell axes are perpendicular to both sheets and such that the bottom contour of the bonded bumper assembly closely matches the front face contour of the main honeycomb assembly.

Clearance holes for mounting the deformable barrier are located in the flange of the main honeycomb base plate as shown in Figure 1.

Barrier Identification and Marking

Each barrier shall carry a serial number that is stamped, etched, or otherwise permanently attached, from which the manufacturing details and version can be established.

Barrier Certification

Each barrier shall have (included in its shipping container or in electronic format) a certification package available providing information according to US Department of Transportation, NHTSA, Lab Test Procedure for FMVSS No. 214 “Dynamic” Side Impact Protection, TP214D Appendix C TP214D-08 C-1.

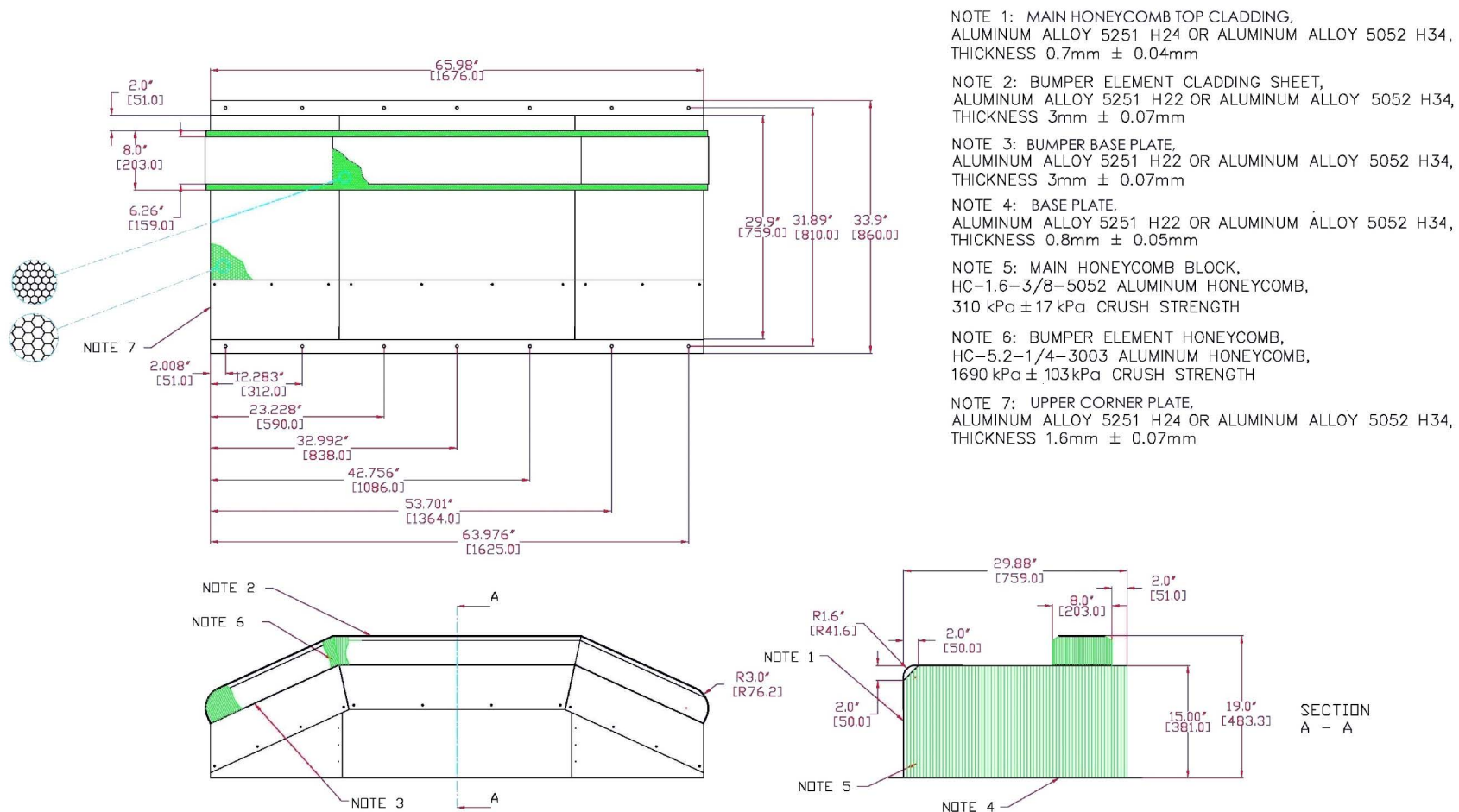
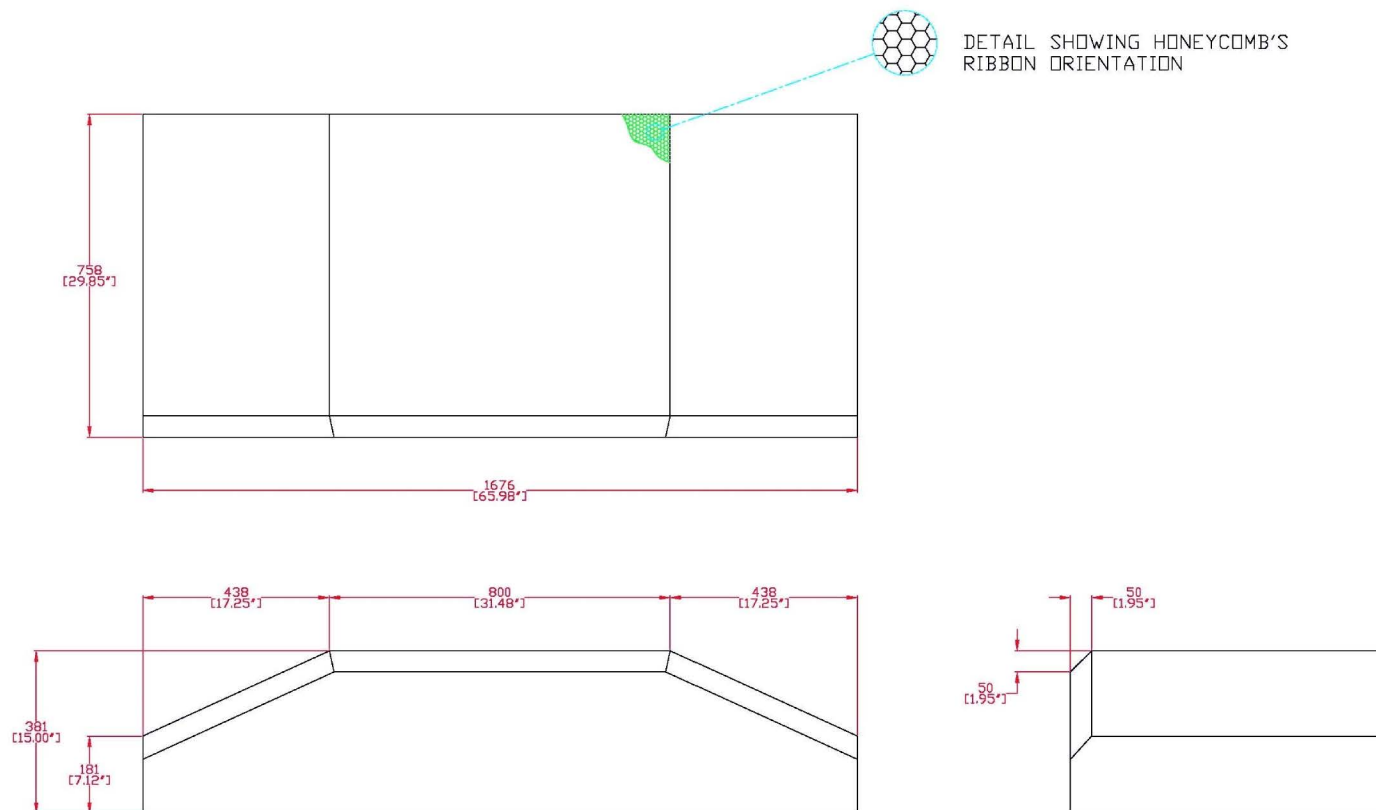


FIG 1.

IIHS Specification
Side Impact Moving Deformable Barrier

Side Impact barrier
General Assembly

Rev 2, 20-9-2007



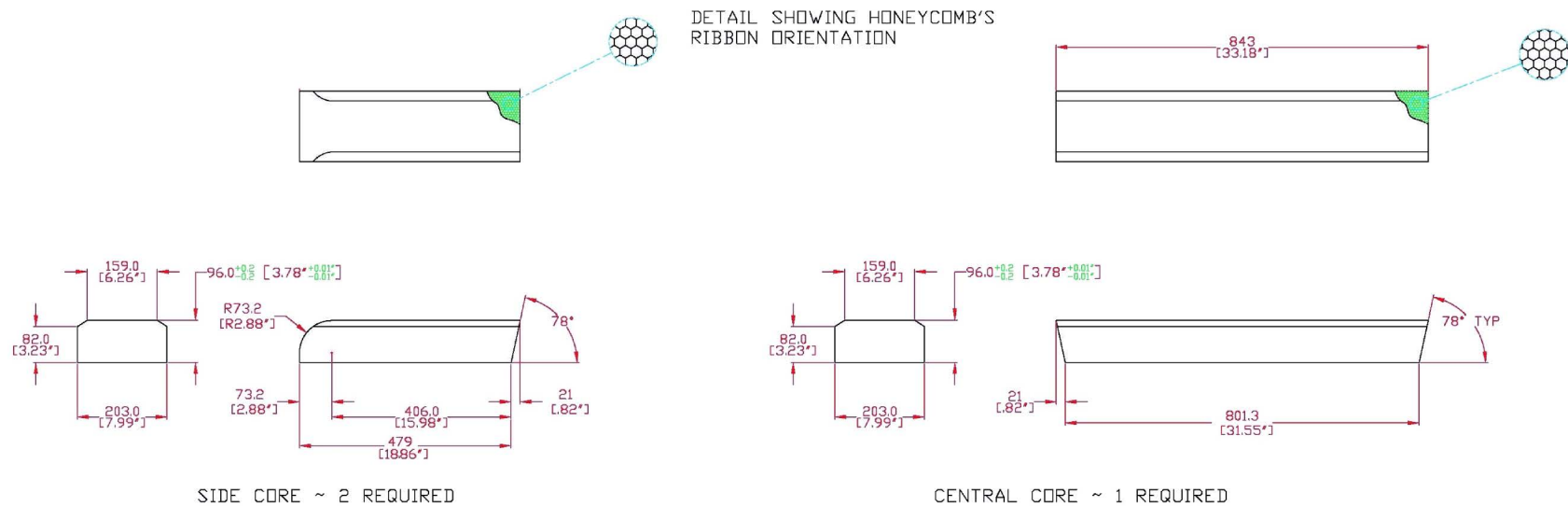
NOTE: DUE TO THE NATURE OF HONEYCOMB AND MANUFACTURE
USED, DETAILED DIMENSIONAL CHECKS ARE NOT PERFORMED
UNTIL THE CLADDING AND CORE HAVE BEEN BONDED

FIG 2.

IIHS Specification
Side Impact Moving Deformable Barrier

Main Honeycomb Block
Material: Aluminum Honeycomb
HC-1.6-3/8-5052

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NOTE: DUE TO THE NATURE OF HONEYCOMB AND MANUFACTURE USED, DETAILED DIMENSIONAL CHECKS ARE NOT PERFORMED UNTIL THE CLADDING AND CORE HAVE BEEN BONDED

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FIG 3.

IIHS Specification
Side Impact Moving Deformable Barrier

Bumper Element Honeycomb Blocks
Material: Aluminum Honeycomb
HC-5.2-1/4-3003

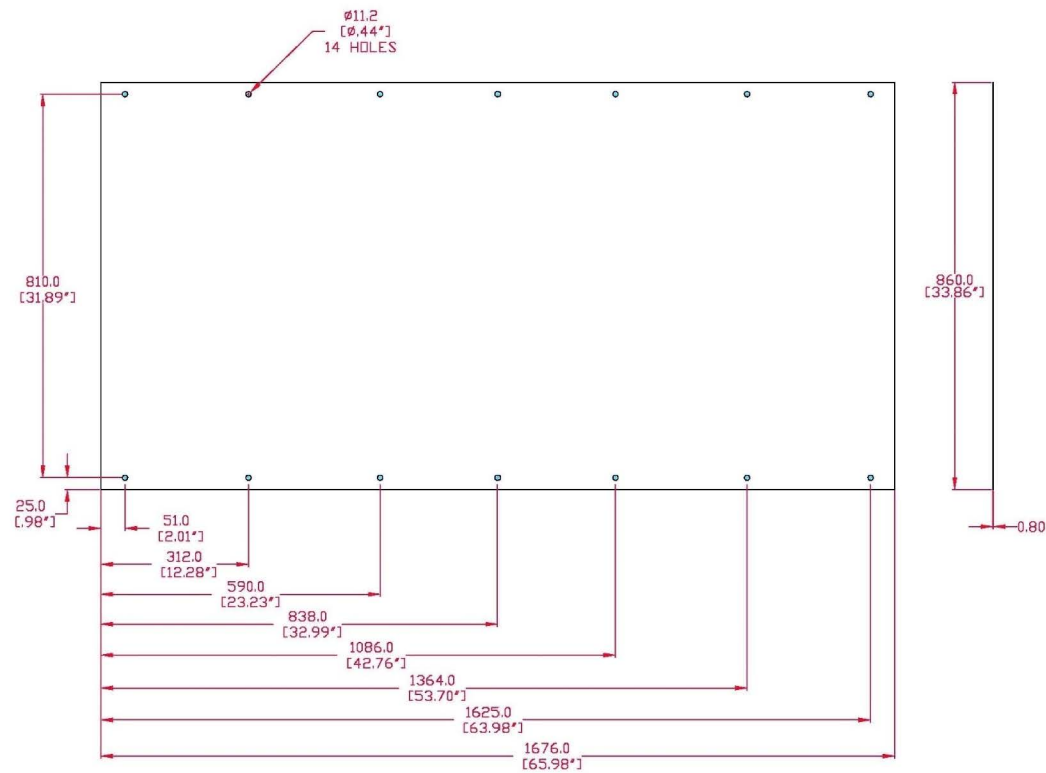


FIG 4.

IIHS Specification
Side Impact Moving Deformable Barrier

Base Plate

Material: Al. Alloy 5251 H22 0.8mm
Or Al. Alloy 5052 H34 0.8mm

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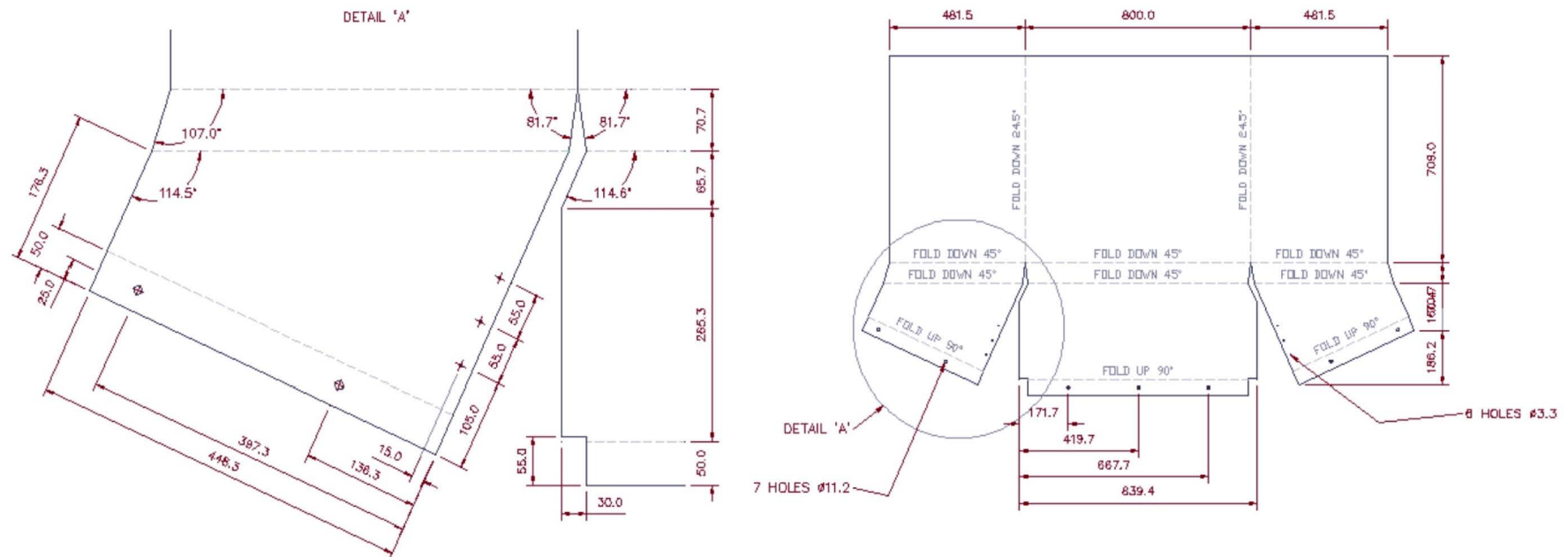
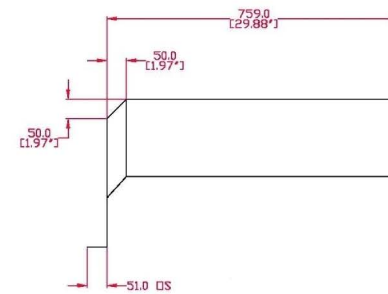
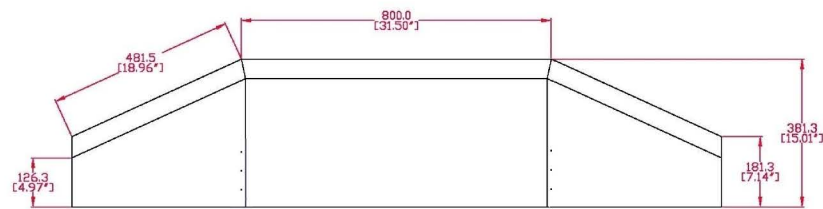
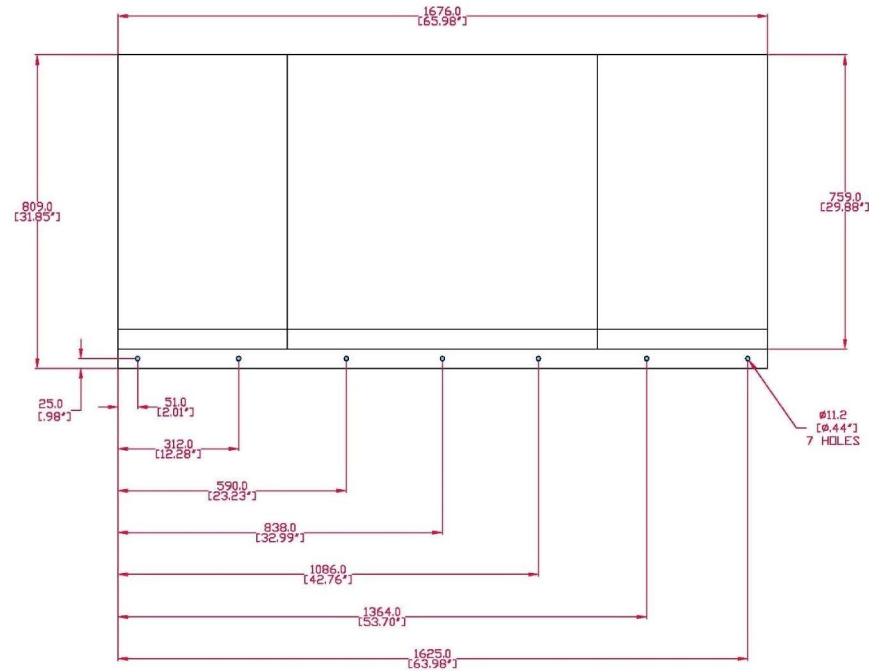


FIG 5.

IIHS Specification
Side Impact Moving Deformable Barrier

Main Honeycomb Top
Cladding ~ blank
Material: Al. Alloy 5251 H24 0.7mm
or Al. Alloy 5052 H34 0.7mm

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FIG 6.

IIHS Specification
Side Impact Moving Deformable Barrier

Main Honeycomb Top
Cladding ~ folded
Material: Al. Alloy 5251 H24 0.7mm
Or Al. Alloy 5052 H34 0.7mm

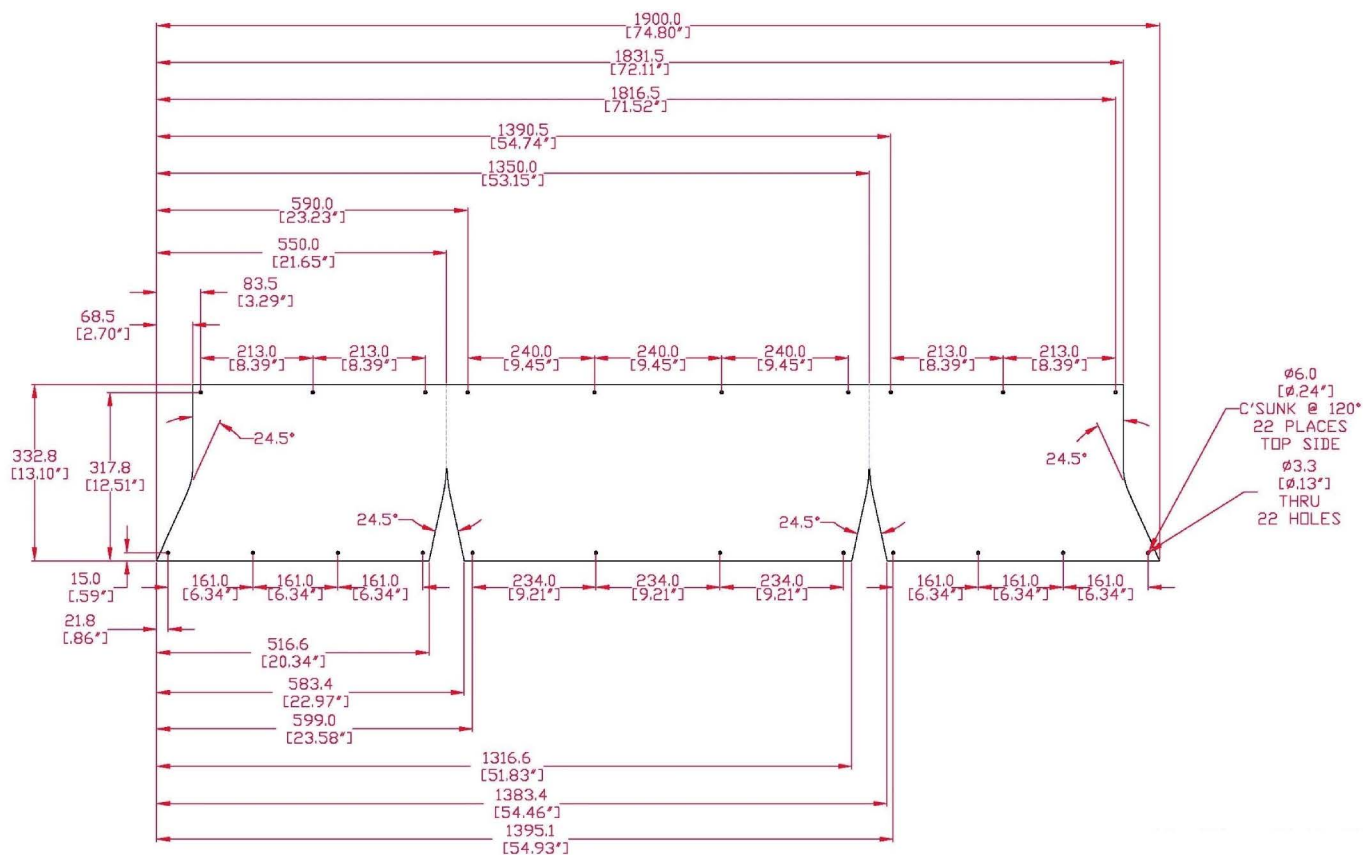
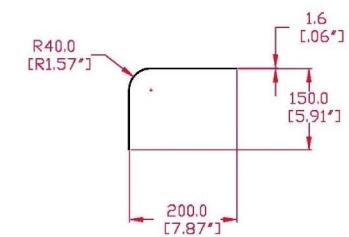
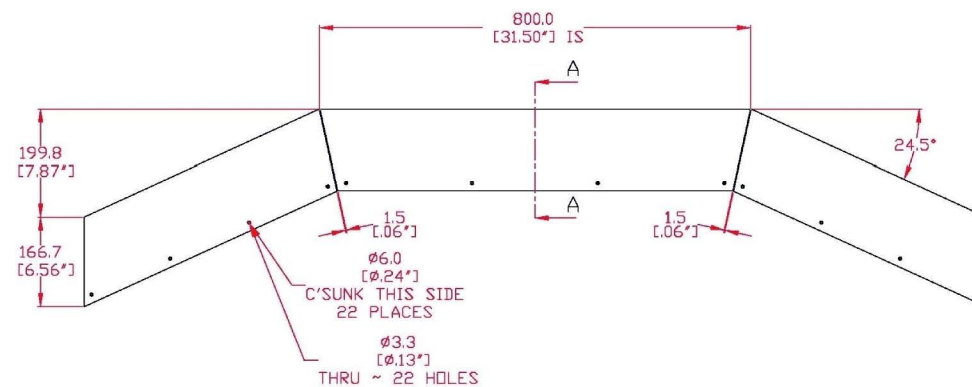


FIG 7.

IIHS Specification
Side Impact Moving Deformable Barrier

Upper Corner Plate ~ blank
Material: Al. Alloy 5251 H24 1.6mm
Or Al. Alloy 5052 H34 1.6mm

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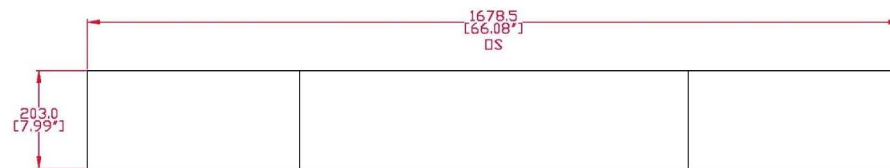
SECTION: A - A

FIG 8.

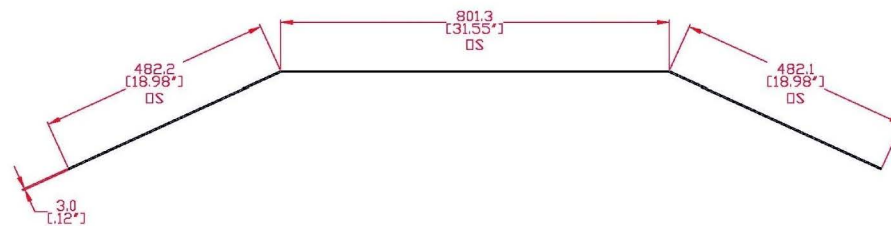
IHS Specification
Side Impact Moving Deformable Barrier

Upper Corner Plate ~ folded

Material: Al. Alloy 5251 H24 1.6mm
Or Al. Alloy 5052 H34 1.6mm



FOLDED PART DIMENSIONS



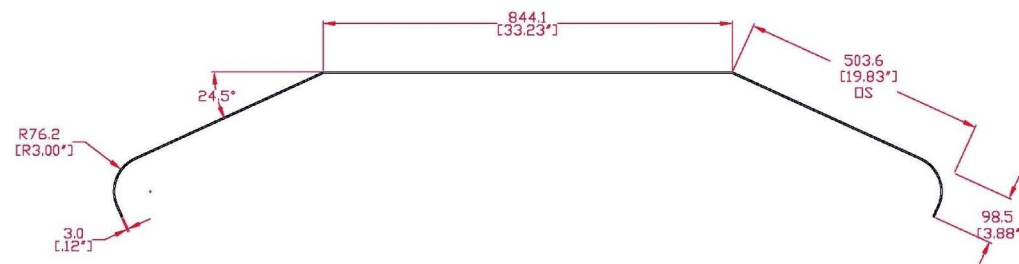
Rev 2, 20-9-2007

FIG 9.

IIHS Specification
Side Impact Moving Deformable Barrier

Bumper Base Plate ~ folded

Material: Al. Alloy 5251 H22 3.0mm
Or Al. Alloy 5052 H34 3.0mm



FOLDED PART DIMENSIONS

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FIG 10.

IIHS Specification
Side Impact Moving Deformable Barrier

Bumper Profile Sheet ~ folded

Material: Al. Alloy 5251 H22 3.0mm
Or Al. Alloy 5052 H34 3.0mm

Annex V: Can be found in “NCAP Side Barrier Test Procedure”:

<http://www.safercar.gov/Vehicle+Shoppers/5-Star+Safety+Ratings/NCAP+Test+Procedures>

Annex VI:

https://users.ece.cmu.edu/~koopman/depend/ahsstudy/tr_97_44.pdf

Annex VII:

<http://www.ein.org.pl/sites/default/files/2014-03-02.pdf>

Annex VIII:

https://www.lne.be/themas/veiligheidsrapportage/rlbvr/bestanden-rlbvr/tr/vr_rlbvr_rl_hbff_EN.pdf

