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Side Impact of a Paratransit Bus

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SIDES IMPACT OF A PARATRANSIT BUS

By

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ABSTRACT

The Florida Department of Transportation—Transit Office has endeavored to quantify the safety of a paratransit bus in a side impact collision. They have provided funded to produce this work. The goal of this work is to determine the likeliness that an occupant in a paratransit bus will experience an unacceptable amount of harm during a side impact collision. A side impact experiment was performed. An impactor weighing 4,400 lbs consisting of a crash cart with an attached IIHS deformable barrier was suspended between two steel towers. The impactor was raised to a height of 31 ft and let swing into the side of a stationary paratransit bus in a pendulum motion impacting at an angle of 90 degrees. Inside the bus a Hybrid III 50th percentile Anthropomorphic Test Dummy (ATD) was seated near the region of impact. The ATD recorded values that were all below Injury Assessment Reference Values (IARV) which indicates a favorable crashworthiness result for a side impact of similar paratransit bus. There was a significant amount of crush in the deformable barrier where it contacted the bus deck and indicates that should the impactor impact the bus higher or the bus have a low deck construction the results may be significantly different. This should be investigated in future research.
CHAPTER ONE

INTRODUCTION

1.1 Purpose of Research

The purpose of this research is to determine the likeliness of injury for an occupant of a paratransit bus being side impacted by the average car in the American fleet. In addition, this research will determine the structural performance of the passenger compartment framing for a typical paratransit bus. Finally, any injury mechanisms will be determined, analyzed, and structural modifications or safety mechanisms will be suggested.

The research that exists concerning paratransit buses currently consists mostly of their performance in a roll over event. There is little if no research on side impacts involving paratransit buses. There is much research concerning side impacts with regular passenger cars. This research uses the comparable research for passenger cars as a model for conducting research and experimentation with paratransit buses.

1.2 Paratransit Bus Side Impact

A paratransit bus has a wheelbase that ranges from approximately 138 inches to 217 inches. The gross vehicle weight rating ranges from approximately 8300 lbs to 21600 lbs. It does not travel a fixed route as do city buses. It is built in two phases by two different manufacturers. The first manufacture builds the cab and the chassis. The second manufacturer builds a frame and passenger seating compartment on the back of the chassis. The cab a chassis construction is highly regulated and consistent. The passenger compartment construction is varied and loosely regulated. This can be a cause for safety concern. A paratransit bus can be seen in Figure 1.

A side impact crash is when two vehicles collide with one vehicle impacted laterally by the other vehicle. The angle at which the impacting vehicle collides with the impacted vehicle may vary but at an undefined very small angle the impact may be considered a side swipe instead. For this research the angle investigated will be 90 degrees.
1.3 Interested Parties

The main interested party behind this research is the Florida Department of Transportation—Transit Office. This is a taxpayer funded state government institution. They have provided the funding for this research and they are highly interested in the results of this research. The results may have an impact on the department’s decisions for future policy and procedures pertaining to the governing and regulation of the various aspects of the use of paratransit buses. They are interested in making sure the design and construction of paratransit buses provide adequate performance as pertains to the safety and well-being of the bus occupants among other things.

One area of interest is the cage or frame that is built on the chassis and comprises the passenger compartment of the paratransit bus seen in Figure 2. Depending on the design and
construction there may be deficiencies in performance which would cause a hazard for the occupants. Such hazards may be faulty welds or poorly designed connections. There may also be improperly placed or sized members that lead to a deficient structural performance.

Figure 2: Paratransit bus construction showing chassis and passenger compartment being constructed

Ultimately the performance is measured by the effects on an occupant in a side impact crash. If a member fails but does not do an unacceptable amount of harm to the occupant, then the design and construction is satisfactory. If neither connections nor members fail but unacceptable harm is done to the occupant, then it may be in the best interest of the occupant to have strategic components fail if the end result is less harm.

In addition to evaluating the safety of a bus which is an exemplar of what is currently in the American fleet, consideration of what kind of buses may be in the future fleet is also important. For instance there is a likely hood that many buses in the future will have low floors which will be closer to the roadside curb and allow for easier entrance and exit from the bus. The
different structural system may pose an as yet un-evaluated risk to occupants. This should be taken into consideration as the results of the side impact experiment are evaluated.

1.4 Implications of Research

If the results of the impact are unfavorable then the expected harm to occupants may be reduced if specific performance issues can be determined and addressed. This may mean redesigning key structural components or among other things may mean a more rigorous quality assurance system. This quality assurance system may focus on key aspects of performance identified by the experimentation. If there are no design or construction deficiencies there may be a need to add additional crash safety components.

This research may instead establish that the design and construction of the particular bus is satisfactory if the results of the impact are favorable. This may indicate the need to focus on other impact scenarios. Regardless of the results, this research should provide an indication of what future research should be conducted to achieve an acceptable level of risk of harm to occupants.

1.5 Brief Description of the Experiment

In order to determine the effects of a side impact on the occupants of a paratransit bus a simulation of the event is required. This research will conduct an experiment where a decommissioned paratransit bus will be impacted by a device which will simulate the average impacting vehicle seen in Figure 3. The impacting device is referred to as a movable deformable barrier (MDB) or herein an impactor. The impactor is comprised of a steel chassis upon which a deformable barrier will be placed. The deformable barrier will simulate the stiffness of the average impacting vehicle in the American fleet. The impactor will be accelerated into the bus. To collect data pertaining to the effects on the occupant an anthropomorphic test dummy (ATD) will be used. The ATD is wired with various sensors to collect the necessary data.
Figure 3: Impacting device
CHAPTER TWO
LITERATURE REVIEW

2.1 Crashworthiness Research

There is very little if essentially no literature on the side impact of paratransit buses. Recently the Florida Department of Transportation has funded research to quantify the safety level of the paratransit buses it purchases and owns. This has led to this current research determining the effects of a side impact of a paratransit bus.

Since research on the crashworthiness of paratransit buses is fairly novel the research and evaluation of the crashworthiness of passenger vehicles may be used as a model for research and evaluation of the crashworthiness of paratransit buses. There are three major categories of research which combine to aid in determining the crashworthiness of passenger vehicles. One of the branches examines the biomechanics of the human body. This branch looks at what effects cause injury to biological structures like the head, ribs, pelvis etc. An example of this kind of investigation can be found in S.M. Duma et al. which looks at the biomechanics of rib fracture in cadavers (Duma 2011). Charles K. Kroell and Lawrence M. Patrick show that instrument panel impact types with cadavers produce femur fractures at 1500 lbs of load (Patrick 1965). R.P Hubbard looks at the flexure properties of layered cranial bone by using segments as beams in three point bending tests (Hubbard 1971). An exhaustive recount of biomechanical injury research is beyond the scope of this exposition. The provided references should be sufficient to exemplify the characteristics of this branch of research.

Another branch of research is the development of ATD’s. This research has the general goal of substituting a human occupant with an ATD in crash simulations with the highest degree of biofidelity, repeatability, and reproducibility possible. The characteristic process of developing ATD’s can be seen in (Massing 1977) which looks at the repeatability of three advanced 50th percentile male anthropomorphic test dummy designs. J. A. Tennant et al. looks at the biofidelity, repeatability, and reproducibility of the GM-ATD 502 (Tennant 1974). P. Prasad et al. examines the biofidelity, repeatability, and reproducibility of the Hybrid III, the Hybrid III with the RID neck, and the TAD-50 (Prasad 1997). An exhaustive recount of the development of ATD’s is not the purpose of this effort. ATD’s are more favorable to human cadavers because
they can increase repeatability compared to cadavers for the crash simulations. An ATD provides the possibility of using a representative for a range of body types with additional quality of being repeatable.

Crash event simulations are the final major category of research. This effort can be broken up into research covering the method of simulation and the individual simulations for the individual vehicles. A sample of the research that goes into the method of simulation can be seen in (Seiffert 1976) which looks at the development of movable deformable barriers. Smyth, B. and Smith, J. look at developing a sled test to reproduce the dynamic condition of full scale crash test (Smyth 2007). Ohmae H. examines the results of eight different impact configurations (Ohmae 1989). These examples are meant to give a sample of the different aspects of the method of simulation which are researched. An exhaustive list is beyond the scope of this work. The individual crash simulations collect data to be used to determine the crashworthiness of the particular vehicle in question. The New Car Assessment Program (NCAP) and also the Insurance Institute of Highway Safety (IIHS) among others perform these tests.

Three expansive categories of research have been laid out pertaining to the crashworthiness of passenger vehicles. Their complete framework and state of the art cannot be dealt with here. By themselves none of these categories can certify which vehicles have a satisfactory level of crashworthiness. It is an agreed upon standard which binds all these categories together and effectively creates the state of the art for crashworthiness investigation. Usually it is a governmental standard such as the Federal Motor Vehicle Safety Standard (FMVSS) 214 which provides side impact safety standards for the side impacts of passenger vehicles. This standard specifies the Injury Assessment Reference Values (IARV), the ATD’s to be used, and the crash simulations setup. These specifications are derived from the three major research categories detailed earlier. The IARV are obtained from the biomechanical research, the ATD’s from ATD research, and the simulations prescribes are the result of method of simulation research.

The development of safety standards follows in the same fashion as (Eppinger 1999) which looks at the development of advanced injury criteria for restraint systems. First, a committee looks at the available research and findings and suggests standards. Then, the public
is provided the opportunity to comment on the proposed standards. Finally, the governmental organization makes a final determination and issues safety standards.

This research will follow in a similar fashion as passenger car crashworthiness research. The biomechanics of humans are independent of the vehicle which they are in. This research assumes the impacting vehicle is the same as for passenger cars. Therefore, this research falls into the third category. The first two are applicable to passenger cars as well as any other impacted vehicle only the impacted vehicle is different. This research comprises an individual crash simulation and its results. Therefore the method of simulation is similar to the passenger car method described in the FMVSS 214.

2.2 Safety Thresholds

Safety thresholds or IARV are government boundary values on the magnitude of effects measured in a crash simulation. These define for the industry what is safe and what is unsafe and what product may be placed in the marketplace. The threshold values established for the occupants of passenger cars in a side impact event are found in the Federal Motor Vehicle Safety Standard 214 (FMVSS 214). They can be seen in Table 1.

Table 1: FMVSS 214 Side impact injury thresholds from FMVSS 214

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic trauma index</td>
<td>85 g’s</td>
</tr>
<tr>
<td>Pelvis</td>
<td>130 g’s</td>
</tr>
<tr>
<td>HIC –Head injury criteria</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>The unit-less result of equation:</td>
</tr>
<tr>
<td></td>
<td>[ HIC = \left( \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a , dt \right)^{2.5} (t_2 - t_1) ]</td>
</tr>
<tr>
<td></td>
<td>Where a= head acceleration and t is a 36 millisecond interval</td>
</tr>
<tr>
<td>Rib deflection</td>
<td>44 mm</td>
</tr>
<tr>
<td>Abdominal forces</td>
<td>2,500 N</td>
</tr>
<tr>
<td>Pubic symphysis</td>
<td>6000 N</td>
</tr>
</tbody>
</table>
2.3 ATD’s (Anthropomorphic Test Dummies)

ATD’s have become a critical component in crash test evaluation. They allow a record of the forces that would be experienced by a human without the need to use actual people and also increase repeatability. A brief history of the milestones in the use of ATDs can be seen in Table 2 (Smrka 2013).

Table 2: ATD history

<table>
<thead>
<tr>
<th>Year</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930s</td>
<td>1930s Fatalities per 100 million vehicle miles reach 15.6. Auto designers begin to pay serious attention to safety.</td>
</tr>
<tr>
<td>1949</td>
<td>1949 Alderson Research Labs (ARL) Sierra Engineering build &quot;Sierra Sam,&quot; an engineering dummy.</td>
</tr>
<tr>
<td>1950s</td>
<td>Early 1950s Cornell Aeronautical Laboratories study vehicle accidents to determine how to make cars safer. &quot;Gard Dummy,&quot; a research dummy, is produced by Grumman-Alderson.</td>
</tr>
<tr>
<td>1950</td>
<td>1950 Hollaman Air Force Base conducts crash tests using the ARL VIP 50th Dummy and Sierra Sam.</td>
</tr>
<tr>
<td>1950s</td>
<td>Late 1950s First cars with significant safety features introduced.</td>
</tr>
<tr>
<td>1950-1970</td>
<td>1950 - 1970 Automotive crash test dummies are developed based on aerospace models. 50th and 95th percentile males and 5th percentile female dummies produced.</td>
</tr>
<tr>
<td>1971</td>
<td>1971 The Hybrid I, a standardization of the ARL &amp; Sierra 50th percentile male dummies, is introduced.</td>
</tr>
<tr>
<td>1972</td>
<td>1972 The Hybrid II is developed, with improved shoulders, spine and knees. It also offered better documentation than the Hybrid I</td>
</tr>
<tr>
<td>Year</td>
<td>Detail</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1973</td>
<td>1973 The standard Hybrid II 50th percentile dummy is introduced. National Highway Transportation Safety Administration (NHTSA) contracts with General Motors to produce improved heads, necks, joints, ribs, knees, human-like posture and a new spine design. (ATD 502) Highway Safety Research Institute (HSRI) receives contract from Motor Vehicle Manufacturers Association (MVMA) to develop a 50th percentile male dummy with a new head, neck, thorax, spine, lumbar, pelvis, legs and joints.</td>
</tr>
<tr>
<td>1976</td>
<td>1976 Hybrid III is introduced. General Motors improves ATD 502 with a new neck, thorax and more transducers for more extensive data.</td>
</tr>
<tr>
<td>1979-987</td>
<td>1979 - 1987 NHTSA contracts with the University of Michigan Transportation Institute (UMTRI) to produce a new side impact dummy (SID). It is a Hybrid II type dummy with a new thorax.</td>
</tr>
<tr>
<td>1988-1989</td>
<td>1988 - 1989 Humanetics and SAE develop Hybrid III type small female and large male scaled dummies from Hybrid III 50th dummy. General Motors and Society of Automotive Engineers (SAE) develop Biosid, a Hybrid III based biofidelic side-impact dummy. AATD (advanced dummy project) completed. University of Michigan and Wayne State University receive NHTSA contract to develop an advanced dummy. First Technology Safety Systems is a subcontractor.</td>
</tr>
<tr>
<td>1995-96</td>
<td>1995 - 1996 First Technology Safety Systems and Occupant Safety Research Partnership jointly develop the SID IIs, a small adult/teenager side impact dummy for side air bag development.</td>
</tr>
<tr>
<td>1996</td>
<td>1996 First Technology Safety Systems develops the FT-Arup™ FE-Model Series, a highly precise and detailed finite element crash test dummy computer model.</td>
</tr>
</tbody>
</table>
2.4 Testing Procedures

Table 4 summarizes the three most common side impact testing procedures for passenger cars. The first two are governmental regulations; the first is FMVSS 214 which is the US regulation and the second is ECE R95 the European regulation. The Insurance Institute of Highway Safety (IIHS) is an independent body that conducts its own testing that meets or exceeds FMVSS 214. It can be seen that based on velocity and mass FMVSS 214 is a more severe test than ECE 95. The IIHS test has by far the highest mass for the MDB or impactor. Another major difference is the angle of attack. In the FMVSS 214 the impact velocity is not perpendicular to the stationary vehicle. The reason is that in most real side impacts the impacted vehicle is not stationary. In order to replicate the resultant velocity of the two moving cars the impacting vehicles trajectory is adjusted for the FMVSS 214 side impact test. This can be seen clearly in Figure 4 below which compares the figures from the FMVSS214 standard to the IIHS Side Impact Protocol.

Table 4: Comparison of side impact testing procedures

<table>
<thead>
<tr>
<th>Side Impact Tests</th>
<th>Velocity of the MDB</th>
<th>Mass of the MDB</th>
<th>Aluminum block type</th>
<th>Width</th>
<th>Total Length</th>
<th>Wheel base</th>
<th>Ground clearance</th>
<th>Angle of Evaluation Criteria</th>
<th>Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMVSS 214</td>
<td>53 km/h</td>
<td>1366 kg</td>
<td>As specified under 49CFR587</td>
<td>1880 mm</td>
<td>3832 mm</td>
<td>2591 mm</td>
<td>200 mm</td>
<td>63 deg</td>
<td>Accelerations to dummies, structural integrity</td>
</tr>
<tr>
<td>ECE R95</td>
<td>50 km/h</td>
<td>950 kg</td>
<td>As specified under ECE R95</td>
<td>1500 mm</td>
<td>Not Specified</td>
<td>3000 mm</td>
<td>260 mm</td>
<td>90 deg</td>
<td>Accelerations to dummies, structural integrity</td>
</tr>
<tr>
<td>IIHS</td>
<td>50 km/h</td>
<td>1500 kg</td>
<td>As specified under IIHS Protocols</td>
<td>1880 mm</td>
<td>3632 mm</td>
<td>2591 mm</td>
<td>379 mm</td>
<td>90 deg</td>
<td>Accelerations to dummies, head contact areas, structural integrity</td>
</tr>
</tbody>
</table>
The evaluation criterion to judge whether a vehicle passed the respective tests are based on the following categories according to the FMVSS 214: The first category is the effects imposed on the crash dummies in terms of safety thresholds which have been discussed previously. Each regulation has its own limits of acceptable effects such as rib deflections, accelerations, and forces in the different parts of the dummies. The next category is structural integrity. For the FMVSS 214 and ECE R95 there are several structural integrity requirements. No interior device or component shall become detached in such a way as noticeably to increase the risk of injury from sharp projections or jagged edges. During impact no doors can open and after impact a sufficient number of doors need to be able to be opened by hand without any special equipment so as to allow the occupants to exit the vehicle and also their restraints. Also, there are limitations on the amount of crush the vehicle can exhibit.

This research will closely follow the IIHS method of simulation which was derived from the FMVSS 214. The difference being the IIHS deformable barrier is designed to simulate an impacting SUV which is the average car in the American fleet. For this experiment the impactor is swung as a pendulum from two towers versus being accelerated on a track as in the IIHS protocol. The angle of impact is 90 degrees for this experiment as in the IIHS protocol versus a
crabbed angle of impact in the FMVSS 214 exemplified in Figure 4. A crabbed angle of side impact is relevant only to passenger vehicles due to the close proximity of the driver and rear passenger occupants as well as the location of the primary framing members of the passenger compartment. A bus does not have the same framing or seating setup so the experiment is not as sensitive to a change in the angle of impact.
CHAPTER THREE

DESCRIPTION OF THE EXPERIMENT

3.1 Overview

In this side impact experiment an impactor will be accelerated into a stationary bus in which will be seated an ATD nearest the point of impact. Typically crash tests are done with impactors that have wheels and are accelerated horizontal to the ground on a track or some other propulsion device that mechanically pushes or pulls the impactor. For economic reasons this experiment will use a pendulum mechanism to accelerate the impactor into the bus. The impactor will be suspended from two towers and then be raised to a particular height to impart potential energy to the impactor. Once the impactor is released the impactor will convert its potential energy to kinetic energy by the acceleration due to gravity. The impactor will impact the stationary bus orthogonally at the lowest point of its pendulum motion. The ATD will record the forces imparted to the simulated occupant. In addition to the information collected by the ATD photographs and video have also been recorded.

3.2 Pendulum Components

The impactor is suspended from two of three towers and raised by means of a wench and pulley system on a third tower. The test site where the towers are located was Florida Department of Transportation (FDOT) Mark H. Ansley Structures Research Center. The tower setup can be seen in Figure 5. A plan diagram of the towers can be seen in Figure 6. The towers form an equilateral triangle in plan. Each tower is composed of three pipe columns which are braced against each other with steel angles as can be seen in Figure 5 and Figure 7.

Each tower has a drilled pier foundation as seen in Figure 8. The towers were originally designed to perform impact testing on road signs and bridge beams. The tower setup is designed to swing a pendulum of up to 10,000 lbs. The impactor is suspended by steel cables which stretch from the impactor to hangers at the tops of the towers as seen Figure 9 and
**Figure 10.** The wench is located at the base of the third tower as can be seen in **Figure 11.** The wench pulls the steel cable which passes over a pulley on the third tower as seen in **Figure 12,** which attaches to the impactor then.

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**Figure 5:** Elevation view of impactor towers

**Figure 6:** Plan view of impactor towers

**Figure 7:** Impactor towers elevation diagram

**Figure 8:** Tower column on pier pedestal
Figure 9: Tower hangers for suspending cable

Figure 10: Tower hanger diagram

Figure 11: Wench used to raise impactor

Figure 12: Tower pulley system used with wench
The impactor was modeled after the impactor used in FMVSS 214 combined with an IIHS deformable barrier for side impacts. There were changes to the design due to the different method of accelerating the impactor. The impactor is composed of a cart frame and an IIHS deformable barrier. The cart frame provides the weight and the structural integrity. The deformable barrier provides the stiffness interaction upon collision.

<table>
<thead>
<tr>
<th>Key Impactor Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 IIHS deformable barrier</td>
</tr>
<tr>
<td>2 Rigid aluminum plate</td>
</tr>
<tr>
<td>3 Typical steel HSS4x4x1/4 construction</td>
</tr>
<tr>
<td>4 Metal protective box for gyro and accelerometer</td>
</tr>
<tr>
<td>5 360 degree swiveling eyebolts</td>
</tr>
<tr>
<td>6 Typical concrete filled HSS lateral members</td>
</tr>
<tr>
<td>7 Additional steel plates for positioning longitudinal COG</td>
</tr>
<tr>
<td>8 Aesthetic steel plate webbing</td>
</tr>
<tr>
<td>9 Casters for mobility</td>
</tr>
</tbody>
</table>

Figure 13: Impactor diagram with key features
The cart is the base structural frame onto which the different components of the impactor are attached. The cart frame can be seen under construction in Figure 14, and finished in Figure 15. The cart is composed of steel HSS 4x4x1/4 frame members welded with a typical 1/4 inch fillet weld. The frame includes concrete filled HSS 4x4x1/4 lateral members which are for the purpose of adding weight to the impactor. The cart has 360 degree swiveling eye bolts. These bolts which can be seen attached to the lifting straps in Figure 15 and are used so that while the impactor is swinging the steel cables connected to it do not bind. The cart has castors which only serve the purpose of making it easier to move from location to location while not in use. The cart was finished with a coating of red or black paint to prevent corrosion.

As shown in Figure 13 item number 2 there is an aluminum plate which has been bolted onto a ¼ inch steel plate which has then been welded to the cart frame. The aluminum plate is 66x33.9x2 inches in dimension. The purpose of the plate is to provide a rigid barrier between the cart and the IIHS deformable barrier. This ensures that the stiffness properties of the cart are isolated from the progressive differential stiffness of the deformable barrier. This way the stiffness interaction in the collision is between the bus and the deformable barrier and not the rest of the components of the impactor. This will more readily mimic a collision between a bus and the average car.

The IIHS moveable deformable barrier seen in Figure 16 is made of blocks of aluminum honeycomb. The different blocks have different stiffness characteristics and by adjusting the
sizes and locations of the blocks a specific progressive differential stiffness can be achieved. The IIHS barrier is designed to mimic the front end stiffness of the average car in the American fleet. The cars in the US are typically stiffer and higher due to the large number of SUV’s in the fleet compared to the European fleet. The stiffness of the IIHS barrier increases with increased crush.

![IIHS deformable impact barrier](image)

**Figure 16: IIHS deformable impact barrier**

The impactor is designed to be accelerated by gravity as a pendulum. The pre-collision weight of the impactor is 4400 lbs. The impactor was raised to a height of 31 ft with its suspending cables taught as can be seen in **Figure 17**.
The peak pre-impact velocity of the impactor is calculated by determining its potential energy in the fully raised position and then converting that to kinetic energy which is what the impactor will have at the bottom of its swing. It is assumed that only an insignificant amount of energy will be used in friction, heat, and sound. The calculation is as follows:

\[ mgh = \frac{1}{2}mv^2 \]

\[ v = \sqrt{2gh} = 13.6 \, \frac{m}{s} = 30.5 \text{ mph} \]

### 3.3 Test specimen and Instrumentation

The test bus is a paratransit bus seen in [Figure 19](#) that has been retired from service due to age and minor rear impact. It is built on a Ford E350 cutaway chassis with 138” wheelbase, GVWR of 10700 lbs., and date of manufacture 12/2004. The measured weight in the as-tested configuration is 9233 lbs. (1 ATD, 1 driver, 7 passengers, 1 wheelchair).
The point of impact on the bus was centered longitudinally on the buses center of gravity and then moved slightly forward so that the impactor would not contact the rear bus wheel. This was done to make sure that the maximum effect to the ATD could be attained. The bottom of the bumper of the barrier is 18 inches off the ground. This location puts the impactors swing path through the first driver’s side passenger seat. The impact position can be seen in Figure 20. The light black vertical line is the longitudinal position of the buses center of gravity.
The test dummy, a Hybrid III 50th percentile ATD (Humanetics Innovative Solutions, Plymouth Michigan), was seated in the vehicle for the test. The ATD’s transducers were wired to an EME 1600LDAS (EME Corporation, Arnold Maryland) for data collection. The ATD, ATD instrumentation, and ATD data post-processing software follow SAE J2113, SAE J17334, and SAE J17275.

The ATD was seated in the driver’s side front passengers seat. The ATD was secured with the passenger safety belt. The ATD was dressed in a cotton short sleeve shirt and short pants with leather dress shoes. A more exact seating position is related in the following figures:
Figure 21: ATD seating positioning
In order to determine the accelerations of the impactor and the bus each was fixed with a Summit Instruments 3500B Digital/Analog Accelerometer. The accelerometers were placed on the longitudinal center of gravity on both the impactor and the bus as exemplified in Figure 22. A National Instruments NI cDAQ-9172 data acquisition unit seen in Figure 23 was used to collect the acceleration data. The DAQ was equipped with a National Instruments NI9239 also module seen in Figure 23. The software used to record the data was Labview. The data is presented herein unfiltered.

Figure 22: Summit Instruments 35200B Accelerometer used to record impactor and bus accelerations

Figure 23: National Instruments NI cDAQ-9172 data acquisition unit with NI9239 module
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 ATD Results

On execution of the experiment the impactor was raised, released, and it swung without incident smoothly into the bus and impacted on target. The ATD coordinate system convention can be seen in Figure 24 (Figure from SAE J1733 Information Report, titled “Sign Convention for Vehicle Crash Testing,” dated July 12, 1994). The time origin was the moment of impact as recorded by a tape switch installed on the target surface of the bus. The times series of the data recorded by the ATD can be seen in Figure 25-Figure 30. The extreme effects on the ATD can be seen in Table 5.

![Figure 24: ATD sensor coordinate system](image-url)
Figure 25: ATD chest acceleration in the X, Y, and Z axes

Figure 26: ATD chest acceleration resultant
Figure 27: ATD upper neck forces in the X, Y, and Z axes

Figure 28: ATD upper neck moments in the X, Y, and Z axes
Figure 29: ATD pelvis acceleration in the X, Y, and Z axes

Figure 30: ATD pelvis resultant acceleration
Table 5: ATD effect matrix showing results of the experiment

<table>
<thead>
<tr>
<th>Description</th>
<th>Max</th>
<th>Millisecond</th>
<th>Min</th>
<th>Millisecond2</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head X</td>
<td>3.2</td>
<td>189</td>
<td>-4.8</td>
<td>64</td>
<td>g</td>
</tr>
<tr>
<td>Head Y</td>
<td>15.1</td>
<td>88</td>
<td>-6.5</td>
<td>26</td>
<td>g</td>
</tr>
<tr>
<td>Head Z</td>
<td>20.8</td>
<td>22</td>
<td>-10.8</td>
<td>27</td>
<td>g</td>
</tr>
<tr>
<td>Head Resultant</td>
<td>21.1</td>
<td>22</td>
<td></td>
<td></td>
<td>g</td>
</tr>
<tr>
<td>HIC 15</td>
<td>19.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest X</td>
<td>28.4</td>
<td>27</td>
<td>-7.3</td>
<td>14</td>
<td>g</td>
</tr>
<tr>
<td>Chest Y</td>
<td>15.7</td>
<td>20</td>
<td>-9.8</td>
<td>31</td>
<td>g</td>
</tr>
<tr>
<td>Chest Z</td>
<td>7.1</td>
<td>14</td>
<td>-7.3</td>
<td>19</td>
<td>g</td>
</tr>
<tr>
<td>Chest Resultant</td>
<td>29.5</td>
<td>21</td>
<td></td>
<td></td>
<td>g</td>
</tr>
<tr>
<td>Chest 3ms Clip</td>
<td>26.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Neck Fx</td>
<td>129.6</td>
<td>196</td>
<td>-181.2</td>
<td>64</td>
<td>N</td>
</tr>
<tr>
<td>Upper Neck Fy</td>
<td>553.4</td>
<td>93</td>
<td>-201</td>
<td>26</td>
<td>N</td>
</tr>
<tr>
<td>Upper Neck Fz</td>
<td>909.1</td>
<td>22</td>
<td>-478.4</td>
<td>28</td>
<td>N</td>
</tr>
<tr>
<td>Upper Neck Mx</td>
<td>55.5</td>
<td>98</td>
<td>-29.1</td>
<td>53</td>
<td>N-m</td>
</tr>
<tr>
<td>Upper Neck My</td>
<td>12</td>
<td>79</td>
<td>-11.5</td>
<td>205</td>
<td>N-m</td>
</tr>
<tr>
<td>Upper Neck Mz</td>
<td>10.6</td>
<td>98</td>
<td>-2.6</td>
<td>184</td>
<td>N-m</td>
</tr>
<tr>
<td>Pelvis X</td>
<td>43.5</td>
<td>32</td>
<td>-36</td>
<td>31</td>
<td>g</td>
</tr>
<tr>
<td>Pelvis Y</td>
<td>88.2</td>
<td>21</td>
<td>-47.6</td>
<td>44</td>
<td>g</td>
</tr>
<tr>
<td>Pelvis Z</td>
<td>13</td>
<td>20</td>
<td>-25.2</td>
<td>33</td>
<td>g</td>
</tr>
<tr>
<td>Pelvis Resultant</td>
<td>88.3</td>
<td>21</td>
<td></td>
<td></td>
<td>g</td>
</tr>
</tbody>
</table>

After review of the slow motion video of the experiment the ATD is struck by the portion of interior wall of the bus under the window partly because of crush and partly because the inertia of the ATD keeps it in place while the entire bus moves around the ATD. The windows appear to shatter due to the crush of the body before the head of the ATD comes into contact with the intact window. The final position of the ATD can be seen in Figure 31.
Figure 31: Final Position of ATD
### 4.2 ATD Analysis

#### Table 6: ATD recorded values compared to the Injury Assessment Reference values

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IARV</th>
<th>Recorded value</th>
<th>% IARV</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC15 (Head Injury Criterion 15 millisecond)</td>
<td>700</td>
<td>19.7</td>
<td>2.8 %</td>
</tr>
<tr>
<td>Peak Upper Neck Shear Force Fx</td>
<td>3100 [N] (697 lbf)</td>
<td>129.6[N] (29.1 lbf) max -181.2[N] (-40.70 lbf) min</td>
<td>5.8 %</td>
</tr>
<tr>
<td>Peak Upper Neck Tension Fy</td>
<td>3100 [N] (697 lbf)</td>
<td>553.4[N] (124.4 lbf) max -201.0[N] (-45.2 lbf) min</td>
<td>17.9 %</td>
</tr>
<tr>
<td>Peak Upper Neck Compression Fz</td>
<td>4000 [N] (899 lbf)</td>
<td>909.1[N-m] (204.4 lbf) max -478.4[N-m] (-107.6 lbf) min</td>
<td>22.7 %</td>
</tr>
<tr>
<td>Peak Upper Neck Lateral Moment Mocx</td>
<td>143 [N-m] (105.5 ft-lbf)</td>
<td>55.5[N-m] (41.0 ft-lbf) max -29.1[N-m] (-21.5 ft-lbf) min</td>
<td>38.8 %</td>
</tr>
<tr>
<td>Peak Upper Neck Flexion Moment +Mocy</td>
<td>190 [N-m] (140.1 ft-lbf)</td>
<td>12.0[N-m] (8.8 ft-lbf)</td>
<td>6.3 %</td>
</tr>
<tr>
<td>Peak Upper Neck Extension Moment -Mocy</td>
<td>96 [N-m] (70.8 ft-lbf)</td>
<td>-11.5[N-m] (-8.4 ft-lbf)</td>
<td>12 %</td>
</tr>
<tr>
<td>Peak Upper Neck Torsional Moment Mz</td>
<td>96 [N-m] (70.8 ft-lbf)</td>
<td>10.6[N-m] (7.8 ft-lbf) max -2.6[N-m] (-1.9 ft-lbf) min</td>
<td>11 %</td>
</tr>
<tr>
<td>3ms Continuous Interval – Chest Acceleration Lateral</td>
<td>60 [g]</td>
<td>26.4 [g]</td>
<td>44 %</td>
</tr>
<tr>
<td>Pelvis Acceleration</td>
<td>130 [g]</td>
<td>88.20 [g] max -47.60 [g] min</td>
<td>67.8 %</td>
</tr>
</tbody>
</table>
Table 6 shows the recorded ATD values compared to the Injury Assessment Reference Values (IARV) which comprise significant boundary values for the Hybrid III 50th percentile ATD. These values were referenced from FMVSS 214 and Mertz et al (Mertz 2003). SAE J1727 provides calculation guidelines. As can be seen all the recorded values from the ATD are below the IARV. The value that comes closest to the threshold value is the pelvis acceleration at 67.8% of IARV. This makes sense because the primary area of contact between the bus and the ATD was the interior of the bus underneath the window. The windows shatter before the ATD contacts them and it is the wall of the bus and the seatbelt that are the primary sources of force to the ATD. As can be seen the HIC % IARV is very low at 2.8%. This agrees with the observation that the windows shatter before the head comes into contact with them. The head itself does not contact much yet there is a sideways whiplash motion which accounts for the higher % IARV values for the neck up to 38.8%. These results signify an acceptable level of expected harm in a similar impact event. Considering the impactor in this experiment was heavier than the impactors used in IIHS side impact experiments, 4400 lbs vs. 3307 lbs, the expected level of harm is all the more reduced.

4.3 Impactor and bus results

In the collision the deformable barrier experienced crush as was expected. Most notably, the area where the deformable barrier contacted the deck of the bus had much more crush than any other part of the barrier. This occurred right above the bumper of the barrier and can be seen in Figure 35. The sign conventions for the accelerometers on the bus and impactor can be seen in Figure 32. The impactor has an accelerometer which has one axis. This axis is oriented such that the positive direction is opposite the impactor pendulum motion. This can be seen in the time series of the impactor accelerations. When the impactor impacts the bus it is registered as a positive acceleration. Clearly the impactor does not speed up upon collision with the bus. The impactor accelerates positively in the direction opposite of the pendulum motion so a positive acceleration recorded in fact indicates that the impactor is slowing down upon collision with the paratransit bus. The time series of the acceleration of the impactor on collision with the bus can be seen in Figure 33. The maximum acceleration experienced was 16.6 g’s at 0.042 seconds.
Figure 32: Bus and impactor acceleration sign conventions
Figure 33: Acceleration of the impactor center of gravity in axis 1

Figure 34: Acceleration of the impactor center of gravity in axis 1 short interval
In the collision the driver’s side windows of the bus shattered as seen in Figure 42. The body of the bus at the location of the impact experienced a small amount of crush as seen in Figure 43. The crush on the bus did not exceed 6 inches and extended longitudinally from the front edge of the passenger compartment to the front edge of the rear wheel well. The crush zone extended vertically from the base of the passenger window to the bottom of the bus. The acceleration of the bus at its center of gravity about its different axes can be seen in Figure 32-Figure 40 and the peak values can be seen in Table 7.
Figure 36: Acceleration of the bus at its center of gravity in the direction of axis 1
Figure 37: Acceleration of the bus at its center of gravity in the direction of axis 1 short interval
Figure 38: Acceleration of the bus at its center of gravity in the direction of axis 2
Figure 39: Acceleration of the bus at its center of gravity in the direction of axis 2 short interval
Figure 40: Acceleration of the bus at its center of gravity in the direction of axis 3
Figure 41: Acceleration of the bus at its center of gravity in the direction of axis 3 short interval
Table 7: Peak acceleration values and times for the bus center of gravity along the three axes

<table>
<thead>
<tr>
<th>Axis</th>
<th>Acceleration (g)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max</td>
<td>10.04</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-16.11</td>
</tr>
<tr>
<td>2</td>
<td>Max</td>
<td>42.47</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-9.91</td>
</tr>
<tr>
<td>3</td>
<td>Max</td>
<td>27.02</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-29.13</td>
</tr>
</tbody>
</table>

Figure 42: Post impact shattered windows of bus
Figure 43: Crush exhibited by the post impact

Figure 44: Lateral displacement of bus before and after impact
The bus was displaced laterally in the direction of the motion of the impactor approximately 8 feet 11 inches as seen in Figure 44. There was a slight rotation of the bus. This was expected due to the eccentricity imposed by shifting the target location away from the center of gravity to the front of the bus slightly in order to avoid the impactor contacting the rear bus wheels. The bus wheels slid on a portland cement surface until it reached the edged of the surface and then slid on earth. The bus did not rollover.

The interior of the bus in the region of the crush did not significantly intrude upon the occupant seating space as seen in Figure 45. The bus seat where the ATD was positioned is constructed similar to a simple moment frame. There is evidence of yielding at the corners of the frame as seen in Figure 46. The bus deck shows signs of failure as seen in . This region of failure was in the region denoted in Figure 48.

Figure 45: Post crash photograph showing little intrusion of bus wall interior into the occupant seating space
Figure 46: Yielding experienced at the corners of the ATD bus seat frame

Figure 47: Instance of tensile failure of the bus deck
4.4 Impactor and Bus Analysis

One reason for the low values recorded from the ATD could be the structure of the bus and the point of impact of the deformable barrier. As seen in the Figure 35 there was a noticeably more crush in the barrier in the region where it contacts the deck of the bus compared to the amount of crush in the barrier in the region where it did not contact the deck of the bus. Similarly the region of the bus where the deck exists there is limited crush compared to the regions above and below the deck. It follows that the deck of the bus acts as a diaphragm and in a sense is a large deep beam. This means the deck is extremely stiff compared to the other components in the impact. Taking into account the principle that stiffness attracts load, a larger percentage of the force of the impact is transferred into the deck of the bus. The nature of the failure of the deck corresponds to this postulation. It is found that the deck experiences a tensile failure in the area which represents the tensile region of the bus deck acting as a diaphragm or beam as seen in and Figure 48. The width of the tensile failure increases as it reaches the extreme fiber of the deck diaphragm as expected. This force transfer into the deck acting as a diaphragm or deep beam then translates into the lateral motion of the entire bus. This expends a lot of energy which is not channeled into the ATD directly. In this case the impactor essentially has to move the entire bus in order for the wall to contact the ATD primarily through inertia instead of the impactor crushing the wall significantly and impacting the ATD through the deformation of the wall as observed in the recorded video and also in Figure 45. The framing of the ATD bus seat further resists contact from the crush of the bus wall which is exemplified in Figure 46.
A paratransit bus was positioned at rest on a portland cement pad. It consisted of a passenger compartment built on a Ford E350 cutaway chassis with 138” wheelbase, GVWR of 10700 lbs., a date of manufacture 12/2004, with an as-tested measured weight of 9233 lbs (1 ATD, 1 driver, 7 passengers, 1 wheelchair). It was impacted with a movable deformable barrier or impactor. The impactor was fabricated following the design of the IIHS and FMVSS 214 impactor with modifications which allow it to be accelerated by gravity in a pendulum motion. The impactor weighs 4,400 lbs and is suspended from two steel column towers by steel cable attached to the impactor at 360 degree swiveling eye bolt connections. The impactor was raised by a pulley and wench system on a third tower to a height of 31 feet. The impactor was released and allowed to swing freely in a pendulum motion impacting the paratransit bus orthogonally at the lowest point in elevation of its pendulum motion at 30 mph.

The data was collected from the collision by means of accelerometers positioned on the center of gravity of the impactor and the bus. An ATD was seated in the bus. Photographs were taken before and after the collision. Video was taken of the collision with regular and high speed cameras. The ATD was a Hybrid III 50th percentile ATD (Humanetics Innovative Solutions, Plymouth Michigan). The ATD’s transducers were wired to an EME 1600LDAS (EME Corporation, Arnold Maryland) for data collection. The accelerometers were Summit Instruments 3500B Digital/Analog Accelerometers wired to a National Instruments NI cDAQ-9172 data acquisition unit equipped with a National Instruments NI9239 module.

The major results of the experiment are as follows:

- During the collision the impactor experienced a peak acceleration of 16.6 g’s at 0.042 seconds.

- During the collision the bus experienced a peak acceleration in the direction of the motion of the impactor of 42.5 g’s at .009 seconds.
• The effects on the ATD are all below the Injury Assessment Reference Values (IARV) with the highest percent of IARV being the pelvic acceleration at 67.8 % and the lowest being the HIC at 2.8%. This shows the occupant is not at an unacceptable risk of harm. Should any harm occur it would most likely be a pelvic injury.

• The bus experienced not more than 6 inches of crush and there was no significant intrusion of the bus wall into the occupant seating space. This shows that intrusion into the passenger compartment is not a significant cause for concern or risk of harm.

• The bus was displaced laterally in the direction of the motion of the impactor approximately 8 feet 11 inches.

5.2 Experiment Assessment and Future Research

The experiment was performed without incident and as expected. The accelerometer data was unfiltered and corresponds well with the visual accelerations observed in the video. The ATD results were obtained in cooperation with CAPE a professional testing agency and are highly reliable. The following items were neglected or could use improvement in future experimentation:

• The crush experienced by the bus and the impactor was not well quantified and could use improvement. Future research would benefit from a systematic quantification of crush possibly with 3D mapping technology. A pre-impact map of the bus might be compared to a post-impact map.

• The bus slid off the portland cement pads during the collision and slid for a short distance on earth. The distance the bus slid on the earth was not measured. It would be favorable in future experimentation to enlarge the portland cement pad so as to provide a continuous coefficient of friction between the tires and the surface they rest on.

• This experiment was conducted along with a roll over test and for budget reasons the ATD used was chosen to try to accommodate both tests. As such it is not the ideal
ATD for a side impact tests. In the future an ATD designed primarily for side impacts should be used.

- The impact velocity was not verified. Photogates were setup to determine the impact velocity but due to the amount of sunlight outdoors they did not function properly.

With this experimentation it has been shown that there is an acceptable risk of harm for an occupant in a paratransit bus with a similar construction and undergoing a similar side impact event. Future research is required to determine the risk of harm for impacts that do not primarily contact the deck of the bus. This includes low floor buses or impacting vehicles with higher front ends such as municipal or construction industry trucks. The effects on the ATD for such an impact may be drastically different. In addition, future research might look into the kinematic interaction between occupants in a side impact event. An unacceptable risk of harm might exist where during the collision occupant may contact each other, especially head to head contact. To answer this question future research might use multiple ATD’s in a collision and seat them next to each other. The multiple ATD research is especially important when considering the tendency of occupants not to wear seat belts. Another important question for future research is the relationship between the expected demographics of paratransit bus occupants and the IARV used herein. It may be the case that the IARV used here is typical of the average occupant for a passenger car where the average occupant of the paratransit bus may be older or have handicaps. This may mean that results lower than the IARV used here may cause an unacceptable risk of harm. If such is the case the passenger car IARV may need to be reassessed for paratransit bus occupants.
APPENDIX A

SIDE IMPACT PROTOCOL DRAFT (VERSION 1)

TEST SETUP

Paratransit Bus Side Impact Configuration

The side impact crash test is comprised of a stationary paratransit test bus struck on the driver’s side with an impactor. The impactor consists of a crash cart fitted with an IIHS deformable barrier. The impactor is suspended from two towers and is raised and swung into the bus in a pendulum motion. The impactor with its deformable barrier weighs a minimum of 4,400 lbs. and has an impact velocity of 30 mph. The impactor strikes the bus orthogonally on the driver’s side. The longitudinal impact point of the impactor on the driver’s side of the bus varies depending on the wheel base of the test bus. The impact reference distance (IRD) is the longitudinal distance from the point of the longitudinal center of gravity of the bus to the centerline of the impactor when it first contacts the bus. Toward the front of the bus is the positive direction and toward the back of the bus is the negative direction. The configuration can be seen in Figure 49.

The impactor alignment is configured to create the maximum loading on the passenger compartment and thus obtain the maximum effect on the Anthropomorphic Test Dummies (ATD’s). Specifically the impactor is aligned so that it does not contact the wheels of the test bus and is centered as much as possible on the ATD positioned in the passenger compartment. Due to the number of different wheelbase and seating configurations for paratransit buses the optimal alignment of the impact position should be determined on a case by case basis. Typically the alignment procedure is as follows:

1. Determine the longitudinal center of gravity of the test bus.
2. Line the impactor up orthogonally with the test bus longitudinal center of gravity.
3. Determine the length of overlap of the impactor on any wheels.
4. Shift the impactor in the direction opposite of the overlapped wheel by the overlapped amount plus 6 inches.
5. Determine the longitudinal distance between the centerline of the impactor and the centerline of the bus seat in which the ATD will be placed.

6. Shift the impactor toward the ATD by the distance determined in 5 observing a 6 in clearance of the impactor overlapping any wheels.

7. The ideal position is with the impactor at least 6 in. clear of any wheels centered on the ATD with the distance between the centerline of the impactor and the longitudinal center of gravity of the test bus minimized.

Figure 49: Side Impact configuration of bus and impactor

The impactor is raised 31 feet and then released so that the impact velocity at the bottom of the swing is 30 mph. The impact point tolerance is +/- 6 inches of the target of the horizontal
and vertical axes. The impact speed tolerance is 30 +/- 2 mph. There is no breaking system for
the impactor. A braking system would be necessary to ensure there were no significant second
impacts. Experimentation shows that a braking system is not necessary.

IIHS MDB Properties

The Moveable Deformable Barrier (MDB) or impactor is comprised of an IIHS
deformable barrier mounted to a crash cart. The crash cart is structurally similar to the crash cart
specified in the Federal Motor Vehicle Safety Standards (FMVSS) 214 with modifications seen
in Figure 50. The crash cart has been modified to be suspended from cables by 360 degree
rotational eye bolts. The wheels have been eliminated and replaced with castors to enable
movement while not suspended. When suspended the aluminum mounting plate is 100 mm
higher off the ground than the FMVSS cart and it is 200 mm taller to accommodate the IIHS
deformable barrier. The mass of the crash cart can be modified by adding concrete filled 4x4
HSS tubes. The impactor test weight is 4,400 lbs +/- 5 lbs including the barrier, the added ballast,
the mounted camera, and the attached sensors.

Figure 50: Impactor
The deformable barrier is 1,676 mm wide and 759 mm high with a ground clearance of 379 mm when suspended as seen in Error! Reference source not found.. Detailed information on the IIHS barrier development and evaluation testing has been documented previously (Arbelaez et al., 2002).

TEST BUS PREPARATION

Paratransit Bus Acquisition

Each bus is inspected on acquisition by the FAMU-FSU Crashworthiness and Impact Analysis Laboratory (CIAL). Bus acquisitions are facilitated by the Florida Department of Transportation—Transit Office. The vehicles are examined to note any defects and prior damage and to assure they are in substantial operating condition. Only buses free of any defects or prior damage that would affect experimental data acquisition are used.

Typically a bus which is structurally sound with the proper mass and configuration of the interior passenger compartment is used. It is not necessary for the bus to be road operable. A bus which is structurally sound has no damage to the framing members of the passenger compartment or chassis. The exterior skin of the bus has to be largely intact and damage free. Cosmetic damage is disregarded.

Fluids

Gasoline is removed from the bus. The weight of the removed gasoline is insubstantial compared to the gross weight of most paratransit buses. In addition, the testing at the CIAL focuses on structural integrity. Therefore, it is not necessary to replace the gasoline with any solvents. An approved absorbent is kept on hand should there be any significant fluid leaks after the collision.
Test Bus Instrumentation

Four kinds of instrumentation are installed in the interior of the bus, displacement transducers, accelerometers and gyroscopes, Anthropomorphic Test Dummies (ATD’s), and video cameras. Sensors such as string pot displacement transducers are mounted on steel assemblies which are bolted to the floor of the center aisle of the bus. The strings are attached to any members of the frame designated for data acquisition of linear displacement. A small section of the interior skin of the bus is removed and the string is attached to the steel framing member by means of an eye hook. Accelerometers and gyroscopes are mounted on steel assemblies and bolted to the floor at the center of gravity of the test bus. The wiring for the string transducers, accelerometers, and gyroscopes is routed out through the rear of the bus to a computer station in a safe location removed from the bus. Enough length of wire is laid out slack so that the instrumentation is not effected by the motion of the bus during impact. An ATD is installed in the chosen location inside the bus. The wiring for the sensor of the ATD is routed to the rear of the bus where an instrument panel is bolted to the floor. A minimum of three video cameras are installed on the interior of the bus, one in the front of the bus, one in the rear, and one laterally opposite the ATD to captured a profile recording. The cameras are mounted in dynamic motion isolation housing affixed to steel assemblies which are bolted to the floor.

Water tank dummies seen in Figure 51 are positioned in passenger seats not occupied by ATD’s. The dummies are water tanks filled with 150 lbs of water and strapped in place using the passenger safety belts. These dummies mimic the weight of a passenger and aid in giving the test bus a final test weight and weight distribution that more accurately reflects an actual loaded bus.
The position of the longitudinal center of gravity of the bus and the impact target location is marked on the body of the bus as seen in **Figure 52**.

**Figure 52: Marked impact location**

**Antiroll Devices to Prevent Rollover**

Most buses will not require antiroll devices as demonstrated in experimentation. Should an antiroll device be determined as necessary the antiroll device may consist of cables attached to the main framing member of the chassis underneath the bus. At the framing member the cables will end in a heavy duty spring link to dampen the force of the cable in tension. The other end of the cable is attached to a track which is anchored to the ground. The track will run laterally underneath the bus in the direction of the post impact bus motion. The cable will be attached to the track with a mechanism allowing it to slide along the track and remain anchored to it. Two cable assemblies such as this will be attached to the ground and bus, one towards to front of the bus forward longitudinally of the center of gravity of the bus and one toward the rear longitudinally aft of the center of gravity of the bus. Both cables will be mounted to the main
framing member of the chassis closest to the impactor. These devices will allow the bus to move laterally in the direction of the swing of the impactor but will not allow the impacted side of the bus to rise high enough for the bus to roll. It has not been necessary to date to fabricate these devices.

**Test Bus Mass and Center of Gravity Determination**

Determine the buses center of gravity. The method of determining the center of gravity of a paratransit bus may be found in the ECE Regulation 66. The weights under each of the tires are determined and then the bus is lifted on one end. The weight are then again recorded and through the equations which can be followed in the regulation the center of gravity may be determined.

**ATD Seat Placement**

ATD’s are typically seated in the passenger compartment of the bus. Seats which are fixed and immovable without adjustments are not modified and the ATD is seated and secured with the passenger safety belt. Seats which are foldable are folded down in the fully locked position. The ATD is seated in the foldable seat and secured with the passenger safety belt. Wheelchair anchors are attached to the wheel chairs and locked per the manufacturer’s specifications. Any head restraints are positioned in the fully down position. Any arm rests are positioned in the fully down position and locked if allowable. If armrests have multiple locking positions the position that orients the armrest most parallel to the floor is chosen.

**Doors and Windows**

The windows on the non-impacted side of the bus are fully closed and locked. The windows on the struck side of the bus are fully closed but not locked. If the windows on the struck side cannot remain unlocked while the bus is in motion then they are left in their default locked and closed position. The driver’s side door is locked and the window is rolled up. The bus passenger door is fully closed. The bus rear emergency door is closed and locked with its windows fully closed and locked.
Transmission and Ignition

The transmission is set to the neutral position and the ignition is switched to the on position. The steering wheel is checked to ensure free movement of the bus wheels. The front wheel of the bus is chocked to ensure that the bus does not move before impact.

Crash Dummy Setup and Preparation

(The following procedure has been adapted from the IIHS Dummy Seating Procedure for Rear Outboard Positions)

On bucket or contoured seats, center the dummy on the seat cushion so that its midsagittal plane is vertical and coincides with the vertical longitudinal plane through the center of the seat cushion.

On bench seats, position the midsagittal plane of the dummy vertical and parallel to the vehicle’s longitudinal centerline and positioned so that some portion of the dummy just touches, at or above the seat level, the side interior surface of the vehicle.

Place the lower legs at 90 degrees to the thighs. Push rearward on the dummy’s knees to force the pelvis into the seat so there is no gap between the pelvis and the seatback or until contact occurs between the back of the dummy’s calves and the front of the seat cushion, without allowing the angle between the thighs and lower legs to change. In vehicles with long seat pans, the dummy’s pelvis may not be in contact with the seatback even when the back of the calves are touching the front of the seat cushion. In cases where the gap between the pelvis and seatback exceeds 50 mm, the lower legs can be straightened to a tibia-thigh angle of 135 degrees to allow the pelvis to slide rearward.

Hold the dummy’s thighs down and push rearward on the upper torso to maximize the dummy’s pelvic angle.
Gently rock the upper torso relative to the lower torso laterally in a side-to-side motion 3 times through a ±5 degree arc (approximately 50 mm side to side) to reduce friction between the dummy and the seat.

If the feet can reach the floorpan, they should be placed flat on the floorpan and beneath the front seat as far as possible without interference. After initial positioning, it should be possible to lift the legs behind the ankles and, when slowly released, the legs should return to the original position with the heel contacting the floor. Upper and lower legs should have centerlines that are close to longitudinal and vertical planes, respectively.

If the feet are suspended above the floorpan, they should be left alone. Rest the dummy’s thighs against the seat cushion and set the initial transverse distance between the longitudinal centerline of the dummy’s knees at 160-170 mm, with the thighs and legs of the dummy in vertical planes. Measure the dummy’s pelvic angle. The angle should be set to 20 ±2.5 degrees for small female dummies and 22.5 ±2.5 degrees for midsize and large male dummies.

If the measured pelvic angle is below the specified range, hold the dummy’s thighs down and push rearward on the upper torso to maximize the dummy’s pelvic angle. If the pelvic angle is still below the specified range and the seatback is adjustable, adjust the seatback rearward one notch (or 2 degrees for infinitely adjustable seatbacks) and again hold the dummy’s thighs down and push rearward on the upper torso; check the pelvic angle. Repeat the previous step until the pelvic angle is within the specified range or until the seatback is in the full-rearward position. If the pelvic angle is still below the specified range or the seatback is not adjustable, proceed with the following: Lift the thighs and pelvis and move them forward (away from the seatback) the minimum amount necessary (not exceeding a distance of 50 mm between the seatback and dummy) to achieve the correct pelvic angle. Hold the dummy’s thighs down and push rearward on the upper torso to maximize the dummy’s pelvic angle. Repeat this step until the pelvic angle is within the specified range.

If the measured pelvic angle is above the specified range, rotate the torso forward. This will push the pelvis rearward and decrease the pelvic angle. Holding the dummy’s thighs down, slowly rotate the torso rearward until it is supported by the seatback. If the pelvic angle remains above the specified range and the seatback is fixed, record the pelvic angle. If the seatback is
adjustable, adjust the seatback forward one notch (or 2 degrees for infinitely adjustable seatbacks) and again rotate the torso forward and then hold the dummy’s thighs down and slowly rotate the torso rearward until it is supported by the seatback; check the pelvic angle. Repeat the previous step until the pelvic angle is within the specified range or until the seatback is in the full-forward position.

Measure the head transverse instrumentation platform angle. The anterior-posterior and medial-lateral angle should be level to within ±0.5 degrees. Adjust the lower neck bracket to level the head in the anterior-posterior direction. If it is not possible to achieve the head level within ±0.5 degrees, minimize the angle by moving the seatback one notch (or 2 degrees for infinitely adjustable seatbacks) in the appropriate direction to achieve the head level. After moving the seatback, if the pelvic angle is above the specified range, decrease the pelvic angle by rotating the torso forward and then holding the dummy’s thighs down and slowly rotating the torso rearward until it is supported by the seatback; record the pelvic angle and head angle, making sure the head is level within ±0.5 degrees. If the pelvic angle is below the specified range, hold the dummy’s thighs down and push rearward on the upper torso to maximize the dummy’s pelvic angle; record the pelvic angle and head angle, making sure the head is level within ±0.5 degrees. If it is not possible to achieve both the head level and the specified pelvic angle, priority goes to leveling the head.

Place safety belt around the dummy and fasten the latch.

Apply an 8-18 Newton (2-4 pound) load to the lap belt by pulling the upper torso belt adjacent to the latchplate. The lap belt should lie across the top of the thighs close to the pelvis, but not pushing into the abdomen.

If the belt has an automatic retractor, remove all slack from the lap belt and pull all webbing out of the retractor and allow it to retract against tension by holding pressure on the webbing with fingers. Repeat this operation four times.

The upper portion of the belt should lie flat on the dummy’s chest. Pull the belt 50-100 mm from the chest and allow it to retract on its own.
Position the dummy’s arms and hands. For dummies with half arms (BioSID, EuroSID-1, EuroSID-2, and SID-IIs), adjust the upper arm to the stop position 45 degrees forward of the neutral (down) position.

PHOTOGRAPHY

Still Photography

Photographs are taken of the precrash and postcrash condition of the paratransit bus. Photographs are taken in elevation around the entire perimeter of the bus. Each photograph will slightly overlap the nearest photograph. Each corner of the bus will have a photograph of the edge in the center of the view, a photograph at a 45 degree angle to the corner, and a photograph with the adjoining corner in the center of the view in turn. The camera positioning moving around a corner is seen in Figure 53. The positioning and condition of the ATD will be photographed precrash and postcrash. A list will be made in advance of performing the experiment of items of interest for photography. These items of interest may include the ATD, paratransit bus translation, crush experienced by the paratransit bus, structural aspects of the bus wall such as protrusion into the occupant seating compartment, and other items of like interest. As a general rule of thumb more pictures are better than fewer pictures as the state of the subject once disturbed will no longer be observable by the researchers.

Figure 53: Corner photography
As a general rule each photography subject shall be treated as a box with each side photographed as well as the corners. The first photograph of the subject will be at a distance to orient the viewer then the closer photographs will be made. Each photograph will slightly overlap the next so the viewer can orient themselves easily when viewing the progression of the photographs.

**Motion Photography**

Motion photography will be captured with nine 16 mm high speed video cameras as seen positioned in Figure 54. The frame rates for the cameras are accurate to +/- 1 percent of the set frame rate.

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**Figure 54: Motion photography camera positioning**
MEASUREMENT AND OBSERVATIONS

Test Weight

The weight of the test bus is determined by placing scales under each of the bus wheels. The bus is tested with all test apparatus installed. This included ballast weight to represent the ATD. Water dummies are installed prior to test weight determination.

Impact Speed

The velocity of the impactor just before impact is determined with two photogates. A photogate is a device which records the time instant when a beam of laser light is broken. A laser is set up on one side of the impactor path and the photogate receiving unit is set up on the opposite side. A beam of laser light is channeled into the photogate. When the impactor breaks the laser beam by passing through it the photogate records the time the beam was broken by an increase in voltage reading. With two photogates set up 1 meter apart the velocity can be determined by taking the difference in the time stamps for when each photogate was passed through and dividing it by one meter.

Impact Position

The impact position is determined by inserting a 0.125 in diameter threaded rod into a tapped hole in the deformable barriers bumper. The rod is inserted in the leading edge of the bumper centered both vertically and horizontally. The tip of the rod is sharpened so that it may easily puncture the skin of the test bus. A photo target is attached to the desired impact position on the skin of the test bus. Upon impact the rod will puncture the photo target and give a record of the impact position of the impactor as it collides with the bus. The rod is extended from the deformable barrier 30 mm and will make first contact with the test bus.
Component Accelerations

The acceleration of the impactor is determined by placing an accelerometer on longitudinal center of gravity of the impactor. The acceleration of the bus is determined by placing an accelerometer on the interior floor of the bus at the point of its longitudinal center of gravity. The data is recorded and filtered with data acquisition hardware and software.

Bus crush Profile and Compartment Intrusion

The amount of crush exhibited by the bus is determined by recording the three dimensional surface of the bus exterior in the region of the impact both before and after impact. The position of the surface of the bus is determined by using three dimensional laser mapping hardware. Control points are installed by inserting 7 #10 self drilling screws into the skin of the bus. Four screws are inserted around the expected perimeter of the bus crush zone and three are inserted within the expected crush zone. The three dimensional laser mapping hardware will provide a surface crush determination by comparing the difference in the precrash surface of the bus and the post crash surface of the bus.

ATD Kinematics and Contact Positions

The ATD is observed in its final undisturbed post-crash position. The final position of the ATD is recorded. Any damage is noted and photographed. Places where grease paint from the ATD’s head that have been deposited on the bus or impactor during impact are noted and photographed. Any entrapment of lower extremities during extrication of the ATD is noted and photographed.

Review and analysis of the high speed film will determine the ATD kinematics and time of any contact between the ATD and its surroundings. The camera that provides the best view is used to determine ATD kinematics for each event of interest. The initial time of impact is determined by the lighting of an LED positioned next to the ATD in the view of all cameras. The LED is wired to a taped switch installed on the surface of the bus in the impact zone. The first
frame in which the LED lights up will be considered the first frame in the recording of the impact kinematics of the ATD. The time recorded for each kinematic ATD event is based on the frame rate of the camera being used. Any significant passenger compartment phenomena is also noted and recorded such as glass shatter or safety belt failure.

**ATD Responses**

Due to budget constraints ATD test data acquisition is outsourced. Each entity subcontracted to provide the ATD and the ATD data acquisition is to submit a report of all testing apparatus, installation, recording processes, and recorded findings. The subcontracted entity will also provide a record of ATD instrument calibrations including method, results, and dates of calibrations.

In addition to a summary of all recorded data calculations may be made but not limited to the following:

- vector resultant of the head acceleration
- 3 ms of the vector resultant head acceleration; head injury criterion (HIC)
- 15 ms; thoracic and abdominal rib deflection rate (calculated by differentiating the rib deflection data)
- thoracic and abdominal viscous criterion
- 3 ms clip of the anterior-posterior and lateral-medial femur forces
- 3 ms clip of the anterior-posterior and lateral-medial femur bending moments

The HIC is calculated as follows:

\[
HIC = \left( \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t) \, dt \right)^{2.5} (t_2 - t_1)
\]

where,

\[a(t) = \text{resultant head acceleration}\]
\[t_1, t_2 = \text{start and stop times of the integration, which are selected to give the largest HIC value.}\]

For the HIC analysis, \(t_1\) and \(t_2\) are constrained such that \((t_2 - t_1) \leq 15\) ms.
The velocity (deflection rate) for each rib is calculated by differentiating the rib deflection data:

\[ V(t)_i = D'(t)_i \]

where,

\[ D(t)_i = \text{the deflection of rib } i \text{ at time } t, \text{ measured with linear potentiometers and filtered to SAE CFC 180 (mm)}. \]

The viscous criterion (VC) for each rib is calculated as follows:

\[ VC(t)_i = 1.0 \times V(t)_i \times \frac{D'(t)_i}{138 \text{mm}} \]

where,

\[ V(t)_i = \text{the velocity of rib } i \text{ at time } t, \text{ from Eq. 2 (m/s)} \]
\[ D(t)_i = \text{the deflection of rib } i \text{ at time } t, \text{ measured with linear potentiometers and filtered to SAE CFC 180 (mm)}. \]

A total struck side lateral pelvis force \( F_p(t) \) is computed by adding the instantaneous lateral acetabulum \( F_A(t) \) force with the instantaneous lateral iliac force \( F_I(t) \):

\[ F_p(t) = F_A(t) + F_I(t) \]

**SIDE IMPACT PROTOCOL (VERSION 1) REFERENCES**

REFERENCES


BIOGRAPHICAL SKETCH

This thesis was composed by Joshua Turley. He graduated from Florida State University in 2011 with a BA in Philosophy and a BS in Civil Engineering. He is currently seeking to complete his MS in Civil Engineering with a focus on structural engineering.