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Hurricane Rated Pet Door Final Design Report

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Pet Door
Final Design Report

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1 Executive Summary

Our Senior Design group has been commissioned by a major pet door distributor, Pet Doors USA, to create a working prototype of a hurricane rated pet door. The main goal of this project is to meet specifications set out for us by our sponsor which include; making the door accessible to a 25-100 lb dog and meeting DP50 Hurricane Code. The final design is a rotating door that utilizes a worm gear and worm screw that turn a shaft to which the door is attached. A polycarbonate front panel is used due to its strength and impact resistance. The automation is accomplished with the use of RFID tags and sensors. The pet wears an RFID tag and when it comes in range of the sensors it signals the door to open.

The final tests to be performed on the door included the water infiltration test, the final impact test, and the pressure/deflection test. For the water infiltration test, cobalt chloride paper was used to determine whether any moisture came through the door after spraying it with a hose. During the test, water began to infiltrate the corner of the door where the individual pieces of the weather-stripping meet and allow for a small crack. The pressure test setup was to place the door horizontally and place a box full of sand directly above the door. This test was successful with no permanent deflection or perceived damage to the pet door. For the impact test, a rack of weights with a 2x4 attached to it was dropped onto the door panel. The panel withstood the impact with no signs of cracks, indentions, or any other damage.

When the door was tested for functionality, it was discovered that the power generated by the controller is insufficient to open the door. However, by attaching the motor to an external power source, the door was able to open easily. Thus, both the mechanical and electrical assemblies work independently but in order to merge them there needs to be more time and effort devoted to this project. Aside from this, the project can be considered a success in that all failures have been identified and a minimal amount of additional work is needed to create a working prototype that can pass all the required tests.

2 Introduction

The purpose of this report is to provide information about the final design and the results of the tests conducted on the pet door. In addition recommendations are made to further develop the presented prototype.

2.1 Hurricane Information

One of nature's most destructive and devastating storms, hurricanes have had a huge impact on mankind, costing millions of people their homes, property, and lives. For a person that lives in the eastern coastal regions of the United States there is about a 40 to 50 percent chance of being hit by either a tropical storm or hurricane every single year. The U.S. sees an average of 17 hurricanes per decade, of which 6 to 7 of those hurricanes reach a 3, 4, or a 5 on the Saffir-Simpson Hurricane Scale [2]. These storms are considered to be major hurricanes and can cause billions of dollars in damages once they make landfall. Hurricane Ike that recently hit the Texas coastal region is estimated to cost between 27 billion to 52 billion dollars in damage [5]. Hurricane Katrina, which hit Louisiana and Mississippi in 2007, has an estimated cost upward of 200 billion dollars.

To safeguard against a hurricane's deadly force, homes in these areas should be built to standards that qualify them as hurricane-rated. This is especially true for their fenestration systems; windows, doors, and other openings which could allow for water infiltration or could be damaged from flying debris. One opening that is often overlooked is the pet door. Currently, there are no pet doors that have been designed to withstand the destructive force of a hurricane. Cognizant of this, Pet Doors USA, a leading pet door distributor, contacted Trinity University to propose a senior design project to design, test and build a hurricane rated pet door. If successful, not only will Pet Doors, USA become the first company to market a hurricane rated design but also will be able to give homeowners in hurricane prone areas a new sense of convenience and security knowing that their pet doors are rated to withstand one of nature's most destructive storms.

2.2 Problem Statement

The purpose of this project is to design a prototype for a hurricane rated pet door that will be able to meet the DP50 Hurricane Code and allow the entry of a 25 to 100 pound dog [3]. The DP stands for "design pressure," which is the pressure that a door or window is designed to withstand severe weather conditions such as hurricanes. This hurricane code includes three major tests that the pet door must pass to be "hurricane-rated." These three tests rate the pet door according to requirements of water infiltration, pressure, and impact testing. To actually be considered hurricane rated, the door must be tested at a registered testing facility, which cost a significantly large amount of time and money that the budget and schedule do not allow. Instead, the goal of this project is to attempt to duplicate these tests as closely as possible to determine how the design will stand up to hurricane conditions.

2.3 Requirements and Goals

The requirements set forth by Pet Doors USA were to allow entry of a 25-100 lb dog and to meet the DP50 Hurricane Code. The DP50 Hurricane Code specifies that the door must be tested per ASTM E 1996 standards [1]. The water infiltration test of the DP50 Code tests the pet door by placing a water nozzle facing the door and spraying at a minimum of 5 gallons/ft^2-hr. The total pressure applied from these nozzles must be 7.5 PSF, and the pet door must not allow "any drops of water [to] pass the most interior plane of the frame" of the interior of the home [4]. The pressure test includes a load of 50 PSF for 52 seconds, and then a load of 75 PSF for ten seconds. After this test, the deflection of the door must not exceed 0.4 percent of the largest dimension of the door. The impact or "missile" test involves a 2"x4"x8' piece of lumber traveling at 50 feet per second towards different locations of the door. If the door remains intact, meaning nothing passes through any part of the door while closed, the design is deemed "hurricane rated." The other main requirement is that the door will work in a safe, effective manner, allowing the entry of the pet only and giving enough time for the pet to pass through before closing. This will keep the pet safe and the home secure.

2.4 Entailment of a Successful Project

A successful project will consist of designing a prototype that performs in the desired manner and passes all tests. If the reason for failure that can be identified and a plan for solving this problem in future production can be determined, then the project will also have been a success. Pet Doors USA is looking for a prototype that will be the basis for a new product and that can be improved upon with more time and resources.

3 Final Design Components

Once the final design was selected each component of the design was specified and ordered. The components were then tested, modified, and redesigned until arriving at the current design configuration. Figure 1 and 2 displays these components.

3.1 Door Panel

Originally, the design for the door panel included a domed panel with bracing on the rear side. However, after ordering this design from a SLA rapid prototype company, it was determined that the SLA parts do not have the structural strength of a molded part. When tested with a baseball at 90 miles per hour,

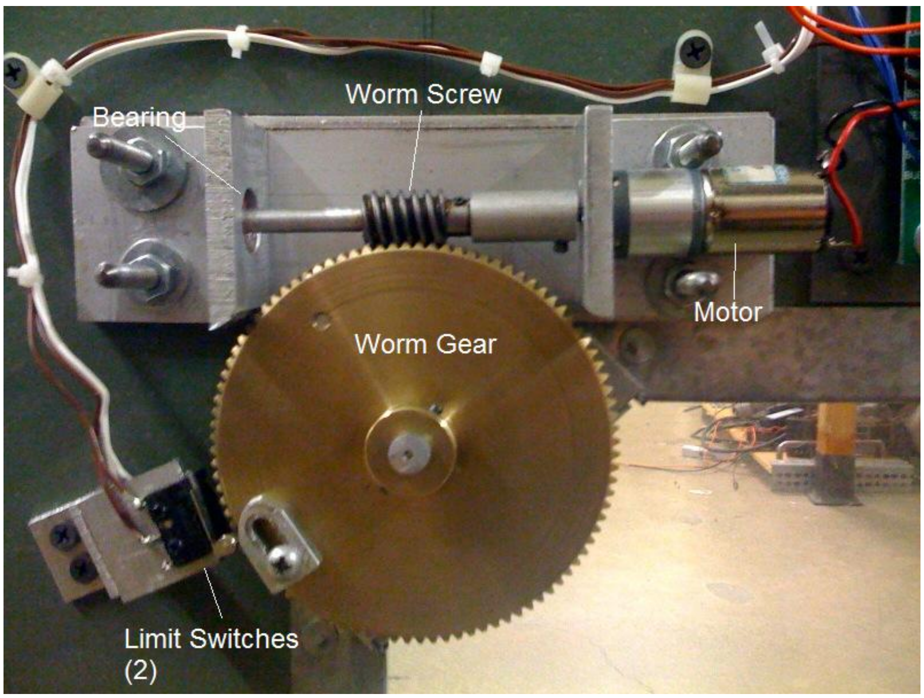

Figure 1: Diagram listing the major components of the pet door.

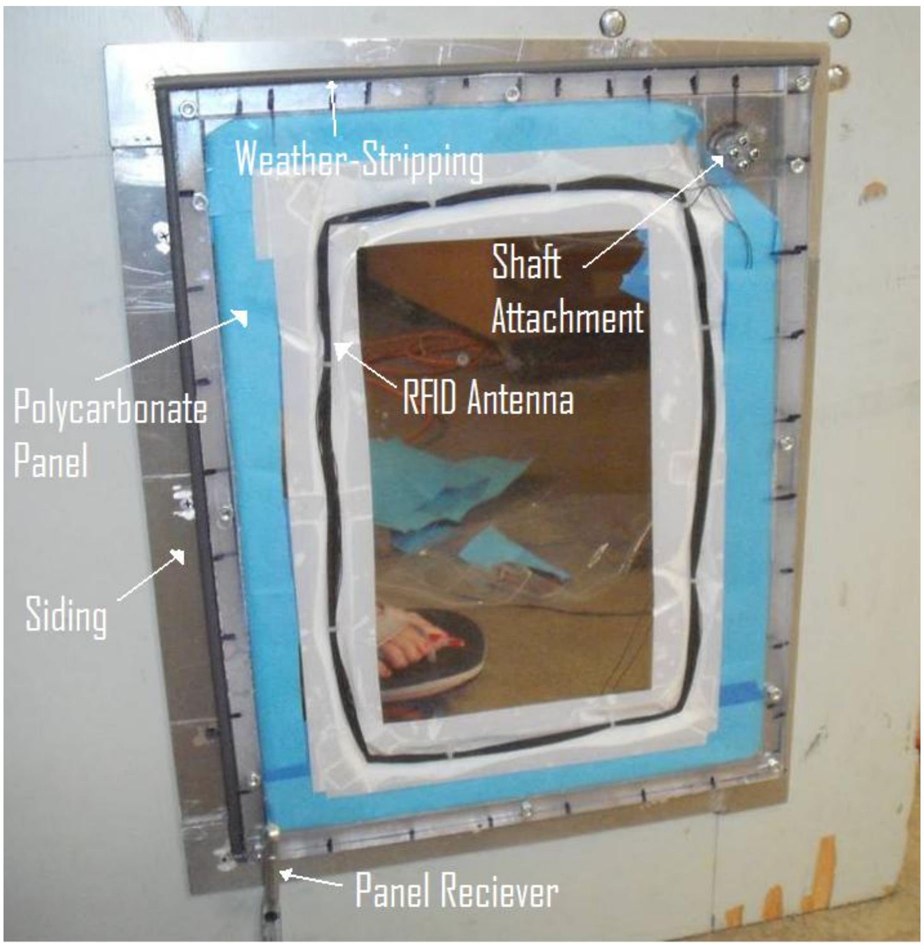

Figure 2: Major components on the outside of the door.

the SLA part broke into multiple of pieces. In the final design prototype, a flat polycarbonate sheet with thickness of 1/4" was used for the door panel. Ideally, the original domed shape panel would be made out of polycarbonate, instead of the SLA rapid prototype material Acurra 60. From the analysis in Pro-E, the stresses would be significantly smaller in the domed panel in comparison with a flat panel. However, without the funds and machinery needed for molding a panel out of polycarbonate, the best solution for a hurricane-proof prototype would be to use the flat panel. In the future, the domed shape can be considered for improved stability and strength, and can be molded for less than a dollar per panel once the mold is made.

3.2 Worm Gear

The worm gear and worm screw, ordered from SDP/SI, system worked perfectly. This is the ideal way to transfer motion from one direction to another. The worm gear also worked as a locking system for the door, which would help with security. The motor can turn the worm screw, which turns the worm gear, but a burglar could not get inside the house. If the gear is lifted, the worm screw locks and does not turn. This can be used as a second type of security measure, along with the alarm that sounds when the limit switch is opened.

3.3 Motor

The motor selected was a geared motor from Robot Marketplace, the Beetle B62 Gearmotor. This motor has a gear ratio of 62:1. The geared motor that was used worked very well. The motor is mounted to an aluminum shaft, which connects the motor to the worm screw. This shaft runs through the worm gear and rides on a pressed bearing, which keeps the shaft from wobbling. When connected to an external power supply, the motor lifted the door panel easily.

3.4 Shaft

The aluminum shaft that the door panel rotated on ran through two bearings in the door, but the shaft diameter could be adjusted to any bearing size. In this prototype, the shaft diameter and the Timken 204PP bearing inside diameter were 7/8 in. The end of the shaft was turned down with the lathe to fit snugly into the inside diameter of the worm gear, and was fastened with a roll pin. It is very important that this connection is very tight, and could eventually be molded into one piece to prevent slippage while turning.

3.5 Controller and Sensors

The only other modification that was made to the controller was to replace the magnetic inductance switch with a limit switch, and use the other limit switch mounted together with this switch on either side of the worm gear. The worm gear has two adjustable stops to adjust the position these switches are contacted, therefore adjusting the position where the panel closes and opens to. In the future, these adjustable features can be removed, when the motor mount and the limit switch mount are combined into a single piece of aluminum.

3.6 Weather-Stripping

The weather-stripping bought from Home Depot was cut to the length of the sides of the panel, and screwed to the door panel with machine screws. This weather-stripping worked very well, but could be improved by a permanent attachment on the corners, where the two sides of weather-stripping come together. During the water infiltration test, the water seemed to come through to the other side in the corners where we had attempted to super-glue the two sides together. Another solution to this problem would be to use a single piece of weather-stripping around the edge that is manufactured to the specific size of the door panel. This would eliminate most of the problems the group had with water infiltration.

4 Budget

Initially, the group had planned on a total budget of $11,200 for the project, $1,200 from the department, and $10,000 from Pet Doors USA, Inc. The majority of the money had been budgeted towards testing, $6,450, and of that $6000 had been budgeted for the impact test.

Unfortunately, in the Spring semester, the project suffered a major budget cut. Our sponsor was forced to cut the funding in half to due the economic recession. In the end however, the project was significantly under budget, so this decrease in available funds had no effect on the end result. The updated income for the project came to $6,860.00 which includes donations from the Engineering Department, Pet Doors USA, and material and service donations from Trinity University as well as Boedecker Plastic.

One of our potential plans for impact testing included a trip to Texas Tech University to utilize their ballistic range. After deliberation it was decided that this trip was unnecessary. Communication with our contacts at the University revealed that ballistic missile tests on polycarbonate panels have been performed in the past and there is data already available on what these panels could withstand. The decision not to test at Texas Tech saved the group a predicted $500 in travel expenses.

Overall the group spent $1292.28 on this project with a remaining budget of $5,567.72 Of this, the majority was used in ordering components for the door. By constructing and designing our own test set-ups using inexpensive materials, the initial planned testing budget was dramatically reduced. Table 1 shows the final budget.

In the end, the project was significantly under budget, most materials were donated and those that were purchased were much less expensive than the group had planned for.

Table 1: Project Budget

Expenses					**Status (Check one)**		
Date	**Vendor**	**Item Description**	**Budgeted Amount**	**Actual Amount**	**DeptPO**	**PCARD**	**Reim-burse-ment**
12/10/2008	Acu-Cast Tech., LLC	Front Panel	$500.00	$298.12		X	
	Acu-Cast Tech., LLC	Front Panel	$500.00	$0.00			
	Acu-Cast Tech., LLC	Front Panel	$500.00	$0.00			
12/10/2008	SDPSI	Worm	$75.00	$66.64	X		
12/10/2008	SDPSI	Worm Gear	$75.00	$28.98	X		
12/10/2008		Shipping for Worm/Worm Gear		$11.99	X		
1/22/2009	Purvis Industries	Bearings	$40.00	$37.02			X
2/3/2009	ASTM International	ASTM E 1996-08	$50.00	$49.20		X	
	Pet Doors USA	Controller/Driver	$100.00	$100.00			
12/10/2008	Robot Marketplace	Motor	$40.00	$15.49	X		
	Robot Marketplace	Extra Motor	$40.00	$37.39	X		
		Sensors	$60.00	$12.00			
		Raw Materials	$75.00	$8.39			X
		Manuel's Materials	$50.00	$65.00			
Fall 2008	Physical Plant	Testing Door	$200.00	$200.00			
	Home Depot	Weather Stripping	$50.00	$27.48			X
	Trinity Baseball	Impact Testing	$150.00	$150.00			
3/31/2009	Home Depot	Tarp	$15.00	$3.49			X
3/24/2009	Indigo Instruments	Cobalt Chloride Paper	$100.00	$75.85		X	
4/2/2009	Northern Tools	pully clip, rope	$30.00	$27.97			
4/2/2009	Home Depot	Sand/weatherstripping	$30.00	$27.27			X
3/17/2009	Boedeker Plastic	Polycarbonate Panels	$50.00	$50.00			
Total Expenses			$2,730.00	$1,292.28			

5 Schedule

The schedule for spring consisted of four main activities; ordering parts, construction, testing, and documentation/presentations preparation. In January, the parts that were ordered before Christmas break arrived and initial construction began. The initial rapid prototype panel had arrived and a regular door had been acquired from physical plant to house the pet door.

In early February, construction began in earnest with the manufacturing of the shaft, bearings and door liners. The mechanical assembly of the door including the worm screw, worm gear, motor, mounts, shaft and panel was completed in late February. Component testing also took place around this time with the motor test and the baseball preliminary impact test. The technical presentation on February 17^{th} focused on the results of these tests.

The results of the preliminary impact test created a minor setback in the schedule as the group had to decide on a new material and order the polycarbonate panels.

Around this time, the electrical/control assembly was constructed using sensors from the department and a controller from Pet Doors USA. Construction without the panel was finalized on March 4^{th}. Having ordered the polycarbonate panels before spring break, when the group returned the panels had already arrived. A final decision to not travel to Tech was agreed upon and the polycarbonate panel was attached to the shaft. Final touches to the prototype including the addition of weather-stripping took place in late March.

In April, the group conducted the final tests and began to prepare for the final report and presentation. As a whole, the group closely followed the schedule and met deadlines. The project was seldom behind schedule and all deliverables were turned in on time. Table 2 shows the schedule for Spring 2009.

6 Methods

Professional stipulations and requirements have created and compiled over time in effort to regulate the safety of "hurricane rated" products. Though no exact requirements have been issued pertaining specifically to pet doors, there are three specific tests that were methodically simulated during the design process; water infiltration, pressure and deflection, and an impact test.

6.1 Preliminary Testing

In an effort to maintain effective time management, a limited amount of preliminary testing was conducted to ensure basic functionality of a couple individual pet door components. Specifically, initial testing was conducted to ensure the integrity of the door material and the strength of the motor.

6.1.1 Motor

The torque equation 1 was used in both determining the required torque to move the door and the amount of torque the motor was capable of producing. The Door is 17 in. tall and 13 in. wide. Due to the placement of the motor in the upper corner of the door, the radius, r, was calculated in equation 2, where the center of gravity is located. In addition, the door weight, w, is 4 lbs. Using equation 1, the required minimum torque to move the door is approximately 41 lb-in. Measuring the power of the motor was done in a similar way to calculating the required torque to move the door. Figure 3 displays the test assembly.

$$T = r \times W \tag{1}$$

$$r = \sqrt{\left(\frac{l}{2}\right)^2 + \left(\frac{w}{2}\right)^2} \tag{2}$$

A worm screw was attached to the motor through the factory built in coupling of the motor. Then weight was added by a 2 in. screw attached to the end of the worm gear. Weight was continually added until the motor stalled. This testing help to ensure the motor could support opening the pet door.

6.1.2 Baseball

A simple impact test utilizing a baseball-pitching machine was used to ensure a minimum strength requirement of the pet door. Baseballs traveling at speeds

Table 2: Project Schedule

PROJECT ACTIVITIES			
Ordering	4 days	12/8/08	12/11/08
Create Final Parts List	4 days	12/8/08	12/11/08
Deliver Ordering Information to Secretaries	1 day	12/10/08	12/10/08
Christmas Break	19 days	12/19/08	1/14/09
Building	27 days	1/15/09	2/20/09
Construct Shaft	5 days	1/15/09	1/21/09
Construct Bearing Housings	5 days	2/2/09	2/6/09
Construct Door Liners	5 days	2/2/09	2/6/09
Construct Weather-stripping	5 days	2/9/09	2/13/09
Construct Worm Gear, Worm Screw, and Motor Mount	5 days	2/16/09	2/20/09
Mechanical Construction Complete	0 days	2/20/09	2/20/09
Pre-Testing - Baseballs	1 day	2/23/09	2/23/09
Second Pre-Testing Baseballs -Polycarbonate Panels	1 day	2/26/09	2/26/09
Programming	8 days	2/23/09	3/4/09
Place Sensors and Program Timers	5 days	2/24/09	3/2/09
Assemble Parts and Subsystems	8 days	2/23/09	3/4/09
Assembly Complete - Without Panel	0 days	3/4/09	3/4/09
Spring Break	7 days	3/7/09	3/15/09
Order Second Panel	11 days	3/4/09	3/15/09
Attach Second Panel	3 days	3/4/09	3/6/09
Attach Weatherstripping	5 days	3/16/09	3/20/09
Make Decision on Tech Trip	1 day	3/17/09	3/17/09
Modifications? Final Painting and Construction	1 day	3/27/09	3/27/09
Final Prototype Complete	1 day	3/27/09	3/27/09
Water Infiltration Test	7 days	4/1/09	4/7/09
Pressure Test	7 days	4/1/09	4/7/09
Impact Test	13 days	4/1/09	4/14/09
PRESENTATIONS/ PAPERS			
Spring Technical Presentation	0 days	2/17/09	2/17/09
Complete Individual writing responsibilities	13 days	4/1/09	4/14/09
Compilation/formatting	2 days	4/14/09	4/16/09
Final Report Draft Due to Leifer/Nickels	0 days	4/16/09	4/16/09
Complete Individual Slides for Final Presentation	3 days	4/17/09	4/20/09
Compile, Finalize and Practice Final Presentation	3 days	4/20/09	4/23/09
Incorporate Leifer's comments and other editing for Final Report	5 days	4/23/09	4/28/09

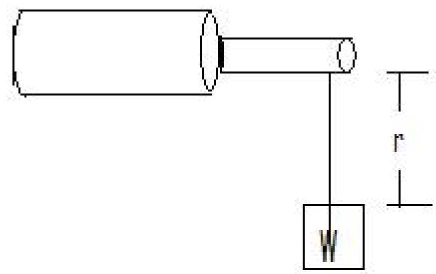

Figure 3: Motor Testing Schematic

of approximately 90-100 MPH impacted the door, which was then examined for small fractures or breaks. A camera and the impact-momentum equation 3 were used to calculate the approximate force of each baseball.

$$Fdt = m \times V \tag{3}$$

Though a baseball could only test a fraction of the door's actual strength requirements, it was a sufficient preliminary procedure to ensure no time would be wasted during the actual impact test by testing a faulty design.

6.2 Final Testing Methods

Though complete, certified testing fell outside the scope of this project, methods for on-campus testing were developed and used to test all certified hurricane rated requirements.

6.2.1 Water Infiltration

The water infiltration test was one of the most important tests of the entire project. Water leakage through the door frame would indicate the lack of an airtight seal and could be devastating to a home. If there is a small weatherproof discontinuity that allows for water infiltration, then there is likewise nothing to maintain the pressure differences between the inside and outside of the home. A sudden pressure influx within the home can force the roof off a house or circulate water throughout house drenching everything. For this vital test Cobalt Chloride paper, paper infused with a chemical that changes color when touched by water, was taped around the inside of the pet door frame. Also, a tarp was taped around the entire test door to isolate the Cobalt Chloride paper from outside splashing. The door was held vertically and sprayed with a simple garden house for approximately five minutes at a distance that varied from 1 to 5 ft. Actual

DP50 testing requirements are much more stringent, however this method of water infiltration testing was deemed acceptable by the project's sponsor due to limited time and budget. After the hose had been turned off, the tarp was removed and the Cobalt Chloride paper was examined for color change.

6.2.2 Pressure

Massive air speeds during a hurricane cause huge pressures on the sides of homes. Using an approximate average wind speed of 150 MPH during a hurricane, part of Bernouli's equation 4 was used calculate the pressure such wind velocity could cause against a home. Where P is the pressure, V is the wind velocity, and ρ is the density of air. From the pressure a mass was calculated using equations 5 and 6. Where F is the force, A is the area and g is the gravitational acceleration constant.

$$P = \frac{1}{2} \times V^2 \times \rho \tag{4}$$

$$F = P \times A \tag{5}$$

$$M = \frac{F}{g} \tag{6}$$

To encompass the entirety of the door an area of 340 in^2 (.219 m^2) was used throughout the calculations. A mass of 65.2 kg (123.88 lbs) was found and used to calculate the exact amount of sand to be used in order to represent the pressure difference. A 17"x 20"x17" hollow box was constructed using 4 pieces of sheet wood. The box was stabilized over the pet door frame, which was suspended horizontally along with the test door, and a pre-weighted 65 kg bag of sand was poured into the box. The sand was left on top of the door for approximately ten minutes while deflection measurements were taken. After the initial measurements approximately 75 kg of sand of extra sand was added to simulate unforeseeable circumstances as well as to alleviate some possible testing discrepancies associated with the lack of a longer test period.

6.2.3 Impact

The final test of the DP50 test codes requires that the door be able to withstand an impact from a 8'x2"x4" board traveling at 50 ft/s. The force of such an impact was calculated using equation 3. Lack of a required apparatus that could fire a 2x4 at the door lead to an alternate means of duplicating this test. Figure 4 illustrates the exact impact test set up.

The impact force of the 2x4 traveling at 50 ft/s was used in 6 to calculate the amount of weight required to load the contraption. The weight was loaded on top of a small piece of 2x4 and suspended 1.5 m. above the door as shown in Figure 4. During the test, the chain was released and the head of the 2x4 loaded with weight impacted the door. The size of the machine restricted the test to 394.5 J of impact energy concentrated on the pet door as opposed to an actual 474.4 J of energy that a certified impact test would produce. Again

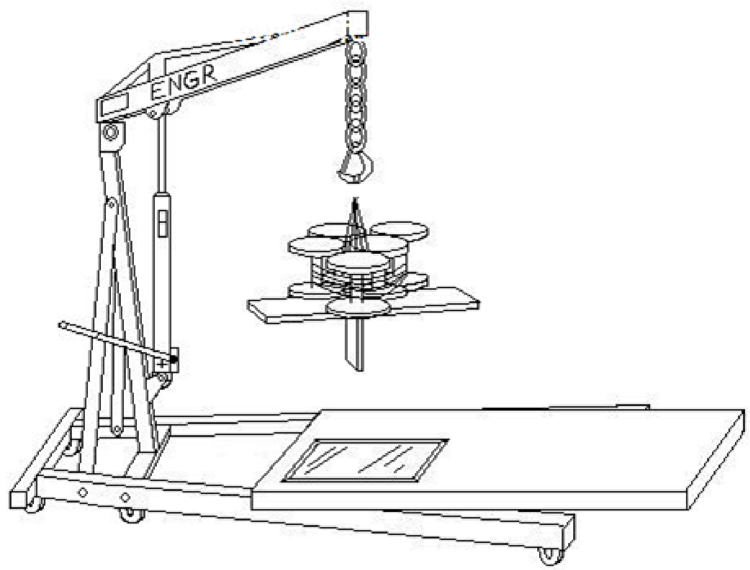

Figure 4: Apparatus used to simulate the impact of a 2x4 at 50 ft/s.

however, this was deemed acceptable for the scope of this project. The door was then observed for damage.

7 Results

The preliminary and final test results were analyzed to judge the pet door's components and overall performance. From these results, conclusions and recommendations could be drawn for future improvements.

7.1 Preliminary Testing

Preliminary testing and evaluation was incorporated in the design process to make sure that the right design and materials are being used. It is beneficial to check each component to make sure they function properly and to specifications before performing full tests. Preliminary testing is cost and time effective because they usually test the component on the same order of magnitude as the real test and they give indications whether the component is ready to move on to the next phase or if the design needs to be altered.

7.1.1 Baseball

For preliminary impact testing of the panel the group contacted Coach Scannell, the head baseball coach at Trinity, and arranged for testing on the baseball field. Using a radar gun, pitching machine, old baseballs and a video camera, it was possible to complete results for a test matrix which obtained the following data for each ball pitched at the panel: approximate speed of pitched ball, position of impact on the panel, and slow motion video of the impact to see what failed. It turns out that the first pitch fractured the Accura 60 plastic panel at approximately 85 mph. The next 2 balls that were pitched had passed completely through the panel and helped formulate a general consensus that the material of the panel was too brittle and a switch to a flat polycarbonate panel would significantly enhance the overall strength of the door. The preliminary test was performed on the new polycarbonate material and it passed the baseball pitching preliminary test at maximum speeds without fracture.

7.1.2 Motor

Although preliminary testing of the motor torque had calculated that the door's current geared DC motor would be enough to lift the panel and its components (220 lb-in before adding the worm gear and worm screw which were supposed to add a 48:1 ratio to the stalling torque), only after the door had been fully constructed did the group realize that the power supply for the motor was not powerful enough to fully lift the panel to 90 degrees. However, it should be noted that by implementing a larger external power supply it would be possible to raise the voltage and increase the power supplied to the motor in order to lift the panel to 90 degrees successfully. In future iterations, a larger power supply can easily be implemented and therefore this does not create too much of a problem.

7.2 Final Testing

Once the main components appeared to be functioning to specifications, more rigorous test apparatuses are constructed and the refined design of the door is ready for further testing.

7.2.1 Water Infiltration

The weather-stripping that was used around the door panel worked very well but could be improved by a permanent attachment on the corners, where the sides of weather-stripping come together. During the first water infiltration test with no markers, the water did not appear to be infiltrating through any cracks. However in the second test with the indicators, the water indeed penetrated through to the other side in the corners where the group had attempted to super-glue the two sides together. The infiltration was minimal and happened after 30 seconds of continuous spraying. A solution to this issue would be to use a single piece of weather-stripping around the edge that is manufactured to the specific size of the door panel. This would eliminate most of the problems encountered regarding water infiltration.

7.2.2 Pressure

The door has successfully completed the pressure testing. According to DP50 hurricane code, the permanent deflection of the door must not exceed 0.4 percent of the largest dimension of the door. In the deflection test, the initial distance that the panel was from the door before adding sand was 3.75 in. and after adding the sand and leaving it for a considerable amount of time, the loaded distance was measured to be 3.48 in. away from the 2x4. This resulted in a total deflection of .27 in. Once the sand was removed there was no permanent deflection in the panel resulting in a successful test.

7.2.3 Impact

The setup of the impact test was more difficult than initially planned. It was more difficult than expected to align and manage dumbbell weights and to consistently repeat the experiment as well due to issues with the cable getting tied up in knots and the fatigue involved with handling the weights. They turned out to be extremely heavy to lift by hand so the method used to test on this specific apparatus was to secure all the weights (approximately 225 lb_m) together with the 2x4 positioned at the center of gravity of the weights and pointing downwards towards the panel, and tie a knot at the top of the suspension (remove the pulley and replaced with a knot). Then after lifting the weight to a height of approximately 4.5 feet, the knot was untied and the weighted 2x4 fell directly onto the panel. The experiment was repeated twice and the panel was barely scratched which indicates a success of the impact energy approximation test. The 2x4 impact energy at 50 ft/s is approximately equivalent to 475 J depending largely on the density of the type of wood used, and this impact test was approximately equivalent to 400 J. The energy quantities were calculated using kinetic and potential energy balances and were only used to compare the forces involved in the test to the 2x4 impact requirements. The two ways of increasing the impact energy and improving the overall experiment would be to lift the dumbbells at distances greater than 1.5 m (4.5 ft) or to increase the mass of the load on the 2x4 in the weight impact test.

8 Conclusions and Recommendations

As previously mentioned the most important conclusion that the group decided on after preliminary testing was to change the material of the panel to polycarbonate which was much more ductile and less brittle and could withstand a large forceful impact simulation of a 2x4 at 50 ft/s. Even though this decision leaves the Pro-E and Pro Mechanica design behind for a simple flat panel design, the results in the preliminary test proved that this was a major enhancement in the overall structural integrity of the pet door. The cost of the polycarbonate material in bulk would also be within a reasonable range for commercial business.

It was decided that the current power supply for the motor was not sufficient to lift all of the required components at 90 degrees and would need to be replaced when mass produced and marketed to the public. Although an increase in power would slightly increase the cost of production, it would also provide more reliability at the specified height of 90 degrees, allowing the entry of a large pet.

It was found that it would have been much easier to weatherproof and seal the pet door had the door not been designed to open and shut through rotation. The currently installed weather-stripping is considered an overall success but for future variations of the product it is highly recommended to add permanent attachments to the corners to ensure a reliable water proof panel or to manufacture the weather-stripping as one solid piece with dimensions specifically customized for the door. Again this could possibly increase cost slightly but is very important for hurricane proofing the pet door and should absolutely be considered in future models of the door.

The impact testing was more of an afterthought after it was decided to forgo a trip to TTU's Wind Science And Engineering Research Center. Had there been more time and focus on this test there would have been much more accurate results rather than an approximation using conservation of energy and Newton's second law. Also the equipment was not optimal; it would be preferable to use barbell weights instead of dumbbells next time in order to distribute the weight more evenly on the 2x4. Using dumbbell plates would also ease the process of adding to the load. There are impact test apparatuses that are specifically designed for impact tests such as this. Therefore it is recommended to send future versions of the door to a facility with equipment that can more accurately measure its performance under high impact energies.

References

[1] ASTM Standard E1996 08e2. Standard specification for performance of exterior windows, curtain walls, doors and impact protective systems impacted by windborne debris in hurricanes. Technical report, ASTM International, 2008.

[2] U.S. Hurricane Center. U.s. hurricane strikes by decade, November.

[3] John Mitchell. Door and hardware. Technical report, Diamond Simoncon Windows, July 2006.

[4] John Mitchell. Door and hardware. Technical report, Tech.No. Product Development Center, Simonton Windows, 2006.

[5] STEWART M. POWELL and BENNETT ROTH. Texans seek aid in congress as ike cost estimates soar, September.

Appendices

A Bill of Materials and Vendor Information

Table A-1: Bill of Materials

Vendor	Item	Part Name	Cost
SDPSI	Worm	A1Q5-Y24	$66.64
SDPSI	Worm Gear	A1B6-Y24096	$28.98
Purvis Industries	Bearings	Timken 204PP	$37.02
Pet Doors USA	Controller/Driver	PE117	$100.00
Robot Marketplace	Motor	Beetle B62 Gearmotor	$37.39
	Sensor	Limit Switch	$12.00
Boedeker Plastic	Polycarbonate Panel	1/4" Polycarbonate	$50.00
Thermwell	Weather-stripping	Model VA17H	$25.00

Table A-2: Vendor Contact Information

Item/Services	Vendor	Phone	Address	Website
Stereolithography	Accu-Cast Tech LLC	(931)762-6004	3535 Waynesboro Highway Lawrenceburg, TN 38464	www.acu-cast.com
Worm Gear	SDPSI	(516)328-3300	2101 Turnpike, Box 5416 New Hyde Park, New York 11040	www.sdp-si.com
Bearings	Purvis Industries	(800) 580-5588	10500 North Stemmons Frwy P.O. Box 540757 Dallas, TX 75220	www.purvisindustries.com
Standards	ASTM International	(610) 832-9585	ASTM International, 100 Barr Harbor Drive, PO Box C700 West Conshohocken PA 19428	www.astm.org
Controller	Pet Doors USA	(800) 749-9609	4523 30th Sr. West, Brandenton, FL 34207	www.dogdoors.com
Motor	Robot Marketplace	(877) 762-6899	The Robot Marketplace 5129A 53rd Avenue East Bradenton, FL 34203	www.robotmarketplace.com
Weather-stripping	Home Depot	(210) 824-9677	435 Sunset Rd West San Antonio, TX 78209	www.homedepot.com
Cobalt Chloride paper	Indigo Instruments	(877) 746-4764	169 Lexington Court, Unit I Waterloo, ON, N2J 459	www.indigo.com
Pulleys	Northern Tools	(210) 344-4294	2505 NW Loop 410 San Antonio, TX 78230	www.northerntool.com
Polycarbonate panel	Boedeker Plastic	(800)444-3485	904 West 6th Steet Shiner, TX 77984	www.boedeker.com