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Aerodynamics of Wind Loading on Buildings

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MAE S20-2

Aerodynamics of Wind Loading on Building

By: Kayla Burch, Timothy Holleque, Anna Litvinova

April 2020

Reviewed by: ______________________ Approved by: ______________________

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This work was performed in the period of October 2019 - April 2020.

Disclaimer

Abstract

A three-dimensional model of a one-story residential home, with an emphasis on the roof style and structure, was modeled using CATIA and then built and tested in the wind tunnel at Western Michigan University. The wind tunnel allowed an airflow over different style roofs to be tested at 100 mile per hour winds, strengths typical for hurricanes and other natural phenomena. The measured results show the lift and drag, along with the pressure gradient and the skin friction over the roofs. The effect of these aerodynamic characteristics of the building due to adding solar panel prototypes were also evaluated. The results would have been presented here and will be applied to guidelines and building codes. Future work and continued research are recommended due to the unexpected circumstances from the Covid-19 pandemic.

Table of Contents

List of Tables

List of Figures

1. Introduction

With the patterns of weather changing, strong winds are formed more frequently than ever before while causing significant damages to homes, and in worst cases, leading to loss of lives. This project focuses on conducting wind tunnel testing to replicate sustained winds on a residential building. An emphasis is made on the roof which is an important element in the structure of a home.

As there has been a recent trend to expand the number of functions of a traditional roof, the use of roofs for solar thermal and/or solar energy has increased drastically in the last decade. Based on that, wind tunnel testing is conducted for a roof with solar panels attached in addition to a standard roof structure. The following paper presents the background, experimental set-up, and analysis of aerodynamic testing of wind loads on a residential building, specifically a home that interacts with strong wind forces.

1.1 The Need

Several families have experienced serious injuries and/or loss of lives when their roof collapsed during a storm with strong winds. Due to the impact of global warming, hurricane force winds are becoming more frequent across North America, Europe, and Asia. Many families' lives are being turned upside down because the hurricanes are destroying their homes. Usually the first thing to break down on a home is the roof. The roof is higher up and is more subjected to the wind loading from the storms and are more likely to fly off or the shingles will fall apart. As the main emphasis of the project is to test the safety of someone's potential home, the model needs to be representative of a realistic residential building.

1.2 Background Research

Literature review needed to be conducted to receive a solid understanding of the frequency and magnitude of hurricanes, residential building dimensions and requirements, and solar panel use and regulations. Additionally, significant background knowledge and guidance was received through communicating with a civil engineering expert.

Most of the background research was conducted in regard to the solar panel sizing and its tilt. Depending on the season of the year and the latitude of the location, the tilting angle of solar panels can be found by adding 15 degrees to the location latitude in winter and subtracting 15 degrees from the location latitude in the summer.

1.3 Objectives

Roofs collapsing due to hurricane force winds is a unique problem because hurricanes are a regional issue. Houses in hurricane zones need to be able to withstand the force of the winds and the amount of flooding that it will encounter. The objective of the project was to test a flat roof, as the control model, in the wind tunnel at hurricane force speeds. The tests will determine the lift, drag, and pressure gradient of the residential building along with a skin friction analysis. Pressure transducers and Arduino boards were used and programmed with the software LabVIEW to measure the values mentioned above. A flat roof with solar panels will also be tested using the same procedure as the control roof. The results of the two cases will then be compared to study the effects that rooftop structures have on the flow over a building.

2. Approach

2.1 Design Criteria

The model design is representative of a one-story, residential building with a flat roof at a 1:24 scale. The model additionally has a secondary roof with four rows of 3D printed solar panels to be attached during testing. Both the building material and solar panels have smooth surfaces to ensure accurate results in the wind tunnel.

2.1.1 Constraints

For the model to be representative of a full-sized building, it must adhere to general building codes and dimensions. The size of the wind tunnel is also a limiting factor in the building size. The blockage ratio, defined by the cross-sectional area of the model divided by that of the wind tunnel test section, must be 10% or less.

2.1.2 Scope and Limitations

The project is limited by the amount of funding received. A budget has been set for the minimal amount of supplies that will need to be purchased. Another limitation of the wind tunnel is the maximum speed of the flow velocity. Hurricane force winds range from 74 to 156 miles per hour [1]. This flow regime is unrealistic to recreate given the size of the model and wind tunnel. The maximum speed the wind tunnel can reach is 163.636 miles per hour. Lastly, time is a limitation of this project. A limited number of models can be built during the project period. Also, only a limited number of tests can be performed at the wind tunnel due to supervision and scheduling conflicts.

2.1.3 Assumptions

One assumption that will be made in the wind tunnel, is that the air flow will be perfectly in the center of the tunnel, and therefore in the center of the model. This will impact the skin friction testing. Second, the air is assumed to be incompressible, meaning the density is constant. The flow is considered incompressible at speeds under 220 miles per hour [2]. Due to this, a steady flow is also simulated. Another assumption is made during the calculations. A drag coefficient for a cube on the ground was used because a coefficient for drag of a residential building is not fully documented. This value was found to be approximately 1.05 [3].

Values used in initial estimations were obtained using standard atmospheric data [4] at the elevation of Kalamazoo, MI and the average temperature at that elevation. The values used can be found in the following table.

Table 1: Standard Atmosphere Values

Elevation (Kalamazoo, MI)	~1000 ft
Temperature, T	~55 °F (~515 °R)
Atmospheric Pressure, p_atm	2.0409e+3 lb/ft^2
Density,	2.3081e-3 slug/ft^3
Dynamic viscosity, μ	~ 0.3713e-6 lbf*s/ft^2

The Reynold's number for the full-scale building was then calculated using the building's characteristic length (20 ft) and the values in Table 1. For a hurricane force wind speed (~75 mph), the Reynold's number is on the order of 10-15 million. Given the size of the wind tunnel and the model size, this flow regime is unobtainable. It was decided to run all tests at a constant speed of 100 MPH. This speed will still simulate a moderate sustained wind on a full-scale building and will give insight on the impact of rooftop structures on the flow around a building. The Reynold's number of the flow regime just described is on the order of 50-100 thousand.

2.2 Specifications

The model and all attachments must be built strong enough to withstand the force imparted on it in the wind tunnel. For this reason, it was necessary to estimate the pressure it will face as well as the drag force.

2.2.1 Aerodynamic Forces

The dynamic pressure, q, was determined using the flow velocity and the density. Calculations can be found in Appendix A. The drag force was estimated using two different methods. The first method used the definition of pressure (force divided by area) and used the cross-sectional area multiplied by the dynamic pressure. The second method used the drag coefficient of a cube on the ground stated in section 2.1.3, Assumptions. These two values agreed within a reasonable margin and are found in Table 2 below. Equations used are found in Appendix A.

Table 2: Force Estimates

Wind Speed, v	100 MPH (~147 ft/s)
Dynamic Pressure, q	24.94 lb/ft^2
Drag Force, D (method 1)	8.66 lb
Drag Force, D (method 2)	9.09 lb

3. The Design

3.1 Concept

A standard-sized residential building of dimensions 20 ft x 20 ft x 10 ft was chosen as a guideline for this design. As the dimensions of the wind tunnel are 32 inches in height and 25 inches in width, an appropriate scaling needed to be applied to the model. After applying a scaling factor of 1:24, the size of the model was determined to be 10 in x 10 in x 5 in with a material thickness of 0.75 in. Before physically constructing the building, the software CATIA was used to model the building to ensure appropriate dimensions which can be seen in Figure 1.

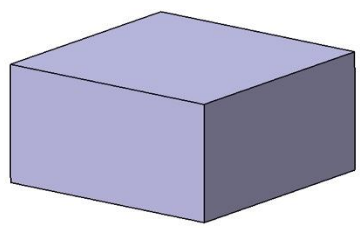


Figure 1: CATIA Building Model

Additionally, solar panels were designed in accordance to appropriate regulations. The solar panels must be compatible with the building dimensions; otherwise, if the solar panels are too large, the wind flow patterns will not be realistic. Real-life dimensions of a solar panel placed on a residential home were determined to be 65 in x 39 in based on background research [5]. A scaling factor of 1:24 was applied to those real-life dimensions and resulted in solar panel model dimensions of 8.125 in x 1.625 in.

Four solar panel rows were determined to be sufficient for a residential building while creating appropriate spacing between each row. A solar panel with fixtures was first designed with the software CATIA which can be seen in Figure 1 below. Afterwards, the solar panel models were developed with a 3D printer.

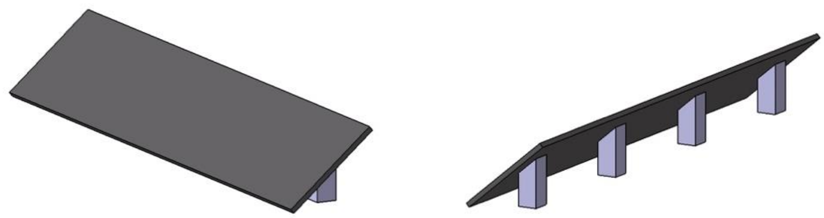


Figure 2: CATIA Solar Panel Model

3.2 Roof Styles

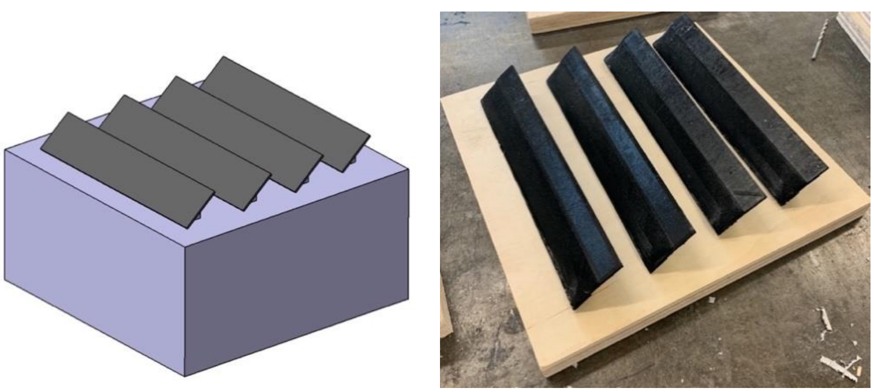
3.2.1 Flat roof

The first roof style chosen for this project was a traditional flat roof. The model was developed during the initial design of the building model which can be seen in Figure 1. The flat roof consists of a roof structure without obstacles, geometrical indentations or lumps. After developing the model in CATIA, the model was constructed with materials such as birch wood and screws. The physically constructed building model with a flat roof can be seen in Figure 3 below.

Figure 3: Built Flat Roof Building Model

3.2.2 Roof with solar panel arrays

The second roof style chosen for this project was a flat roof with solar panel arrays. The model was first designed with the help of the software CATIA, which can be seen in Figure 4 below. The 3D modeling allowed for a determination of appropriate dimensions for solar panel placements in addition to performed calculations. The constructed roof with solar panel arrays can be seen in Figure 5.



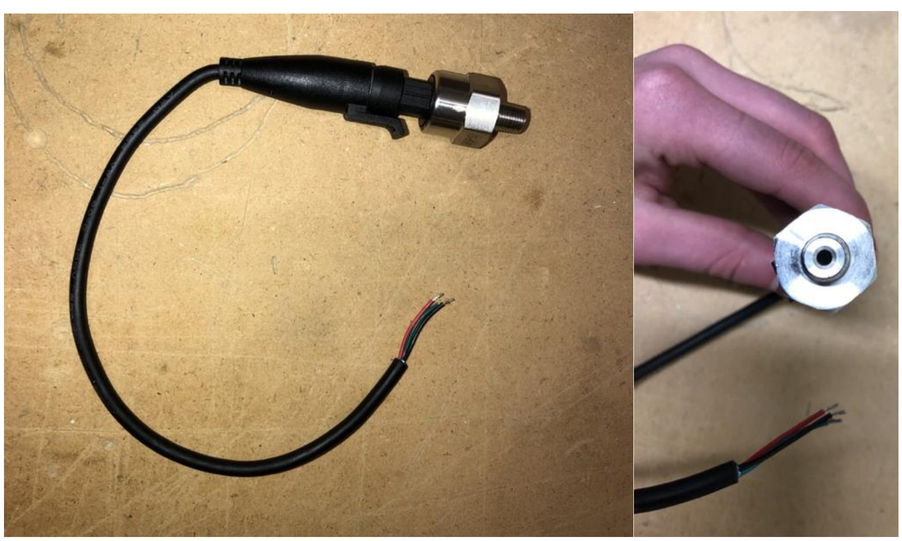
Figures 4 and 5: CATIA Roof with Solar Panel Arrays and Built Roof with Solar Panel Arrays

3.3 Controls

A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. Air is made to move past the object by a powerful fan or other means. The test object, in this case the residential building model, is instrumented with suitable sensors to measure aerodynamic forces and pressure distributions. The sensors are then programmed to an electronic platform.

3.3.1 Pressure Transducers

The sensors fitted in the building model are pressure transducers. The pressure transducers that were purchased can be seen at different angles in Figure 6 and 7. Smaller sized transducers allow for a more accurate reading, lightweight, and make it convenient to install. Air is not the only application for these transducers; oil, fuel, diesel, gas, and water can also be tested in these pressure transducers. They also have a surge voltage protection function.



Figures 6 and 7: Side and Top Views of a Pressure Transducer

3.3.2 Arduino Boards

Arduino UNO boards were the electronic platform mentioned above. The Arduino boards used during testing are shown in Figure 8. Arduino UNO is an open-source microcontroller board and is used to collect inputs and turn them into outputs. The board was chosen because it is equipped with easy to use hardware and software.

Figure 8: Arduino UNO Board

3.4 Methods

The model will be tested in the wind tunnel for two different cases:

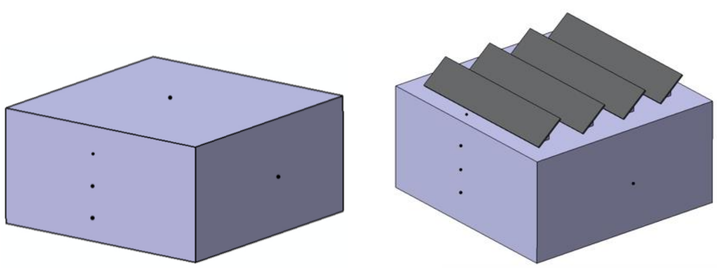
Case 1: Flat roof

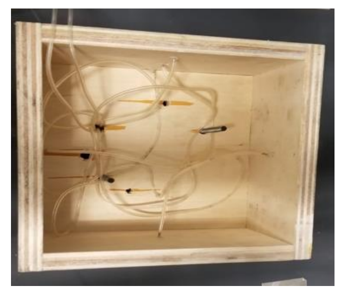
Case 2: Flat roof with 4 rows of solar panel arrays

Each of these cases will be tested with the front of the building positioned at 0° and 45° relative to the incoming flow. The data collected for each test will include the aerodynamic forces, such as lift and drag, pressure gradient, and skin friction analysis.

3.4.1 Pressure Measurement

In order to read the pressure at various points of the model, several 1/16th inch holes were drilled in the sides of the model and on each of the two roofs. The locations of these points are indicated in Figure 9 below. A small aluminum capillary tube was glued into each of these and a total of 8 tubes were connected on the inside of the model as shown in Figure 10 Each of these tubes were labeled and fed through the bottom of the wind tunnel test platform to the pressure transducer. For each test, average pressure would be recorded from each of these points to create a pressure gradient for the building.





Figures 9 & 10: Pressure Tap Locations and Installed Pressure Taps

3.4.2 Force Measurement

The lift and drag force for each test were to be obtained using the force balance in the wind tunnel. The model was bolted directly to the wind tunnel test platform, as can be seen in Figure 10 above and Figures 11 and 12 below. The aerodynamic force data for Case 1 and Case 2 were to be compared with emphasis on the drag force.

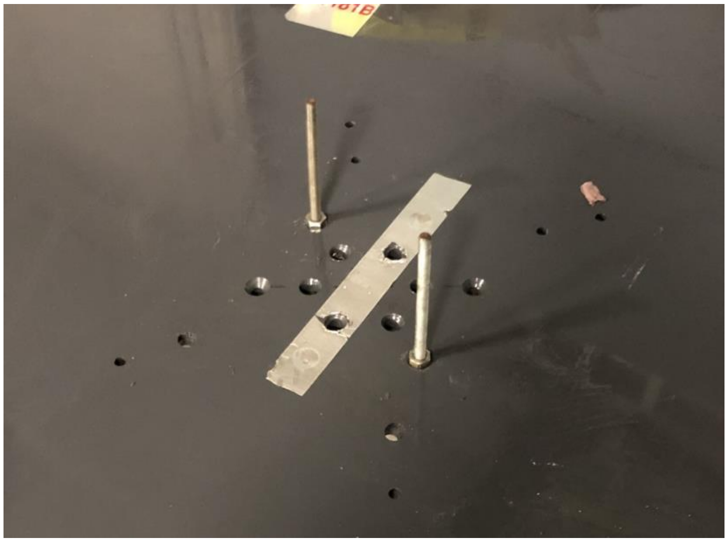


Figure 11: Bolts in the bottom of the wind tunnel

Figure 12: Model Fixed in Wind Tunnel

3.4.3 Skin Friction Analysis

The skin friction analysis was to be performed by painting the surface of the roof with Mylar or spray paint and photographing the top surface during the wind tunnel test. These pictures will then be analyzed to determine the change in skin friction forces between each case.

3.5 Results

Due to the unprecedented situation with Covid-19, which developed globally starting January 2020 and caused the closures of WMU facilities in March 2020, the project was not able to reach the stage of experimental wind tunnel testing.

The following tests are planned to be performed for the completion of the project:

- Test 1: Building with flat roof, 0 degrees' orientation
- Test 2: Building with flat roof, 45 degrees' orientation
- Test 3: Building with solar panel on roof – Case 1 Orientation [40 degrees' inclination, 0 degree building rotation, facing wind stream directly]
- Test 4: Building with solar panel on roof – Case 1 Orientation [40 degrees' inclination, 45 degrees building rotation]

Each test is planned to be conducted for a duration of 15 minutes with a wind tunnel speed of 100 mph. The time can be adjusted based on wind tunnel time availability.

3.5.1 Expectations

The purpose of the testing of two different roof styles is to understand the effect which the strong wind can cause on different types of roof setups. The solar panels which are added onto a flat roof are an additional structure which can have significant effect on the stability of a building and especially the roof. It either can provide additional support to the roof which could slow down the building destruction due to the strong winds or cause a more rapid damage to the building.

The drag force experienced on the flat roof model at 0-degrees orientation is expected to be similar to the values found in section 2.2.1. The drag force should be slightly lower for the model at 45-degrees as the coefficient of drag is lowered when in this orientation [3]. When the solar panels are added to the flat roof, it is expected that the drag force will increase some amount at both 0 and 45-degrees orientation.

The experiments performed by Aly, Chokwitthaya, & Poche (2017), Qiu, San, & Zhao (2019) and Xin, Jeimin & Changke (2019) on aerodynamic features on flat roofs were reviewed in order to speculate possible experimental results. Based on the work and results of these studies it is expected that this model would have similar pressure distribution to that seen in Figure 13 for Case 1 at 0 and 45-degrees. It is also expected for Case 2, that the pressure will be highest at the leading edge of the roof and lower at the trailing edge. It is unclear how this will compare to the rooftop pressure for Case 1 [8, 9, & 10].

(a) (b)

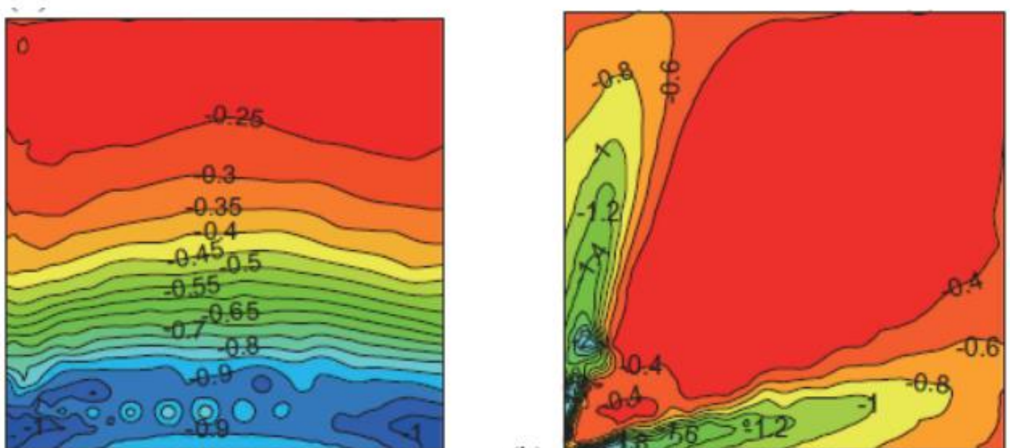


Figure 13: Pressure Distribution Results: Building with Flat Edge. (a) 0° (b) 45° [10]

As there are only seven pressure tap locations for the flat roof model, the skin friction test would give a more detailed image of the flow conditions on the roof. The skin friction analysis should show evidence of vortices formed at the building edges, and more prominently in the 45-degree orientation [9]. These cortices are illustrated in Figure 14.

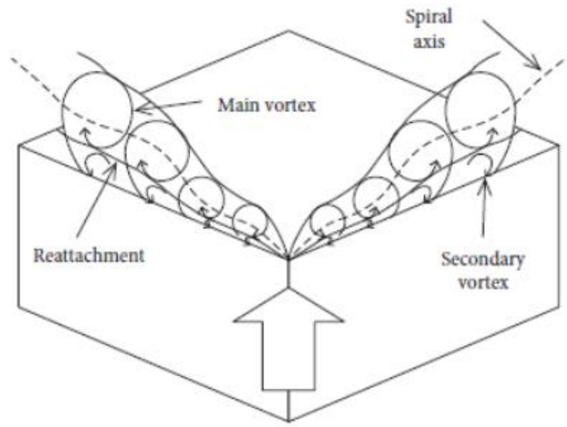


Figure 14: Vortex Formation Illustration [9].

Successful completion of the testing phase is necessary to confirm these hypothesized results. Case 2 tests will give insight on how the addition of a solar panel array will affect the conditions.

4. Analysis

4.1 Stress

4.1.1 Material Selection

During the beginning phase of the project, it was determined that acrylic material can be used to 3D-print the building model in addition to printing the solar panels using plastic. Wood was another option which was considered. However, concerns were expressed as some types of wood could be not strong enough to withstand the high force inside the wind tunnel. After performing research, time and cost analysis, as well as consulting with experts, it was decided to use a strong plywood as the main material for the building model. Birch wood was chosen due to its strength, and an emphasis on the thickness of the wood was made while choosing the appropriate type.

4.1.2 Safety Factors

The model needed to be assembled with accuracy and secured with several screws to not cause any damage under the application of the strong wind force in the wind tunnel. Additionally, solar panel arrays were secured with screws on the top of the roof. The whole building model was attached to the wind tunnel fixture and fastened with additional screws as shown in Figure 11.

4.2 Cost

The materials which were purchased for the execution of this project are the following:

- Birch wood, 2 sheets - $27 each
- Plywood, 2 sheets - $18 each
- Screws, 2 types - $5 each
- Glue - $10
- Pressure transducer, 11 - $20 each
- Arduino board, 2 - $25 each

Due to several trials performed while determining the best type of wood, additional material was purchased to ensure a safe and stable model as the outcome. Funding, which covered the costs, was granted by the WMU Research and Creative Scholarship Excellence award.

5. Facilities

5.1 Needs and Availabilities

The Western Michigan University Applied Aerodynamics Laboratory was the main facility used for this project. Access to the wind tunnel was essential as the main point of the project was to test building safety in strong winds. As several groups demanded the use of the wind tunnel for their projects, a schedule was set up during the Spring 2020 semester. Access to the laboratory is restricted. Times were discussed with professors and appropriate graduate students for supervision during certain time periods.

Access to the Ergonomics Laboratory and the Students Projects Lab were also required. These labs were equipped with the proper tools needed to cut, drill, and assemble the 3D model of the residential building.

5.2 Instrumentation/Equipment

Pressure transducers and Arduino boards were used to take measurements in the wind tunnel and can be seen in Figures 6 through 8 in section 3.3.

The pressure taps were programmed by the aerospace engineering PhD student, David Moussa Salazar, to use with the instrumentation software LabVIEW.

Miter saws were needed in the Ergonomics Laboratory to cut the wood for the building model. A drill press out of the Student Projects Lab was used to determine the location and depth of each hole used for the screws and pressure taps. Hand drills were then used to assemble the wood pieces together for the final product.

5.3 Computers/Software

The Applied Aerodynamics Laboratory had computers that the group could use. The computers were already set up next to the wind tunnel for easy access. The instrumentation software LabVIEW was already installed on the computer as well. This software communicated with the Arduino boards that were purchased.

CATIA, a computer-aided design software, was accessed through the College of Engineering and Applied Sciences computer laboratory. The residential building model was designed in CATIA along with the flat roof. The solar panels were separately designed and saved as an STL file to be used in the 3D printer.

The software Matlab, which allows numerical analysis and modeling, was used to determine aerodynamic parameters such as the Reynold's number for the given characteristics.

6. Conclusion

Due to the increase in occurrence of strong winds globally, it is important to minimize the damages caused by such natural events. Residential buildings, in particular, and its residents are at risk. Additionally, as there has been a recent trend to expand the number of functions of a traditional building roof, the use of roofs for solar thermal and/or solar energy has increased drastically in the last decade. This project focused on conducting wind tunnel testing to replicate sustained winds on a residential building. An emphasis was made on the roof which is an important element in the structure of a home while assuming two roof styles – a flat roof and a roof with solar panels.

Acknowledgments

This research is supported by the Research and Creative Scholarship Excellence Award granted by Western Michigan University. The authors would like to thank both Dr. William Liou and Dr. Tianshu Liu for being helpful mentors and advisors. David Moussa Salazar, a current aerospace engineering PhD Student, programmed the pressure transducers, supervised the research in the wind tunnel and gave valuable advice. Kanchani Mudiyanselage, a current civil engineering PhD student, assisted with background research and recommended several building codes and requirements to follow while creating the model and appropriate dimensions. Additionally, the authors would like to thank Mr. David Middleton for printing off 3D models of the solar panels. Dr. Steven Butt and Dr. Tycho Fredericks provided lab space and tools to build the model as well.

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Appendix A: Calculations

Reynold's Number:

$$Re = \frac{v * l * \rho}{\mu} = \frac{v * l}{\nu}$$

Dynamic Pressure:

$$q = 0.5 * \rho * v^2$$

Drag Force (method 1):

$$D = q * A,$$ where A is the cross-sectional area

Drag Force (method 2):

$$D = 0.5 * C_D * S * \rho * v\text{^}2,$$ where S is the reference area

Building size scaling:

$$20\ ft = 240\ in; \quad 240\ in * \frac{1}{24} = 10\ in; \quad 10\ ft = 120\ in; \quad 120\ in * \frac{1}{24} = 5\ in$$

Solar panel size scaling:

$$65\ in * \frac{1}{24} = 2.71\ in \ - \ Length\ of\ 1\ solar\ panel\ cluster$$

$$39\ in * \frac{1}{24} = 1.625 - \ Width\ of\ 1\ solar\ panel\ cluster$$

Appendix B: Cost Analysis

The materials which were purchased for the execution of this project are the following:

- Birch wood, 2 sheets - $27 each
- Plywood, 2 sheets - $18 each
- Screws, 2 types - $5
- Glue - $10
- Pressure transducer, 11 - $20 each
- Arduino board, 2 - $25 each

Appendix C: Resumes

KAYLA BURCH

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847-809-6933, kayla.r.burch@wmich.edu

OBJECTIVE

A hard working student with proven leadership and organizational skills. Seeking to apply my abilities to fill a part-time job or an internship. Dedicated team player who can be relied upon for completion and to help your company achieve its goals.

EDUCATION

Bachelor of Science in Engineering — Expected Graduation: May 2020
Western Michigan University — Kalamazoo, MI
Major: Aerospace Engineering — GPA: 3.58
Minor: Mathematics — Lee Honors College

WORK EXPERIENCE

Student Office Assistant — Western Michigan University, Kalamazoo, MI — 2017-Present

- Organize paperwork for accreditation, answer phones and emails, log information into Excel sheets, pay bills and handle credit cards, and copy documents and course work.
- Accompany professors in luncheons and banquets, and help in any projects that arise.

Dining Center Employee — Western Michigan University, Kalamazoo, MI — 2017

- Made fifty or more pizzas daily, washed dishes on weekends, and served food to all patrons.

Pet Sitter — Schaumburg, IL — 2005-2015

- Catered to the neighbor's needs, based on customer specifications, after school and on weekends, when necessary.
- Prepared water and food for cats and dogs, handled on walks, and examined animal to give medication when needed.

Swimming Manager — Schaumburg High School, Schaumburg, IL — 2013-2014

- Analyzed and collected data for records by using Excel to organize swimmers for each race.
- Developed time management skills and team communication by scheduling practices while collaborating with team member's and other managers.
- Strengthened leadership skills by coaching the swimmers during practice.

ACHIEVEMENTS AND AWARDS/HONORS

Western Michigan University Presidential Gold Scholarship — 2016
Western Michigan University Advantage and Dean's Award — 2016 - Present
College of Engineering and Applied Science Award — 2016 - Present
Alpha Lambda Delta — 2017 - Present

ACTIVITIES/INTERESTS

- Member of High School Softball — 2012-2014
- Freshmen Club — 2012
- Society of Women Engineers — 2016 - Present
  - Social Media Chair/Board Member — 2018 - Present
  - Member — 2016 - Present

VOLUNTEER EXPERIENCE

Students Helping Others — 2014-2016

- Connected with the community by collecting food at a food drive to support the underprivileged and people in need.

Hanover Park Library — 2015

- Over 20 hours of volunteer work through the library by shelving books, checking books in and out of the system, and interacted with patrons.

Click here to enter text.

Timothy T. Holleque

1235 W North St., Kalamazoo, MI 49006 | (517) 879-8839 | timothy.t.holleque@wmich.edu

Objective

- Obtain an internship, co-op or entry level position in Aerospace or Mechanical Engineering.

Education

Western Michigan University, Kalamazoo, MI

- Major: Bachelor of Science in Aerospace Engineering (Expected May 2020)
- Minor: Mathematics
- GPA: 3.00
- Related coursework: Calculus 1-4, Computational Fluid Dynamics, Aircraft Structural Mechanics, Flight Test Engineering and Design, Heat Transfer

Work Experience

Line Cook - Bell's Eccentric Café, Kalamazoo, MI June 2017-Present

- Developed creative recipes and maintained a high standard expected by customers
- Was able to work with urgency and efficiency in a fast paced, high stress environment while communicating effectively with coworkers to complete high volumes of orders.

Academics

Finite Element Analysis Project – WMU, Kalamazoo, MI Fall 2018

- Designed and optimized a wing box structure using Abacus FEA software.
- Delivered a wing box design well within the specified weight and maximum deflection limitations.

SR-20 Climb Performance Test – WMU, Kalamazoo, MI Spring 2019

- Developed testing procedure for the climb performance of a Cirrus SR-20 at multiple velocities and altitudes.
- Coordinated and conducted testing procedure with pilot and collected data during the flight.
- Analyzed and presented results of test to WMU faculty and students.

Study Abroad – Sichuan University, Chengdu, China July 2019

- Participated in a cultural exchange with students and faculty at Sichuan University (SCU).
- Enrolled in and passed a course on Theoretical & Computational Fluid Mechanics at SCU.
- Learned to work through language and cultural barriers in order to communicate ideas with host students as well as navigate the city.

Skills

- Microsoft Office, MatLab, AutoCAD, SolidWorks.

e

Anna Litvinova

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EDUCATION

Western Michigan University — Kalamazoo, United States
Bachelor of Science in Aerospace Engineering — *Expected graduation: May 2020*
GPA: 3.1/4.0

Honors and Awards
- Member of National Honors and Leadership Society
- Awarded Research and Creative Scholarship Excellence Award
- Selected as Forbes Under 30 Scholar amongst top ~1,000 students across United States

Harvard Business School — *May 2019 – Jul. 2019*
- Completed online courses such as Strategic Thinking, Business Cases and Project Management

PROFESSIONAL EXPERIENCE

Parker Hannifin – Aerospace – Hydraulic Systems Division — Kalamazoo, United States
Product Support Engineering Intern — *Sep. 2018 – Present*
- Delivered technical reports for 20+ projects while implementing client's requirements
- Investigated defective aircraft parts, analyzed potential issues, and recommended solutions
- Designed and engineered circuit wiring board that is currently implemented in 10+ products
- Developed an Excel model for price comparison of future purchases cutting down cost by 30%
- Created 25+ technical drawings and 3D designs based on client's specifications and requirements

Parker Hannifin – Aerospace – Hydraulic Systems Division Europe — Wiesbaden, Germany
International Engineering Intern — *Jan. 2018 – Aug. 2018*
- Developed technical reports for 10+ projects in both English and German
- Performed error calculations, tolerance and failure analyses for 5+ projects
- Organized 4 collaboration activities to enhance team dynamics and working culture
- Examined the quality of project documentation for 10+ projects before final release to client
- Mastered CATIA software independently and utilized it to create technical drawings for 15+ projects

WMU Haenicke Institute for Global Education — Kalamazoo, United States
Student Orientation Leader — *Mar. 2016 – Jan. 2020*
- Coordinated 500+ international students through a week of orientation program
- Supervised and assisted students during a transition period throughout the semester
- Developed activities and events for students to ease the transition to new environment
- Collaborated with a diverse team of 20 leaders and a group of international students every semester

PROFESSIONAL DEVELOPMENT PROGRAMS

- McKinsey Virtual Academy (Agile 101, Power of Digital, Communicating for Impact)
- Misk Foundation Future Fit (Agility and Resilience, Emotional Intelligence, Design Thinking)

SKILLS

- **Languages:** German (native), Russian (native), English (fluent)
- **Software:** Microsoft Office, Enovia, CATIA, AutoCAD 2D, Inventor, Abaqus, Matlab, LabVIEW

EXTRACURRICULAR ACTIVITIES

Gateway KSA — Riyadh, Saudi Arabia
Scholarship recipient — *Nov. 2019 – Dec. 2019*
- Visited several cities in Saudi Arabia to understand culture and development of the country
- Selected from competitive candidate poll to participate in sponsored cultural exchange program
- Explored KAUST and its perspective research facilities while meeting with faculty and students
- Engaged in discussions with government officials about topics such as Women's Rights, Vision 2030

Refugee Outreach Collective — Kalamazoo, United States
Volunteer — *Apr. 2019 – Present*
- Assisted refugee family weekly with tutoring and daily needs for successful adaptation in United States

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Appendix D: ABET Criteria

Outcome (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Indicators:

1. Generates a detailed statement of all the specified engineering needs for the design project.
2. Identifies and lists potential public health, safety and welfare concerns for consideration in the design process.
3. Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product.
4. Produces solutions that satisfy the engineering needs, address the public concerns and consider the effects of the relevant design factors.

Outcome (2) Scoring Rubric

	4- Exceeds	3- Meets	2-Progressing	1-Below
Generates a detailed statement of all the specified engineering needs for the design project	Project goals, objectives and performance criteria and constraints are clearly listed. Customer expectation and verification methods are clearly listed.	Project goals, objectives and performance criteria and constraints are listed. Customer expectation and verification methods are listed.	Project goals, objectives and performance criteria and constraints are not adequately listed. Customer expectation and verification methods are not adequately listed.	Project goals, objectives and performance criteria and constraints are not or partially listed. Customer expectation and verification methods are not addressed.
Identifies and lists potential public health, safety and welfare concerns for consideration in the design process	Potential risks in the development of the product or process and future end of the life disposal methods are adequately listed and evaluated.	Potential risks in the development of the product or process and future end of the life disposal methods are listed and evaluated.	Potential risks in the development of the product or process and future end of the life disposal methods are listed somewhat but not evaluated.	Potential risks in the development of the product or process and future end of the life disposal methods are not addressed.
Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product	Aspects of adaptation of the product to different societies are clearly listed and in depth discussed in the view of cost, local standards and legal systems, aesthetics and marketing as appropriate.	Aspects of adaptation of the product to different societies are listed and discussed in the view of cost, local standards and legal systems, aesthetics and marketing as appropriate.	Aspects of adaptation of the product to different societies are not adequately listed and/or discussed in the view of cost, local standards and legal systems, aesthetics and marketing as appropriate.	Aspects of adaptation of the product to different societies are not listed or discussed in the view of cost, local standards and legal systems, aesthetics and marketing.

Produces solutions that satisfy the engineering needs, address the public concerns and consider the effects of the relevant design factors	The product is extensively tested and verified by experiment, or simulations/ calculations or both to satisfy all requirements. Decisions methods about prioritizing the various considerations and their effects on the final product are explained and justified in details.	The product is tested and verified by experiment, or simulations/ calculations or both to satisfy all requirements. Decisions methods about prioritizing the various considerations and their effects on the final product are explained and justified.	The product is somewhat tested and verified by experiment, or simulations/ calculations or both to satisfy all requirements. Decisions methods about prioritizing the various considerations and their effects on the final product are not adequately explained and justified.	The product is not adequately tested and verified by experiment, or simulations/ calculations or both to satisfy all requirements. Decisions methods about prioritizing the various considerations and their effects on the final product are not presented.

Outcome (3) an ability to communicate effectively with a range of audiences.

Performance Indicators:

1. Writing of senior design final report uses technical style and format.
2. Appropriate use of visual aids during oral presentation at the senior design conference[1].
3. Communication within the group and with the mentor[2].

Outcome (3) Scoring Rubric

	4- Exceeds	3- Meets	2-Progressing	1-Below
Writing of senior design final report uses technical style and format	Final report is written strictly using technical style and format. Extensive use of Figures enhances explanations.	Final report is written using technical style and format. More explanations can be aided by graphics.	Final report contains parts written using technical style but requires rework. Limited use of graphics.	Final report is not written using technical style. Many Figures used in the report are either irrelevant or not explained.
Appropriate use of visual aids during oral presentation at the senior design conference	Graphics, animations, and/or prototypes used for senior design presentation clearly explain project to a technical as well as non-technical audience	Graphics used in senior design presentation convey limited information to a technical as well as non-technical audience	Selection of graphics in senior design presentation is highly technical and ignores audiences who are not familiar with the subject.	Selection of graphics in senior design presentation produces misunderstandings about the engineering project.
Communication within the group and with the mentor[2].	Students submit detailed project review reports at the beginning and middle of the semester, clearly describing results of their own meetings and meetings with the faculty and industrial mentors on the progress of the project.	Students submit project review reports at the beginning and middle of the semester, indicating the outlines of group meetings and meetings with the faculty and industrial mentors on the progress of the project.	Students submit project review reports at the beginning and middle of the semester indicating the results of meetings with the faculty and industrial mentors on the progress of the project.	Students submit partial project review reports indicating the results of occasional meetings with the faculty and industrial mentors on the progress of the project.

Technical writing is direct, informative, clear, and concise language written specifically for an identified audience. The content must be accurate and complete with no exaggerations. To deliver the intended message, the text must be objective and persuasive without being argumentative.

Technical reports use formal English, direct language, and simple terms. Avoid words that are a

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problem for the foreign reader, such as the verb "do" and words with multiple meanings (feel, do, as, like).

Technical reports avoid contractions (I'm, don't) and personal pronouns, which include: first person (e.g., I, we, our, us): second person (you, your, yours); and third person (he, her, it, theirs). Technical text is also void of colloquialisms, jargon, clichés, and sexist language [Michigan State University Department of Biosystems and Agricultural Engineering Farrall Hall, East Lansing, Michigan]

[1] Senior design conference is an open, publicized event and the audience regularly consists of high-school students, college students, parents, and general public.
[2] It is expected for the mentor to ask senior design group members to hold periodical meetings to review progress and document these meetings in minutes. Team members must alternate in writing of these minutes.

Outcome (4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Performance Indicators:

1. Student is able to recognize ethical and professional responsibilities in various engineering situations.
2. Student is able to make informed judgements based on the impact of engineering solutions in global, economic, environmental, and societal contexts

Outcome (4) Scoring Rubric

	4- Exceeds	3- Meets	2-Progressing	1-Below
Student is able to recognize ethical and professional responsibilities in various engineering situations	Student writes two report* assignments in the ethics cases, one of which should be related to the project, presents to the class and answers the questions. Student addresses all ethical and professional responsibilities.	Student completes the assignments and presents the cases to the class. Some questions remain unanswered.	Student completes the assignments and presents the cases to the class. Most questions remain open.	Student partially completes the assignments and presents the incomplete cases to the class.
Student is able to make informed judgements based on the impact of engineering solutions in global, economic, environmental, and societal contexts	The senior design report includes specific statements about the impact of the engineering solutions in global, economic, environmental and societal context. The statements are comprehensive, explained in detail and include examples.	The senior design report includes specific statements about the impact of the engineering solutions in global, economic, environmental and societal context. The statements are comprehensive but generic.	The senior design report includes specific statements about the impact of the engineering solutions in global, economic, environmental and societal context. The statements are incomplete.	The senior design report does not include specific statements about the impact of the engineering solutions in global, economic, environmental and societal context.

* Each report should address

- Background information of the ethical case
- Fundamental Principles and Canons of Ethics involved
- How the case is resolved
- Your opinion about the resolution adequateness
- How the case is related to your own senior design project (at least one must be related)

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Outcome (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

Performance Indicators:

1. Student's ability to function effectively
2. Student provides task specific leadership.
3. Student creates a collaborative and inclusive environment.
4. Group establishes goals.
5. Group plans tasks
6. Group meets objectives.

Outcome (5) Scoring Rubric

	4- Exceeds	3- Meets	2-Progressing	1-Below
Student's ability to function effectively	Student completed assigned tasks and engaged to provide support to team members.	Student completed assigned task.	Student completed assigned task with assistance from team members.	Student did not complete assigned tasks.
Provide leadership	Group defined leaders for all goals / tasks / objectives	At least 80 % of the goals / tasks / objectives have an assigned leader.	60 % to 79 % of the goals / tasks / objectives have an assigned leader.	Less than 60 % of goals / tasks / objectives have an assigned leader.
Create a collaborative and inclusive environment	All project tasks completed with voluntary inputs, feedbacks, supportive actions of team members other than the leaders of the tasks	Project progress is based on inputs and feedback of all team members	Team often held group meetings to discuss project progress.	Team members fail to collaborate inclusively for the completion of the project.
Establish Goals	Project goals are clearly defined.	Project goals are satisfactorily defined.	Project goals are defined with insufficient focus.	Project goals are poorly defined.
Plan Tasks	Plan tasks are clearly defined to support goals.	Plan tasks are satisfactorily defined to support goals.	Plan tasks are insufficiently defined to support goals.	Plan tasks do not support goals.
Meet Objectives	All objectives are met with high quality	All objectives are met with satisfactory quality	Most objectives are met but some with insufficient quality	Most objectives are with insufficient quality

Outcome (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Indicators:

1. Student is able to find information relevant to problem solution without guidance.
2. Student has the ability to identify the additional knowledge is needed to complete project.
3. Student is able to acquire and apply the additional knowledge needed to complete project.

Outcome (7) Scoring Rubric

	4- Exceeds	3- Meets	2-Progressing	1-Below
Student is able to find information relevant to problem solution without guidance	Student independently conducts broad search of background information relevant to problem's solution. Search is clearly documented in report	Student independently conducts search of information relevant to problem's solution.	Search of background information relevant to problem is limited and not documented	Student fails to search for background information relevant to the solution of the engineering problem
Student has the ability to identify what additional knowledge is needed to complete project and to acquire the needed knowledge	Student independently identifies and acquires the additional knowledge needed for project's completion. Additionally, student helps team partners and acquires skill not strictly needed for completing corresponding portion of project	Student independently identifies and acquires the additional knowledge needed for project's completion	Student identifies additional knowledge needed for project's completion but needs instructors/team partners aid to complete corresponding portion of project	Student fails to identify the additional knowledge needed for project's completion
Student has the ability to apply the acquired knowledge	Student applies acquired knowledge to successfully solve engineering problems using more than one solution methods	Student applies acquired knowledge to solve engineering problems	Student applies acquired knowledge to solve engineering problems with significant aids from instructors/team partners	Student fails to apply the acquired knowledge to solve problems.