**Saanjali Maharaj**
**NIHERST-NASA International Internship Program 2019**

# Final Internship Report

## Acknowledgements

I wish to extend my sincerest thanks to NIHERST, especially to the Program Coordinator, Ms. Darielle Rampersad, for facilitating this internship and ensuring a smooth journey every step of the way.

Thank you to United Airlines for so kindly sponsoring my travel to and from California.

I am deeply grateful to Dr. William Warmbrodt and Ms. Shannah Withrow at NASA for going above and beyond in their mentorship roles for me. Thank you for the lessons in both engineering and life.

I wish to thank my teammates in the Rotorcraft Aeromechanics department. I am proud of what we have achieved together.

To my fellow Trinidadian interns and my new American friends, thank you for making this summer so enjoyable.

Finally, to my family, thank you for always supporting me and encouraging me to reach for the stars.

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## Introduction

NIHERST and NASA formed a partnership in 2012 to facilitate the participation of Trinidadian & Tobagonian tertiary students in an exchange at NASA. This program has been extremely successful, resulting in cohorts of interns being selected from Trinidad & Tobago every year since 2014. This year, I was fortunate to be afforded the opportunity to participate in the NIHERST-NASA International Internship Program ($I^2P$) from June 3rd to August 10th, 2019. Together with four other Trinidadian students, I arrived at the NASA Ames Research Center, in the heart of Silicon Valley, to embark on this life-changing experience. This report details my experience there; the research I conducted and its potential impact on Trinidad & Tobago; and the way this internship has since shaped my academic career.

## Professional Summary

Saanjali Maharaj is beginning her third year of the Engineering Science program at the University of Toronto. This program is one of the most selective and advanced in the world, allowing students to gain an understanding of a wide range of fields in the first two years, followed by specializing in the final two years. Saanjali has chosen to specialize in the Aerospace option as she has been an avid space lover since the age of four. Following her summer internship at NASA, she is excited by all the possibilities for applications of the Aerospace industry right here on Earth. Upon graduation from the Engineering Science program, Saanjali wishes to pursue graduate school in the United Kingdom on her President's Medal Open Scholarship, to further study engineering applications. After the duration of her scholarship, Saanjali will return to her home country of Trinidad and Tobago where she will have the opportunity to apply the skills and knowledge gained to address issues and solve problems there.

While extremely passionate about engineering, Saanjali is a well-rounded individual. She has been a student of classical Indian dance at the Kala Mandir since the tender age of two and received a diploma in Odissi dance at the age of eighteen. Saanjali also studied classical piano at the Charles Brunner Music School and placed 2nd in Trinidad and Tobago Music Festival Junior Piano Solo category. She also plays guitar and harmonium. She received a certificate in Comic Art from The University of the West Indies. Saanjali enjoys archery, tennis, badminton and swimming. She volunteered with the Autistic Society of Trinidad & Tobago for some time. Saanjali was elected to serve as the Marketing Director of the University of Toronto West Indian Students' Association for a second year. Her graphic design skills are also demonstrated in the design of the official logo for the Radiological Society of Trinidad and Tobago. Saanjali is also a member of the Rocketry team at her university, where she conducts solid modeling and analysis using Solidworks and Ansys.

Saanjali aims to combine her engineering knowledge and her passions to give back to her home-country.

## Overview of Internship Experience

On the first day of my internship, the Chief of the Aeromechanics Branch, Dr. William Warmbrodt, fondly known as Bill, welcomed the cohort of sixty odd interns and gave us our first assignments - study the Rotorcraft Handbook that actual helicopter pilots need to learn, and watch the LEGO movie. Both assignments would be put to the test in the New Examination for Warmbrodt's Branch Interns (NEWBI) test at the end of the week. Almost every Friday, Dr. Warmbrodt would close the week with a session known as Taste of California History. He would tell us about a particular sweet treat that was invented in his home state of California and then he would actually provide this snack for us to taste! He would also discuss fun activities to do in state, inspiring many a weekend plan.
This summer was my first visit to the West coast of the United States. Almost every weekend, I explored a new place. I visited the Golden Gate Bridge in San Francisco, the SpaceX Falcon 9 Rocket in Hawthorne, and the Santa Cruz beaches which were nothing like the warm Caribbean beaches to which I am accustomed. I was also able to attend many concerts. I saw Carlos Santana with fellow Trinidadian intern, Ruth, and Paul McCartney with my roommate, Yana. Bill kindly sponsored tickets for any interested interns to see Beck and Cage the Elephant so many of us in the Aeromechanics branch attended this concert.

*Fig 1: The Golden Gate Bridge*


*Fig 2: SpaceX Falcon 9 Rocket*

One morning at 3 a.m., the Aeromechanics interns crawled out of their warm beds at the NASA Exchange Lodge to board a bus headed to the Mojave desert. There, we were able to visit The Spaceship Company and see WhiteKnightTwo and SpaceShipTwo. These vehicles are designed for space tourism in the not-so-distant future. Next, we visited NASA Armstrong Flight Research Center, where we were able to fly simulators and explore a hangar filled with fighter jets.

Living at the Nasa Exchange Lodge with a couple hundred other interns was such an exciting experience. It was easy to bond with my colleagues outside of the work environment when we would come home to cook in the same kitchen and do our laundry in the same room. I also had an amazing roommate, Yana, from Thailand. She and I would go exploring around the base together and we made some fun discoveries like finding a Lockheed P-3 Orion. Yana, the Trinidadian interns and a few other American friends would soon bond during Friday night hangouts, either going to the movies or a new restaurant, or simply during some late night games in the kitchen.


*Fig 3: Lockheed P-3 Orion with Yana*

*Fig 4: Celebrating a friend's birthday in the Lodge kitchen*

There were also many interesting activities on base. Embedded under the wind tunnel was the Fitness Center on base. The center was equipped with many gym machines but I was most interested in the free classes given by the fitness instructors. I attended kickboxing classes most frequently. Another free class that I took on base was Salsa Rueda. In addition to learning so much at work, it was a great opportunity to learn new skills like kickboxing and build on my existing dancing skills by trying a new style of dance.

The Summer Seminar Series held at Ames was an opportunity to attend intriguing talks by some of the top minds in their fields. Ames hosted the Chief Scientist of NASA to discuss the upcoming Artemis mission to return to the moon, and Dr. Katherine Boumann, the computer scientist who recently went viral for the image of her joy upon seeing her work on black hole imagery come into fruition. I even met Astronaut Yvonne Cagle after her talk about her experience as an astronaut. Apart from the scientific talks, I was also able to attend a seminar on Neil Armstrong's life as a test pilot before his astronaut accomplishments, and a talk by a concept artist and designer who has worked on science fiction films such as Star Trek.

*Fig 5: Astronaut Yvonne Cagle*

Another amazing aspect of being on base was being able to tour the world-class facilities. I was able to learn about the vertical gun range, the supercomputing facility, the Mars Roverscape and the vertical motion simulator to name a few. As an Aeromechanics intern, I have to say that my favourite tours involved the world's largest wind tunnel. The tours were given by Bill himself. He first showed us the test section of the 80 x 120 foot wind tunnel. We were all in awe of the sheer size of the tunnel and we were further impressed when Bill described the various tests of parachutes, propellers and even trucks that take place in the test section. Later on, we were privileged to tour the drive system of the wind tunnel since there was a break in the testing taking place. As you can see, the drive system consists of 6 large fan motors. We were able to walk right under one of them and then through the vane sets into sections of the tunnel where usually no humans go.

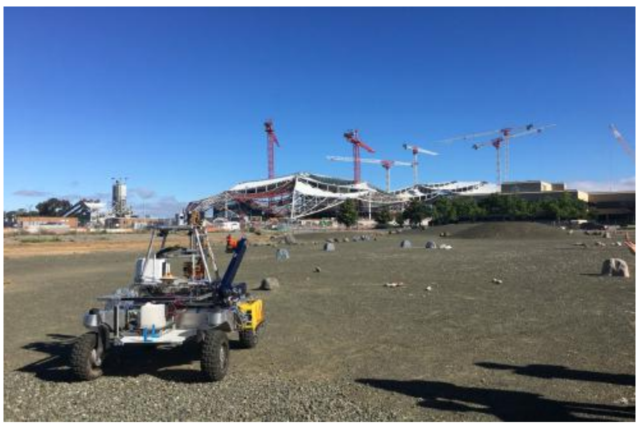

*Fig 6: The Mars Roverscape*

*Fig 7: Vertical Gun Range*


*Fig 8: The World's Largest Wind Tunnel*

*Fig 9: Inside the tunnel, in front of the drive system*

I was even luckier to visit the wind tunnel for a third time when my family came to visit. Bill took the time to give them personal tours of the tunnel and the vertical motion simulator. I was so happy to have this opportunity to show my parents and little sister what I was experiencing this summer.


*Fig 10: Family visit*

This summer was such a prime time to be at NASA - celebrating the 50th anniversary of Apollo 11 landing on the moon, and in the wake of Space Directive 1 which involves returning to the moon. As a young woman with a penchant for Aerospace, I was truly excited to be at NASA at this time to learn about the plans to put the first woman on the moon.

## Research Conducted

Within the department of Rotorcraft Aeromechanics, I was assigned to the Helicopter Rescue Operations (HeRO) team. The seven of us were tasked with developing two projects that use drones to assist in emergency situations. One subteam worked on "DemoBot" for urban search and rescue, which involves locating victims in buildings that have collapsed due to earthquakes, for example. My subteam focused on "FireBot" for assisting emergency professionals in controlling wildfires, a prevalent issue in both California and Trinidad & Tobago. Due to the length of the internship and the complexity of the project, we were tasked with designing the proof-of-concept for each mission so we worked on terrestrial robots that would eventually be adapted to the final drone versions. While our focus was on developing the mission and defining the operation of the bot, there was another team focused on designing the drone body that would be suited to the specific tasks.

Our mentor, Shannah, hosted a brainstorming session to facilitate the scoping of our respective projects. She introduced Systems Engineering tools such as a Concept of Operations (ConOps) and Success Criteria. Soon after this session, both DemoBot and FireBot teams were required to prepare a System Concept Review to be presented to Shannah and two other experts - Dr. Lee Kohlman and Larry Young, who would provide feedback on our preliminary designs. The FireBot team collaborated with the drone design team to prepare a joint presentation. I was selected as the FireBot representative to present to the panel. We presented our scope of the project, which was to focus on extinguishing spot fires[1] semi-autonomously so the emergency professionals could focus on maintaining and increasing control of the main fire. Taking the vital feedback we received into account, we proceeded to the next stage in the design process.

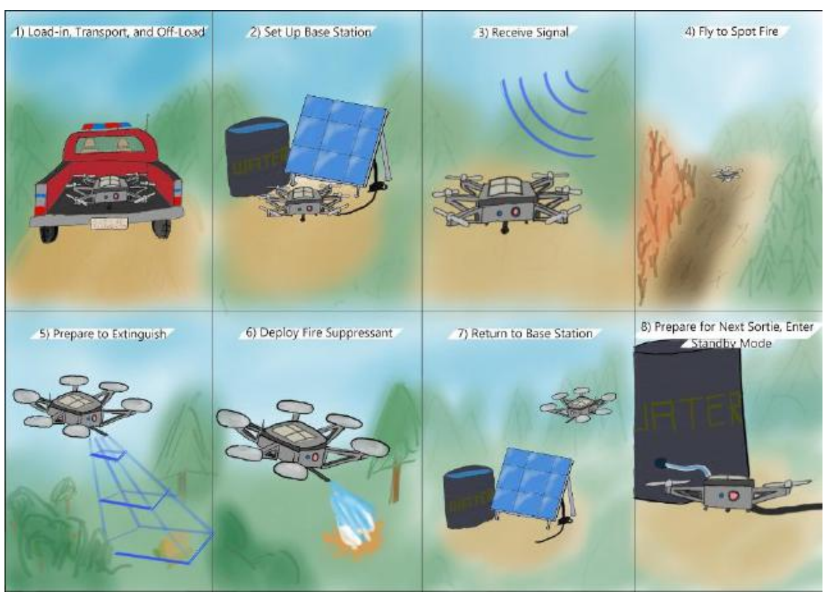


*Fig 11: Concept of Operations (ConOps)*

[1] Emergency responders work to contain wildland fires by creating regions of space without combustible material, called firelines. Wind can cause hot embers to drift over firelines, igniting small spot fires outside the contained area. If spot fires are not extinguished, they expand and compromise the fireline.

FireBot was divided into three subsystems - Software, Fire Suppression and Thermal. The Software member was responsible for programming the bot using an Arduino while the Fire Suppression member was tasked with determining the most effective and appropriate suppression system for our purposes. I was in charge of the Thermal subsystem so I had to ensure that the bot, especially its susceptible electronic components, was able to withstand the extreme temperatures to which it would be exposed in wildfire situations. Having taken courses on Thermodynamics, Heat Transfer and Materials Science, I was excited to apply my theoretical knowledge on this project.

First, I conducted preliminary materials research - searching for lightweight and cost-effective materials with low thermal conductivity. Next, I carried out calculations by modelling the problem as a thermal resistor network to determine the thickness of each material needed to keep the electronic components at an optimum operating temperature. Based on these calculations, I determined that a suitable choice would be ceramic paper. A thickness of ⅛" met the 1.5 factor of safety requirements. We ordered this material and I was able to conduct physical testing.

The first phase of testing was conducted in the office using a space heater as the heat source. A test grid of 36 evenly spaced points spanning the size of the robot chassis was drawn on a sheet of 3170 Ceratex ceramic paper. I used a non-contact laser thermometer to determine the temperatures at each point on the test grid at certain distances from the space heater. The experiment was repeated using two and three sheets of ceramic paper to obtain data for different thicknesses. The analysis of the data collected from this test phase was insufficient to validate the theoretical calculations. This is due to the fact that scaling the space heater's maximum temperature to the temperature of an actual wildfire was inappropriate because the environmental conditions of the room could only be so cold in comparison to the space heater temperature. Thus the temperature gradient could not be accurately modelled in this way. Clearly, a second phase of testing was necessary.

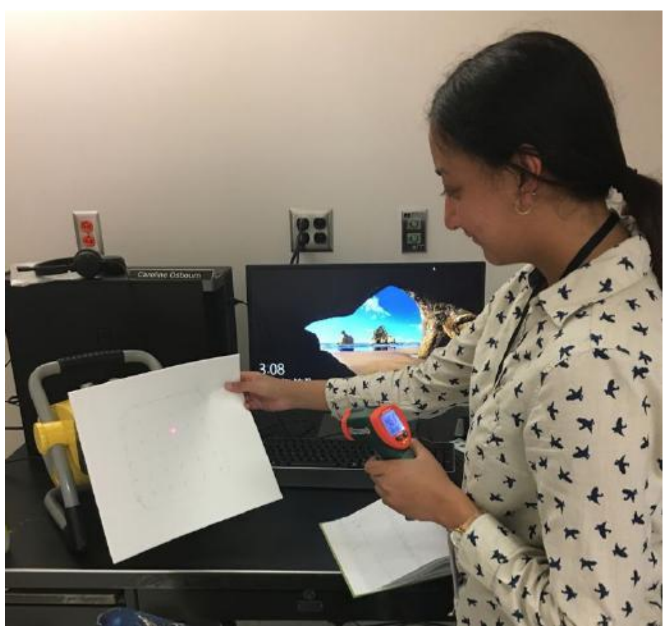


*Fig 12: First Phase of Testing using a Space Heater*

After work one Tuesday, Shannah and the FireBot team headed to a nearby beach where bonfires were permitted. The Fire Suppression member was able to conduct testing on three different suppression methods - a sprayer system, water bubbles[2] made of calcium alginate and sodium lactate, and a bucket - to determine the most effective one. Meanwhile, I was able to conduct a similar test with a non-contact laser thermometer this time, using an actual fire as the heat source. The data collected from this experiment validated my theoretical calculations that determined ⅛" of ceramic paper would sufficiently protect the electronics components of FireBot from wildfire temperatures.

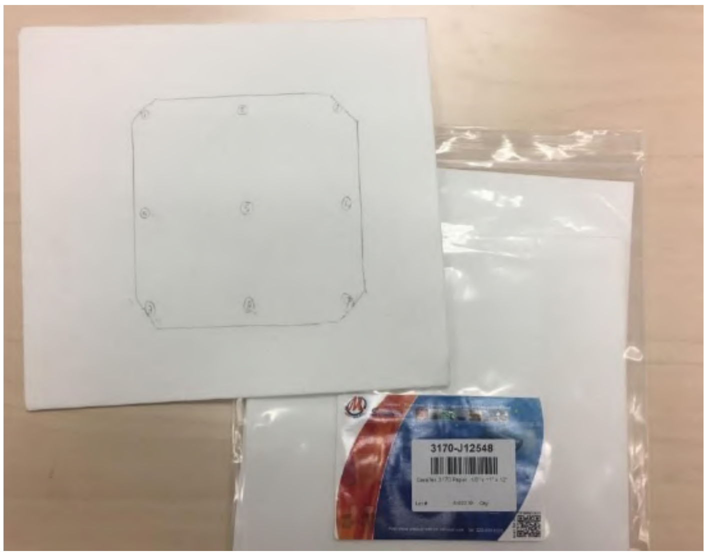


*Fig 13: Test grid on 3170 Ceratex Ceramic Paper*

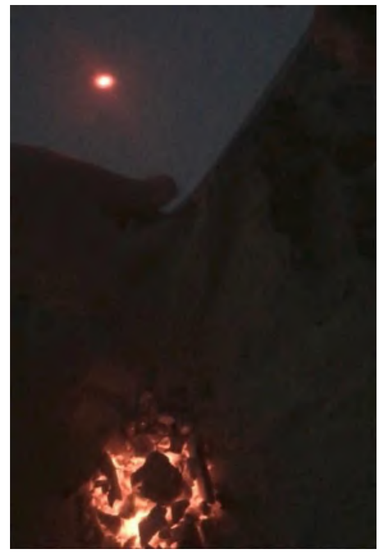

*Fig 14: Second Phase of Testing using Fire*

Now that each subsystem was completed independently, it was time to run full-system testing. The most effective fire suppression system, determined to be the sprayer system, was mounted atop the robot chassis, and all necessary sensors were attached. FireBot was programmed to receive GPS co-ordinates of the general spot fire location from its base station, then navigate to that general location using its ultrasonic sensors to avoid obstacles. When sufficiently near the spot fire, FireBot would switch to navigating using its infrared sensors to detect the precise location of the spot fire. Using a Grid-Eye to determine the hottest pixel, FireBot would position itself and deploy its fire suppressant from the pump at that pixel. It would continue until a) it ran out of fire suppressant or fuel and needed to return to the base station to reload or refuel, b) the safety of FireBot was compromised due to some failure of the insulation system causing the bot to reach its maximum operating temperature, or c) the spot fire has been completely extinguished. This operation was tested using a human as the heat source (due to time constraints, we were unable to return to the beach to conduct testing with fire) and placing obstacles in the

[2] It is effective to attack fires at the base so the idea of the water bubbles is that they would be deployed and reach the base of the fire then burst, releasing the water to extinguish the flames from the base. This was an environmentally friendly alternative to suppression methods such as foam balls which may pollute wildlands. While this method was relatively effective in the tests, it was concluded that it was not feasible since the water bubbles would require a lot of effort to produce and transport in a temperature-controlled environment to the wildfire location.

way to determine whether FireBot could successfully navigate to the heat source and deploy its fire suppressant. We had several successful runs of this test, including the one we demonstrated to the Chief, Bill.

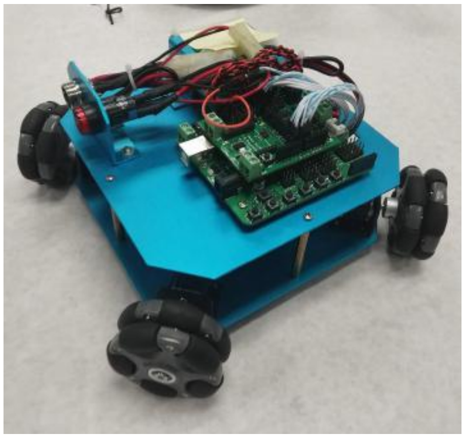

*Fig 15: Initial robot chassis*

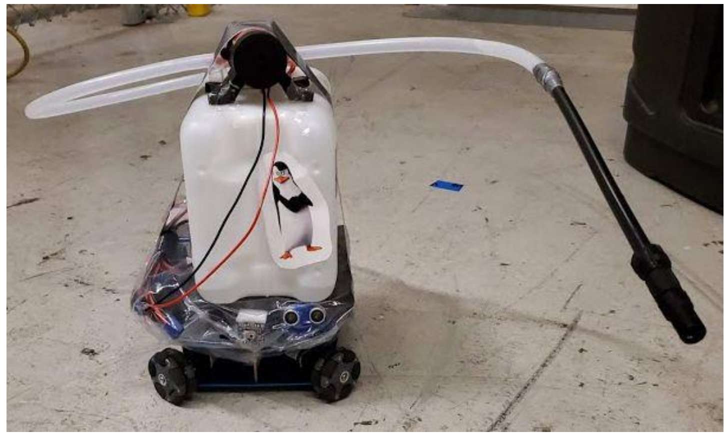

*Fig 16: Final proof-of-concept design with suppression system*

After the testing phase was completed and the internship drew to a close, we were able to present our research in the form of a poster at a symposium. We explained the operation of our bot and the impact that the concept could have on wildfires to several eager listeners. The hope for this project, following the proof-of-concept phase that my teammates and I spearheaded, is that it will be fully developed into a drone with corresponding capabilities. The robot chassis used was an omni-wheel drive so it can be easily adapted by accounting for pitch, roll, and heave motions. If this drone is successfully integrated into firefighting operations, the next step would be to upgrade to a swarm of drones to make the process even more efficient and even fully autonomous. Ideally, there would be a few small seeker drones to determine the location of spot fires and send these co-ordinates to many, larger suppressant drones so that they could effectively extinguish the fires. By increasing automation in this process, we hope to reduce the cost and more importantly, loss of life, incurred in fighting wildfires and therefore mitigate the negative effects of their occurrence.

## Application to Trinidad & Tobago

The prevalence of wildfires, commonly known as “bush fires”, in my home-country, our country, is what led me to choose to work on the FireBot team. According to the ODPM [1], while bush fires may serve important ecological purposes such as contributing to soil fertility, they have the potential to destroy ecosystems and cause damage to property and livelihoods. Furthermore, since these bush fires destroy watershed catchments, they not only cause direct damage in the dry season, but also worsen the effects of flooding, a common issue during the rainy reason. Some recent occurrences include the five-day bush fire in April 2019 that affected the air quality for Point Fortin residents, and the April 2017 bush fire that led to the collapse of a portion of the South Trunk road. It is clear that there is a need for more effective control of these bush fires in our country. A sound recommendation - to make the best use of the personnel and resources that we have - would be the use of a drone like FireBot. We already use helicopters in the bush fire extinguishing effort, but these drones have the potential to be even more efficient. It would be more cost-effective to deploy several drones that can get closer to the base of the flames and effectively allow the firefighting professionals to maintain control. This is key to prevent situations where the bush fire spreads, such as the time it spread to the road in 2017. An investment in this research could significantly benefit both the citizens and wildlife of our beautiful country.

## Lessons Learned & Next Steps

As a student of Aerospace Engineering, I was over the moon when I learned that I would be an intern at NASA, a world leader in the Aerospace industry. Especially during the summer of the 50th anniversary of the Apollo 11 moon landing and during the early phases of the Artemis program, it was easy to become enthralled with the outer-space applications of my studies. However, my project helped me to discover the potential of the applications of the industry right here on Earth. While space exploration is fascinating, I am also excited by the possibilities to use my degree to make a concrete positive impact on our society in terms of issues that are already prevalent on our home planet.

Following the completion of my undergraduate degree, I intend to pursue graduate studies and further my research in the Aerospace field. It is my hope that by then there will be more advances in the use of drones to address disaster situations. I am interested in continuing to contribute to these efforts because I was inspired by the positive impact they can have.

## References

[1] “Fires | Office of Disaster Preparedness and Management - ODPM, Odpm.gov.tt. [Online]. Available: http://www.odpm.gov.tt/node/19. [Accessed: 03- Nov- 2019].