# Cancer Immunotherapy Microfluidic Device

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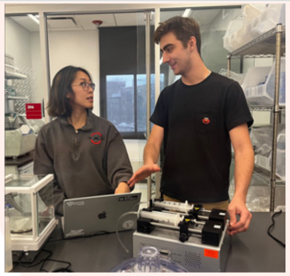
[1]Boston University, [2]Brown University, [3]The Charles Stark Draper Laboratory, Inc.



Student Researchers Patra & Benedek in BU's Bioengineering Technology & Entrepreneurship Center (BTEC)

## ABSTRACT

3D tumor models require constant perfusion to sustain tumor viability over long periods which is necessary for determining the efficacy of cancer therapies. A single-channel additive-manufactured monolithic device was developed by Markoski et al. (2021), who pioneered a biologically compatible platform design with 3D printable microfeatures for the sustainment and research of multicellular tumor spheroids (MTS). However, drug development calls for high-throughput alongside replicable experiments, and consequently, there is a need for a multiplexed design that would allow for the testing of multiple samples under similar conditions for standardization. A fourchannel device was then proposed and designed from a literature review and then successfully fluidically validated through simulation to prepare for physical prototype validation via the insertion of MTS.

## INTRODUCTION

2D tissue models have been the standard for preclinical cancer studies in the past; however, new examinations show that they do not provide translatable models of tumor microenvironments. Multicellular tumor spheroids (MTS) under constant perfusion behave similarly to in-vivo tumor tissue and are promising in the development of targeted cancer therapies as they provide a more translatable tumor microenvironment than current 2D models. Past microfluidic devices that used polydimethylsiloxane (PDMS) require multipart assemblies, which limits their life-spans and makes them leakage-prone. There has been prior development of a single channel testing and imaging platform using additive manufacturing; however, there is a need to improve the design to increase throughput and functionality for drug development applications. We hypothesize that a 6-channel design would allow for the simultaneous testing and validation of cancer therapies, and that 300±20μm spheroids can be created and fluorescence-imaged.

## METHODS

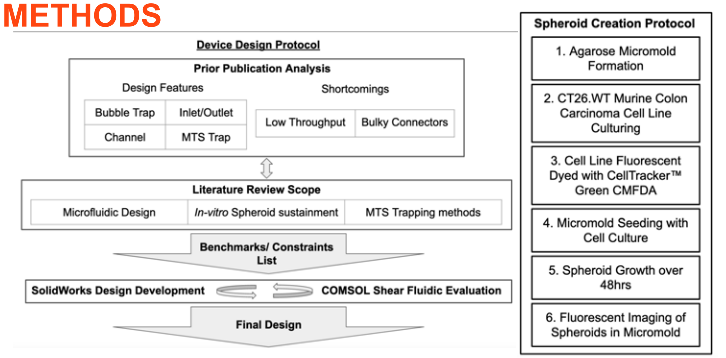



*Fig 1A.* Final 4-channel multiplexed design with spheroid retrieval backflow system, a bubble trap, barbed inlet/outlet connectors, and a female screw connector.

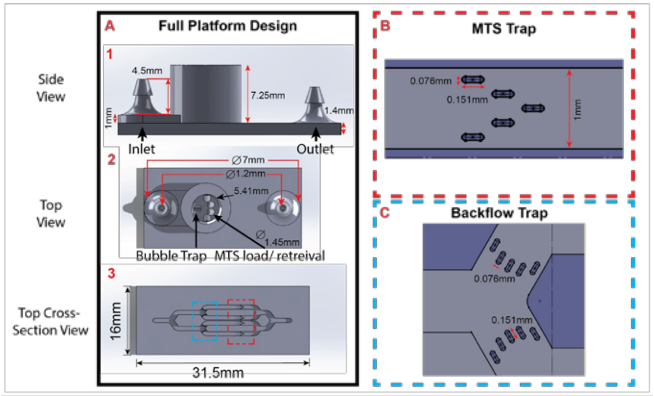



*Fig 2B.* MTS Trap. *2C.* Backflow Traps for two channels. Backflow traps allow for reverse flow from outlet to release MTS from the MTS trap into individualized retrieval holes for post-analysis. Ovals in represent posts to capture a singular MTS.

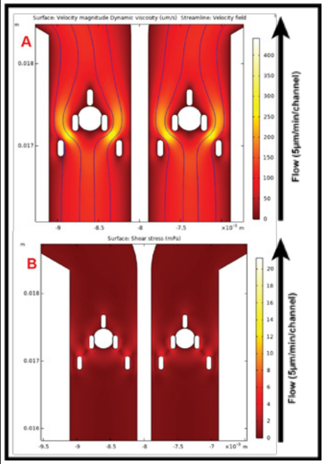



*Fig 3A.* Surface Velocity Magnitude of 2/4 COMSOL-simulated channels with 300μm spheroid models. The initial flow was 20μm/min before the initial channel splits, and falls to 5μm/min/channel at each capture geometry

*Fig 3B.* Surface Shear Stress of 2/4 COMSOL-simulated channels with spheroid models.

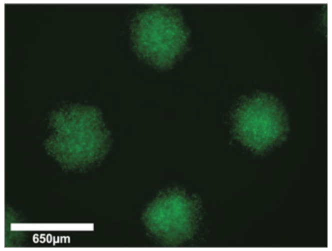



*Fig 4.* ~500μm spheroids labeled with CellTracker Green under fluorescent imaging with EVOS M7000 Imaging System.

## DISCUSSION

The bulky connectors and the low-throughput shortcomings were addressed in this design. Screw cap connectors were replaced with barbed connectors at the inlet and outlet to increase the packability, and the bubble trap connector was multiplexed to fit 4 tumor loading/retrieval ports. COMSOL was used to determine that inlet flow rates exceeding 160 μl/min induce shear stresses which exceed the MTS-damaging biological threshold of .04 Pa. The design was limited by the ability to include independent loading ports for more than four channels inside the bubble trap due to the minimum effective MTS loading channel diameter for each. This hampers standardization, as 6-well plates are usually standard across research. Nonetheless, we were still able to multiplex the design by 400% than prior. The spheroid creation resulted in larger spheroids than expected, but the fluorescence and creation provides a valuable proof of concept for future work for spheroid insertion and imaging in the device.

## CONCLUSIONS

- Takeaways: Successful fluidic simulation verification and exploratory spheroid creation holds promise for physical device validation in future steps
- Future Steps: physical device print, MTS trap section polishing for confocal imaging, device biological validation with 300μm MTS in constant perfusion in all channels.

## ACKNOWLEDGMENTS & REFERENCES

- Special Thanks: Jeffrey T. Borenstein & Alex Markoski
- Additional Thanks: Professors Diane Joseph-McCarthy, Kavon Karrobi, & Xin Brown

Markoski A, Wong I, Borenstein J. "3D Printed Monolithic Device for the Microfluidic Capture, Perfusion, and Analysis of Multicellular Spheroids" Frontiers in Medical Technology, (2021), 3

# PREDICT96 Data Analysis Pipeline

Stephen Sweet, Jin San Yoon, Jeevith Chandrasekar, and Sumner Warden

Boston University

## ABSTRACT

PREDICT96, a high throughput multi-variable device used for the analysis of compound interaction with a single organ system, requires the development and use of a data pipeline for downstream analysis of the device findings. Built off of experimental data from open-source data platforms, we have developed a pipeline for both single-cell and bulk-cell RNA sequencing in order to understand connections between differentially expressed genes and their associations with known diseases. Additionally, we have developed a vascular atlas to compile public data into an integrated database which is essential to the analysis of the PREDICT96 results.

## INTRODUCTION

- PREDICT96 is a single organ system that allows for researchers to analyze the interactions between tissues and compounds through gene expression analysis. This device features 96 separate devices, each with 2 microfluidic chambers separated by a semipermeable membrane.
- System requires a high throughput system for the analysis of RNA sequencing to understand the changes to gene expression as a result of the compound and the tissue interaction
- Our *long-term goal* is to build a database from external experimental data to later conduct cross comparisons with in-house experimental data to perform novel downstream analyses

## METHODS

- Preprocess the single-cell RNA-seq data using Cellranger and Seurat to generate gene-level counts
- Filter out low-quality cells and genes based on various quality control metrics and normalize gene-level counts
- Perform dimensionality reduction using techniques such as PCA or t-SNE.
- Conduct multiple downstream analyses
- Visualize results using various plots such as heatmaps, dot plots, and network graphs

## RESULTS

- Since the project is entirely data analysis and pipeline creation, our results during the pipeline creation stages are simply bypassing errors and troubleshooting compatibility between data inputs and outputs. Following the completion of the analysis pipeline, we will produce graphical representations from the top expressed genes within the dataset
- The output of our pre-processing steps within the single-cell sequencing pipeline result in analyzable data files which we export into Rstudio and use Seurat tools to find the differentially expressed genes and the markers that define clusters
- From the differentially expressed genes, we will be able to use analysis packages to further investigate and understand the relation between the gene expressions in the samples, including CellphoneDB, STRING, and netGSA
- Further results will include a Venn diagram for each type of data output with a percent similarity score metric for each output. We will compare the changes in DEGs between various datasets. Heatmaps will be produced to show top DEGs and pathways.

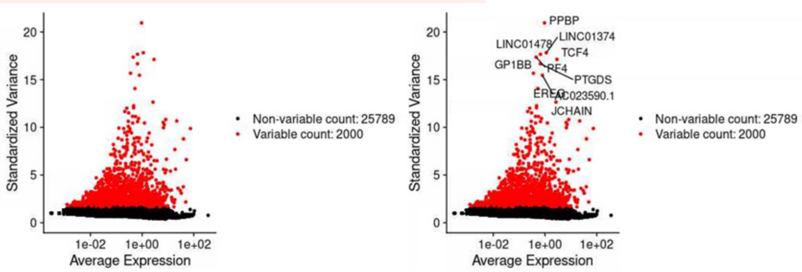



Figure 1: Features that exhibit high cell-to-cell variation which will be used for further downstream analysis such as PCA

## DISCUSSION

- Being able to compare in-house data to the external datasets we have collected will enable the PREDICT96 models to be better deployed and validated for testing absorption, distribution, metabolism, and excretion of candidate drugs
- For the sample data, we were able to successfully generate the top differentially expressed genes and their corresponding p-values seen in the table above. From this point on, we will work with the data provided recently from Draper

## CONCLUSIONS

- 70 percent of drugs tested in human clinical Phase II trials are unsuccessful, resulting in millions of dollars spent on an inefficient compound
- These data analysis pipelines allow for increased accuracy of the PREDICT96 chip in commercial applications

## ACKNOWLEDGMENTS OR REFS

- Thank you to our advisors Jennifer Walker and Daniel Matera for the step by step support throughout this research

# Development of Burst Pressure/Leak Test System for Surgical Adhesives

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## ABSTRACT

Surgical adhesives are a novel way to heal and repair incisions in tissue. They are increasingly being used as an alternative to sutures or staples since they are more effective and result in better wound healing in patients. Since tissues in the body undergo stress and strain, mechanical strength of the adhesive is critical in its effectiveness in wound healing. Our project is to design a testing system to measure the mechanical strength of the surgical adhesives through a metric called “burst pressure.” Burst pressure is the maximum pressure the adhesive can handle, before it fails (bursts open). The results of our project will help in the development of Draper’s own bioadhesive by examining the reasons why current surgical adhesives fail and how to improve upon them.

## INTRODUCTION

Surgical adhesives are natural polymer-based glues that are innovative replacements for traditional wound-closing methods such as sutures or staples. They are more biocompatible and less traumatic to the injury site, resulting in better patient outcomes. Mechanical strength is an important metric in determining the effectiveness and usability of various surgical adhesives and can be quantified using the burst pressure of an adhesive placed on a blood vessel. Pre-existing products must be tested against developing ones in order to complete preliminary efficacy trials. Our project aims to improve and refine Draper’s burst pressure/leak testing system for surgical adhesives. We will continue to improve the current testing setup, establish a pressure data visualization method, and optimize the system through bioadhesive testing. The outcome of this project will allow for a better selection of surgical adhesives for appropriate implementation and aid in the development of Draper Laboratories' own microstructured bioadhesive.

## METHODS

**CAD Design:** Box, luer connector and insert designs were done in Onshape and all were manufactured via 3D printing.
**Burst Pressure Trials:** Vessel patched with of BioGlue pressurized with a syringe pump until failure. Data collected as Biopac pressure measurements and video camera footage. Repeated for six trials with faux vessels (Dragon Skin) and real vessels (porcine aorta).
**Data Visualization System:** Matlab script will synthesize the video, pressure and time data to enhance post processing and analysis.
**Statistical Analysis and Design Validation:** Will determine statistical significance of our system with uncorrelated t-tests (p>0.05) comparing collected data to literature values. Accuracy and precision will be determined by confidence intervals and standard error respectively.

## RESULTS

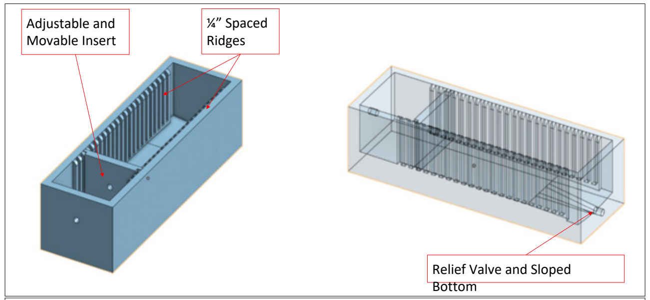


**Figure 1:** Latest 3D CAD Model of main box used for housing vessel during testing. The addition of a relief valve and sloped bottom allows for draining of water after each trial. Movable insert allows for testing of various vessel lengths up to 14 inches long.

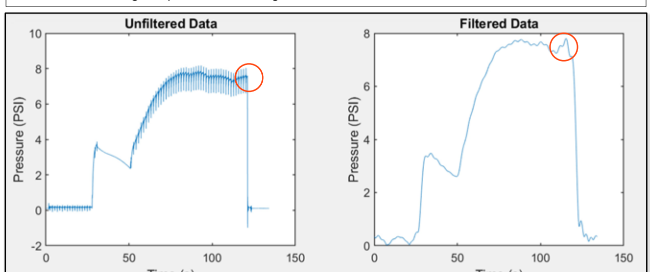


**Figure 2:** Plots of the unfiltered and filtered burst pressure data for balloon vessel sealed with BioGlue. A notch filter was designed using Matlab to eliminate the unwanted noise that is visible in the left subplot. The filter removes the noise that obscures the burst event making identification of burst pressure difficult.

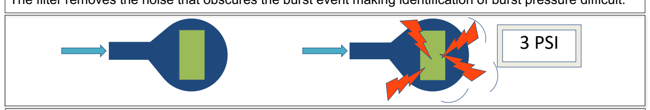


**Figure 3:** Preliminary testing was conducted using balloons and tape resulting in burst pressure values above 3 psi.

## DISCUSSION

- Testing box internal length was lengthened to 14.5 inches to accommodate larger blood vessels
- Designed vacuum-based draining system built into testing box
- Implemented a notch filter in processing the pressure measurement from vessels
- Burst Pressure of tape was recorded at around 4 psi when tested on balloon vessels
- Future work:
  - Testing on faux and real blood vessels using Bioglue and other surgical adhesives
  - Compare burst pressure measurements to literature values using correlated T test
  - Assess systems accuracy and precision

## CONCLUSIONS

- Burst pressure testing of different surgical adhesives will improve on the development of Draper’s bioadhesive
- Testing of failure rates of surgical adhesives will expose weaknesses and design flaws that Draper can avoid
- Development of a strong surgical adhesive will improve outcomes of surgery, decrease infection, and minimize recovery time

## ACKNOWLEDGEMENTS

We would like to thank the Boston University Senior Design Program and Professors Darren Roblyer and Diane Joseph-McCarthy for their support. We would also like to thank BU’s Bioengineering Technology & Entrepreneurship Center for providing the space and resources help prototype our project.

BOSTON UNIVERSITY

Draper Research Symposium / April 12, 2023

DRAPER

# Development of an In Vitro Flow Test to Examine A Growth - Adaptive Pediatric Heart Valves

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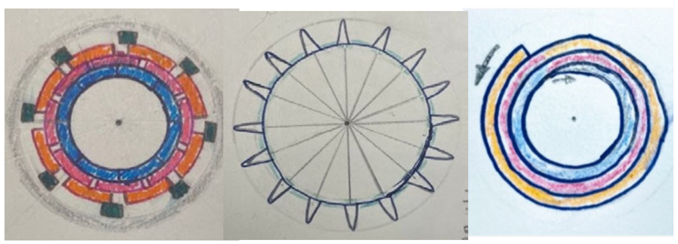
## INTRODUCTION

- Current pediatric heart valve replacements do not adapt with a growing child.
- There is a need to develop a valve that changes in diameter to reduce surgery
- We developed a test analysis the flow through an adaptive valve.

## Methods

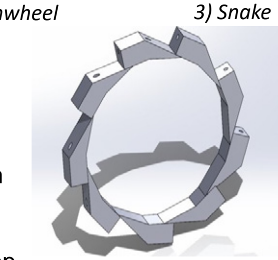
**First Phase:** Brainstorm concepts for expanding valve



*1)Step R&B* *2) Pinwheel* *3) Snake*

--> Focus on furthering 4th design

Transition to modeling contraction mechanism that mimics drawn design

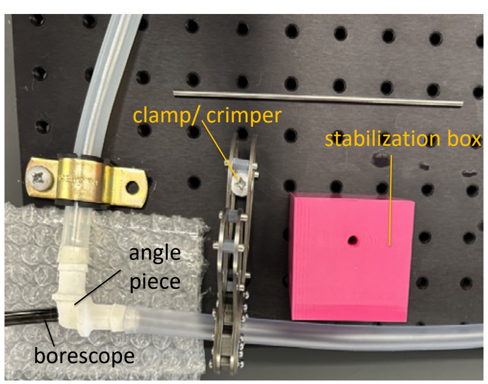


*4) Octo*

**Second Phase:** Assemble testing app aratus

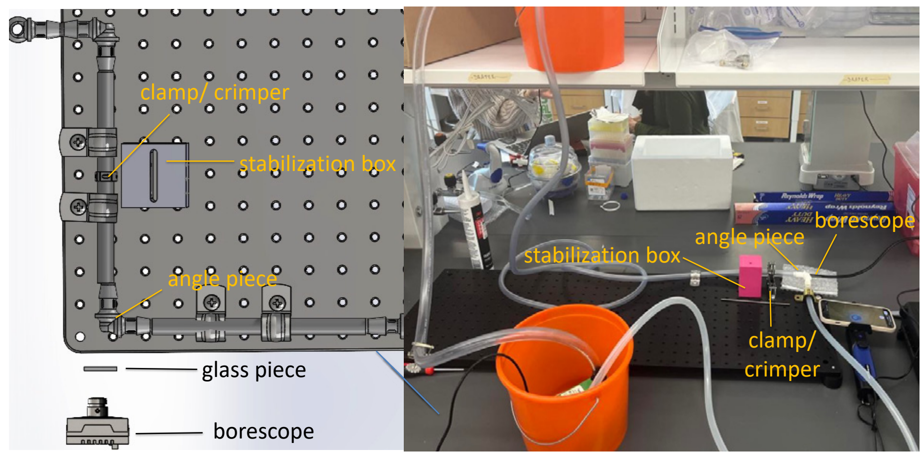
*IRIS Crimper*

*Hose Clamp*



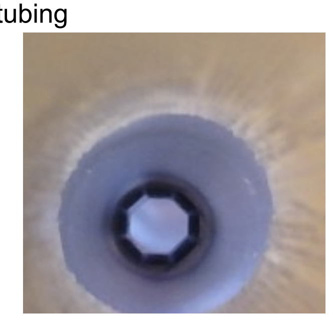

## RESULTS

- IRIS crimper shows uniform compression and does not appear to damage tubing
- For comparison hose clamp is non uniform in its compression and with time warps the tubing in this shape

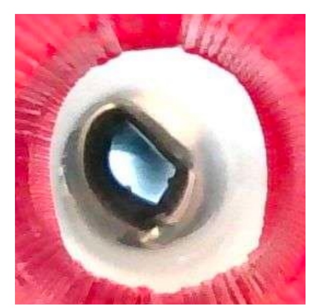



**Third Phase:** In Vitro Testing

- Analyze water flow through both Draper crimper and hose clamp.
- Observe diameter changes
- Measure/analyze borescope images with ImageJ the
- Observe possible deformation of 4 different compositions of tubing



*IRIS Crimper*



*Hose Clamp*

## DISCUSSION

- Based off the results, IRIS crimper diameter changes are more uniform.
- The symmetrical geometry allows for the compression to be even.
- Crimper has reduced deformation on tubing as well when compared to hose clamp.

**Implication**

- IRIS mechanism can steadily increase or decrease inner diameter.

**Current Limitations**

- System leakage
- Camera stabilization
- Borescope scale

**Future Objectives**

•Complete an original Octo/Iris device for In vitro testing
•Test mechanism's ability to expand with flow model

## CONCLUSIONS

- If the crimper mechanism gives a more constant diameter change with respect to compression levels, this test set up can be used to characterize flow through Draper's pediatric heart valve at different diameters, in the future.

### ACKNOWLEDGMENTS

- We would like to thank professors Dr. Zhenglun Alan Wei and Dr. Scott Stapleton for their assistance through our project along with Draper sponsors Dr. Corin Williams and Giselle Ventura.



UMASS LOWELL DRAPER

# Robotics & IMU

Christopher Castro | Ian Scofield | Cameron Ryals | Atila Sulker

FAMU-FSU College of Engineering

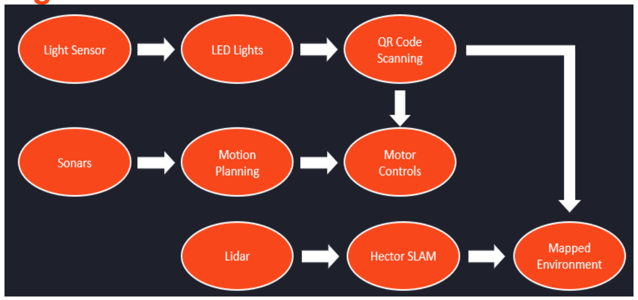
## ABSTRACT

We created a self-driving robot that uses a wall-following algorithm to navigate an office space without collision. While the robot moves it was not allowed to accept any GPS input. The robot constantly scans while it navigates until it finds the QR code on a wall. Once the robot scans the QR code the project is deemed successful, and the robot stops operating.

## INTRODUCTION

Automation in robotics has been a growing topic for years. With its use in warehouses and manufacturing, autonomous robotics help drive the backbone of businesses. These same concepts found in industrial services can be trickled down into helping the day-to-day work of an office. The goal of this project is to build an autonomous robot that could function in an office of people and obstacles that serves the purpose of finding a QR code along the wall.

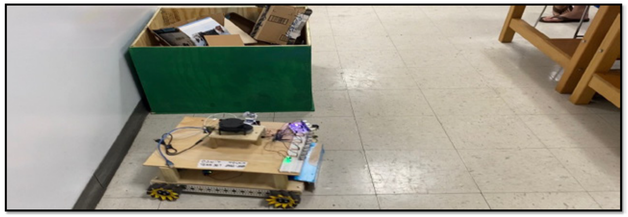
## Algorithm Methods



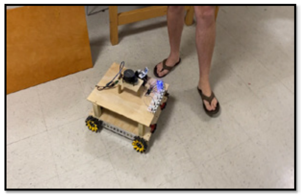

- ROS (Robot Operating System) used for QR code scanning, Lidar and Hector SLAM (Simultaneous Localization and Mapping), and motor controls.
- Scanning the QR code was done using a camera and OpenCV in ROS.
- Motion planning algorithm: wall following using a series of Ultrasonic Sensors and a LIDAR.
- Communication: serial communication between the Pi and Arduino.
- IMU was used in conjunction with motors' encoder feedback to compute command velocity of motors.

## RESULTS

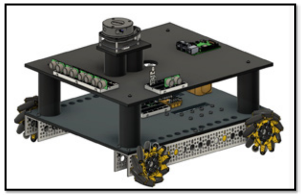
Platform avoiding an obstacle



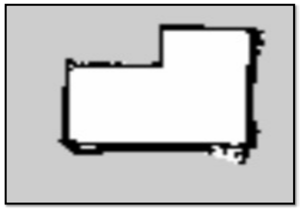
Platform avoiding a person



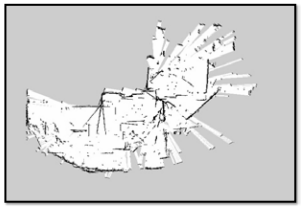
CAD drawing of platform



Hector map of obstacle-free environment



Hector map of environment with obstacles



## DISCUSSION

- Trying to navigate a cluttered environment with our original design of two ultrasonic sensors at the front helped us realize that it had too many dead zones.
- We then added additional ultrasonic sensors, which covered blind spots to better detect obstacles of various dimensions. Positioning of these sensors was found through trial and error, and through understanding the sensors' beam width and length limitations.
- Hector SLAM was chosen for environment mapping because it is accurate for robotics platforms, and only requires laser scan data to work appropriately.
- We realized that rudimentary PWM control of the motors created imbalances on wheel movement, so we created a function that computed the command velocity of the robot.

## CONCLUSIONS

Through completing our goals of autonomously navigating an office while avoiding obstacles, and scanning a QR code at an unknown destination, we demonstrated an understanding of the problem and developed a working model. Next steps for this project would be to focus on speed, efficiency, and accuracy.

## ACKNOWLEDGMENTS

We'd like to thank our project Sponsor Draper, our Draper advisors Gesnel Gachelin and Caitrin Eaton, as well as our faculty advisor Dr. Oscar Chuy. Lastly, we'd like to thank Keenan Wyrobek and Eric Berger the creators of ROS as well as Stefan Kohlbrecher and Johannes Meyer the creators of Hector SLAM.

# Digital Framework for Space Vehicle Attitude Control Requirements Verification

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[1]University of Connecticut ECE Department, [2]University of Connecticut ME Department

## ABSTRACT

We combine system engineering models, establish an authoritative source of truth, and lower the barrier of entry for digital engineering using a digital framework to integrate models. In our application we create the framework with OpenMBEE and apply it to verify the design for the attitude controller of a spacecraft.

## INTRODUCTION

Draper has provided ME 28 and ECE 20 with a system of interest (SOI) to create a digital framework to verify the design of a spacecraft attitude control system with the suggested mission of spacecraft rendezvous and docking. The digital frame work will consist of the following components:

- **Requirements Model**: Contains requirements that are to be verified using the digital framework (Created using SysML).
- **Architecture Model**: Decomposition of the SOI, links the requirements to each component of the SOI (Created using SysML).
- **Physics Model**: Performs simulations and produces data that is used to verify requirements (Created using Matlab).

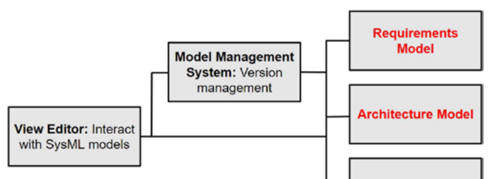



Figure 1: OpenMBEE Framework: High Level

## METHODS

**Components**

- MATLAB/Simulink Models (Attitude Control/Thermal Physics)
- SysML Models (Architecture and Requirements)
- OpenMBEE
  - Model Management System (MMS)
  - View Editor (VE)

**MMS Core Dependencies:**

- Relational Database - Data storage structure (PostgreSQL, MySQL)
- Document store - Database search engine (Elasticsearch)
- S3 Artifact storage - (AWS, MinIO, etc.)

## RESULTS

**Architecture and requirements**

- Requirements table, which describes the verifiable requirements for each subsystem
- Create architectural model in SysML with all requirements satisfied by specific testable metrics

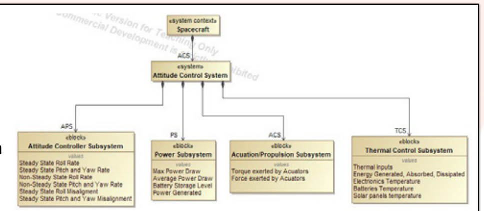



Figure 2: BDD, Architecture Model

**OpenMBEE Framework**

- Models interface with individual MDKs which then interface with the MMS via REST API
- Data is integrated between models and can be interacted with using the View Editor via HTTP
- Versioning is handled using Git

**Physics Model Verification**

- Attitude Control Verification
  - Required values are calculated — Yes
  - Model displays reasonable behavior — Yes
- Thermal Verification
  - Required values are calculated — Yes
  - Model displays reasonable behavior — Yes

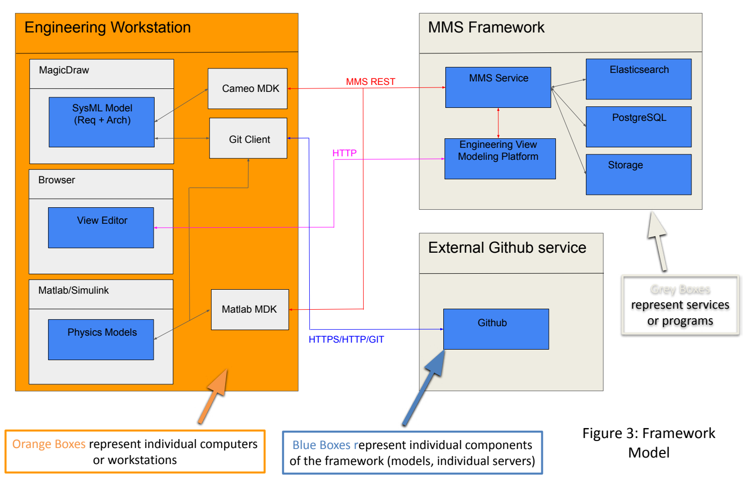
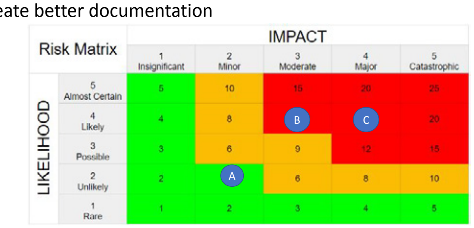



Figure 3: Framework Model

## DISCUSSION

**Current risks and challenges**

- IT infrastructure (UConn hosted servers) issues (A)
  - Current framework is hosted locally and may not be representative of a true industry ready framework
  - **Mitigation**: Continue working with UConn UITS to spin up servers
- Licensing (Matlab and Cameo) issues (B)
  - Lack of individual Matlab and Cameo licenses limits flexibility
  - **Mitigation**: Continue working with IASE to obtain more licenses
- Lack of Cameo MDK documentation and examples (C)
  - **Mitigation**: Work with IASE advisor and industry contacts to find or create better documentation




## CONCLUSIONS

- For industrial implementation breakdown organization into project groups, project groups intro specific projects, specific projects into models and accompanying documentation
- An industry scale implementation of an OpenMBEE framework would need to host any MMS services on dedicated servers rather than locally.
- Our group does not have the IT knowledge to implement an industry level OpenMBEE framework, we will instead document our research, instructions, and progress with a locally hosted version.

## ACKNOWLEDGMENTS OR REFS

- The group would like to thank Professor(s) Amy Thompson, Shalabh Gupta, David Giblin, Draper Liaison Brian Sheehan, and Stephen White from UITS for all their assistance in this project!

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Draper Research Symposium / April 12, 2023

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DRAPER

# Developing a Low Cost Plasma Thruster

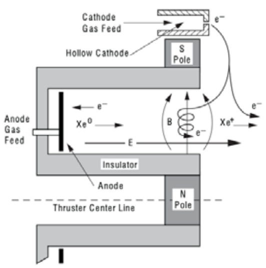
Braden Oh[1], Albert Countryman[2], Avery Clowes[1], Lily Dao[1], James Jagielski[1], and Ben Eisenbraun[1]

[1] Olin College of Engineering, [2] Brandeis University

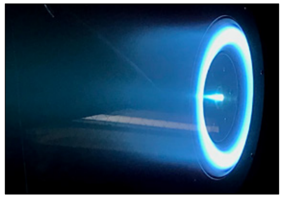
## ABSTRACT

The Hall effect thruster is a highly efficient rocket engine essential to modern satellites. We present the design and test of a low-cost Hall thruster by a team of undergraduate students. This thruster was successfully fired at steady state. A review of fundamental operating principles and practical design considerations was compiled from literature and interviews with industry experts to serve as an entry level resource for future Hall thruster design teams.

## INTRODUCTION




*Cross-sectional diagram of a Hall thruster channel [1]*



*High power Hall thruster developed at NASA JPL*

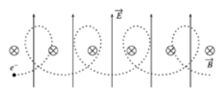
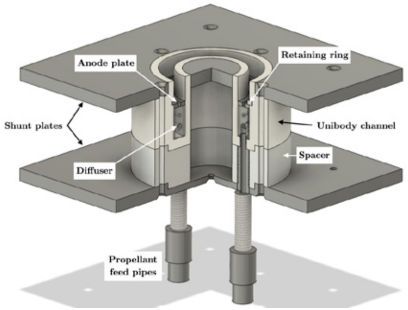


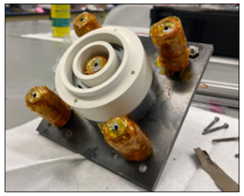
*Illustration of electron ExB drift inside the channel [2]*

## MECHANICAL DESIGN

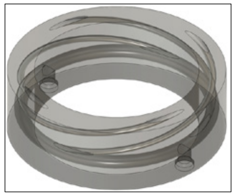
- Thruster **dimensions derived** from fundamental physics, literature reviews, and expert interviews.
- A **3D printed helical gas diffuser** was designed to maximize ionization percentage.




*Quarter section view of our thruster [2]*



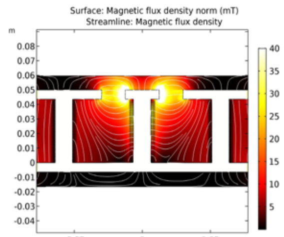
*Partial assembly*



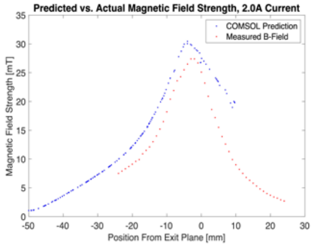
*Helical propellant diffuser*

## ELECTROMAGNETIC DESIGN

- The magnetic circuit was created with five electromagnets and iron shunts.
- Hollow cathodes were too expensive, so low-cost **hot cathodes** were built to supply initial electrons.




*Magnetic field simulation [2]*

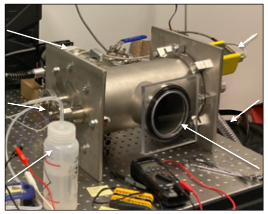



*Field strength measurements [2]*

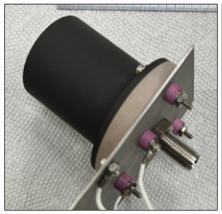
*Hot cathode test*

## HIGH-VACUUM INFRASTRUCTURE

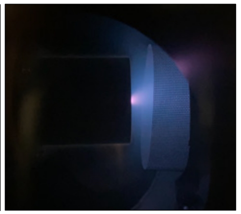
- To facilitate in-house cathode testing we **built a low-cost, turbopump powered vacuum chamber**.
- Features ultimate vacuum of 10^-7 Torr; needle-valve gas feed system; and ion gauge.
- **Ignition characteristics** of a donated hollow cathode were characterized prior to live-fire testing.




*Completed chamber*



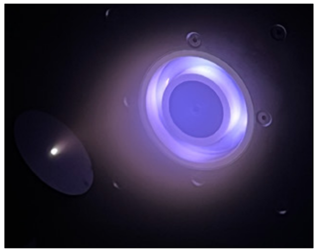
*Donated hollow cathode*



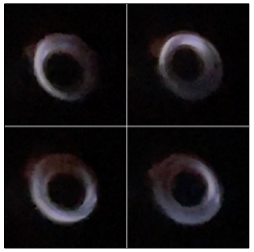
*Our first stable plasma*

## SUCCESSFUL TEST FIRING!

- The thruster was successfully fired at **steady-state** for ~2 hrs and at a peak of 200W.
- **Rotating spoke instabilities** are an expected characteristic of steady state Hall thruster operation.
- Reliable **thrust data could not be collected**, but voltage, current, and flow data allowed us to calculate **upper bounds** on thruster performance.



*Steady state operation on krypton*



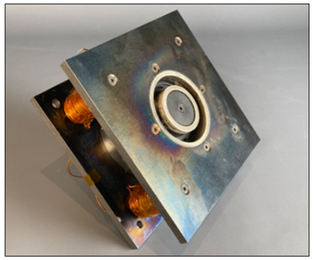
*Rotating spoke instabilities typical of Hall thrusters*

| | Upper Bound | SPT-50 [3] |
|---|---|---|
| Power | **~60 [W]** | 300 [W] |
| Thrust | **<10.0 [mN]** | 19 [mN] |
| Isp | **<1091 [s]** | 1280 [s] |
| Efficiency | **<89 [%]** | 40 [%] |

*Upper bounds for our thruster compared to a flight thruster*

## THE PROBLEM OF ACCESS

- There are **too few electric propulsion specialists** to meet growing industry demand.
- Historically, **research has been confined** to a small number of U.S. graduate institutions.
  **We published the fundamental physics and engineering process** we followed in the Journal of Electric Propulsion.
- **Our publications are already being read** by students at Rose-Hulman and U Michigan.
- Upcoming publications will address **gas diffuser** design and the **ignition** process



*Thruster post-firing*

*Diffuser post-firing*

## CONCLUSIONS

- Successful **steady-state operation** demonstrates a low-cost platform for future undergraduate research!
- Additionally, this operation demonstrates feasibility of a **3D printed, helical gas diffuser** (and patent pending)!
- Successful development by 8 undergraduates in 2 semesters demonstrate **feasibility of electric propulsion** projects at the undergraduate level.

## ACKNOWLEDGMENTS OR REFS

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- Prof. John Williams (CSU) & Plasma Controls LLC
- Prof. Chris Lee, Olin College Faculty Mentor
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*[1] Goebel, Dan and Katz, Ira, "Fundamentals of Electric Propulsion." Fig 7-1. 2008.*
*[2] Oh, Braden, et al. "Design, fabrication, and testing of an undergraduate hall effect thruster." Fig 1. 2023.*
*[3] Clauss C, et al. "Benefits of low-power stationary plasma thruster propulsion for small satellites." Table 2. 1995.*

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