Devices for the Control of Airflow in Wind Instruments

A Senior Project

Engineer: Tyler Griffith

Supervisor: Dr Brian Taylor

Project Objectives

Deliverables

- **Two Systems of Devices** Capable of Providing **Controllable Flow** Into Reedless **Wind Instruments** And Measuring The Sound Produced
- **A detailed report** of the **prototyping methods** of each device and an **evaluation of the advantages and drawbacks** of each device in the context of a tool for future scientific analysis of human music playing

Design Concepts

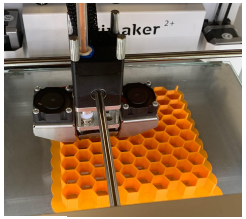
- PWM Fans in Series & 3D Printed Funnel with Aperture
- Piston Cylinder with Linear Actuator, One Way Valve, Funnel & Aperture

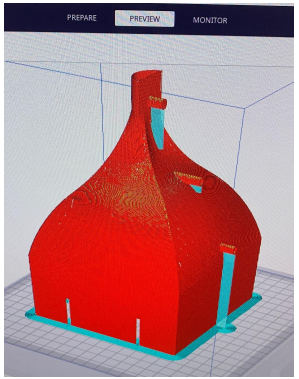
In Scope	Out of Scope
- Two Complete Designs and Prototypes Each With: Flow Generation and Manipulation - Adaptability to flow sensing devices - Interfacing with Ocarinas & Recorders - Audio Measurement System - Simple, Proof of Concept Audio Analysis	- **Mapping Between Flow and Sound Parameters** - MIDI Sheet Music Reading - Dynamic Covering - Transverse Flutes - Reeded Wind Instruments

Design Concepts

PWM Fan

- PWM Fans in Series & 3D Printed Funnel with Aperture and Flow Sending Ports





5 Fans in Series

Funnel with Honeycomb Flow Straightener

Instrument with stand

8 Port PWM Controller

PC Power Supply with Appropriate Connectors

Design Concepts

PWM Fan

- PWM Fans in Series & 3D Printed Funnel with Aperture and Flow Sending Ports

Comments

- Fans and aperture are not orthogonal control levers. Both control pressure and flow rate directly
  - Difficult to manipulate flow precisely even with flow straightener
  - Significant losses and deviations from potential flow analysis requirements

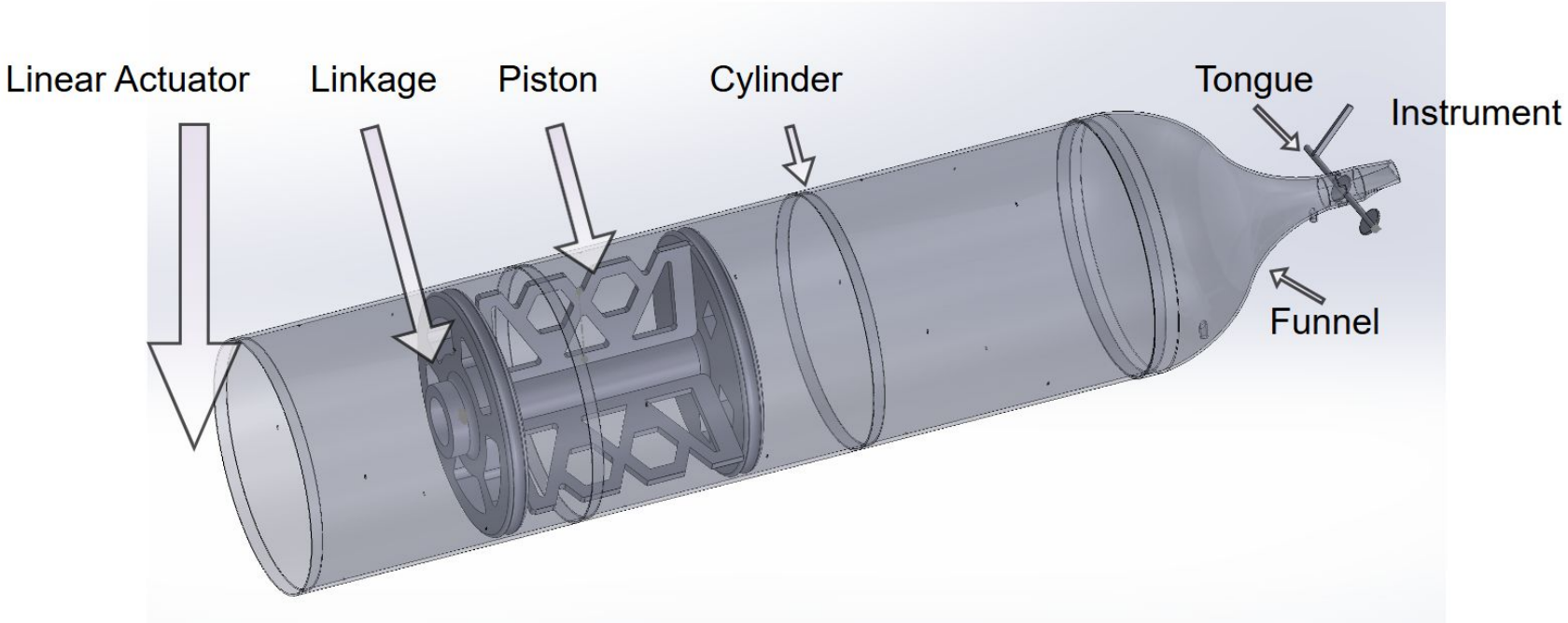
Advantages

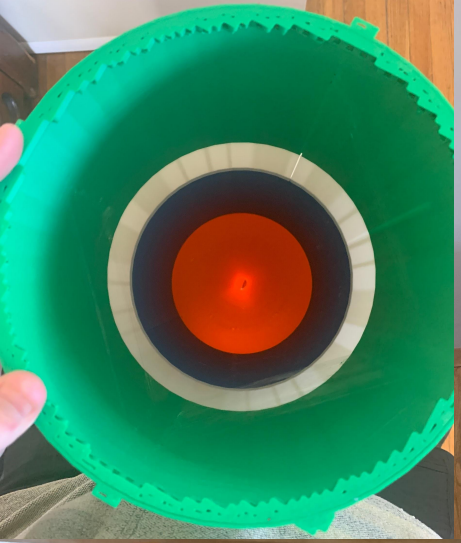
- Produces reliable and consistent notes in an indefinite steady state
- Easy and quick to build once you know what works

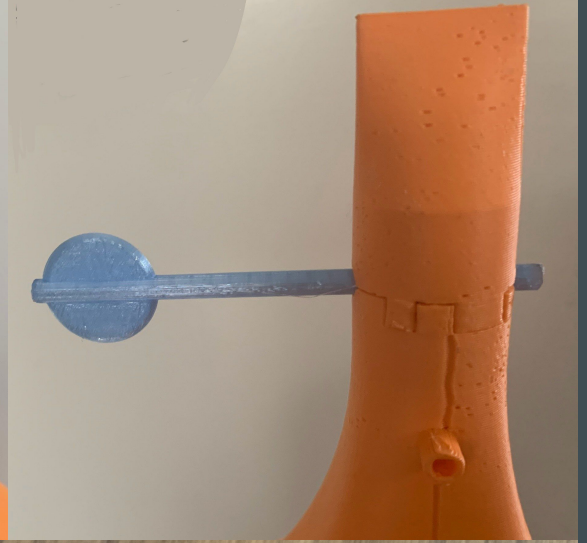
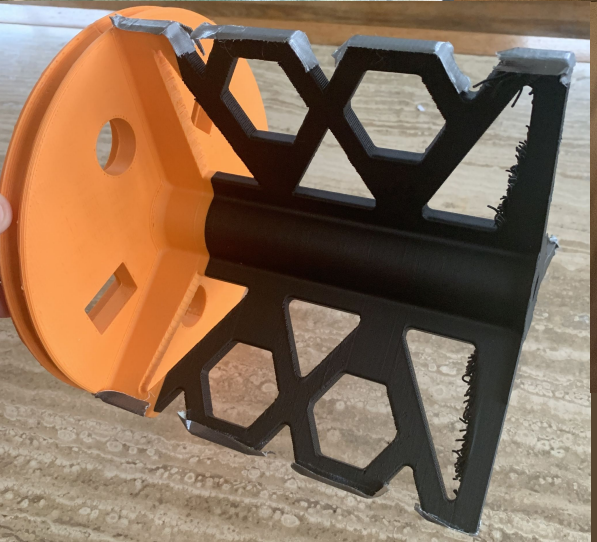
Design Concepts

Piston Cylinder

- Piston Cylinder with One Way Valve, Funnel, Aperture, and Flow Sensing Ports



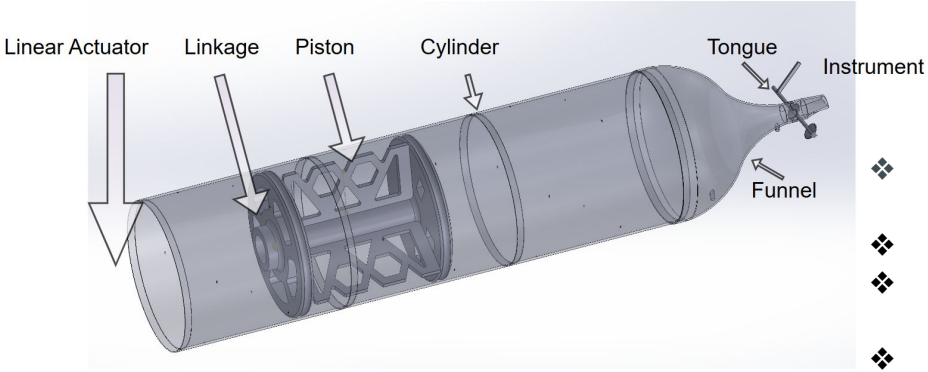



Design Concepts

Piston Cylinder

- Piston Cylinder with One Way Valve, Funnel, Aperture, and Flow Sensing Ports



Comments

- More novel parts
- More complicated theory of operation
  - More linkages and moving interfaces
  - More opportunity for failure
- Limit on duration of steady output

Advantages

- Directly Control the volumetric flow rate
  - More independence in control axes
- More Closely simulates human anatomy
- More scalable and adaptable to various means of control
- More aligned with analytical theory
  - Potential flow model is appropriate
  - Directly aligned with assumptions which make the NS Eqns solvable

Control Plan, Data Collection, & Results

Data Parameters to Control	PWM Fans		Piston Cylinder	
	Control Plan	Measurement Plan	Control Plan	Measurement Plan
Flow Rate	PWM	Anemometer	Linear Actuator + Cylinder Geometry	Calculation from Linear Actuator Feedback
Flow Acceleration	Operator Controlled Aperture	Human Operator	Operator Controlled Aperture	Human Operator
Pressure	Linked to flow rate + stator blades / funnel	Chimney Ports with Barometric Tubes	Linked to flow rate + funnel	Chimney Ports with Barometric Tubes

Results Include:

- **Two Assembled Prototypes** Capable Of Controlling And Measuring These Parameters As Described
- **A Detailed Report** Evaluating Each Prototype's Efficacy in the Greater Context as a Tool for Scientific Use Including:
  - Process Flow Charts
  - Labeled Diagrams and Figures of Both Design Concepts and Completed Prototypes
  - Catalogue of Bought & Created Parts and of Device Assembly Processes
  - Basic Fluid Analysis Calculations of Expected Flow Patterns
  - Basic Control Axis Analysis
  - Basic Sensitivity Analysis

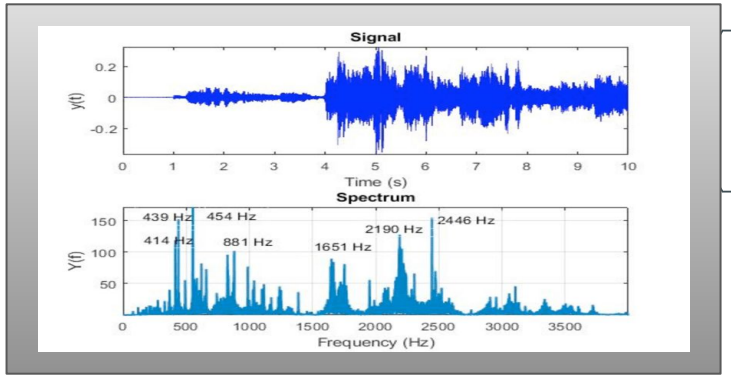
Supplementary Data Collection & Results
(Proof Of Concept Sound Measurement)

Data Parameters to Measure/Collect	Measurement Plan
Volume	Volume vs Time
Articulation	Analysis of Volume vs Time
Pitch/Frequency	Steady Frequency Content
Tamber	Analysis of Steady Frequency Content
Affect Unquantifiables*	My layman's ear trained by research

Affect Parameters*

Broad
Soft
Bright
Warm
Dark

Example Data



Budget & Resources

Item ID	Category	Item	Item Description	Source	Cost / Instance	Quantity	Total Cost
01	Material	PLA TB	For 3D Printing	Think[box]	$0.15 / gram	260	$ 39.00
02	Material	PLA Spools	For 3D Printing	Bambu Labs	$17 / spool	4	$ 68.00
03	Material	PLA Spools	For 3D Printing	Amazon	$22.67 / spool	1	$ 22.67
04	Part	Fan Type 1	First Prototype	Amazon	$16.19 / fan	9	$ 16.19
05	Part	Fan Type 2	Optimized For Pressure	Amazon	$27.90 / fan	1	$ 29.90
06	Part	Fan Type 3	Optimized For Pressure (cheaper)	Amazon	$9.99 / fan	3	$ 43.16
07	Part	Power Supplies & Connectors	12 V Power Supplies	Amazon	$37.02	1	$37.02
07	Part	PC Power Supply & Connectors	PC Power Supply	Amazon	$20.00	1	$20.00
08	Part	PWM Controller 1	One Outlet	Amazon	$11.93	1	$11.93
10	Part	PWM Controller 2	8 Outlets	Amazon	$19.30	1	$19.30
11	Instrument	6-Hole Ocarina	Ceramic	Amazon	$12.91	1	$12.91
12	Instrument	12-Hole Ocarina	Ceramic	Amazon	$22.67	1	$22.67
13	Instrument	Soprano Recorder	Plastic	Amazon	$7.19	1	$7.19
			Total				**$349.94**

Total Spending : $350

Meeting Records

Date (Fri Every Week)	Present	Summary Sentence	Next Steps
8/28/24	tsg, bkt	Initial Meeting, presented ambitions and discussed options (piano, bagpipe, string). Agreed to be supervisor	Detailed breakdown of tasks to focus in.
9/6/24	tsg, bkt	Discussed flute idea, end goals and next steps. Goals (Create device which produces notes on recorder/ocarina, Define relationship between fluid/flow parameters and musical parameters)	Research musical parameters and the quantification thereof, Create a makeshift first protoprototype with fan
9/13/24	tsg, bkt	Discussed the issue of providing enough flow to produce any noise. Discussed static pressure and propellors and stator blades. Discussed the musical sound parameters both quantitative and affective. Discussed bellows and firestoker possibilities.	Use Vane Anemometer to measure human blow characteristics, Continue protoprototype (MAKE NOISE), Finalize Organizational documents
9/20/24	tsg, bkt	After presentation week. Demonstrated flute sound production research. Demonstrated my funnel with fan and voltage controller. Discussed how to troubleshoot voltage controller not always working. Discussed alternative anti-turbulence methods such as flow straightener and pulling flow. Asked Rob about anemometer.	Print honeycomb and revised funnel. Hook up 4 new fans. Troubleshoot voltage controller. Research audio recording/manipulation. Remind Dr Taylor to bring in microphone. Get anemometer from Rob.
9/27/24	tsg, bkt	Dr Taylor brought in microphone equipment and explained how it can be used to record an audio file. I demonstrated my matlab code to display frequency content and volume vs time data for an audio file. I demonstrated my funnel with honeycomb flow straightener and 5 fans. We discussed moving forward with this successful design type as opposed to attempting a below system. Discussed audio filtering. Discussed tongue analog. Obtained anemometer from Rob directly before meeting.	Assemble with batteries and new controller Play around with different coverings and fan speeds to understand what the initial output space looks like qualitatively Take initial recordings with plots (just fan at various speeds, recorder with various coverings at full speed, one covering at varied fan speeds) Figure out how to filter out fan noise (and how big of an impact that makes) Use the anemometer to measure flow going into funnel, coming out of funnel, and flow of my breath as if I was playing the instrument Design next funnel iteration with tongue analog (hinged plate with string and spring) Do fluid flow analysis of fans and funnel and recorder set up Research 3D printers to buy **Optional / low priority:** Design stator blades to compare to honeycomb Get controllable mister and heating implement Design dynamic covering device (clips onto recorder in between holes and has padded switches over each hole)
10/4/24		**Dr Taylor Unavailable**	
10/11/24			
10/18/24	tsg, bkt	Discussed Direction. Input variable linkage sensativity. Discussed the intricacies of a piston cylinder design	Design volumetric (piston-cylinder) prototype
10/25/24	tsg, bkt	Shared CAD Assembly of new prototype. Discussed Actuators, Tube materials, fittings, coatings, one way valves. Discussed similar designs to draw inspiration from: Baby food syringe, bicycle pump.	Iterate Designs. Start Printing!
11/1/24		**Unavailable**	
11/8/24	tsg, bkt	Discussed Curent State of P/C Prototype. Discussed report structure.	Finishing details on both proottypes and write report
11/15/24		**Unavailable**	
11/22/24	tsg, bkt	Discussed presentation of results	Finish Presentation Poster and Report
11/29/24		**Thanksgiving**	

Appendix

Task List

ID	Category	Task Name	Task Description	Deliverable	Time Estimate (Days)	Effort	Task Owner
01	Research	Musical Instrument Control Scheme Research	Explore similar projects and research the ways human musicians control their instruments	Sources, Written Notes, New Knowledge/Context	4	Low	Tyler
02	Research	Flute Sound Production Research	Explore the physics behind sound production in ocarinas and recorders	Sources, Written Notes, New Knowledge/Context	2	Low	Tyler
03	Research	Flow Production Research	Explore various methods of flow production and how each of them are variable with respect to the fluid fow parameter space. Also how to optimize flow for pressure, how to straighten flow, what devices can augment flow production?	Sources, Written Notes, New Knowledge/Context	12	High	Tyler
04	Research	Fluid Manipulation Research	Explore methods of changing temperature and water content of air in a resevoir or in a stream	Sources, Written Notes, New Knowledge/Context	6	Low	Tyler
05	Research	Relevant Flow Parameters Research	Determine the types of relevant variables in the fluid parameter space. Which are coupled, which are important ito control in this context	Sources, Written Notes, New Knowledge/Context	21	Medium	Tyler
06	Research	Flute Musical Parameters Research	Find the scientific and musical standard quantification of the sound produced from similar instruments	Sources, Written Notes, New Knowledge/Context	30	Medium	Tyler
07	Planning	Task List	Determine set of requirements for end goals	Spreadsheet	1	Low	Tyler
08	Planning	Gantt Chart	Plan out each stage, milestone and sub-task, assign a task id, description, deliverable, and estimated time/effort for completion	Gantt Chart (in spreadsheet form)	2	Low	Tyler
09	Planning	Derive Requirements	Determine schedule of tasks to be completed with deliverables and milestones	List of derived requirements	2	Low	Tyler
10	Planning	Initial Economic Eval.	Budget and Projected Resources	Budget & Resources	1	Low	Tyler
11	Concept Design	Protoprototype Design Figures	Put together a makeshift device to supply a somewhat controllable airflow to inform on the next iteration of the prototype and to allow for data collection and parameter recording to start	Collage Images & Labeled Diagrams	14	High	Tyler
12	Concept Design	Project Proposal Presentation	Create and compile figures documenting and explaining this earliest design	Slide Deck and Oral Presentation	3	Low	Tyler
13	Concept Design	Makeshift Protoprototype	Present the project motivation, goals, budget, strategies, and early progress	Imperfect, Controllable Airflow Mechanism and Flute Mount	8	High	Tyler
14	Concept Design	Next Iteration Design Brainstorm	Based on the initial makeshift prototype and research, sketch and brainstorm the design of the prototype to be delivered by this project	List of Potential Designs & OneChosen Design	6	Medium	Tyler
15	Concept Design	Theory of Operation	Demonstrate the main design via a detailed flow chart	Flow Chart	3	Low	Tyler
16	Concept Design	Intial Prototyping Methods Plan	Determine the strategies for constructing the main prototype	List of methods	5	Medium	Tyler
17	Prototyping	Buy Parts & Materials	Put in purchase requests early	Parts & Materials	30	Medium	Tyler
18	Analysis	Secondary Economic Eval.	Determine the costs of production	Cost Breakdown Spreadsheet	2	Low	Tyler
19	CAD	Part CAD Design	Create the design in Solidworks	Parts Files	12	Medium	Tyler
20	Analysis	Written Report Draft	Create the design in Solidworks	LaTeX Document: Introduction, Background, Methods, References	4	Medium	Tyler
21	CAD	CAD Assembly	Create the design in Solidworks	Assembly File	3	Low	Tyler
22	CAD	Engineering Drawings	Detailed Budget	Drawing Files	2	Low	Tyler
23	Analysis	Design Cost Estimate	Introduction, Background, Methods, References	Spreadsheet	30	High	Tyler
24	Prototyping	Build Parts for Design Prototype	Construct or obtain each component of main design according to the prototyping methods plan	Prototype Parts	14	High	Tyler
25	Prototyping	Assemble Design Prototype	Complete main prototype	Workable Gen 2 Prototype	7	High	Tyler
26	Analysis	Progress Report Presentation	Update CWRU stakeholders of progress	Slide Deck	12	Medium	Tyler
27	Analysis	Parameter Mapping	Empirically determine relationships between the controllable fluid/flow input parameters to the device and the specific parameters of the sounds produced	Parameter Map	35	High	Tyler
28	Analysis	Final Report	Abstract, Introduction, Background, Methods, Results, Discussions, Conclusions, Further Work, References	Final Report in LaTeX Document	30	High	Tyler
29	Analysis	Final Presentation	Communicate deliverables and journey to achieve them	Slide Deck & Oral Presentation	21	High	Tyler

Gantt Chart

ID	Category	Task Name	Deliverable	Week Number 2 (9/1)	3 (9/8)	4 (9/15)	5 (9/22)	6 (9/29)	7 (10/6)	7.5 (10/11)	8 (10/13)	9 (10/20)	9.5 (10/23)	10 (10/27)	11 (11/3)	12 (11/10)	13 (11/17)	14 (11/24)	15 (12/1)	16 (12/8)
01	Research	Musical Instrument Control Scheme Research	Sources, Written Notes, New Knowledge/Context		-															
02	Research	Flute Sound Production Research	Sources, Written Notes, New Knowledge/Context		-															
03	Research	Flow Production Research	Sources, Written Notes, New Knowledge/Context		-															
04	Research	Fluid Manipulation Research	Sources, Written Notes, New Knowledge/Context		-															
05	Research	Relevant Flow Parameters Research	Sources, Written Notes, New Knowledge/Context		-															
06	Research	Flute Musical Parameters Research	Sources, Written Notes, New Knowledge/Context		-															
07	Planning	Task List	Spreadsheet			x														
08	Planning	Gantt Chart	Gantt Chart (in spreadsheet form)			x														
09	Planning	Derive Requirements	List of derived requirements			x														
10	Planning	Initial Economic Eval.	Budget & Resources			x														
11	Concept Design	Protoprototype Design Figures	Collage Images & Labeled Diagrams			x														
12	Concept Design	Project Proposal Presentation	Slide Deck and Oral Presentation			x														
13	Concept Design	Makeshift Protoprototype	Imperfect, Controllable Airflow Mechanism and Flute Mount			-	-	x												
14	Concept Design	Next Iteration Design Brainstorm	List of Potential Designs & OneChosen Design						x											
15	Concept Design	Theory of Operation	Flow Chart						x											
16	Concept Design	Intial Prototyping Methods Plan	List of methods						x											
17	Prototyping	Buy Parts & Materials	Parts & Materials						x											
18	Analysis	Secondary Economic Eval.	Cost Breakdown Spreadsheet						x											
19	CAD	Part CAD Design	Parts Files							x										
20	Analysis	Written Report Draft	LaTeX Document: Introduction, Background, Methods, References							x										
21	CAD	CAD Assembly	Assembly File								x									
22	CAD	Engineering Drawings	Drawing Files								x									
23	Analysis	Design Cost Estimate	Spreadsheet								x									
24	Prototyping	Build Parts for Design Prototype	Prototype Parts										x							
25	Prototyping	Assemble Design Prototype	Workable Gen 2 Prototype											x						
26	Analysis	Progress Report Presentation	Slide Deck											x						
27	Analysis	Parameter Mapping	Parameter Map													x				
28	Analysis	Final Report	Final Report in LaTeX Document: Abstract, Introduction, Methods, Results, Discussion, Summary and Conclusions, Further Work to be Done, References																x	x
29	Analysis	Final Presentation	Slide Deck & Oral Presentation																x	
						Proposal Presentation				Written Report Draft		Fall Break		Informal Progress Report w/ Slides					Final Presentation	Final Report


Bambu Lab

Stakeholder Delivery Plan

Tyler Griffith

- Priority: Very High
- Deliverable: A functioning, controllable **music playing device**

Potential Manufacturer

- Priority: Medium-Low
- Deliverable: **Simple to Manufacture**, workable drawings

Potential Other Users

- Priority: Medium-Low
- Deliverable: **Easy to assemble**, work with and control

Musical Scientist

- Priority: High
- Deliverable: **Reproducible mapping** of flow parameters to musical parameters

Dr Taylor

- Priority: Medium
- Deliverable: A **successful** mentored **project** of interesting content

CWRU/Prof/TAs

- Priority: Low
- Deliverable: Presentations, Reports, and final prototype

Internal Communication Plan

Google Drive

Used to keep meeting notes, organization documents, and spreadsheets

Solidworks PDM

CAD drawings, parts, and assemblies will be stored in PDM

Weekly Meetings

Every Friday 4:00 pm Dr Taylor's Office

Office Hours

Scheduled class time usable to consult TAs and/or Dr Daltorio

Email

Main form of quick communication, logistics, ideas

Risk Management Plan

Risk	Preventative/Cause	Trigger	Plan
Scope Creep.	Personally review the current projected scope weekly before advising meeting.	New major sub-goal discovered.	Discussion with Dr Taylor about priorities and reshape expected outcomes.
Lack of Clear Objectives.	Meeting notes will be taken and action items will be listed for the following week.	Appears at meeting with little/no progress updates.	Revisit the task list and specific goals laid out in Gantt chart. Consult advisors.
Major life event renders Dr Taylor unable to meet or advise.	Communicate in advance as much as possible.	Any number of personal or professional obligations arise	Consult with Dr Schmidt, Dr Daltorio, Dr Chua or other professors if necessary to find a new advisor.
Major life event renders me unable to spend the time.	Plan ahead as much as possible.	A colossal personal or professional obligations arise.	Drop the class or drop all classes and push everything to next semester.
Document Corruption or Loss.	Save backups of CAD, google drive, and other documents.	Unexpected tech problem.	Move forward from backups.

Project References

Comparison Between a Novice and an Experienced Flautist: De, Patricio & de la Cuadra, Patricio & Fabre, Benoit & Montgermont, Nicolas & de Ryck, Laurent. (2008). Analysis of Flute Control Parameters: A Comparison Between a Novice and an Experienced Flautist. Acta Acustica United With Acustica - ACTA ACUST UNITED ACUST. 94. 10.3813/AAA.918091.

Sensing Control Parameters of Flute from Microphone Sound Based on Machine Learning from Robotic Performer: Kuroda J, Koutaki G. Sensing Control Parameters of Flute from Microphone Sound Based on Machine Learning from Robotic Performer. Sensors (Basel). 2022 Mar 7;22(5):2074. doi: 10.3390/s22052074. PMID: 35271221; PMCID: PMC8914778.

Flute acoustics: an introduction to how a flute works

Science of Vessel Flutes