ROCKET LAUNCHES AS A CAPSTONE PROJECT

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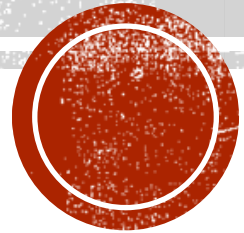


SCHOOL DESCRIPTION

- The Central Virginia Governor's School (CVGS) is a half-day program for gifted Juniors and Seniors in the Lynchburg Area
- In the Junior year, students take physics, mathematics (pre-calculus or calculus), and research 4 days a week
- 75 students in each year from 5 school divisions/10 High Schools
- Complete autonomy in our scheduling while students are on site (2 hours, 40 minutes)

CENTRAL VIRGINIA
Governor's School
FOR SCIENCE & TECHNOLOGY

RATIONALE FOR CAPSTONE

- Attendance can be spotty at the end of the year due to testing in base schools
- We wanted an advanced project that would be open ended, collaborative, and enjoyable for the students.
- An essential element of the design was to include aspects from each of the three junior courses (physics, mathematics, and research).

PROJECT GOALS

- Research topics related to rocketry
- Perform Ground tests to gather data on rocket performance
- Build a mathematical model to predict maximum height
- Build and test a rocket
- Present results

TEAMING DEMOGRAPHICS

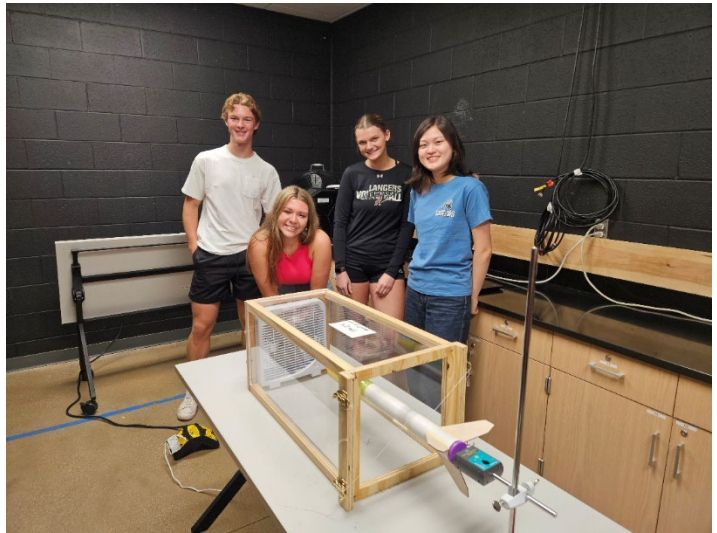
- 3-4 persons per team
- 1 student, if possible, from calculus
- Grouping outside of normal peer groups

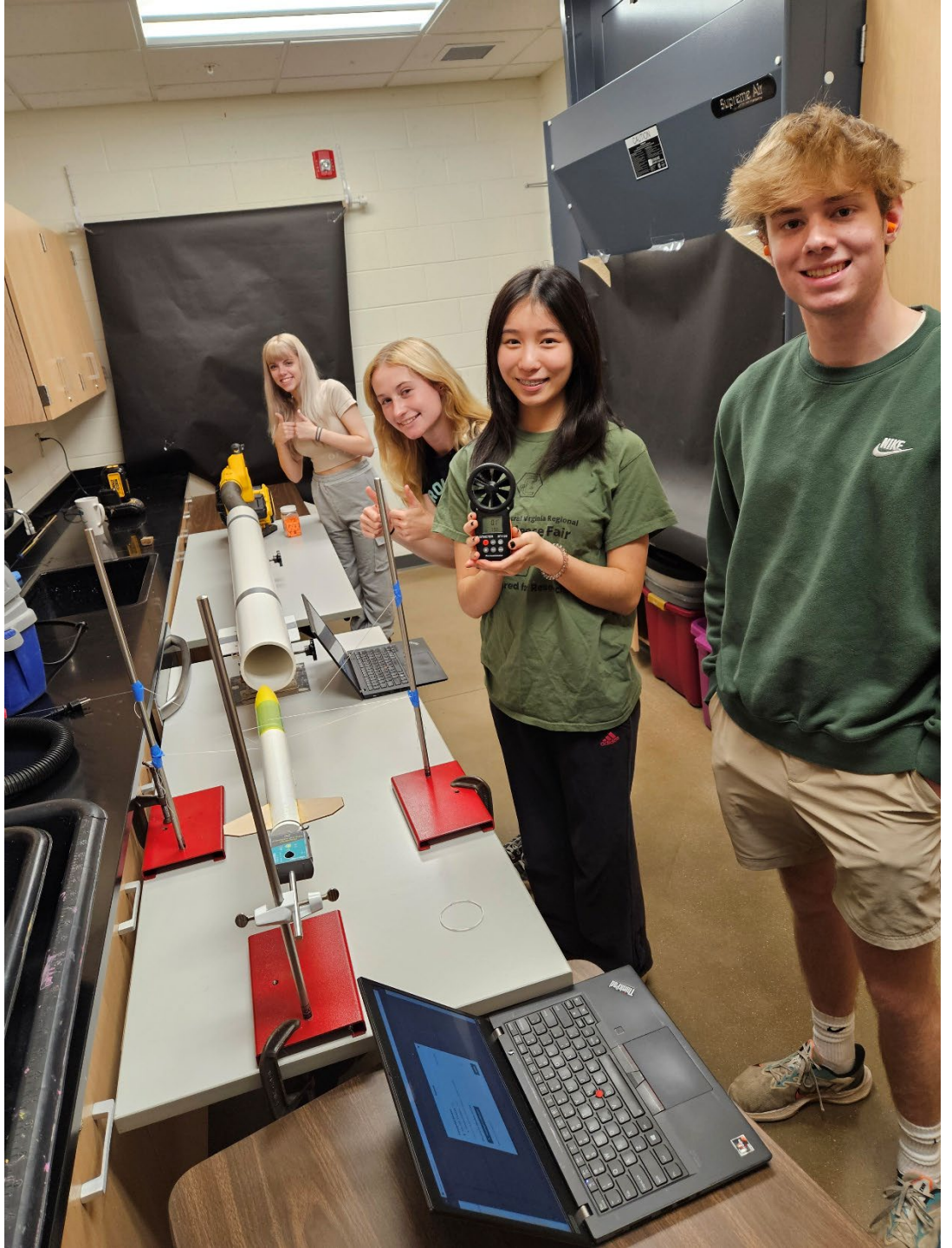
TIMELINE (12 DAYS)

- Days 1-4
  - Introduction of project
  - Instruction in numerical modeling, Euler's Method, Physics of Rocket flight
  - Ground testing
  - Beginning of mathematical model
  - Rocket Construction
- Days 5-8
  - Rocket Launch
  - Completion of Mathematical Model
  - Research Topics
  - Preparation for second launch
- Days 9-12
  - Preparation and rehearsal of presentation
  - Second Launch
  - Presentations
  - End of year ceremony

GROUND TESTING - DRAG

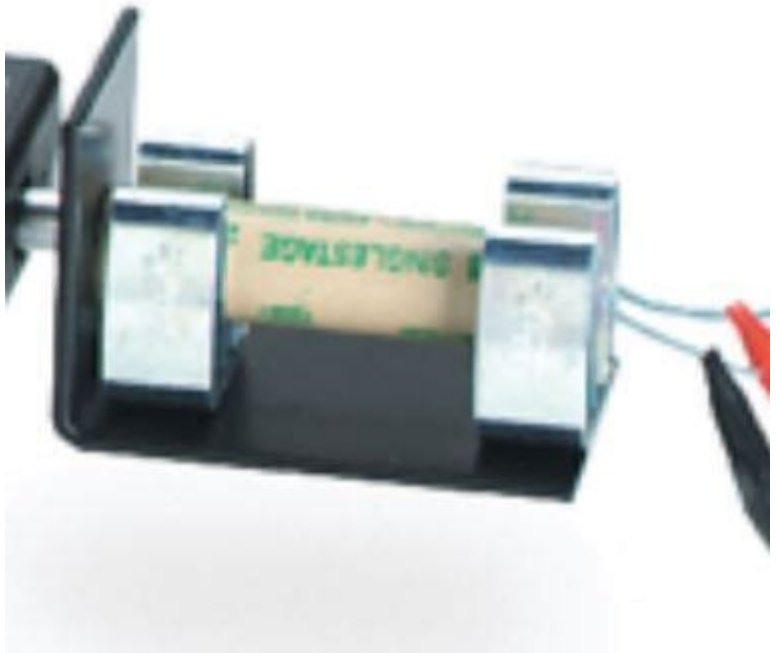
- Various ‘wind tunnels’ to gather data on drag
- Windspeed & force is measured
  - BTMeter BT-100 Anemometer from Amazon
- 3D Printed part that inserts into the rocket engine cavity





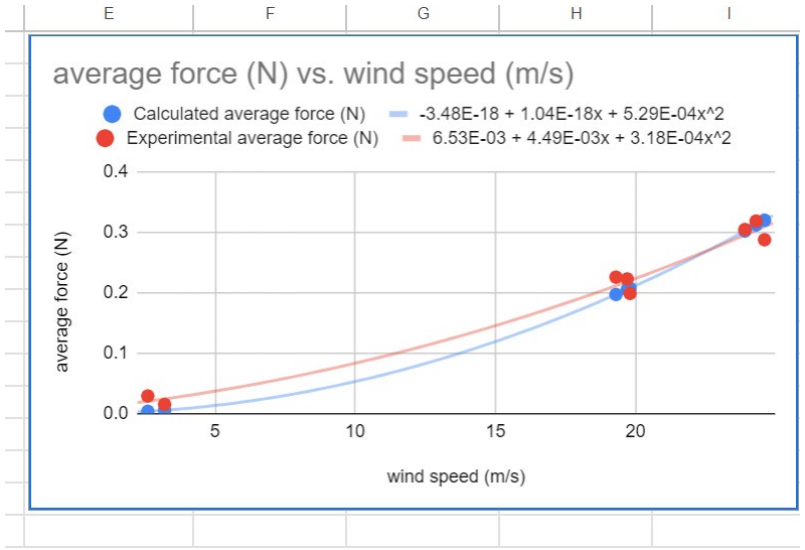
GROUND TESTING - THRUST

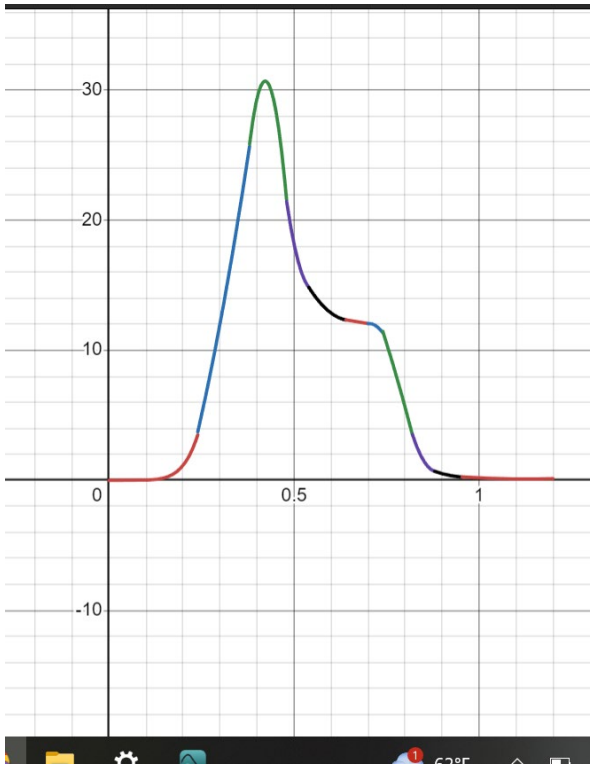
- Pasco force plates for rocket engines
- Testing done outside
- Students press the red button – always!
- Force v. time graph produced
- Students receive instruction on creating a piecewise function that will model the thrust as a function of time



SAMPLE RESULTS

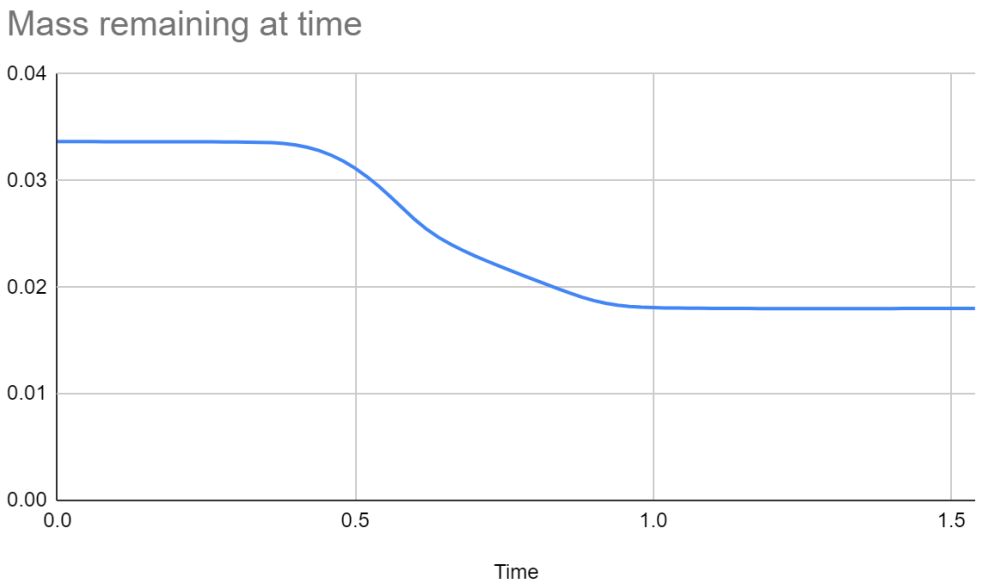
wind speed (m/s)	Calculated average force (N)	Experimental average force (N)
2.6	0.0035793186	0.029
3.2	0.0054219264	0.015
19.3	0.1972278677	0.226
19.7	0.2054878337	0.223
19.8	0.2075792994	0.199
23.9	0.3024471269	0.305
24.3	0.3126555977	0.319
24.6	0.3204231426	0.288
	C=0.00105897	
	F=.5*C*v^2	
	*Fetched Constant with Python	

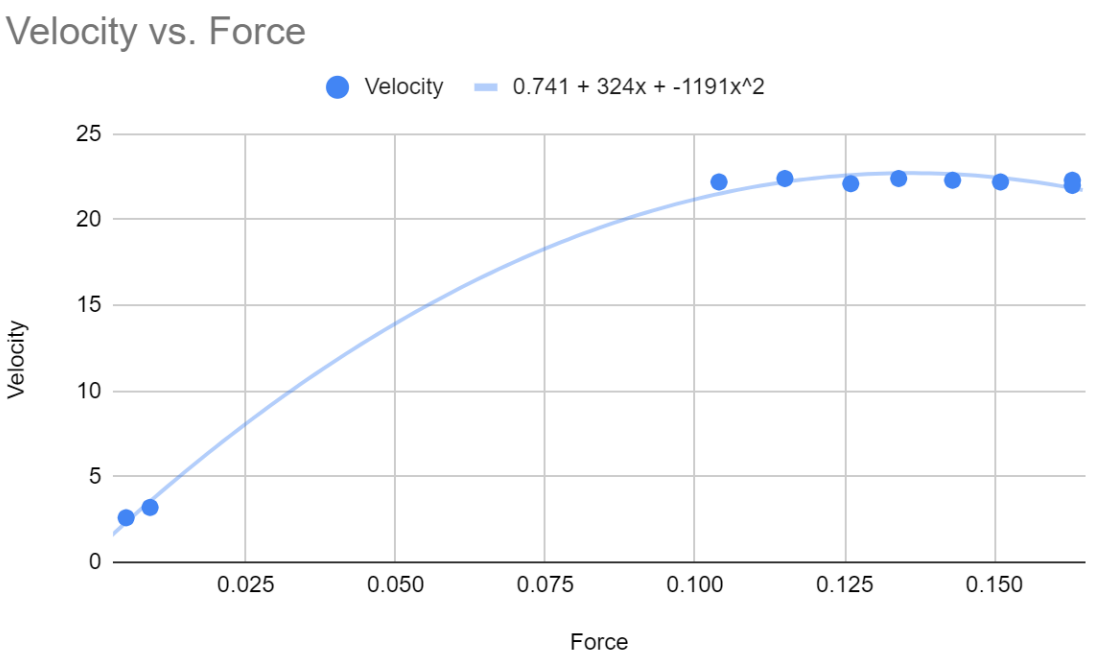




End Points	Start Points	Equations
0.03357791545	0.03366	y = -0.0004x + 0.0337
0.03306126564	0.03357791545	y = -0.0065x + 0.0349
0.03107675093	0.03306126564	y = -0.0248x + 0.04
0.02845809283	0.03107675093	y = -0.0436x + 0.0468
0.02320629113	0.02845809283	y = -0.0328x + 0.0422
0.0200355742	0.02320629113	y = -0.0198x + 0.0347
0.018888	0.0200355742	y = -0.0082x + 0.0261

SAMPLE RESULTS





MATHEMATICAL MODELING

- Initial practice with creating a piecewise function from data
- Modeling the Drag Force with $$F_D = \frac{1}{2} C v^2$$
- Model the Thrust with a piecewise function
- Model change of mass from mass difference of spent/unspent engine
- Use Euler's Method to calculate maximum height (spreadsheet) with recursive equations

DURING ACCELERATION PHASE OF LAUNCH: $a = \frac{1}{m}\left(F_T - F_g - F_D\right)$

(recall we are neglecting lift)

The climb phase is identical to the acceleration phase with these two exceptions:

1. $F_T = 0$ in the climb phase
2. Mass is constant in the climb phase.

Set up the final tab in your spreadsheet with the iterative calculations. Make each column as follows;

Column 1: time
Column 2: mass

$$x(t_n) = v(t_{n-1}) * \Delta t + x(t_{n-1})$$

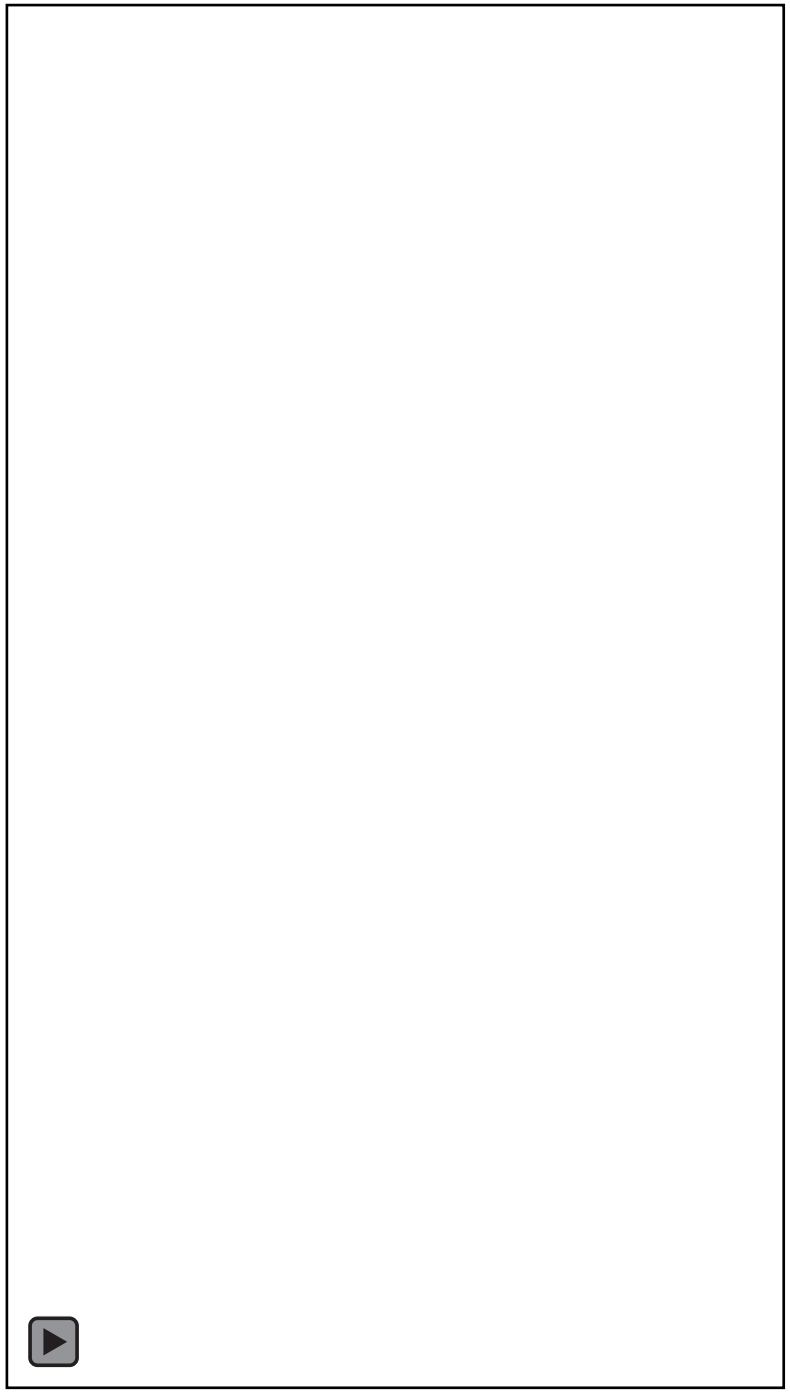
$$v(t_n) = a(t_{n-1}) * \Delta t + v(t_{n-1})$$

MATHEMATICAL MODELING

Time	Mass	Ft	Fg	Fd	Acceleration	Velocity v(tn) = a(tn-1)*T + v(tn-1)	Position x(tn) = v(tn-1)*T + x(tn-1)
0.225	0.1717375	15.90513242	1.6830275	0.009793634072	82.75601594	2.951515016	0.06110880003
0.23	0.171665	16.79237531	1.682317	0.0127321042	87.9464434	3.365295095	0.07586637511
0.235	0.1715925	17.68283473	1.6816065	0.01627681532	93.15646906	3.805027312	0.09269285059
0.24	0.17152	18.57312416	1.680896	0.0205056864	98.36591927	4.270809658	0.1117179872
0.245	0.1714475	19.45968143	1.6801855	0.02550053273	103.5535391	4.762639254	0.1330720354
0.25	0.171375	20.33876875	1.679475	0.03134647187	108.6969936	5.28040695	0.1568852317
0.255	0.1713025	21.20647268	1.6787645	0.03813120169	113.7728695	5.823891918	0.1832872665
0.26	0.17123	22.05870416	1.678054	0.04594414481	118.7566782	6.392756265	0.212406726
0.265	0.1711575	22.89119848	1.6773435	0.05487545523	123.6228592	6.986539657	0.2443705074
0.27	0.171085	23.69951531	1.676633	0.06501488397	128.3447843	7.604653953	0.2793032057
0.275	0.1710125	24.47903867	1.6759225	0.07645050213	132.8947631	8.246377874	0.3173264754
0.28	0.17094	25.22497696	1.675212	0.08926728163	137.2440487	8.91085169	0.3585583648
0.285	0.1708675	25.93236293	1.6745015	0.1035455356	141.3628449	9.597071933	0.4031126232
0.29	0.170795	26.59605371	1.673791	0.1193592229	145.2203138	10.30388616	0.4510979829
0.295	0.1707225	27.21073078	1.6730805	0.1367741226	148.7845841	11.02998773	0.5026174137
0.3	0.17065	27.7709	1.67237	0.1558458888	152.0227607	11.77391065	0.5577673523
0.305	0.1705775	28.27089158	1.6716595	0.1766179966	154.9009341	12.53402445	0.6166369056
0.31	0.170505	28.70486011	1.670949	0.1991195937	157.3841912	13.30852912	0.6793070278
0.315	0.1704325	29.06678453	1.6702385	0.2233632779	159.436626	14.09545008	0.7458496734
0.32	0.17036	30.02920192	1.669528	0.2493428192	165.0054655	14.89263321	0.8163269238
0.325	0.1702875	29.56298125	1.6688175	0.2777344089	162.1753173	15.71766053	0.8907900898
0.33	0.170215	29.05865532	1.668107	0.3071303353	159.1129923	16.52853712	0.9693783925
0.335	0.1701425	28.52114002	1.6673965	0.337407978	155.8478072	17.32410208	1.052021078
0.34	0.17007	27.95516512	1.666686	0.3684438813	152.4080393	18.10334112	1.138641588

LAUNCH DAY

- Good weather is a must
- Clear area – do not launch on artificial turf
- Students press the button!
- Altimeter prepacked into rocket – students recover and record maximum altitude. Mechanical backup
- Consider launching in waves – a lot of standing around with multiple groups otherwise



RESEARCH TOPICS

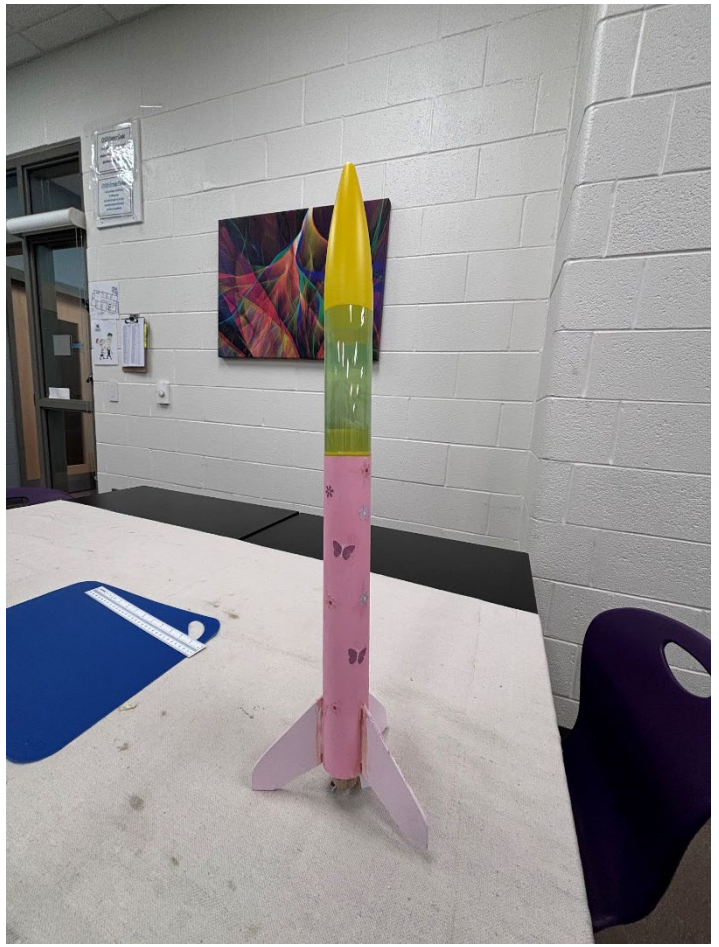
- Each team must present at least one topic from each group, each member presents two topics
- **Category 1 - Physics & Mathematics**
  - Drag Force
  - Impulse-Momentum Theorem
  - Numerical Modeling
- **Category 2 - Rocket Design and Physics**
  - Center of Pressure
  - Fins
  - Nose/Rocket Shape
  - Weather Cocking
  - Model Rocket Motor function (emphasis on our motor - C11-3)
  - Rocket Guidance systems
- **Category 3 - Rockets in practice**
  - Multi-stage Rockets
  - Solid Fuel Rocket Propellant
  - Liquid Fuel Rocket Propellant
  - Artemis (SLS Block II)
  - Apollo (Saturn V Rocket)
  - Parachutes for planetary entry
  - Robert Goddard
  - V2 Rocket

PRESENTATIONS

- 10 minute time limit
- Each member presents their research
- Divided up into small groups of presentations (otherwise repetitive)

ODDS AND ENDS

- Grading is based on
  - Correct development of model, not accuracy of prediction
  - Creative Theme
  - Individual Research
  - Presentation
  - Payload survival of second launch
  - Team Grade



POTENTIAL AREAS FOR IMPROVEMENT

- Improved Wind Tunnels
- Timing such that a research – test – build process is followed
- Student choice in fin and nose cone shape
- Additional Research topics
- Incorporation of OpenRocket Software

EQUIPMENT LIST

- From Estes Rockets
  - Green Eggs Rocket Kits
  - C11-3 Engines (3 per group)
  - Altimeters
  - Construction tools (optional)
- From Other Sources
  - Construction tools
  - Anemometers
  - Pasco Rocket Engine Test Bracket
  - Force Probes

ACKNOWLEDGEMENTS

- Dr. Melisa Shifflett for assistance in the creation of the capstone project
- CVGS Foundation and Dr. Stephen Smith for funding support for the project
- My students for their hard work shown in this presentation

THANK YOU!