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# HORIZONTAL PROPULSION USING MODEL ROCKET ENGINES (PART B)

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## Abstract

This paper describes a follow up project that provides the first-year engineering students with hands-on experiences while learning the applications of physics. In Fall 2021, this team project used 6” or 8” long ash blocks with 2.5″x 2.5″ cross sections to remedy some of the shortcomings of the earlier project and extend it with a design experience using the impulse equation. These blocks (or vehicles or busses) were propelled horizontally with various grades of model rocket engines. The vehicles have wheels inserted on axles. Each vehicle was hooked on to and guided by two 1/16″ diameter steel cables stretched along a 32-foot track. A special jig was designed to line up axle holes on both sides. Two or three 2″ deep engine compartments, (45/64)″ and/or (61/64)″ in diameter, were drilled on the back of each block. An altimeter that acts as an accelerometer was fitted on top of each vehicle. Fully loaded initial vehicle masses (including engines) ranged from 0.4 kg to 1.1 kg. As before, this team project was centered on derivation of the speed and distance curves by numerically integrating the acceleration data downloaded after each run with the goal of calculating impact speed and energy. Here, a design experience was added to determine the launch mass and/or the total impulse that allows the vehicle to traverse the entire track with a decreasing acceleration to achieve a lower impact upon arrival speed. Students learned how to code several sets of dynamics and other physics equations using MS Excel. They were also exposed to the concepts of numerical integration. The students’ knowledge gain and engagement surveys were analyzed showing positive educational impacts of this project.


## 1. Introduction

Since this work is based on our previous contribution [1] only the improvements are emphasized. The complete work is justified by a large body of knowledge in favor of experiential learning [2-4], implementations of Kolb’s experiential learning cycle/spiral (KLC) [5-7], and project-based learning (PBL), the pedagogy heavily implemented in early engineering education [8-10]. Model rockets are very convenient tools for illustrating important engineering concepts and principles [11-23]. This paper describes another successful and fun implementation of PBL in an introductory course using “rocket buses” as its focus instead of the flight-based focus found in previous publications. Hence, this paper is the second of its kind in the literature and is a follow up on the earlier paper [1] that described the experiments in 2020 using shorter tracks (16 and 24 feet) and lighter vehicles that were propelled along a single steel cable guided by two hooks underneath the vehicles. As a result, in previous experiments the undesirable movements in X and Z directions were higher then in in the current work, as well as the impact speeds (in some cases) were too high for any meaningful measurements due to low vehicle masses.

### *1.1 Imrovements to the Earlier Project*

With launch masses ranging between 0.1 to 0.4 kg., the impact speeds were generally too high in the earlier project [1]. This resulted in a low validation rate where, as defined later, validation occurs when numerically calculated distance travelled matches the actual track length minus the allowances due to offsets. Excessive vibration in X and Z directions also contributed to this problem. Some vehicles also flipped sideways resulting in no data. In the current setup, vehicles were secured using two cables instead of one. This was recommended by the students after the 2020 project experience. Dual cable use resulted in a major improvement of the problems mentioned above. In addition, the current experience includes a design component that was not included in the earlier work [1]. With impact speeds still high, each team had to decide how to reduce it. This was accomplished by calculating either a lower impulse value and/or higher launch mass as explained later in this paper. Also, friction effects were considered in the calculations.

### *1.2 Curricular Context, Educational Goals and Outcomes*

As described in Part A [1], the team project was implemented in a one-semester, 2 credit-hour, required introduction to engineering and technology course at the Old Dominion University. Also, the educational goals and the resulting student learning outcomes (SLOs) remained the same. The project learning outcomes still included "1) development of teamwork skills, 2) increased appreciation for current and future coursework in physics and dynamics, 3) an early understanding of the role of experimental and analytical approaches to engineering problem solving, 4) development of written communication skills through writing technical team reports, 5) development of MS Excel programming skills directly applicable to a real-life like project and 6) increased appreciation for engineering by experiencing a hands-on engineering project from start to finish" [1]. These outcomes are closely related to ABET-EAC Criterion 3, 1-7 SLOs. In this work, Outcome 6 (an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions) was achieved at a much higher level (vs. the earlier project) due to the design decision component included in this project.

## 2. Horizontal Propulsion Project

### *2.1 Project Components and Track*

As in previous work [1], each team collected three data sets using the vehicle constructed by that team. Figures 1 and 2 of this work show somewhat larger vehicles used in 2021, while Figure 3 shows other project components. An additional engine type, D12-0, was used as well. Figure A.1 in the Appendix shows an example engine data for a B engine. As before, the engines used had no delay charge to prevent additional turbulence during the coasting phase of the guided ride along the track. As an improvement, in this work, vehicles moved along two steel cables instead of a single steel cable as implemented previously.


**Figure 1. Spring 2021 Double Decker Rocket Busses (7″ L, 2.5″ H, 1-11/16″ W)**

AltimeterThree is used as an accelerometer. The reader is referred to the earlier project [1] for additional details on this instrument.

**Figure 2. Fall 2021 Larger 6″ or 8″ Long (2.5″ x 2.5″) Rocket Busses**


**Figure 3. Other project components: hub caps, wheels, axles cut in half, altimeter seats**

### *2.2 Sample Results*

An analysis of results in this work is similar to the analysis performed in previous work [1] except for using much heavier vehicles, different track conditions, and accounting for friction effects. Table 1 shows downloaded data for an 8″ vehicle with a launch mass of 700 grams (Vehicle 1) including AltimeterThree and 3 B6-0 engines. Figure A.1 shows that each B engine has an average and peak thrusts of 5.03 and 12.14 Newtons, respectively. The average burn time is 0.86 seconds. The peak thrust occurs at t = 0.18 seconds after ignition. A ride analysis can be performed right up to the impact at t = 9.90 seconds. The acceleration values are in units of G's; thus, one must multiply each with 9.81 to get the actual acceleration in correct units of $m/s^2$. Again, only Y direction accelerations (along the track) are considered.

**Table 1. Data for 8″ Vehicle 1 with 3 B6-0 Engines – Launch Mass: 0.700 kg**

| Time | Press | Altitude | Xacc | Yacc | Zacc | TotalAcc | Vehicle |
|---|---|---|---|---|---|---|---|
| seconds | Pa | meters | Gs | Gs | Gs | Gs | Status |
| 0.00 | 101911.00 | 0.30 | 0.01 | **0.06** | 0.82 | 0.82 | Waiting |
| 0.05 | 101916.00 | 0.00 | 0.00 | **0.06** | 0.81 | 0.81 | Waiting |
| 0.10 | 101916.00 | 0.00 | 0.04 | **0.05** | 0.82 | 0.82 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 1.40 | 101916.00 | 0.00 | 0.02 | **0.07** | 0.79 | 0.79 | Waiting |
| 1.45 | 101920.00 | 0.00 | 0.01 | **0.02** | 0.82 | 0.82 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 5.55 | 101922.00 | 0.00 | 0.01 | **0.05** | 0.81 | 0.82 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 6.85 | 101922.00 | -0.30 | 0.02 | **0.06** | 0.82 | 0.83 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 7.75 | 101917.00 | 0.00 | -0.02 | **0.05** | 0.81 | 0.81 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 8.45 | 101921.00 | -0.30 | 0.00 | **0.02** | 0.80 | 0.80 | Waiting |
| .. | .. | .. | .. | **..** | .. | .. | Waiting |
| 8.55 | 101922.00 | -0.30 | 0.00 | **0.06** | 0.81 | 0.81 | Waiting |
| 8.60 | 101925.00 | -0.30 | 0.02 | **0.07** | 0.81 | 0.82 | Waiting |
| 8.65 | 101923.00 | -0.30 | 0.01 | **0.05** | 0.82 | 0.82 | Waiting |
| 8.70 | 101919.00 | -0.30 | 0.01 | **0.05** | 0.80 | 0.80 | Waiting |
| 8.75 | 101922.00 | -0.30 | 0.02 | **-0.01** | 0.86 | 0.86 | Waiting |
| 8.80 | 101920.00 | 0.00 | 0.01 | **0.05** | 0.82 | 0.82 | Waiting |
| 8.85 | 101922.00 | 0.00 | 0.00 | **0.06** | 0.80 | 0.81 | Ignition |
| 8.90 | 101919.00 | 0.00 | -0.01 | **0.58** | 0.85 | 1.03 | Thrusting |
| 8.95 | 101921.00 | 0.30 | -0.15 | **1.67** | 0.69 | 1.81 | Thrusting |
| 9.00 | 101913.00 | 0.30 | -0.55 | **3.48** | 0.81 | 3.62 | Thrusting |
| 9.05 | 101909.00 | 0.60 | -0.82 | **4.70** | 0.61 | 4.81 | Thrusting |
| 9.10 | 101906.00 | 0.60 | 0.18 | **2.02** | 1.04 | 2.27 | Thrusting |
| 9.15 | 101908.00 | 0.90 | -3.43 | **1.61** | 0.64 | 3.84 | Thrusting |
| 9.20 | 101907.00 | 1.20 | 3.48 | **1.11** | 1.06 | 3.80 | Thrusting |
| 9.25 | 101896.00 | 1.20 | 1.95 | **2.85** | 1.45 | 3.75 | Thrusting |
| 9.30 | 101888.00 | 1.50 | 4.28 | **1.22** | 1.05 | 4.57 | Thrusting |
| 9.35 | 101898.00 | 1.80 | 1.40 | **0.86** | 0.09 | 1.64 | Thrusting |
| 9.40 | 101895.00 | 2.10 | 1.87 | **1.09** | 0.01 | 2.17 | Thrusting |
| 9.45 | 101892.00 | 2.40 | -3.53 | **3.42** | -0.85 | 4.99 | Thrusting |
| 9.50 | 101886.00 | 2.40 | 4.83 | **1.67** | 1.01 | 5.21 | Thrusting |
| 9.55 | 101881.00 | 2.40 | 6.66 | **1.23** | 1.27 | 6.89 | Thrusting |
| 9.60 | 101875.00 | 2.40 | 0.15 | **1.81** | -0.53 | 1.89 | Thrusting |
| 9.65 | 101878.00 | 2.10 | 2.91 | **-0.29** | 4.61 | 5.46 | Thrusting |
| 9.70 | 101884.00 | 1.80 | 2.62 | **3.51** | -0.23 | 4.39 | Thrusting |
| 9.75 | 101864.00 | 1.80 | 0.43 | **0.79** | -0.06 | 0.90 | Thrusting |
| 9.80 | 101896.00 | 1.50 | 4.27 | **-2.27** | 3.52 | 5.98 | Slowing |
| 9.85 | 101874.00 | 1.20 | 0.18 | **-2.18** | 1.90 | 2.90 | Slowing |
| 9.90 | 101933.00 | 0.90 | -4.40 | **-9.35** | 0.29 | 10.34 | Impact |

Note that 0.06 G at t = 8.85 is really zero and the bus is not moving. The acceleration (Y direction) values per 0.05 seconds are 0.58, 1.67, 3.48, …, 3.51, 0.79, -2.27, -2.28, and -9.35 at impact. Notice that right before impact, acceleration was negative at t = 9.80 s. This makes sense because the fuel was all consumed around starting at t = 8.85 s for an average burn duration of 0.86 s. At t = 8.85 + 0.86 = 9.71 s, there was no fuel in any of the three engines. Top speed was not at impact. But that means that at impact there must have been some residual thrust.

This vehicle contains 3 x 5.6 = 16.8 gr of propellant which is totally consumed at the terminal point. Hence, the terminal mass is 700-16.8 = 683.2 gr. The impact force in Y direction is calculated as -9.35 * 9.81 * 0.6832 = -63.30 N. Table 1 also shows the total acceleration as 10.34 G which corresponds to a total force of 69.28 N. Note that the Z acceleration are not 1.00 G as a default at rest; the gravity pull at sea level is 1 G or 9.81 $m/s^2$. If the vehicle jumps up, the Z acceleration will be higher. X acceleration is lateral movement. Both X and Z will be steady (0 for X, 1 for Z) if the vehicle can be secured very tightly and device is well calibrated. As Table 1 shows, this was not the case in this launch due to inherent error in the device. Ideally X and Z acceleration values are 0 and 1 G respectively both when vehicle is in motion and when it hits the terminal.

Table 1 shows the representative and the relevant sections of the downloaded launch data. Vehicle status column has been added for interpretation. Each launch has a wait time once a connection is established with the AltimeterThree device while various checks are performed. AltimeterThree device is fairly accurate in its air pressure report as 1 atmosphere (atm) is 101,325 Pascals (Pa). The campus is located at sea level with air pressure of 1 atm. Altitude data is also accurate enough as the exact altitude of the test site is around 2 meters above sea level. While waiting, X acceleration values are nearly 0 indicating good calibration, but Z acceleration values are less than 1.00 indicating poor calibration in the Z direction. Calibration errors in X and Z directions are ignored, especially since these errors were negligible in about half of the 90 launches performed by 30 student teams in 2021. Calibration errors in the Y acceleration are present during the waiting period shown in Table 1. Instead of an ideal value of 0 G, waiting period Y acceleration values had a maximum of +0.08 G. These errors indicate that thrusting period acceleration values are inflated. In other launches, errors were on the negative side indicating that thrusting period acceleration values are deflated. The maximum error was deducted or added to account for these calibration errors. No Y acceleration calibration error was found in about 20% of the launches.

The next task is the determination of the ignition time. In Table 1, Y acceleration values are unchanged (and 0) until t = 8.85. At t = 8.90, Y acceleration is 0.58 G. Hence, t = 8.85 is the ignition time. Engine B6-0 data (Figure A.1) shows peak thrust (and acceleration) occurs just around 0.20 seconds post ignition and the total burn time is 0.86 +/- 0.15 seconds per engine. This vehicle has 3 engines that fire simultaneously, and it is likely that these times are slightly different for each engine. At t = 9.05 seconds, (8.85 + 0.20), a peak acceleration of 4.70 G occurs as expected. Furthermore, the last positive Y acceleration (0.79 G) occurs at t = 9.75 seconds. This suggests a burn time of 9.75 - 8.85 = 0.90 seconds which is consistent with the engine burn duration specification of 0.86 +/-0.15 seconds. There is a negative acceleration at t = 9.65 seconds, and it is ignored as a bump on the track or another unexplainable cause. As the fuel is used up, the vehicle slows down at t = 9.80 and t = 9.85 second intervals. At t = 9.90 seconds, there is a large negative Y acceleration of 9.35 G indicating impact. The impact time is also interpreted as 0 G when the vehicle comes to a very brief stop before snapping back. Both ignition and impact times are recorded as 0 G events as end points of the acceleration curve data used in numerical integration and other analysis.

The data in Table 1 is a near ideal case and not all launch data were this easy to explain. Some data had more frequent intermittent negative Y accelerations and the impact time was not always easy to determine. Few launch data were never recorded due to transmission and/or clerical errors. Nevertheless, students in each team truly enjoyed this “detective” work performed on three launch data using the vehicle they built. Each launch used a different combination of engines resulting in various launch masses for the same vehicle. The concepts and the equations taught and used in this project are described elsewhere [1].

### *2.3 Practical Students' Experiences*

With the exception of cutting out 8” or 6” blocks from a stock of 26” long ash blocks and drilling of the engine housings, student teams built the vehicles. This process was very enjoyable. Photographs in the Appendix, Figure A.2 show a part of the process. About 75 launches with increasing masses were performed. Figures 4, 5, 6, and 7 show launch pictures. Figures 6 and 7 show busses hitting a coke can at the end of the track to slow down their motions. Using aluminum cans proved to be very useful to prevent vehicles from bouncing back excessively after hitting the terminal post. Kinetic energy was absorbed into the can instead of being used to bounce back the bus a lot.

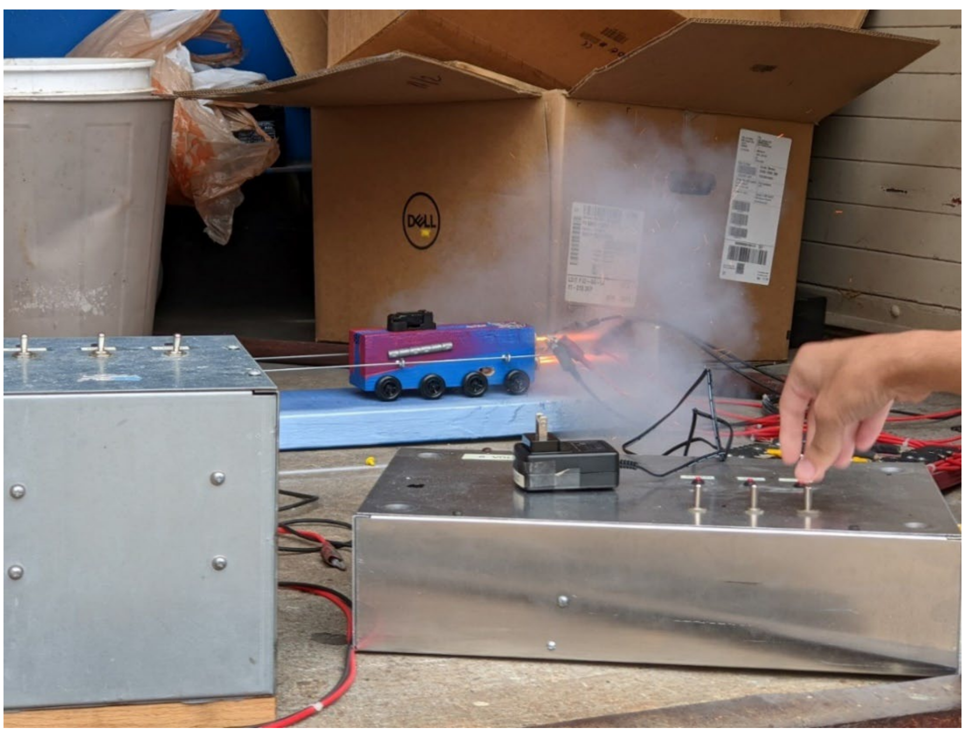

**Figure 4. An 8″ long vehicle takes off with 3 engines firing**

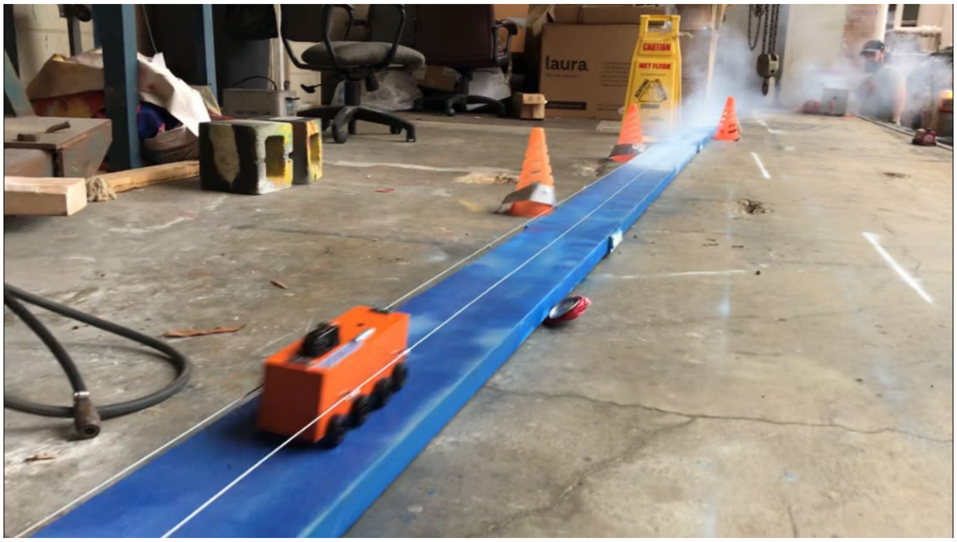

**Figure 5. An 8″ rocket bus in transit**

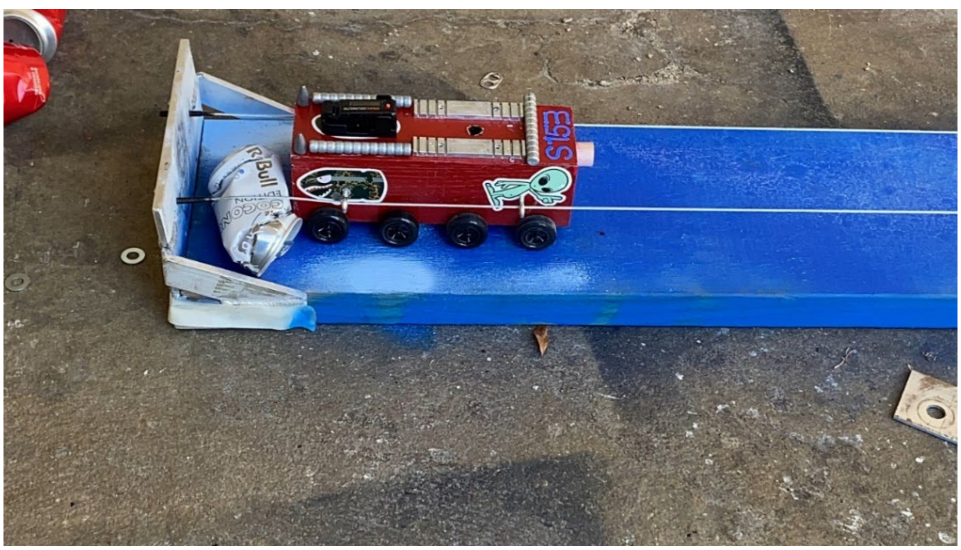

**Figure 6. An 8″ rocket bus with four axles after arrival**

**Figure 7. An 8″ rocket bus with four axles impacts with engines still thrusting**

Tables 2 and 3 show how downloaded acceleration data in Figure 8 and Table 1 is converted into velocity (Figure 9) and distance (Figure 10) traveled using numerical integration. Students felt these two steps were exciting and fun using real data they collected.

**Table 2. Vehicle 1 Data Analysis (Part 1)**

| Time (seconds) | Raw Y acc (G) | AdjustedY acc (G) | Y acc (m/s2) | Trapezoid | Width | Left Hght | Right Hght | Area |
|---|---|---|---|---|---|---|---|---|
| 8.85 | 0.00 | 0.00 | 0.000 | | | | | |
| 8.90 | 0.58 | 0.50 | 4.929 | 1 | 0.05 | 0.000 | 4.929 | 0.1232 |
| 8.95 | 1.67 | 1.59 | 15.551 | 2 | 0.05 | 4.929 | 15.551 | 0.5120 |
| 9.00 | 3.48 | 3.40 | 33.367 | 3 | 0.05 | 15.551 | 33.367 | 1.2229 |
| 9.05 | 4.70 | 4.62 | 45.369 | 4 | 0.05 | 33.367 | 45.369 | 1.9684 |
| 9.10 | 2.02 | 1.94 | 19.000 | 5 | 0.05 | 45.369 | 19.000 | 1.6092 |
| 9.15 | 1.61 | 1.53 | 15.012 | 6 | 0.05 | 19.000 | 15.012 | 0.8503 |
| 9.20 | 1.11 | 1.03 | 10.103 | 7 | 0.05 | 15.012 | 10.103 | 0.6279 |
| 9.25 | 2.85 | 2.77 | 27.179 | 8 | 0.05 | 10.103 | 27.179 | 0.9321 |
| 9.30 | 1.22 | 1.14 | 11.138 | 9 | 0.05 | 27.179 | 11.138 | 0.9579 |
| 9.35 | 0.86 | 0.78 | 7.638 | 10 | 0.05 | 11.138 | 7.638 | 0.4694 |
| 9.40 | 1.09 | 1.01 | 9.931 | 11 | 0.05 | 7.638 | 9.931 | 0.4392 |
| 9.45 | 3.42 | 3.34 | 32.756 | 12 | 0.05 | 9.931 | 32.756 | 1.0672 |
| 9.50 | 1.67 | 1.59 | 15.587 | 13 | 0.05 | 32.756 | 15.587 | 1.2086 |
| 9.55 | 1.23 | 1.15 | 11.253 | 14 | 0.05 | 15.587 | 11.253 | 0.6710 |
| 9.60 | 1.81 | 1.73 | 17.003 | 15 | 0.05 | 11.253 | 17.003 | 0.7064 |
| 9.65 | -0.29 | -0.37 | -3.660 | 16 | 0.05 | 17.003 | -3.660 | 0.3336 |
| 9.70 | 3.51 | 3.43 | 33.626 | 17 | 0.05 | -3.660 | 33.626 | 0.7492 |
| 9.75 | 0.79 | 0.71 | 6.941 | 18 | 0.05 | 33.626 | 6.941 | 1.0142 |
| 9.80 | -2.27 | -2.35 | -23.093 | 19 | 0.05 | 6.941 | -23.093 | -0.4038 |
| 9.85 | -2.18 | -2.26 | -22.216 | 20 | 0.05 | -23.093 | -22.216 | -1.1327 |
| 9.90 | 0.00 | 0.00 | 0.000 | 21 | 0.05 | -22.216 | 0.000 | -0.5554 |

**Table 3. Vehicle 1 Data Analysis (Part 2)**

| Area | Speed (m/sec) | Trapezoid | Width | Left Hght | Right Hght | Area | Distance (meters) | Distance (feet) |
|---|---|---|---|---|---|---|---|---|
| | 0.000 | | | | | | 0.000 | 0.00 |
| 0.1232 | 0.123 | 1 | 0.05 | 0.000 | 0.123 | 0.0031 | 0.003 | 0.01 |
| 0.5120 | 0.635 | 2 | 0.05 | 0.123 | 0.635 | 0.0190 | 0.022 | 0.07 |
| 1.2229 | 1.858 | 3 | 0.05 | 0.635 | 1.858 | 0.0623 | 0.084 | 0.28 |
| 1.9684 | 3.827 | 4 | 0.05 | 1.858 | 3.827 | 0.1421 | 0.226 | 0.74 |
| 1.6092 | 5.436 | 5 | 0.05 | 3.827 | 5.436 | 0.2316 | 0.458 | 1.50 |
| 0.8503 | 6.286 | 6 | 0.05 | 5.436 | 6.286 | 0.2930 | 0.751 | 2.46 |
| 0.6279 | 6.914 | 7 | 0.05 | 6.286 | 6.914 | 0.3300 | 1.081 | 3.55 |
| 0.9321 | 7.846 | 8 | 0.05 | 6.914 | 7.846 | 0.3690 | 1.450 | 4.76 |
| 0.9579 | 8.804 | 9 | 0.05 | 7.846 | 8.804 | 0.4162 | 1.866 | 6.12 |
| 0.4694 | 9.273 | 10 | 0.05 | 8.804 | 9.273 | 0.4519 | 2.318 | 7.61 |
| 0.4392 | 9.713 | 11 | 0.05 | 9.273 | 9.713 | 0.4746 | 2.793 | 9.16 |
| 1.0672 | 10.780 | 12 | 0.05 | 9.713 | 10.780 | 0.5123 | 3.305 | 10.84 |
| 1.2086 | 11.988 | 13 | 0.05 | 10.780 | 11.988 | 0.5692 | 3.874 | 12.71 |
| 0.6710 | 12.659 | 14 | 0.05 | 11.988 | 12.659 | 0.6162 | 4.491 | 14.73 |
| 0.7064 | 13.366 | 15 | 0.05 | 12.659 | 13.366 | 0.6506 | 5.141 | 16.87 |
| 0.3336 | 13.699 | 16 | 0.05 | 13.366 | 13.699 | 0.6766 | 5.818 | 19.09 |
| 0.7492 | 14.448 | 17 | 0.05 | 13.699 | 14.448 | 0.7037 | 6.522 | 21.40 |
| 1.0142 | 15.463 | 18 | 0.05 | 14.448 | 15.463 | 0.7478 | 7.269 | 23.85 |
| -0.4038 | 15.059 | 19 | 0.05 | 15.463 | 15.059 | 0.7630 | 8.032 | 26.35 |
| -1.1327 | 13.926 | 20 | 0.05 | 15.059 | 13.926 | 0.7246 | 8.757 | 28.73 |
| -0.5554 | 13.371 | 21 | 0.05 | 13.926 | 13.371 | 0.6824 | 9.439 | 30.97 |

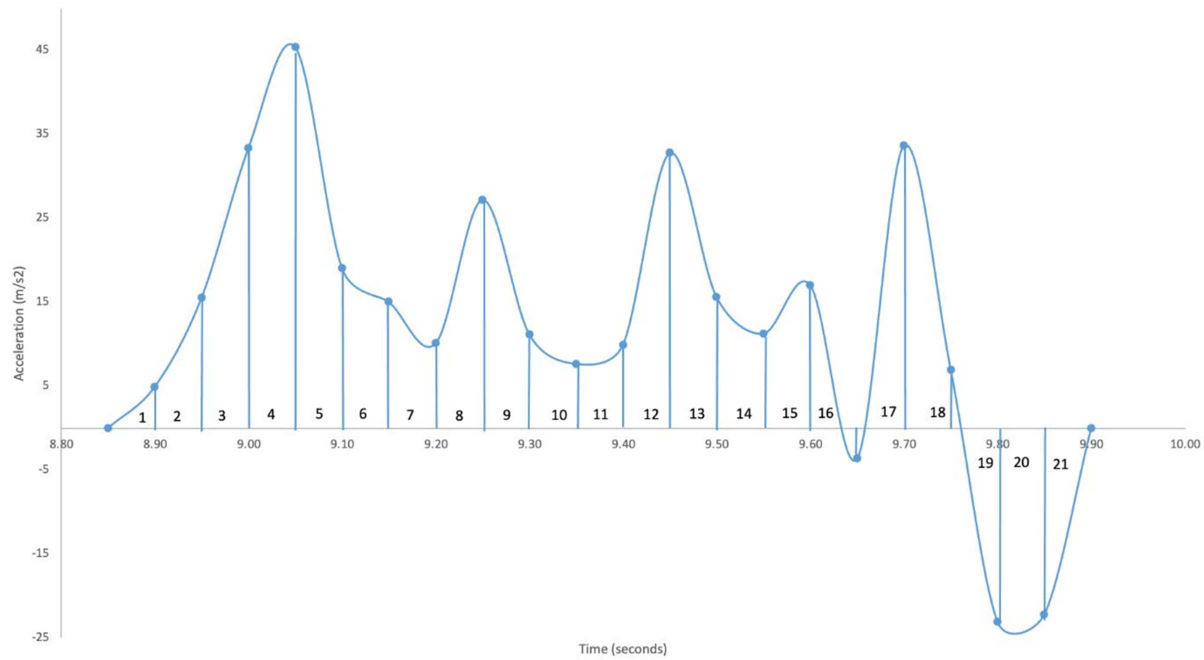


**Figure 8. Acceleration data of Vehicle 1**

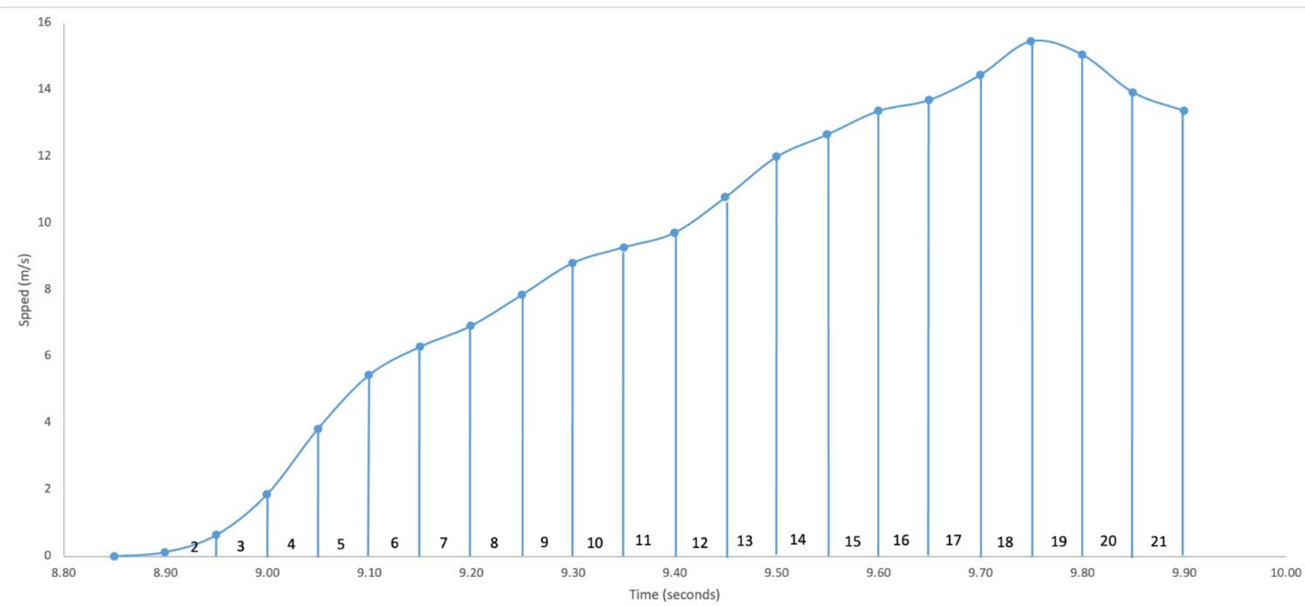


**Figure 9. Speed Data of Vehicle 1 (Derived by Numerical Integration of Figure 8)**

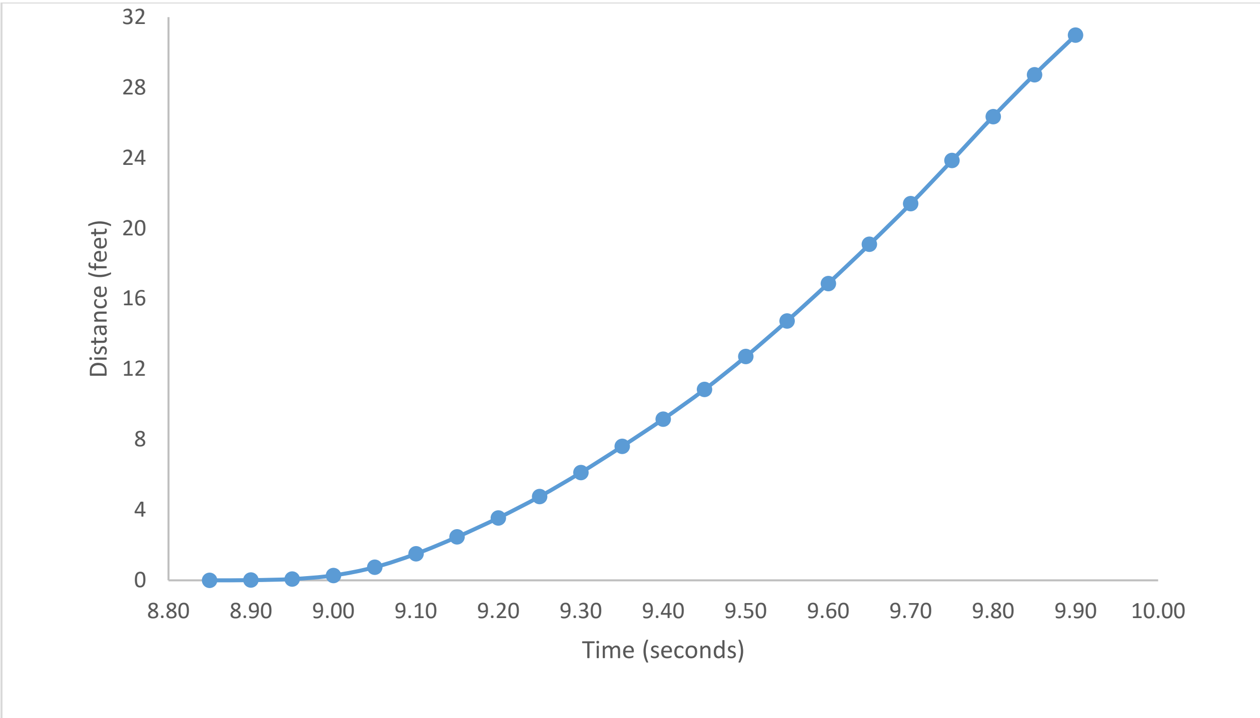


**Figure 10. Distance Travelled Data of Vehicle 1 (Derived by Numerical Integration of Figure 9)**

Table 4 summarizes the results of the calculations each team performed for their own vehicle. In addition to learning how to numerically integrate data, students were also able to check if observed data can be predicted with equations presented in [1]. Each vehicle has up to 3 holes to vent out the ejection thrust which really acts to slow the vehicle by providing a small thrust like the friction effect. It is noted that friction force was not explicitly considered in this project but accounted for as a part of the design experience.

For vehicle 1, Table 4 shows the numerically calculated travel distance of 9.44 meters or 30.97 feet when the total track is 32 feet. The calculated distance must be less than 32 feet because the AltimeterThree sits about in the middle of each vehicle with 4 to 7 inches away from both ends of the track. In this case, Table 4 shows the calculated distance is 12.66 inches shorter than the track length making it very reasonable. It is then concluded that the corresponding impact speed numerically calculated in Table 4 (13.37 m/s or 29.91 mph) must be correct. This also suggests that the value of the corresponding kinetic energy in Table 4 is also correct.

The impact speed (18.77 m/s) calculated from the impulse equation is much higher than the realized impact speed of 13.37 m/s or the speed calculated from the realized acceleration (12.76 m/s). The impulse equation ignores friction loses due to the interaction between the wheels and the track as well as the friction loses due to both cables and the hooks on the vehicle. Table 4 also shows similar summaries for two other representative vehicles.

**Table 4. Summary Data & Results for Sample Launches (*)**

| | **Vehicle 1** | **Vehicle 2** | **Vehicle 3** |
|---|---|---|---|
| Track Length (ft) | 32 | 32 | 32 |
| Vehicle Type | 8″ Bus | 6″ Bus | Double Bus |
| AltimeterThree Installed | Yes | Yes | Yes |
| Launch Mass (gr.) | 700 | 545 | 319.40 |
| Average Mass in Motion (gr.) | 691.60 | 559.30 | 313.80 |
| Total Propellant (gr.) | 3 x 5.60 | 3 x 3.84 | 2 x 5.60 |
| Engine Type | 3 x B6-0 | 3 x A8-0 | 2 x B6-0 |
| Burn Time (s) | 0.86 | 0.53 | 0.86 |
| Engine Impulse (N-s) | 3 x 4.33 | 3 x 2.15 | 2 x 4.33 |
| Average Actual Acceleration ($m/s^2$) | 12.16 | 5.60 | 23.13 |
| Average Actual (numerical integration) Speed (m/s) | 8.89 | 6.61 | 11.18 |
| Numerical integration-based Impact Speed (m/s) | 13.37 | 8.12 | 20.82 |
| Impact Speed in mph unit | 29.91 | 18.17 | 46.58 |
| Impact Speed (m/s) using Equation 3 [1] | 12.76 | 7.84 | 19.66 |
| Impact Speed (m/s) using Equation 7 [1] | 18.77 | 11.52 | 27.60 |
| Numerical integration-based distance Traveled (m.) | 9.44 | 9.38 | 9.54 |
| Distance Traveled using Equation 6 (m.) [1] | 9.33 | 9.26 | 9.50 |
| Distance Traveled Short of Track Length (in) | 12.36 | 14.64 | 8.4 |
| Reasonable Given Vehicle Length allowance? | Yes | Yes | Yes |
| Kinetic energy at impact (J) using Equation 9 [1] | 61.05 | 18.76 | 66.81 |
| Impact Force using equation 8 (N) [1] | 63.30 | 40.00 | 8.19 |

*(*) Refer to the earlier project [1] for the equations.*

### *2.4 Design to achieve acceptable Impact Speed*

Each team decided how to lower the impact speed to 5 m/s. They observed that friction losses were responsible for reduction in impact speeds from being even higher. Each vehicle lost some speed due to air resistance and friction forces due to the wheels. In the vacuum of space, equation $V_t = I/m_e$ results in a speed that will not change, but that is not the case with horizontal terra-based propulsion.

Note: C and D engines were still too powerful even for the newer and much heavier busses used. The results using C and D engines were not as expected in some cases. However, these engines provided some very interesting explosion scenes. This problem will be fixed by using even a longer track and heavier buses.

### *2.5 Design Example Using Vehicle 3 in Table 4.*

Five m/s impact speed is considered acceptable, but Vehicle 3 had an actual impact speed of 20.82 m/s. Using equation $V_t = I/m_e$ with an effective (or average) mass of 0.3138 kg and an impulse of 8.66 N-s, impact speed of 8.66/0.3138 = 27.60 m/s is possible if friction effects are ignored. Hence, 75.45% (20.82/27.60) of the maximum possible impact speed was realized. To achieve an actual 5 m/s impact speed, it is inferred that equation $m_e\ V_t = I$ should yield 5/0.7545 = 6.63 m/s. Each launch has two major inputs: total mass and total impulse of the engines included (and actually fired) in the mass. The impulse equation results in either an effective mass of 8.66/6.63 =1.31 kg (vs. 0.3138 kg in Table 4) or a total impulse of only 0.3138 x 6.63 = 2.08 N-s if the original mass is kept. This approximation worked well. Effective mass is the average launch and arrival masses.

It is not practical to procure engines with any desired impulse value. It was easier to add excess mass to busses to reduce the impact speeds, but no bus was made heavy enough as reflected in the example above. Each team made its busses heavier by adding metal bars as seen in Figures 4 through 7. They observed (by validated numerical integration) reduced impact speeds, but they also realized that it was not possible to add enough mass to achieve 5 m/s impact speed. Actual impact speeds were reduced to 8 to 12 m/s, but not down to 5 m/s. Students performed their calculations and included them in their team reports. Students observed that increasing mass naturally resulted in slower impact. The main goal was to achieve a soft tolerable impact for cargo and/or passengers while still arriving to the destination.

## 3. Assessment and Evaluation

There were no changes in assessment and evaluation methods and techniques from the ones used in Part A [1]. Here, as mentioned earlier, Outcome 6 of ABET-EAC Criterion 3 was achieved at a higher level due to the design decision component emphasized in the project.

### *3.1 Quantitative Analysis of Students' Perceptions*

An anonymous exit survey (shown in Figure 11) using a 5-point Likert scale (developed in Part A [1]) was completed by 101 of the 130 students in 9 sections in Spring and Fall semesters of 2021. The results are shown in red using mean and standard deviation format. The results were like the results of the previous year [1] where Q1: 4.50/1.09, Q2: 4.34/0.61, Q3: 4.25/0.65, and Q4:

3.76/0.67. Again, most of the freshmen felt this project was a good learning experience for all the educational goals.

**Please rate the following questions:**

1. **Building and working with model cars and rocket motors was (4.40/1.12).**
   1 = boring, 2 = somewhat boring, 3 = OK, 4 = somewhat exciting, 5 = very exciting
2. **From this project I learned (4.14/0.71) about horizontal dynamics.**
   1 = nothing, 2 = little, 3 = something, 4 = much, 5 = very much
3. **By performing calculations using Excel I became (3.85/0.95) with coding in Excel.**
   1 = less proficient, 2 = somewhat less proficient, 3 = neither less nor more proficient, 4 = somewhat proficient, 5 = very proficient
4. **Physical model bus launches, and the calculations were (4.26/0.45) in gaining some understanding of dynamics as an important engineering topic.**
   1 = unhelpful, 2 = somewhat unhelpful, 3 = neither unhelpful nor helpful, 4 = helpful, 5 = very helpful.

**Figure 11. Students' Opinion Survey and the Results (in Red Mean/Standard Deviation)**

### *3.2 Qualitative Feedback*

As in previous years, many students enjoyed this project and learned from it. Some sample feedback from team reports is provided below.

*"In this project, we learned many things, from understanding the real-life procedures and requirements for engineering to gathering data and compiling it into a report. It made for a fun and great class that will stick with us moving forward as we become engineers. Not to mention the professor was great at being friendly, helpful, and available when we needed him. We learned more than we could have ever expected from this class"*

*"Over the course of this semester, we developed an understanding of the processes that go into engineering. We did this all through the supersize rocket bus project. We were taught the fundamental engineering knowledge that we will need for our future in this career. Using the data, we collected from the launches, we learned about excel, numerical integration, graphing, and calculations. Although the first data set was inconclusive, the other two sets of data were able to create data that made accurate distance, speed, and velocity. The inconclusive data did still provide a necessary engineering lesson which is that all data cannot be conclusive. Some will not work out and that why we do multiple trials. Along with data, we also learned many skills that will be useful for our engineering career. Teamwork and collaboration were a valuable skill that be essential to all project we will have in future not only in college but in our careers as engineers. Overall, this project has provided us an introduction into the skills and knowledge that will be essential for our future as engineer".*

## 4. Conclusions and Plans

This detailed project not only introduced the concepts of dynamics and propulsion, but also provided calculations for these topics based on real physical experiments. Students learned and programmed many engineering and science calculations they are expected to encounter in their future studies. Concepts of acceleration, speed, distance, Newton's laws, impulse, thrust, and propulsion were studied analytically and experimentally in a fun, drawn out, challenging, and sometimes frustrating team environments. Students enjoyed conducting experiments with engines and model vehicles while meeting the SLOs for this course. A students' attitude assessment survey was designed, implemented, and analyzed. Overall, students felt this was an exciting real life-like worthwhile learning experience that taught them the usefulness and importance of physics and programming in engineering projects.

This project will be enhanced by one or more the following additions: 1) a longer and elevated 40-foot track as used in Spring 2022, 2) A 48-foot aluminum track is planned for Fall 2022, as the engines may be still too powerful, 3) model rocket parachutes will be used to slow down, 4) the track will be inclined, and 5) even heavier buses will be built so that powerful engine combinations (1 D + 1 C or 3C) can be fired at once.

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## APPENDIX

# ESTES B6

### CERTIFIED VALUES

Total Impulse: 4.90 newton-seconds
Delays: 0, 2, 4, 6 seconds

Propellant Type: Black Powder
Propellant Mass: 5.6 grams

Casing Dimensions: 18 mm × 70 mm

Certification Date: Continuing
Contest Use Date: Continuing

Certification Type: Model Rocket

### STATIC TEST DATA

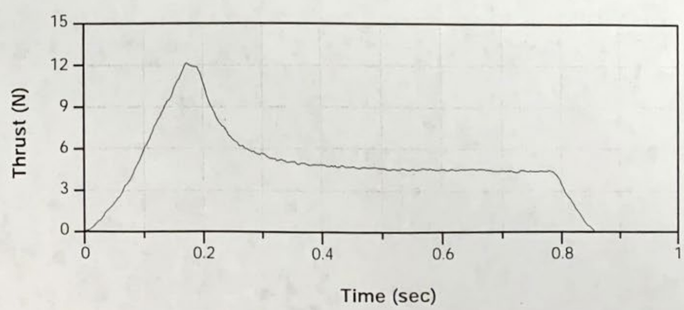
Date Tested: 95-March 25

Total Impulse: 4.33 newton-seconds (σ 0.08)
Peak Thrust: 12.14 newtons (σ 1.57)
Burn Time: 0.86 seconds (σ 0.15)
Average Thrust: 5.03 newtons

Mass After Firing: 9.7 grams

| Delay Time | Average Measured Delay | Initial Mass | Mfg Recommended Max Liftoff Weight |
|---|---|---|---|
| 0 | 0.00 | 15.6 g | 113.2 g |
| 2 | 1.53 | 18.8 g | 127.4 g |
| 4 | 3.68 | 19.1 g | 113.2 g |
| 6 | 5.44 | 19.4 g | 56.6 g |

### TYPICAL THRUST-TIME CURVE




### REMARKS

Updated: 8/96



Figure A.1. B6-0 Engine Specification Data [24]


**Figure A.2. Jig use to locate and drill axles and hook holes**