APPENDIX B

LONGITUDINAL DECELERATION MODULES

Oregon TECH

CE 551
Geometric Design of Roadways

Braking and stopping deceleration

Objective: To understand the development of the AASHTO stopping sight distance, and to directly measure this value.

Reference: Chapter 2 - Mannering

Road Vehicle Performance

- Straight-line performance - Chp. 2
  - acceleration / deceleration
  - engine characteristics
  - top speed
  - hill climbing ability
- Cornering performance - Chp. 3

Stopping Sight Distance

- Distance required for vehicle to stop in addition to distance traveled during perception/reaction time
- Distance for vehicle to stop also called *Practical Stopping Distance*

Braking - Theoretical

- Theoretical stopping distance equation:

$$S = \frac{\gamma_b W}{2g \frac{\rho}{2} C_D A_f} \ln\left[\frac{\eta_b \mu W + \frac{\rho}{2} C_D A_f V_1^2 + f_{rl} W \pm W \sin\theta_g}{\eta_b \mu W + f_{rl} W \pm W \sin\theta_g}\right]$$

- Handbook simplification:

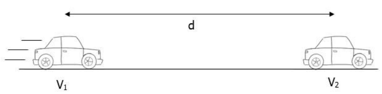
$$S = \frac{V_1^2}{2g(f \pm G)}$$

Braking - Practical

- Further simplification (Equation 2.45):

$$d = \frac{V_1^2 - V_2^2}{2a}$$

- *d* is the *practical* stopping distance
- *a* is the acceleration/deceleration



Braking - Practical

- This equation doesn't take into account any vehicle or roadway characteristics, but can be used to find a stopping distance for any speed change with an assumed *a*

- AASHTO recommends 11.2 ft/s² for a conservative value of *a*

Example

- A car *(W=2200 lbs, C_D=0.25, A_f= 22 ft^2, μ=0.7, η_b=0.9, γ_b=1.04, f_{rl}=0.015, ρ=0.0024)* is traveling at 75 ft/s along a flat grade. Determine theoretical stopping distance and practical stopping distance using AASHTO recommendation for deceleration.

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Measuring Deceleration

- "Approximately 90% of drivers decelerate at rates greater than [11.2ft/s^2], and this deceleration rate is well within a driver's capability to maintain steering control during a braking maneuver on wet surfaces." (AASHTO)

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Measuring Deceleration

- We now have the ability to directly measure acceleration/deceleration inexpensively

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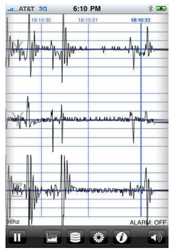
Measuring Deceleration

- iSeismometer app 
- Can measure acceleration along three axis



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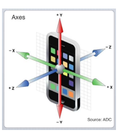
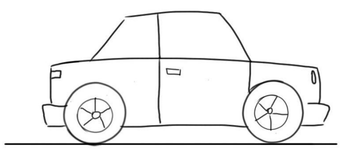
Measuring Deceleration





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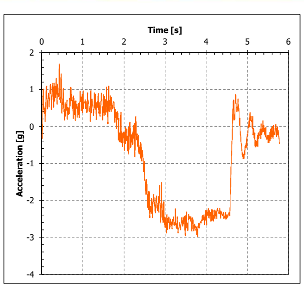
Measuring Deceleration



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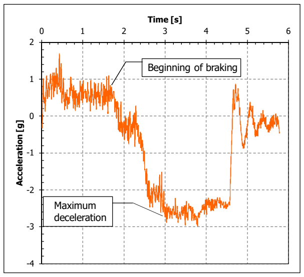
Measuring Deceleration



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Braking and Stopping Deceleration

Objectives

Compare Green Book average deceleration values used in design to actual deceleration measured in the field.

Deliverables

Technical memorandum, including:

- Methodology
- Graphs with summary of results for each test
- Comparison of Green Book to measured results
- Answers to all questions
- Analysis of which values you think more accurately describe vehicle deceleration and which values should be used for design

Materials Needed

- iSeismometer app, available for iPhone and Android:

  https://itunes.apple.com/us/app/iseismometer/id304190739?mt=8

- Bubble Level app, available for iPhone and Android:

  https://itunes.apple.com/us/app/bubble-level-for-iphone-and-ipad/id465613917?mt=8

- Velcro for mounting your phone to the dashboard of the vehicle
- A working vehicle and licensed driver. Sanity optional.
- Section 2.9 of the Mannering textbook, relating to Principles of Braking
- Section 3.2.2 of the Green Book, relating to Stopping Sight Distance

When determining stopping sight distance (SSD), one of the most important factors to consider is the rate of deceleration of a vehicle when braking. As noted in Chapter 3 of the Green Book, AASHTO recommends using 11.2 ft/s^2, or approximately 1/3 g, for determining SSD. In this exercise you will measure the deceleration rate directly and compare it to the Green Book recommendation.

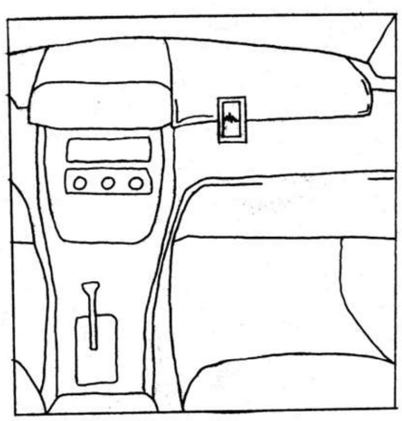
Recall Equation 3-1 for braking distance:

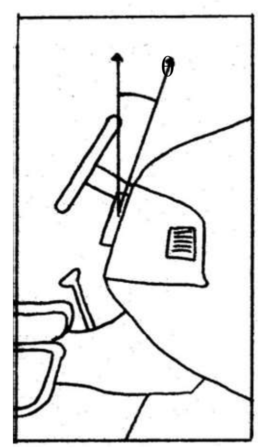
$$d_B = 1.075\frac{V^2}{a}$$

Procedures

1. With your group, setup a closed course along a flat grade in the Cornett parking lot. The course should allow for the driver to bring the vehicle up to 20 mph before braking begins and then to stop safely. Some trial runs through the parking lot may be necessary to determine an approximate setup to use. Use cones to mark off a point where the vehicle will begin braking. Use the following figure as a guide:

2. Install the iSeismometer and Bubble Level apps on your phone, and mount the phone on your dashboard where it can be easily reached by the passenger using the strip of Velcro. With the phone mounted use the Bubble Level app to determine the inclination of your phone on the dashboard from the vertical, and record this value. The phone should be aligned as close as possible along the horizontal.


Phone mounting position



Angle of inclination

3. To run the test you should have three people in the vehicle: A driver, an operator for the app, and a time recorder with a stopwatch. Open the app and pause the recording with the button at the bottom left. In the settings menu turn the Real Time Animation to OFF and the High-Pass Filter to ON. Set the sampling rate to between 100 and 200 samples per second. A higher sampling rate will give you more accurate data, but a smaller time period of data will be recorded by the device. For the length of this test you should be able to use 200/s.

a) From the start of the course accelerate to the desired test speed (20 mph), and try to maintain a constant speed. When the test speed is reached, start recording on the app.
b) Begin braking at the marked point. As soon as the driver starts braking start recording time on the stopwatch.
c) As soon as the vehicle comes to a complete stop, stop the stopwatch and record the time it took to brake. Stop the app recording and use the Data Transfer menu to send a CSV file to your email, with the appropriate test name or number in the subject line.
d) While each test is run there should be at least two people waiting at a safe distance to the side of the course. One will use the radar gun to determine the exact speed of the vehicle before braking, while the other will have chalk to mark the location of the stopped vehicle. After, *and only after*, the vehicle has come to a complete stop mark the location of the center of the front tire and write the test number next to the line for use later. After every test has been run use a wheel walker to measure the distance traveled from the start of braking for each test.

For each vehicle try to run at least six tests. Three at a comfortable braking level and three at an urgent or emergency braking level. For a comfortable braking level imagine pulling up to a stop sign on an uncrowded residential road. For an emergency braking level imagine braking suddenly to avoid an animal jumping into the road. If your vehicle is equipped with Antilock Brakes, try to brake hard enough to just avoid engaging the ABS. The driver may need several trial runs to get a feel for a consistent initial speed and braking level.

Note: In order to avoid confusion when analyzing the data, the team in the vehicle and the team outside should agree on a consistent naming system for each test beforehand.

Analysis Procedure

The data will be formatted as a comma separated values in your email. Copy the data, paste into the first column of the Data sheet, and run text-to-columns to delineate the data. In the Results sheet you will need to enter in the sampling rate you used as well as the inclination of your phone found using the Bubble Level. You should then have plots of acceleration over time in both *g* and ft/s^2. The spreadsheet will output the maximum acceleration experienced as well as the average Kth percentile acceleration value for forward and side directions.

To confirm the accuracy of your tests, use Equation 3-1 calculate your average constant deceleration for each test. Use the distance measured with the wheel walker and the initial speed measured using the radar gun.

Questions

1. How does your measured maximum deceleration compare to your calculated deceleration found using time and distance? If they differ, use the information in your textbook to try and explain why.

2. How does your measured maximum deceleration compare to the 11.2 ft/s^2 given by AASHTO? Does the AASHTO value seem like an appropriate value to use when determining SSD, why or why not?

3. Your test did not take into account driver perception-reaction time for braking. NCHRP Report 400 *Determination of Stopping Sight Distances* describes the methodology and results of several braking studies. Compare the measured perception-reaction time from these studies with the AASHTO recommendation of 2.5s. Do you think that the AASHTO value should be revised to more accurately reflect real driver behavior?

4. Identify any other sources of error in the test not already discussed and ways that they could be minimized.

0.0534185	-0.04775	-0.18113	1.46E+12
-0.018865	0.266803	0.412523	1.46E+12
-0.036279	0.045457	0.030665	1.46E+12
-0.011071	0.074461	-0.02771	1.46E+12
-0.014703	0.022351	-0.01701	1.46E+12
-0.028832	-0.00133	-0.0425	1.46E+12
0.0045224	0.046302	0.038706	1.46E+12
0.0114102	0.034505	0.027399	1.46E+12
-0.035843	-0.08379	0.008292	1.46E+12
-0.032536	-4.25E-04	-0.02243	1.46E+12
-0.048685	0.037201	0.020849	1.46E+12
0.0013542	0.005624	-0.06035	1.46E+12
-0.028132	0.032579	-0.00258	1.46E+12
-0.031821	-0.0654	-0.0477	1.46E+12
-0.003898	0.028704	0.072805	1.46E+12
0.0656632	0.040733	-0.04868	1.46E+12
-0.039215	-0.01216	-0.01441	1.46E+12
-0.03589	-0.00959	-0.07782	1.46E+12
0.0062226	-0.0092	-0.06591	1.46E+12
0.0258526	0.001474	-0.02098	1.46E+12
-0.025996	0.034147	-0.05535	1.46E+12
-0.02033	0.038188	-0.10836	1.46E+12
-0.022711	-0.04589	-0.02624	1.46E+12
0.0124618	0.043378	0.12059	1.46E+12
-0.022563	0.016887	0.123846	1.46E+12
0.034796	-0.07337	0.062001	1.46E+12
-0.037489	0.030553	0.023181	1.46E+12
0.0023363	0.016304	-0.05629	1.46E+12
0.0315529	-0.01235	0.043794	1.46E+12
-0.011797	-0.00248	0.016765	1.46E+12
0.0244096	0.015597	0.002619	1.46E+12
0.0242009	0.002073	0.071765	1.46E+12
-0.004204	0.052973	0.044222	1.46E+12
0.0416651	-0.02906	-0.05306	1.46E+12
0.0447479	-0.08213	0.049815	1.46E+12
-0.024298	-0.04554	0.031307	1.46E+12
0.0181932	-0.01712	-0.02473	1.46E+12
-0.009492	0.017408	0.06508	1.46E+12
-0.005561	-0.00779	-0.07613	1.46E+12
-0.014123	-0.07663	-0.02662	1.46E+12
-0.010436	-0.03037	0.003401	1.46E+12
0.0358014	-0.09001	0.053618	1.46E+12
0.0211573	-0.00608	0.073721	1.46E+12
0.0523498	-0.00649	-0.01061	1.46E+12
-0.001053	-7.43E-04	-0.0197	1.46E+12
0.0293504	-0.04315	0.043946	1.46E+12
-0.03346	0.048652	-0.02318	1.46E+12

-0.035483	0.016665	0.067457	1.46E+12
-0.011913	-0.01184	-0.08079	1.46E+12
6.68E-04	0.003875	0.010675	1.46E+12
-0.035729	-0.00937	0.075363	1.46E+12
0.0190629	0.01669	0.097171	1.46E+12
0.0304345	0.003099	0.054019	1.46E+12
0.0178244	0.07123	0.088197	1.46E+12
0.0225113	0.020506	0.018083	1.46E+12
0.0196135	0.005513	0.057037	1.46E+12
0.0223122	0.011754	-0.01784	1.46E+12
-7.45E-04	-0.02375	-0.01567	1.46E+12
8.17E-05	0.008683	0.056066	1.46E+12
0.0339006	0.023396	0.046468	1.46E+12
-0.012829	0.205262	-0.0774	1.46E+12
-0.005082	0.020489	-0.03025	1.46E+12
-4.02E-04	-0.07223	-0.00925	1.46E+12
0.0081206	0.013629	-0.04189	1.46E+12
-0.002502	0.029256	-0.01636	1.46E+12
-0.005163	-3.06E-04	0.052107	1.46E+12
-0.002352	0.025506	0.013498	1.46E+12
0.0077657	-0.01803	-0.01538	1.46E+12
-6.27E-04	0.013245	0.034622	1.46E+12
0.0086249	-0.00803	0.004027	1.46E+12
-0.003825	-0.00997	-0.01663	1.46E+12
5.62E-04	0.002857	0.006411	1.46E+12

	Input Data [g]								
Time [s]	X-Axis	Y-Axis	Z-Axis		J	sum [g]	sum [ft/s'	A	ABS [g]
0.0	0.05342	-0.0477	-0.1811	1.5E+12	0	0	0	0	0
0.1	-0.0189	0.2668	0.41252	1.5E+12	-0.128	-0.128	-4.1228	-0.0064	0.12804
0.2	-0.0363	0.04546	0.03066	1.5E+12	0.00763	-0.1204	-3.8772	-0.0124	0.12041
0.3	-0.0111	0.07446	-0.0277	1.5E+12	0.07041	-0.05	-1.6099	-0.0085	0.05
0.4	-0.0147	0.02235	-0.017	1.5E+12	0.02759	-0.0224	-0.7213	-0.0036	0.0224
0.5	-0.0288	-0.0013	-0.0425	1.5E+12	0.03069	0.00829	0.26695	-0.0007	0.00829
0.6	0.00452	0.0463	0.03871	1.5E+12	0.00222	0.01051	0.33838	0.00094	0.01051
0.7	0.01141	0.03451	0.0274	1.5E+12	0.00273	0.01324	0.42618	0.00119	0.01324
0.8	-0.0358	-0.0838	0.00829	1.5E+12	-0.0622	-0.049	-1.5777	-0.0018	0.049
0.9	-0.0325	-0.0004	-0.0224	1.5E+12	0.01638	-0.0326	-1.0502	-0.0041	0.03261
1.0	-0.0487	0.0372	0.02085	1.5E+12	0.0094	-0.0232	-0.7476	-0.0028	0.02322
1.1	0.00135	0.00562	-0.0603	1.5E+12	0.04861	0.02539	0.8177	0.00011	0.02539
1.2	-0.0281	0.03258	-0.0026	1.5E+12	0.02372	0.04911	1.58138	0.00373	0.04911
1.3	-0.0318	-0.0654	-0.0477	1.5E+12	-0.0083	0.0408	1.31364	0.0045	0.0408
1.4	-0.0039	0.0287	0.0728	1.5E+12	-0.0349	0.0059	0.18992	0.00233	0.0059
1.5	0.06566	0.04073	-0.0487	1.5E+12	0.06343	0.06933	2.23236	0.00376	0.06933
1.6	-0.0392	-0.0122	-0.0144	1.5E+12	0.00258	0.07191	2.31539	0.00706	0.07191
1.7	-0.0359	-0.0096	-0.0778	1.5E+12	0.05142	0.12332	3.97101	0.00976	0.12332
1.8	0.00622	-0.0092	-0.0659	1.5E+12	0.04283	0.16615	5.35007	0.01447	0.16615
1.9	0.02585	0.00147	-0.021	1.5E+12	0.01658	0.18273	5.88397	0.01744	0.18273
2.0	-0.026	0.03415	-0.0554	1.5E+12	0.06398	0.24671	7.94421	0.02147	0.24671
2.1	-0.0203	0.03819	-0.1084	1.5E+12	0.10608	0.35279	11.36	0.02998	0.35279
2.2	-0.0227	-0.0459	-0.0262	1.5E+12	-0.0112	0.34159	10.9992	0.03472	0.34159
2.3	0.01246	0.04338	0.12059	1.5E+12	-0.0606	0.281	9.04816	0.03113	0.281
2.4	-0.0226	0.01689	0.12385	1.5E+12	-0.0807	0.20026	6.44847	0.02406	0.20026
2.5	0.0348	-0.0734	0.062	1.5E+12	-0.0952	0.1051	3.38406	0.01527	0.1051
2.6	-0.0375	0.03055	0.02318	1.5E+12	0.00322	0.10831	3.48766	0.01067	0.10831
2.7	0.00234	0.0163	-0.0563	1.5E+12	0.05274	0.16105	5.18588	0.01347	0.16105
2.8	0.03155	-0.0123	0.04379	1.5E+12	-0.0408	0.12024	3.87186	0.01406	0.12024
2.9	-0.0118	-0.0025	0.01676	1.5E+12	-0.0141	0.10613	3.41732	0.01132	0.10613
3.0	0.02441	0.0156	0.00262	1.5E+12	0.00849	0.11462	3.69069	0.01104	0.11462
3.1	0.0242	0.00207	0.07177	1.5E+12	-0.0519	0.06267	2.01806	0.00886	0.06267
3.2	-0.0042	0.05297	0.04422	1.5E+12	0.00258	0.06525	2.10121	0.0064	0.06525
3.3	0.04167	-0.0291	-0.0531	1.5E+12	0.01999	0.08525	2.74493	0.00753	0.08525
3.4	0.04475	-0.0821	0.04982	1.5E+12	-0.092	-0.0067	-0.2166	0.00393	0.00673
3.5	-0.0243	-0.0455	0.03131	1.5E+12	-0.0537	-0.0605	-1.947	-0.0034	0.06046
3.6	0.01819	-0.0171	-0.0247	1.5E+12	0.00693	-0.0535	-1.7239	-0.0057	0.05354
3.7	-0.0095	0.01741	0.06508	1.5E+12	-0.0367	-0.0903	-2.9062	-0.0072	0.09025
3.8	-0.0056	-0.0078	-0.0761	1.5E+12	0.05136	-0.0389	-1.2523	-0.0065	0.03889
3.9	-0.0141	-0.0766	-0.0266	1.5E+12	-0.0315	-0.0704	-2.2665	-0.0055	0.07039
4.0	-0.0104	-0.0304	0.0034	1.5E+12	-0.0228	-0.0932	-3.0022	-0.0082	0.09324
4.1	0.0358	-0.09	0.05362	1.5E+12	-0.1001	-0.1933	-6.2247	-0.0143	0.19331
4.2	0.02116	-0.0061	0.07372	1.5E+12	-0.0589	-0.2522	-8.1197	-0.0223	0.25217
4.3	0.05235	-0.0065	-0.0106	1.5E+12	0.00354	-0.2486	-8.0057	-0.025	0.24862

4.4	-0.0011	-0.0007	-0.0197	1.5E+12	0.01414	-0.2345	-7.5504	-0.0242	0.23449
4.5	0.02935	-0.0431	0.04395	1.5E+12	-0.0615	-0.296	-9.5317	-0.0265	0.29601
4.6	-0.0335	0.04865	-0.0232	1.5E+12	0.04978	-0.2462	-7.9287	-0.0271	0.24623
4.7	-0.0355	0.01666	0.06746	1.5E+12	-0.039	-0.2852	-9.1839	-0.0266	0.28521
4.8	-0.0119	-0.0118	-0.0808	1.5E+12	0.05212	-0.2331	-7.5057	-0.0259	0.2331
4.9	0.00067	0.00387	0.01067	1.5E+12	-0.0053	-0.2384	-7.6776	-0.0236	0.23844
5.0	-0.0357	-0.0094	0.07536	1.5E+12	-0.0623	-0.3007	-9.6828	-0.027	0.30071
5.1	0.01906	0.01669	0.09717	1.5E+12	-0.061	-0.3618	-11.648	-0.0331	0.36175
5.2	0.03043	0.0031	0.05402	1.5E+12	-0.0381	-0.3998	-12.874	-0.0381	0.39982
5.3	0.01782	0.07123	0.0882	1.5E+12	-0.0179	-0.4177	-13.45	-0.0409	0.4177
5.4	0.02251	0.02051	0.01808	1.5E+12	0.00028	-0.4174	-13.441	-0.0418	0.41742
5.5	0.01961	0.00551	0.05704	1.5E+12	-0.0387	-0.4561	-14.687	-0.0437	0.45612
5.6	0.02231	0.01175	-0.0178	1.5E+12	0.02112	-0.435	-14.007	-0.0446	0.43499
5.7	-0.0007	-0.0237	-0.0157	1.5E+12	-0.0042	-0.4392	-14.143	-0.0437	0.43923
5.8	8.2E-05	0.00868	0.05607	1.5E+12	-0.0359	-0.4751	-15.298	-0.0457	0.47509
5.9	0.0339	0.0234	0.04647	1.5E+12	-0.0189	-0.494	-15.906	-0.0485	0.49397
6.0	-0.0128	0.20526	-0.0774	1.5E+12	0.19487	-0.2991	-9.631	-0.0397	0.2991
6.1	-0.0051	0.02049	-0.0302	1.5E+12	0.03619	-0.2629	-8.4657	-0.0281	0.26291
6.2	-0.0004	-0.0722	-0.0093	1.5E+12	-0.0415	-0.3044	-9.8006	-0.0284	0.30437
6.3	0.00812	0.01363	-0.0419	1.5E+12	0.04025	-0.2641	-8.5047	-0.0284	0.26412
6.4	-0.0025	0.02926	-0.0164	1.5E+12	0.03173	-0.2324	-7.4829	-0.0248	0.23239
6.5	-0.0052	-0.0003	0.05211	1.5E+12	-0.0389	-0.2713	-8.7364	-0.0252	0.27132
6.6	-0.0024	0.02551	0.0135	1.5E+12	0.00704	-0.2643	-8.5099	-0.0268	0.26428
6.7	0.00777	-0.018	-0.0154	1.5E+12	-0.0006	-0.2649	-8.5303	-0.0265	0.26492
6.8	-0.0006	0.01325	0.03462	1.5E+12	-0.0169	-0.2818	-9.0734	-0.0273	0.28178
6.9	0.00862	-0.008	0.00403	1.5E+12	-0.0084	-0.2901	-9.3427	-0.0286	0.29015
7.0	-0.0038	-0.01	-0.0166	1.5E+12	0.00568	-0.2845	-9.1597	-0.0287	0.28446
7.1	0.00056	0.00286	0.00641	1.5E+12	-0.0029	-0.2873	-9.2515	-0.0286	0.28731
7.2	0	0	0	0	0				
7.3	0	0	0	0	0				
7.4	0	0	0	0	0				
7.5	0	0	0	0	0				
7.6	0	0	0	0	0				
7.7	0	0	0	0	0				
7.8	0	0	0	0	0				
7.9	0	0	0	0	0				
8.0	0	0	0	0	0				
8.1	0	0	0	0	0				
8.2	0	0	0	0	0				
8.3	0	0	0	0	0				
8.4	0	0	0	0	0				
8.5	0	0	0	0	0				
8.6	0	0	0	0	0				
8.7	0	0	0	0	0				
8.8	0	0	0	0	0				
8.9	0	0	0	0	0				
9.0	0	0	0	0	0				

9.1	0	0	0	0	0
9.2	0	0	0	0	0
9.3	0	0	0	0	0
9.4	0	0	0	0	0
9.5	0	0	0	0	0
9.6	0	0	0	0	0
9.7	0	0	0	0	0
9.8	0	0	0	0	0
9.9	0	0	0	0	0
10.0	0	0	0	0	0

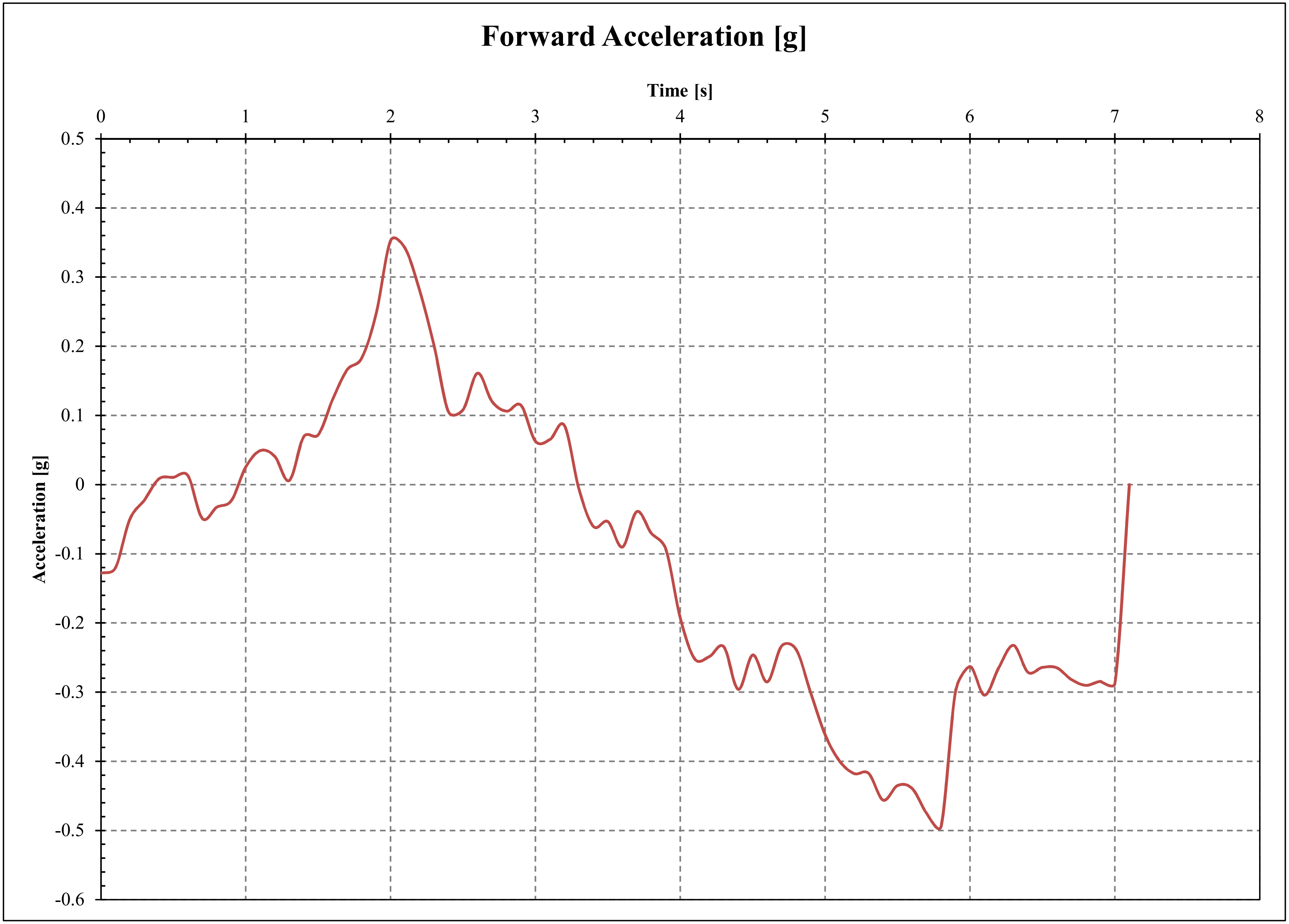
Sampling Rate:	10	Hz
θ =	48.0	°
	0.8378	Radians
K=	0.9500	

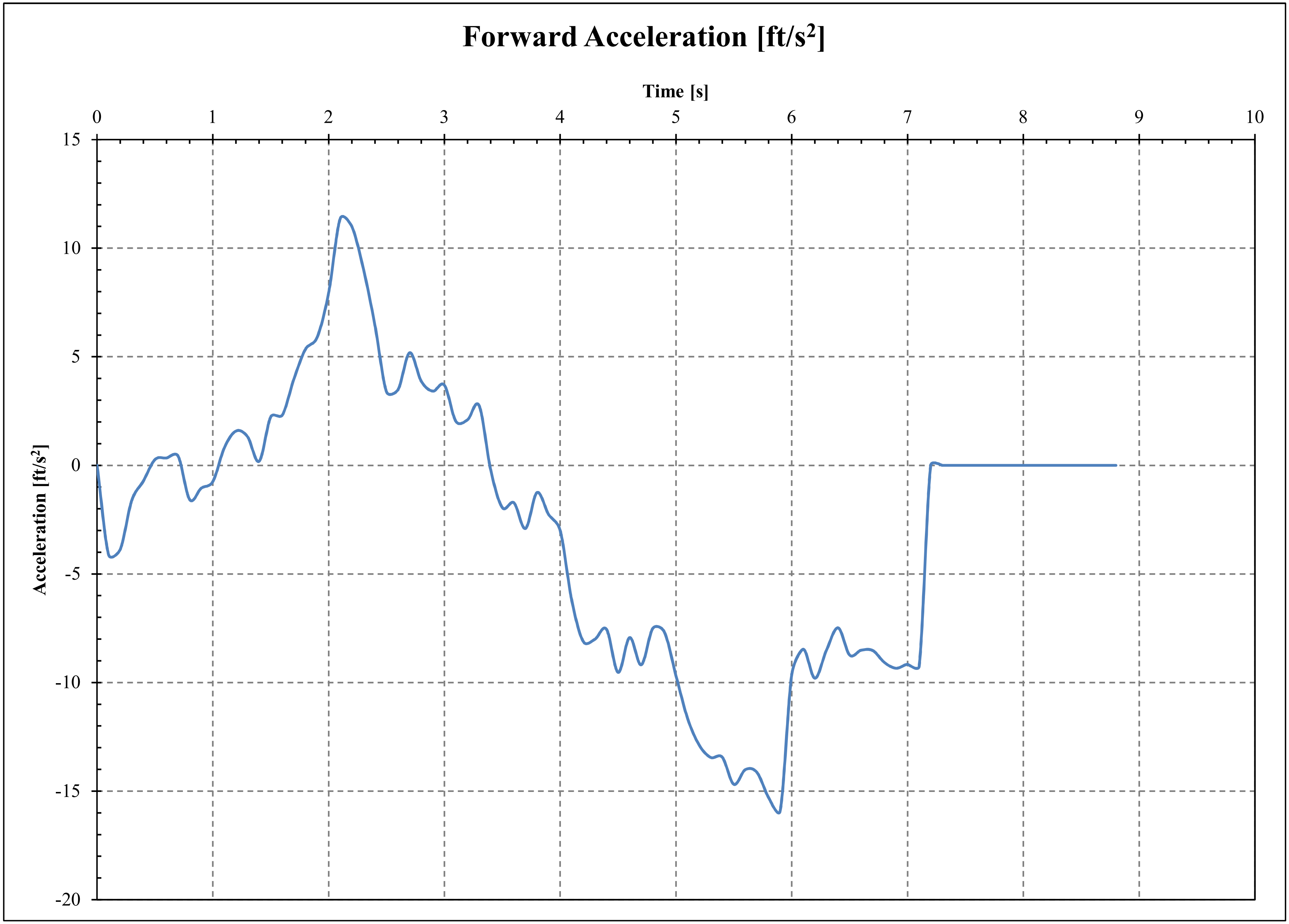
Maximum Forward Acceleration:	**0.49**	g
	15.91	ft/s^2
Average K^{th} Percentile Forward Acceleration:	**0.436902**	g
	14.068	ft/s^2

Instructions:

Copy and paste acceleration data into the data tab, and run Text to Columns.

Enter in the sampling rate of your device, the angle of inclination, and the desired K value.


Forward Acceleration [g]
Time [s]
0
1
2
3
4
5
6
7
8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Acceleration [g]


Forward Acceleration [ft/s²]
Time [s]
0
1
2
3
4
5
6
7
8
9
10
15
10
5
0
-5
-10
-15
-20
Acceleration [ft/s²]

Memorandum

To: Dr. Lindgren

From: Samuel Lozano

Date: 2/27/17

Subject: Vehicle Dynamics – Feasibility of digital ball banking units for use in brake testing

As part of the CE-507 Vehicle Dynamics project educational module development, one of the considered options for making the lab section simpler at the junior class level was to use the Rieker digital inclinometer units for braking deceleration measurement as well as ball banking. This would allow the junior class to test braking deceleration without having to learn how to use a new accelerometer system.

Unfortunately, after field testing the inclinometers in this capacity and contacting product engineers at Rieker Inc., the digital inclinometer devices proved to be unsuitable for brake testing. This is due to the specific accelerometer unit used within the inclinometer unit. The accelerometers used in the department's specific inclinometer model are factory calibrated for use in curve testing and have a maximum readable value of 30°, corresponding to 16.1 ft/s^2. While this value is above the value of 11.2 ft/s^2 found in the Green Book as a recommended value of deceleration for use in stopping sight distance determination, results from the CE-551 project and the field testing of the inclinometers show that this measurement range is insufficient for practical braking deceleration measurements.

In the long term, Rieker costumer support noted that inclinometer units are available that are calibrated for measuring a more broad range of accelerations than the model the department has currently, and this may become a more practical solution as such technology becomes the new standard. However in the short term the final learning module for both junior and graduate level classes will incorporate use of the iSeismometer app on smartphones.

Oregon TECH

CE 351
Introduction to Transportation Engineering

Braking and stopping deceleration

Objective: To understand the development of the AASHTO stopping sight distance, and to directly measure this value.

Reference: Chapter 2 - Mannering

OREGON TECH Lindgren 1

Road Vehicle Performance

- Straight-line performance - Chp. 2
  - acceleration / deceleration
  - engine characteristics
  - top speed
  - hill climbing ability
- Cornering performance - Chp. 3

OREGON TECH Lindgren 2

Stopping Sight Distance

- Distance required for vehicle to stop in addition to distance traveled during perception/reaction time
- Distance for vehicle to stop also called *Practical Stopping Distance*

OREGON TECH Lindgren 3

Braking - Theoretical

- Theoretical stopping distance equation:

$$S = \frac{\gamma_b W}{2g \frac{\rho}{2} C_D A_f} \ln \left[\frac{\eta_b \mu W + \frac{\rho}{2} C_D A_f V_1^2 + f_{rl} W \pm W \sin\theta_g}{\eta_b \mu W + f_{rl} W \pm W \sin\theta_g} \right]$$

- Handbook simplification:

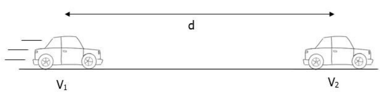
$$S = \frac{V_1^2}{2g(f \pm G)}$$

Braking - Practical

- Further simplification (Equation 2.45):

$$d = \frac{V_1^2 - V_2^2}{2a}$$

- *d* is the *practical* stopping distance
- *a* is the acceleration/deceleration



Braking - Practical

- This equation doesn't take into account any vehicle or roadway characteristics, but can be used to find a stopping distance for any speed change with an assumed *a*
- AASHTO recommends 11.2 ft/s^2 for a conservative value of *a*

Example

- A car *(W=2200 lbs, C_D=0.25, A_f= 22 ft^2, μ=0.7, η_b=0.9, γ_b=1.04, f_{rl}=0.015, ρ=0.0024)* is traveling at 75 ft/s along a flat grade. Determine theoretical stopping distance and practical stopping distance using AASHTO recommendation for deceleration.

Measuring Deceleration

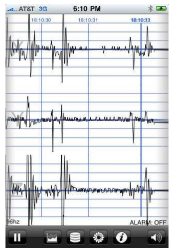
- "Approximately 90% of drivers decelerate at rates greater than [11.2ft/s^2], and this deceleration rate is well within a driver's capability to maintain steering control during a braking maneuver on wet surfaces." (AASHTO)

Measuring Deceleration

- We now have the ability to directly measure acceleration/deceleration inexpensively

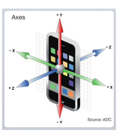
Measuring Deceleration

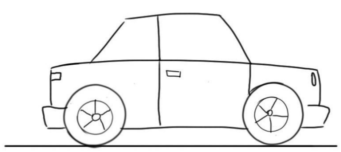
- iSeismometer app 
- Can measure acceleration along three axis



OREGON TECH Lindgren 10

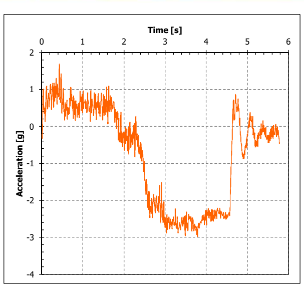
Measuring Deceleration





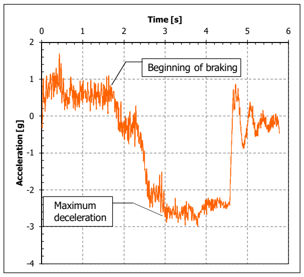
OREGON TECH Lindgren 11

Measuring Deceleration



OREGON TECH Lindgren 12

Measuring Deceleration



OREGON TECH Lindgren 13

Braking and Stopping Deceleration

Objectives

Compare given AASHTO deceleration values used in design to actual deceleration measured in the field.

Deliverables

Technical memorandum, including:

- Methodology
- Graphs with summary of results for each test
- Comparison of AASHTO values to measured results
- Answers to all questions

Materials Needed

- iSeismometer app, available for iPhone and Android:

  https://itunes.apple.com/us/app/iseismometer/id304190739?mt=8

- Bubble Level app, available for iPhone and Android:

  https://itunes.apple.com/us/app/bubble-level-for-iphone-and-ipad/id465613917?mt=8

- Velcro for mounting your phone to the dashboard of the vehicle

- A working vehicle and licensed driver. Sanity optional.

- Section 2.9 of the Mannering textbook, relating to Principles of Braking

Background

When determining stopping sight distance (SSD), one of the most important factors to consider is the rate of deceleration of a vehicle when braking. As noted in Section 2.9.5 of your textbook AASHTO recommends using 11.2 ft/s^2, or approximately 1/3 g, for determining SSD. In this exercise you will measure the deceleration rate directly and compare it to AASHTO's recommendation.

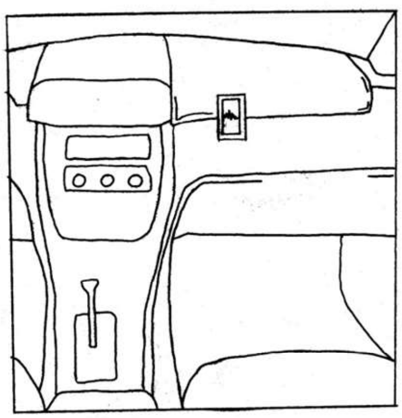
Recall from lecture the equation for practical stopping distance:

$$d = \frac{{V_1}^2 - {V_2}^2}{2a}$$

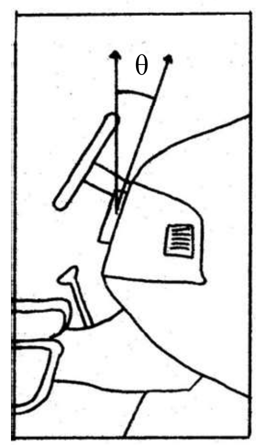
Procedures

1. With your group, setup a closed course along a flat grade in the Cornett parking lot. The course should allow for the driver to bring the vehicle up to 20 mph before braking begins and then to stop safely. Some trial runs through the parking lot may be necessary to determine an approximate setup to use. Use cones to mark off a point where the vehicle will begin braking. Use the following figure as a guide:

2. Install the iSeismometer and Bubble Level apps on your phone, and mount the phone on your dashboard where it can be easily reached by the passenger using the strip of Velcro. With the phone mounted use the Bubble Level app to determine the inclination of your phone on the dashboard from the vertical, and record this value. The phone should be aligned as close as possible along the horizontal.



Phone mounting position



Angle of inclination

3. To run the test you should have three people in the vehicle: A driver, an operator for the app, and a time recorder with a stopwatch. Open the app and pause the recording with the button at the bottom left. In the settings menu turn the Real Time Animation to OFF and the High-Pass Filter to ON. Set the sampling rate to between 100 and 200 samples per second. A higher sampling rate will give you more accurate data, but a smaller time period of data will be recorded by the device. For the length of this test you should be able to use 200/s.

a) From the start of the course accelerate to the desired test speed (20 mph), and try to maintain a constant speed. When the test speed is reached, start recording on the app.
b) Begin braking at the marked point. As soon as the driver starts braking start recording time on the stopwatch.
c) As soon as the vehicle comes to a complete stop, stop the stopwatch and record the time it took to brake. Stop the app recording and use the Data Transfer menu to send a CSV file to your email, with the appropriate test name or number in the subject line.
d) While each test is run there should be at least two people waiting at a safe distance to the side of the course. One will use the radar gun to determine the exact speed of the vehicle before braking, while the other will have chalk to mark the location of the stopped vehicle. After, *and only after*, the vehicle has come to a complete stop mark the location of the center of the front tire and write the test number next to the line for use later. After every test has been run use a wheel walker to measure the distance traveled from the start of braking for each test.

For each vehicle try to run at least three tests at a comfortable braking level. For a comfortable braking level, imagine pulling up to a stop sign on an uncrowded residential road. The driver may need several trial runs to get a feel for a consistent initial speed and braking level.

Note: In order to avoid confusion when analyzing the data, the team in the vehicle and the team outside should agree on a consistent naming system for each test beforehand.

Analysis Procedure

The data will be formatted as a comma separated values in your email. Copy the data, paste into the first column of the Data sheet, and run text-to-columns to delineate the data. In the Results sheet you will need to enter in the sampling rate you used as well as the inclination of your phone found using the Bubble Level. You should then have plots of acceleration over time in both *g* and ft/s^2. The spreadsheet will output the maximum acceleration experienced as well as the average Kth percentile acceleration value for forward and side directions.

To confirm the accuracy of your tests, use Equation 2.45 from the textbook to calculate your average constant deceleration for each test. Use the distance measured with the wheel walker and the initial speed measured using the radar gun.

Questions

1. How does your measured maximum deceleration compare to your calculated deceleration found using time and distance? If they differ, use the information in your textbook to try and explain why.

2. How does your measured maximum deceleration compare to the 11.2 ft/s^2 given by AASHTO? Does the AASHTO value seem like an appropriate value to use when determining SSD, why or why not?

3. Using Section 2.9 of the textbook, identify one factor in braking distance that cannot be measured or accounted for by this test.

4. Identify any other sources of error in the test not already discussed and ways that they could be minimized.

0.0534185	-0.04775	-0.18113	1.46E+12
-0.018865	0.266803	0.412523	1.46E+12
-0.036279	0.045457	0.030665	1.46E+12
-0.011071	0.074461	-0.02771	1.46E+12
-0.014703	0.022351	-0.01701	1.46E+12
-0.028832	-0.00133	-0.0425	1.46E+12
0.0045224	0.046302	0.038706	1.46E+12
0.0114102	0.034505	0.027399	1.46E+12
-0.035843	-0.08379	0.008292	1.46E+12
-0.032536	-4.25E-04	-0.02243	1.46E+12
-0.048685	0.037201	0.020849	1.46E+12
0.0013542	0.005624	-0.06035	1.46E+12
-0.028132	0.032579	-0.00258	1.46E+12
-0.031821	-0.0654	-0.0477	1.46E+12
-0.003898	0.028704	0.072805	1.46E+12
0.0656632	0.040733	-0.04868	1.46E+12
-0.039215	-0.01216	-0.01441	1.46E+12
-0.03589	-0.00959	-0.07782	1.46E+12
0.0062226	-0.0092	-0.06591	1.46E+12
0.0258526	0.001474	-0.02098	1.46E+12
-0.025996	0.034147	-0.05535	1.46E+12
-0.02033	0.038188	-0.10836	1.46E+12
-0.022711	-0.04589	-0.02624	1.46E+12
0.0124618	0.043378	0.12059	1.46E+12
-0.022563	0.016887	0.123846	1.46E+12
0.034796	-0.07337	0.062001	1.46E+12
-0.037489	0.030553	0.023181	1.46E+12
0.0023363	0.016304	-0.05629	1.46E+12
0.0315529	-0.01235	0.043794	1.46E+12
-0.011797	-0.00248	0.016765	1.46E+12
0.0244096	0.015597	0.002619	1.46E+12
0.0242009	0.002073	0.071765	1.46E+12
-0.004204	0.052973	0.044222	1.46E+12
0.0416651	-0.02906	-0.05306	1.46E+12
0.0447479	-0.08213	0.049815	1.46E+12
-0.024298	-0.04554	0.031307	1.46E+12
0.0181932	-0.01712	-0.02473	1.46E+12
-0.009492	0.017408	0.06508	1.46E+12
-0.005561	-0.00779	-0.07613	1.46E+12
-0.014123	-0.07663	-0.02662	1.46E+12
-0.010436	-0.03037	0.003401	1.46E+12
0.0358014	-0.09001	0.053618	1.46E+12
0.0211573	-0.00608	0.073721	1.46E+12
0.0523498	-0.00649	-0.01061	1.46E+12
-0.001053	-7.43E-04	-0.0197	1.46E+12
0.0293504	-0.04315	0.043946	1.46E+12
-0.03346	0.048652	-0.02318	1.46E+12

-0.035483	0.016665	0.067457	1.46E+12
-0.011913	-0.01184	-0.08079	1.46E+12
6.68E-04	0.003875	0.010675	1.46E+12
-0.035729	-0.00937	0.075363	1.46E+12
0.0190629	0.01669	0.097171	1.46E+12
0.0304345	0.003099	0.054019	1.46E+12
0.0178244	0.07123	0.088197	1.46E+12
0.0225113	0.020506	0.018083	1.46E+12
0.0196135	0.005513	0.057037	1.46E+12
0.0223122	0.011754	-0.01784	1.46E+12
-7.45E-04	-0.02375	-0.01567	1.46E+12
8.17E-05	0.008683	0.056066	1.46E+12
0.0339006	0.023396	0.046468	1.46E+12
-0.012829	0.205262	-0.0774	1.46E+12
-0.005082	0.020489	-0.03025	1.46E+12
-4.02E-04	-0.07223	-0.00925	1.46E+12
0.0081206	0.013629	-0.04189	1.46E+12
-0.002502	0.029256	-0.01636	1.46E+12
-0.005163	-3.06E-04	0.052107	1.46E+12
-0.002352	0.025506	0.013498	1.46E+12
0.0077657	-0.01803	-0.01538	1.46E+12
-6.27E-04	0.013245	0.034622	1.46E+12
0.0086249	-0.00803	0.004027	1.46E+12
-0.003825	-0.00997	-0.01663	1.46E+12
5.62E-04	0.002857	0.006411	1.46E+12

	Input Data [g]								
Time [s]	X-Axis	Y-Axis	Z-Axis		J	sum [g]	sum [ft/s	A	ABS [g]
0.0	0.05342	-0.0477	-0.1811	1.5E+12	0	0	0	0	0
0.1	-0.0189	0.2668	0.41252	1.5E+12	-0.128	-0.128	-4.1228	-0.0064	0.12804
0.2	-0.0363	0.04546	0.03066	1.5E+12	0.00763	-0.1204	-3.8772	-0.0124	0.12041
0.3	-0.0111	0.07446	-0.0277	1.5E+12	0.07041	-0.05	-1.6099	-0.0085	0.05
0.4	-0.0147	0.02235	-0.017	1.5E+12	0.02759	-0.0224	-0.7213	-0.0036	0.0224
0.5	-0.0288	-0.0013	-0.0425	1.5E+12	0.03069	0.00829	0.26695	-0.0007	0.00829
0.6	0.00452	0.0463	0.03871	1.5E+12	0.00222	0.01051	0.33838	0.00094	0.01051
0.7	0.01141	0.03451	0.0274	1.5E+12	0.00273	0.01324	0.42618	0.00119	0.01324
0.8	-0.0358	-0.0838	0.00829	1.5E+12	-0.0622	-0.049	-1.5777	-0.0018	0.049
0.9	-0.0325	-0.0004	-0.0224	1.5E+12	0.01638	-0.0326	-1.0502	-0.0041	0.03261
1.0	-0.0487	0.0372	0.02085	1.5E+12	0.0094	-0.0232	-0.7476	-0.0028	0.02322
1.1	0.00135	0.00562	-0.0603	1.5E+12	0.04861	0.02539	0.8177	0.00011	0.02539
1.2	-0.0281	0.03258	-0.0026	1.5E+12	0.02372	0.04911	1.58138	0.00373	0.04911
1.3	-0.0318	-0.0654	-0.0477	1.5E+12	-0.0083	0.0408	1.31364	0.0045	0.0408
1.4	-0.0039	0.0287	0.0728	1.5E+12	-0.0349	0.0059	0.18992	0.00233	0.0059
1.5	0.06566	0.04073	-0.0487	1.5E+12	0.06343	0.06933	2.23236	0.00376	0.06933
1.6	-0.0392	-0.0122	-0.0144	1.5E+12	0.00258	0.07191	2.31539	0.00706	0.07191
1.7	-0.0359	-0.0096	-0.0778	1.5E+12	0.05142	0.12332	3.97101	0.00976	0.12332
1.8	0.00622	-0.0092	-0.0659	1.5E+12	0.04283	0.16615	5.35007	0.01447	0.16615
1.9	0.02585	0.00147	-0.021	1.5E+12	0.01658	0.18273	5.88397	0.01744	0.18273
2.0	-0.026	0.03415	-0.0554	1.5E+12	0.06398	0.24671	7.94421	0.02147	0.24671
2.1	-0.0203	0.03819	-0.1084	1.5E+12	0.10608	0.35279	11.36	0.02998	0.35279
2.2	-0.0227	-0.0459	-0.0262	1.5E+12	-0.0112	0.34159	10.9992	0.03472	0.34159
2.3	0.01246	0.04338	0.12059	1.5E+12	-0.0606	0.281	9.04816	0.03113	0.281
2.4	-0.0226	0.01689	0.12385	1.5E+12	-0.0807	0.20026	6.44847	0.02406	0.20026
2.5	0.0348	-0.0734	0.062	1.5E+12	-0.0952	0.1051	3.38406	0.01527	0.1051
2.6	-0.0375	0.03055	0.02318	1.5E+12	0.00322	0.10831	3.48766	0.01067	0.10831
2.7	0.00234	0.0163	-0.0563	1.5E+12	0.05274	0.16105	5.18588	0.01347	0.16105
2.8	0.03155	-0.0123	0.04379	1.5E+12	-0.0408	0.12024	3.87186	0.01406	0.12024
2.9	-0.0118	-0.0025	0.01676	1.5E+12	-0.0141	0.10613	3.41732	0.01132	0.10613
3.0	0.02441	0.0156	0.00262	1.5E+12	0.00849	0.11462	3.69069	0.01104	0.11462
3.1	0.0242	0.00207	0.07177	1.5E+12	-0.0519	0.06267	2.01806	0.00886	0.06267
3.2	-0.0042	0.05297	0.04422	1.5E+12	0.00258	0.06525	2.10121	0.0064	0.06525
3.3	0.04167	-0.0291	-0.0531	1.5E+12	0.01999	0.08525	2.74493	0.00753	0.08525
3.4	0.04475	-0.0821	0.04982	1.5E+12	-0.092	-0.0067	-0.2166	0.00393	0.00673
3.5	-0.0243	-0.0455	0.03131	1.5E+12	-0.0537	-0.0605	-1.947	-0.0034	0.06046
3.6	0.01819	-0.0171	-0.0247	1.5E+12	0.00693	-0.0535	-1.7239	-0.0057	0.05354
3.7	-0.0095	0.01741	0.06508	1.5E+12	-0.0367	-0.0903	-2.9062	-0.0072	0.09025
3.8	-0.0056	-0.0078	-0.0761	1.5E+12	0.05136	-0.0389	-1.2523	-0.0065	0.03889
3.9	-0.0141	-0.0766	-0.0266	1.5E+12	-0.0315	-0.0704	-2.2665	-0.0055	0.07039
4.0	-0.0104	-0.0304	0.0034	1.5E+12	-0.0228	-0.0932	-3.0022	-0.0082	0.09324
4.1	0.0358	-0.09	0.05362	1.5E+12	-0.1001	-0.1933	-6.2247	-0.0143	0.19331
4.2	0.02116	-0.0061	0.07372	1.5E+12	-0.0589	-0.2522	-8.1197	-0.0223	0.25217
4.3	0.05235	-0.0065	-0.0106	1.5E+12	0.00354	-0.2486	-8.0057	-0.025	0.24862

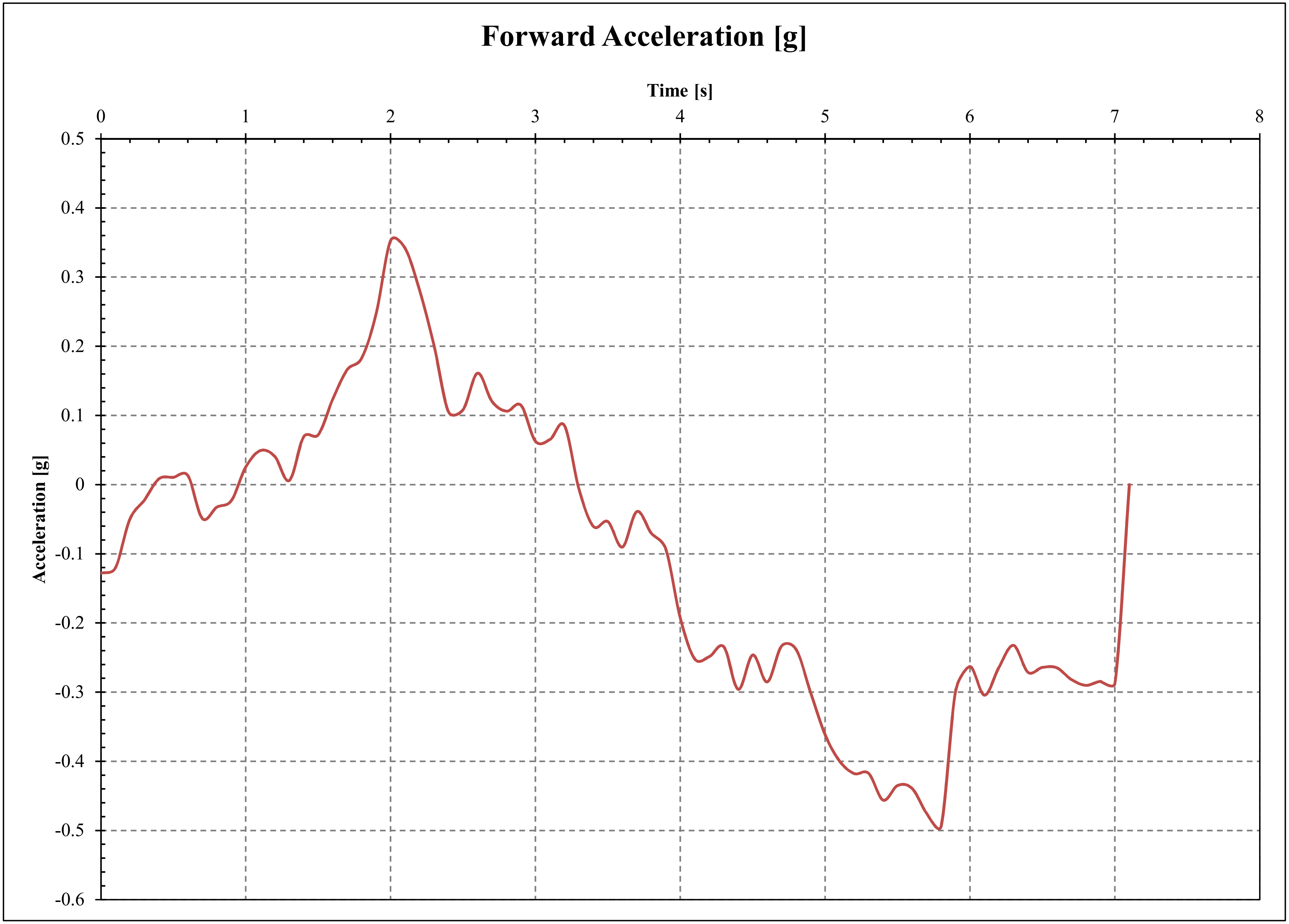
4.4	-0.0011	-0.0007	-0.0197	1.5E+12	0.01414	-0.2345	-7.5504	-0.0242	0.23449
4.5	0.02935	-0.0431	0.04395	1.5E+12	-0.0615	-0.296	-9.5317	-0.0265	0.29601
4.6	-0.0335	0.04865	-0.0232	1.5E+12	0.04978	-0.2462	-7.9287	-0.0271	0.24623
4.7	-0.0355	0.01666	0.06746	1.5E+12	-0.039	-0.2852	-9.1839	-0.0266	0.28521
4.8	-0.0119	-0.0118	-0.0808	1.5E+12	0.05212	-0.2331	-7.5057	-0.0259	0.2331
4.9	0.00067	0.00387	0.01067	1.5E+12	-0.0053	-0.2384	-7.6776	-0.0236	0.23844
5.0	-0.0357	-0.0094	0.07536	1.5E+12	-0.0623	-0.3007	-9.6828	-0.027	0.30071
5.1	0.01906	0.01669	0.09717	1.5E+12	-0.061	-0.3618	-11.648	-0.0331	0.36175
5.2	0.03043	0.0031	0.05402	1.5E+12	-0.0381	-0.3998	-12.874	-0.0381	0.39982
5.3	0.01782	0.07123	0.0882	1.5E+12	-0.0179	-0.4177	-13.45	-0.0409	0.4177
5.4	0.02251	0.02051	0.01808	1.5E+12	0.00028	-0.4174	-13.441	-0.0418	0.41742
5.5	0.01961	0.00551	0.05704	1.5E+12	-0.0387	-0.4561	-14.687	-0.0437	0.45612
5.6	0.02231	0.01175	-0.0178	1.5E+12	0.02112	-0.435	-14.007	-0.0446	0.43499
5.7	-0.0007	-0.0237	-0.0157	1.5E+12	-0.0042	-0.4392	-14.143	-0.0437	0.43923
5.8	8.2E-05	0.00868	0.05607	1.5E+12	-0.0359	-0.4751	-15.298	-0.0457	0.47509
5.9	0.0339	0.0234	0.04647	1.5E+12	-0.0189	-0.494	-15.906	-0.0485	0.49397
6.0	-0.0128	0.20526	-0.0774	1.5E+12	0.19487	-0.2991	-9.631	-0.0397	0.2991
6.1	-0.0051	0.02049	-0.0302	1.5E+12	0.03619	-0.2629	-8.4657	-0.0281	0.26291
6.2	-0.0004	-0.0722	-0.0093	1.5E+12	-0.0415	-0.3044	-9.8006	-0.0284	0.30437
6.3	0.00812	0.01363	-0.0419	1.5E+12	0.04025	-0.2641	-8.5047	-0.0284	0.26412
6.4	-0.0025	0.02926	-0.0164	1.5E+12	0.03173	-0.2324	-7.4829	-0.0248	0.23239
6.5	-0.0052	-0.0003	0.05211	1.5E+12	-0.0389	-0.2713	-8.7364	-0.0252	0.27132
6.6	-0.0024	0.02551	0.0135	1.5E+12	0.00704	-0.2643	-8.5099	-0.0268	0.26428
6.7	0.00777	-0.018	-0.0154	1.5E+12	-0.0006	-0.2649	-8.5303	-0.0265	0.26492
6.8	-0.0006	0.01325	0.03462	1.5E+12	-0.0169	-0.2818	-9.0734	-0.0273	0.28178
6.9	0.00862	-0.008	0.00403	1.5E+12	-0.0084	-0.2901	-9.3427	-0.0286	0.29015
7.0	-0.0038	-0.01	-0.0166	1.5E+12	0.00568	-0.2845	-9.1597	-0.0287	0.28446
7.1	0.00056	0.00286	0.00641	1.5E+12	-0.0029	-0.2873	-9.2515	-0.0286	0.28731
7.2	0	0	0	0	0				
7.3	0	0	0	0	0				
7.4	0	0	0	0	0				
7.5	0	0	0	0	0				
7.6	0	0	0	0	0				
7.7	0	0	0	0	0				
7.8	0	0	0	0	0				
7.9	0	0	0	0	0				
8.0	0	0	0	0	0				
8.1	0	0	0	0	0				
8.2	0	0	0	0	0				
8.3	0	0	0	0	0				
8.4	0	0	0	0	0				
8.5	0	0	0	0	0				
8.6	0	0	0	0	0				
8.7	0	0	0	0	0				
8.8	0	0	0	0	0				
8.9	0	0	0	0	0				
9.0	0	0	0	0	0				

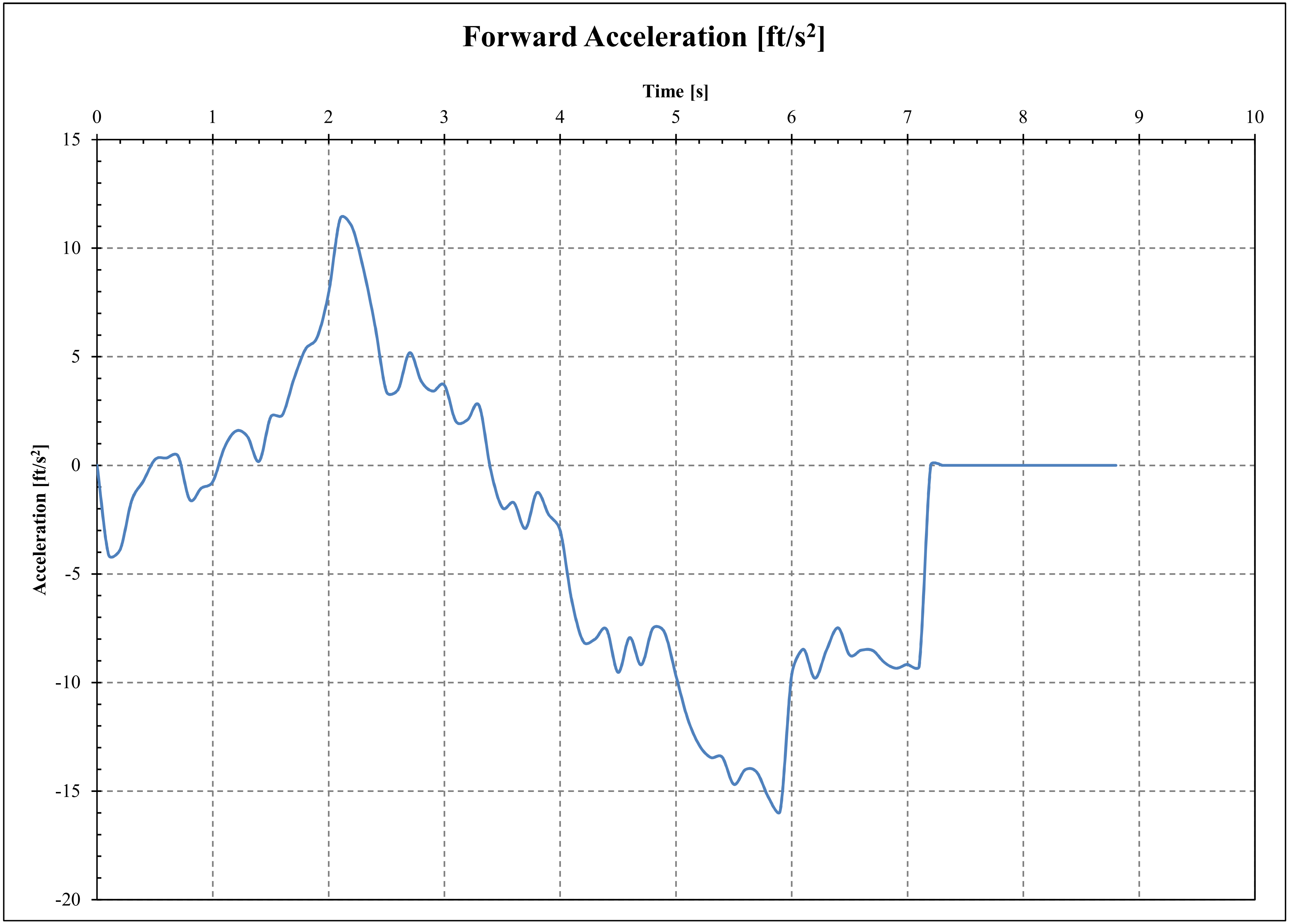
9.1	0	0	0	0	0
9.2	0	0	0	0	0
9.3	0	0	0	0	0
9.4	0	0	0	0	0
9.5	0	0	0	0	0
9.6	0	0	0	0	0
9.7	0	0	0	0	0
9.8	0	0	0	0	0
9.9	0	0	0	0	0
10.0	0	0	0	0	0

Sampling Rate:	10	Hz
θ =	48.0	°
	0.8378	Radians
K=	0.9500	

Maximum Forward Acceleration:	0.49	g
	15.91	ft/s^2
Average K^{th} Percentile Forward Acceleration:	0.436902	g
	14.068	ft/s^2

Instructions:
Copy and paste acceleration data into the data tab, and run Text to Columns.
Enter in the sampling rate of your device, the angle of inclination, and the desired K value.


Forward Acceleration [g]
Time [s]
0
1
2
3
4
5
6
7
8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Acceleration [g]


Forward Acceleration [ft/s²]
Time [s]
0
1
2
3
4
5
6
7
8
9
10
15
10
5
0
-5
-10
-15
-20
Acceleration [ft/s²]