APPENDIX J. SAMPLE WIND FORCE CALCULATION

Wind Effect Analysis

Given: Vehicle velocity during breaking with no wind at 0.1-second intervals
Note: Refer to the following three spreadsheets throughout the process below.

1) Calculate stopping distance with no wind:
   a) Find deceleration (a1) (a1 is negative since it is a deceleration):
   $$a1 = \frac{\Delta v1}{\Delta t}$$
   b) Find the stopping force (F1) by Newton's Law (also negative):
   $$F1 = Mass * a1$$
   c) Calculate the stopping distance using the given velocity:
   $$d1_n = d1_{n-1} + v1_{n-1} * \Delta t$$

2) Determine the drag forces caused by head and tail winds:
   a) First, calculate the drag force with no wind:

   $$D_1 = \frac{C_D A_P \rho V^2}{2}$$

   $D_1 = DragForce(lb)$
   $C_D = DragCoefficient = .3$
   $A_P = FrontalArea(ft^2) = 25$
   $\rho = AirDensity(lb * s^2 / ft) = .00234$
   $V = Velocity(ft / s)$

   b) Add 14.7 ft/s (10 mph) of wind to the velocity for a head wind and subtract it for a tail wind.
   c) Calculate the drag forces with head and tail winds using the new velocities (D_+ and D_-).
   d) Since the drag force with no wind is already included in the calculation of step 1, only the difference in drag caused by wind is needed for the calculations:
   $$D_2 = D_1 - D_+$$
   $$D_3 = D_1 - D_-$$

3) Calculate the stopping distances as affected by wind:
   a) Add the drag forces by the wind from the stopping force without wind to get the total stopping forces in wind:
   $$F_2 = F_1 + D_2$$
   $$F_3 = F_1 + D_3$$
   b) Calculate the deceleration rates by dividing the mass of the vehicle from these new stopping forces
   $$a_2 = \frac{F_2}{m}$$
   $$a_3 = \frac{F_3}{m}$$
   c) Calculate the new velocity profiles using these decelerations:
   $$V2_n = V2_{n-1} + a2_n * \Delta t$$
   $$V3_n = V3_{n-1} + a3_n * \Delta t$$
   d) Using these velocities, calculate the stopping distance in the same way as in step 1-c.
   e) To find the differences in stopping distance due to wind, subtract the no wind stopping distance from each of the two distances:
   $$\Delta d_2 = d_2 - d_1$$
   $$\Delta d_3 = d_3 - d_1$$

4) These results can be further refined by additional iteration. To do this, substitute the results for V2 and V3 into the procedure at step 2-b, and repeat the remaining calculations. Continue to iterate this process until the stopping distance results converge. The results from this analysis converged after three iterations.

ABERDEEN PROVING GROUND
FRICTIONAL SKID RESISTANCE TESTING
ASTM E 274 - 90 / ASTM E 1337 - 90 (Reapproved 1996)

DATE OF TESTING :	11/24/98	PAGE:	1/2
TARGET SPEED :	40 MPH	TEST WHEEL :	LEFT

TEST SITE : RUNWAY 22 & 17
PAVEMENT TYPE : ASPHALT
TEST TYPE : DRY
COMMENTS : ASTM E 1337 - 90

TEST NUMBER	PEAK VALUE	TEST SPEED	AIR TEMP
1	93.4	40.0	60
2	91.0	39.2	60
3	91.7	40.8	59
4	91.0	39.6	59
5	89.2	39.5	59
6	93.1	40.4	59
7	92.7	40.3	59
8	91.7	40.3	59
9	91.0	40.3	59
10	91.1	40.3	59

TEST SITE : RUNWAY 22 & 17
PAVEMENT TYPE : ASPHALT
TEST TYPE : WET
COMMENTS : ASTM E 1337 - 90

TEST NUMBER	PEAK VALUE	TEST SPEED	AIR TEMP
1	87.5	39.7	59
2	87.9	39.1	59
3	88.9	38.5	59
4	86.8	39.5	59
5	84.3	41.5	59
6	87.6	40.4	59
7	87.2	40.0	59
8	86.7	39.7	59
9	86.8	39.9	59
10	87.4	40.1	59

TEST SITE : RUNWAY 17 (LARGE RADIUS)
PAVEMENT TYPE : JENNITE
TEST TYPE : WET
COMMENTS : ASTM E 1337 - 90

TEST NUMBER	PEAK VALUE	TEST SPEED	AIR TEMP
1	35.4	40.2	62
2	37.1	39.8	62
3	38.0	39.8	62
4	35.8	39.8	62
5	33.8	39.5	62
6	34.4	39.7	60
7	33.2	39.2	60
8	34.8	38.8	59
9	38.9	40.0	59
10	35.2	40.1	60

TEST SITE : RUNWAY 17 (SMALL RADIUS)
PAVEMENT TYPE : JENNITE
TEST TYPE : WET
COMMENTS : ASTM E 1337 - 90

TEST NUMBER	PEAK VALUE	TEST SPEED	AIR TEMP
1	43.1	40.7	60
2	41.9	40.8	60
3	39.2	40.9	60
4	40.9	40.8	60
5	38.0	40.6	60
6	45.8	40.1	60
7	40.1	39.9	60
8	41.1	39.8	60
9	44.4	39.6	60

Vehicle frontal area (ft^2): 25
Vehicle coefficient of drag: 0.3
Vehicle mass (slugs): 101.9
Wind velocity (mph): 10

	Delta1	-0.77	2nd iter	-0.78	3rd iter
	Delta2	0.58	2nd iter	0.58	3rd iter

v1 (mph)	y1 (lbs)	a1 (ft/s^2)	F1 (lbf)	Drag(nom) (lbf)
61.00	89.06	0.00	0.00	70.55
60.88	88.49	-1.78	-180.95	70.27
59.79	87.80	-15.88	-1629.25	67.78
59.73	86.69	-31.98	-3256.83	62.94
57.81	84.69	-31.98	-3256.65	58.23
56.44	81.50	-38.08	-3880.45	52.89
52.76	77.59	-33.74	-3437.60	48.33
50.49	74.22	-26.83	-2713.60	44.93
48.68	71.55	-26.83	-2713.65	61.95
46.88	68.88	-28.41	-2894.90	58.28
44.93	66.05	-28.41	-3497.60	34.47
42.84	62.88	-33.74	-3818.55	30.68
40.22	60.13	-38.51	-2894.90	27.80
38.28	56.28	-28.41	-3075.70	24.90
38.24	53.27	-30.18	-3818.55	21.69
33.62	49.72	-26.51	-3437.60	18.84
31.52	48.34	-33.74	-3256.65	16.34
29.35	43.15	-26.83	-2713.85	14.38
27.54	40.48	-26.83	-2713.65	11.97
25.12	34.63	-35.5	-3818.55	10.09
23.07	33.91	-30.18	-3075.85	8.18
20.78	30.54	-33.74	-3437.60	6.82
18.98	27.88	-28.83	-2713.95	5.34
18.79	24.68	-31.98	-3256.65	4.19
14.86	21.84	-28.41	-2894.75	3.11
12.60	18.82	-30.18	-3075.85	2.14
10.53	15.62	-31.98	-3256.65	1.32
8.53	12.25	-33.74	-3437.60	0.75
6.28	9.23	-30.18	-3075.85	0.32
4.11	6.04	-31.98	-3256.65	0.07
1.93	2.84	-31.98	-3256.65	0.00
-0.48	-0.71	-35.51	-3618.65	0.00

1st Iteration

Wind Vel(-) (mph)	Drag(-) (lbf)		Wind Vel(+) (mph)	Drag(+) (lbf)
51.00	49.31		71.00	95.56
50.88	49.08		70.88	95.25
49.79	47.00		69.79	92.85
47.61	42.09		67.61	88.89
45.44	39.15		65.44	81.20
42.78	34.71		62.78	74.74
40.49	31.36		60.49	68.38
38.68	28.36		58.68	65.28
36.68	25.77		56.88	61.31
34.93	23.14		54.83	57.22
32.84	20.20		52.84	52.64
30.22	17.32		50.22	47.83
28.29	15.17		48.29	44.22
26.24	13.05		46.24	40.64
23.82	10.78		43.82	36.41
21.52	8.79		41.52	32.70
19.35	7.10		39.35	28.38
17.54	5.83		37.54	28.72
15.12	4.34		35.12	23.39
13.07	3.24		33.07	20.74
10.76	2.20		30.78	17.96
8.08	1.52		28.98	15.81
6.79	0.87		26.79	13.61
4.68	0.45		24.68	11.72
2.80	0.15		22.60	9.86
0.69	0.01		20.83	8.07
-1.67	-0.06		18.33	6.37
-3.72	-0.28		16.28	5.63
-5.89	-0.69		14.11	3.77
-8.07	-1.23		11.93	2.70
-10.48	-2.09		9.52	1.72

Drag D2 (lbf)	Drag D3 (lbf)
-25.03	21.24
-24.88	21.18
-24.57	20.78
-23.75	19.95
-22.92	19.13
-21.91	18.12
-21.04	17.25
-20.36	16.58
-19.67	15.88
-18.91	15.14
-18.07	14.27
-17.15	13.38
-16.42	12.62
-15.84	11.85
-14.77	10.98
-13.95	10.06
-13.03	9.23
-12.34	8.55
-11.42	7.63
-10.85	6.85
-9.77	5.98
-9.09	5.30
-8.20	4.47
-7.59	3.74
-6.76	2.96
-5.93	2.13
-5.08	1.37
-4.28	1.01
-3.45	0.38
-2.63	1.30
-1.71	2.09

F2 (lbf)	F3 (lbf)	a2 (ft/s^2)	a3 (ft/s^2)	v2 (fps)	v3 (fps)	d1 (ft)	d2 (ft)	d3 (ft)
-25.03	21.24	0.00	0.00	89.06	89.06	0.00	0.00	0.00
-205.99	-159.76	-2.02	-1.57	89.46	88.50	8.97	8.97	8.97
-1652.82	-1807.47	-16.22	-15.77	87.84	87.93	17.92	17.91	17.82
-3260.55	-3238.85	-32.19	-31.76	84.62	84.75	26.70	28.70	28.71
-3278.57	-3237.52	-32.16	-31.77	81.40	81.57	35.17	35.16	35.18
-4002.38	-3902.33	-38.28	-38.88	77.47	77.88	43.32	43.30	43.34
-3468.64	-3420.85	-33.94	-33.57	74.39	74.33	51.08	51.04	51.11
-2734.18	-2897.24	-24.83	-28.47	71.39	71.58	58.50	59.45	56.54
-2733.62	-2984.07	-26.83	-28.48	64.71	68.03	65.09	65.59	65.71
-2915.84	-2878.78	-28.60	-28.28	65.85	66.24	72.55	72.48	72.81
-3455.67	-3423.33	-38.91	-33.59	62.48	62.85	79.15	79.06	79.23
-3835.70	-3805.19	-35.68	-35.38	58.89	59.31	85.42	85.29	85.52
-2911.32	-2852.28	-28.57	-28.29	58.03	55.48	91.33	91.13	91.45
-3291.34	-3093.55	-30.34	-30.07	53.00	53.47	86.96	96.79	97.10
-3633.27	-3887.62	-35.44	-35.40	49.44	49.09	102.29	102.09	102.44
-3451.45	-3427.54	-33.87	-33.64	46.05	46.57	107.28	107.03	107.44
-3269.68	-3247.41	-32.09	-31.87	42.84	43.38	111.89	111.83	112.10
-2726.29	-2705.40	-28.75	-28.55	40.10	40.73	116.21	115.62	116.43
-3629.97	-3610.92	-35.62	-35.44	38.69	37.18	120.28	119.93	120.91
-3086.46	-3069.00	-30.20	-30.12	33.57	34.17	123.95	123.59	124.22
-3447.37	-3431.62	-33.83	-33.86	30.19	30.80	127.34	126.95	127.84
-2723.01	-2708.65	-26.72	-26.58	27.52	28.15	130.40	129.97	130.72
-3264.81	-3252.18	-32.04	-31.92	24.31	24.96	133.13	132.72	133.54
-2902.28	-2891.01	-28.48	-28.37	21.47	22.12	135.65	135.15	138.03
-3082.60	-3072.88	-30.25	-30.16	18.44	19.70	137.84	137.30	138.24
-3287.58	-3254.51	-32.02	-31.94	15.24	15.81	139.72	139.14	140.15
-3142.85	-3490.23	-33.76	-33.72	11.86	12.54	141.28	140.67	141.75
-3080.13	-3074.84	-30.23	-30.18	8.84	9.52	142.50	141.85	143.00
-3280.10	-3255.67	-31.95	-31.95	5.84	6.32	143.43	142.74	143.95
-3259.23	-3255.34	-31.99	-31.96	2.44	3.13	144.03	143.30	144.58
-3520.26	-3618.46	-35.53	-35.49	-1.11	-0.42	144.32	143.55	144.80

d Iteration

new V+ (ft/s)	new D+ (lb)
104.36	95.57
104.16	95.20
102.54	92.26
99.32	86.58
96.10	81.04
92.17	74.55
88.78	69.16
86.09	65.04
83.41	61.05
80.55	56.84
77.16	52.25
73.59	47.53
70.74	43.91
67.70	40.22
64.14	36.10
60.75	32.39
57.54	29.06
54.87	26.42
51.31	23.10
48.28	20.45
44.89	17.69
42.22	15.64
39.02	13.36
36.17	11.48
33.15	9.64
29.94	7.87
26.57	6.19
23.54	4.88
20.34	3.63
17.15	2.58
13.58	1.62

new V- (ft/s)	new D- (lb)
74.96	49.31
74.80	49.10
73.23	47.05
70.05	43.06
66.87	39.24
62.98	34.81
59.63	31.20
56.98	28.49
54.33	25.80
51.51	23.28
48.15	20.34
44.61	17.46
41.76	15.32
38.77	13.18
35.23	10.89
31.87	8.91
28.68	7.22
26.03	5.94
22.48	4.44
19.47	3.33
16.10	2.28
13.44	1.59
10.25	0.92
7.42	0.48
4.40	0.17
1.21	0.01
-2.17	-0.04
-5.18	-0.24
-8.38	-0.62
-11.57	-1.18
-15.12	-2.01

new D2 (lb)	new D3 (lb)
-25.02	21.24
-24.93	21.17
-24.47	20.73
-23.61	19.88
-22.75	19.04
-21.72	18.02
-20.82	17.14
-20.11	16.44
-19.41	15.74
-18.66	15.00
-17.77	14.13
-16.85	13.21
-16.11	12.48
-15.33	11.71
-14.41	10.80
-13.54	9.93
-12.72	9.12
-12.04	8.44
-11.13	7.53
-10.36	6.77
-9.50	5.91
-8.82	5.23
-8.01	4.42
-7.30	3.70
-6.53	2.94
-5.73	2.13
-4.88	1.36
-4.12	0.98
-3.31	0.94
-2.51	1.25
-1.62	2.01

new F2 (lb)	new F3 (lb)	new a2 (ft/s^2)	new a3 (ft/s^2)	new v2 (ft/s)	new v3 (ft/s)	new d2 (ft)	new d3 (ft)
-25.0	21.2	0.00	0	88.66	89.66	0	0
-205.9	-159.8	-2.02	-1.57	89.46	89.50	8.97	8.97
-1652.7	-1607.5	-16.22	-15.78	87.84	87.93	17.91	17.82
-3280.4	-3236.9	-32.19	-31.77	84.62	84.75	26.70	26.71
-3279.4	-3237.6	-32.18	-31.77	81.40	81.57	35.16	35.18
-4002.2	-3962.4	-39.28	-38.89	77.47	77.88	43.30	43.34
-3458.4	-3420.5	-33.94	-33.57	74.08	74.33	51.04	51.11
-2733.9	-2697.4	-26.83	-26.47	71.39	71.88	58.45	58.54
-2733.4	-2898.2	-26.82	-28.48	68.71	69.03	65.59	65.71
-2913.6	-2879.9	-28.59	-28.28	65.85	66.21	72.46	72.61
-3455.4	-3423.5	-33.91	-33.60	62.46	62.85	79.05	79.23
-3635.4	-3605.3	-35.68	-35.38	58.89	59.31	85.29	85.52
-2911.0	-2882.4	-28.57	-28.29	56.04	56.48	91.18	91.45
-3091.0	-3064.0	-30.33	-30.07	53.00	53.47	96.79	97.10
-3633.0	-3607.8	-35.85	-35.40	49.44	49.93	102.09	102.44
-3451.1	-3427.7	-33.87	-33.64	48.05	48.57	107.03	107.44
-3269.4	-3247.5	-32.08	-31.87	42.84	43.38	111.64	112.09
-2726.0	-2705.5	-26.75	-26.55	40.17	40.73	115.92	116.43
-3629.7	-3611.0	-35.62	-35.44	36.61	37.18	119.94	120.50
-3086.2	-3069.1	-30.28	-30.12	33.58	34.17	123.60	124.22
-3447.1	-3431.7	-33.83	-33.68	30.19	30.80	126.98	127.64
-2722.8	-2708.7	-26.72	-26.58	27.52	28.14	129.98	130.72
-3264.7	-3252.2	-32.04	-31.82	24.32	24.95	132.73	133.53
-2902.0	-2891.0	-28.48	-28.37	21.47	22.12	135.16	136.03
-3082.4	-3072.9	-30.25	-30.16	18.45	19.10	137.31	138.24
-3262.4	-3254.5	-32.02	-31.94	15.24	15.91	139.15	140.15
-3442.5	-3436.2	-33.78	-33.72	11.87	12.53	140.68	141.74
-3080.0	-3074.9	-30.23	-30.18	8.84	9.52	141.86	143.00
-3260.0	-3255.7	-31.99	-31.95	5.64	6.32	142.75	143.95
-3259.2	-3255.4	-31.98	-31.95	2.45	3.13	143.31	144.58
-3620.2	-3616.5	-35.53	-35.49	-1.11	-0.42	143.56	144.89

-0.76   0.58

0.58