17

Load Transfer – Open Wheel
Inertial and Aerodynamic Loading
(*It's just not this simple!)*

Important Note: **As is the case with all chapters using the Wan31 model, the information in this chapter is cumulative and should not be omitted**.

Chapter 17 introduces the effects of aerodynamic loads while working with an open wheel road course chassis. The subject of aerodynamics, like everything else, is immense, and, as such, will only be covered in the briefest of manners in Book One. Book Two covers aerodynamics and aero mapping in considerably more detail, some three hundred pages, but even Book Two only scratches the surface. In both cases, we are only looking at how teams develop and use aero maps for the basic chassis as delivered from the builder. Neither book attempts to explain the science of aerodynamic design. This is not to say that race engineers do not need to acquire a considerable amount of aero knowledge because they most certainly do. However, there is simply not enough space in this particular set of books to include everything. As discussed in Chapter 1, if the reader is not an aerodynamicist, he/she will need to begin their aero studies by reading Dr. Joseph Katz's book, "Race Car Aerodynamics – Designing for Speed", and Pi's aerodynamic application notes.

An Ever So Brief Introduction to Aero Maps

No matter what type of car a team is racing, they need to develop a comprehensive series of aero maps to help develop their static set up. Aero maps are developed from two primary sources: wind tunnel aero mapping and on track aero mapping. Additionally, wind tunnel mapping is divided into scale model mapping and full scale mapping while on track mapping is divided into straight line mapping and on circuit mapping. In order to be of use to the race engineer, aero maps from all of these sources need to have a high degree of correlation. **No** successful team would rely on wind tunnel data only.

Aero Maps: Normally in tabular form, these maps are used to show the changes in aero load (lift), drag, percentage of total aero load seen at the front and Lift/Drag ratio (L/D). The **base** aero map illustrates the changes in load for particular combinations of front and rear ride heights. Once a base map is developed and validated for equal left to right side ride heights, a second ride height versus downforce map is developed which includes roll increments, asymmetrical left to right side ride heights and yaw increments. This second map is considerably more time consuming to develop but is essential when calculating corner loads during lateral acceleration. From this point, teams will develop a series of **base** best fit equations that can be run with their set up simulation programs (see best fit equations in Chapter 20).

Secondary maps are then developed that show the aero changes from base setting of each individual aero related component (wings, flaps, turning vanes, strakes, fences, fillets, Gurney lips, end plates, diffuser, etc.). A series of factors are then attached to the base map that will allow the race engineer to look at how changing individual components from their base setting affects the total aero load, total drag and aero pressure center positioning. For a modern aero chassis, this can add up to a considerable number of secondary factors - a good sized algorithm.

Unlike the very simple maps we will use while working with Wan31A, the aero pressure center during roll is often laterally offset from the longitudinal centerline of the chassis, particularly with chassis running tunnels (underwings). For open wheel chassis running on oval tracks, asymmetric aero loads are

often built into the set up particularly at the front aero components. Book Two devotes four chapters to the development of open wheel and closed wheel aero maps.
Downforce, Drag and Pressure Center: The three primary elements of aerodynamic performance.

- **Downforce** is the normal load seen at the contact patches as the result of aerodynamic forces. An increase in downforce produces a potential increase in lateral and longitudinal acceleration force.

    - **Downforce** varies with airspeed squared with the base wind tunnel pressure generally given @ 150 mph. If the aero map shows a downforce of 1500 lb. @ 150 mph, then @ 100 mph it would produce 667 lb. or 44% of the base load - $(100)^2/(150)^2 = 0.444$. *It's not this linear*.

- **Pressure Center:** The distribution of the aero loads at the four corners is determined by the co-ordinates of the pressure center. If the aero center of pressure is not at the same point as the CG, the aero load will result in a change in chassis balance. The aero balance is given as the percentage of aerodynamic downforce seen at the front. *It's not that simple*.

    - The aero pressure center, for practical purposes, is often shown as resolved into the plane of the road – Figure 17-1. The actual height of the pressure center is quite difficult to calculate. Formulas such as those found on the last two pages of Chapter 13 are used to calculate the pressure center height of each individual component of aerodynamic downforce. Ideally the pressure center should not shift dramatically as the chassis pitches, rolls and yaws. Ground effect chassis are hyper sensitive to ride height changes, particularly flat bottom chassis with rear diffusers. Chassis running underwings are slightly less sensitive because the venturi of the tunnel is normally quite close to the CG. As a result, when the chassis pitches, it will tend to rotate about the venturi.

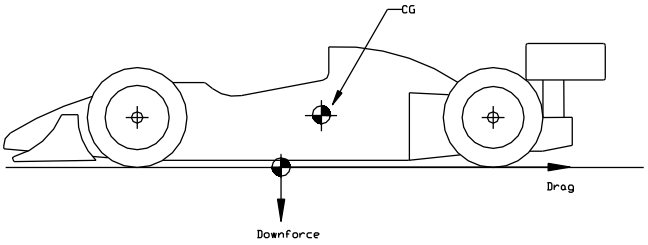


Figure 17-1

- **Drag**, the black sheep of aerodynamics, increases the chassis' resistance to forward movement (forward acceleration). As drag goes up, the engine torque must increase by the same amount in order to maintain a constant speed. On an aero chassis, drag is a primary factor controlling the rate of forward acceleration and the chassis' terminal speed, as well as the rate of braking, particularly from a high rate of speed.

- The **Lift/Drag** (L/D) ratio shows the relationship between the amount of downforce compared to the amount of drag. A chassis with 1500 lb. of downforce and a L/D ratio of 3.14 will have 478 lb. of drag – 1500/3.14. If the L/D ratio can be increased to 3.52, the drag will be reduced to 426 lb. – 1500/3.52. The higher the L/D ratio, the lower the drag component.

Note: the L/D ratio is **not** the same as the coefficient of drag (Cd) which is a non-dimensional number. The lower the Cd, the lower the drag component.

- Drag, like downforce, varies with airspeed squared. If the aero map shows a drag force of 478 lb. @ 150 mph, then @ 100 mph the drag force would be 212 lb. or 44% of the base load - $(100)^2/(150)^2 = 0.444$. *It's not this linear*

- Chassis running on larger oval tracks are generally trimmed out to the lowest downforce level with which the driver can cope in order to decrease drag and increase top speed. In this case, available engine power rather than available grip restricts the speed through the corners. On a road course

with small radius corners where speed gained through the corners produces lower lap times than higher ultimate speed on the straight bits, a much higher aero component is used.

Wan31A Aerodynamic Maps

As previously discussed, a complete set of aero maps can involve a large number of component maps (as many as one hundred) which all need to be tied to the base ride height versus downforce map. Each time a component is changed, for example the angle of incidence of the front wing flaps, the total aero load will change together with the pressure center co-ordinates and the amount of aero drag.

Basic Maps

For the purposes of Book One, we will only use two **very** simple maps – "**Low** downforce road course" and "**High** downforce road course".

The base maps show:

- Map number (#)
- Front and Rear Ride Heights
- Downforce for various combinations of front and rear ride heights
- Percentage of aero load seen at the front for various combinations of front and rear ride heights
- Drag for various combinations of front and rear ride heights
- L/D ratio for various combinations of front and rear ride heights

All base data was recorded at 150 mph, 59º F and 14.7 psi of barometric pressure. For the purposes of Book One, we are going to ignore the fact that a change in air temperature and/or barometric pressure will have a considerable effect on downforce, drag and the center of pressure location.

For the purpose of Chapters 17 and 19, we will use two base ride heights versus downforce maps. The first map, as shown in Figure 17-2, is our low down force aero map where the chassis is trimmed out for less downforce but higher top speed. The second map, as shown in Figure 17-3, is our high down force map where the chassis will see a higher level of down force but lower top speeds.

Note: For simplicity sake, we have kept the same percentage of front down force for both maps. This, in fact, would be very difficult to accomplish. We have also maintained the same L/D ratio, which, when working with an actual chassis, would virtually never happen.

Aero drag, like rolling drag (tire, bearing etc.), engine friction and drive train friction restricts the rate of chassis acceleration and the chassis' ultimate speed (terminal speed). Aero drag almost always holds the highest component of total drag. With an aero driven chassis, drag is far from insignificant in reference to the chassis' overall performance level. A **basic** formula for calculating the amount of hp needed to overcome the aero drag = (drag*speed)/375. A drag versus hp calculator is included on the **Aero** worksheet. *It's not this simple*.

<u>Drag vs hp</u>:

- 974 lb. of drag at 130 mph requires 338 hp while at 160 mph, it requires 416 hp. At 80 mph, 974 lb. of drag requires 208 hp.

- 542 lb. of drag at 130 mph requires 188 hp while at 160 mph it requires 231 hp. At 80 mph, 542 lb. of drag requires 116hp.

Base Ride vs Downforce (Lift) Aero Map - Open Wheel Chassis

Low Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Bressure

Map #	Front Ride	Rear Ride	Downforce	% Front	Drag	L/D
1-1	0.250	0.250	1689	39.45%	538	3.14
1-2	0.250	0.375	1700	39.66%	540	3.15
1-3	0.250	0.500	1723	40.14%	542	3.18
1-4	0.250	0.750	1712	40.63%	538	3.18
2-1	0.375	0.250	1690	38.75%	545	3.10
2-2	0.375	0.375	1700	39.14%	543	3.13
2-3	0.375	0.500	1700	39.53%	538	3.16
2-4	0.375	0.750	1678	39.90%	536	3.13
2-5	0.375	1.000	1644	40.26%	535	3.07
3-1	0.500	0.250	1695	38.38%	542	3.13
3-2	0.500	0.375	1683	38.60%	540	3.12
3-3	0.500	0.500	1672	38.75%	543	3.08
3-4	0.500	0.750	1644	39.16%	537	3.06
3-5	0.500	1.000	1610	39.54%	535	3.01
3-6	0.500	1.500	1542	40.49%	530	2.91
4-1	0.750	0.250	1678	37.29%	541	3.10
4-2	0.750	0.375	1649	37.41%	543	3.04
4-3	0.750	0.500	1632	37.46%	544	3.00
4-4	0.750	0.750	1570	37.72%	540	2.91
4-5	0.750	1.000	1542	38.14%	535	2.88
4-6	0.750	1.500	1474	39.04%	526	2.80
4-7	0.750	2.000	1428	40.16%	523	2.73
5-2	1.000	0.375	1604	36.23%	542	2.96
5-3	1.000	0.500	1564	36.29%	541	2.89
5-4	1.000	0.750	1519	36.49%	539	2.82
5-5	1.000	1.000	1485	36.75%	540	2.75
5-6	1.000	1.500	1417	37.74%	529	2.68
5-7	1.000	2.000	1372	38.78%	526	2.61
6-3	1.500	0.500	1462	34.15%	540	2.71
6-4	1.500	0.750	1411	34.29%	541	2.61
6-5	1.500	1.000	1372	34.56%	538	2.55
6-6	1.500	1.500	1309	35.25%	532	2.46
6-7	1.500	2.000	1270	36.34%	525	2.42
7-4	2.000	0.750	1304	32.40%	539	2.42
7-5	2.000	1.000	1264	32.52%	538	2.35
7-6	2.000	1.500	1213	33.22%	532	2.28
7-7	2.000	2.000	1179	34.02%	529	2.23

Figure 17-2

Base Ride vs Downforce (Lift) Aero Map - Open Wheel Chassis

High Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

Map #	Front Ride	Rear Ride	Downforce	% Front	Drag	L/D
1-1	0.250	0.250	2484	39.45%	791	3.14
1-2	0.250	0.375	2501	39.66%	794	3.15
1-3	0.250	0.500	2534	40.14%	797	3.18
1-4	0.250	0.750	2517	40.63%	792	3.18
2-1	0.375	0.250	2486	38.75%	801	3.10
2-2	0.375	0.375	2501	39.14%	799	3.13
2-3	0.375	0.500	2501	39.53%	791	3.16
2-4	0.375	0.750	2467	39.90%	788	3.13
2-5	0.375	1.000	2417	40.26%	787	3.07
3-1	0.500	0.250	2493	38.38%	794	3.13
3-2	0.500	0.375	2475	38.60%	793	3.12
3-3	0.500	0.500	2459	38.75%	798	3.08
3-4	0.500	0.750	2417	39.16%	790	3.06
3-5	0.500	1.000	2367	39.54%	786	3.01
3-6	0.500	1.500	2267	40.49%	779	2.91
4-1	0.750	0.250	2467	37.29%	796	3.10
4-2	0.750	0.375	2425	37.41%	798	3.04
4-3	0.750	0.500	2400	37.46%	800	3.00
4-4	0.750	0.750	2309	37.72%	793	2.91
4-5	0.750	1.000	2267	38.14%	787	2.88
4-6	0.750	1.500	2167	39.04%	774	2.80
4-7	0.750	2.000	2100	40.16%	769	2.73
5-1	1.000	0.375	2359	36.23%	797	2.96
5-2	1.000	0.500	2300	36.29%	796	2.89
5-3	1.000	0.750	2234	36.49%	792	2.82
5-4	1.000	1.000	2184	36.75%	794	2.75
5-5	1.000	1.500	2084	37.74%	778	2.68
5-6	1.000	2.000	2017	38.78%	773	2.61
6-1	1.500	0.500	2150	34.15%	794	2.71
6-2	1.500	0.750	2075	34.29%	795	2.61
6-3	1.500	1.000	2017	34.56%	791	2.55
6-4	1.500	1.500	1925	35.25%	783	2.46
6-5	1.500	2.000	1867	36.34%	772	2.42
7-1	2.000	0.750	1917	32.40%	792	2.42
7-2	2.000	1.000	1859	32.52%	791	2.35
7-3	2.000	1.500	1784	33.22%	782	2.28
7-4	2.000	2.000	1734	34.02%	777	2.23

Figure 17-3

The table in Figure 17-4 shows the required hp to overcome the aero drag . As is so often stated, “nothing is for free” and the balance between downforce and aero drag is no exception. Teams are always trying to find the right balance between downforce for the twisty bits and the reduction of drag limiting the top speed on the straight bits. Drag at the various speed iterations is an important component in calculating theoretical rates of acceleration.

With 1400 lb. of drag at 200 mph, 747 hp is required to overcome just the aero drag.

Drag vs hp

		mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph	mph
Drag	Required	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**
974	hp =	78	104	130	156	182	208	234	260	286	312	338	364	390	416	442	468	493	519
954	hp =	76	102	127	153	178	204	229	254	280	305	331	356	382	407	432	458	483	509
934	hp =	75	100	125	149	174	199	224	249	274	299	324	349	374	399	423	448	473	498
914	hp =	73	97	122	146	171	195	219	244	268	292	317	341	366	390	414	439	463	487
894	hp =	72	95	119	143	167	191	215	238	262	286	310	334	358	381	405	429	453	477
874	hp =	70	93	117	140	163	186	210	233	256	280	303	326	350	373	396	420	443	466
854	hp =	68	91	114	137	159	182	205	228	251	273	296	319	342	364	387	410	433	455
834	hp =	67	89	111	133	156	178	200	222	245	267	289	311	334	356	378	400	423	445
814	hp =	65	87	109	130	152	174	195	217	239	260	282	304	326	347	369	391	412	434
794	hp =	64	85	106	127	148	169	191	212	233	254	275	296	318	339	360	381	402	423
774	hp =	62	83	103	124	144	165	186	206	227	248	268	289	310	330	351	372	392	413
754	hp =	60	80	101	121	141	161	181	201	221	241	261	281	302	322	342	362	382	402
734	hp =	59	78	98	117	137	157	176	196	215	235	254	274	294	313	333	352	372	391
714	hp =	57	76	95	114	133	152	171	190	209	228	248	267	286	305	324	343	362	381
694	hp =	56	74	93	111	130	148	167	185	204	222	241	259	278	296	315	333	352	370
674	hp =	54	72	90	108	126	144	162	180	198	216	234	252	270	288	306	324	341	359
654	hp =	52	70	87	105	122	140	157	174	192	209	227	244	262	279	296	314	331	349
634	hp =	51	68	85	101	118	135	152	169	186	203	220	237	254	271	287	304	321	338
614	hp =	49	65	82	98	115	131	147	164	180	196	213	229	246	262	278	295	311	327
594	hp =	48	63	79	95	111	127	143	158	174	190	206	222	238	253	269	285	301	317
574	hp =	46	61	77	92	107	122	138	153	168	184	199	214	230	245	260	276	291	306
554	hp =	44	59	74	89	103	118	133	148	163	177	192	207	222	236	251	266	281	295
534	hp =	43	57	71	85	100	114	128	142	157	171	185	199	214	228	242	256	271	285

Figure 17-4

Figures 17-5 and 17-6 show the downforce and drag components at various speeds for the base **low** downforce map while Figures 17-7 and 17-8 show the downforce and drag components at various speeds for the base **high** downforce map. Base values at 150 mph are from the aero maps in 17-2 & 17-3. All other downforce values are computed using $\text{downforce}_2 = \text{downforce}_1 (\text{velocity}_2/\text{velocity}_1)^2$.

Aero Balance vs mph

Base Ride vs Downforce (Lift) Aero Map - Open Wheel Chassis

Low Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

		Speed =	150 mph	125 mph	100 mph	75 mph	50 mph	175 mph	200 mph
Map #	Front Ride	Rear Ride	Downforce	Downforce	Downforce	Downforce	Downforce	Downforce	Downforce
			150 mph	125 mph	100 mph	75 mph	50 mph	175 mph	200 mph
1-1	0.250	0.250	1689	1173	751	422	188	2299	3003
1-2	0.250	0.375	1700	1181	756	425	189	2314	3023
1-3	0.250	0.500	1723	1197	766	431	191	2345	3063
1-4	0.250	0.750	1712	1189	761	428	190	2330	3043
2-1	0.375	0.250	1690	1174	751	423	188	2301	3005
2-2	0.375	0.375	1700	1181	756	425	189	2314	3023
2-3	0.375	0.500	1700	1181	756	425	189	2314	3023
2-4	0.375	0.750	1678	1165	746	419	186	2283	2983
2-5	0.375	1.000	1644	1141	731	411	183	2237	2922
3-1	0.500	0.250	1695	1177	753	424	188	2307	3014
3-2	0.500	0.375	1683	1169	748	421	187	2291	2993
3-3	0.500	0.500	1672	1161	743	418	186	2276	2972
3-4	0.500	0.750	1644	1141	731	411	183	2237	2922
3-5	0.500	1.000	1610	1118	715	402	179	2191	2862
3-6	0.500	1.500	1542	1071	685	385	171	2098	2741
4-1	0.750	0.250	1678	1165	746	419	186	2283	2983
4-2	0.750	0.375	1649	1145	733	412	183	2245	2932
4-3	0.750	0.500	1632	1134	725	408	181	2222	2902
4-4	0.750	0.750	1570	1090	698	392	174	2137	2791
4-5	0.750	1.000	1542	1071	685	385	171	2098	2741
4-6	0.750	1.500	1474	1023	655	368	164	2006	2620
4-7	0.750	2.000	1428	992	635	357	159	1944	2539
5-1	1.000	0.375	1604	1114	713	401	178	2183	2852
5-2	1.000	0.500	1564	1086	695	391	174	2129	2781
5-3	1.000	0.750	1519	1055	675	380	169	2067	2700
5-4	1.000	1.000	1485	1031	660	371	165	2021	2640
5-5	1.000	1.500	1417	984	630	354	157	1929	2519
5-6	1.000	2.000	1372	953	610	343	152	1867	2438
6-1	1.500	0.500	1462	1015	650	366	162	1990	2600
6-2	1.500	0.750	1411	980	627	353	157	1921	2508
6-3	1.500	1.000	1372	953	610	343	152	1867	2438
6-4	1.500	1.500	1309	909	582	327	145	1782	2328
6-5	1.500	2.000	1270	882	564	317	141	1728	2257
7-1	2.000	0.750	1304	905	579	326	145	1774	2318
7-2	2.000	1.000	1264	878	562	316	140	1720	2247
7-3	2.000	1.500	1213	842	539	303	135	1651	2156
7-4	2.000	2.000	1179	819	524	295	131	1605	2096

Figure 17-5

Drag vs mph

Base Ride vs Drag Aero Map - Open Wheel Chassis

Low Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

Map #	Front Ride	Rear Ride	L/D Ratio	Drag 150 mph	Drag 125 mph	Drag 100 mph	Drag 75 mph	Drag 50 mph	Drag 175 mph	Drag 200 mph
1-1	0.250	0.250	3.14	538	374	239	134	60	732	956
1-2	0.250	0.375	3.15	540	375	240	135	60	735	960
1-3	0.250	0.500	3.18	542	376	241	135	60	737	963
1-4	0.250	0.750	3.18	538	374	239	135	60	733	957
2-1	0.375	0.250	3.10	545	379	242	136	61	742	969
2-2	0.375	0.375	3.13	543	377	241	136	60	739	966
2-3	0.375	0.500	3.16	538	374	239	135	60	732	957
2-4	0.375	0.750	3.13	536	372	238	134	60	730	953
2-5	0.375	1.000	3.07	535	372	238	134	59	729	952
3-1	0.500	0.250	3.13	542	376	241	135	60	737	963
3-2	0.500	0.375	3.12	540	375	240	135	60	734	959
3-3	0.500	0.500	3.08	543	377	241	136	60	739	965
3-4	0.500	0.750	3.06	537	373	239	134	60	731	955
3-5	0.500	1.000	3.01	535	371	238	134	59	728	951
3-6	0.500	1.500	2.91	530	368	235	132	59	721	942
4-1	0.750	0.250	3.10	541	376	241	135	60	737	962
4-2	0.750	0.375	3.04	543	377	241	136	60	738	965
4-3	0.750	0.500	3.00	544	378	242	136	60	741	967
4-4	0.750	0.750	2.91	540	375	240	135	60	734	959
4-5	0.750	1.000	2.88	535	372	238	134	59	729	952
4-6	0.750	1.500	2.80	526	365	234	132	58	716	936
4-7	0.750	2.000	2.73	523	363	233	131	58	712	930
5-1	1.000	0.375	2.96	542	376	241	135	60	738	963
5-2	1.000	0.500	2.89	541	376	241	135	60	737	962
5-3	1.000	0.750	2.82	539	374	239	135	60	733	958
5-4	1.000	1.000	2.75	540	375	240	135	60	735	960
5-5	1.000	1.500	2.68	529	367	235	132	59	720	940
5-6	1.000	2.000	2.61	526	365	234	131	58	715	934
6-1	1.500	0.500	2.71	540	375	240	135	60	734	959
6-2	1.500	0.750	2.61	541	375	240	135	60	736	961
6-3	1.500	1.000	2.55	538	374	239	134	60	732	956
6-4	1.500	1.500	2.46	532	370	237	133	59	724	946
6-5	1.500	2.000	2.42	525	364	233	131	58	714	933
7-1	2.000	0.750	2.42	539	374	239	135	60	733	958
7-2	2.000	1.000	2.35	538	373	239	134	60	732	956
7-3	2.000	1.500	2.28	532	369	236	133	59	724	946
7-4	2.000	2.000	2.23	529	367	235	132	59	720	940

Figure 17-6

Aero Balance vs mph

Base Ride vs Downforce (Lift) Aero Map - Open Wheel Chassis

High Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

		Speed =	150 mph	125 mph	100 mph	75 mph	50 mph	175 mph	200 mph
Map #	**Front Ride**	**Rear Ride**	Downforce	Downforce	Downforce	Downforce	Downforce	Downforce	Downforce
			150 mph	125 mph	100 mph	75 mph	50 mph	175 mph	200 mph
1-1	0.250	0.250	2484	1725	1104	621	276	3381	4416
1-2	0.250	0.375	2501	1736	1111	625	278	3403	4445
1-3	0.250	0.500	2534	1760	1126	633	282	3449	4505
1-4	0.250	0.750	2517	1748	1119	629	280	3426	4475
2-1	0.375	0.250	2486	1726	1105	622	276	3384	4420
2-2	0.375	0.375	2501	1736	1111	625	278	3403	4445
2-3	0.375	0.500	2501	1736	1111	625	278	3403	4445
2-4	0.375	0.750	2467	1713	1097	617	274	3358	4386
2-5	0.375	1.000	2417	1679	1074	604	269	3290	4297
3-1	0.500	0.250	2493	1731	1108	623	277	3393	4432
3-2	0.500	0.375	2475	1719	1100	619	275	3369	4401
3-3	0.500	0.500	2459	1708	1093	615	273	3347	4371
3-4	0.500	0.750	2417	1679	1074	604	269	3290	4297
3-5	0.500	1.000	2367	1644	1052	592	263	3222	4208
3-6	0.500	1.500	2267	1574	1008	567	252	3086	4030
4-1	0.750	0.250	2467	1713	1097	617	274	3358	4386
4-2	0.750	0.375	2425	1684	1078	606	269	3301	4312
4-3	0.750	0.500	2400	1667	1067	600	267	3267	4268
4-4	0.750	0.750	2309	1603	1026	577	257	3143	4105
4-5	0.750	1.000	2267	1574	1008	567	252	3086	4030
4-6	0.750	1.500	2167	1505	963	542	241	2950	3853
4-7	0.750	2.000	2100	1459	934	525	233	2859	3734
5-1	1.000	0.375	2359	1638	1048	590	262	3211	4193
5-2	1.000	0.500	2300	1598	1022	575	256	3131	4090
5-3	1.000	0.750	2234	1551	993	558	248	3040	3971
5-4	1.000	1.000	2184	1517	971	546	243	2972	3882
5-5	1.000	1.500	2084	1447	926	521	232	2836	3704
5-6	1.000	2.000	2017	1401	896	504	224	2745	3586
6-1	1.500	0.500	2150	1493	956	538	239	2927	3823
6-2	1.500	0.750	2075	1441	922	519	231	2824	3689
6-3	1.500	1.000	2017	1401	896	504	224	2745	3586
6-4	1.500	1.500	1925	1337	856	481	214	2621	3423
6-5	1.500	2.000	1867	1297	830	467	207	2541	3319
7-1	2.000	0.750	1917	1331	852	479	213	2609	3408
7-2	2.000	1.000	1859	1291	826	465	207	2530	3304
7-3	2.000	1.500	1784	1239	793	446	198	2428	3171
7-4	2.000	2.000	1734	1204	771	433	193	2360	3082

Figure 17-7

Drag vs mph

Base Ride vs Drag Aero Map - Open Wheel Chassis

High Downforce Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

Map #	Front Ride	Rear Ride	L/D	Drag 150 mph	Drag 125 mph	Drag 100 mph	Drag 75 mph	Drag 50 mph	Drag 175 mph	Drag 200 mph
1-1	0.250	0.250	3.14	791	549	352	198	88	1077	1406
1-2	0.250	0.375	3.15	794	551	353	198	88	1080	1411
1-3	0.250	0.500	3.18	797	553	354	199	89	1085	1417
1-4	0.250	0.750	3.18	792	550	352	198	88	1077	1407
2-1	0.375	0.250	3.10	802	557	356	200	89	1092	1426
2-2	0.375	0.375	3.13	799	555	355	200	89	1087	1420
2-3	0.375	0.500	3.16	791	550	352	198	88	1077	1407
2-4	0.375	0.750	3.13	788	547	350	197	88	1073	1401
2-5	0.375	1.000	3.07	787	547	350	197	87	1072	1400
3-1	0.500	0.250	3.13	796	553	354	199	88	1084	1416
3-2	0.500	0.375	3.12	793	551	353	198	88	1080	1411
3-3	0.500	0.500	3.08	798	554	355	200	89	1087	1419
3-4	0.500	0.750	3.06	790	549	351	197	88	1075	1404
3-5	0.500	1.000	3.01	786	546	350	197	87	1070	1398
3-6	0.500	1.500	2.91	779	541	346	195	87	1060	1385
4-1	0.750	0.250	3.10	796	553	354	199	88	1083	1415
4-2	0.750	0.375	3.04	798	554	355	199	89	1086	1418
4-3	0.750	0.500	3.00	800	556	356	200	89	1089	1423
4-4	0.750	0.750	2.91	793	551	353	198	88	1080	1410
4-5	0.750	1.000	2.88	787	547	350	197	87	1071	1399
4-6	0.750	1.500	2.80	774	537	344	193	86	1053	1376
4-7	0.750	2.000	2.73	769	534	342	192	85	1047	1368
5-1	1.000	0.375	2.96	797	553	354	199	89	1085	1417
5-2	1.000	0.500	2.89	796	553	354	199	88	1083	1415
5-3	1.000	0.750	2.82	792	550	352	198	88	1078	1408
5-4	1.000	1.000	2.75	794	551	353	199	88	1081	1412
5-5	1.000	1.500	2.68	778	540	346	194	86	1058	1382
5-6	1.000	2.000	2.61	773	537	343	193	86	1052	1374
6-1	1.500	0.500	2.71	794	551	353	198	88	1080	1411
6-2	1.500	0.750	2.61	795	552	353	199	88	1082	1413
6-3	1.500	1.000	2.55	791	549	352	198	88	1077	1406
6-4	1.500	1.500	2.46	783	544	348	196	87	1065	1391
6-5	1.500	2.000	2.42	772	536	343	193	86	1050	1372
7-1	2.000	0.750	2.42	792	550	352	198	88	1078	1408
7-2	2.000	1.000	2.35	791	549	352	198	88	1077	1406
7-3	2.000	1.500	2.28	782	543	348	196	87	1065	1391
7-4	2.000	2.000	2.23	777	540	346	194	86	1058	1382

Figure 17-8

One of the primary tools teams use to adjust the chassis balance with aerodynamics is to change the percentage of front to rear aero load. This is accomplished by changing the angle(s) of incidence, adding/changing or removing aero components, changing the size/shape of flaps and changing the amount of chassis rake (pitch), etc. As previously discussed, each of these changes and their effects need to be separately mapped and then combined with the base downforce versus ride height map. For a very basic aero chassis, this may involve as few as twenty additional maps while with a more complex aero chassis, it can easily involve over one hundred additional maps. Obviously, this is well out of the realm of Book One so until we introduce this type of algorithm in Book Two, we will use a very simple table as shown in Figure 17-9. The table shows the base percentage, two percentages that move the aero balance towards the rear and three percentages that move the aero balance towards the front. *It is far from this simple*. We will use these percentages for both the low and high downforce maps when working with Wan31A. An **Aero Balance** calculator is included on the **Aero** worksheet to convert the percentages into actual co-ordinates required by Wan31A.

Changes in Front To Rear Aero Balance

Base Ride vs Downforce (Lift) Aero Map - Open Wheel Chassis

Road Course Set Up

Downforce @ 150 mph - 59°F - 14.7 psi Barometric Pressure

			Aero Center	Aero Center	Aero Center	Aero Center	Aero Center	Aero Center
Map #	**Front Ride**	**Rear Ride**	Base	To Rear	To Rear	To Front	To Front	To Front
			% Front #1	% Front #2	% Front #3	% Front #4	% Front #5	% Front #6
1-1	0.250	0.250	39.45%	38.30%	36.53%	41.53%	46.41%	50.58%
1-2	0.250	0.375	39.66%	38.50%	36.72%	41.74%	46.65%	50.84%
1-3	0.250	0.500	40.14%	38.97%	37.17%	42.25%	47.22%	51.46%
1-4	0.250	0.750	40.63%	39.45%	37.62%	42.77%	47.80%	52.09%
2-1	0.375	0.250	38.75%	37.62%	35.88%	40.79%	45.59%	49.68%
2-2	0.375	0.375	39.14%	38.00%	36.24%	41.20%	46.05%	50.18%
2-3	0.375	0.500	39.53%	38.38%	36.60%	41.61%	46.51%	50.68%
2-4	0.375	0.750	39.90%	38.74%	36.95%	42.00%	46.94%	51.16%
2-5	0.375	1.000	40.26%	39.09%	37.28%	42.38%	47.37%	51.62%
3-1	0.500	0.250	38.38%	37.26%	35.54%	40.40%	45.15%	49.20%
3-2	0.500	0.375	38.60%	37.48%	35.74%	40.64%	45.42%	49.49%
3-3	0.500	0.500	38.75%	37.62%	35.88%	40.79%	45.59%	49.68%
3-4	0.500	0.750	39.16%	38.02%	36.26%	41.22%	46.07%	50.21%
3-5	0.500	1.000	39.54%	38.39%	36.61%	41.62%	46.52%	50.69%
3-6	0.500	1.500	40.49%	39.31%	37.49%	42.62%	47.63%	51.91%
4-1	0.750	0.250	37.29%	36.20%	34.52%	39.25%	43.87%	47.80%
4-2	0.750	0.375	37.41%	36.32%	34.64%	39.38%	44.01%	47.96%
4-3	0.750	0.500	37.46%	36.37%	34.69%	39.43%	44.07%	48.03%
4-4	0.750	0.750	37.72%	36.62%	34.92%	39.70%	44.37%	48.36%
4-5	0.750	1.000	38.14%	37.03%	35.32%	40.15%	44.87%	48.90%
4-6	0.750	1.500	39.04%	37.90%	36.15%	41.09%	45.93%	50.05%
4-7	0.750	2.000	40.16%	38.99%	37.18%	42.27%	47.25%	51.49%
5-1	1.000	0.375	36.23%	35.17%	33.54%	38.13%	42.62%	46.44%
5-2	1.000	0.500	36.29%	35.23%	33.60%	38.20%	42.69%	46.52%
5-3	1.000	0.750	36.49%	35.43%	33.79%	38.41%	42.93%	46.79%
5-4	1.000	1.000	36.75%	35.68%	34.03%	38.68%	43.24%	47.12%
5-5	1.000	1.500	37.74%	36.64%	34.94%	39.73%	44.40%	48.38%
5-6	1.000	2.000	38.78%	37.65%	35.91%	40.82%	45.62%	49.72%
6-1	1.500	0.500	34.15%	33.16%	31.62%	35.95%	40.18%	43.79%
6-2	1.500	0.750	34.29%	33.29%	31.75%	36.09%	40.34%	43.96%
6-3	1.500	1.000	34.56%	33.55%	32.00%	36.38%	40.65%	44.30%
6-4	1.500	1.500	35.25%	34.22%	32.64%	37.10%	41.47%	45.19%
6-5	1.500	2.000	36.34%	35.28%	33.65%	38.25%	42.75%	46.59%
7-1	2.000	0.750	32.40%	31.46%	30.00%	34.11%	38.12%	41.54%
7-2	2.000	1.000	32.52%	31.57%	30.11%	34.23%	38.26%	41.69%
7-3	2.000	1.500	33.22%	32.25%	30.76%	34.97%	39.08%	42.59%
7-4	2.000	2.000	34.02%	33.03%	31.50%	35.81%	40.02%	43.62%

Figure 17-9

Wan31A – Open Wheel Chassis

Because Chapter 14 and 16 introduced many of the components involved in mechanical balance, including the anti and jacking forces, Chapter 17 will deal primarily with changes in aero balance. However, the reader is strongly encouraged to continue working with the various mechanical components while going through Chapter 17. As discussed in previous chapters, the material presented in each chapter barely **scratches** the surface of what a race engineer needs to know. It's up to the reader to go beyond this starting point.

- Load the Wan31A Open Wheel **Low** Downforce Chassis. Check to see that all of the appropriate anti/jacking green cells found in **A4** are turned **on**.

- The static corner loads are LF = 328 lb., RF = 328 lb., LR = 457 lb. and RR = 457 lb. Load transfer is zero. Ride heights are LF = 0.638", RF = 0.638", LR = 0.1.051" and RR = 1.051".

Note: Rather than building best fit ride height versus downforce/drag aero map calculators for Book One, we will simply select the ride height combinations in the base aero maps which most closely match the resulting ride heights shown in Wan31A and then enter the corresponding loads and percentages. Actual aero maps need to be far more precise than the ones offered in Book 1.

Note: Determining the aero loads from the dynamic ride heights is very much a closed loop iterative process. In Chapters 17 through 21 we will simply perform one manual iteration to find the aero loads. For example, once the dynamic mechanical ride heights are determined, we will add the appropriate aero loads, compare the new ride heights with the base aero map and then enter the new aero loads. As in all other situations where closed loop calculations are required, if the reader is well acquainted with the Excel circular calculator, he/she should feel free to build in his/her own solvers.

Corner Entry

- **Phase One – Hard Braking and Rapidly Decreasing Throttle** – (B = 1.00 g - T_L = 0.0)

    - The dynamic mechanical corner loads with the anti and jacking components included in the calculations are LF = 441.0 lb., RF = 441.0 lb., LR = 344.0 lb. and RR = 344.0 lb.

        - Ride heights are LF = 0.541", RF = 0.541", LR = 1.132" and RR = 1.132".

        - The total chassis weight is 1570.0 lb.

        - The kinetic CG is 6.44" **ahead** of the chassis centerline (Z25).

    - Low Downforce: Entering the low Downforce aero load from Figure 17-5 (Map #3-4), the aero load = 1644 lb. at 150 mph with 39.04% of the load on the front wheels. Using the **Aero Balance** calculator found in the **Aero** worksheet, we find that 39.04% results in the aero pressure center being 11.423" to the rear of the longitudinal center line of the chassis for our 104.22" wheelbase.

    - Enter 1644 lb. of aero load in cell **A3** and indicate the pressure center longitudinal co-ordinate by entering -11.423 in the longitudinal (x) aero cell.

        - The combined mechanical and aerodynamic corner loads are now LF = 761.9 lb., RF = 761.9., LR = 845.1 lb. and RR = 845.1 lb.

        - Ride heights are LF = 0.102", RF = 0.102", LR = 0.734" and RR = 0.734".

        - The total dynamic/combined chassis weight is 3214.0 lb as shown in A6.1.

- The kinetic CG is now –2.70" **behind** the chassis longitudinal centerline. The aero load has **shifted** the kinetic CG **rearward** by 9.14".

(Compensating for the new ride heights)

- Comparing the new **ride heights** with the base low downforce aero map, Figure 17-5 (Map #1-4) shows 1712 lb. aero load and 39.90% longitudinal balance. The aero balance calculator shows the new x co-ordinate is 10.526" rearward of the chassis' longitudinal centerline, which is 0.897" less than in the previous non-corrected calculation.

- Enter 1712 lb. of aero load in cell **A3** and indicate the pressure center longitudinal co-ordinate by entering –10.526 in the longitudinal (x) aero cell.

- The combined mechanical and aerodynamic corner loads are now LF = 782.5 lb., RF = 782.6 lb., LR = 858.5 lb. and RR = 858.5 lb.

- The combined chassis weight is now 3282.0 lb.

- Ride heights are LF = 0.076", RF = 0.076", LR = 0.724" and RR = 0.724". The values in cells W35 to Z35 are only the aero heights under particular set up conditions for the Initial Cells W31 to Z31. If the chassis ends up being too low under dynamic conditions the chassis static ride height can be raised and the Initial Wan31 cells changed to reflect these new static ride heights.

- The kinetic CG is now 2.41" **behind** the chassis longitudinal centerline. The aero load has **shifted** the kinetic CG **rearward** by 8.85".

- The aero drag is at 538 lb. (Figure 17-6 Map #1-4)

As we will see in Chapter 21, even this low downforce configuration will dramatically increase the chassis braking performance. Additionally, under braking conditions, drag is actually a good thing. Once the throttle is closed, the aero drag will produce 538 lb. of braking force or 538/1570 = 0.343 g. Notice that we use the chassis non-aerodynamic weight to calculate the braking forces. Closing the throttle at high speed with a high downforce aero configuration can produce more than 1g of braking.

Instantaneous Aero Loads

It is important to remember that all aerodynamic loads, forces and co-ordinates, like all other dynamic conditions, are instantaneous in nature. Any type of change will result in a change in the aero loads. Changes in speed, ride heights, yaw, proximity to another chassis and/or a wall, wind shear, etc. will all change the chassis aerodynamics.

Downforce versus mph

As the chassis slows in braking, both the level of downforce and drag will diminish. Looking at aero Map # 1-4 in Figures 17-5 and 17-6 we see that at 150 mph, the downforce = 1712 lb. and drag = 538 lb. while at 50 mph, the downforce is only 190 lb. with a drag of only 60 lb. With the current chassis set up and 39.9% front aero load, the difference between 150 and 60 mph represents a ride height change of 0.414" at the front and 0.363" at the rear. Of course, as the ride height changes, so will the aero loads. At 1712 lb. of downforce, the front ride height will be close to 0.076 of an inch off the track. For a chassis running a goodly amount of rake the front wing will be getting rather close to the track and, depending on the front wing's angle of incidence, the front downforce could be dramatically **decreased** because of the "Hook" phenomenon. Our **high** downforce configuration under 1g of braking at 200 mph will provide approximately 4474 lb. of aero downforce. In this case, either the static ride heights and/or the wheel rates will need to be increased (see Chapter 21).

At 1712 lb. of downforce and a front balance of 39.9%, the front tires will each see a load of 782.5 lb. while the rear tires will each see a load of 858.5 lb. With 190 lb. of aero load and a front balance of 39.9%, the front tires only see a load of 478.9 lb. while the rear tires only see 401.1 lb. As we will discover in Chapter 21, this type of load change results in a massive variation in braking performance. As in most cases, the race engineer needs to use on track data from the acquisition system to calculate changes in braking performance due to changes in the aero settings i.e. speed versus distance and ride height information.

Note: The **lowering** of lap times due to aerodynamic loads may have as much to do with an increase in **longitudinal** performance as it does with an increase in **lateral** performance.

Aero Balance

Using the front to rear aero balance percentages from Figure 17-9, we can see how the aero balance affects the corner loads (the changes in balance percentages are **inline** with actual wind tunnel data). The aero load in the following example is 1712 lb. taken from the base Map #1-4 low Downforce map at 1g of braking.

- @ 39.45% (-10.995")
    - The combined mechanical and aerodynamic corner loads @ 150 mph and **39.45%** front balance are LF = 778.7 lb., RF = 778.7 lb., LR = 862.3 lb. and RR = 862.3 lb.
        - Ride heights are LF = 0.080", RF = 0.080", LR = 0.721" and RR = 0.721".
- @ 37.62% (-12.902) - Less front
    - The combined mechanical and aerodynamic corner loads @ 150 mph and **37.62%** front balance are LF = 763.0 lb., RF = 763.0 lb., LR = 878.0 lb. and RR = 878.0 lb.
        - Ride heights are LF = 0.096", RF = 0.096", LR = 0.707" and RR = 0.707".
- @ 35.00% (-15.633) - Less front (*not shown on map*)
    - The combined mechanical and aerodynamic corner loads @ 150 mph and **35.00%** front balance are LF = 740.6 lb., RF = 740.6 lb., LR = 900.4 lb. and RR = 900.4 lb.
        - Ride heights are LF = 0.119", RF = 0.119", LR = 0.687" and RR = 0.687".
- @ 42.77% (-7.535) - Higher front
    - The combined mechanical and aerodynamic corner loads @ 150 mph and **42.77%** front balance are LF = 807.1 lb., RF = 807.1 lb., LR = 833.9 lb. and RR = 833.9 lb.
        - Ride heights are LF = 0.050", RF = 0.050", LR = 0.746" and RR = 0.746".
- @ 47.80% (-2.293) - Higher front
    - The combined mechanical and aerodynamic corner loads @ 150 mph and **47.80%** front balance are LF = 850.1 lb., RF = 850.1 lb., LR = 790.9 lb. and RR = 790.9 lb.
        - Ride heights are LF = 0.006", RF = 0.006", LR = 0.784" and RR = 0.784". (At this point, let's hope the ride heights were measured from the skid plates rather than the bottom of the tub.)

With mechanical loads only, the front percentage of load at 1g braking is 56.2%. With 1712 lb. of aero load, the front percentage of total load is (100% -rear bias):

- @ 39.45% aero load, the front combined load percentage is 47.5%
- @ 37.62% aero load, the front combined load percentage is 46.5%

- @ 35.00% aero load, the front combined load percentage is 45.10%
- @ 42.77% aero load, the front combined load percentage is 49.2%

- @ 47.80% aero load, the front combined load percentage is 51.80%

Even if the aero load had a front balance of 51.16%, the combined braking load at the front would still be 2.62% less than without the aero loads. At 39.45% of front aero load the combined front braking load is 8.70% less than without the aero loads. For optimal braking performance, a change in the aero balance also requires a change in the front to rear braking **bias**.

Corner Apex

- **Phase Five – Constant Steer Angle with No Throttle** – (B = 0.05 g - T_L = 1.53g)

    - The dynamic mechanical corner loads with the anti and jacking components included in the calculations are LF = 130.0 lb., RF = 537.3 lb., LR = 81.3 lb. and RR = 821.4 lb.

        - Ride heights are LF = 0.710", RF = 0.578", LR = 1.150" and RR = 1.032".

        - The total chassis weight is 1570.0 lb.

        - The kinetic CG is –7.81" **behind** the chassis longitudinal centerline and –22.95" to the **right** of chassis lateral centerline.

        - The front split = -407.2 lb. while the rear split = -740.0 lb.

        - The dynamic wedge = 39.4%, left side bias = 13.5% and rear bias = 57.5%.

        - Roll angle = -0.476 degrees to the right.

        - Pitch angle = 0.281 degrees nose down.

    Adding an aero load of 1600 lb. at **38.00%** front balance

    - The combined corner loads are LF = 451.6 lb., RF = 823.7 lb., LR = 558.4 lb. and RR = 1336.3 lb.

        - Ride heights are LF = 0.282", RF = 0.166", LR = 0.750" and RR = 0.646".

        - The combined chassis weight is 3170 lb.

        - The kinetic CG is –10.18" **behind** the chassis longitudinal centerline and -11.37" to the **right** of chassis lateral centerline.

        - The dynamic wedge = 43.6%, left side bias = 31.9% and rear bias = 59.8%.
        - The front split = -372.1 lb. while the rear split = -778.0 lb.

        - Roll angle = 0.418 degrees to the right.

        - Pitch angle = 0.298 degrees nose down.

    Adding an aero load of 1600 lb. at **45.00%** front balance

    - The combined corner loads are LF = 504.5 lb., RF = 882.8 lb., LR = 505.7 lb. and RR = 1277.0 lb.

- Ride heights are LF = 0.225”, RF = 0.108”, LR = 0.800” and RR = 0.695”.
- The combined chassis weight is 3170 lb.
- The kinetic CG is –6.50” **behind** the chassis longitudinal centerline and -11.37” to the **right** of chassis lateral centerline.
- The dynamic wedge = 43.8%, left side bias = 31.9% and rear bias = 56.2%.
- The front split = -378.4 lb. while the rear split = -771.2 lb.
- Roll angle = 0.422 degrees to the right.
- Pitch angle = 0.365 degrees nose down.

Though not shown in the basic aero maps we are using for Book One, a chassis aero load, as previously discussed, is often laterally offset from the longitudinal centerline, particularly when the chassis shows some degree of roll. In the case of the preceding example, the left side of the chassis would see less aero load. The center of pressure would move towards the right side of the chassis.

The difference in right and left side ride heights during roll **does** affect the aero pressure center. The change in pressure center co-ordinates almost always degrades the chassis ultimate lateral acceleration performance. The problem is additionally compounded by the fact that the extra right side load (left turn scenario) further decreases right side ride height (increasing the right side aero loads) and increases the left side ride heights (decreasing the left side aero loads).

With a corrected aero pressure center of **x = -6.464”** to the rear and **y = -3.211**” to the right:

- The combined corner loads are LF = 464.2 lb., RF = 903.9 lb., LR = 464.4 lb. and RR = 1337.6 lb.
- Ride heights are LF = 0.217”, RF = 0.109”, LR = 0.805” and RR = 0.682”.
- The combined chassis weight is 3170 lb.
- The kinetic CG is –7.13” **behind** the chassis longitudinal centerline and –12.99” to the **right** of chassis lateral centerline.
- The dynamic wedge = 43.2%, left side bias = 29.3% and rear bias = 56.8%.
- The front split = -439.7 lb. while the rear split = -873.2 lb.
- Roll angle = 0.497 degrees to the right.
- Pitch angle = 0.356 degrees nose down.

Aerodynamic forces increase the chassis’ lateral acceleration performance in direct relationship to the level of downforce and the pressure center positioning. If the aero pressure center is along the chassis longitudinal centerline, the aero loads will tend to lessen the effects of lateral load transfer. If the aero pressure center can be offset to the inside of the turn, this will further offset the effects of lateral load transfer. For example, during a left turn, if the aero pressure center is laterally offset to the left of the chassis’ y axis center line, the positioning of the chassis’ y kinetic co-ordinate will migrate back from its mechanical only load transfer position towards the lateral center of the chassis – Figure 17-10. It is possible, through aero loading, to have the y axis kinetic co-ordinate to the inside of the turn i.e. on a winged sprint car the chassis can be turning left while the car is rolling to the left.

Additionally, remember that the level of aero downforce is in direct relationship to the chassis' speed. Setting the chassis up with a high downforce configuration helps lateral acceleration and braking but degrades inline acceleration.

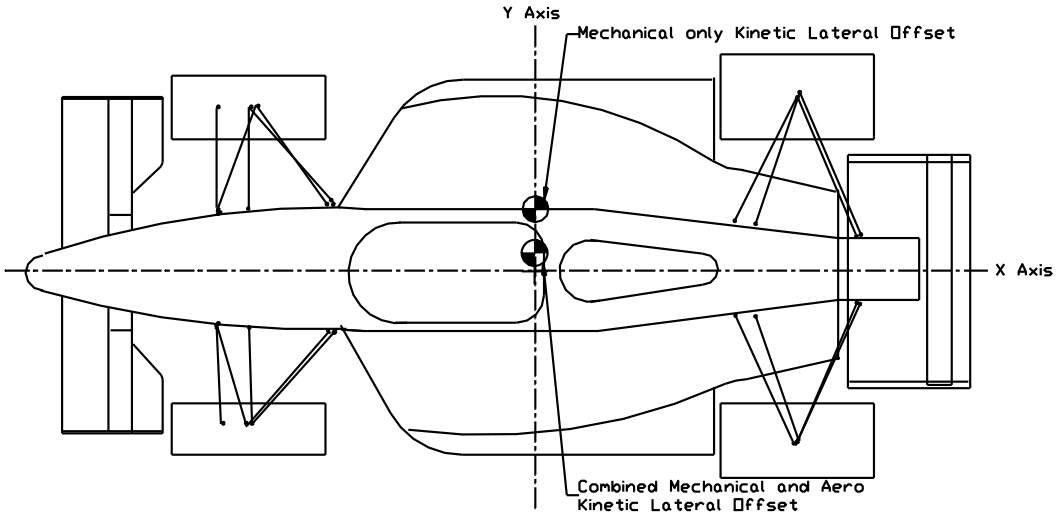


Figure 17-10

Corner Exit

- **Phase Nine – Slowly Decreasing Steer Angle with Rapid Pick Up on Throttle** – (A = 0.65 - T_L = 0.5 g)

    - The dynamic mechanical corner loads with the anti and jacking components included in the calculations are LF = 189.5 lb., RF = 319.7 lb., LR = 408.0 lb. and RR = 652.9 lb.

        - Ride heights are LF = 0.740", RF = 0.697", LR = 1.032" and RR = 0.994".

        - The total chassis weight is 1570.0 lb.

        - The kinetic CG is –18.31" **behind** the chassis longitudinal centerline and –7.50" to the **right** of chassis lateral centerline.

        - The front split = -130.2 lb. while the rear split = -245.0 lb.

        - The dynamic wedge = 46.3%, left side bias = 38.1% and rear bias = 67.6%.

        - Roll angle = 0.153 degrees to the right.

        - Pitch angle = 0.185 degrees nose down.

    Adding an aero load of 1600 lb. at 38.00% front balance:

    - The combined corner loads are LF = 499.2 lb., RF = 617.9 lb., LR = 897.8 lb. and RR = 1155.1 lb.

        - Ride heights are LF = 0.318", RF = 0.281", LR = 0.635" and RR = 0.602".

        - The combined chassis weight is 3170 lb.

- The kinetic CG is –15.38" **behind** the chassis longitudinal centerline and –3.71" to the **right** of chassis lateral centerline.
- The dynamic wedge = 47.8%, left side bias = 44.1% and rear bias = 64.8%.
- The front split = -118.7 lb. while the rear split = -257.4 lb.
- Roll angle = 0.134 degrees to the right.
- Pitch angle = 0.201 degrees nose down.

As we will see in Chapter 21, adding the aero loads increases the rear tires' longitudinal acceleration potential. However, as previously discussed, the actual acceleration rate and ultimate top speed depend on the engine having sufficient torque to overcome the drag forces. At 150 mph a drag of 543 lb. is using up 217 hp.

Note: The following downforce and drag numbers are **not** ride height corrected.

Looking at the low downforce aero map- for a 0.5, 0.5 height, Map 3-3 from Figure 17-5 and Map 3-3 from Figure 17-6:

- At 50 mph downforce = 186 lb. and drag = 60 lb.
  - Hp used to overcome the aero drag = 8.0 hp
- At 75 mph downforce = 418 lb. and drag = 136 lb.
  - Hp used to overcome the aero drag = 27.2 hp
- At 100 mph downforce = 743 lb. and drag = 241 lb.
  - Hp used to overcome the aero drag = 64.3 hp
- At 125 mph downforce = 1161 lb. and drag = 377 lb.
  - Hp used to overcome the aero drag = 125.7 hp
- At 150 mph downforce = 1672 lb. and drag = 543 lb.
  - Hp used to overcome the aero drag = 217.2 hp
- At 175 mph downforce = 2276 lb. and drag = 739 lb.
  - Hp used to overcome the aero drag = 344.9 hp
- At 200 mph downforce = 2972 lb. and drag = 965 lb.
  - Hp used to overcome the aero drag = 514.7 hp

Looking at the proceeding numbers for longitudinal acceleration, it's pretty clear that the aero loads are very much a mixed blessing. The downforce loads are at their lowest level when we need them the most during initial acceleration while the drag forces are at their highest when the engine is already running out of torque. Anything a team can do to reduce the L/D ratio will help longitudinal forward acceleration. In actual fact, because the rear ride heights will tend to squat during inline acceleration, the rear downforce and drag numbers will actually be greater at the rear and less at the front than indicated in

the previous examples. Aero loads tend to help braking performance **much** more than inline acceleration performance.

Wan31C Supplementary

There are four Wan31C models included on the accompanying CD. They are intended to briefly outline several of the next steps involved in developing dynamic simulation models. Wm. C. Mitchell and the author, as well as Dr. Juan Salinas and the author are currently developing a series of software packages for individual teams in addition to an exciting new commercially available simulation model published by Wm. C. Mitchell that use the types of concepts introduced in this supplementary section.

Wan31C – Short Track

This model slightly expands a concept briefly introduced in Chapter 16, regarding the download of on track data such as acceleration forces and IC co-ordinates. As stated in Chapter 16 this type of information can be placed in table form either by the user manually entering the information or using the table writer offered in WinGeo3. Users of the WinGeo3 premier version can download virtually any type of track data directly from the acquisition system into the WinGeo3 table writer. For example, at 10 samples per second, a road course lap taking 1:14 would require a table of 740 lines. Each line can contain a large number of columns such as IC heights and lengths, acceleration forces, damper velocities, etc. the information presented in the table can then be used to run simulation models such as Wan31 or the new WinGeo3 Vehicle Dynamics Model.

The Wan31C Short Track model uses a spinner found on the upper right hand corner of the main worksheet which allows the user to toggle though 10 different cornering phases. Each phase changes the acceleration forces as well as the front and side view instant center co-ordinates. The table found beginning at cell AG61 was downloaded from WinGeo3. An actual on track example could easily contain over three thousand lines of information.

- All acceleration forces and IC co-ordinates are entered by using the spinner. For this example, do not enter acceleration and IC co-ordinate information directly into the cells.

Wan31C – Short Track Fuel Consumption

This model is exactly the same as the Short Track Wan31A model except for the fact that it allows the user to toggle through a variety of different fuel loads and resulting changes in CG co-ordinates. The user should feel free to change the data currently entered into the table. The table begins at cell AG62.

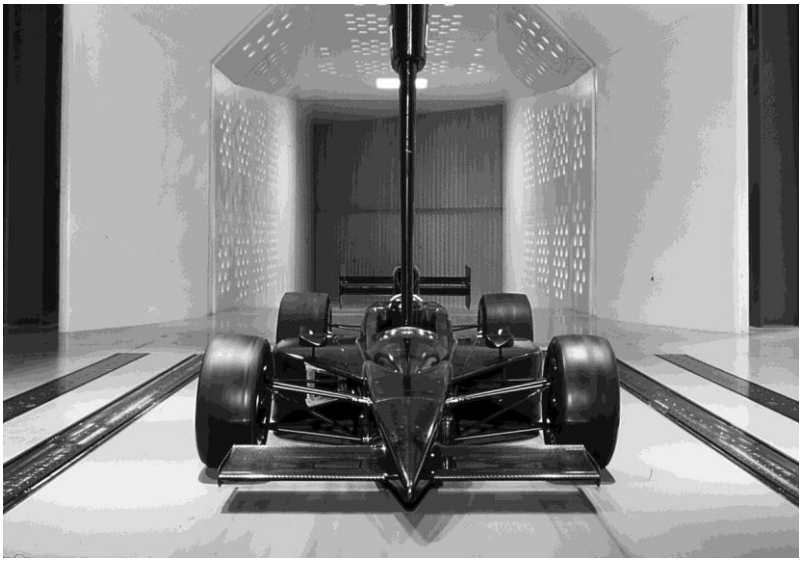
- All fuel loads and resulting changes in CG co-ordinates are entered by using the spinner.

Wan31C – Open Wheel High Downforce

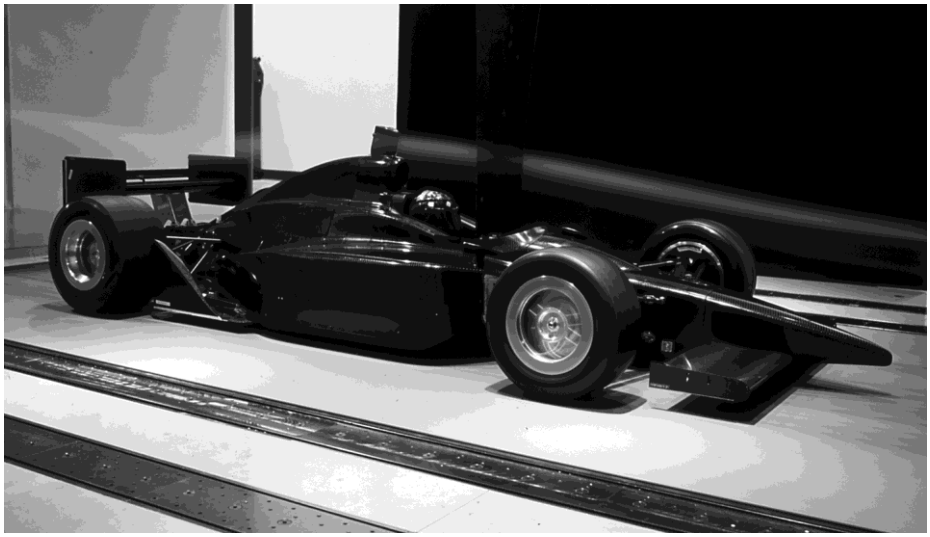
The Wan31C Open Wheel High Downforce model uses a spinner found on the upper right hand corner of the main worksheet which allows the user to toggle though 10 different cornering phases. Each phase changes the acceleration forces as well as the front and side view instant center co-ordinates. It also changes the **Aero Loads**. The table found beginning at cell AG61 was downloaded from WinGeo3. *The aero loads for this example are simply a figment of the author's imagination.* The user should feel free to change the **Aero Load** data currently entered into the table. An actual on track example could easily contain over three thousand lines of information.

- All acceleration forces, IC co-ordinates and aero loads are entered by using the spinner. For this example, do not enter acceleration, IC co-ordinates and aero load information directly into the cells.

Wan31C – Damper Wan enters the damper forces, acceleration rates and IC co-ordinates through the spinner.



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