WRI 2023

Vehicle design - influenced by wheel rail interaction
A case study

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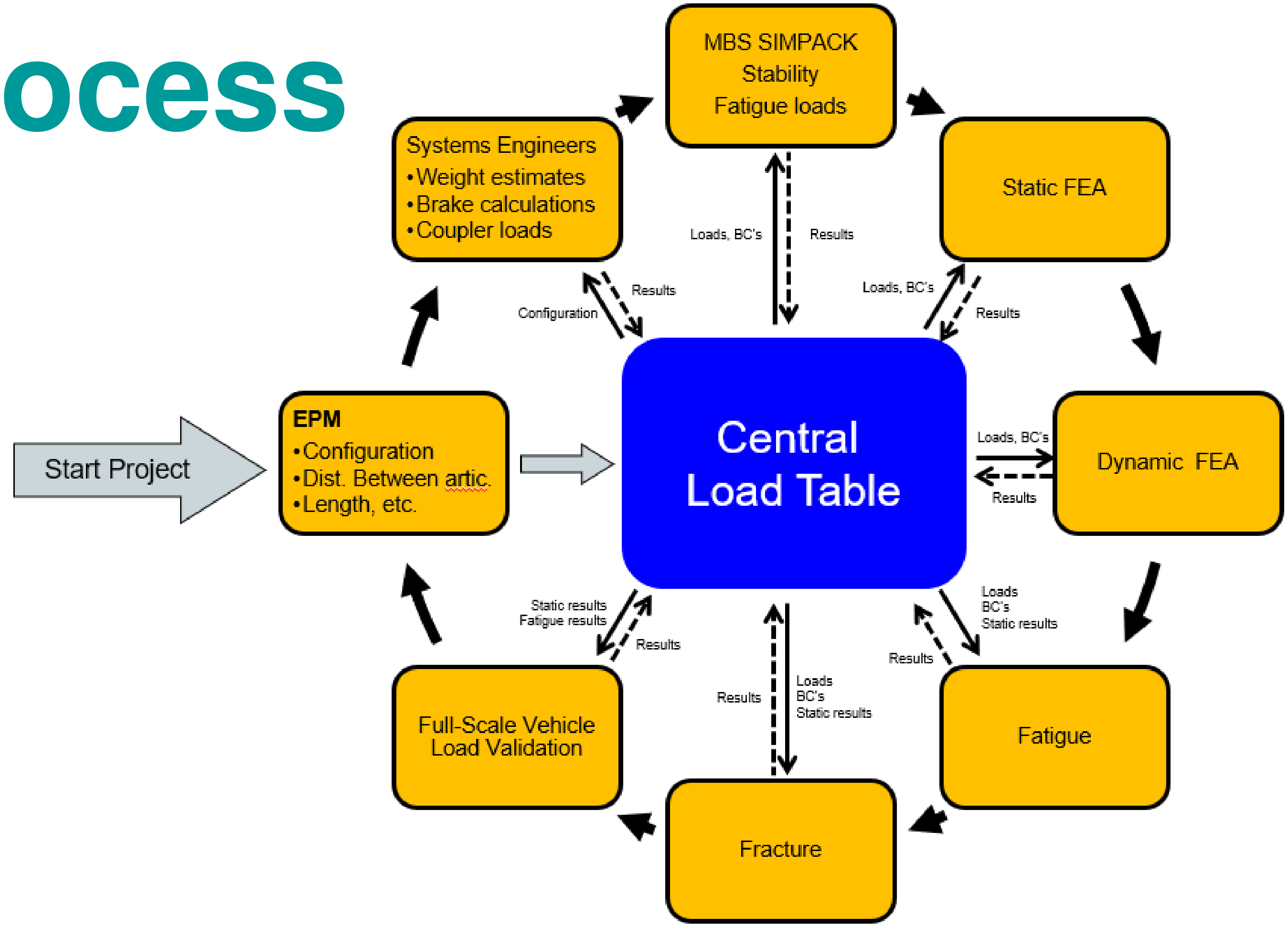
Overview

Vehicle design influenced by wheel/rail interaction

- Advantages of vehicle development when as built track data is available.
- Overview of vehicle characteristics dependent on track interaction.
- Case study of 3D track facilitated optimization of a new light weight vehicle.
- Variance in design characteristics; measured trackwork vs standards.
- The presentation will conclude with a dialog of how the availability of measured track data has a positive influence with development of efficient vehicle designs with minimal environmental disturbances.

Design process

At a glance...



Vehicle Design – characteristics

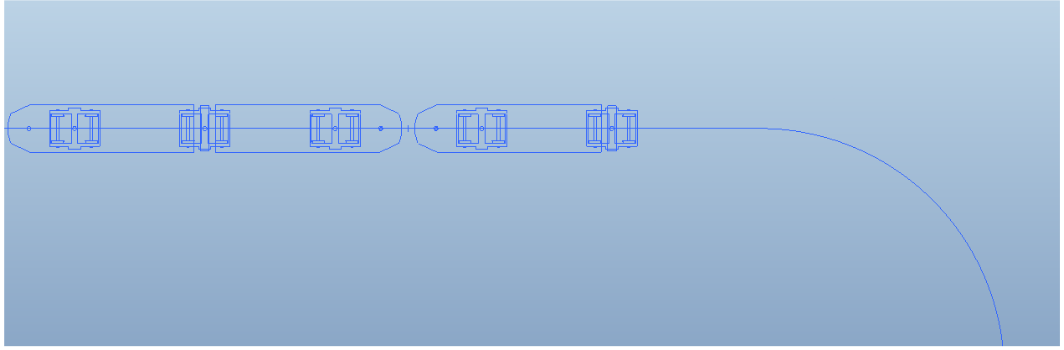
Vehicle Characteristics influenced by track interaction

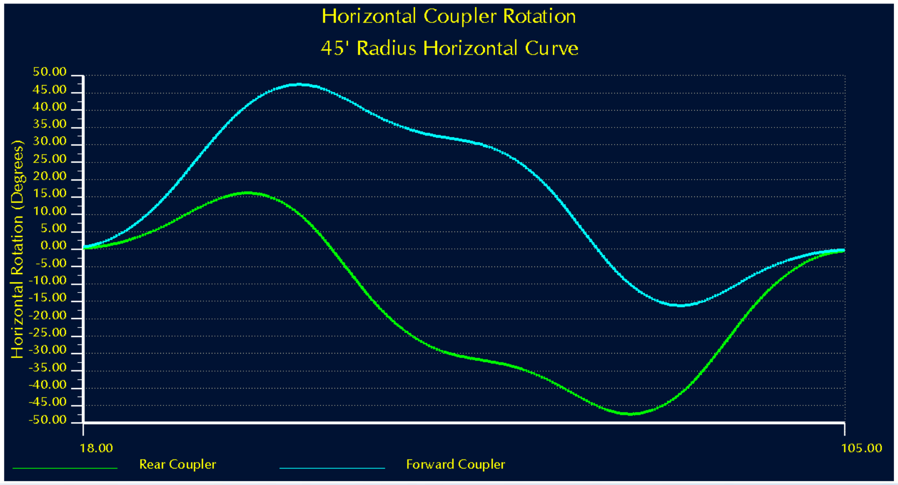
- Vehicle kinematics (motion)
- Vehicle dynamics (forces)
- Structural loads (forces, moments)
- Propulsion (power)

Vehicle Design – kinematics

Vehicle Characteristics, cont…

- Vehicle kinematics (motion)
  - articulations angles
  - coupler clearances
  - carbody clearances

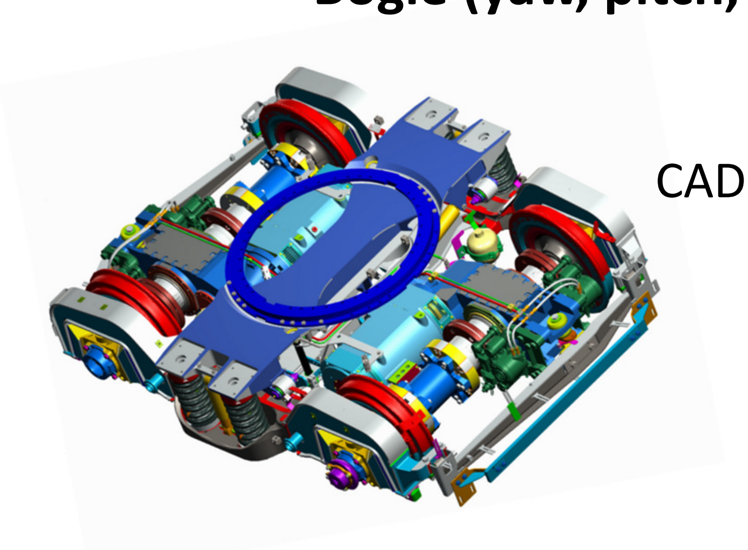




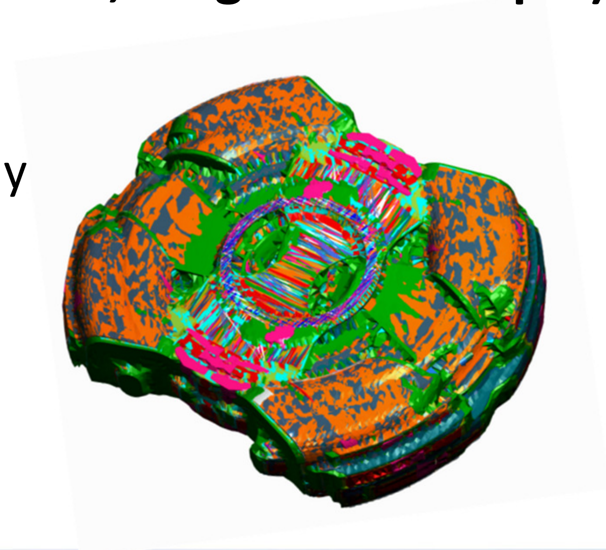
Vehicle Design – kinematics

Vehicle Characteristics, cont…

- Vehicle kinematics (motion)
  - Bogie (yaw, pitch, roll, vertical, lateral, longitudinal displ..)



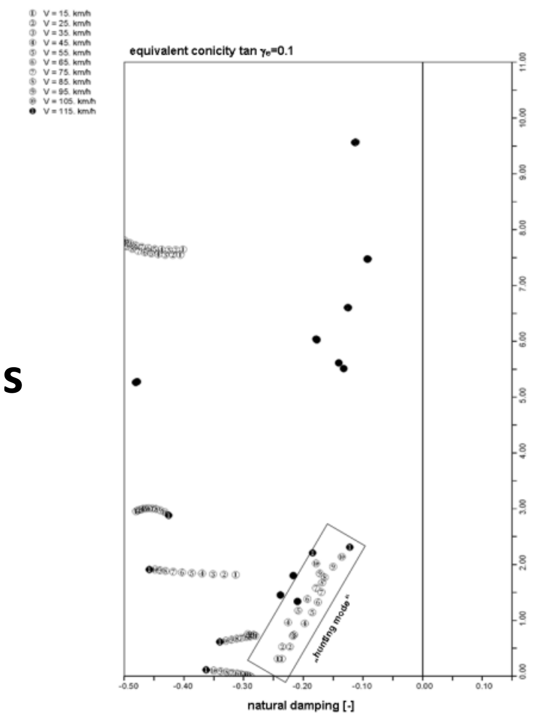
CAD Shrink wrap study



Vehicle Design – dynamics

Vehicle Characteristics, cont…

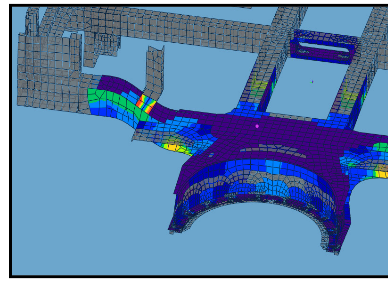
- Vehicle dynamics (forces)
  - Wheel / Rail interface studies
    - Geometric wheel / rail CAD investigations
  - Derailment propensity
    - Damping, velocity, conicity by MBS
  - Ride comfort
    - Vertical, lateral, horizontal acceleration by MBS

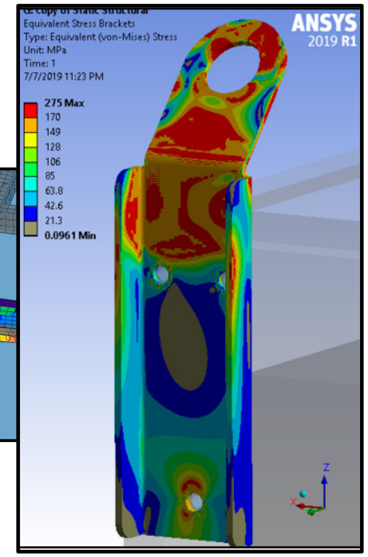


Vehicle Design – structural

Vehicle Characteristics, cont…

- Structural (forces, moments)
  - Customer technical specification
  - Regulatory
    - APTA, ASME, CPUC,FRA, PRIIA, other..
  - Car builder Internal
    - Static, quasi-static, MBS





LOAD CASE NUMBER	REFERENCE CASE	DESCRIPTION	SOURCE	SOURCE SECTION	ASME RT-1 2009 Item #	REQUIREMENT (SUMMARY)	APPENDIX (REPORT)	APPENDIX (RESULT FILES)	NOTES
1	N	Vertical operating loads at AW4.	ASME RT-1 2009 (LRV)	Table 1	1	Stress not to exceed 65% of the yield strength and no loss of local stability.	A,K,M	B,L,N	
2	N	End sill compression.	ASME RT-1 2009 (LRV)	Table 1	2	No permanent deformation of any structural member or structural sheathing, with the possible exception of the Zone 1 energy absorption area.	A	B	Enveloped by CPUC end-load conditions. Included for completeness.

Vehicle Design – Propulsion

Vehicle Characteristics, cont…

- Propulsion (power)
  - Distances, gradients, station stops
    - Brakes (forces, thermal capacities)
    - Drives (efficiencies, forces, power, thermal capacities)
    - Traction inverters (efficiencies, power, thermal capacities)

Case Study – existing track

Overview - new vehicle procurement

- Existing track network
  - Alignment within proximity of historic buildings
    - Ground borne vibrations of concern - unsprung mass sensitivity
  - Historic existing track work
    - Vehicle weight of concern – light weight construction required
  - Track work located in high gradient landscape
    - Derailment propensity – bogie stiffness sensitivity
    - Large moments due to torsion – carbody fatigue sensitive

Case Study – existing track

Overview - new vehicle procurement cont…

- Problem statement
  - Competing system integration sensitivities
    - Lightweight vehicle and low unsprung mass complement each other.
    - Fatigue resistance due to large torsional loads can be contradictory

Case Study – existing track

Overview - new vehicle procurement cont…

- The plan
  - Verify technical requirements
    - Examine track drawings – compare to standards
    - Measure track – compare to drawings and standards
    - Measure existing vehicle dynamics – compare to technical specification and standards

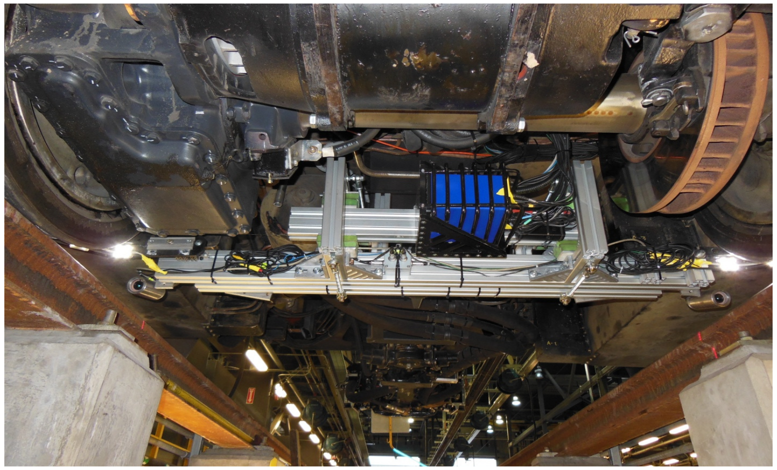
Case Study – existing track

Overview - new vehicle procurement cont…

- The plan cont…
  - Define existing trackwork design criteria
    - Use the worse case characteristics
      - Track drawings
      - Measured track
      - Measured existing vehicle dynamic loads

Case Study – existing track

Investigation approach



- Instrument existing cars
  - Rail geometry – 3D scanners
    - Rail profile
    - Rail gage width
  - Track Curvature – GPS, Accelerometers, Inertial Measurement Unit (IMU)
    - Curve Radius
    - Grade
    - Cross Level

Case Study – existing track

Investigation approach cont…

- Instrument existing cars
  - Bogie Movements – Displacement Transducers
    - Bogie Yaw, Pitch, Roll relative to the carbody
  - Carbody Movements – Displacement Transducers
    - Center Articulation between Carbody Sections
      - Yaw, Pitch, Roll
  - Vehicle Location – GPS
  - Vehicle Accelerations – Accelerometers

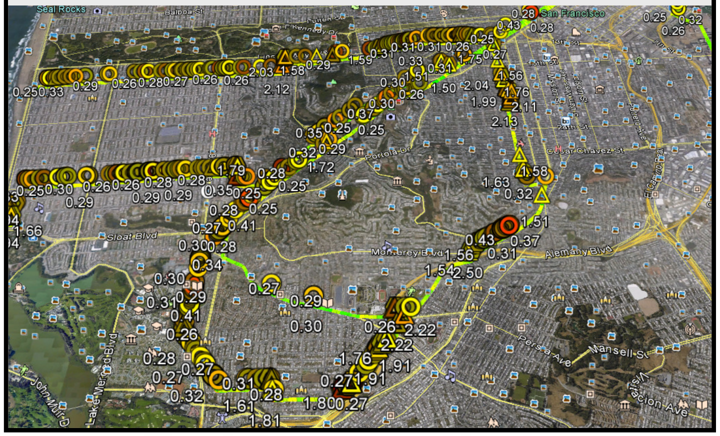
Case Study – existing track

Investigation approach cont…

- **Results**
  - **Areas of interest plotted on Google Earth maps using GPS data for visualization.**

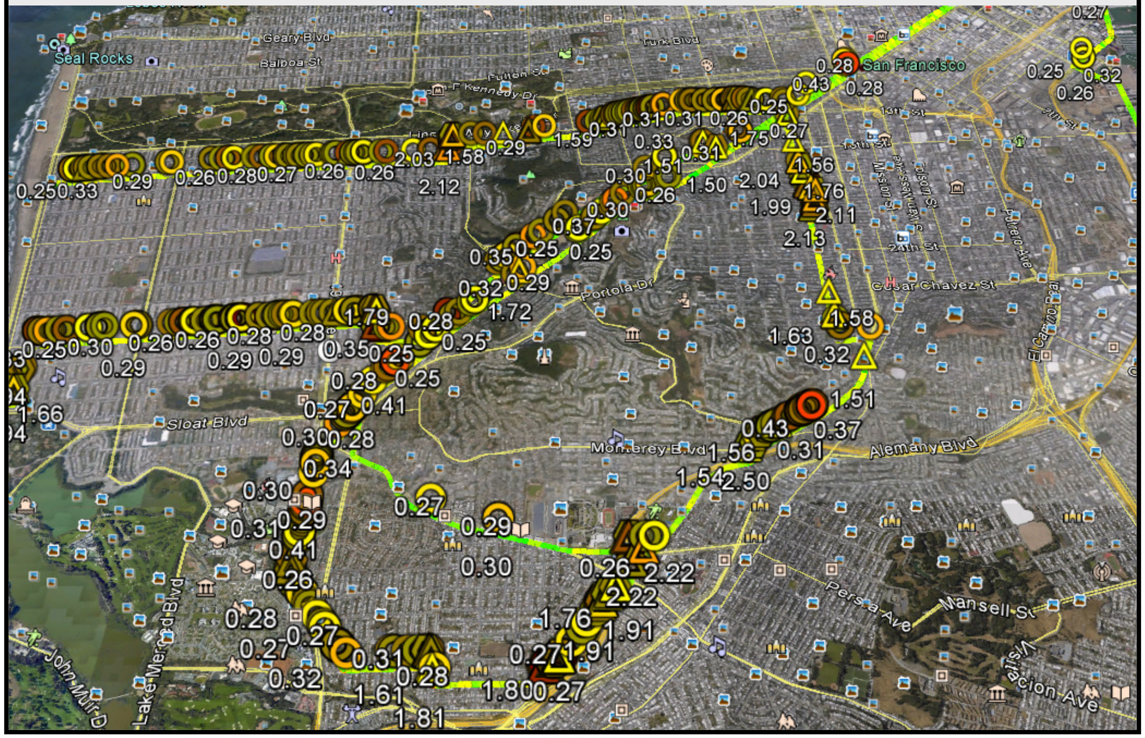
Track Parameters
warp 31 ft > 1.75 (below 30mph)
warp 31 ft > 1.50 (above 30mph)
warp 62 ft > 3.00 (FRA class 1)
warp 62 ft > 2.25 (FRA class 2)
narrow gage > 0.25 (mainline)
narrow gage > 0.39 (Vehicle dynamics max new)
narrow gage > 0.41 (Vehicle dynamics max worn)

Warp, gage via Google Earth



Case Study – existing track

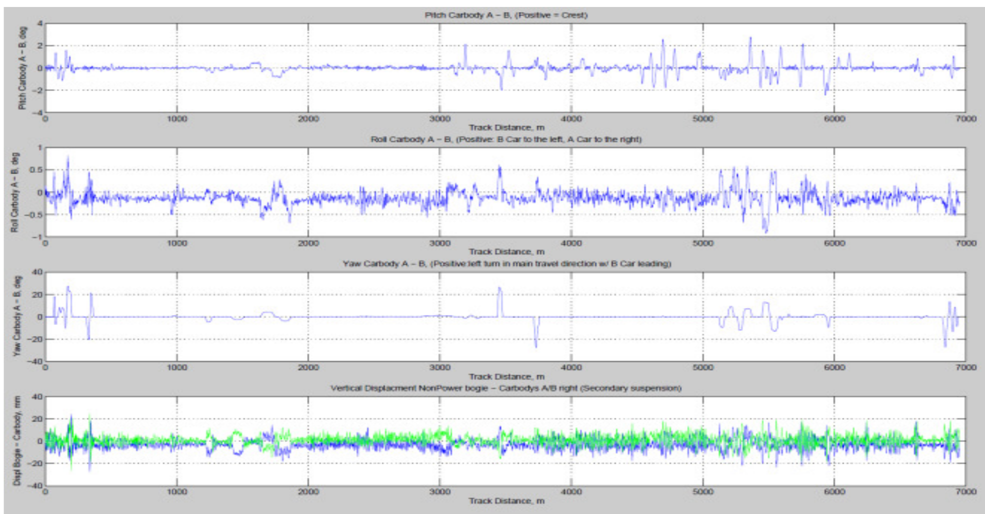
Warp, gage via Google Earth



Case Study – existing track

Investigation approach cont…

- **Results**
  - **Measure track profiles used to create MBS tracks for simulations.**



	pitch A-B [°]	roll A-B [°]	yaw A-B [°]	bounce 1 [mm]	bounce 2 [mm]	bounce 3 [mm]	roll 1 [°]	roll 2 [°]	roll 3 [°]	yaw 1-A [°]	yaw 2-A [°]	yaw 2-B [°]	yaw 3-B [°]
1	2.97	0.30	0.44	2.77	-3.89	-0.65	0.16	0.14	0.23	0.14	0.04	0.07	0.72
2	2.78	0.31	6.41	-4.47	-1.71	-2.65	0.18	0.09	0.52	4.76	2.47	3.41	2.53
3	2.77	0.47	0.49	3.61	-3.03	-2.80	0.24	0.28	0.15	0.32	0.12	0.05	0.52
4	2.70	0.32	0.52	-0.80	-1.68	-0.42	0.09	0.39	0.08	0.34	0.10	0.05	0.57
5	2.69	0.36	0.51	-0.48	-0.55	-0.95	0.25	0.08	0.29	0.22	0.06	0.04	0.47
6	2.60	0.31	0.43	0.22	-2.31	-1.24	0.12	0.15	0.25	0.16	0.07	0.03	0.52
7	2.58	0.41	0.58	-0.30	-2.29	0.51	0.27	0.62	0.12	0.12	0.03	0.05	0.53
8	2.58	0.25	0.58	-2.97	-2.42	0.32	0.17	0.46	0.18	0.03	0.11	0.04	0.55
9	2.54	0.51	7.44	2.78	-2.10	-4.55	0.21	0.06	0.43	3.63	4.17	2.38	3.70
10	2.52	0.50	0.36	1.73	-4.17	-1.91	0.26	0.28	0.26	0.44	0.04	0.02	0.42
11	2.48	0.39	0.59	0.06	-2.88	-0.64	0.38	0.59	0.13	0.43	0.20	0.14	0.62
12	2.46	0.37	0.52	-0.08	-1.29	-0.27	0.09	0.16	0.04	0.10	0.17	0.04	0.46
13	2.44	0.35	0.40	-1.62	-3.46	-0.47	0.19	0.21	0.09	0.19	0.05	0.02	0.45
14	2.32	0.74	21.66	1.20	2.19	-1.96	0.61	0.62	0.43	5.00	10.99	11.69	13.45
15	2.25	0.22	21.79	2.83	-0.06	-3.85	0.54	0.50	0.43	15.01	14.75	5.64	4.45
16	2.25	0.11	6.99	2.32	-0.77	-0.63	0.34	0.12	0.04	3.45	3.85	2.33	3.66
17	2.22	0.33	0.55	-0.85	-2.73	-0.20	0.11	0.31	0.20	0.19	0.16	0.02	0.42
18	2.21	0.37	0.34	2.94	-1.06	-0.37	0.15	0.12	0.12	0.23	0.04	0.03	0.57
19	2.19	0.40	0.10	-1.16	-0.07	-1.50	0.66	0.26	0.30	0.51	0.18	0.31	0.84
20	2.18	0.18	0.33	1.83	-2.70	-0.95	0.45	0.43	0.14	0.19	0.16	0.26	0.78
21	2.16	0.39	0.41	-0.10	-1.24	1.12	0.06	0.14	0.07	0.12	0.11	0.05	0.44
22	2.16	0.15	1.41	-0.26	-2.53	0.69	0.07	0.08	0.04	1.01	0.49	1.12	0.32
23	2.13	0.31	6.10	0.29	-0.03	-0.88	0.25	0.09	0.20	1.84	3.43	2.84	3.76
24	2.10	0.25	0.41	-0.41	-2.32	1.37	0.16	0.23	0.08	0.18	0.13	0.04	0.51
25	2.08	0.26	0.36	1.58	-3.45	-1.75	0.16	0.24	0.16	0.27	0.15	0.03	0.62
26	2.04	0.33	0.37	-0.33	-1.09	-2.06	0.24	0.28	0.34	0.16	0.08	0.02	0.30
27	1.99	0.02	0.23	-0.40	0.01	-2.34	0.27	0.37	0.59	0.26	0.07	0.57	2.49
28	1.95	0.05	0.24	-0.19	1.49	0.69	0.20	0.42	0.53	0.07	0.02	0.12	0.68
29	1.95	0.24	0.32	1.82	-0.41	-1.78	0.07	0.19	0.11	0.18	0.03	0.01	0.47
30	1.94	0.31	0.40	-0.01	0.79	1.19	0.26	0.17	0.10	0.19	0.14	0.03	0.44
31	1.92	0.33	0.52	-0.43	-1.81	-0.91	0.11	0.34	0.07	0.16	0.25	0.07	0.32
32	1.91	0.17	0.34	1.09	-0.78	-0.88	0.10	0.08	0.14	0.30	0.08	0.01	0.62
33	1.90	0.12	0.37	-0.66	0.32	-1.13	0.26	0.21	0.35	0.22	0.07	0.61	0.42

Case Study – existing track

	pitch A-B [°]	roll A-B [°]	yaw A-B [°]	bounce 1 [mm]	bounce 2 [mm]	bounce 3 [mm]	roll 1 [°]	roll 2 [°]	roll 3 [°]	yaw 1-A [°]	yaw 2-A [°]	yaw 2-B [°]	yaw 3-B [°]
1	2.97	0.30	0.44	2.77	-3.89	-0.65	0.16	0.14	0.23	0.14	0.04	0.07	0.72
2	2.78	0.31	6.41	-4.47	-1.71	-2.65	0.18	0.09	0.52	4.76	2.47	3.41	2.53
3	2.77	0.47	0.49	3.61	-3.03	-2.80	0.24	0.28	0.15	0.32	0.12	0.05	0.52
4	2.70	0.32	0.52	-0.80	-1.68	-0.42	0.09	0.39	0.08	0.34	0.10	0.05	0.57
5	2.69	0.36	0.51	-0.48	-0.55	-0.95	0.25	0.08	0.29	0.22	0.06	0.04	0.47
6	2.60	0.31	0.43	0.22	-2.31	-1.24	0.12	0.15	0.25	0.16	0.07	0.03	0.52
7	2.58	0.41	0.58	-0.30	-2.29	0.51	0.27	0.62	0.12	0.12	0.03	0.05	0.53
8	2.58	0.25	0.58	-2.97	-2.42	0.32	0.17	0.46	0.18	0.03	0.11	0.04	0.55
9	2.54	0.51	7.44	2.78	-2.10	-4.55	0.21	0.06	0.43	3.63	4.17	2.38	3.70
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13	2.44	0.35	0.40	-1.62	-3.46	-0.47	0.19	0.21	0.09	0.19	0.05	0.02	0.45
14	2.32	0.74	21.66	1.20	2.19	-1.96	0.61	0.62	0.43	5.00	10.99	11.69	13.45
15	2.25	0.22	21.79	2.83	-0.06	-3.85	0.54	0.50	0.43	15.01	14.75	5.64	4.45
16	2.25	0.11	6.99	2.32	-0.77	-0.63	0.34	0.12	0.04	3.45	3.85	2.33	3.66
17	2.22	0.33	0.55	-0.85	-2.73	-0.20	0.11	0.31	0.20	0.19	0.16	0.02	0.42
18	2.21	0.37	0.34	2.94	-1.06	-0.37	0.15	0.12	0.12	0.23	0.04	0.03	0.57
19	2.19	0.40	0.10	-1.16	-0.07	-1.50	0.66	0.26	0.30	0.51	0.18	0.31	0.84
20	2.18	0.18	0.33	1.83	-2.70	-0.95	0.45	0.43	0.14	0.19	0.16	0.26	0.78
21	2.16	0.39	0.41	-0.10	-1.24	1.12	0.06	0.14	0.07	0.12	0.11	0.05	0.44
22	2.16	0.15	1.41	-0.26	-2.53	0.69	0.07	0.08	0.04	1.01	0.49	1.12	0.32
23	2.13	0.31	6.10	0.29	-0.03	-0.88	0.25	0.09	0.20	1.84	3.43	2.84	3.76
24	2.10	0.25	0.41	-0.41	-2.32	1.37	0.16	0.23	0.08	0.18	0.13	0.04	0.51
25	2.08	0.26	0.36	1.58	-3.45	-1.75	0.16	0.24	0.16	0.27	0.15	0.03	0.62
26	2.04	0.33	0.37	-0.33	-1.09	-2.06	0.24	0.28	0.34	0.16	0.08	0.02	0.30
27	1.99	0.02	0.23	-0.40	0.01	-2.34	0.27	0.37	0.59	0.26	0.07	0.57	2.49
28	1.95	0.05	0.24	-0.19	1.49	0.69	0.20	0.42	0.53	0.07	0.02	0.12	0.68
29	1.95	0.24	0.32	1.82	-0.41	-1.78	0.07	0.19	0.11	0.18	0.03	0.01	0.47
30	1.94	0.31	0.40	-0.01	0.79	1.19	0.26	0.17	0.10	0.19	0.14	0.03	0.44
31	1.92	0.33	0.52	-0.43	-1.81	-0.91	0.11	0.34	0.07	0.16	0.25	0.07	0.32
32	1.91	0.17	0.34	1.09	-0.78	-0.88	0.10	0.08	0.14	0.30	0.08	0.01	0.62
33	1.90	0.12	0.37	-0.66	0.32	-1.13	0.26	0.21	0.35	0.22	0.07	0.61	0.42

Case Study – existing track

Investigation approach cont…

- **Results**
  - **Vehicle kinematics (motion) – combinations based on measurements**

CASE NO	ENV COLOR	ROLL (± DEG)	PITCH (± DEG)	YAW (± DEG)	LON (± MM)	LAT (± MM)	VERT (SECONDARY, + MM)	VERT (PRIMARY, + MM)	COMMON SPACE FILE NAME
1PT		0	2.2	17	5	30	45	30	A6MSF4SIM00_-_PWR_TRK_ENV_1PT
2PT		0.66	2.97	15.01	5	30	31.61	30	A6MSF4SIM00_-_PWR_TRK_ENV_2PT
3PT		1.31	1.41	15.06	5	30	31.54	30	A6MSF4SIM00_-_PWR_TRK_ENV_3PT
4PT		1.28	1.98	16.29	5	30	31.05	30	A6MSF4SIM00_-_PWR_TRK_ENV_4PT
5PT		0.92	1.33	4.1	5	30	44.53	30	A6MSF4SIM00_-_PWR_TRK_ENV_5PT
6PT		0	4.1	0	0	0	0	0	A6MSF4SIM00_-_PWR_TRK_ENV_6PT
7PT		0.66	2.97	15.01	5	30	31.61	30	A6MSF4SIM00_-_PWR_TRK_ENV_7PT (CASE 2PT WITH BEAM REMOVED)
8PT		1.28	1.98	16.29	5	30	31.05	30	A6MSF4SIM00_-_PWR_TRK_ENV_8PT (CASE 4PT WITH BEAM REMOVED)

NOTE: A-CAR DEFLECTION WITH RESPECT TO B-CAR *NOT* CONSIDERED (0° PITCH, 0° ROLL).

Case Study – existing track

Investigation approach cont…

- **Results**
  - **Vehicle dynamics (forces) – simulated via MBS**

Case Study – existing track

Investigation approach cont...

- **Results**
  - **Structural loads (forces, moments) – simulated by MBS**
    - **Measured track simulated via MBS**
    - **Track drawing simulated via MBS**
    - **VDV 152 simulated via MBS**

Carbody Operational Loads - Simpack				Rev 3																	
				Full Alignment						Drawing Interpretation						VDV 152					
Number	Channel	Description	Unit	Min	N_mess_min	max	N_mess_max	Mean Force/Moment	Alternating Force/Moment	min	N_mess_min	max	N_mess_max	Mean Force/Moment	Alternating Force/Moment	min	N_mess_min	max	N_mess_max	Mean Force/Moment	Alternating Force/Moment
6	F.x_Car1.B1	x-force A car to pt bolster	N	-43520	38	80529	38	18505	62025	-29862	60	36117	64	3128	32990	-7006	54	6597	54	-205	6801
7	F.y_Car1.B1	y-force A car to pt bolster	N	-17459	27	23507	41	3024	20483	-12156	55	13299	62	572	12727	-15684	53	17067	54	691	16375
8	F.z_Car1.B1	z-force A car to pt bolster	N	112239	40	164489	27	138364	26125	77703	62	135090	56	106396	28693	76487	54	96740	54	86614	10127
9	M.x_Car1.B1	Mx-moment A car to pt bolster	Nm	-40698	27	38596	37	-1051	39647	-26615	56	27843	56	614	27229	-19728	53	20976	53	624	20352
10	M.y_Car1.B1	My-moment A car to pt bolster	Nm	-17640	38	9961	38	-3840	13800	-8396	64	6874	60	-761	7635	-3240	53	1618	54	-811	2429
11	F.x_Car1.CT	x-force A car to ct bolster	N	-50851	38	30980	27	-9935	40915	-23336	64	16123	56	-3607	19729	-12599	51	13289	54	345	12944
12	F.y_Car1.CT	y-force A car to ct bolster	N	-10040	38	13166	41	1563	11603	-7983	63	8062	62	39	8022	-8025	54	8955	54	465	8490
13	F.z_Car1.CT	z-force A car to ct bolster	N	34467	27	67134	44	50801	16333	17301	61	48431	55	32866	15565	15544	54	25377	54	20460	4917

Case Study – existing track

Investigation approach concluded

- Results - summary
  - Measured track simulations resulted in optimized characteristics
    - Vehicle kinematics (motion) – track warp combinations
    - Vehicle dynamics (forces) – gage, warp, curvature combinations
    - Structural loads (forces, moments) – warp, curvature combinations
    - Propulsion (power) - gradients

Case Study – existing track

Investigation approach concluded

- Results - summary

Optimized characteristic determination				
	Tech Spec	Standard	Measured	Combined
Kinematics			✓	
Dynamics			✓	
Structural				✓
Propulsion			✓	

Discussion

Infrastructure - vehicle system integration

- Optimization
  - System integration is a partnership between operator and car builder
    - All parties invested to ensure vehicles perform as intended;
    - Track drawings and standards are not enough information to ensure vehicles will perform as required;
      - Curvature, gage, gradients, warp combinations in as built condition are a necessity.

Contact

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