Silverado 1500 Mass-Reduction and Cost Analysis Project Review

Follow-up to NAS/NRC Committee visit to NVFEL
July 31st, 2014

prepared for: National Academy of Science Committee

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Agenda/Content

- **Introduction**
  - Project Overview
  - Project Team's Vehicle Knowledge
  - Project Methodology Overview
- **Results**
  - Vehicle Level Summary
- **Response to Submitted NAS Questions (9)**
- **Question and Answering Session**

Project Overview

Scope of Study

- Based on a 2011 4x4 Silverado 1500 Crew Cab
- Builds off of previous FEV / EDAG / Munro approach used for EPA's midsize CUV study, but with significant tailoring for a pickup truck.
- Addition of dynamic and durability analyses
  - Dynamic analyses done with instrumenting vehicle and running on test track
  - Includes bed and frame durability under loaded conditions

Boundary Conditions

- No degradation in function, performance (including payload and towing capacities), or safety from the baseline vehicle
- Capable of being mass-produced in the 2020-2025 timeframe (defined as 450,000 units per year)
- 10 percent maximum increase in direct manufacturing costs

Report Timing:

- Peer review underway (sent out July 17th, comments due back to team by end of September)
- Will be publically released in late 2014/early 2015

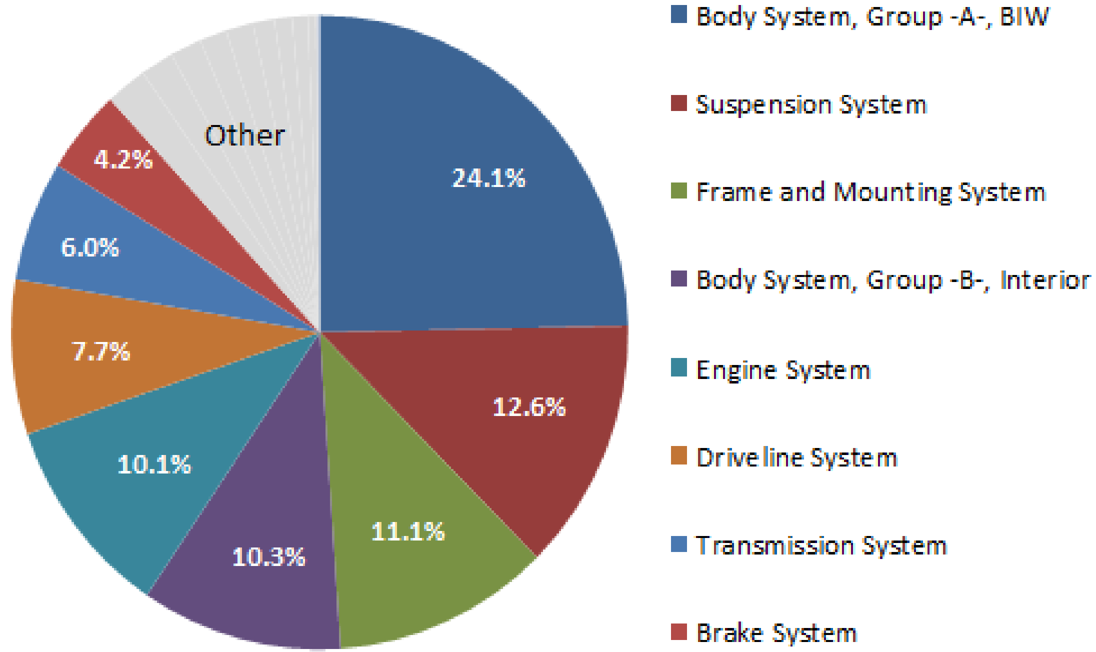
Major deliverables for LD MTE

- Inform the development of cost curves ($/kg per %MR)

Project Team's Vehicle Knowledge

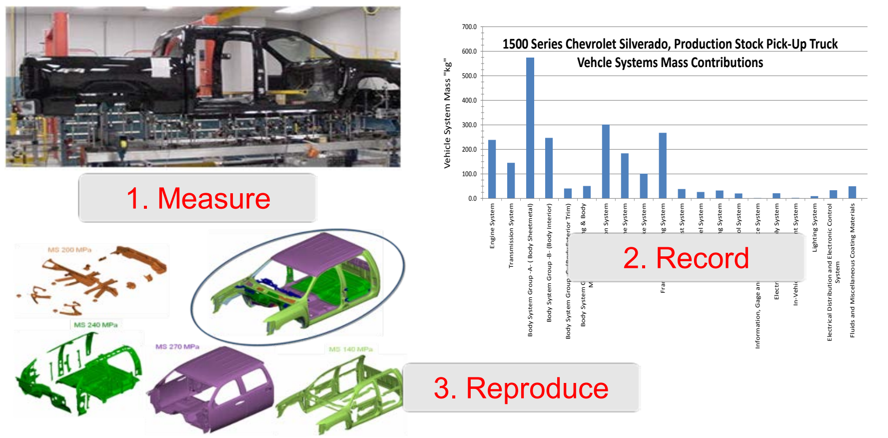
- 24% of vehicle mass is comprised of powertrain and driveline technology (FEV's primary expertise)
- 35% of vehicle mass is comprised of body-in-white and frame and mounting technology (EDAG's primary expertise)
- Remaining systems, including suspension, brakes, and interior components (e.g., seats, instrument panel, climate control), were supported by internal team members from FEV, EDAG, and Munro and Associates
- Also significant external team participation (i.e., material suppliers, component suppliers, equipment suppliers, industry subject matter experts, etc.)

85% of Vehicle Mass Contained Within 8 Primary Vehicle Systems

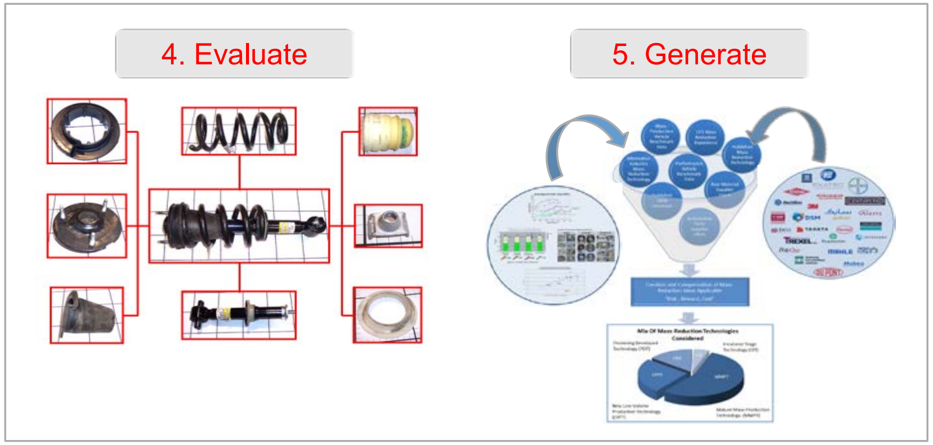


Project Methodology Overview

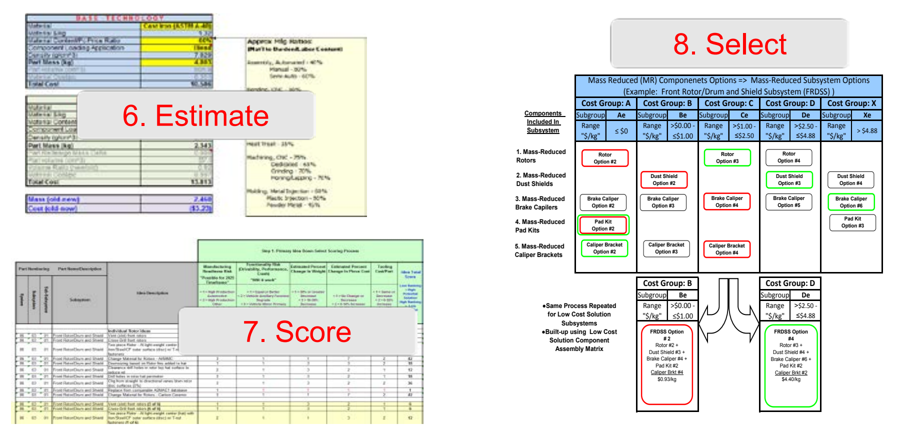
Finger Print Baseline Technology



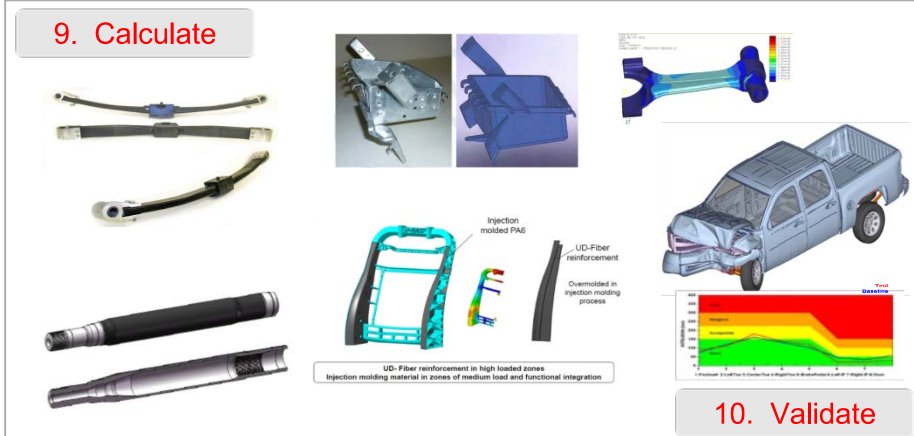
Teardown and Idea Generation



Mass-Reduction and Cost Optimization Process



Detailed Mass-Reduction Feasibility and Cost Analysis



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Summary of Vehicle Results: Mass Reduction and Cost Impact

- **19** vehicle systems investigated for potential mass-reduction opportunities
- Largest contributors to vehicle mass reduction included Body Group -A (BIW), Suspension, Brakes, Engine, Transmission and Body Group-B (e.g. seats, I/P, trim, etc.)
- Net Incremental Direct Manufacturing Costs (NIDMC) are based on mature, high volume production boundary conditions. They do not include OEM mark-up/overhead costs.
- A 50kg, $150 NVH countermeasure allowance was added to protect for negative system interactions

Preliminary results (under peer review)

Item	System ID	Description	Base Mass "kg"	Mass Reduction "kg" (1)	Cost Impact NIDMC "$" (2)	Cost/ Kilogram NIDMC "$/kg" (2)	Cost/ Kilogram NIDMC + Tooling "$/kg" (2)	System Mass Reduction "%"	Vehicle Mass Reduction "%"
			Mass Reduction Impact by Vehicle System (Includes Secondary Mass Savings)						
		1500 Series Chevrolet Silverado Pick-Up Truck							
1	01	Engine System	238.7	37.3	-57.73	-1.55	-1.29	15.6%	1.6%
2	02	Transmission System	145.3	39.4	-96.57	-2.45	-2.47	27.1%	1.6%
3	03A	Body System Group -A- (Body Sheetmetal)	574.7	207.1	-1194.79	-5.77	-5.77	36.0%	8.7%
4	03B	Body System Group -B- (Body Interior)	247.0	34.0	-127.23	-3.74	-3.78	13.8%	1.4%
5	03C	Body System Group -C- (Body Exterior Trim)	40.5	2.1	2.73	1.28	1.28	5.3%	0.1%
6	03D	Body System Group -D- (Glazing & Body Mechatronics)	50.9	4.5	2.30	0.51	0.51	8.9%	0.2%
7	04	Suspension System	301.2	112.7	-26.01	-0.23	-0.24	37.4%	4.7%
8	05	Driveline System	183.8	20.4	38.01	1.86	1.89	11.1%	0.9%
9	06	Brake System	101.0	49.5	-140.06	-2.83	-2.93	49.0%	2.1%
10	07	Frame and Mounting System	267.6	23.7	-54.42	-2.30	-2.30	8.9%	1.0%
11	09	Exhaust System	38.4	6.9	-13.69	-1.97	-1.97	18.1%	0.3%
12	10	Fuel System	26.3	7.3	11.92	1.62	1.77	27.9%	0.3%
13	11	Steering System	32.5	8.5	-147.46	-17.44	-17.45	26.0%	0.4%
14	12	Climate Control System	20.3	1.9	14.71	7.59	7.59	9.5%	0.1%
15	13	Information, Gage and Warning Device System	1.6	0.2	0.66	2.66	2.97	15.7%	0.0%
16	14	Electrical Power Supply System	21.1	12.8	-172.73	-13.49	-13.44	60.6%	0.5%
17	15	In-Vehicle Entertainment System	2.2	0.0	0.00	0.00	0.00	0.0%	0.0%
18	17	Lighting System	9.6	0.4	-2.00	-5.18	-5.18	4.0%	0.0%
19	18	Electrical Distribution and Electronic Control System	33.6	8.5	61.44	7.26	7.27	25.2%	0.4%
20	00	Fluids and Miscellaneous Coating Materials	49.6	0.0	0.00	0.00	0.00	0.0%	0.0%
		a. Analysis Totals Without NVH Counter Measures →	**2386.0**	**577.3**	**-1900.90**	**-3.29**	**-3.28**	**n/a**	**24.2%**
		b. Vehicle NVH Counter Measures (Mass & Cost) →	0.0	-50.0	-150.00	**n/a**	**n/a**	**n/a**	**n/a**
		c. Analysis Totals With NVH Counter Measures →	**2386.0**	**527.3** (Decrease)	**-2050.90** (Increase)	**-3.89** (Increase)	**-3.88** (Increase)	**n/a**	**22.1%**

(1) Negative value (i.e., **-X.XX**) represents an increase in mass
(2) Negative value (i.e., **-$X.XX**) represents an increase in cost

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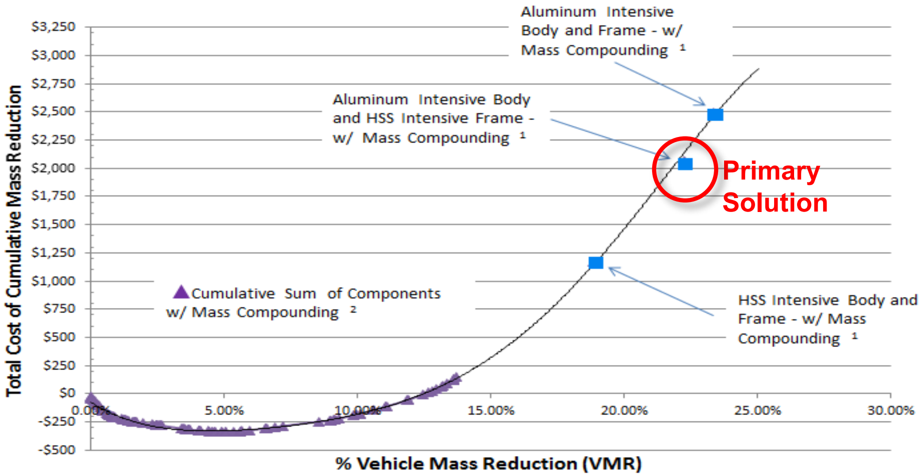
NAS Follow-Up Questions

1. The negative cost mass reduction technologies. What are they? How do they save money?

- Approximately 50% of the mass-reduced components/assemblies selected in the primary solution had some level of cost savings
- But only 20% [106kg/(106kg +421kg)] of the mass reduction involved a cost savings
- The cost savings resulted in a 13% offset towards the cost increases associated with mass-reduction
- Direct manufacturing cost savings associated with mass-savings are derived in a couple different ways
  - Part substitution
  - Design integration and optimization
  - Material substitution
  - Mass-compounding/secondary mass-savings

# Mass Ideas (component and assembly)	Veh MR (kg,%)		NIDMC ($)/ Vehicle
1-70	106	4.5%	- $309
71-145	421	17.6%	+ $2,359

Note: The 145 mass-reduction ideas include individual component ideas as well as larger assemblies (i.e., cabin, cargo box and frame assembly)



1. All vehicle subsystems included in data set
2. Cabin, Cargo Box, Frame and Bumper subsystems not included in data set

Preliminary results (under peer review)

NAS Follow-Up Questions

Examples of Mass-Reduction and Cost Savings Ideas (Long-Term)

Material and Design Optimization

C-70 vs. PM Connecting Rods

Material and Design Substitution

DuPont™ Vespel® SP-21 Thrust Washer vs. roller bearings

Material Processing

PolyOne & Mucell Applications

Material Substitution

Thermoplastic Vulcanizates (TPV) vs. EPDM, Static and Dynamic Weather Seals (Jyco)

Material and Part Consolidation

Passenger Side Airbag Housings (DSM)

Design and Processing

½ Shafts - Vari-lite® tube process (U.S. Manufacturing Corporation)

NAS Follow-Up Questions

2. The compounding mass reductions, what do they consist of, how were their impacts and costs estimated?

- The vehicle systems which incorporated mass compounding (or secondary mass savings) included the body, frame, engine, transmission, suspension, brake, exhaust and fuel systems
- At the component and system level, engineering estimates were made to determine the level of additional mass reduction/downsizing which could be made as a result of the the overall lower vehicle curb weight and corresponding reduced system loading
- For the body and frame analysis, assumed a uniform 20% mass-reduction of the major components in each system. Updates were made to the CAE model to account for the revised weights and distributions for non-body and frame systems.
- All other vehicle systems were first mass-reduced with no consideration of SMS (12.8% vehicle mass reduction). In the next step, mass compounding was considered (also based on an assumption of a 20% lighter vehicle)

NAS Follow-Up Questions

- The incremental mass and cost impact, as a result of mass compounding are shown in the table below
- Since the Body and Frame Systems were only evaluated with consideration to mass compounding at 20% vehicle mass-reduction, these systems are not shown in the table

Preliminary results (under peer review)

			Secondary Mass Savings (SMS) Impact by Vehicle System									
Item	System ID	Description	Base Mass "kg"	Mass Reduction with SMS "kg" (1)	Mass Reduction without SMS "kg" (1)	Incremental Mass Reduction from SMS "kg" (1)	Cost Impact NIDMC with SMS "$" (2)	Cost Impact NIDMC without SMS "$" (2)	Incremental Cost Impact from SMS "$" (2)	Cost/ Kilogram NIDMC with SMS "$/kg" (2)	Cost/ Kilogram NIDMC without SMS "$/kg" (2)	Incremental Cost/ Kilogram NIDMC from SMS "$/kg" (2)
1500 Series Chevrolet Silverado Pick-Up Truck												
1	01	Engine System	238.7	37.3	29.7	7.6	-57.73	-78.75	21.02	-1.55	-2.65	1.10
2	02	Transmission System	145.3	39.4	34.2	5.2	-96.57	-128.20	31.64	-2.45	-3.75	1.30
7	04	Suspension System	301.2	112.7	91.9	20.8	-26.01	-183.78	157.76	-0.23	-2.00	1.77
9	06	Brake System	101.0	49.5	46.6	2.9	-140.06	-159.91	19.85	-2.83	-3.43	0.60
11	09	Exhaust System	38.4	6.9	6.3	0.6	-13.69	-19.54	5.85	-1.97	-3.08	1.11
12	10	Fuel System	26.3	7.3	1.6	5.7	11.92	3.25	8.67	1.62	2.02	-0.40
a. Analysis Totals Without NVH Counter Measures →			**851.0**	**346.5** (Decrease)	**303.8** (Decrease)	**42.8** (Decrease)	**-651.70** (Increase)	**-896.49** (Increase)	**244.79** (Decrease)	**-1.88** (Increase)	**-2.95** (Increase)	**1.07** (Decrease)

(1) Negative value (i.e., -X.XX) represents an increase in mass
(2) Negative value (i.e., -$X.XX) represents an increase in cost

FEV

NAS Follow-Up Questions

The following engine example illustrates how the mass and cost impact associated with mass compounding were calculated

Step 1 – Downsizing Estimate

- Team assumed a 20% curb weight reduction could be achieved based on initial results
- 20% mass reduction = 477 kg
- 477 kg relative to the Gross Combination Weight Rating (GCWR) = 7% mass-reduction (477kg/6804kg)
- Assumed engine could be downsized by approximately 7% maintaining overall vehicle performance (235kW -> 218kW)
- Assuming a constant power/displacement ratio (kW/liter) a new engine displacement of 4.9 liters was calculated

ENGINE SIZING	
Silverado Curb Weight Reduction	**20%**
Lightened Curb Weight (kgs)	1909
Lightened Weight (GCWR)	6327
Chevy Silverado Curb Weight (kgs)	2386
Gross Combination Weight Rating (GCWR)	6804
Power Reduction Factor	0.930
5.3L Power (kW @5200)	235
5.3L Torque (N*m @4000)	454
Reduced-Weight Power (kW)	218
Reduced-Weight Torque (N*m)	422
Vortech 5.3L Displacement (L)	5.3
Downsized Displacement (L)	**4.9**

Preliminary results (under peer review)

NAS Follow-Up Questions

Mass and Cost Compounding Credit Example - Engine

Step 2 - Mass Reduction Calculations

- Two approaches were taken to convert 7% power reduction to component mass reduction
- One approached assumed components could be downsized by the percent power reduction
- Second approach assumed displacement difference is accounted for in the cylinder bore diameter (i.e., baseline bore diameter 96 mm -> new bore diameter 92.4 mm)
- Using one of the two approaches secondary mass savings were calculated on the mass-reduced components

Preliminary results (under peer review)

	Component	New Mass (kg)	Downsizing Approach	% Reduction	Length Reduction (mm)	Component Length (mm)	Compounded Mass Savings (kg)
1	Engine Mounts	4.963	Power Reduction	7.0%			0.348
2	Crankshaft	22.973	Power Reduction	7.0%			1.611
3	Connecting Rod	3.584	Power Reduction	7.0%			0.251
4	Piston	3.392	Area Reduction	7.3%			0.249
5	Engine Block	43.695	Power Reduction	7.0%			3.065
6	Cylinder Head length	22.618	Block Length Reduction	2.9%	14.4	500	0.650
6	Cylinder Head width	21.968	Deck Width Reduction	2.4%	3.6	150	0.526
7	Valve Cover	1.120	Block Length Reduction	3.0%	14.4	480	0.034
8	Camshaft	3.491	Block Length Reduction	2.9%	14.4	500	0.100
9	Harmonic Balancer	3.698	Power Reduction	7.0%			0.259
10	Oil Pan	3.949	Block Length Reduction	2.6%	14.4	560	0.101
11	Windage Plate	0.369	Block Length Reduction	3.1%	14.4	470	0.011
12	Radiator	5.684	Power Reduction	7.0%			0.399
	Total (kg)	141.504					**7.605**

FEV

NAS Follow-Up Questions

Mass and Cost Compounding Credit Example - Engine

Step 3 – Mass Compounding Cost Calculations

- Costs were developed by updating a copies of the original MAQS worksheets without secondary mass savings
- Adjustments were made to material mass, processing parameters and mark-up, were applicable
- Subtracting the "New" mass-reduced component costs from the "Compounded" mass-reduced component costs, the contribution for secondary mass-savings were calculated
- All cost models, where secondary mass savings are applicable, contain "Baseline" "New" and "Compounded" worksheets

Preliminary results (under peer review)

System	Subsystem	Sub-Subsystem	Description	Net Value of Mass Reduction Idea: Idea Level Select	Mass Reduction "kg" (1)	Cost Impact "$" (2)	Average Cost/ Kilogram $/kg	Subsys./ Subsys. Mass Reduction "%"	Vehicle Mass Reduction "%"
			Secondary Mass Reduction						
01	**00**	**00**	**Engine System**						
01	02	00	Engine Frames, Mounting, and Brackets Subsystem		0.348	0.578	$1.66	5.74%	0.01%
01	03	00	Crank Drive Subsystem		2.111	4.100	$1.94	5.70%	0.09%
01	04	00	Counter Balance Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	05	00	Cylinder Block Subsystem		3.065	9.354	$3.05	5.12%	0.13%
01	06	00	Cylinder Head Subsystem		1.210	3.693	$3.05	4.86%	0.05%
01	07	00	Valvetrain Subsystem		0.100	0.144	$1.44	0.62%	0.00%
01	08	00	Timing Drive Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	09	00	Accessory Drive Subsystem		0.259	0.852	$0.00	3.13%	0.01%
01	10	00	Air Intake Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	11	00	Fuel Induction Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	12	00	Exhaust Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	13	00	Lubrication Subsystem		0.112	0.554	$4.94	1.06%	0.00%
01	14	00	Cooling Subsystem		0.399	1.843	$4.62	1.64%	0.02%
01	15	00	Induction Air Charging Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	16	00	Exhaust Gas Re-circulation Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	17	00	Breather Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	60	00	Engine Management, Engine Electronic,		0.000	0.000	$0.00	0.00%	0.00%
01	70	00	Accessory Subsystems (Start Motor, Generator,		0.000	0.000	$0.00	0.00%	0.00%
				A	**7.604** (Decrease)	**21.118** (Decrease)	**2.777** (Decrease)	**3.17%**	**0.32%**

FEV

NAS Follow-Up Questions

4. When the engine was downsized by 5-6% for this study, were cost savings for this downsizing included in the overall costs? What were the cost savings for the engine displacement reduction?

- Engine downsizing was 7% by displacement as shown in previous slides
- Yes, additional cost savings as a result of engine downsizing were included in the overall costs (i.e., the primary solution)
- The engine downsizing mass-reduction was 7.6 kg at a cost savings of $21.2

5. The engine system had 37.3 kg mass savings. Did this include downsizing? Only 9.1 kg of mass savings were shown on Slide 17. What other engine components had mass reductions?

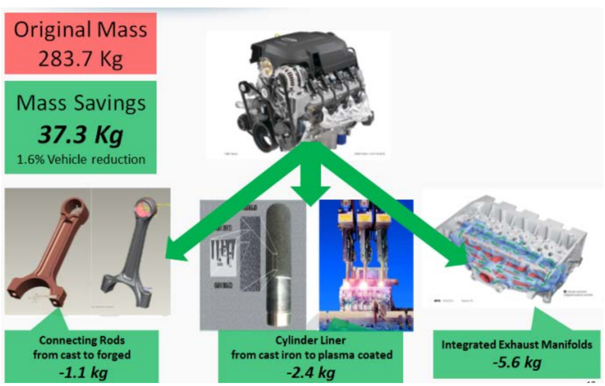
- Yes, the 37.3 kg of mass savings did include the 7.6 kg downsizing credit

Note: Question #3 will be addressed at the end of the presentation

NAS Follow-Up Questions

Engine mass reduction contributions by Subsystem

Engine mass reduction contributions highlighted during the NAS/NRC Committee visit to NVFEL with related subsystems "★"



Preliminary results (under peer review)

				Net Value of Mass Reduction Idea					
System	Subsystem	Sub-Subsystem	Description	Idea Level Select	Mass Reduction "kg" (1)	Cost Impact "$" (2)	Average Cost/ Kilogram $/kg	Subsys./ Subsys. Mass Reduction "%"	Vehicle Mass Reduction "%"
01	**00**	**00**	**Engine System**						
01	02	00	Engine Frames, Mounting, and Brackets Subsystem		1.451	0.568	$0.39	23.91%	0.06%
01	03	00	Crank Drive Subsystem		4.786	7.807	$1.63	12.93%	0.20%
01	04	00	Counter Balance Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	05	00	Cylinder Block Subsystem		6.363	10.151	$1.60	10.63%	0.27%
01	06	00	Cylinder Head Subsystem		2.371	9.751	$4.11	9.52%	0.10%
01	07	00	Valvetrain Subsystem		1.383	-0.542	-$0.39	8.51%	0.06%
01	08	00	Timing Drive Subsystem		0.415	-2.442	-$5.88	23.72%	0.02%
01	09	00	Accessory Drive Subsystem		2.932	0.056	$0.00	35.44%	0.12%
01	10	00	Air Intake Subsystem		1.164	1.316	$1.13	9.74%	0.05%
01	11	00	Fuel Induction Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	12	00	Exhaust Subsystem		5.592	13.621	$0.00	45.96%	0.23%
01	13	00	Lubrication Subsystem		3.194	-11.015	-$3.45	30.28%	0.13%
01	14	00	Cooling Subsystem		4.549	-88.086	-$19.36	18.70%	0.19%
01	15	00	Induction Air Charging Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	16	00	Exhaust Gas Re-circulation Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	17	00	Breather Subsystem		0.000	0.000	$0.00	0.00%	0.00%
01	60	00	Engine Management, Engine Electronic,		0.886	1.973	$2.23	15.63%	0.04%
01	70	00	Accessory Subsystems (Start Motor, Generator,		2.229	-0.892	-$0.40	11.20%	0.09%
				C	**37.316** (Decrease)	**-57.734** (Increase)	**-1.547** (Increase)	**15.55%**	**1.56%**

(1) "+" = mass decrease, "-" = mass increase
(2) "+" = cost decrease, "-" = cost increase

NAS Follow-Up Questions

Selected Engine Component/Assembly Contributions to Mass Reduction

- Cylinder Head Covers: Aluminum valve covers were replaced by plastic. Mass was reduced by 44.0% from 2.64 kg to 1.48 kg.
  - Production examples include Chrysler's 4.7L V8 and the Ford Duratec® 2.0L.
- Camshafts: The core-drilled steel camshaft was replaced with hollow-cast. Mass was reduced by 21.2% from 4.60 kg to 3.63 kg.
  - Production examples include GM's 1.4L Ecotec and BMW's S85B50 (V10 5.8L DOHC ICE) .
- Oil Pan: Mass reduction of the oil pan was achieved on the baseline engine by replacing aluminum with magnesium. Mass was reduced by 25% from 5.27 kg to 3.96 kg. Steel baffle plates are used to control oil flow within the oil pan region. Stamped steel baffle plates were changed to plastic. Mass was reduced by 70.6% from 1.65 kg to 0.49 kg.
  - Nissan GT-R oil pan is constructed from magnesium
  - Ford Mustang has plastic baffle plates
- Water Pump: The conventional mechanical water pump was replaced with an electric water pump. Mass was reduced by 51.9% from 4.68 kg to 2.43 kg.
  - Electric water pumps are found on vehicles such as the BMW 328, 528, and X3/5.

Preliminary results (under peer review)

NAS Follow-Up Questions

6. The integrated exhaust manifold in the cylinder head was shown to save 5.6 kg. Was the cooling system upgraded (adding mass) to accommodate the added cooling load?

- No, an update to the analysis is required to address additional cooling requirements. For passenger car this may not be such an issue. System is sized to handle extreme transients. For truck applications, full power demand more prevalent in average customer duty cycle so larger cooling system likely required.

NAS Follow-Up Questions

7. What are the highlights of the cost savings associated with the transmission mass reduction where 10.7 kg was saved by switching from aluminum to magnesium for the case material?

- The primary mass reduction ideas for the Case Subsystem involved changing selected cases from aluminum to magnesium. The aluminum baseline design mass was 30.7 kg. The magnesium redesign mass was 20.1 kg resulting in an overall mass savings of 10.7 kg (34.7%). Additional mass and cost details found in adjacent table.
- Examples of magnesium transmission and transfer cases include:
  - Mercedes-Benz 7G-TRONIC transmission is an example having a magnesium transmission case
  - General Motors GMT800 full-size trucks and sport utility vehicles (SUV) is an example of a pick-up truck which utilized a magnesium transfer case.

				Net Value of Mass Reduction Idea					
System	Subsystem	Sub-Subsystem	Description	Idea Level Select	Mass Reduction "kg" (1)	Cost Impact "$" (2)	Average Cost/ Kilogram $/kg	Sub-Subs./ Sub-Subs. Mass Reduction "%"	Vehicle Mass Reduction "%"
02	02	00	**Case Subsystem**						
02	02	01	Tranmission Case		6.934	-$21.38	-$3.08	36.91%	0.29%
02	02	02	Transfer Housing		3.408	-$4.50	-$1.32	33.77%	0.14%
02	02	03	Covers		0.014	-$0.13	-$9.51	37.84%	0.00%
02	02	04	Transmission Fluid measurement		0.303	-$1.07	-$3.52	83.47%	0.01%
02	02	05	Bolts		0.000	-$3.53	--	--	0.00%
02	02	99	Misc.		0.000	$0.00	--	--	0.00%
				1C	**10.659** (Decrease)	**-$30.60** (Increase)	**-2.871** (Increase)	**34.69%**	**0.45%**

(1) "+" = mass decrease, "-" = mass increase
(2) "+" = cost decrease, "-" = cost increase

Note:
Negative Cost Values Indicate a Cost Increase
(Base – New = Delta)

Preliminary results (under peer review)

NAS Follow-Up Questions

8. Recognizing that a recent study, 2015 North American Light Vehicle Aluminum Content Study (Ducker Worldwide, 2014), indicated that many pickup trucks, including the Silverado, are likely to introduce aluminum bodies by 2025, how does the FEV study compare with this projection? Can you contrast the cost and benefits of the two strategies: aluminum versus high strength steel?

- The table below highlights the mass and cost difference between an aluminum, and high strength steel intensive, mass reduction strategy

Preliminary results (under peer review)

Item	System ID	Description	Base Mass "kg"	Mass Reduction "kg" (1)	Cost Impact NIDMC "$" (2)	Cost/ Kilogram NIDMC "$/kg" (2)	Cost/ Kilogram NIDMC + Tooling "$/kg" (2)	System Mass Reduction "%"	Vehicle Mass Reduction "%"
		Mass Reduction Impact by Vehicle System							
		1500 Series Chevrolet Silverado Pick-Up - Aluminum Intensive Body and HSS Intensive Frame (i.e., Final Solution)							
		a. Analysis Totals Without NVH Counter Measures	**2386.0**	**577.3**	**-1900.90**	**-3.29**	**-3.28**	**n/a**	**24.2%**
		b. Vehicle NVH Counter Measures (Mass & Cost)	0.0	-50.0	-150.00	n/a	na	na	na
		c. Analysis Totals With NVH Counter Measures	**2386.0**	**527.3** (Decrease)	**-2050.90** (Increase)	**-3.89** (Increase)	**-3.88** (Increase)	**n/a**	**22.1%**
		1500 Series Chevrolet Silverado Pick-Up - HSS Intensive Body and Frame							
		a. Analysis Totals Without NVH Counter Measures	**2386.0**	**489.1**	**-1036.05**	**-2.12**	**-2.11**	**n/a**	**20.5%**
		b. Vehicle NVH Counter Measures (Mass & Cost)	0.0	-42.4	-127.08	n/a	na	na	na
		c. Analysis Totals With NVH Counter Measures	**2386.0**	**446.8** (Decrease)	**-1163.14** (Increase)	**-2.60** (Increase)	**-2.60** (Increase)	**n/a**	**18.7%**
		1500 Series Chevrolet Silverado Pick-Up - Aluminum Intensive Body and Frame							
		a. Analysis Totals Without NVH Counter Measures	**2386.0**	**607.3**	**-2331.32**	**-3.84**	**-3.83**	**n/a**	**25.5%**
		b. Vehicle NVH Counter Measures (Mass & Cost)	0.0	-52.6	-157.79	n/a	n/a	n/a	n/a
		c. Analysis Totals With NVH Counter Measures	**2386.0**	**554.7** (Decrease)	**-2489.11** (Increase)	**-4.49** (Increase)	**-4.48** (Increase)	**n/a**	**23.2%**

(1) Negative value (i.e., **-X.XX**) represents an increase in mass
(2) Negative value (i.e., **-$X.XX**) represents an increase in cost

FEV

NAS Follow-Up Questions

9. The Silverado Study shows a large fraction of mass reductions that come at negative costs (between about 8.5 – 13% of mass reduction at zero to negative costs depending on whether compounding is included). This study adds to other whole vehicle engineering studies of mass reduction opportunities by the agencies (Venza Study - Light-Duty Vehicle Mass Reduction and Cost Analysis – Midsize Crossover Utility Vehicle, Accord study - Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025). Do you have any comments on what additional insights might come from the Silverado study besides the application of this approach to the full sized pickup? Do you have some thoughts on OEMs critiques that some of the light-weighting opportunities indicated in these studies may pose issues related to maintaining baseline vehicle functionality (safety, powertrain performance, manufacturability, maintenance, durability, NVH)?

NAS Follow-Up Questions

- A large percentage of the mass-reduction ideas incorporated into the primary solution have been, or will be in the near-term, incorporated into a mass-production vehicle application. So many of the selected ideas have been proven out in surrogate applications helping establish confidence in-terms of maintaining functionality.
- This is not to say that all ideas are “drop-in-ready” as designs will need to be tailored for each application with consideration to platform specific requirements (e.g. packaging, system interactions, OEM specifications, etc.).
- To help ensure key functionality requirements, including safety and durability, were not degraded with mass-reduction, a significant amount of analytical work (i.e., CAE analysis) was performed. The majority of the CAE work was performed on the body and frame systems; judiciously applied to components in other vehicle systems. In the absence of CAE analyses, the team consulted with industry experts (e.g. material suppliers, component suppliers) to ensure light-weighted components maintained functionality and performance with respect to the baseline vehicle.
- In regards to powertrain systems, the team utilized a combination of benchmark data and internal design team expertise to ensure the selected mass reduction ideas would not negatively impact the powertrain performance.

NAS Follow-Up Questions

- Manufacturability risk level associated with mass reduction was one of the down-selection criteria for determining viable mass-reduction alternatives. For many of the ideas selected, production examples exist. Also because the timeframe for rollout is long-term (2020-2025), any short-term constraints (e.g., material availability, supply base, supporting infrastructure) were considered reconcilable.
- Since the team did not conduct a detailed evaluation on how mass reduced components could potentially impact the NVH performance of the vehicle (from a system/subsystem interaction standpoint), the team added a counter measure allowance of 50 kg and $150 to the final results.
- Maintenance and serviceability feasibility were consider in the analysis. The team did not select mass-reduction ideas where maintenance and serviceability issues could not be overcome long-term. Evaluating maintenance and service cost implications were outside the scope of the analysis – generally addressed through application of EPA ICMs.

NAS Follow-Up Questions

3. a) What are the correct fuel economy impacts of the various percentages of mass reduction? b) Isn't this a matter of the road load induced by acceleration over the test cycles?

- a) In the Lumped Parameter (LP) model, mass reduction effectiveness is coded as
  - 5.1% FE improvement per 10%MR (for non-hybrids)
  - 4.5% FE improvement per 10%MR (for hybrids, due to energy recapture in braking)
- b) Yes, effectiveness values depend on the particular test cycle.
  - Mass reduction primarily affects inertia, but it also affects rolling resistance (since the normal force is reduced). Should have no impact on aero.
  - Ricardo's response surface model (RSM) was used calibrate the LP model for effectiveness
    - Mass sweeps from 0 to 40% MR for all packages (e.g. diesel, STDI, EGRB, etc.) Example shown from "Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe" Ricardo, 2011
    - RSM for two-cycle test was used (combined FTP75 and HWFET)

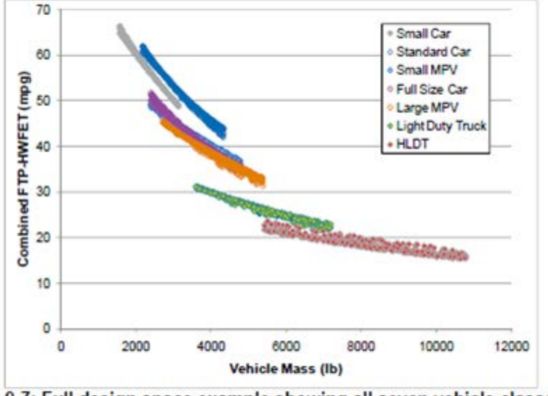


Figure 9.7: Full design space example showing all seven vehicle classes using Stoichiometric DI Turbo engine and advanced automatic transmission with varying vehicle mass and engine displacement.

Question and Answering Session

Q&A