

Development of High Power Density Driveline for Vehicles

O. O. Ajayi, C. Lorenzo-Martin, A. C. Greco,
and G. R. Fenske

Argonne National Laboratory

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Overview

Timeline

- Start date - October 2010
- End date - FY2015
- Percent complete – 5%

Budget

- Total project funding
 - DOE share – 170K
 - Contractor share
- Funding
- FY11 – 170K

Barriers

- Barriers addressed
 - Constant Advances in Technology
 - Computational models, design and simulation methodologies
 - Risk Aversion
 - Cost

Partners

- Interactions/ collaborations
 - General Motors



Project Description and Relevance

- The main goal of DOE-VTP is the reduction of petroleum use in transportation. Such reduction is accompanied by other benefits.
- Significant fuel savings can be achieved by weight reduction in all classes of transportation Vehicles.
- Numerous analyses suggests 2 to 5 % reduction in fuel consumption by 10% reduction in vehicle weight
 - An increasingly necessary approach to fuel saving

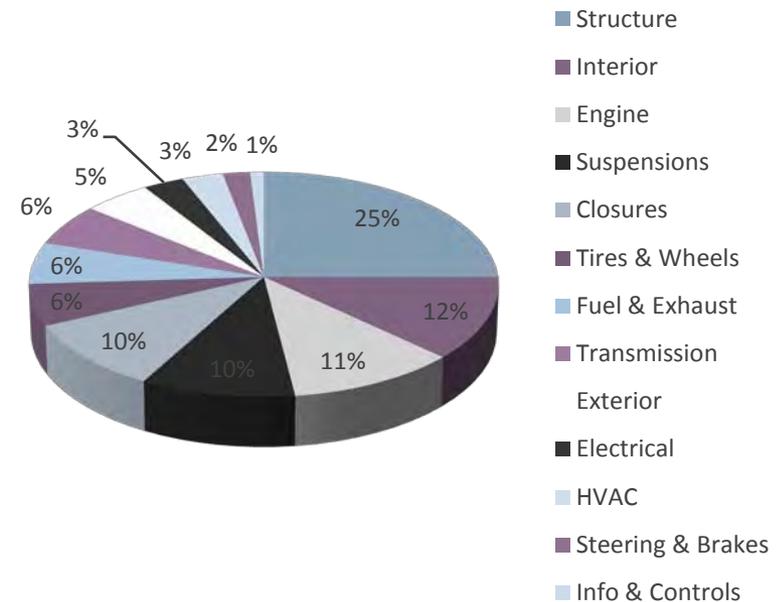
	NEDC ICEV-G	NEDC ICEV-D
Compact Class	-2.6 %	-3.5 %
Mid-Size Class	-1.9 %	-2.7 %
SUV	-2.4 %	-2.6 %

Calculated Fuel savings in
gasoline and diesel vehicles

Project Objective and Relevance

- Weight reduction in vehicles must be accomplished without sacrificing safety, reliability and durability
- Based on weight distribution, systems where significant weight reduction can be achieved are identified.
 - DOE currently have programs for weight reduction in structure and engine – light weight materials
- Driveline system constitutes about 20% of the vehicle's weight
 - Opportunity for weight reduction

Vehicle Weight distribution



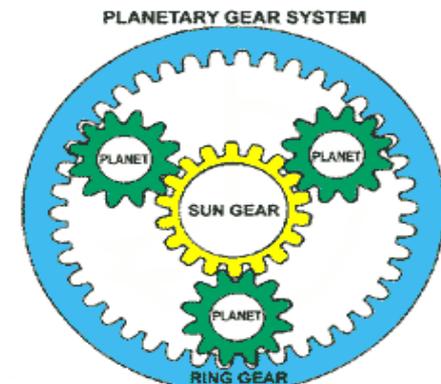
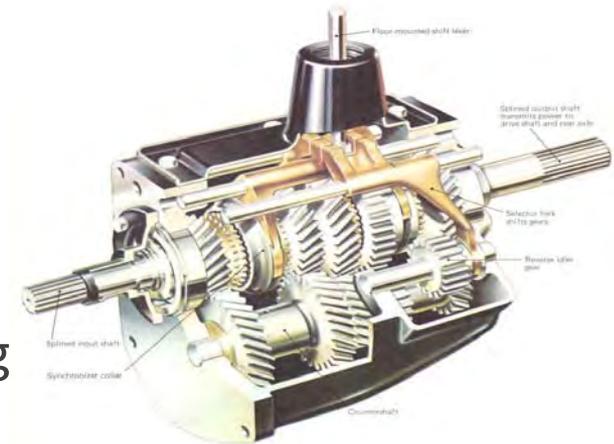
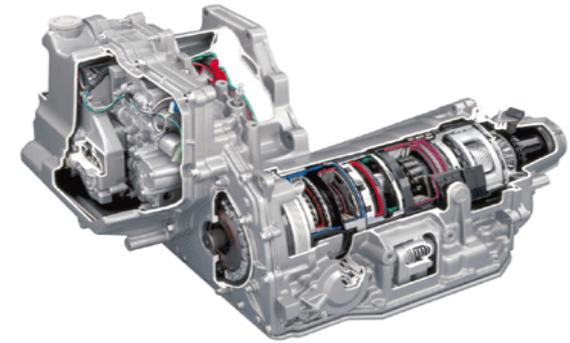
Project Objective and Relevance

- **Objective:** The ultimate objective of this project is to achieve significant vehicle weight reduction through the reduction in size and weight of the driveline systems such as transmission, axle.
- The driveline size reduction will be achieved by increasing the power density of the systems.
 - Can enable downsizing of power-train system without loss of performance
 - Further improvement in fuel savings

	% Improvement in Fuel Economy / % Weight Reduction EPA Combined (Metro-Highway) Drive Cycle			
	Passenger Vehicle		Truck	
	Base Engine	Downsized Engine	Base Engine	Downsized Engine
Gasoline	0.33%	0.65%	0.35%	0.47%
Diesel	0.39%	0.63%	0.36%	0.46%

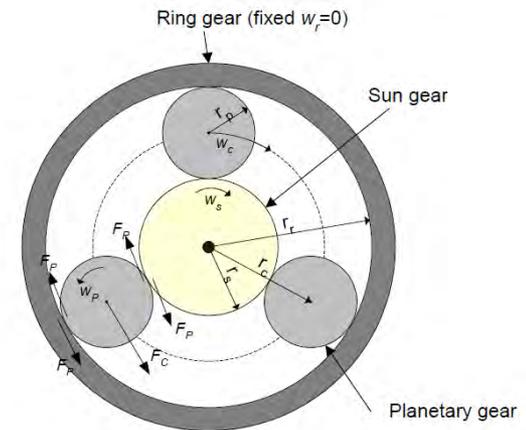
Technical Approach

- Vehicle driveline systems – transmission, axles consist of planetary gear systems and bearings.
- In order to reduce the size of the planetary gear system, high power density gearing and bearings will be required.
 - High severity of contact in gears and bearing
 - Reliability and durability issues
 - Wear; scuffing; and contact fatigue (pitting)
- Integrated materials, surface and lubricant technologies needed



Technical Approach

- In order to establish materials, surface and lubricant technologies target and goals, analyses must be done to - ideally using a model vehicle gearbox
 - Determine gear contact kinematics for gearbox with different levels of size reduction in a planetary gear system
 - Determine impact of new contact parameters on gearbox reliability and durability
 - Wear, scuffing and contact fatigue (pitting) life reduction
- Evaluate performance of some of the existing materials, surface (texture, coatings, treatments.....), and lubricant technologies and their combinations to mitigate reliability and durability issues of high power density (HPD) gearbox.
- Develop and evaluate appropriate surface and lubricant technologies as needed to enhance wear, scuffing and contact fatigue life of gears and bearings.
- In collaboration with OEM partners develop and evaluate prototype HPD gearbox for transportation vehicles.



FY11 Tech. Accomplishments - Contact Kinematics

- Assuming the gear geometry and parameters are unchanged, planetary gearbox size reduction will result in substantial increase in contact and bending stresses and reduction in lubricant entrainment velocity

Size Reduction (%)	Contact Stress Increase (%)	Bending Stress Increase (%)	Entrainment Speed Reduction (%)	Sliding speed
5	5.2	10.8	5.2	No change
10	11.1	23.4	11.1	No change
15	17.6	38.4	17.6	No change
20	25.0	56.2	25.0	No change
25	33.3	77.8	33.3	No change
30	42.9	104.1	42.9	No change
35	53.8	136.7	53.8	No change
40	66.7	177.8	66.7	No change
45	81.8	230.6	81.8	No change
50	100	300.0	100	No change

Opportunity to reduce severity of contact through gear teeth design modifications



FY11 Technical Accomplishments: Failure models

- Scuffing: Scuffing resistance (life) is measured by the contact severity index (CSI)

defined as :

$$CSI = \mu \cdot S_H \cdot S$$

μ = friction coefficient

S_H = Hertzian Stress

S = Sliding Velocity

- Wear: Wear resistance (life) is estimated from Archad's model and wear rate or life is defined as:

$$W = \frac{K \cdot S_H \cdot S}{H}$$

K = Wear factor

S_H = Hertzian Stress

S = Sliding velocity

H = Hardness

- Contact Fatigue: Change in contact fatigue life (CF) as Hertzian contact pressure increases from S_{H1} to S_{H2} can be estimated as:

$$CF = \left(\frac{S_{H1}}{S_{H2}} \right)^{6.666}$$

FY11 Tech. Accomplishments - Implications of new gear contact kinematics

- The new severe contact conditions in gears and bearings as a result of size reduction will have significant effect on gearbox reliability and durability
- Using simple models for wear, scuffing and contact fatigue failure, the impact of new gear contact kinematics on various failure modes are estimated as follows:

Size reduction (%)	Scuffing life reduction (%)	Contact fatigue life reduction (%)	Wear life reduction (%)
5	5.2	28.9	5.2
10	11.1	50.4	11.1
15	17.6	66.1	17.6
20	25.0	77.4	25.0
25	33.3	85.3	33.3
30	42.9	90.7	42.9
35	53.8	94.3	53.8
40	66.7	96.7	66.7
45	81.8	98.1	81.8
50	100	99.0	100

Collaborations

- **General Motors – GM (industry):**
 - Select appropriate gearbox model for HPD technology development
 - Analysis of the real gearbox contact kinematics to determine and quantify required performance properties to ensure adequate reliability and durability

- **Other Potential Collaborators**
 - Wedeven Associates Inc.
 - Leverage their work on helicopter and turbo machinery gearbox

 - DOE Wind Energy Program
 - Leverage efforts on wind turbine gearbox reliability projects

 - Other agencies with programs and projects on gearbox technology development



Proposed Future Work

- Evaluate the wear, scuffing and contact fatigue performance of baseline gear materials and lubricant with appropriate bench-top testing.
 - Effect of load, speed and lubrication on performance will be assessed
- Identify and evaluate the wear, scuffing and contact fatigue performance of some of the current advanced materials, surface (texture, coatings, treatments) and lubricant technologies
 - Effect of load, speed and lubrication on performance will be assessed.
- Develop, and integrate materials, surface and lubricant technologies to meet and perhaps exceed tribological performance targets for smaller and lighter HPD gearbox for transportation vehicles
- In Collaboration with OEM partner(s), optimize design for smaller HPD gearbox
- Build and test prototype HPD gearbox for various transportation vehicle platforms
 - Technology transfer and adoption the ultimate end result

Summary

- Significant weight reduction and consequent fuel savings can be achieved in all transportation vehicle platforms by reducing the size and weight of the driveline system.
 - Can enable downsizing of powertrain system, resulting in more fuel savings.
- In order to reduce the size and weight of driveline systems without loss of transmitted power, high power density gearbox will be required.
- Initial preliminary analysis show that size reduction of driveline system gearbox will be result in significant increase in contact severity of gear teeth.
 - Substantial reduction in reliability and durability as due reduction in wear, scuffing, and contact fatigue life.
- Integrated materials, surface and lubricant technologies will be needed to enable the development of a reliable and durable high power density driveline systems for transportation vehicles.