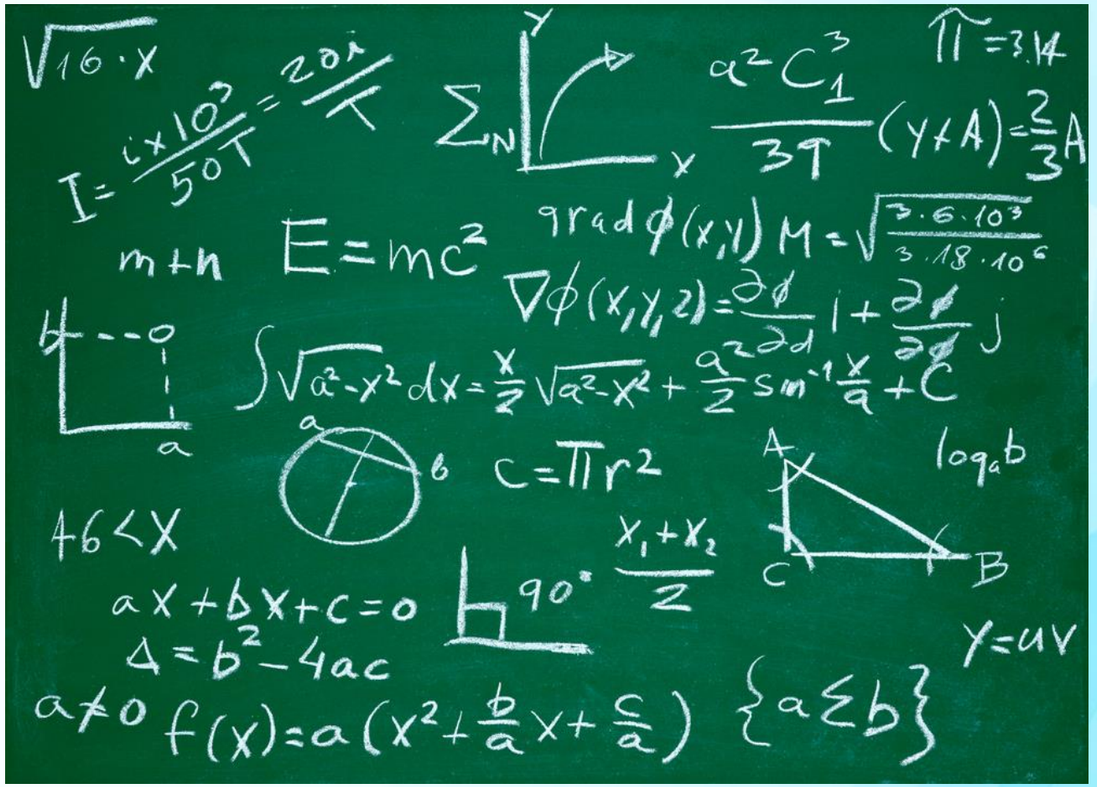
GM RESEARCH & DEVELOPMENT

Math Enabled Innovation



Dr. Paul E. Krajewski

Director, Vehicle Systems Research Lab
GM Global Research & Development

J. T. Wang, Bahram Khalighi, Yilu Zhang

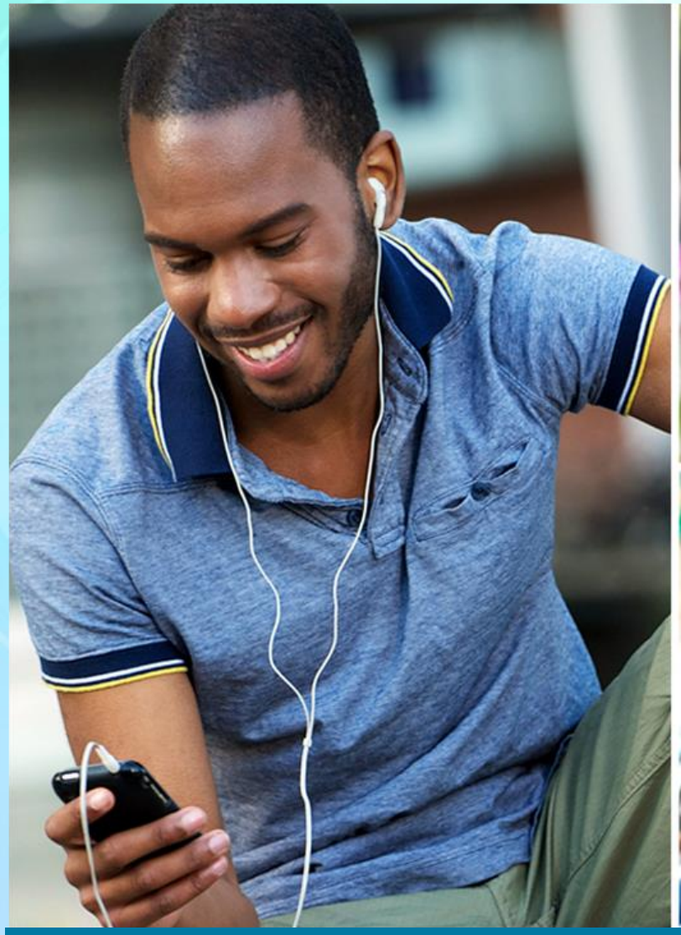
AGENDA

- Connected Living
- Fuel Economy CO_2
  - Aero
  - Electric Vehicles
  - Lightweight Materials
- Personal Security
- Future / Summary

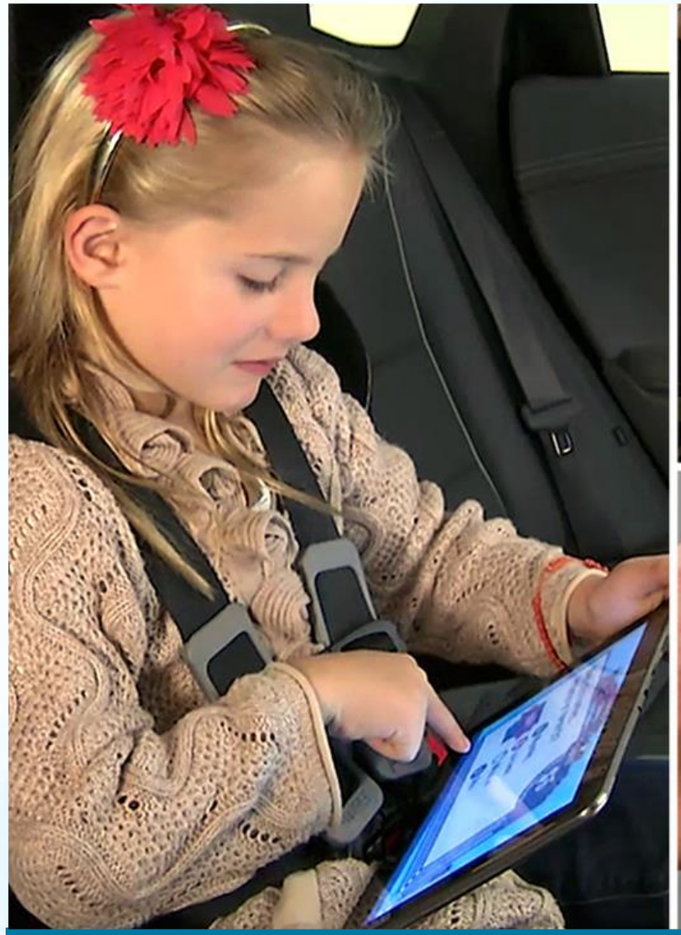
CONNECTED LIVING

- Mobile-cellular subscriptions approaching 7B, the number of people on the earth
- 3B use the Internet
- Facebook has over 1.4 billion active users globally; 85% are mobile users
- 90% of the world's data has been created in the last two years – 2.5 quintillion bytes of data created every day!

CUSTOMER EXPECTATIONS



Bring their digital life into their vehicle



Bring their vehicle into their digital life

WIRELESS CHARGING

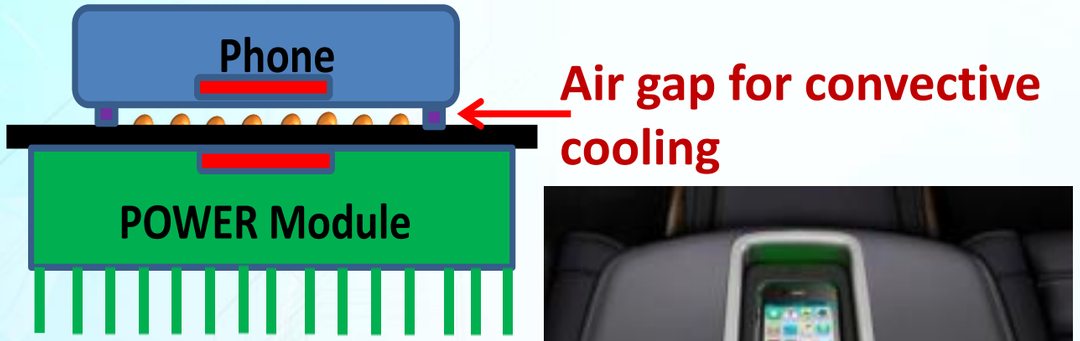
Phone overheating in vehicle cabins using inductive wireless charging led to unacceptable phone charging performance


Arm Rest


Vertical Implementation

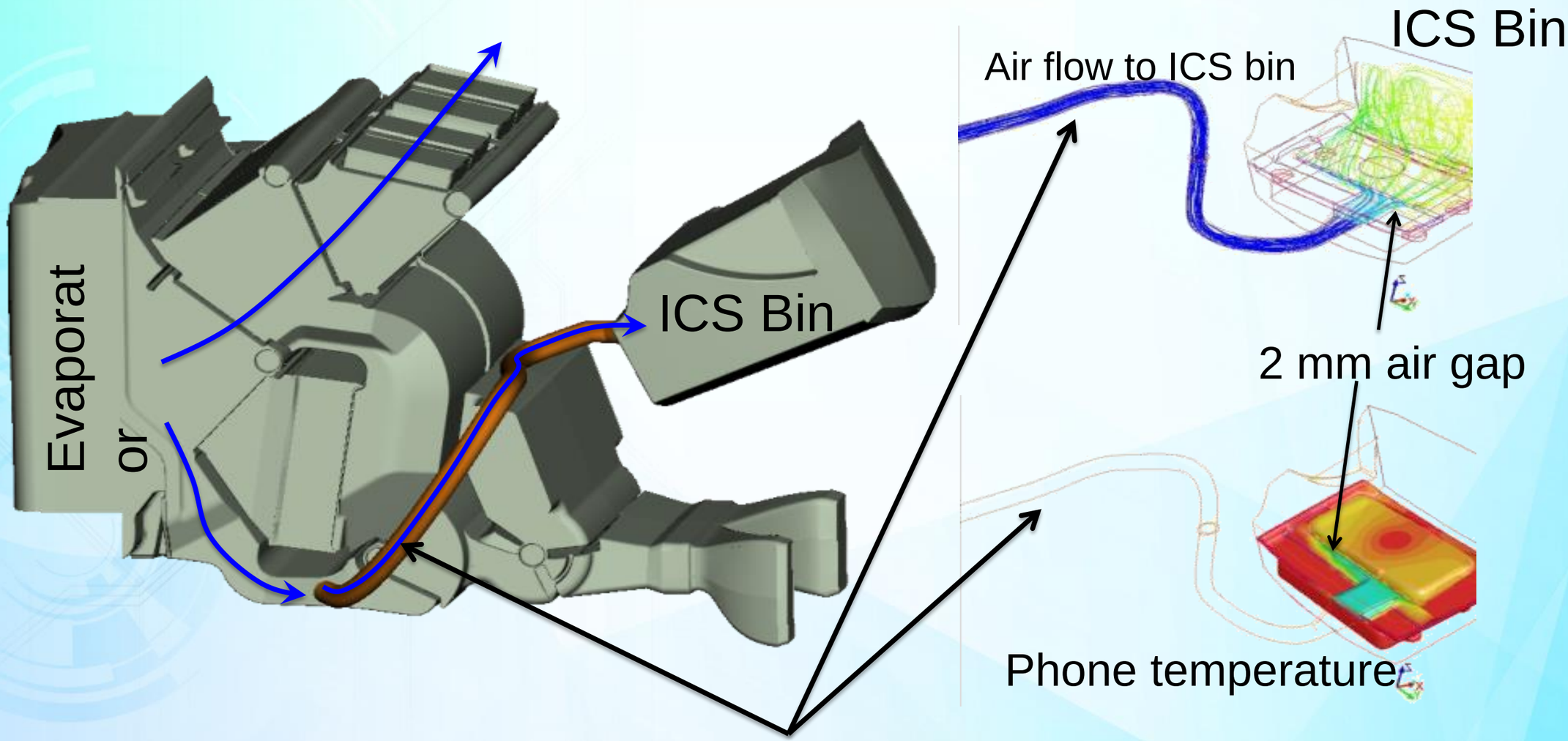
ICS Bin

PASSIVE COOLING



- Passive cooling incorporates an air-gap to facilitate the dissipation of trapped heat from the interface between the phone and charging surface
- CFD tools like Fluent were used to design bumps and spacing

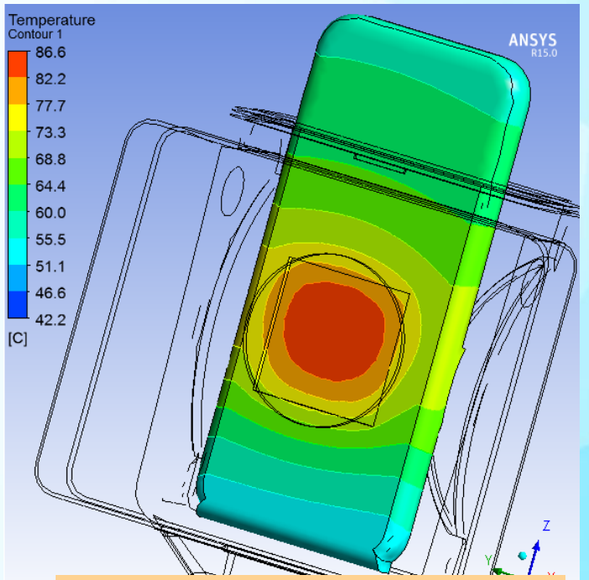
ACTIVE THERMAL MANAGEMENT



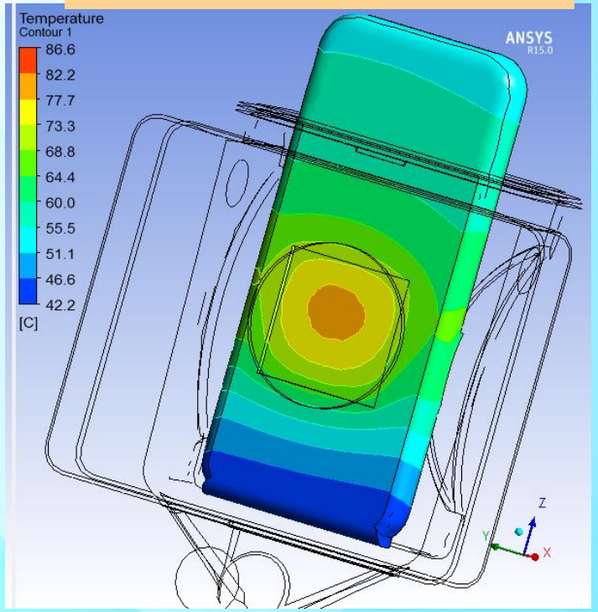
Air from the HVAC module routed to the phone to maintain it within operational temperatures.

RESULTS

- Significant improvement in phone charge times during extreme hot and cold.
- Increased customer acceptance and satisfaction by not compromising charging performance.
- Enabled GM to be the first OEM to provide an integrated dual protocol (WPC and PMA-Powermat) wireless charging system (inductive) in vehicles.



Phone Temperature



2025 CO_2 AND FUEL ECONOMY TARGETS

IHS/CSM Segment	NHTSA Segment	Representative Model	Tailpipe CO_2 (g/KM)	Fuel Economy (mpg)
B-segment Car	Compact Car	Chevrolet Sonic	**78**	**61.1**
D-segment Car	Mid-Size Car	Buick Regal	**88**	**54.9**
E-segment Car	Full-Size Car	Cadillac XTS	**102**	**48.0**
C-segment Truck	Small SUV	Chevrolet Equinox	**102**	**47.5**
D-segment Truck	Mid-Size CUV	Cadillac SRX	**112**	**43.4**
FSFF Truck	Large PU	Chevy Silverado	**150**	**33.0**

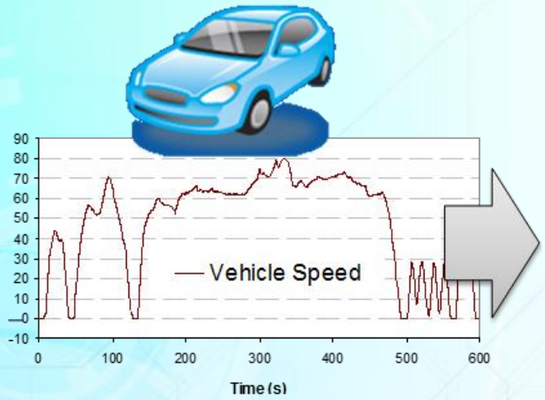
ELECTRIFICATION

BATTERY THERMAL MANAGEMENT

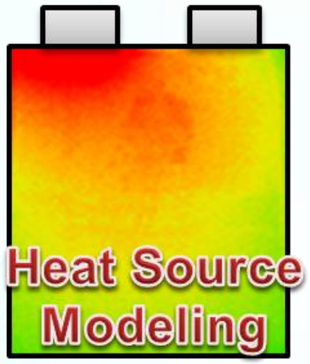
- Temperature impacts battery performance and life.
- Li-Ion batteries in hybrid and EV vehicles undergo constant charging and discharging.
- Active battery cooling is necessary to maintain the cell temperatures within allowable temperature limits (25^oC ~ 35^oC)
- Peak durability and reliability requires $\Delta T<5^oC$ within the cell and across the pack

Chevy Volt
Battery pack

BATTERY PACK DESIGN

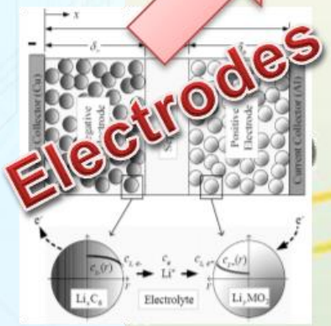


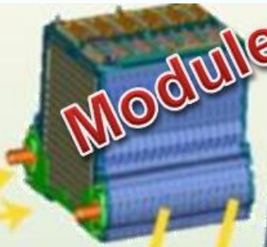
Vehicle Driving Cycle



Electrochemistry
Heat Transfer
Fluid Flow
Material Properties
Design

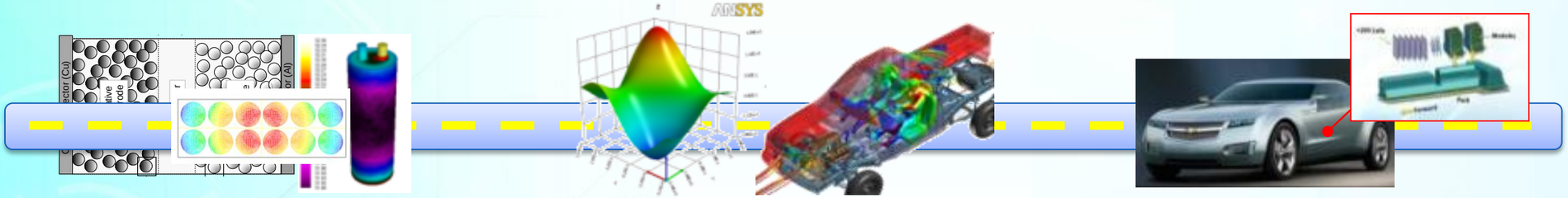
Novel Thermal Concept





Complete Pack

CAEBAT



Computer-aided software design tools for hybrid/electric and electric vehicle (HEV/EV) batteries to reduce cost, improve performance and increase life.

Partners

- GM : End user requirements, verification/validation, project management
- ANSYS : Software dev. and commercialization
- ESim : Cell level sub models, life model
- NREL : Technical monitor

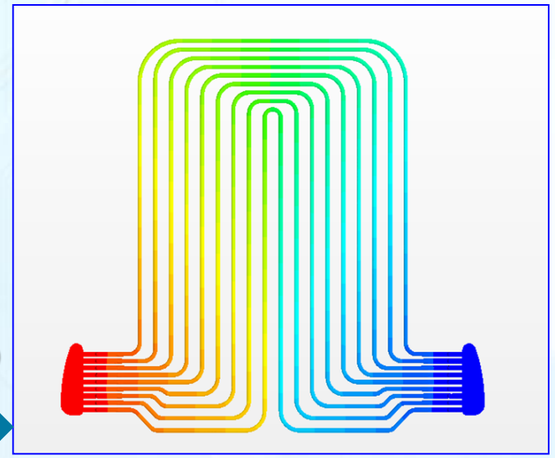
Funding provided by DOE Vehicle Technologies Program .

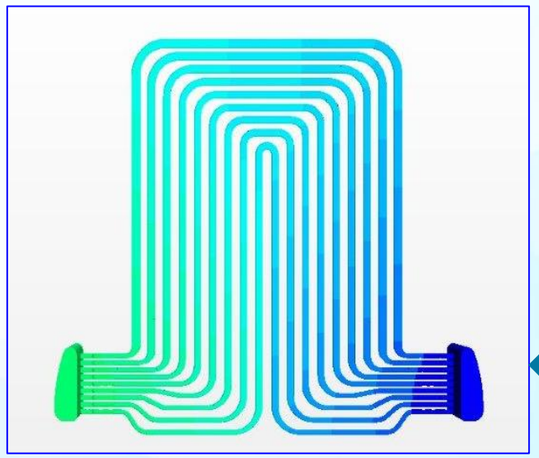
RESULTS

- Cooling design implemented on 2016 Chevy Volt
- Enabled more uniform temperature
- Lower power requirements for cooling

2011 Chevy Volt

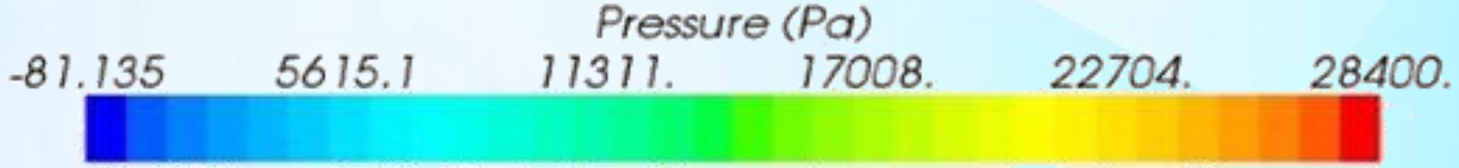
Total pressure drop
= 28.4 kPa



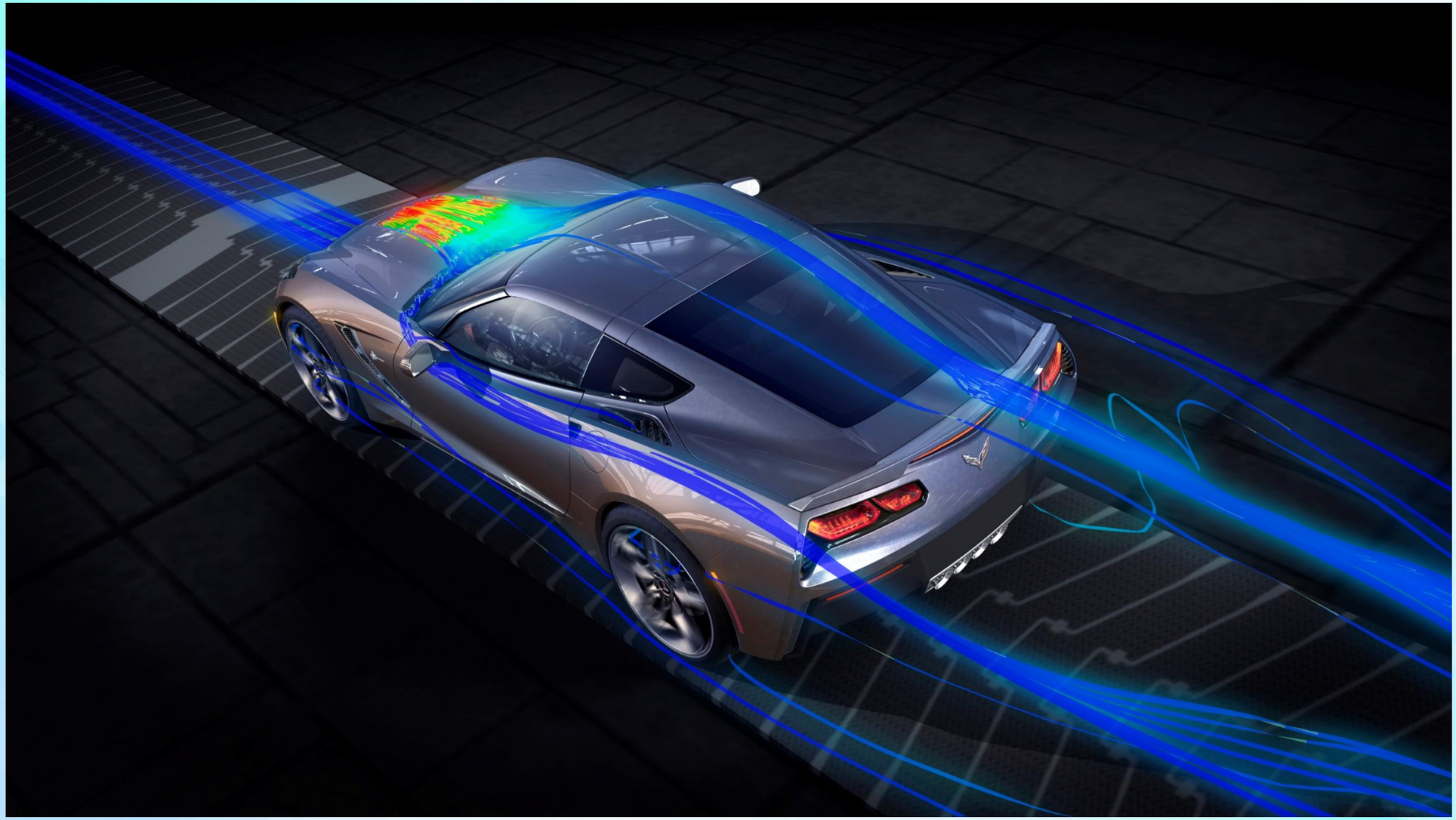


2016 Chevy Volt

Total pressure drop
= 12.4 kPa



AERODYNAMICS



DRAG REDUCTION - CONVENTIONAL METHOD

Parametric sensitivity

- **Approximate a vehicle shape with many design parameters, such as angle, length, curvatures…**
- **Calculate the sensitivity for each design variables**

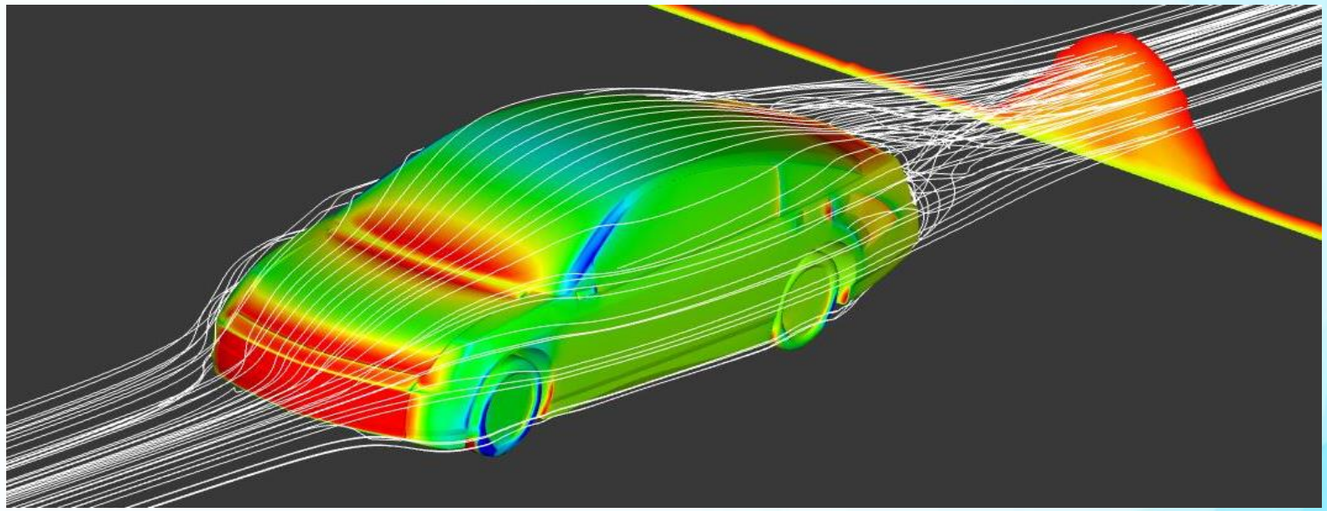
N design parameters

N+1 CFD Flow solutions

- Incremental.
- Takes too long.
- Doesn’t account for multiple interactions

DRAG REDUCTION - ADJOINT METHOD

Precept (Cd=0.19)



- CFD provides diagnostic information for drag reduction.
- CFD is not prescriptive on shape sensitivities nor direction of the shape change.
- Adjoint optimization method provides aerodynamic design information for both shape sensitivity and direction for shape improvements.

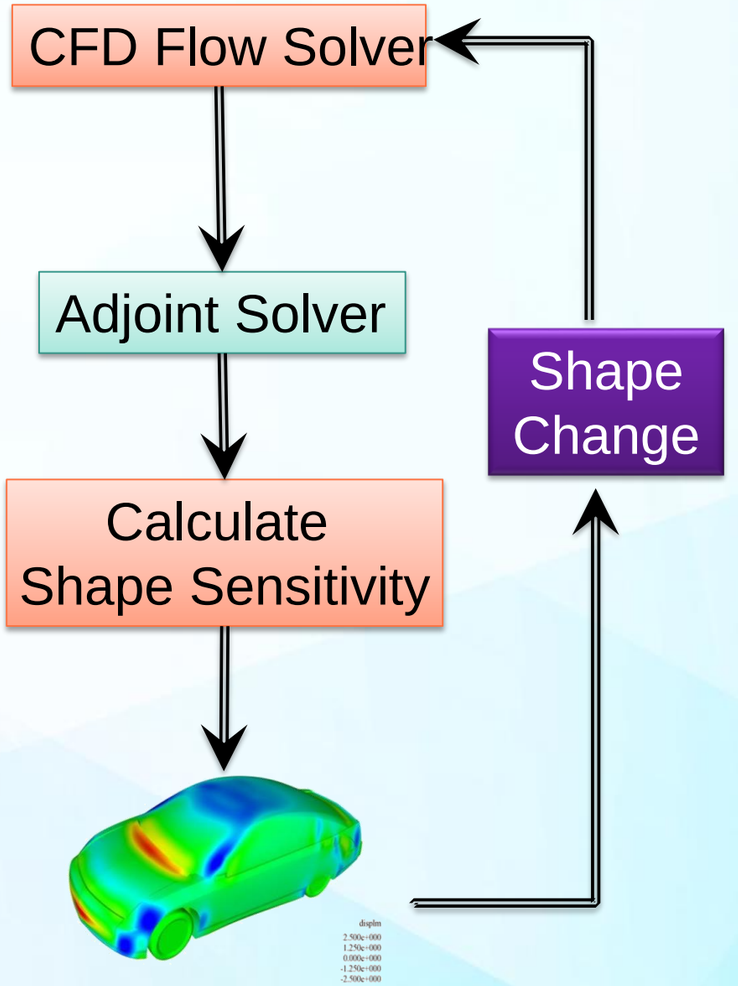
ADJOINT METHODOLOGY

- ***All the surface mesh (x,y,z) locations are the design parameters***
- ***Large number of design parameters 0.5 to 1 million***

N design parameters

1 CFD Flow solution
1 Adjoint solution

Fast & Economical

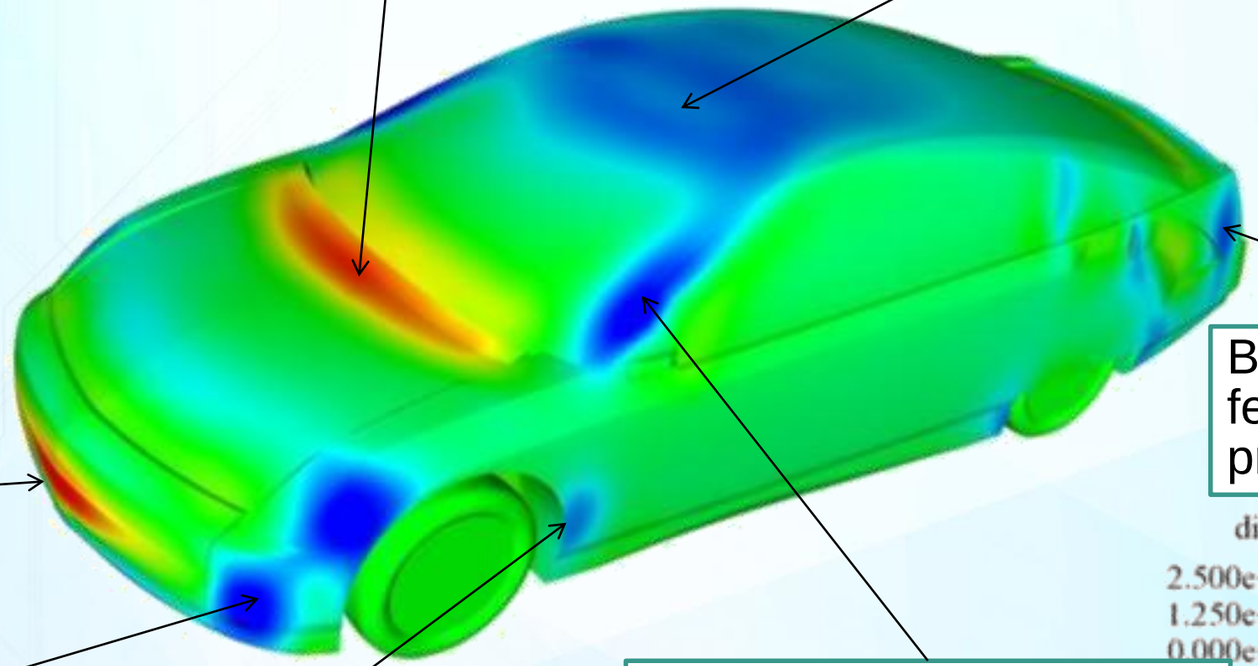


ADJOINT EXAMPLE RESULTS

Red: push outward
Blue: push inward

Raising the cowl area to provide a smooth and continuous flow acceleration

Lowering the roofline to reduce the frontal area



Boat-tailing near the rear fender for a larger pressure recovery

Reduce the stagnation region

Smooth transition near the front fascia

Corner rounding along the sharp corner

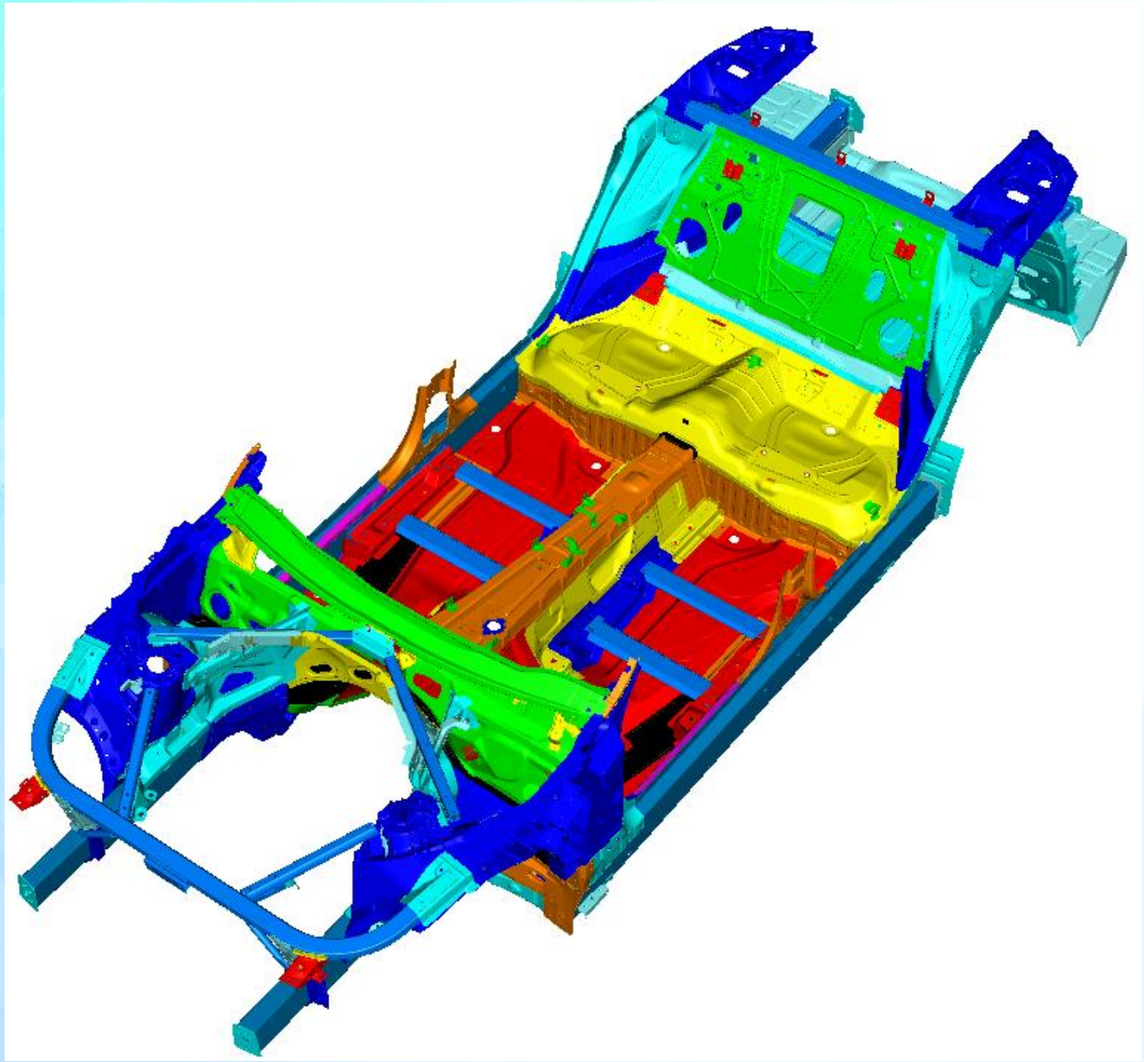
Recessing the A-pillar to reduce the transverse pressure gradient

The modified shape reduced the drag by 4%

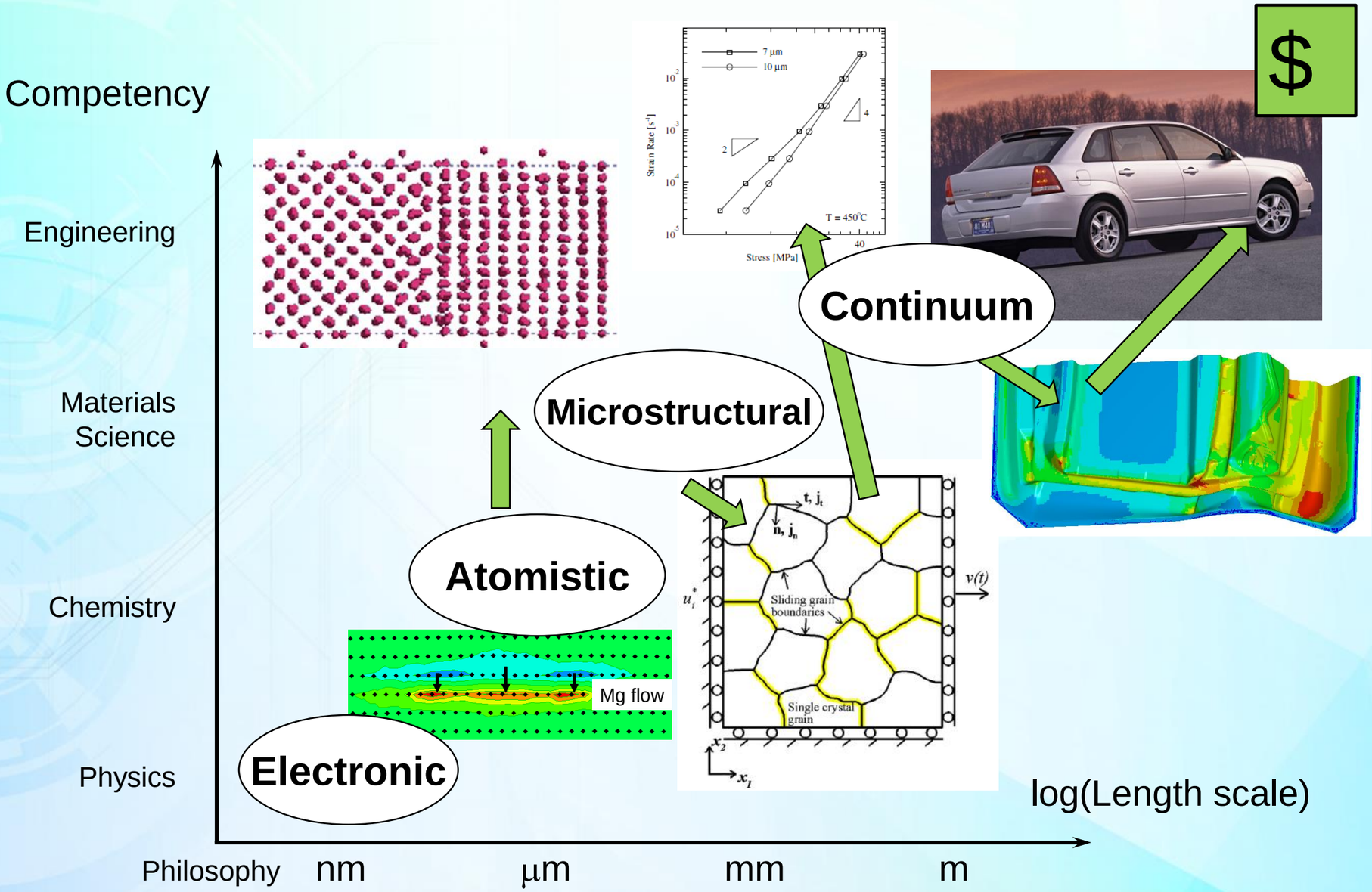
ADJOINT SUMMARY

- Currently using to give guidance to engineers and designers
- Seeing reduction in windtunnel and CFD iterations
- Future integration with other MDO approaches

LIGHTWEIGHT MATERIALS

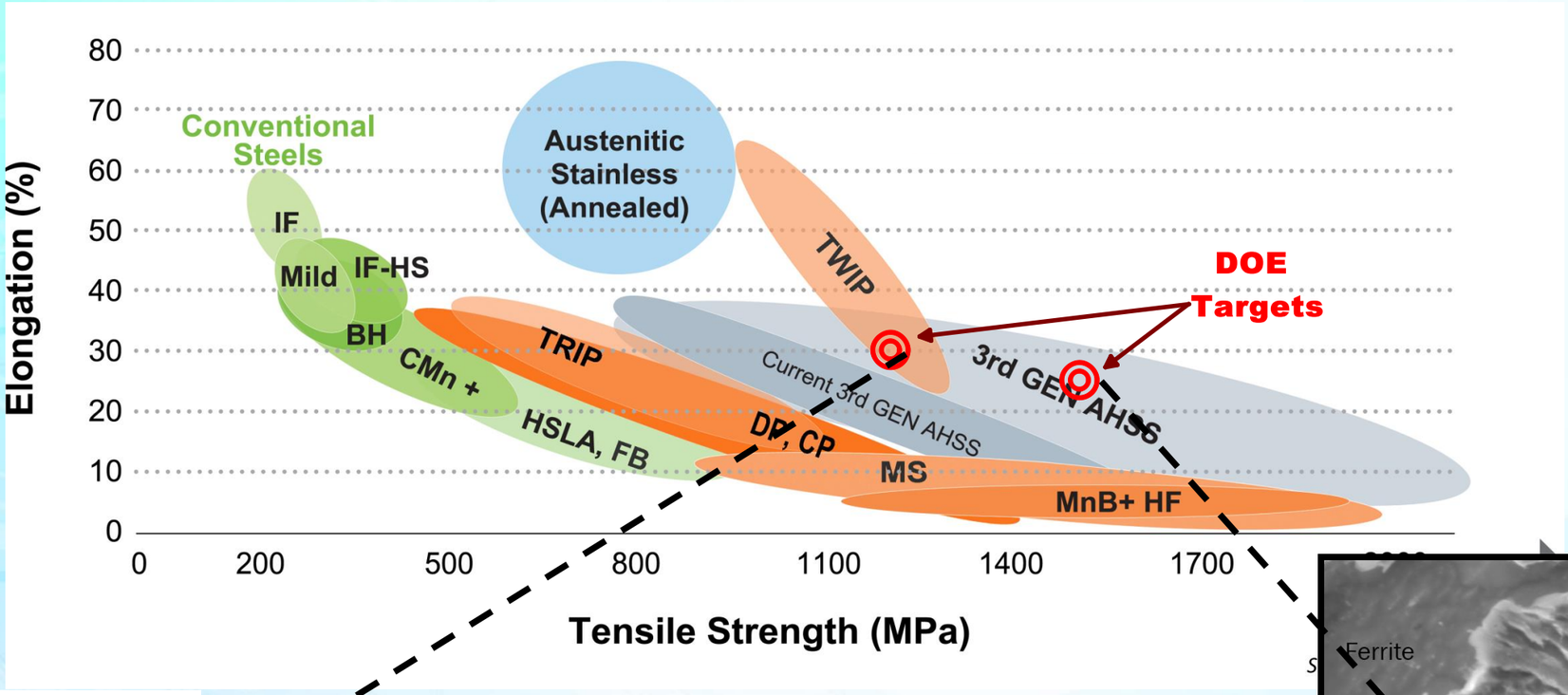


MULTI-SCALE MODELING OF MATERIALS

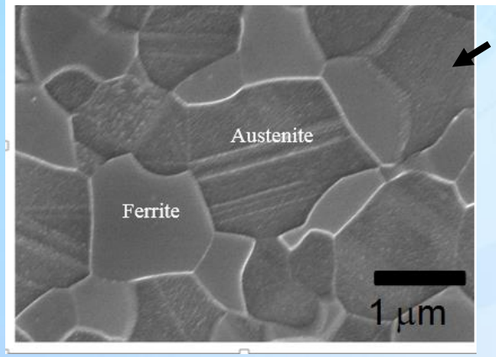


ICME: 3RD GENERATION STEELS

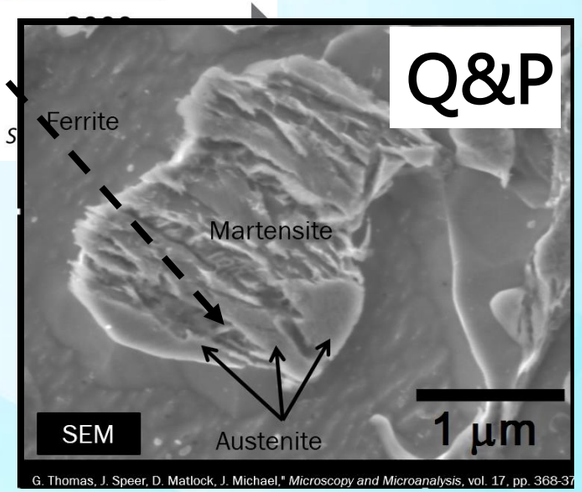
Integrated **C**omputational **M**aterials **E**ngineering



Med. Mn (10wt%)



MathWorks tools used to measure retained austenite volume fraction with strain and parse data



PERSONAL SECURITY

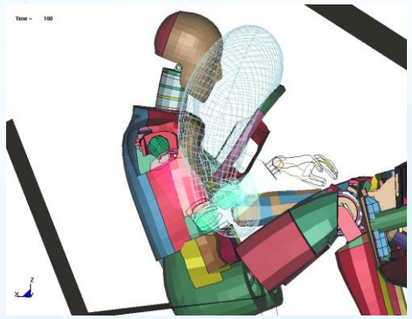
CRASH TEST DUMMIES

CRASH DUMMY BASED SIMULATION

Crash Model

Crash Simulations

Dummy Response



INDIRECT INJURY MEASURES:

- Head injury criterion
- Neck forces
- Chest deflection
- Femur load
- Tibia index

HUMAN-LIKE CRASH TEST/SIMULATION TOOLS

Human

Reduced Biofidelity

Crash Dummies

GLOBAL HUMAN BODY MODELS CONSORTIUM GHBMC

- **Co-founded by GM in 2006, GHBMC is an international consortium of automakers & suppliers working with research institutes and government agencies to advance human body modeling technologies for crash simulations.**

MEMBERS

- **OBJECTIVE: To consolidate world-wide HBM R&D effort into a single global efforts**

- **MISSION: To develop and maintain high fidelity FE human body models for crash simulations**

SPONSOR

NHTSA
www.nhtsa.gov

PARTICIPANTS

Ford

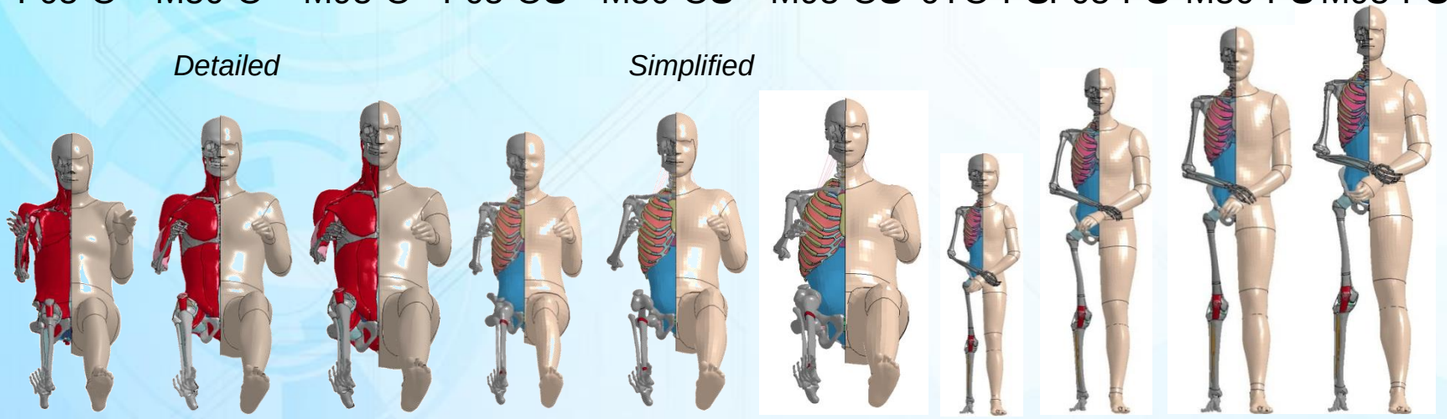
pdb
PARTNERSHIP FOR DUMMY TECHNOLOGY AND BIOMECHANICS

GHBMC DEVELOPMENT STATUS

- **Developed 10 models**
- **Three more detailed pedestrian models (M50-P, F05-P, and M95-P) to be delivered in 2017**

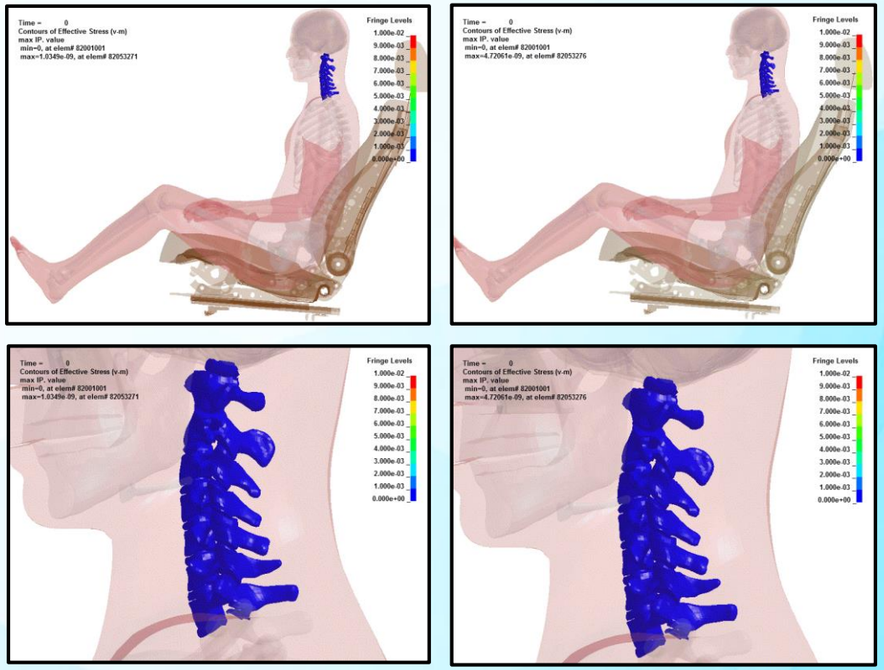
F05-O M50-O M95-O F05-O**S** M50-O**S** M95-O**S** 6YO-P**S** F05-P**S** M50-P**S** M95-P**S**

Detailed *Simplified*



UNBELTED PASSENGER

BELTED PASSENGER



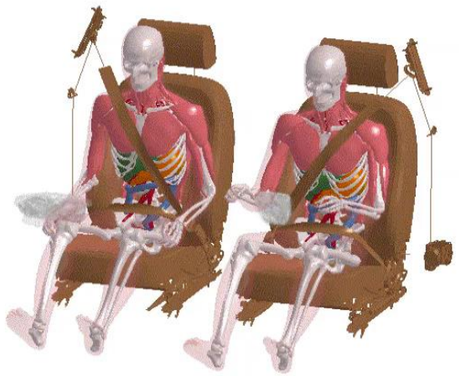
MathWorks tools used for crash sensing algorithm development

FUTURE: A HUMAN BODY MODEL BASED VEHICLE DEVELOPMENT PROCESS

Crash Simulations

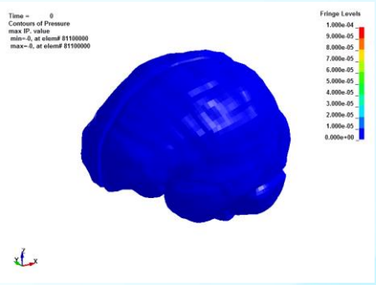
Crash Model

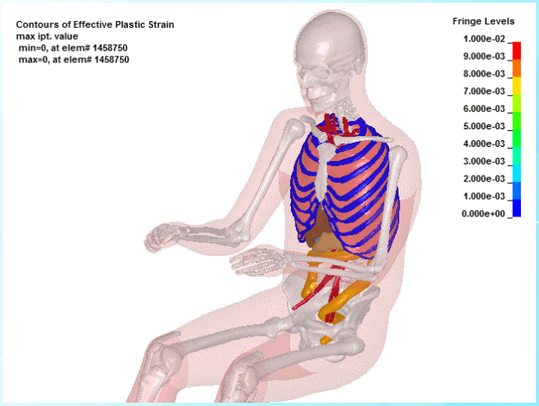
Human Body Response



TISSUE LEVEL INJURY ASSESSMENT:

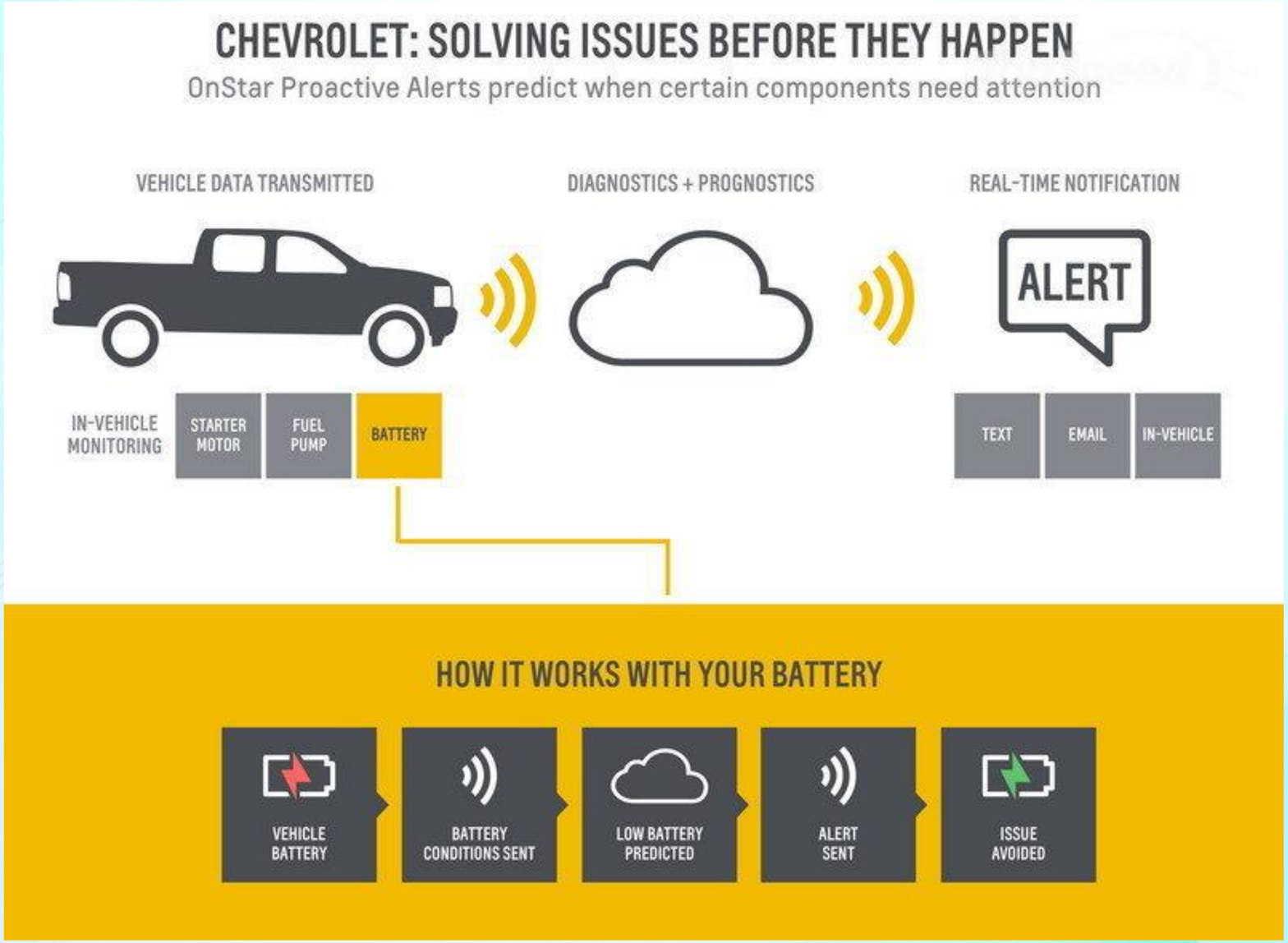
- Skull fracture
- Brain Injury
- Vertebra fracture
- Spinal cord injury
- Rib fracture
- Major artery injury
- Lung injury
- Liver injury
- Pelvis fracture
- Femur fracture
- ……





FUTURE: INFORM FIRST RESPONDERS AND ER

VEHICLE PROGNOSIS



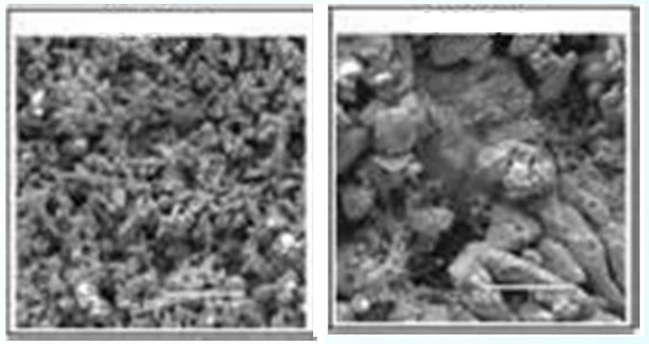
MOTIVATION

- Everything wears out over time
- Customer’s life is disrupted, when his/her vehicle needs repair unexpectedly
- OnStar™ Proactive Alert – A new customer care service
  - Alert before failure happens
  - Transform an emergency repair to planned maintenance
  - Enhance ownership experience - a delight to customers

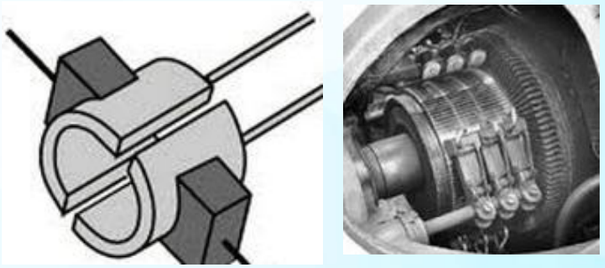
PROGNOSTIC ALGORITHM DEVELOPMENT

Physical-model based algorithm generation:

- Study failure modes - FMEA
- Model physics of failure
- Generate fault signatures and failure precursors
- Develop prognostics algorithm
- Validate concept on benches and test vehicles



Lead Acid Battery
(Plate Surface Scanning Electron Microscopy)



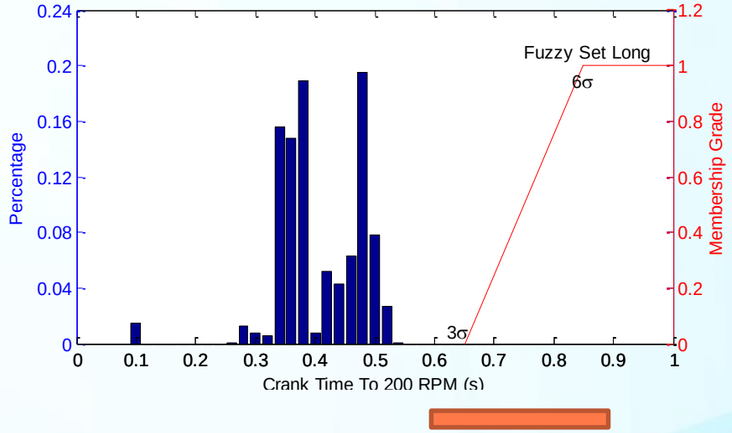
Electric Motor

MathWorks tools used for algorithm development and data analysis

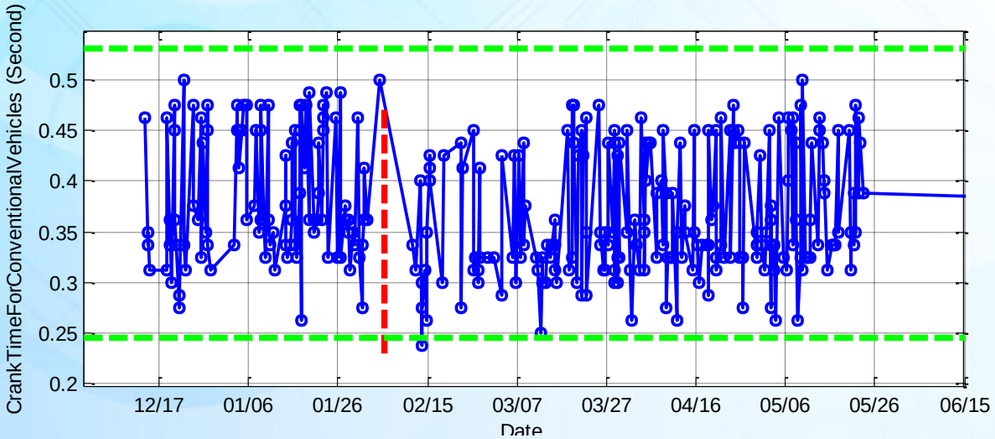
PROGNOSTIC ALGORITHM DEVELOPMENT

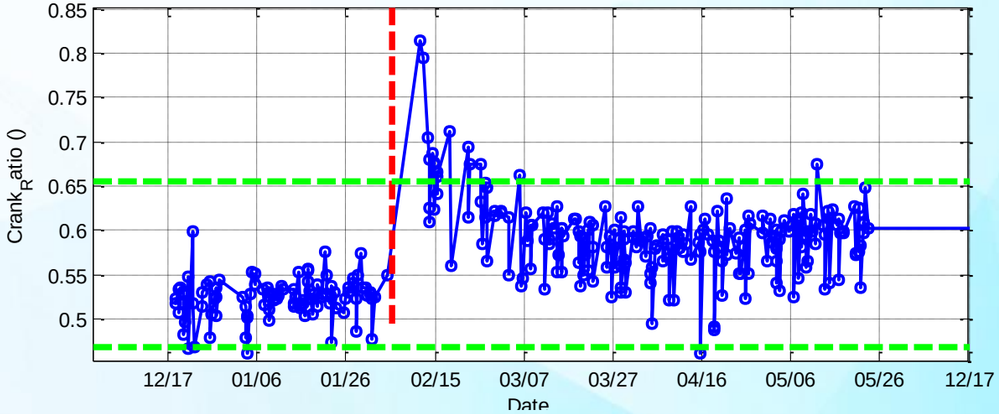
Big-data based algorithm validation:

- Collect data from >1M vehicles
- Analyze warranty return parts
- Correlate algorithm outputs with engineering assessment
- Calibrate algorithm parameters



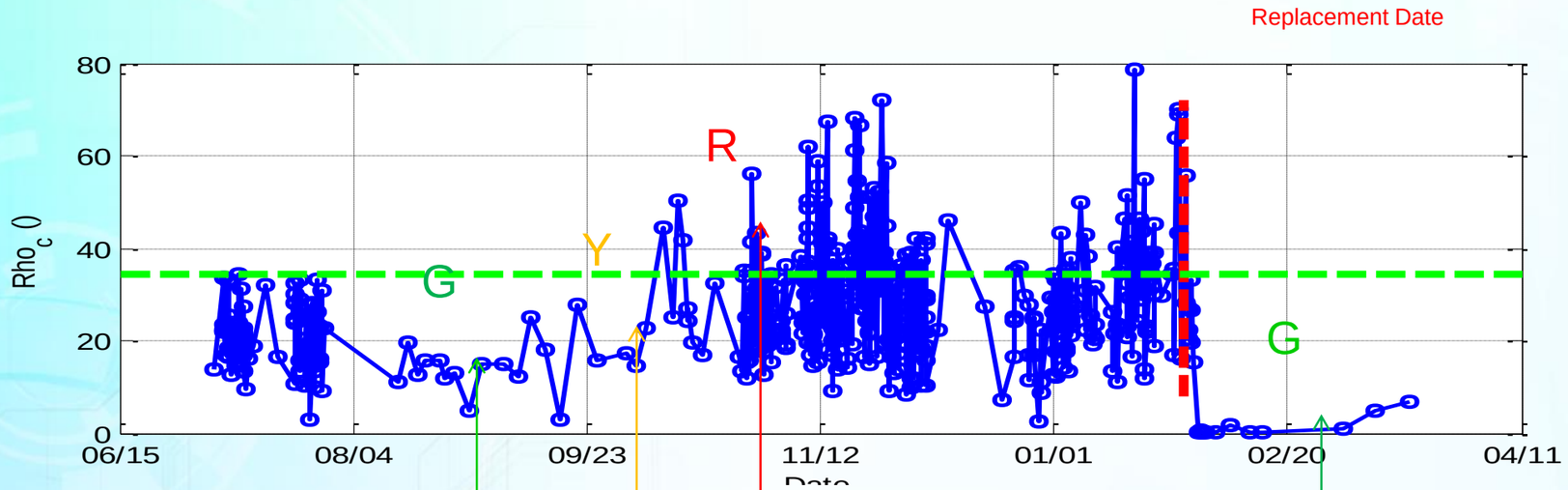
Statistical analysis





Time series analysis

VALIDATION



G

8/17/2013 7:38:55 PM	No Action	Green
8/19/2013 1:38:54 PM	No Action	Green

Y

10/23/2013 9:16:19 AM	Inspect Cra...	Yellow
10/25/2013 6:34:30 PM	Inspect Cra...	Yellow

R

11/2/2013 3:49:36 PM	Replace Bat...	Red
11/2/2013 7:25:07 PM	Replace Bat...	Red

G

1/28/2014 9:20:13 AM	No Action	Green
1/28/2014 11:24:59 AM	No Action	Green

CES: General Motors' OnStar expands with prognostic technology

AUTO NEWS

Chevrolet Onstar breakdown prediction prognostic tool at CES 2015

GIZMODO

+ FOLLOW

Chevrolet Vehicles Will Soon Predict Breakdowns Before They Happen

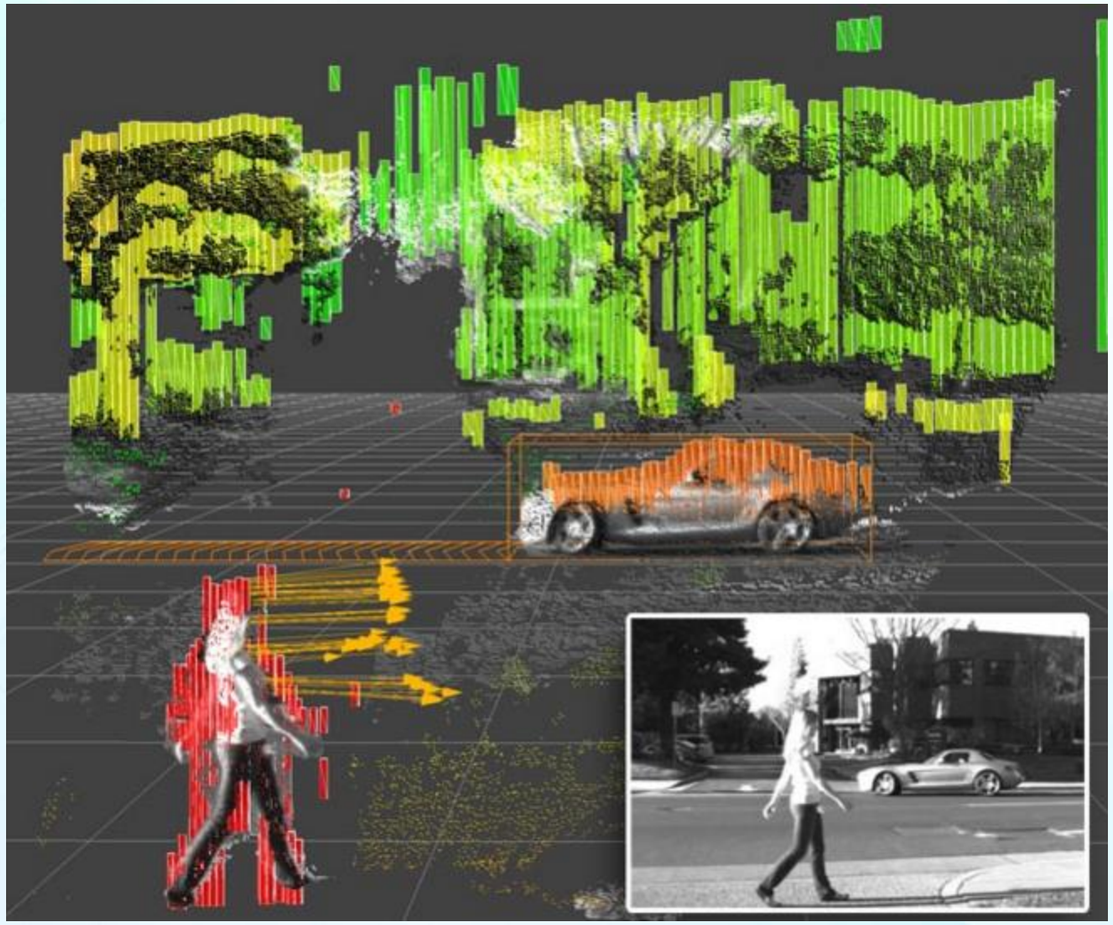
CAR AND DRIVER

CES 2015: SOON GM CARS WILL PREDICT WHEN ENGINE PARTS MIGHT FAIL

REST IN PEACE, CHECK ENGINE LIGHT

Chevrolet to Use Magic Hoodoo to Deliver Prognostic Vehicle Data to Owners

LIDAR DATA



ARTIFICIAL INTELLIGENCE AND LEARNING

SUMMARY

- New mathematical models and methodologies are driving automotive innovation in a variety of areas.
- These approaches have reduced the time to bring innovative solutions to the market.
- Themes
  - Model Integration
  - Collaboration
- The future of mobility will rely on continued breakthroughs in
    - Model integration
    - Big data

GM RESEARCH & DEVELOPMENT