Innovative Windshield Designs

Embracing Change in the Auto Glass Industry

DeWitt Lampman
CEO, Worldwide Glass Consulting, LLC
https://www.worldwideglassconsulting.com

Topics to be Covered

- ❑ Improving Electric Vehicle (EV) Performance
- ❑ Improving Safety and Autonomous Driving Capability
- ❑ Windshield Designs for Stopping Stone Impact Failure

Worldwide Glass Consulting

Improving Electric Vehicle (EV) Performance

- ❑ Windshield Designs to Improve HVAC System Performance
- ❑ Windshield Designs for Weight Reduction

Worldwide Glass Consulting

Reduce Solar Heat Gain Using IRR Coated Windshield

- 75% of cabin heat is from solar radiation passing through glazing[1]
  - 40% of cabin heat enters through windshield[1]
- Benefits of IRR coated asymmetric windshield constructions
  - Minimize solar heat gain, reducing Tts by 33.7%
  - No cabin heat reduction penalty for asymmetric windshield

[1] A. A. Lahimer, et al., "Automotive Cabin Soak Temperature Control Strategies for Improved Safety, Comfort and Fuel Efficiency: a Review," *Solar Energy*, Volume 259, 15 July 2023, pp. 416-436

AC Load Reduction & Fuel Economy Improvement Using IRR Coated Asymmetric Windshields

- Reducing thermal soak load of Cadillac STS by 30% during summer months reduced AC fuel use by up to 26% (NREL 2006).
  - Current coating technology reduces thermal load by additional 19.8%, resulting in a reduction in AC fuel use of 32.9%[1]
- NREL testing of 2006 Toyota Prius hybrid plugin adding coated glass decreased AC compressor power enough to improve fuel economy by 8% (from 38.4 to 41.6 MPG)
  - Using Tts reduction from current coating technology should increase fuel economy to 44.6 MPG[1] *(6.2 Delta MPG = 210 MPGe)*

[1]D. Lampman, et al. "Practical design considerations for lightweight windshield applications", *SAE International Journal of Transportation Safety*, 5 1 (2017), 47 – 57.

Coated Heated Windshields Reduce EV Electrical Loads for Deice, Defrost and Defog

- Deicing windshields shortens EV battery life
  - Standard forced air – least efficient (5kW for 10-min. loses ~1% battery life)
  - Heat pump – more efficient heat transfer; still 5 to 12 kW
  - Heated coated – most efficient using 12 V, 48 V, or 100s V
- Low E coated windshields retain cabin heat and lower battery power for heating and cooling

Standard HVAC Deicing System Heat Transfer Efficiency Issues

- CFD calculated non-uniform windshield temperatures from two manifolds with non-uniform airflow velocity
- Higher bottom glass temperature at manifold exit and lower temperature at driver's viewpoint correspond to the loss of velocity with distance from manifold to driver's viewpoint
- Heat transfer from bottom to top of windshield decreases with airflow velocity along surface

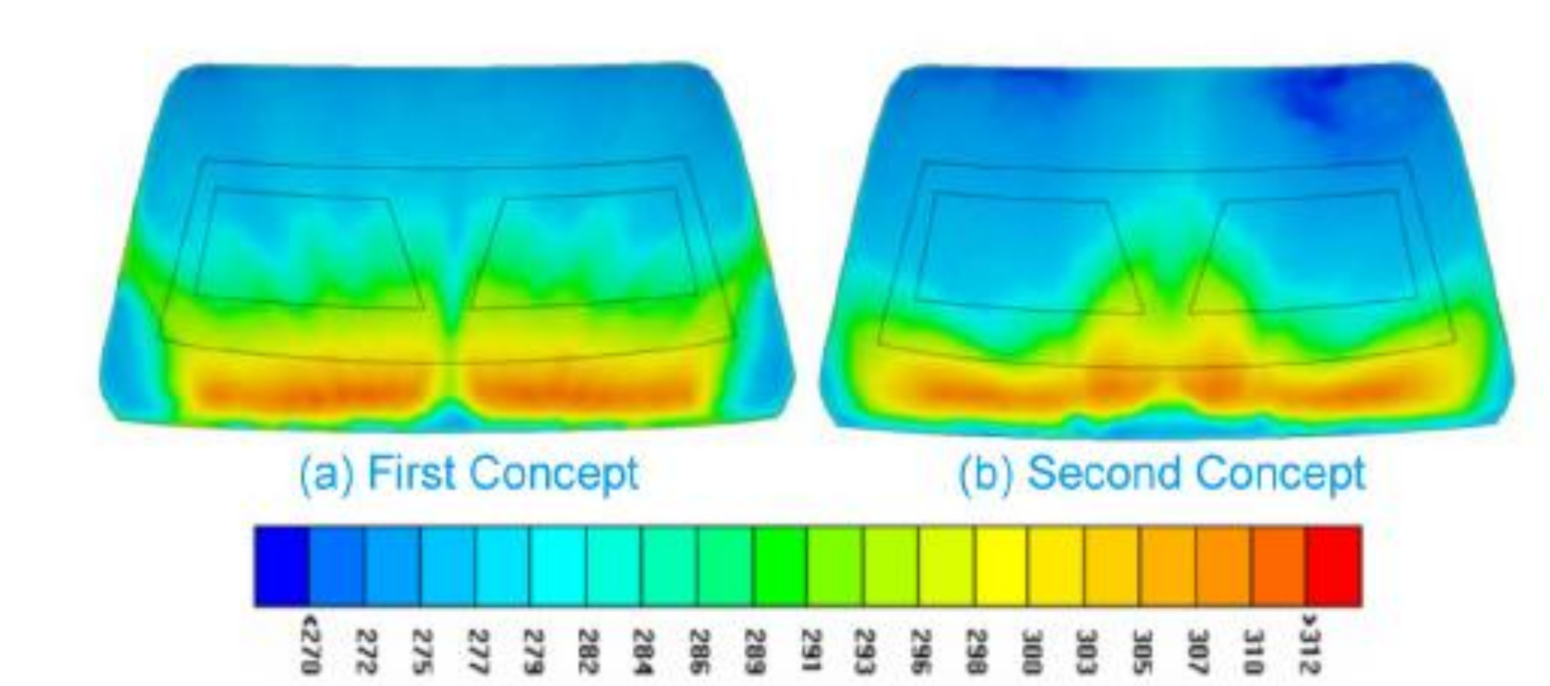


Figure 20. Temperature distribution over windscreen outer surface after 780s[1]

Nonuniform and inefficient heat transfer from standard HVAC system can be avoided by deicing with heated windshield

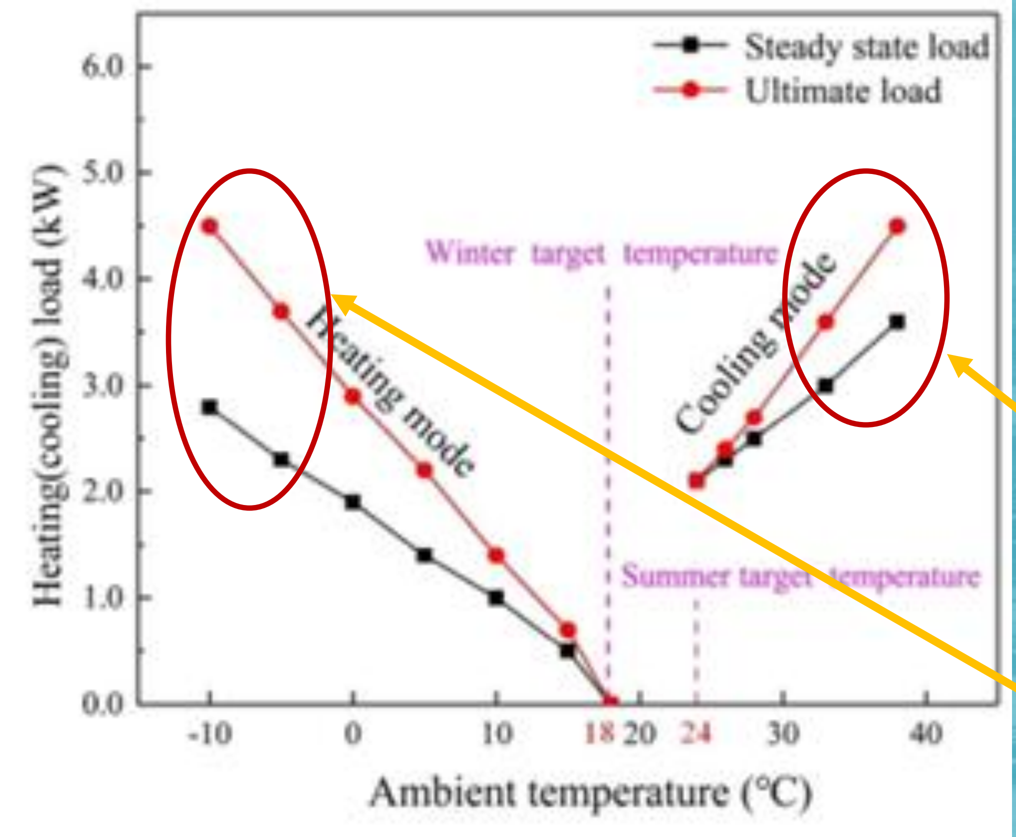
[1]Jahani, K. and Beigmoradi, S., "Utilizing CFD approach for Preeminent Assessment of Defroster Air Flow Distribution and Predicting Windscreen Deicing Behavior," SAE Technical Paper 2014-01-0688, 2014, doi:10.4271/2014-01- 0688

Ultimate EV Windshield Design for Longer Battery Life

- ❑ IRR coated
  - ❑ Full time 34% reduction in HVAC battery load when driving[1]
  - ❑ Part time AC load savings from cabin solar heat gain when parked outdoors
- ❑ Heated IR coated – part time savings from deice and defog battery load
  - ❑ 13.5-volt design does not need transformers or larger alternators
  - ❑ Option for colder regions reducing low temperature battery loads
  - ❑ If IRR coated windshield is standard, only incremental OEM cost
- ❑ Lightweight asymmetric construction – full time battery load savings when driving

[1]D. Lampman, et al. "Practical design considerations for lightweight windshield applications", *SAE International Journal of Transportation Safety*, 5 1 (2017), 47 – 57.

Improve EV Energy Management with Heated Coated Windshield



Li, K., et al., Investigation on the performance and characteristics of a heat pump system for electric vehicles under extreme temperature conditions, Energy Conversion and Management, Vol. 102, 15 Sep 2015, pages 39 to 49.

- ❑ EV heating/cooling load increases with cold & hot ambient temperatures
- ❑ High power 4.5 kW heating/cooling loads are reduced significantly with heated coated windshield.
  - ❑ EV cooling load can be reduced significantly by an IRR coated windshield. Solar heat load Tts is reduced by 34% with coating.
  - ❑ EV heating load from low temperature ambient air & deicing are reduced considerably with heated windshield.

Improve EV Energy Management with Heated Coated Windshield

EV Driving Range and Deterioration with Outside Temperature						
System HVAC Description	- 10 C (14 F)			0 C (32 F)		
	Range (Km)	Range Reduction (Km)	Percent Range Reduction (%)	Range (Km)	Range Reduction (Km)	Percent Range Reduction (%)
HVAC System Off	310	N/A	N/A	310	N/A	N/A
PTC Heater	188	122	**39.4%**	230	80	**25.8%**
ACHP Heat Pump	265	45	14.5%	290	20	6.5%

Note: Constant vehicle speed, 60 Km/H (37 MPH)

Li, K., et al., Investigation on the performance and characteristics of a heat pump system for electric vehicles under extreme temperature conditions, Energy Conversion and Management, Vol. 102, 15 Sep 2015, pages 39 to 49.

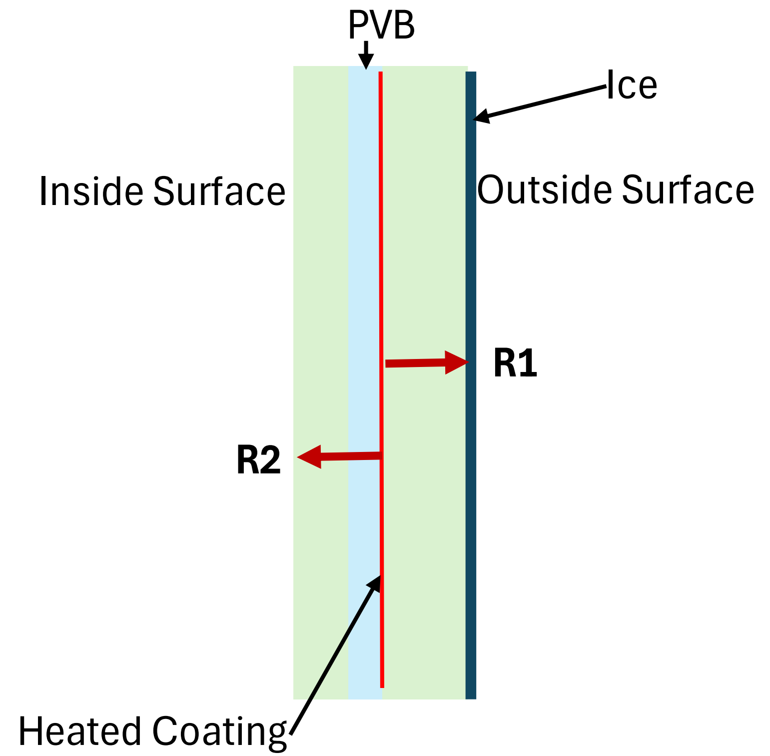
Heated Air HVAC System Deice Design Issues

- Inefficient convection from bottom of windshield on inside surface with conduction of heat to ice-coated outer ply
    - Airflow parallel to windshield rather than perpendicular
    - Airflow nonuniform and from bottom delaying heating drivers vision area
    - Conduction through PVB layer of windshield is 5 times slower than through glass, slowing heating of ice-covered outer ply
- Positive temperature coefficient (PTC) resistance heaters use 5 to 7.5 kW of power for heating air
- Heat pump HVAC systems increase efficiency using much less power (1 to 3 kW)
    - Inefficient convective heat transfer still used
    - Greater ~ 24-lb. weight of heat pump system over resistance heat lowers MPGe by 2.3 kWh

Asymmetric Coated Heated Windshield for EV Deicing

Benefits:

- ❑ Increases thermal efficiency by direct uniform heating of ice-coated outer ply
- ❑ Lowers weight by 9.6 lbs. (4.4 Kg), 0.92 MPGe increase
- ❑ Deicing time is lowered by 17% compared standard symmetric design
- ❑ Compensates for heat pump system low efficiency at low and high temperature



R1 and R2 directions of heat flow when coating heat is turned on.

Improving Safety and Autonomous Driving Capability

- Windshield Designs to Enable and Improve Behind-the-Windshield Sensor Performance
  - Improve LiDAR Performance
  - Enable IR Camera Operation

Worldwide Glass Consulting

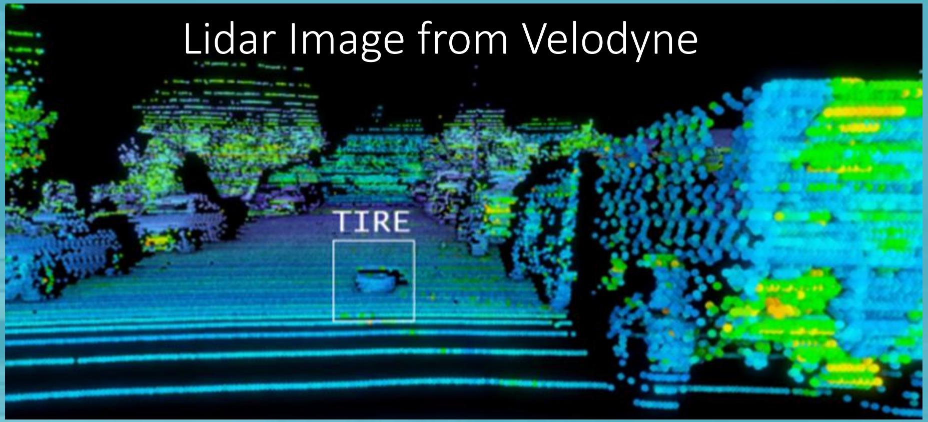
LiDAR Sensor Behind Windshield

- ❑ Specialized windshield construction optimizes transmittance of LiDAR sensor laser frequency, permitting use behind the windshield
  - ❑ Additional dependable input signal for autonomous driving
  - ❑ No issues with dirty sensors

Improving LiDAR Performance by Design

- Windshield design goal: increase transmittance at LiDAR laser wavelength (905 nm)
- Design options for increasing targeted transmittance
  - Borosilicate glass
  - High transmittance low iron float glass
- Thinner asymmetric windshield constructions
  - Thicker outer ply increases impact strength
  - Thinner inner ply reduces transmittance optical path
- Antireflective coating on camera window of inner ply

Windshield Design Options to Improve LiDAR Performance



Asymmetric Windshield Construction Options for Transmittance at 905 nm			
Glass Composition	**Construction**	**Transmittance at 905 nm**	**Comments**
Borosilicate Fusion5/Borosilicate Fusion5	3.1 mm/1.4 mmm	91.80%	Maximum transmittance. Very expensive glass for two plies.
Borosilicate Fusion5/Ultra Clear Float	3.1 mm / 1.4 mm	90.20%	Very high Transmittance. Expensive glass for two plies.
Borosilicate Fusion5/Clear Float	3.1 mm / 1.4 mm	84.70%	Maximum transmittance and high strength at minimum cost.
Clear Float/Clear Float	2.1 mm/2.1 mm	72.30%	Clear standard symmetrical construction.

905 nm = LiDAR Laser Wavelength

Borosilicate Fusion5 is an automotive glass from Corning.

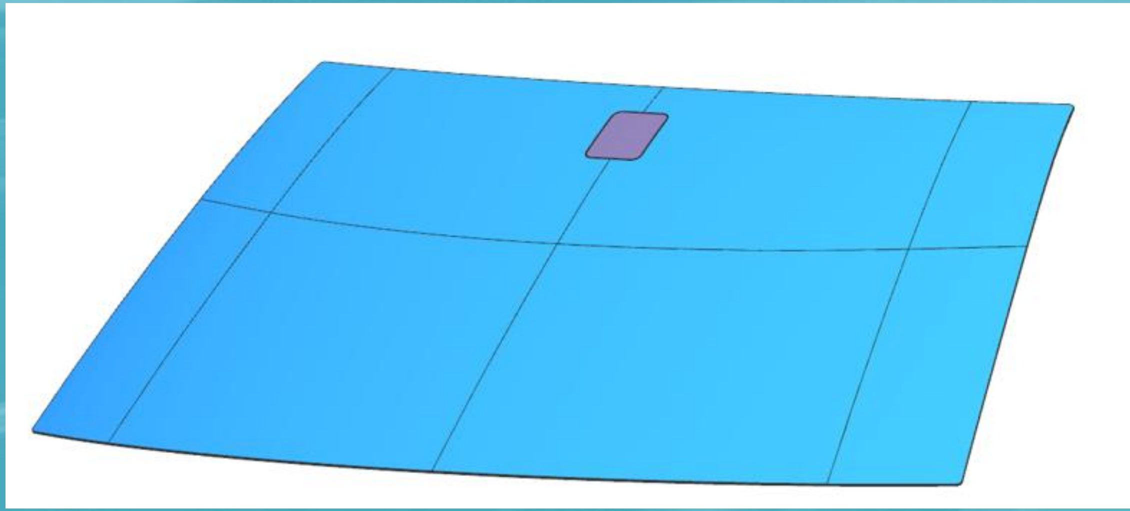
Windshield Design Options to Enable Infrared Camera Operation

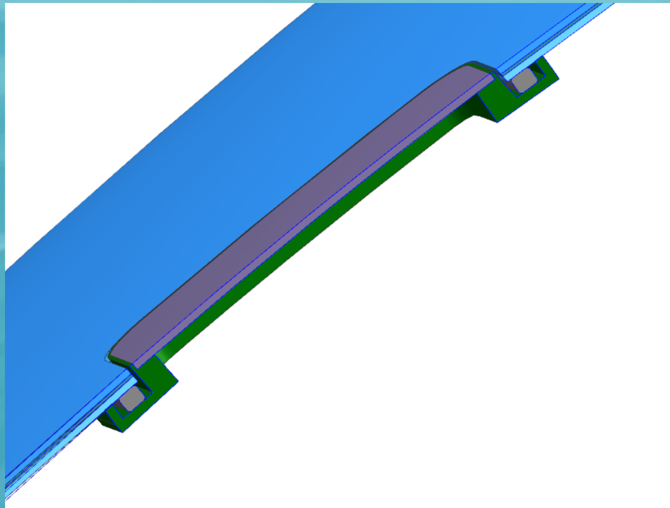
- ❑ Insert specialized glass composition for camera window that transmits at IR camera wavelength[1]
- ❑ Add viewing ports to top edge of windshield[1]

[1]VITRO Automotive Holdings patent US 12,370,778 B2

IR Windshield Design Concept

- IR window area cut from both float windshield plies[1]
- IR transmitting glass or polycarbonate window either encapsulated or adhered to float glass[1]





[1]VITRO Automotive Holdings patent US 12,370,778 B2

IR Sensor Behind Windshield

- Specialized window construction or material transmits IR sensor frequency, permitting use behind windshield
  - Improves safety for night driving
  - Additional dependable input signal for autonomous driving
  - No issues with dirty sensors

Infrared Camera Options Current and Future

- *Current*: automotive infrared cameras integrated into autonomous braking systems but use small cameras exterior to vehicle cabin (FLIR OEM)
- *Future*: windshield designs could enable infrared camera operation behind windshield to protect cameras from environmental viewing issues

Windshield Designs for Stopping Stone Impact Failure

Delawareautoglass.com/Blog/2021

Asymmetric Windshield Designs

- ❑ Significantly increase stone impact strength
- ❑ Can offer weight savings
- ❑ Highly asymmetric can compensate for stress level increases from installation angle

Ford GT Race Car

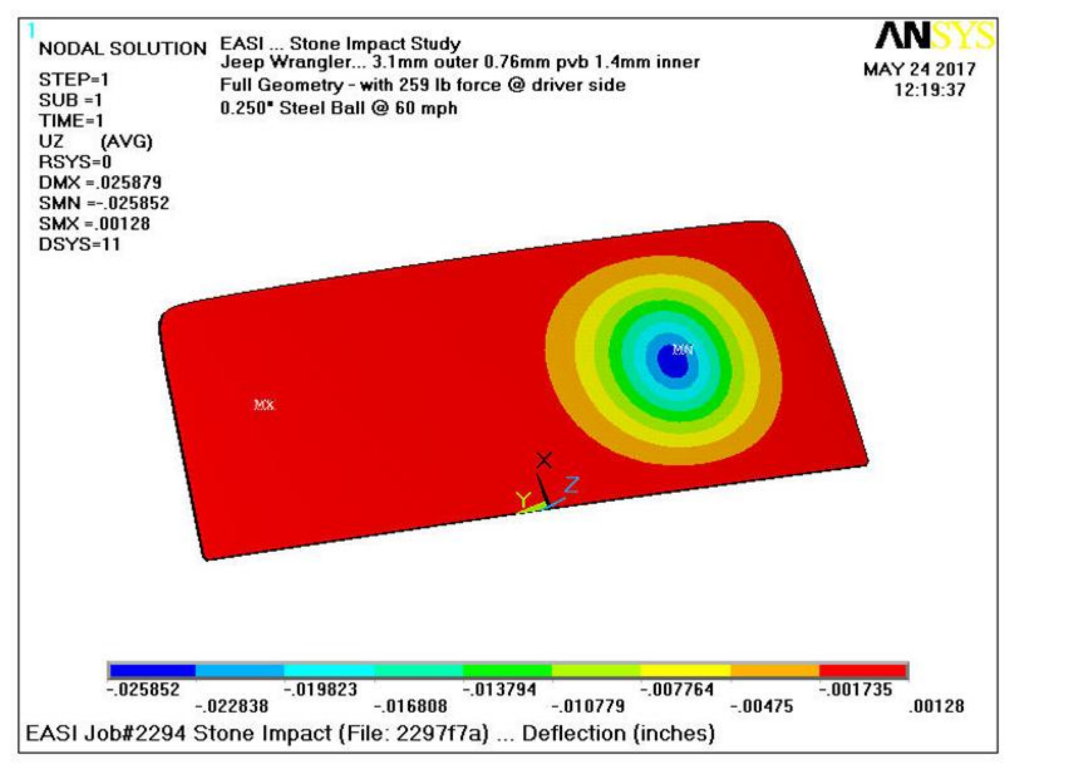
- Most Asymmetric Production Windshield
- 4.3 Kg Weight Savings

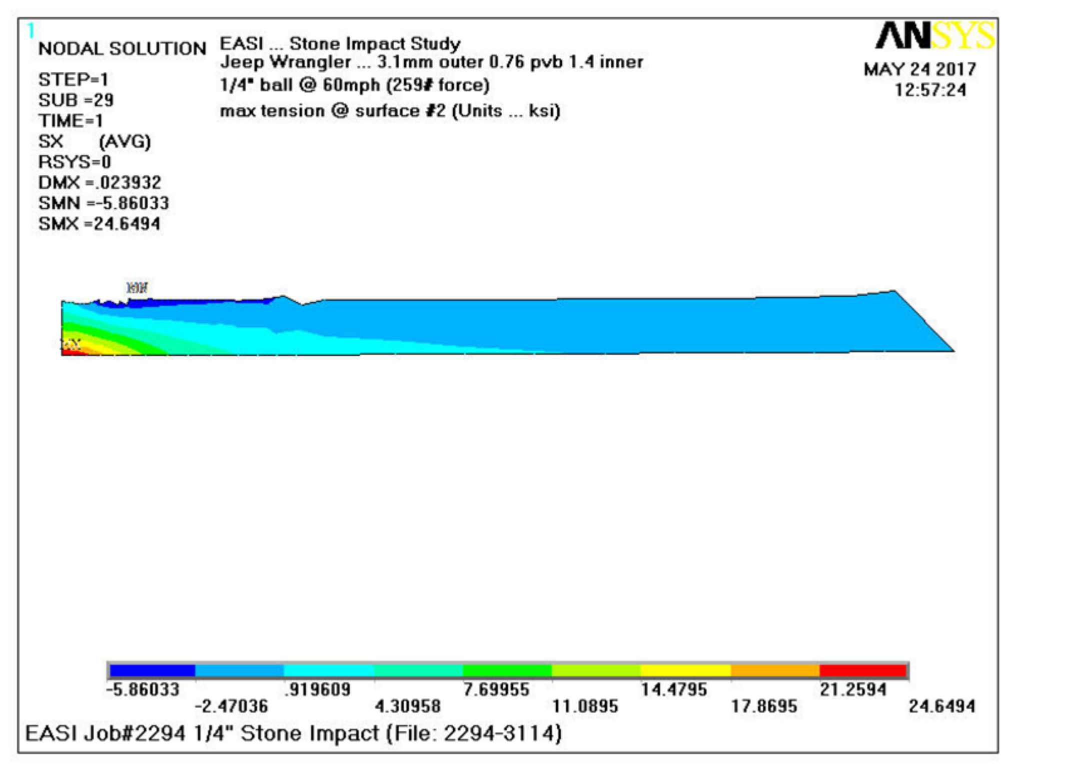
Asymmetric Windshield Design Considerations

- Thinner inner ply impact stress levels range from 31% to 42% lower than outer ply, eliminating breakage
- Thicker outer plies are stiffer and can reduce stress levels from stone impact by 10% to 38%, depending on installation angle
- For same overall glass thickness as symmetric construction, asymmetric outer play can be significantly thicker (61%) than symmetric construction, improving impact strength

Example of ANSYS Full Size Windshield Stone Impact Simulation for Deflection and Tensile Stress Comparisons

- Full size windshield impacted on driver's side – stresses for windshield at installation angle
- Impact with 0.250-in. diameter hardened steel ball at 60 MPH (OEM test)





D. Lampman, "New high strength windshield technology", Vitro White Paper, (2-2025)

Asymmetric Windshield Constructions Can Reduce Impact Stress Up to 38%

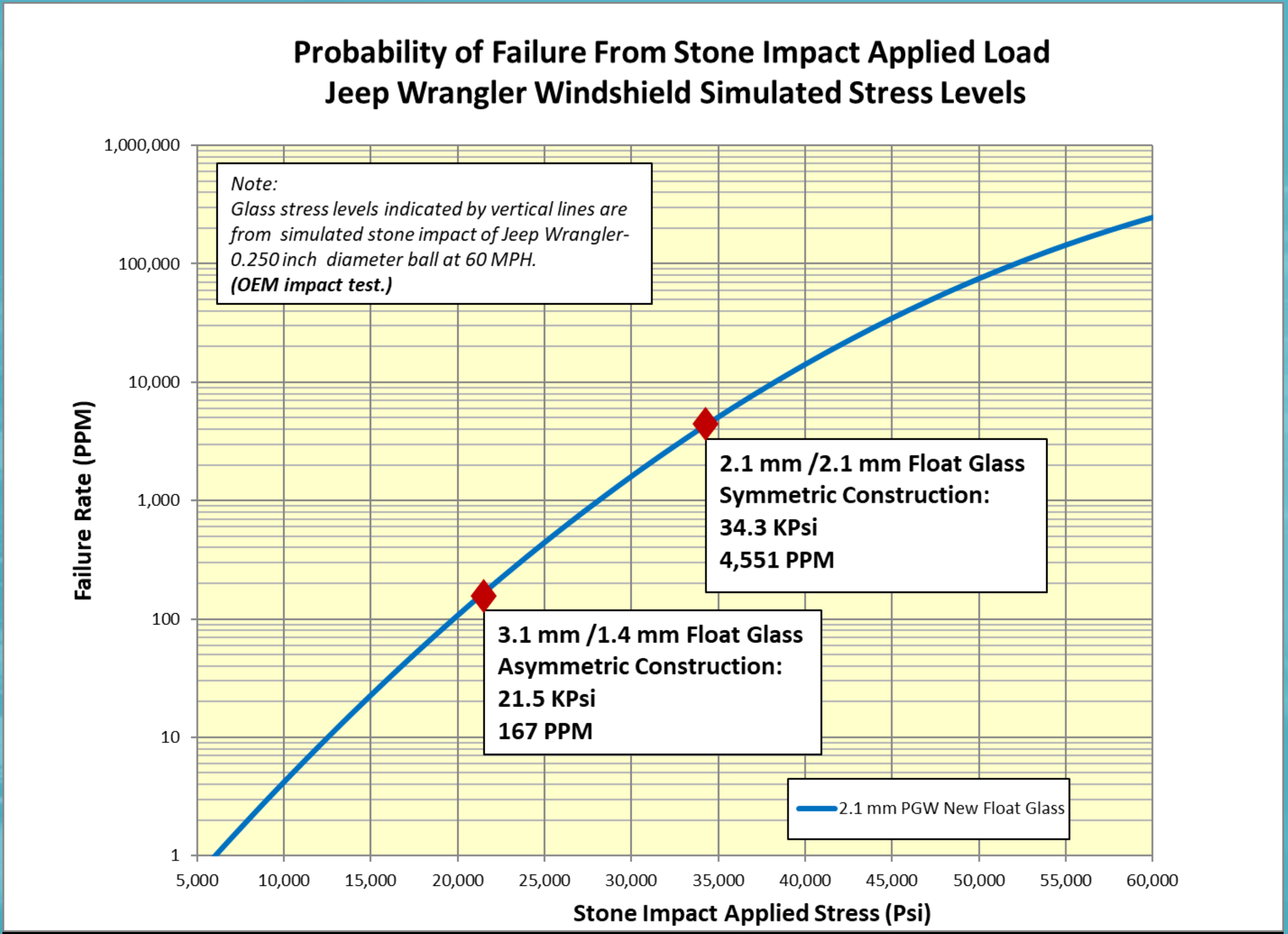
- Thickness of outer ply determines stiffness and stress from impact
- Inner ply thickness reduction does not affect outer ply impact stress level
- Thinner Inner ply saves weight

Jeep Wrangler Stone Impact Stress Simulation Comparison Symmetric Versus Asymmetric			
Type Windshield Construction	Windshield Construction	Tensile Stress Surface 2	Average Asymmetric Percent Stress Reduction 2.1/2.1 mm to 3.1/1.4 mm (%)
Symmetric	**2.1** mm /PVB/ 2.1 mm	34.3	**37.5%**
	2.3 mm /PVB/ 2.3 mm	30.7	
Asymmetric	**3.1** mm /PVB / 1.4 mm	21.3	
	3.1 mm /PVB/ 1.2 mm	21.5	
	3.1 mm /PVB/0.55 mm	21.5	

D. Lampman, “New high strength windshield technology”, Vitro White Paper, (2-2025)

Stone Impact Stress Level Determines Probability of Failure

- For this windshield and installation angle, asymmetric outer ply 3.1 mm glass thickness reduces probability of failure from stone impact by 96% (from 4,551 PPM to 167 PPM)
- Asymmetric windshield can be designed to reduce probability of failure from stone impact while maintaining specified or existing overall thickness



Lampman, “Aircraft Cockpit Window Improvement Enabled by High-Strength Tempered Glass,” SAE Int’l. J. Aerospace, V 133 – 1 EJ

Borosilicate Composition Glass for the Outer Ply in Asymmetric Windshield Construction

[Major Advantages with Borosilicate Composition Glass]

- ❑ Significantly higher fracture toughness than soda lime silica float glass – 52%[1]

  Note: Fracture toughness is a measure of how well glass can withstand external forces without breaking.

- ❑ 10% lower density than float glass – asymmetric windshield construction maintains same weight and thickness as standard symmetric float construction with 38% lower stone impact stress level

[1]H. Liu, et al., "Determination of the Fracture Toughness of Glasses via Scratch Tests with a Vickers Indenter," Acta Mechanica Solids Silica, 9 Aug.2021

Borosilicate Composition Glass for the Outer Ply in an Asymmetric Windshield Construction (cont'd.)

- Significantly higher impact resistance than float glass
  - Sharp impacts cause 69.5% of windshield field failures[1]
    - Vickers diamond drop testing simulates sharp impact
  - Corning Fusion5 borosilicate glass exhibits 120% increase in kinetic energy causing failure versus same asymmetric construction fabricated with all float glass

[1] Cleary, T., et al., "Characterization and Quantification of In-Service Windshield Fracture Mechanisms and Evaluation of Laminate Sharp Impact Resistance as a Function of Construction," SAE Technical Paper 2020-01-0607, 2020.

Standard Baseline

Symmetric Windshield Construction

Weight = 15.2 Kg
11.37 Kg/M2

Outer Ply
2.1 mm Clear Float
0.76 mm Acoustic Vinyl
2.1 mm Clear Float
Inner Ply

Option 1

Asymmetric Borosilicate Windshield Construction

Weight = 15.1 Kg
11.31 Kg/M2

Outer Ply
3.0 mm Borosilicate Fusion 5 Corning
0.76 mm Acoustic Vinyl
1.2 mm Soda Lime Silica Float
Inner Ply

Option 2

Asymmetric Borosilicate Windshield Construction

Weight = 15.8 Kg
11.81 Kg/M2

Outer Ply
3.0 mm Borosilicate Fusion 5 Corning
0.76 mm Acoustic Vinyl
1.4 mm Soda Lime Silica Float
Inner Ply

Borosilicate Glass Asymmetric Construction Option 1 Can Match Thickness and Weight of Symmetric Construction

Note: Average windshield area used = 1.34 M^2

Windshield Installation Angle Considerations

- More vertical installation angles increase stone impact stress levels (kinetic energy is a vector quantity)
  - Worst case impact is perpendicular
  - Installation angle near vertical (vs. low angle) can increase impact stress load by 119%
- Asymmetric constructions can reduce stone impact stress levels

Affect of Installation Angle

Jeep Wrangler vs. Ford Explorer

Symmetric Windshield Construction

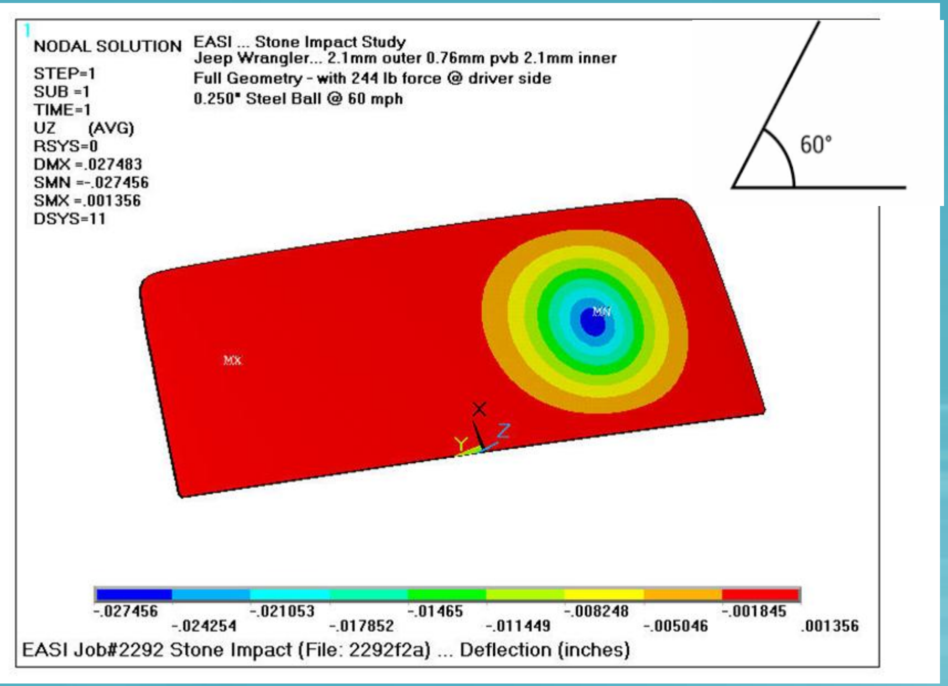
Stress Increases from Installation Angle by *119%*

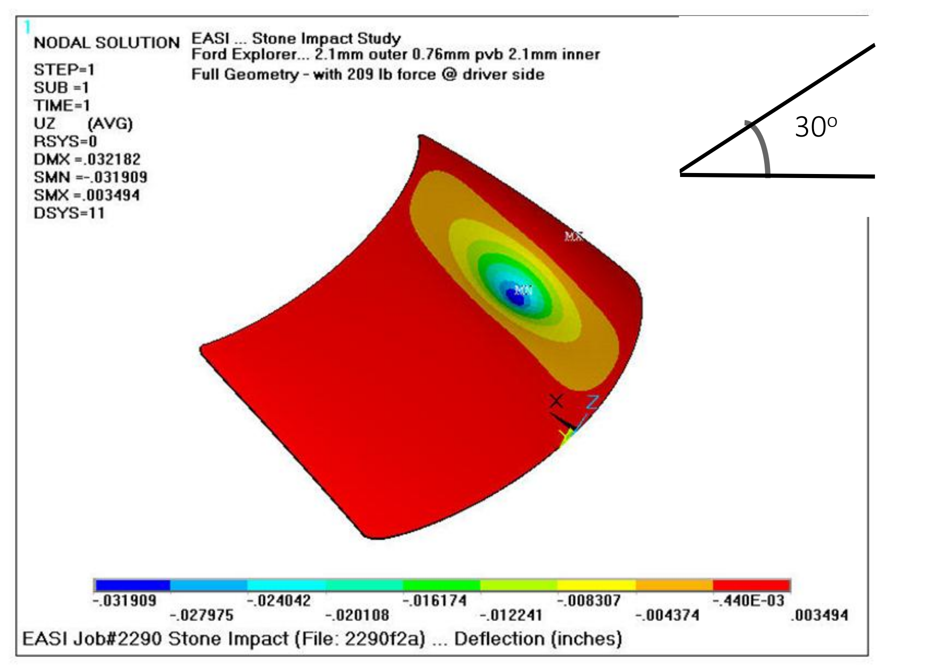
Vehicle Windshield Impact Simulations Completed for	Windshield Construction	Windshield Installation Angle (Degrees from Horizontal)	Maximum Tensile Stress Surface 2 (Ksi)	Percent Increase in Stress From Jeep Installation Angle (%)
Jeep Wrangler	2.1 mm/PVB/2.1 mm	60	34.3	*N/A*
Ford Explorer	2.1 mm/PVB/2.1 mm	30	15.7	***118.5***

Notes:

- Impact from 0.250 inch diameter hardened steel ball
- Impact velocity 60 MPH at Installation Angle

D. Lampman, "New high strength windshield technology", Vitro White Paper, (2-2025)





Best-in-Class Windshield Design Can Stop Stone Impact Breakage

- ❑ Highly asymmetric construction to significantly lower stress level and probability of failure from stone impact to near zero (167 PPM)
- ❑ Borosilicate outer ply to increase fracture toughness by 52% and reduce thickness difference to maintain fit

Questions?

[5 minutes]

Thank You!

DeWitt Lampman
CEO, Worldwide Glass Consulting, LLC
https://www.worldwideglassconsulting.com