

Efficient handling of CFD results through compression

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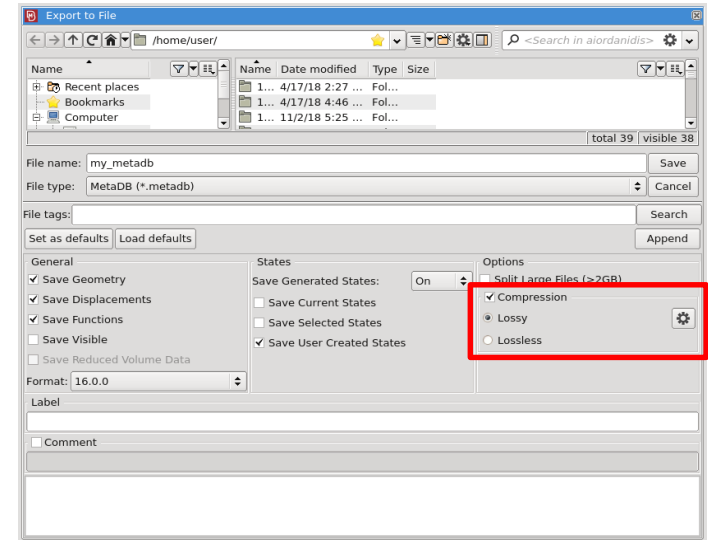
Introduction

Introduction

- Increase in computing power density – models of several hundred million elements
- DES simulations – files require several hundred gigabytes
- Enormous file sizes render model manipulation a real challenge

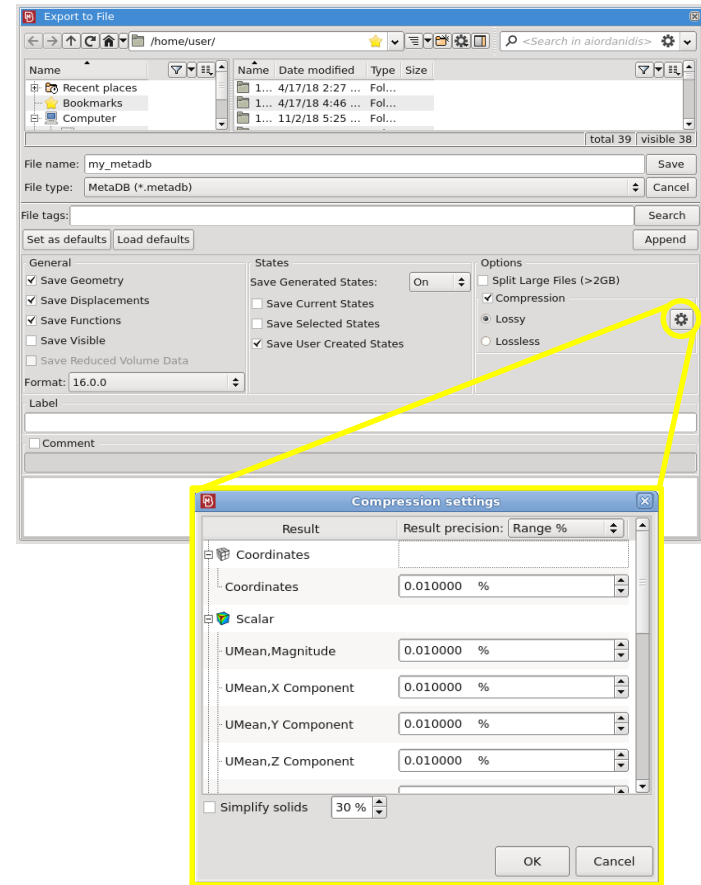
Introduction

- META allows results compression in native metadb format
 - Smaller file sizes
 - Faster loading times
 - No loss of detail



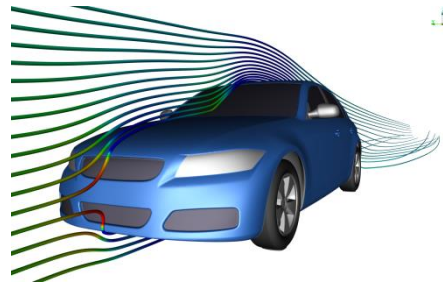
Introduction

- META allows results compression in native metadb format
 - Smaller file sizes
 - Faster loading times
 - No loss of detail
- Fully customizable options
- Smaller storage requirements and easier file sharing



Case characteristics

- DrivAer model of TU Munich, DES in OpenFOAM
- 2.5 million shells – 37 million solids
- Geometry and results (7 total – binary uncompressed): 8.5 GB



Geometry loading time	0:00:35
Results loading time	0:02:08
Additional results calculation time	0:07:50
Total time	0:10:33

Total RAM after loading: 14.23 GB

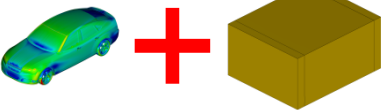
- Case provided by FORD USA

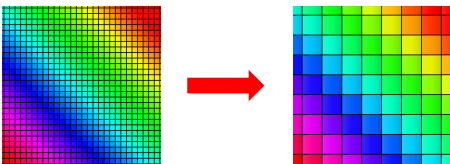
Compression options

- Uncompressed – Reference case
- Lossless – No loss in accuracy (gz compression)
- Lossy – Reduced accuracy controlled as:



➤ Percentage 

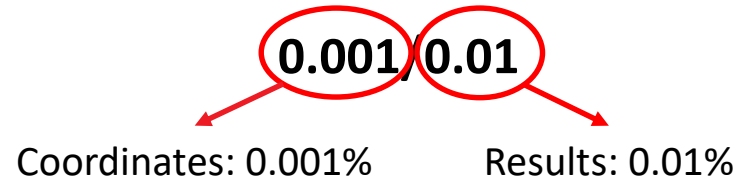
➤ Percentage with Sets – Different compression level on Sets of PIDs/Parts 

➤ Percentage and solids Simplification – Mesh coarsened 

➤ Round off $|Uncompressed - Compressed| \leq 0.001$

Compression options – Naming conventions

- Percentage

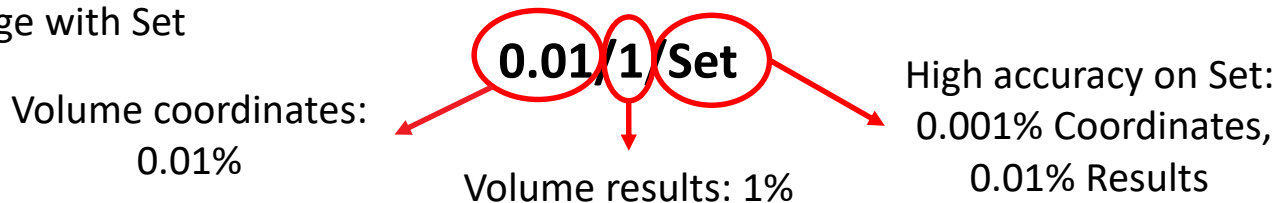


Compression options – Naming conventions

- Percentage



- Percentage with Set



Compression options – Naming conventions

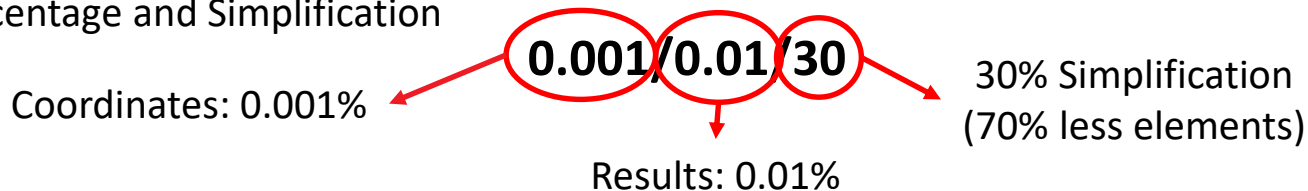
- Percentage



- Percentage with Set



- Percentage and Simplification



Compression options – Naming conventions

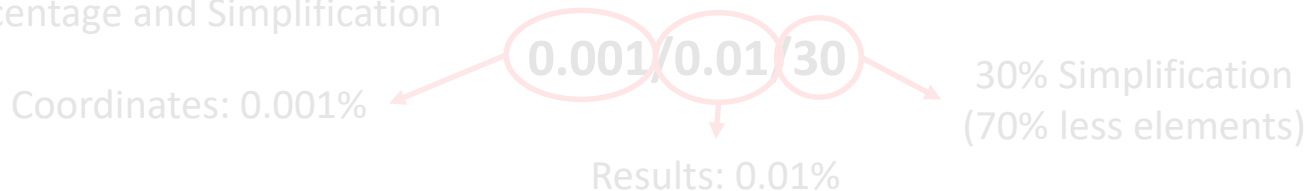
- Percentage



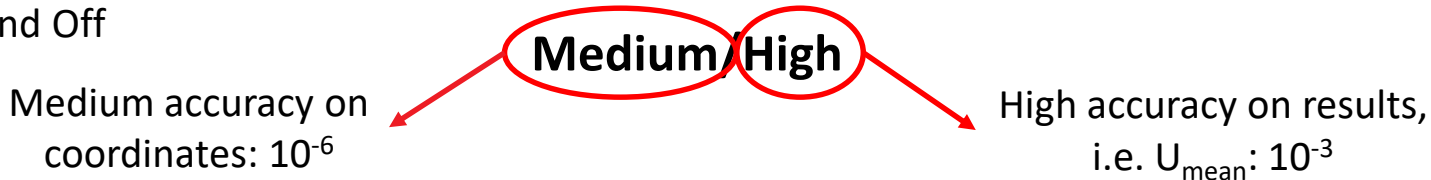
- Percentage with Set



- Percentage and Simplification



- Round Off

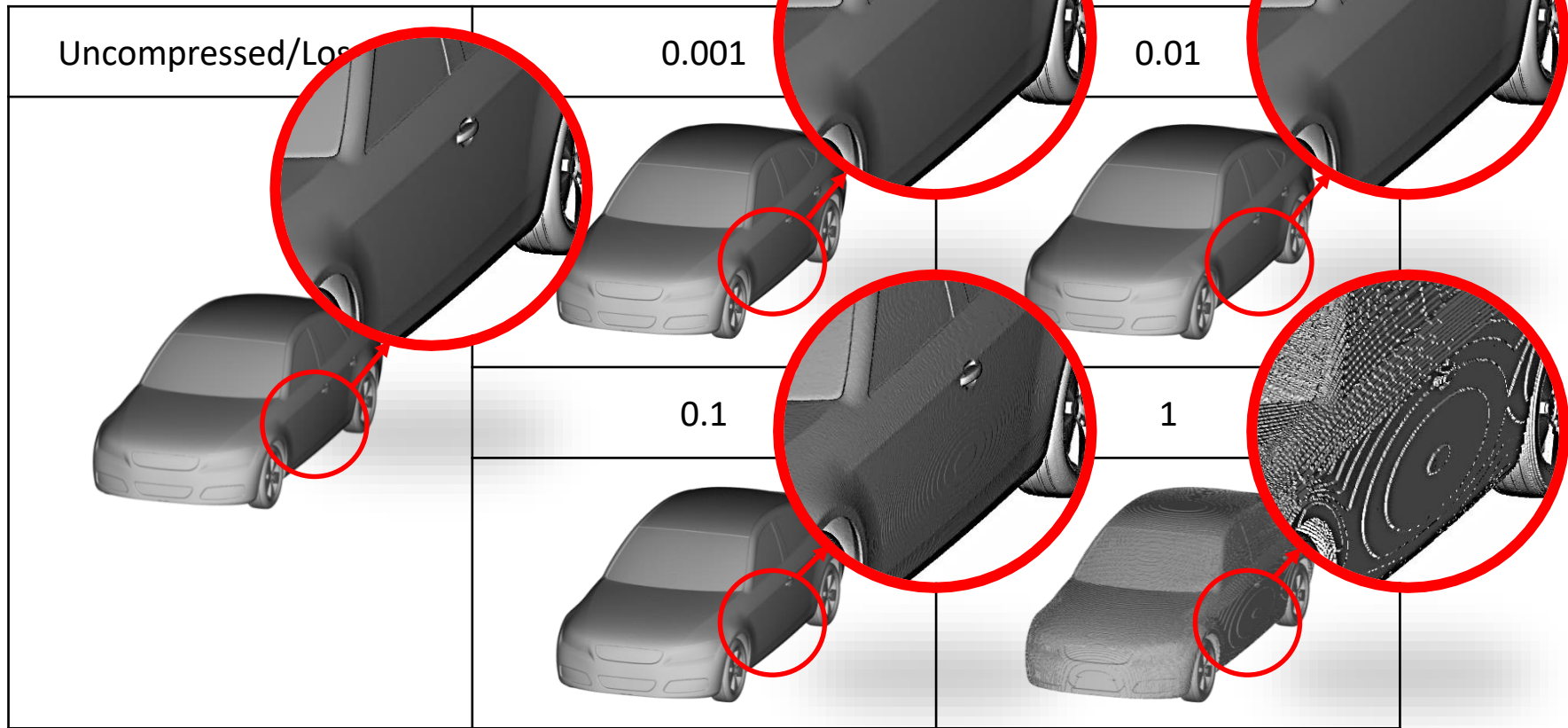


Compression methodology

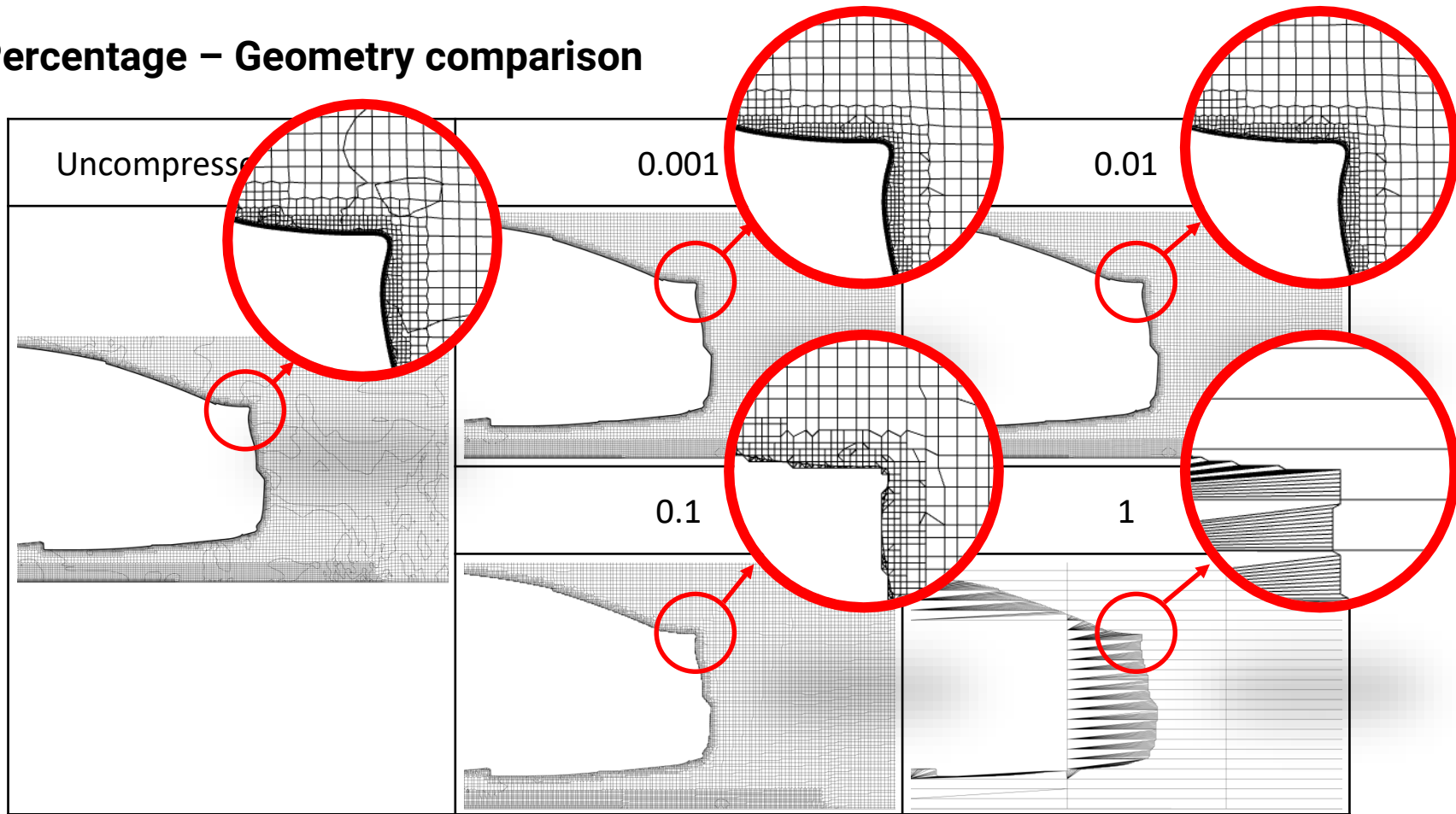
Percentage



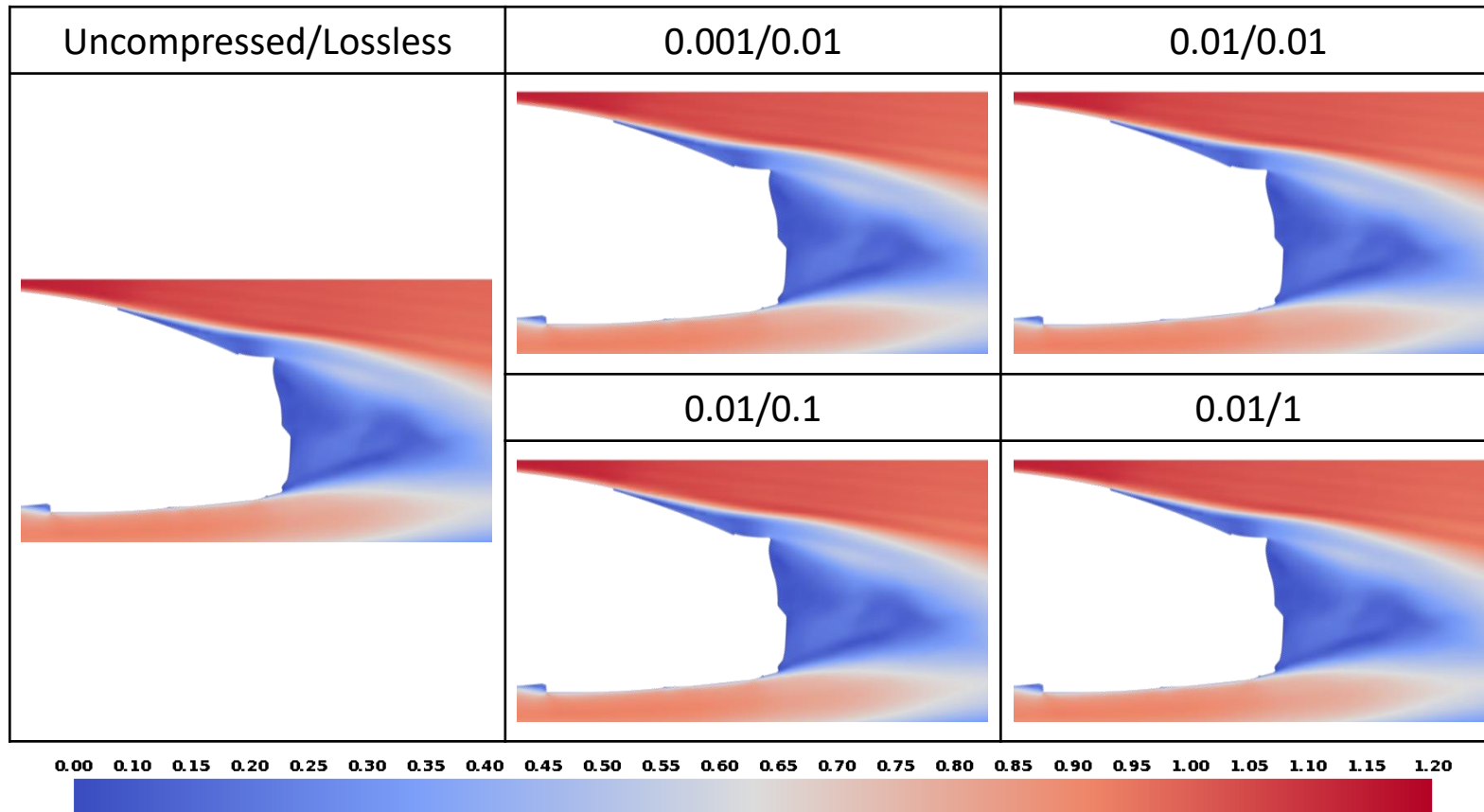
Percentage – Geometry comparison



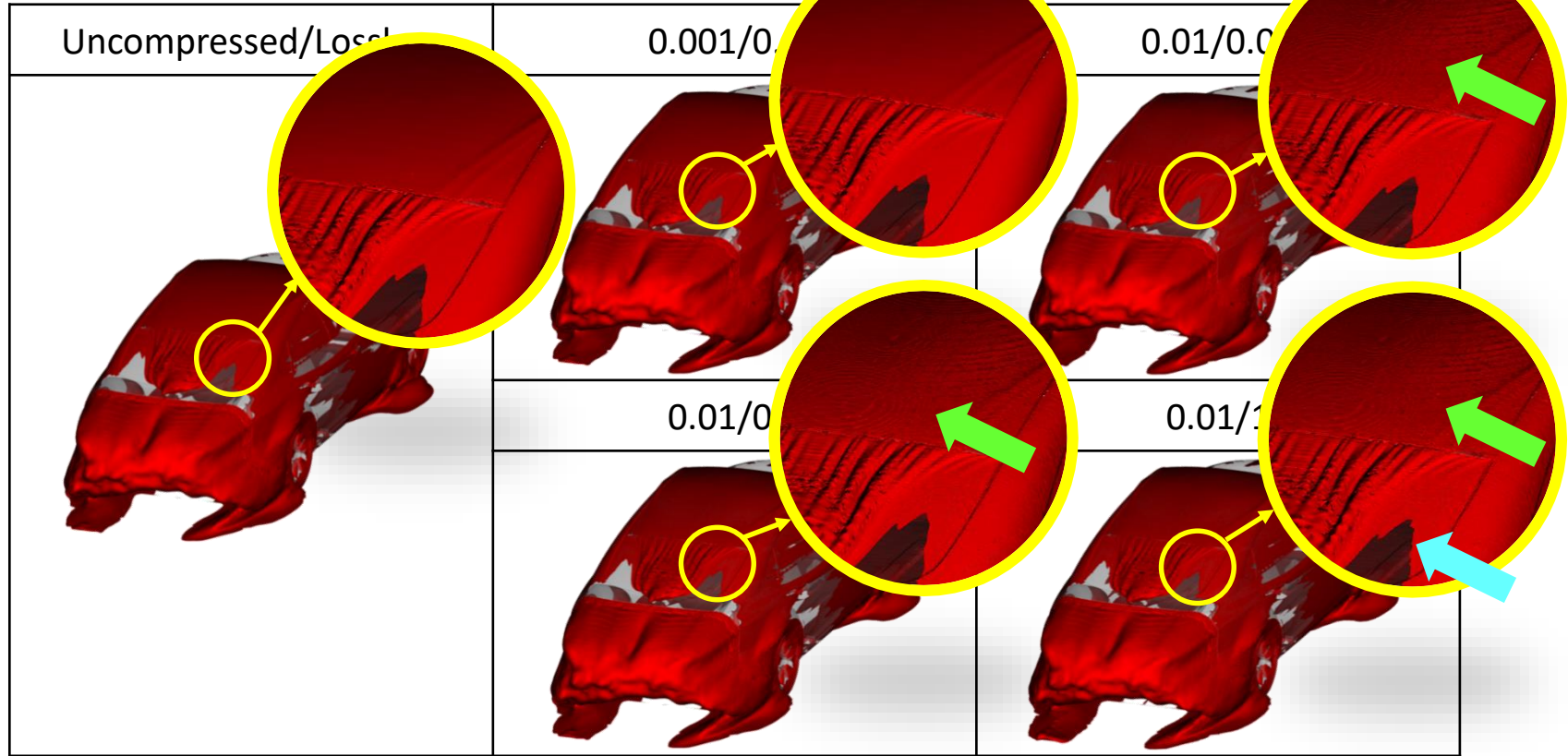
Percentage – Geometry comparison



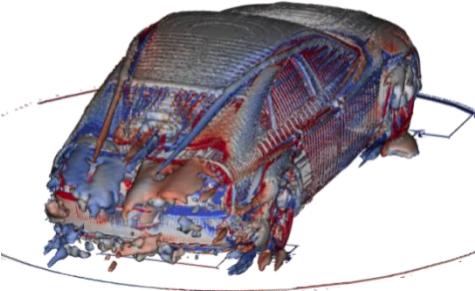
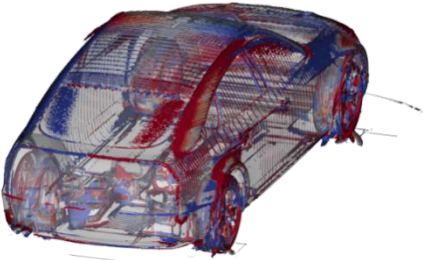
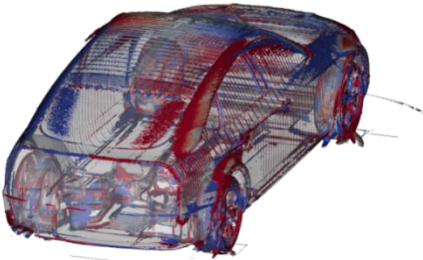
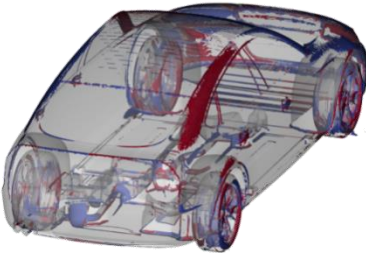
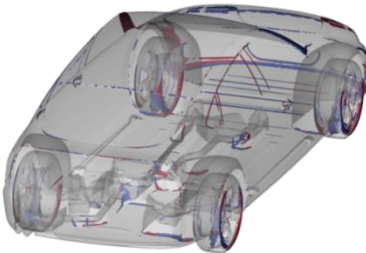
Percentage – Results comparison $U_{\text{mean,mag}}/U_{\infty}$ at $y=0$



Percentage – Mean $C_{p,tot}$ isosurface

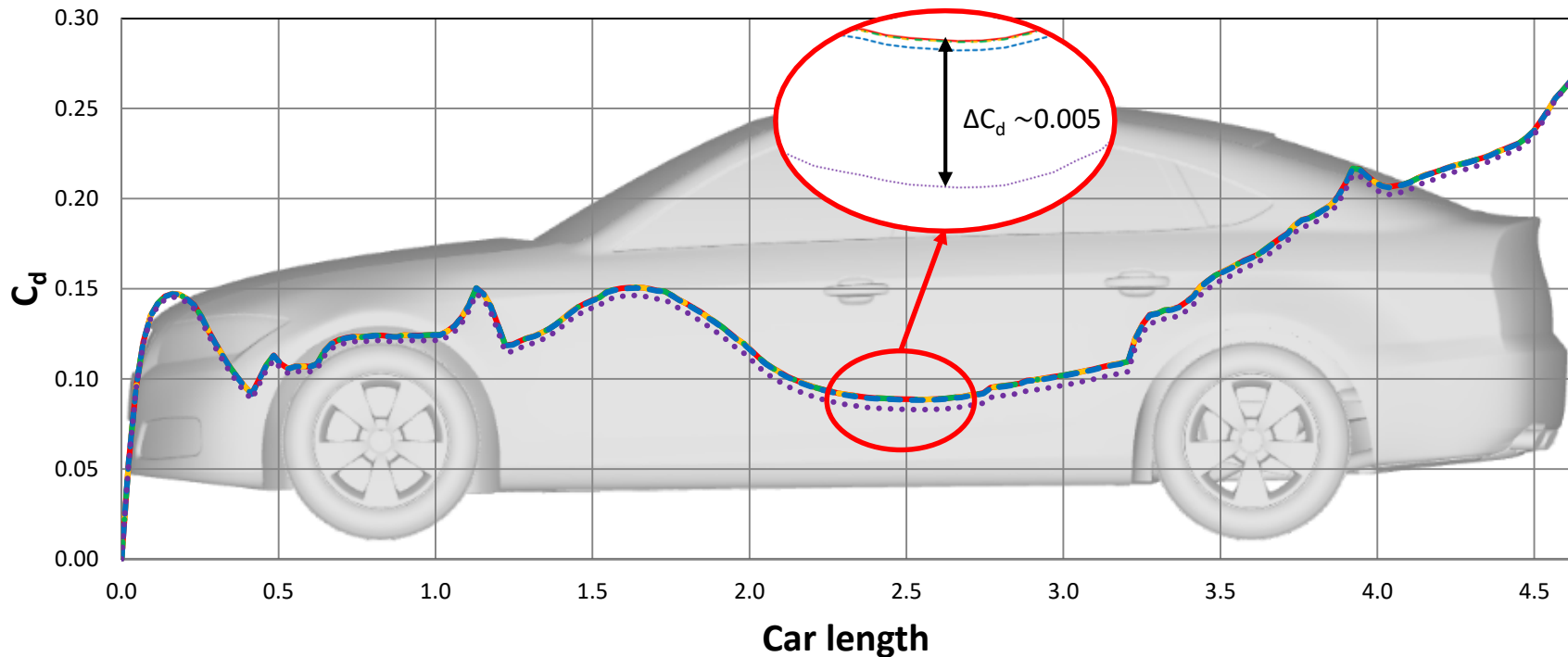


Percentage – Mean Q criterion isosurface

Uncompressed/Lossless	0.001/0.01	0.01/0.01
		
	<p data-bbox="852 547 1000 585">0.01/0.1</p>	<p data-bbox="1392 547 1508 585">0.01/1</p>
		



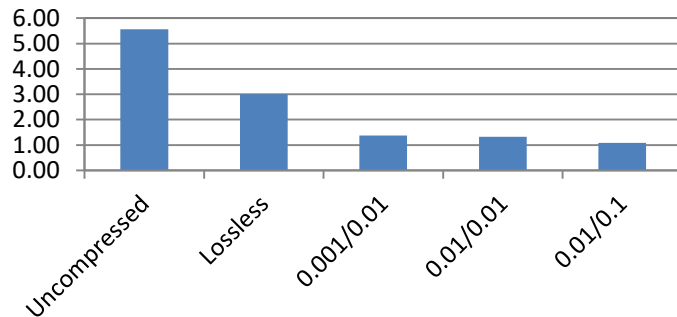
Percentage – Cumulative drag coefficient



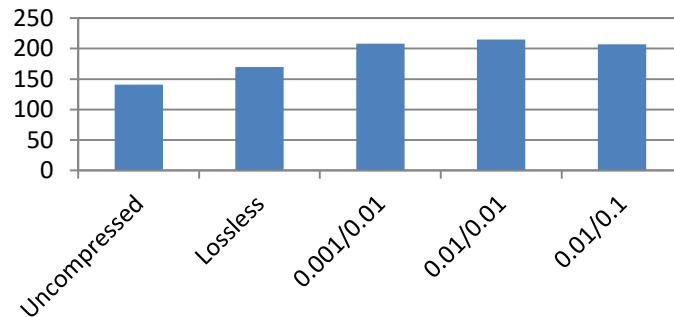
— Uncompressed/Lossless - - 0.001/0.01 - · - 0.01/0.01 - - - 0.01/0.1 ···· 0.01/1

Percentage – File comparison

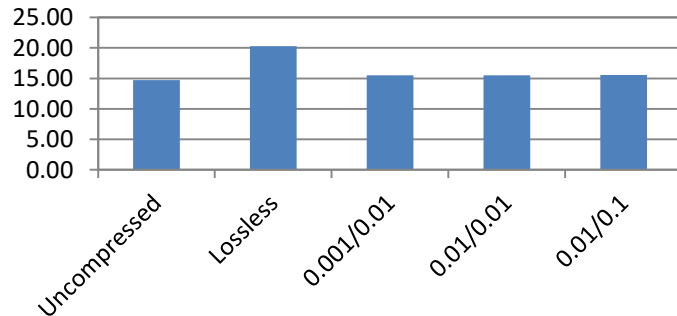
File size [GB]



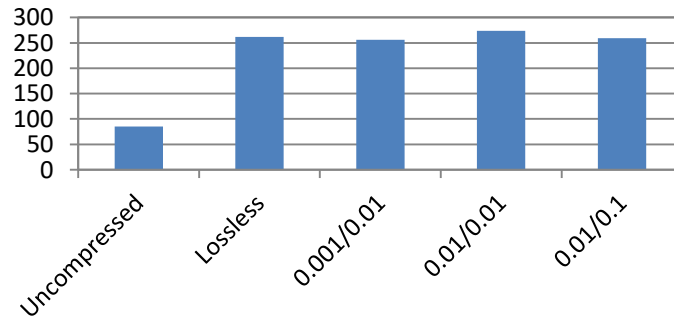
Total reading time [s]



RAM consumption [GB]



Saving time [s]

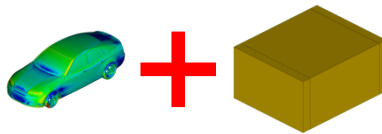


Percentage – Conclusion

- Best cases 0.001/0.01 and 0.01/0.1
 - 0.001/0.01 is 75% (4.2 GB) smaller
 - 0.01/0.1 is 81% (4.5 GB) smaller but introduces “waves” in isofunctions
- Due to big range of Q criterion ($\sim 10^6$) detail is lost
 - More accuracy for Q criterion required

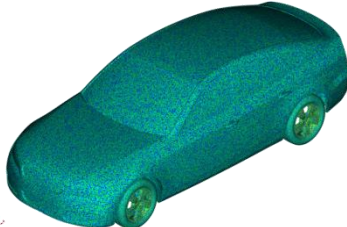
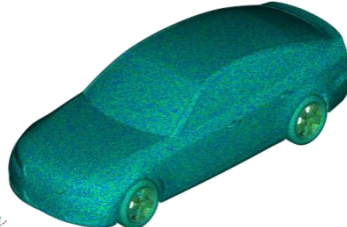
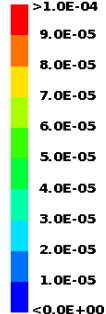
Compression methodology

Percentage with Set

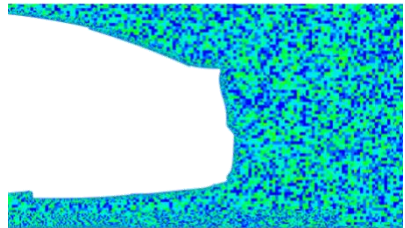
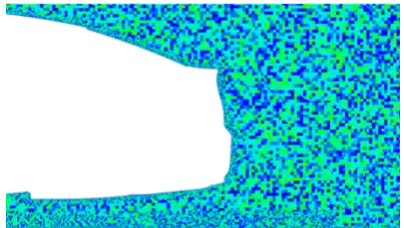
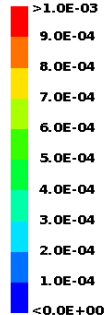


Percentage with Set – Results comparison

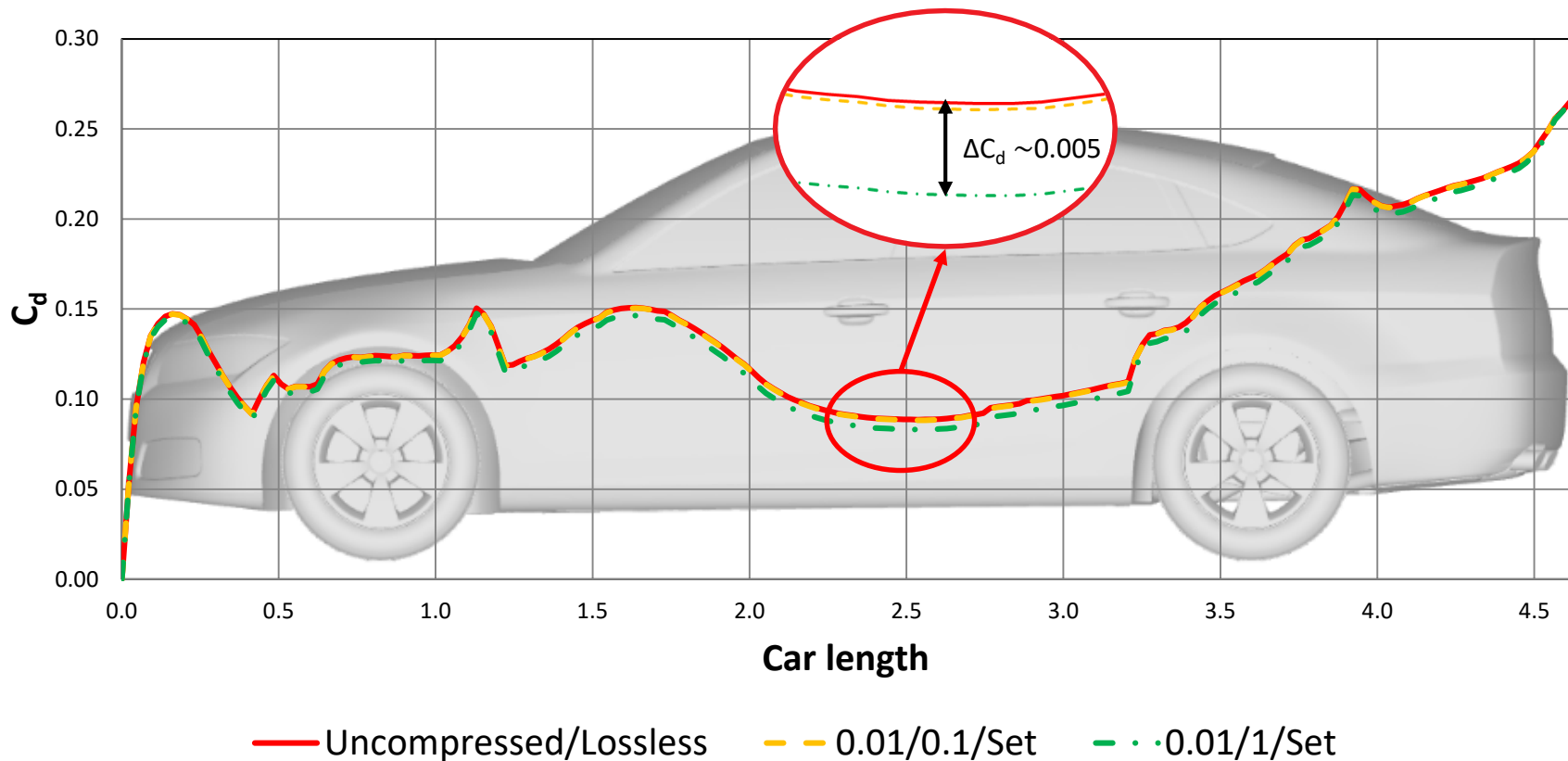
- On Set, deviation same as in Percentage 0.001/0.01

	0.01/0.1/Set	0.001/0.01	
$\left \frac{U_{nw,uncomp} - U_{nw,comp}}{U_{\infty}} \right $	 <p>Max difference on surface: $8 \cdot 10^{-5}$</p>	 <p>Max difference on surface: $8 \cdot 10^{-5}$</p>	

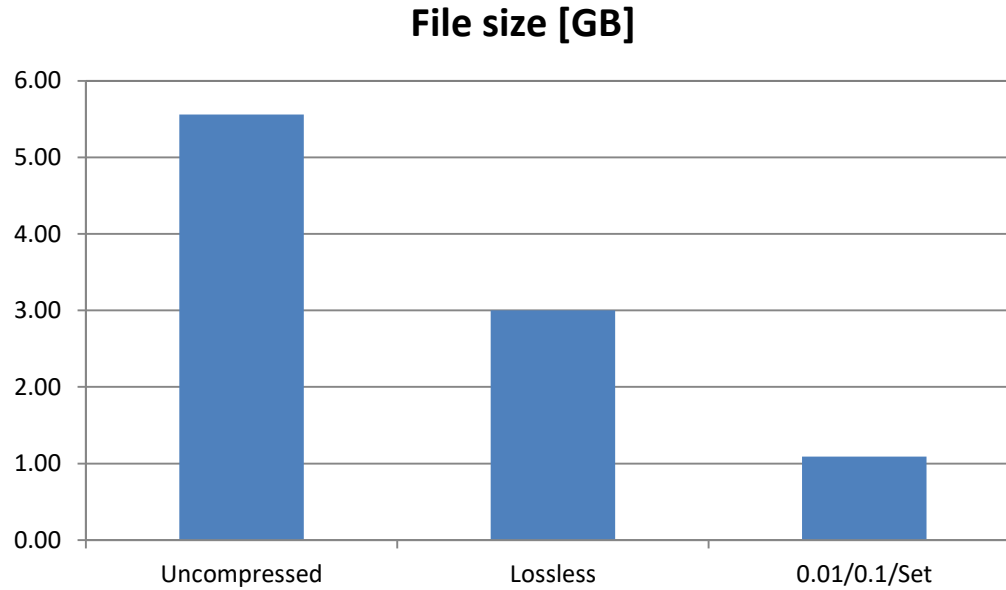
- In volume, deviation same as in Percentage 0.01/0.1

	0.01/0.1/Set	0.01/0.1	
$\left \frac{U_{uncomp} - U_{comp}}{U_{\infty}} \right $	 <p>Max difference globally: $5 \cdot 10^{-4}$</p>	 <p>Max difference globally: $5 \cdot 10^{-4}$</p>	

Percentage with Set – Cumulative drag coefficient



Percentage with Set – File comparison

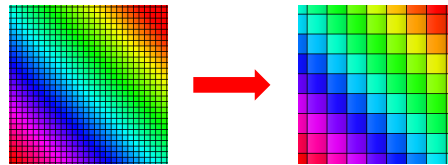


Percentage with Set – Conclusion

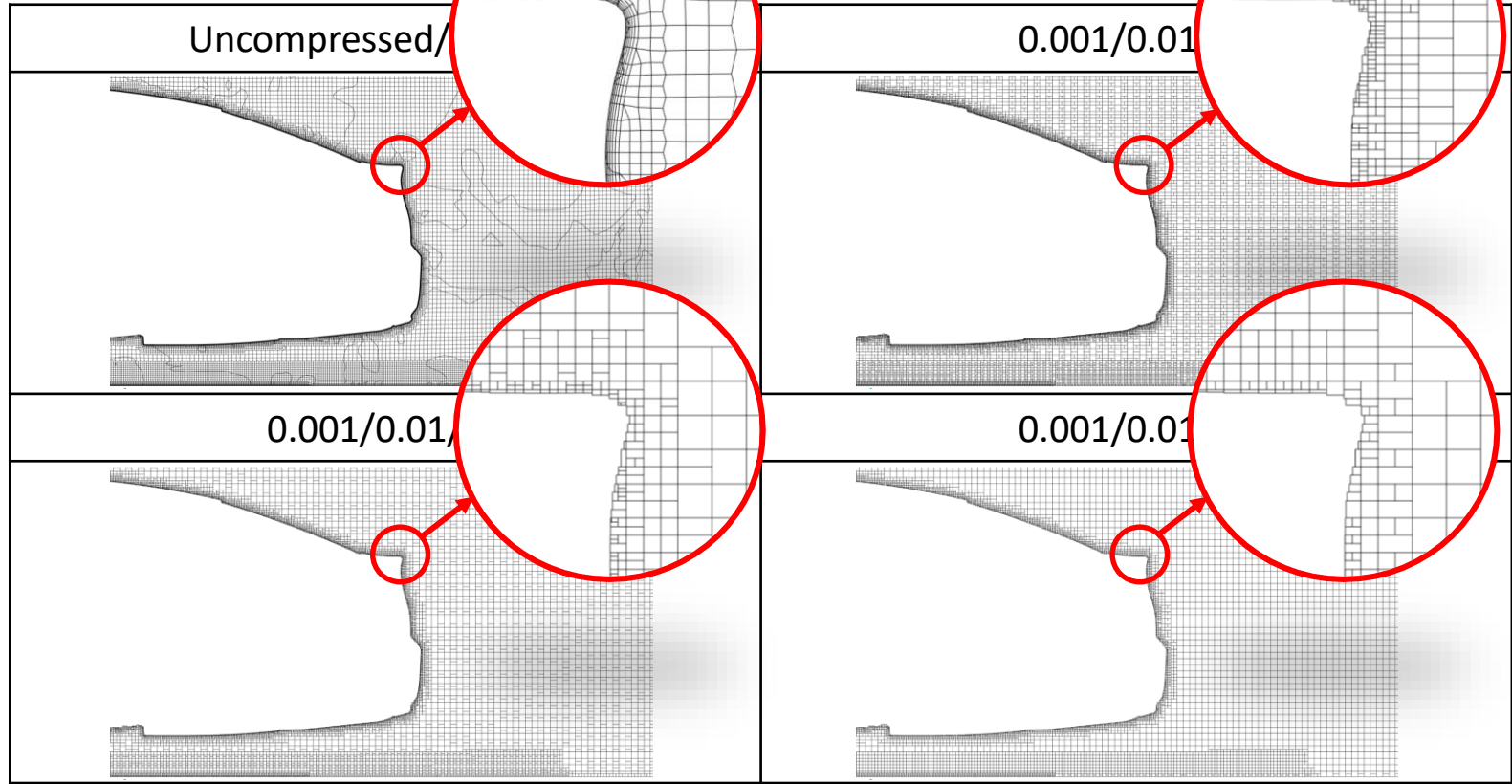
- 0.01/0.1/Set is 80% (4.5 GB) less
- High accuracy on model surface, reduced accuracy in volume
 - “Waves” on isosurfaces

Compression methodology

Percentage and Simplification

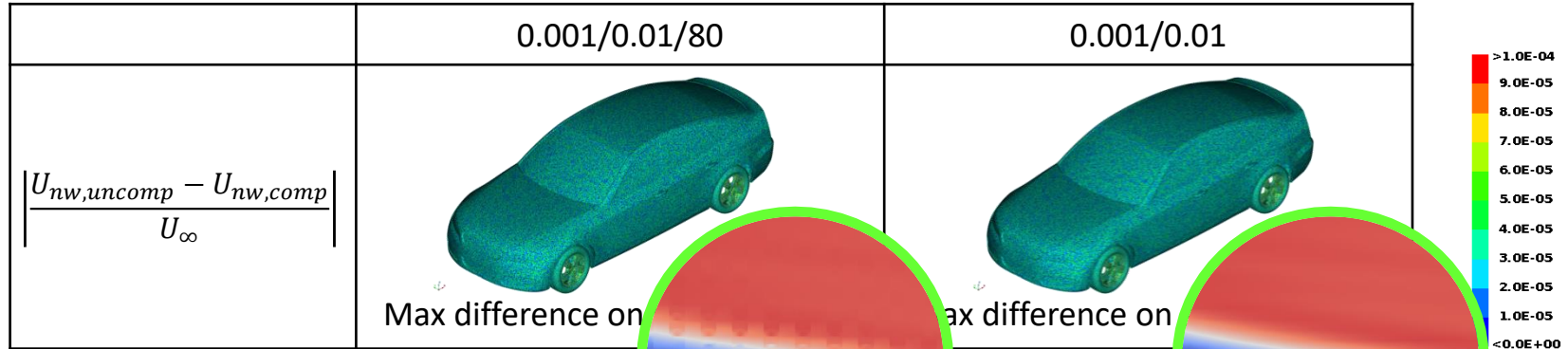


Percentage and Simplified Symmetry comparison

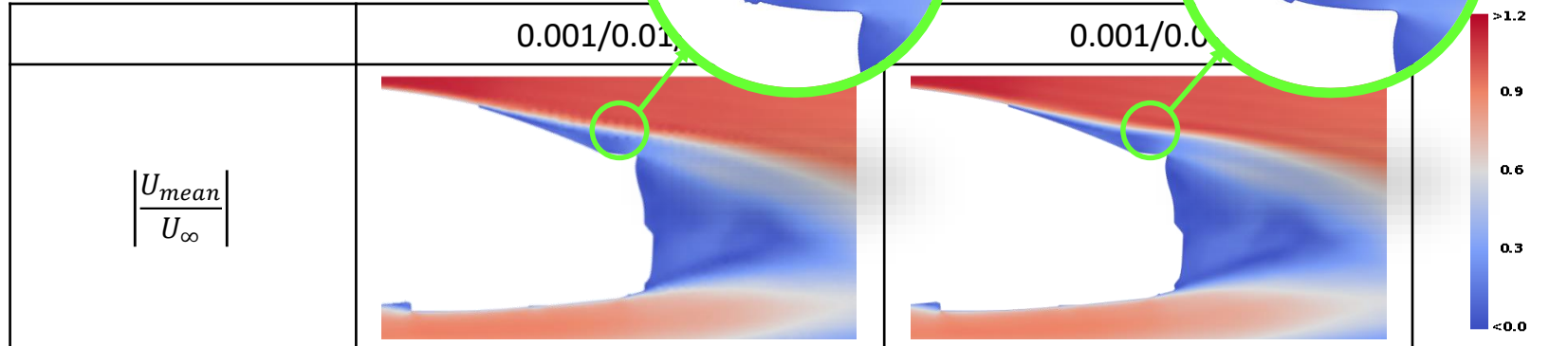


Percentage and Simplification – Results comparison

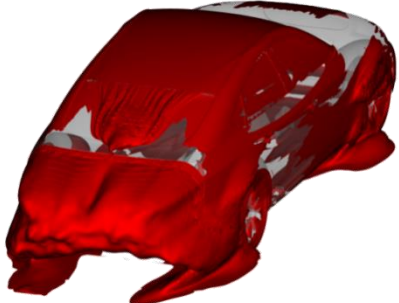
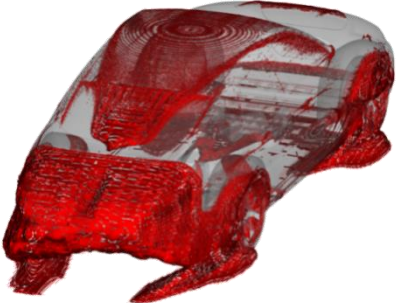
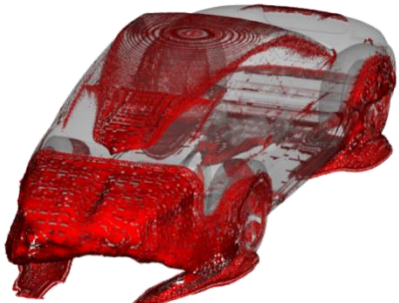
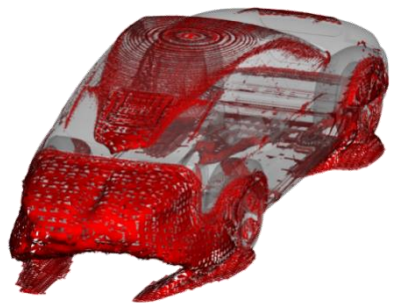
- Simplification does not affect surfaces – same accuracy as in 0.001/0.01



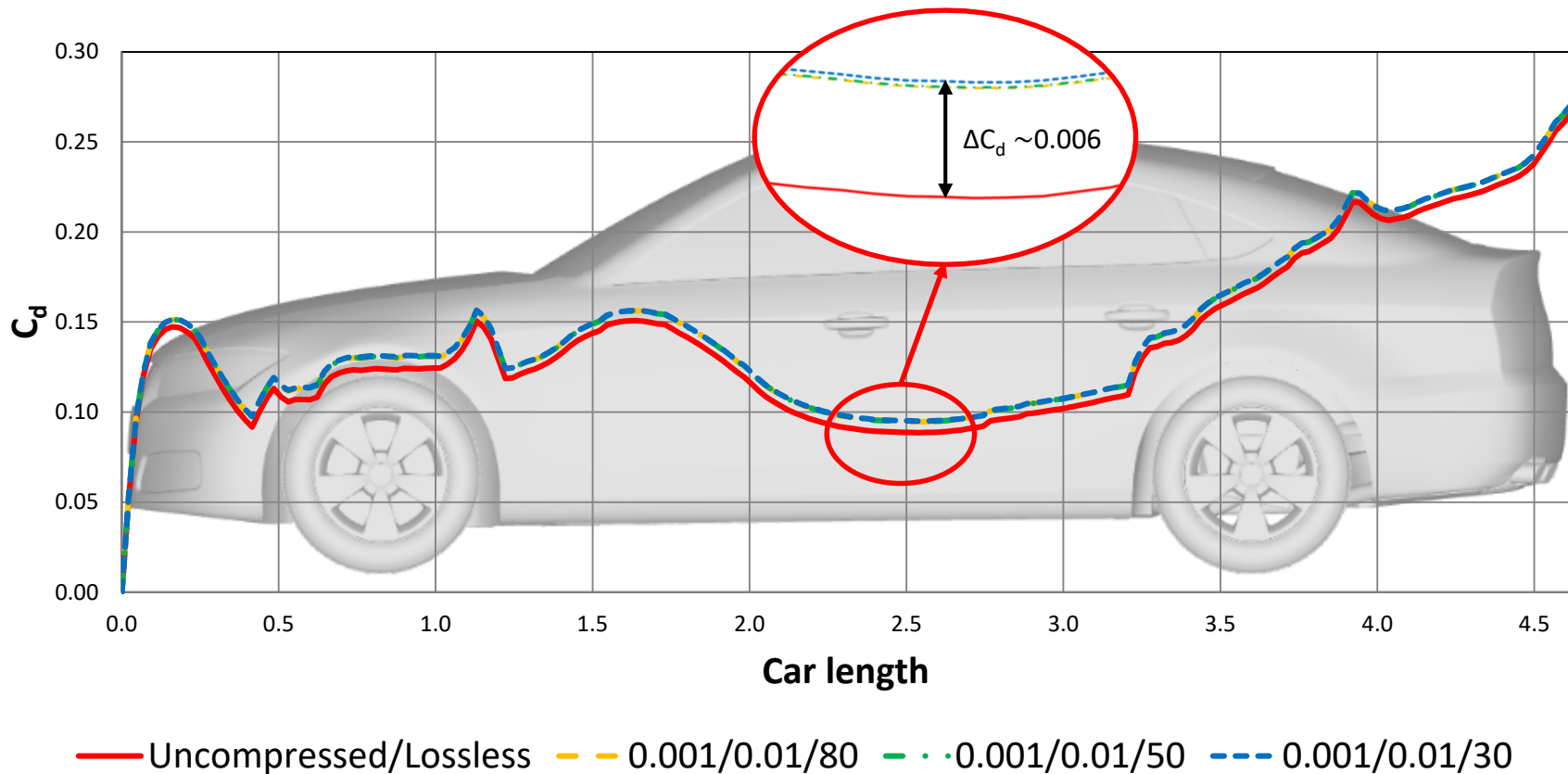
- In volume, deviation visually identical



Percentage and Simplification – Mean $C_{p,tot}$ isosurface

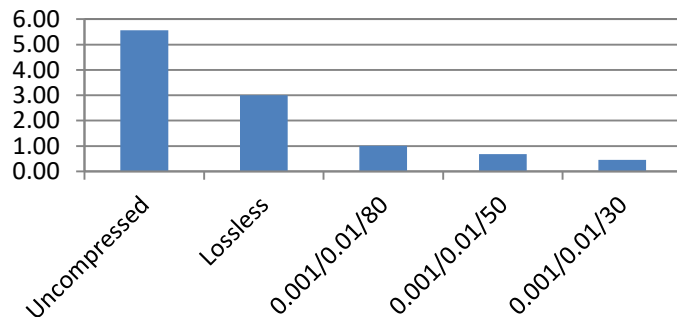
Uncompressed/Lossless	0.001/0.01/80
 A 3D isosurface plot of a car's total pressure coefficient (Cp,tot) mean. The surface is rendered in a semi-transparent red color, showing the car's geometry and internal flow features. The surface is smooth and detailed, representing the uncompressed/lossless data.	 A 3D isosurface plot of a car's total pressure coefficient (Cp,tot) mean, compressed to 0.001/0.01/80. The surface is rendered in a semi-transparent red color. It shows significant blockiness and loss of fine detail compared to the uncompressed version, but the overall shape is preserved.
0.001/0.01/50	0.001/0.01/30
 A 3D isosurface plot of a car's total pressure coefficient (Cp,tot) mean, compressed to 0.001/0.01/50. The surface is rendered in a semi-transparent red color. It shows a similar level of blockiness to the 0.001/0.01/80 version, with some loss of detail.	 A 3D isosurface plot of a car's total pressure coefficient (Cp,tot) mean, compressed to 0.001/0.01/30. The surface is rendered in a semi-transparent red color. It shows a similar level of blockiness to the 0.001/0.01/50 version, with some loss of detail.

Percentage and Simplification – Cumulative drag coefficient

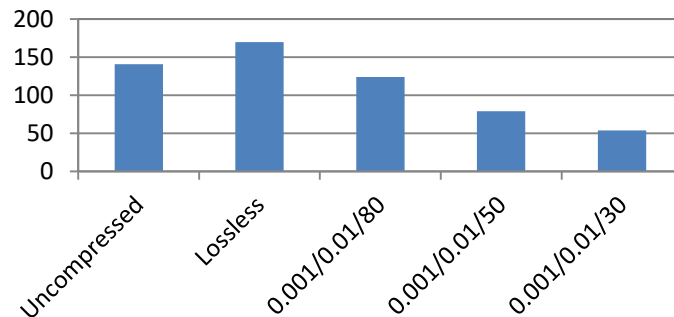


Percentage and Simplification – File comparison

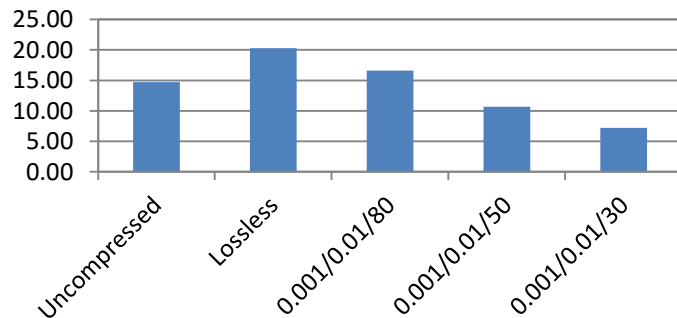
File size [GB]



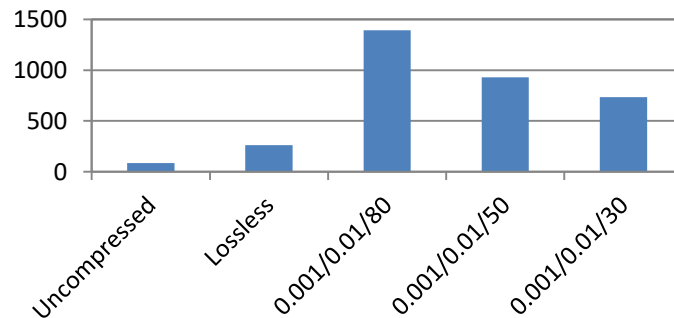
Total reading time [s]



RAM consumption [GB]



Saving time [s]



Percentage and Simplification – Conclusion

- Simplification greatly reduces file size
 - 0.001/0.01/30 is 92% (5.1 GB) less
- Shell mesh remains unaffected – good accuracy on surface results
- Noticeable deviation on volume results
 - Original mesh lost
 - Volume boundaries not respected
 - Boundary layer simplified
- Isosurfaces not properly generated

Compression methodology

Round Off

$$|Uncompressed - Compressed| \leq 0.001$$

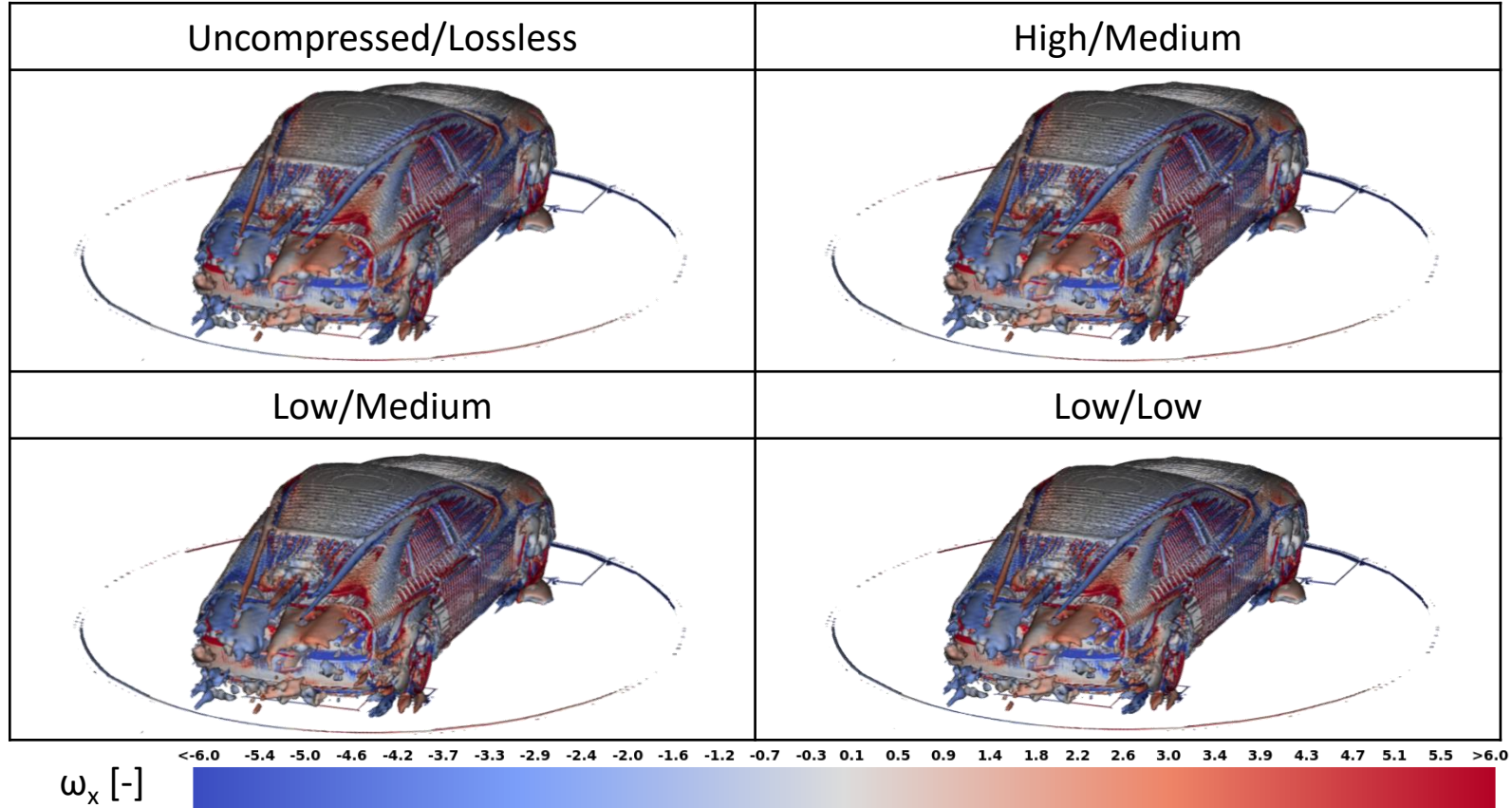
Round Off – Results comparison

	High	Medium	Low
$\left \frac{U_{nw,uncomp} - U_{nw,comp}}{U_{\infty}} \right $	<p>A 3D model of a car, colored solid blue, representing high precision results.</p>	<p>A 3D model of a car, colored blue with a fine, uniform noise pattern, representing medium precision results.</p>	<p>A 3D model of a car, colored green with a coarse, noisy pattern, representing low precision results.</p>
$\left \frac{U_{uncomp} - U_{comp}}{U_{\infty}} \right $	<p>A 2D cross-section of the car, colored solid blue, representing high precision results.</p>	<p>A 2D cross-section of the car, colored blue with a fine, uniform noise pattern, representing medium precision results.</p>	<p>A 2D cross-section of the car, colored green with a coarse, noisy pattern, representing low precision results.</p>
	Max difference: $<10^{-4}$	Max difference: $<10^{-3}$	Max difference: <0.01

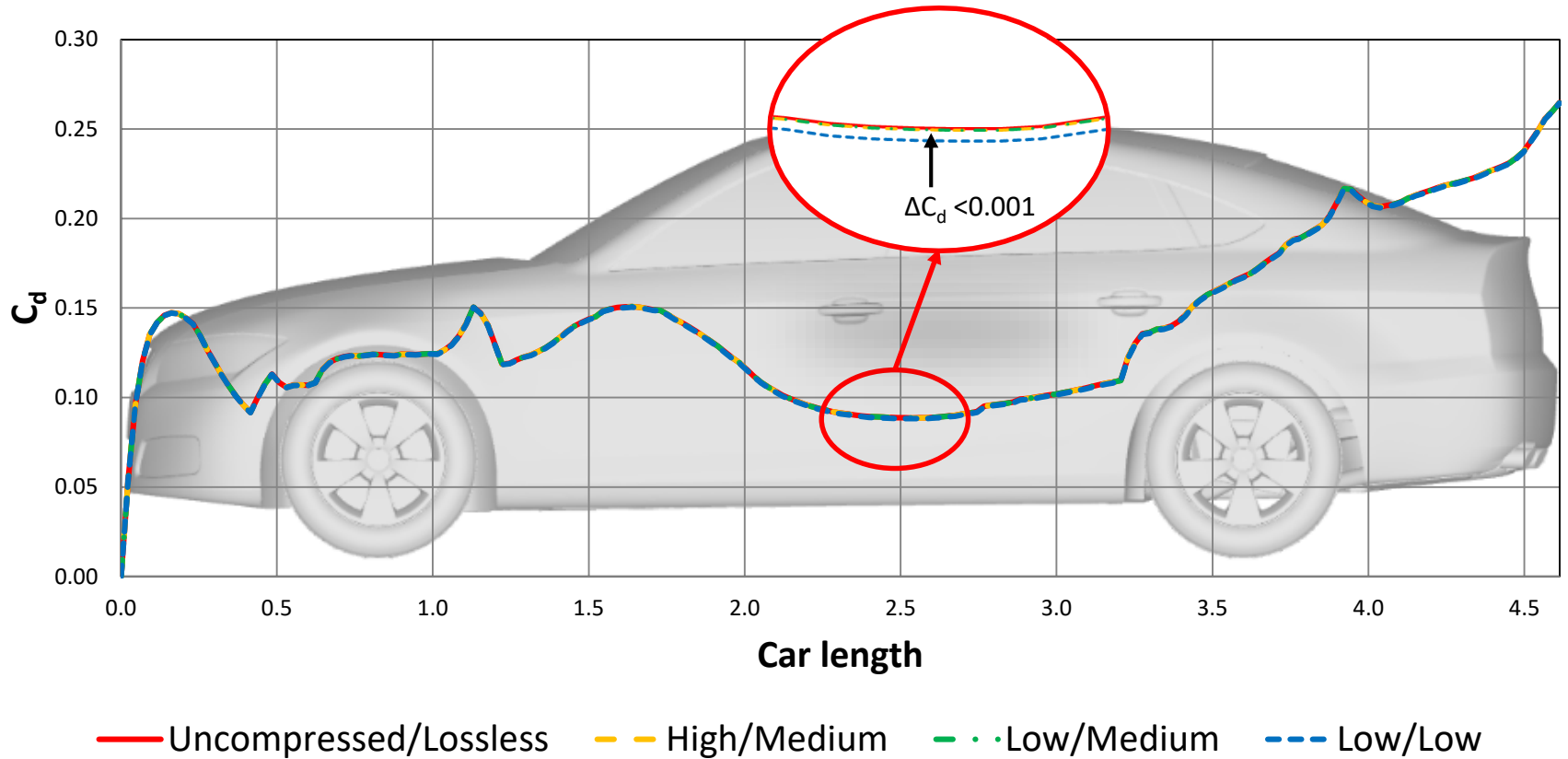
<0.0E+00 5.0E-04 1.0E-03 1.5E-03 2.0E-03 2.5E-03 3.0E-03 3.5E-03 4.0E-03 4.5E-03 5.0E-03 5.5E-03 6.0E-03 6.5E-03 7.0E-03 7.5E-03 8.0E-03 8.5E-03 9.0E-03 9.5E-03 >1.0E-02



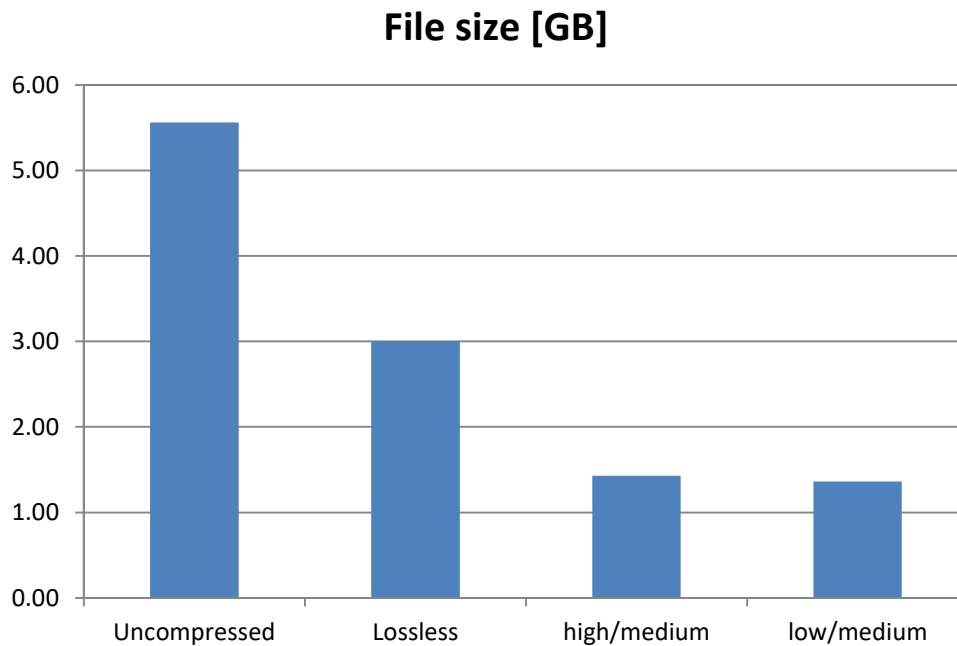
Round Off – Mean Q criterion isosurface



Round Off – Cumulative drag coefficient



Round Off – File comparison



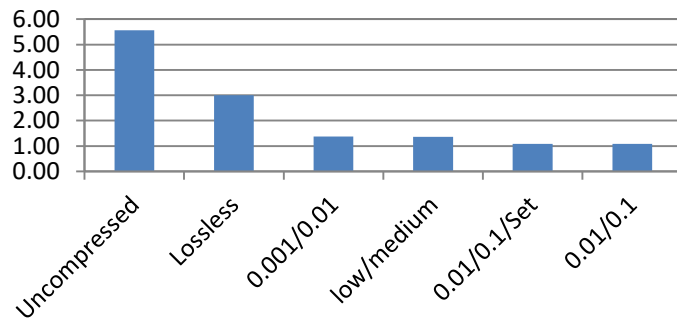
Round Off – Conclusion

- Best case Low/Medium option
 - Low/Medium is 76% (4.2 GB) less
- Careful round off digit selection – small file size, no accuracy loss

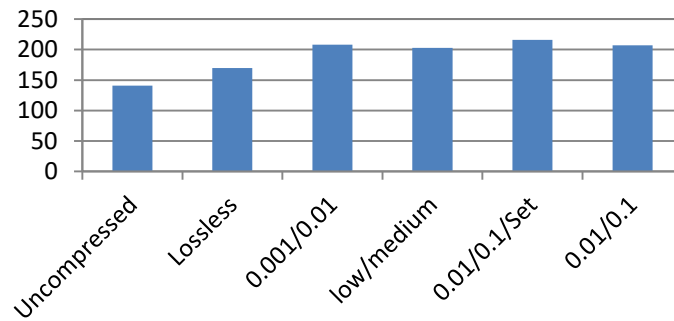
Final Conclusion

File comparison

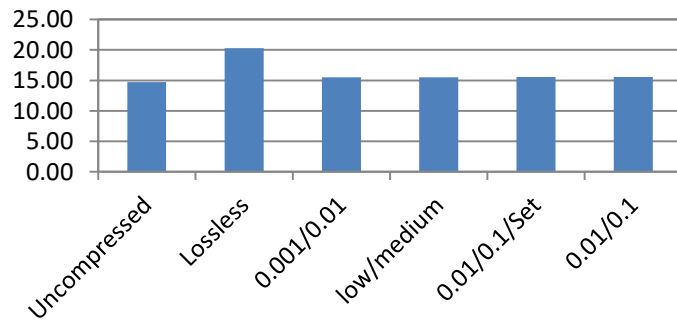
File size [GB]



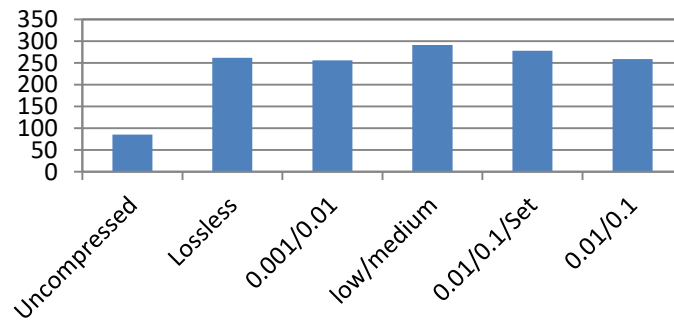
Total reading time [s]



RAM consumption [GB]



Saving time [s]



Conclusion

- Saving metadb without compression required 5.5 GB

- Lossless is 46% (2.5 GB) less

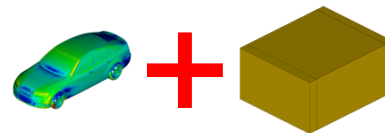


- Percentage: 0.001/0.01 is 75% (4.2 GB) less



- Q criterion required higher accuracy

- Percentage with Set: 0.01/0.1/Set is 80% (4.5 GB) less



- High accuracy on model surface, lower accuracy in volume

- “Waves” on isosurfaces

- Round Off: Low/Medium is 76% (4.2 GB) less

$$|Uncompressed - Compressed| \leq 0.001$$

Conclusion

- Compression by Percentage easier to setup
 - Some results may need more accuracy
- Round Off compression, high accuracy
 - Need to know precision for each result
- Compression by Simplification – smaller size, less accuracy
 - Recommended for usage in a presentation



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