

# Acoustic Digital Prototype Evolution at Bentley

Simon Noble – Bentley Motors Ltd.



# Agenda

1 Introduction and Motivation

2 Virtual Evaluation  
– Constructing a virtual vehicle acoustic evaluation

3 Case Studies x 5  
– Virtual evaluation usage at Bentley (Influencing)

4 Next Steps  
How can we make it better?

5 Summary

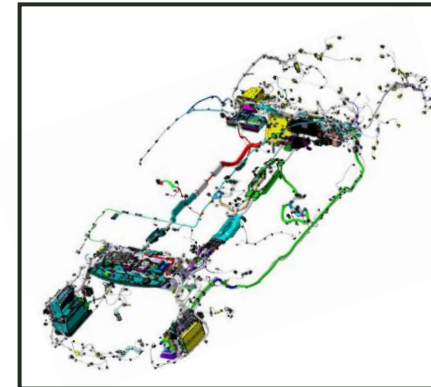
6 Bonus Slide

7 Questions

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# Introduction and Motivation

# Digital Prototype Requirement



## Physical Prototypes

High investment cost for vehicle build and tooling

- Major changes are not possible to implement e.g. interior cavity sizes or BIW materials

## Project Timing

Business desire to release new projects faster

- Shorter/less physical validation phases

## Engineering Change

Time required to validate physical changes

- Some changes are best done in simulation – but then how do we gain engagement?

## Electrical Architecture and Software

Active noise cancellation, pedestrian warning, propulsion sound

- All of the above need to be included and well defined in the very early project stages

## Vehicle Weight/Efficiency

Acoustic attributes can have a significant contribution to improving vehicle efficiency

- BIW material choices, stiffness measures, tyre and powertrain development. Good design from the start is required for optimum efficiency

# The Problem of Engagement with Digital Prototypes – An Example

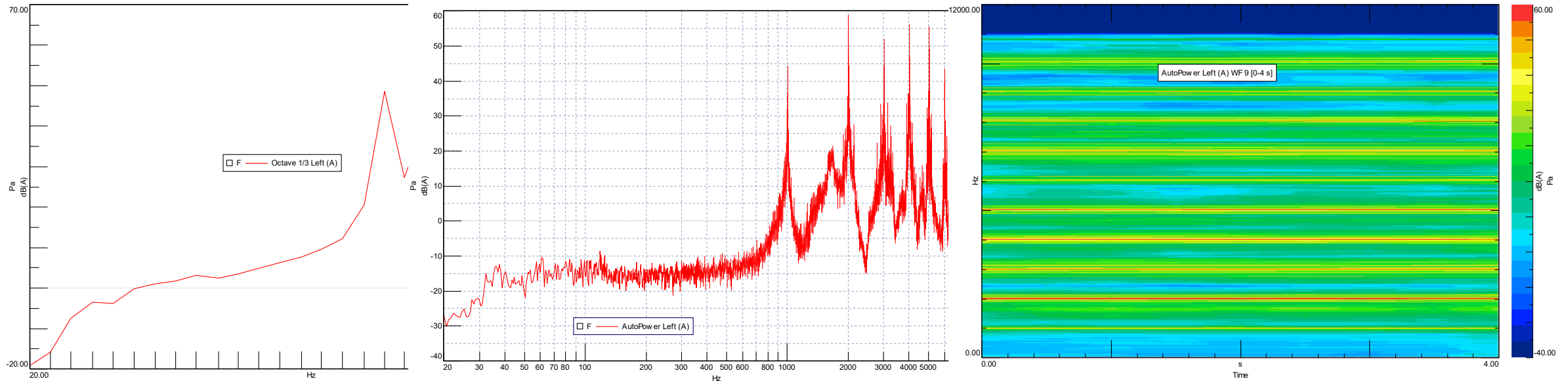
A Theoretical Example:

- We have run a simulation and identified a concern
- The concern requires a large investment to resolve and a major re-design.

At which point in the following line of evidence do you commit to the expenditure



It's 5 dB louder than the background noise



# Influencing Tools for Improving Noise Performance - Automotive Subjective Assessment – Hearing is Believing



## Physical Prototype

- + Exact Customer Experience
- Subtle improvements are lost in car variability or time between assessments



## Virtual Evaluation

- + Instant switch between conditions or vehicles for comparison
- Limited experience in terms of condition possibilities, user environments and spatial audio



# Full Vehicle Simulator and Desk Top Simulator Overview

## Subjective Assessment – Hearing is Believing



### Full Vehicle Simulator

Physical vehicle environment

Simulated road visuals

~~Vibration inputs at tactile points~~

High fidelity audio

Touch screen for assessments



### Desktop Simulator

Desktop scenario – audio only

Simulated road visuals – if desired

Multiple listeners to allow jury assessment

High fidelity audio

Back to back listening capability

This presentation will focus on acoustic evaluation

# 2

## Virtual Evaluation

- Constructing a virtual vehicle acoustic evaluation

# Sources of Noise



Engine / Motor

Ancillaries

Tyre Patches

Gearbox / Driveline

Exhausts (I.C.E Only)

# — The Source Path Receiver Model

## Acoustic Components

We can split a vehicle into its acoustic component parts



Source

$Q$

Path

$$H = \frac{p}{Q}$$

Receiver

$p$

# Quantification of Interior Noise Performance



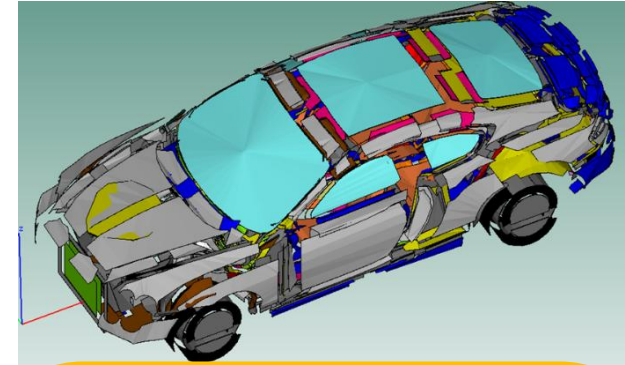
## Physical Track/Dyno Testing

Artificial binaural heads for interior noise measurements



## Static Testing

Quantified sound source input and measured responses



## Simulation

Statistical Energy Analysis (SEA), Finite Element Analysis (FEA), Boundary Element Method (BEM), Computational Fluid Dynamics (CFD).....

Objective is to consolidate and auralise these outputs  
Hearing is Believing

# Constructing a Virtual Vehicle Acoustic Evaluation

Virtual Evaluation Input Requirements		Output
Airborne Sources [ $\text{m}^3/\text{s}$ ] Structure Borne Sources [N]	$\times$ Paths [ $\text{Pa}/(\text{m}^3/\text{s})$ ] Paths [Pa/N]	= Receiver [Pa]
Fr LH Tyre Patch Fr RH Tyre Patch Re LH Tyre Patch Re RH Tyre Patch Engine/Motor Ancillaries Gearbox Driveline LH Exhaust Orifice RH Exhaust Orifice ..... .....	Fr LH Tyre Patch to Drivers Ear Fr RH Tyre Patch to Drivers Ear Re LH Tyre Patch to Drivers Ear Re RH Tyre Patch to Drivers Ear Engine/Motor to Drivers Ear Ancillaries to Drivers Ear Gearbox to Drivers Ear Driveline to Drivers Ear LH Exhaust Orifice to Drivers Ear RH Exhaust Orifice to Drivers Ear ..... to Drivers Ear ..... to Drivers Ear	Drivers Ear

This can be measured or simulated data or a mix if required

# Masking Noise - Path Predictions

Road Noise (Airborne and Structure borne) and Aeroacoustics

## Fast Approach

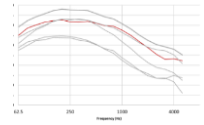
Donor data from head position Operational Transfer Path Analysis (OTPA) / HSVD

## Standard Approach

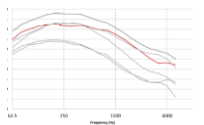
Donor data from Full Transfer Path Analysis (TPA)

CHANGE FILTER

CAE  
Prognosis  
Future  
[Ear Position]



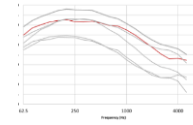
CAE  
Correlated  
Current  
[Ear Position]



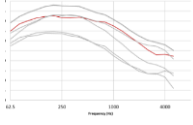
N.B. This operation is required to allow a realistic sounding vehicle and to fill gaps in simulations e.g. SEA gives a 1/3<sup>rd</sup> octave prediction which cannot be directly introduced

CHANGE FILTER

CAE  
Prognosis  
Future  
[Path]



CAE  
Correlated  
Current  
[Path]



Measured  
Current  
Vehicle  
[Time Domain Ear  
Position Masking  
Noises, Pa]

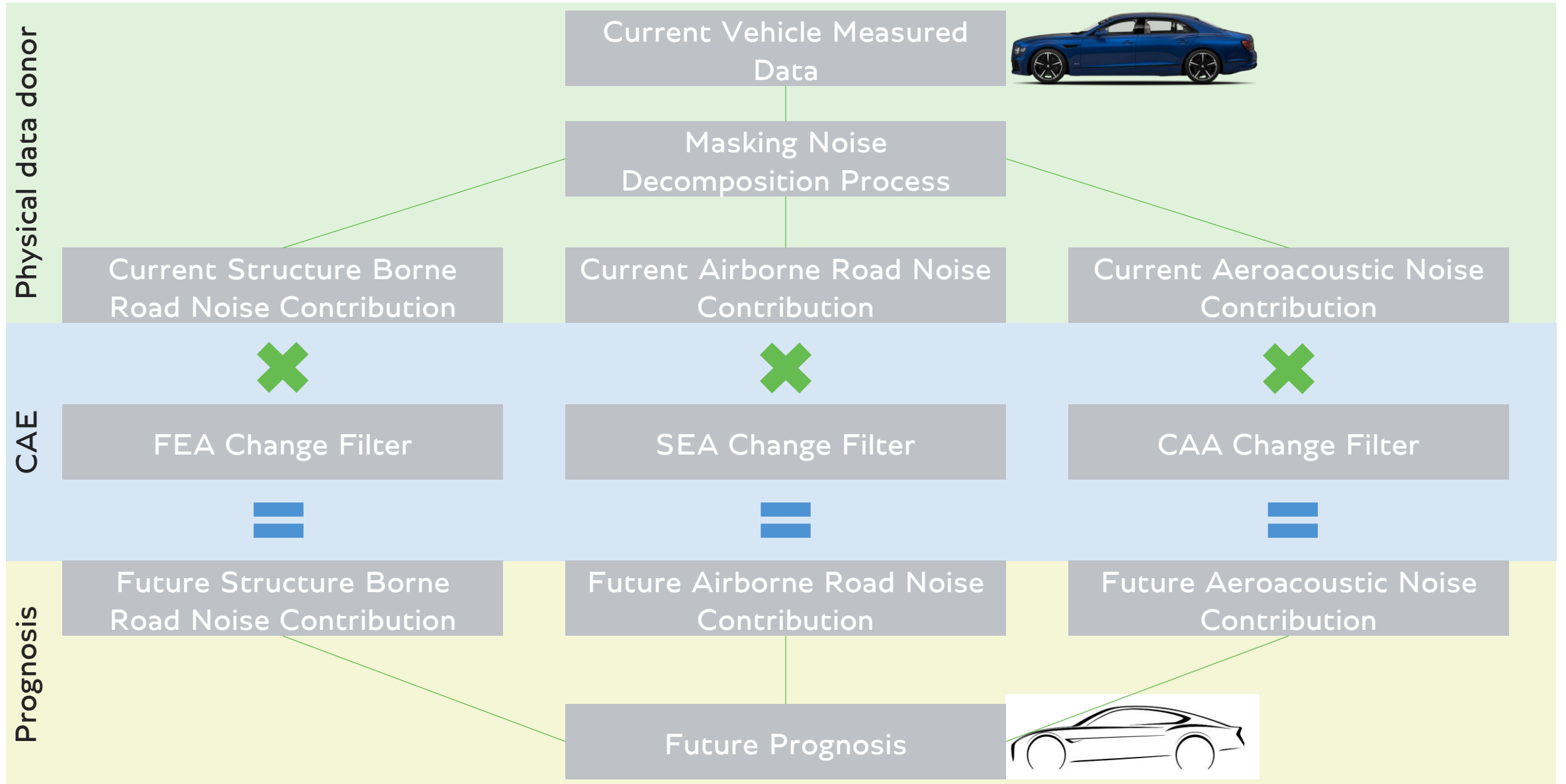
Prognosis  
Future  
Vehicle  
[Time Domain Ear  
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Noises, Pa]

Measured  
Current  
Vehicle  
[Path]

Prognosis  
Future  
Vehicle  
[Path]

# Masking Noise - Path Predictions

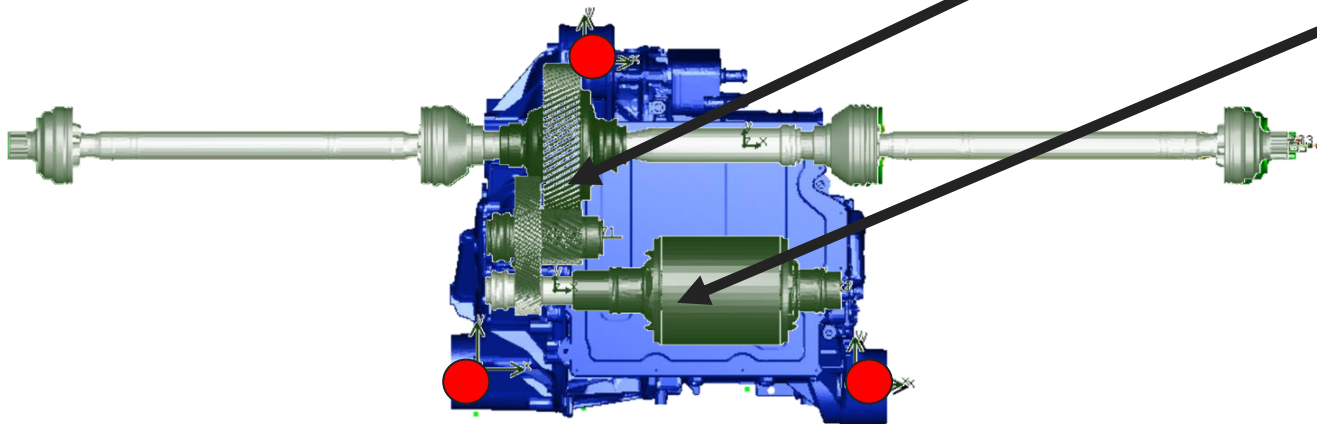
Road Noise (Airborne and Structure borne) and Aeroacoustics



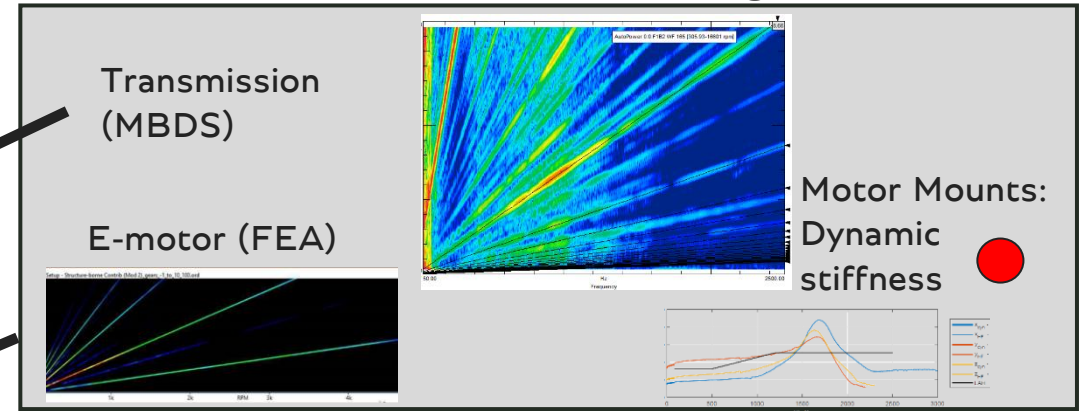
# Powertrain Noise Example – Source to Interior Noise Prediction

E-Motor Whine

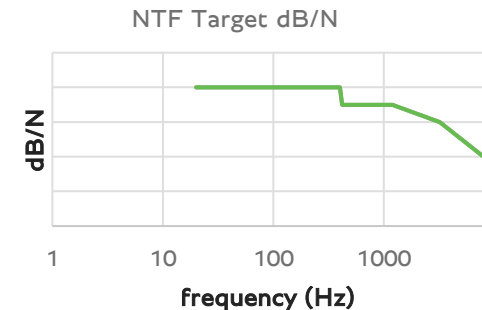
N.B. The corresponding masking noise is essential for understanding if the resulting E-Motor noise is an issue. (Peak Emergence Levels)



Source: vibration/forcing levels



Path: Noise Transfer Function



This can be created using both FEA and SEA to achieve the full spectrum prediction

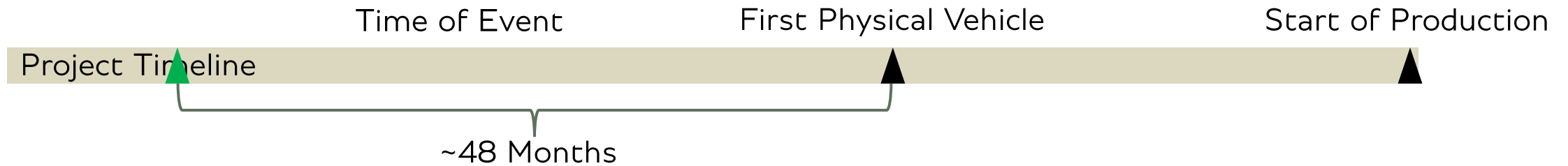
Future Powertrain Noise Contribution

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# Case Studies x 5

– Virtual Evaluation usage at Bentley (Influencing)

# 1. Active Road Noise Cancellation Requirement



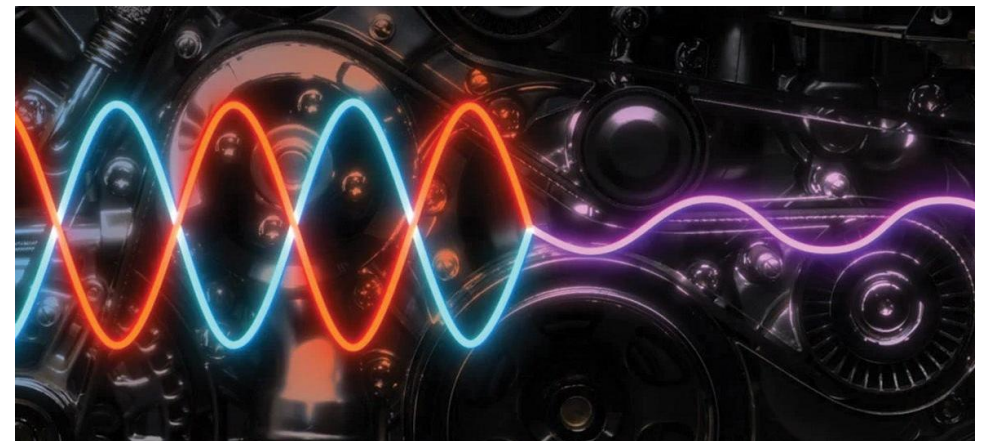
Attribute Assessed	Objective
Structure-borne Road Noise	Justify requirement for active road noise cancellation system inclusion in project (0-200Hz)
Airborne Road Noise	Show that reduction of low frequency upsets 'balance' and drives requirement for mid to high frequency improvement also (500-1kHz)

## Model Construction Method

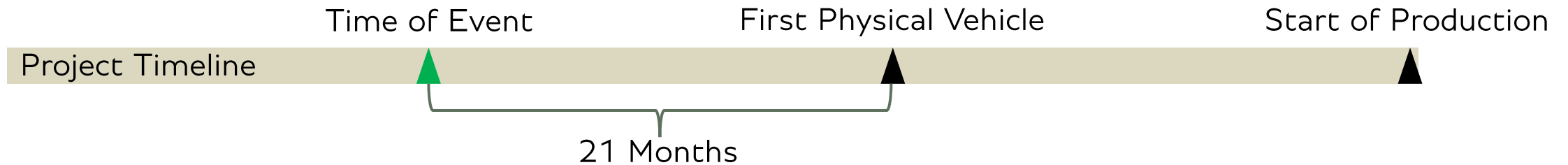
### Masking Noise:

Acoustic simulation models at this early phase were not available

Donor measured physical vehicle used with computational ARNC system overlaid



## 2. All Attributes Gateway Status



Attribute Assessed	Objective	Outcome- Learnings for future
Aeroacoustics	Highlight front end design issue	No sense of sound direction, head movement in real scenario not possible
Structure-borne Road Noise	Low frequency boom noise; tailgate tuned mass damper, sunroof boom	Large room made subwoofer placement tricky, fixed room with tuned sub location required
Airborne Road Noise	justification for rear cabin acoustic pack requirements	N/A
Powertrain	Front motor structure borne whine during regen issue, rear motor airborne noise risks	Just structure borne noise was possible, opportunity missed to demonstrate airborne

### Model Construction Method

#### Masking Noise:

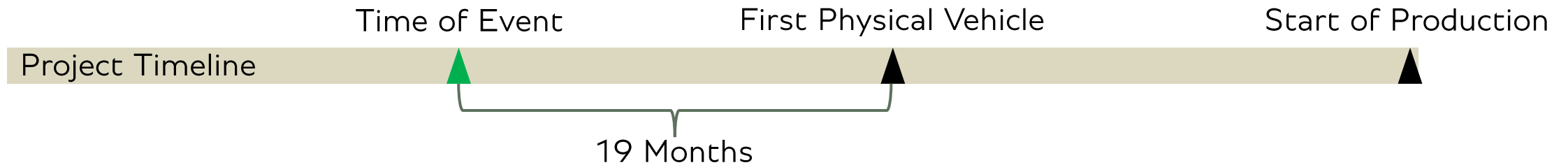
Donor vehicle decomposition with powertrain content removed  
 All attributes applied change filters produced using CAE

#### Powertrain:

Mix of measured rig test data and simulated noise transfer functions



### 3. Carpet EPDM Layer Reduction – 8kg weight reduction



Attribute Assessed	Objective	Outcome – Learnings for future
Structure-borne Road Noise Airborne Road Noise	Optimise weight with minimal acoustic detriment	N/A
Powertrain	Assess rear e-motor whine risk	N/A

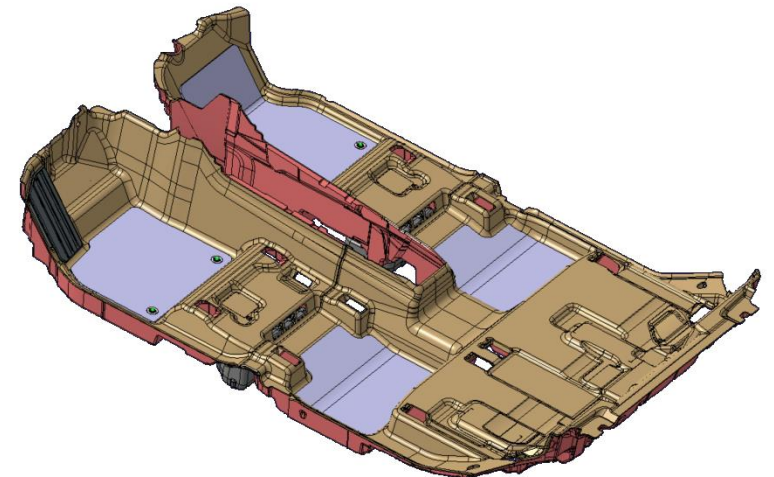
#### Model Construction Method

##### Masking Noise:

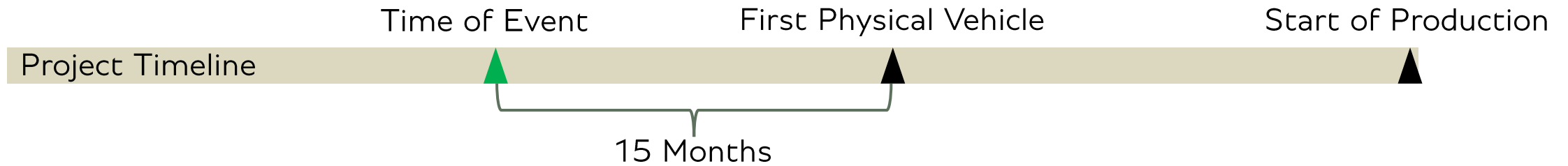
Donor vehicle decomposition with powertrain content removed  
All attributes applied change filters produced using CAE

##### Powertrain:

Source: Measured  
Transfer Path: FEA and SEA simulated deltas applied for condition changes



## 4. Aeroacoustics – Mirror Tonal Concern



Attribute Assessed	Objective	Outcome
Aeroacoustics	Highlight issues with current mirror cap design	Other masking noises cover the tonality

### Model Construction Method

#### Masking Noise:

The aero acoustic element is measured physical wind tunnel data

Tonal noise prominence was assessed using the desk top simulator to include the predicted road noise masking element

This was key to making the correct business decision on the proposed change

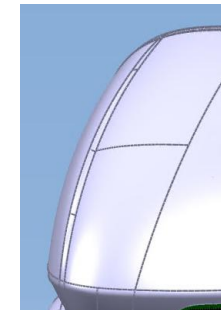


Fig.1 – Std mirror

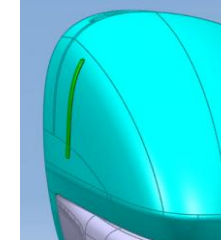
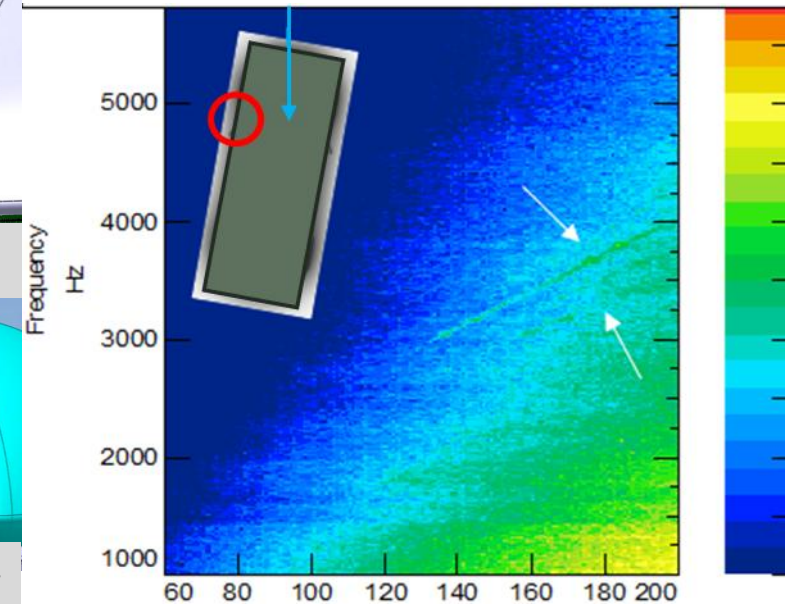
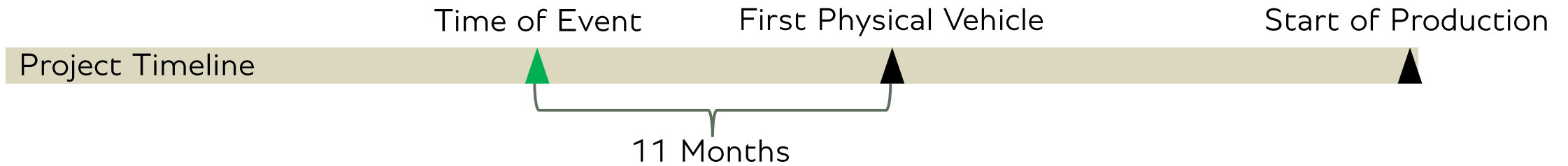


Fig.2 – Cond.2 Mirror cap



## 5. Low Frequency Boom – Tuned Mass Damper Tuning

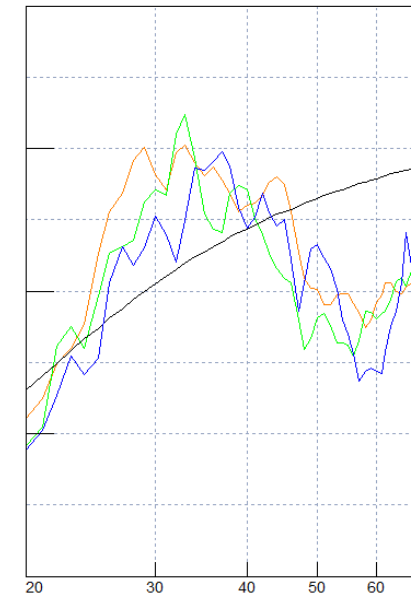
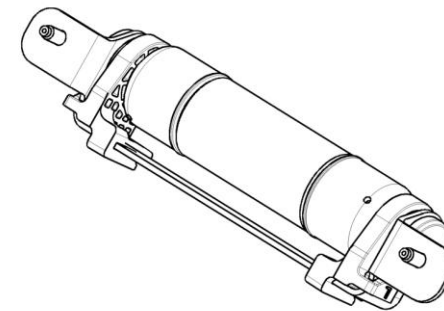


Attribute Assessed	Objective	Outcome – Learnings for future
Structure-borne Road Noise	Justify requirement for Bentley unique tailgate mass damper tuning	Highly dependant on subwoofer, the equalization was double checked prior to the event

### Model Construction Method

#### Masking Noise:

Donor vehicle decomposition with powertrain content removed  
 All attributes applied change filters produced using CAE  
 Effect of tuned mass dampers validated with FEA – applied directly to the future vehicle sound object



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# Next Steps

– How can we make it better?

## How Can We Make It Better?

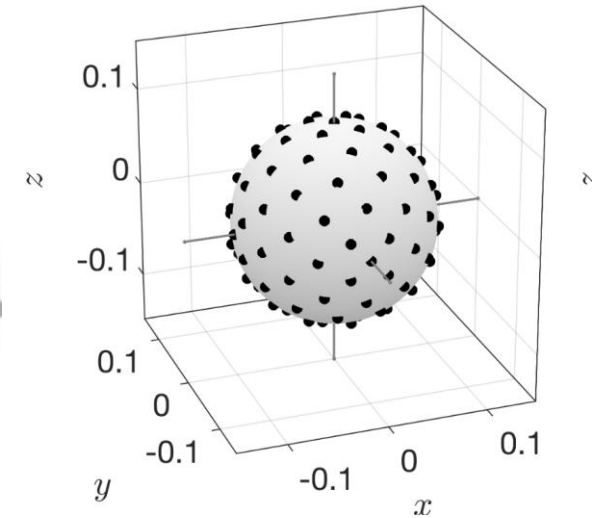
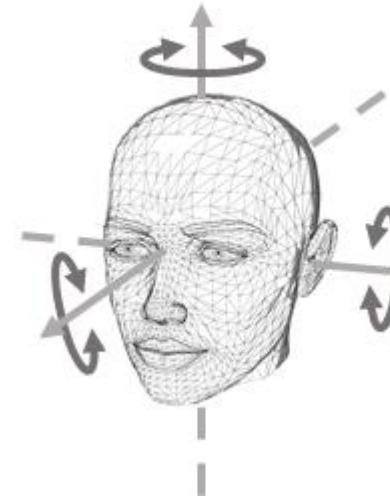
### DTS/FVS Evaluation Current Limitations:

Assessment of sound direction is not currently possible

Our natural reaction is to move our head to be able to locate the direction of a sound

### An example:

The case study for aeroacoustics. In the physical car we would naturally turn to the sound, identify it is coming from a fixed location. This missing real-world element would increase perceived annoyance



### The Fix

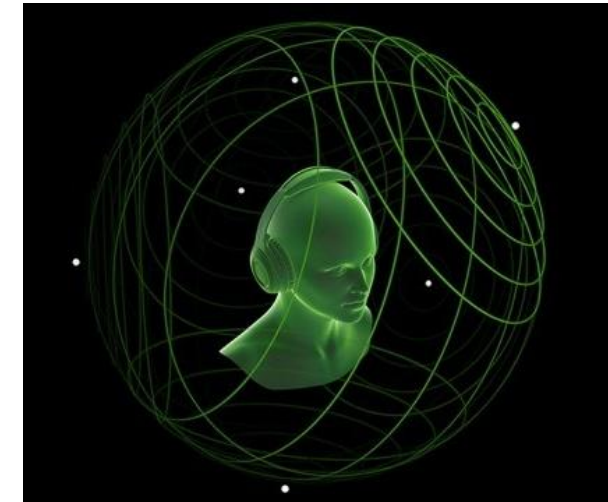
Incorporate a way of including spatial sound with head tracking

### The Challenge

The hardware for replay – Is it a speaker array or headphones and head tracking

The hardware for physical measurements – Microphone sphere

The process - Creating spatial sound environments for assessment, can we utilise game design software



# 5 Summary

# Summary

## 1 Introduction and Motivation

*- Demonstrated the requirement for virtual evaluation*

## 2 Virtual Evaluation

*- Constructing a virtual vehicle acoustic evaluation*

*- Explored what tools are available and how we create virtual listening objects*

## 3 Case Studies

*- Virtual evaluation usage at Bentley (Influencing)*

*- Discussed 5 situations where virtual evaluation has been critical to the decision*

## 4 Next Steps

*How can we make it better?*

*- Showed future evolutions of the existing tools and methods*

## 5 Summary

## 6 Bonus Slide

## 7 Questions

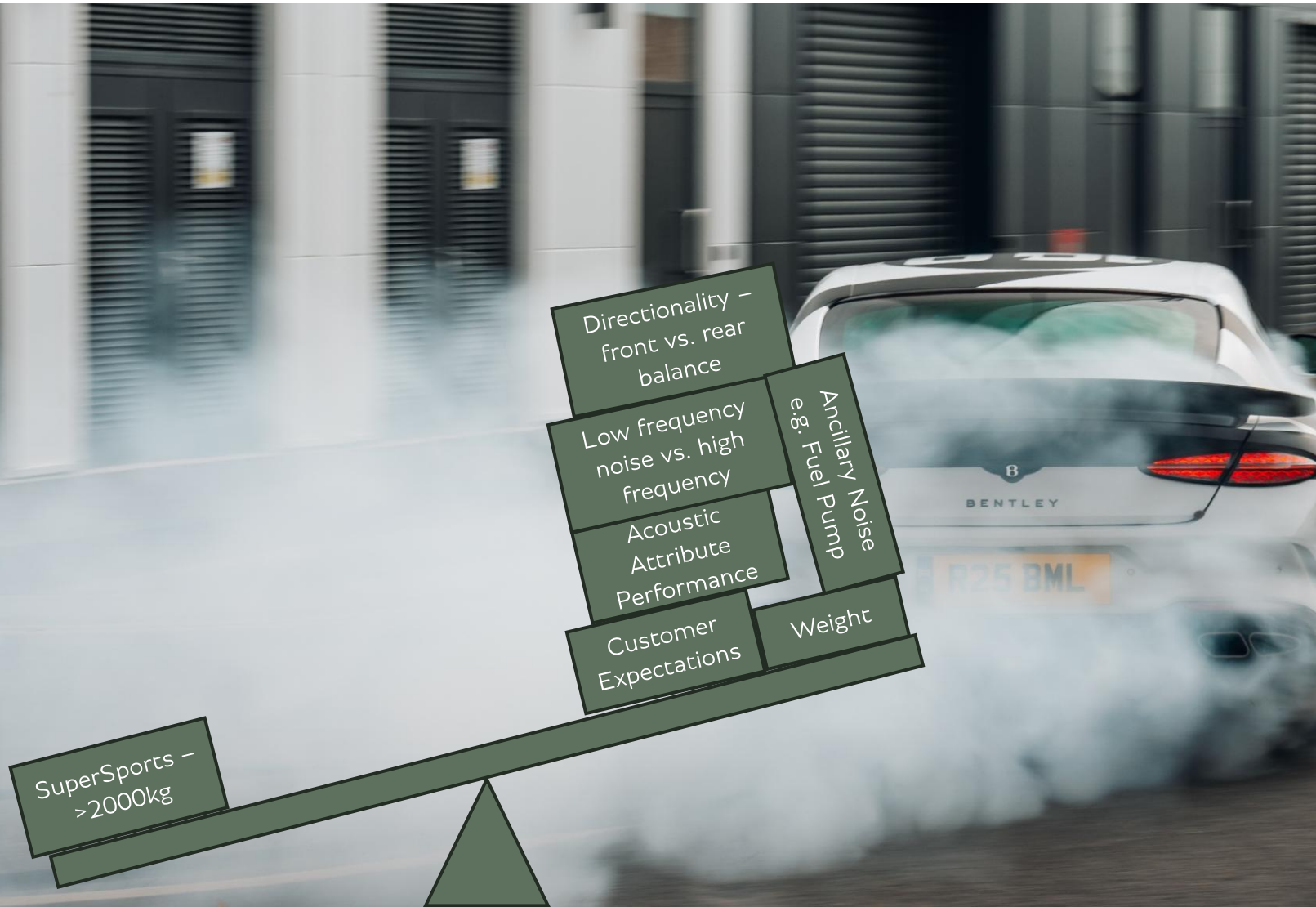
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# Bonus

– Supersports – A Lightweight Bentley

# Supersports – Acoustic Pack Development

An Attribute and Directional Balancing Act



Virtual evaluation was used to set the acoustic targets

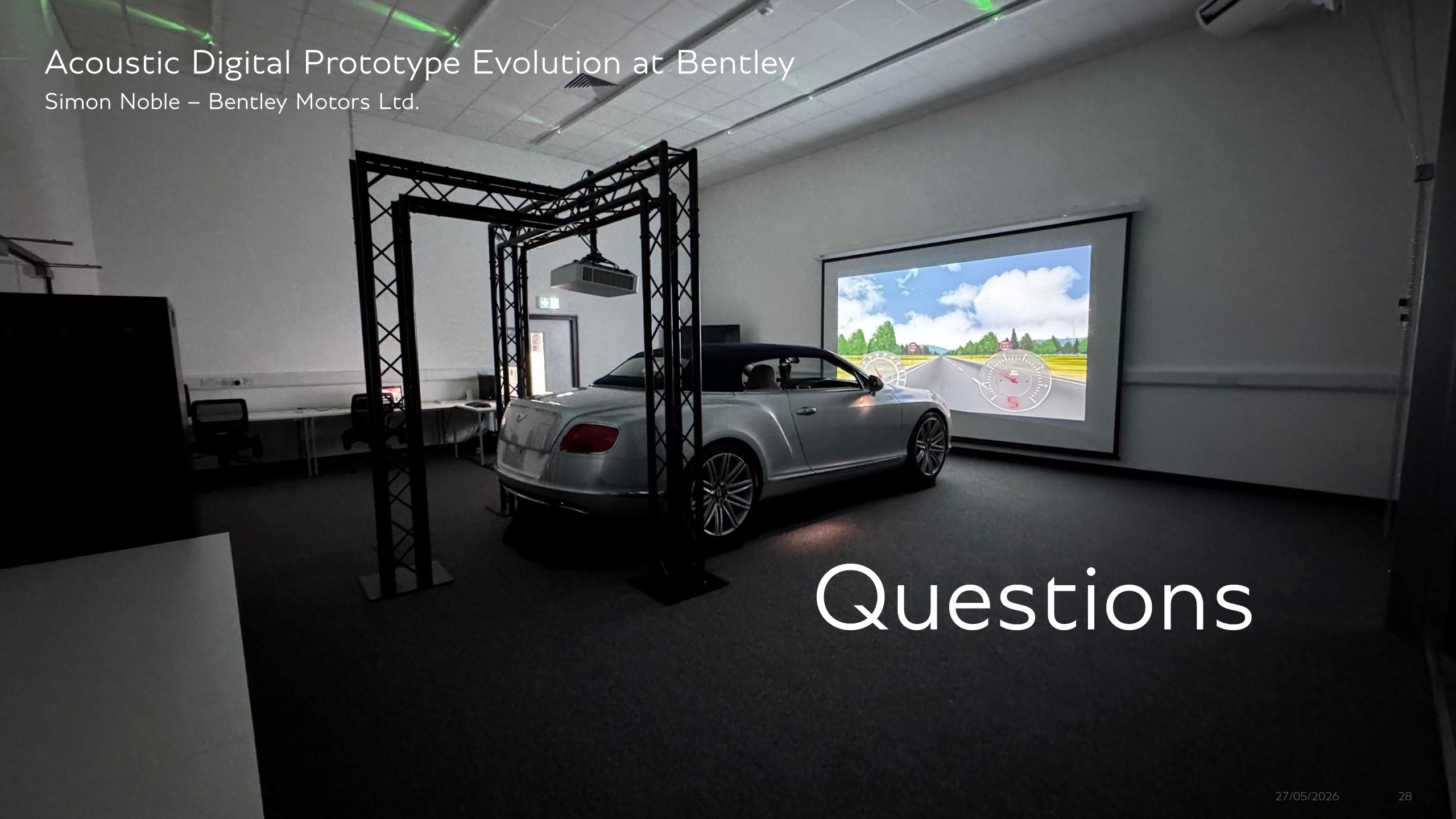
- Target Weight Reduction Achieved
- Acoustic Balance Achieved

Vehicle is louder than a GT, but well balanced acoustically.

The increase in sound pressure level has been managed to improve driver engagement rather than cause annoyance

# Acoustic Digital Prototype Evolution at Bentley

Simon Noble – Bentley Motors Ltd.



# Questions