LESSONS LEARNED FROM FORMULA ONE ENGINE TEST CELL DESIGN

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1 INTRODUCTION

The extremely high sound pressure levels generated by modern racing car engines are difficult enough to deal in the open air, especially in the context of international racing formulae, for which there is no limit on noise emission levels.

Enveloping these noise sources in a factory test bed environment presents a different series of engineering challenges. This paper describes these challenges, and some of the solutions to them, as encountered during the course of three Formula One engine test facility projects.

2 THE BRIEF

Containment of extreme sound fields is a challenge often encountered in industrial noise control projects, from oil exploration platforms to jet fighter test cells, and is usually dealt with using a generous application of over-engineering whenever a specific target or criterion is deemed to be critical, and a liberal interpretation of the performance specification elsewhere.

In this project, however, the client brief was more demanding than most, as the specification called for both maximum and minimum levels of engine noise intrusion, to enable test engineers to listen to the engine note naturally in the control room, without the need for hearing protection, in order to maximize their chance of detecting imminent engine failure and shut down the test to prevent extremely expensive damage.

The process was also hampered by extreme secrecy and technical ambiguity over the nature of the source itself. With client uncertainty over maximum noise levels to which the cell should be designed indicating a source power range somewhere between 10 and 30 dB L_{AW} higher than the previous year's engine it was unclear how to even establish the fundamental performance specification requirements.

When put into context against data for a competitor engine and for a Tornado fighter jet it was clear that a better source estimate was required from the client.

A version of the prototype V10 engine in question was being tested (in Indianapolis) making it was possible to secure some trackside noise data to offer against the engineers' estimates and agree an input spectrum.

This provided a source to model in the test cell as an input to first a room acoustics model and then sound transmission calculations to define the sound insulation requirements of the construction. Even designing to the revised input spectrum, this was a very high performance specification, requiring 80dB level differences between adjoining spaces, which needed to be connected by services and cable penetrations and an observation window.

3 ENGINEERING CHALLENGES

3.1 Direct Observation

A practical compromise in response to the client stated requirement for control room engineers to hear the engine clearly without risk of hearing damage was suggested at an early stage, with a simple monitoring microphone in the cell and monitor loudspeakers in the control room. At this point it was also thought that a video camera system would also obviate the need for direct observation through a glazed window.

The client rejected both of these suggestions, however, re-stating that the engine had to be observed directly, both visually and aurally to eliminate any risk of system malfunction or imperfection preventing the immediate shutdown of an engine which was about to fail. The sound insulation had to be achieved, therefore, as originally intended with a physical glass window and allowing for a specific level of highly controlled audibility. This also prompted concerns about the frequency response of the sound insulation achieved in situ, as the tendency for a heavy double shelled test cell would be to provide ever increasing sound insulation at higher frequency – in the range where the characteristics of the F1 engines would be most significant, sounds which might give the all important cues to imminent engine failure.

3.2 Dual Shell Design

The design fundamentals of a heavy box-in-a-box construction were refined from the initial ‘jet engine’ worst case of a double concrete construction, to a heavy concrete box with an internal shell formed in heavy duty steel acoustic paneling. The external concrete shell was supported from the host building foundations, whereas the inner steel panel shell was constructed on an isolated mass raft foundation covering the footprint of the shell.

The cavity between the two shells was lined with absorptive material to provide a ‘dead’ void and minimize coupling, and an access and cabling trench laid out such that cable connections and penetrations could be managed.

Mounting engine lifting frames and other internal fittings within the inner shell had to be achieved without fixings back to the host shell compromising the separation of the two boxes.

3.3 Ventilation

One of the key design considerations on this project was the provision of a high performance ventilation system, without compromising the integrity of the sound insulation, to fit within an existing factory / research building. Air flow rates in excess of 15m3/s were required for both supply and extract fans for air within the cell, in addition to a purge extraction system.

The final ventilation systems design employed an intricate combination of absorptive plena and silencer elements with flexible ductwork connection between inner and outer shells with matched losses. This design minimised the risk of noise leakage via ductwork, as the noise level at each point was consistent with that breaking through the shell elements. It also enabled the composite attenuation performance, including rooftop elements, to bring noise emissions from both plant and breakout from testing in the cell itself to sufficiently low external levels that the cell could be used whenever required, including at night.

3.4 Access Doors

A similar design approach was adopted for the access doors, with some of the highest performance acoustic doorsets available set in each of the inner and outer shells, selected to be consistent with the performances of each shell, but augmented by absorptive reveal linings and located in the least critical area of the facility.

3.5 Observation Window

The same piecemeal approach could not be adopted for the observation window, however, which had to be treated as a separate 'tunnel' element in it's own right. Angled glass was used (primarily for control of light reflection from the multiple glass panes, as in recording studios) in some elements of the composite system. The glazing was framed in a 'tunnel' of mass loaded absorptive reveal linings, which had to control leakage via the inter-shell cavity while maintaining isolation between the shells. Detailing and workmanship were especially critical in this area, emphasising the need to time site inspection visits carefully and liaise closely with on site inspection personnel.

3.6 Penetrations

Controlling the extent to which services penetrations compromise the sound insulation of any facility is often the most critical element, and the degree to which a test cell is compromised increases dramatically when the performance is very high. In this case, although a degree of flexibility by way of demountability was required by the client, it was accepted that integrity of the cell's performance was paramount, and an element of labour intensive re-working was accepted for any future alterations to instrument cable connections between the cell and control room.

This allowed a significant mass barrier to be directly introduced in the penetration path, by way of a chamber through which the cables exited the cell, designed to be filled with kiln dried sand after all the cables, including a significant redundancy provision, had been laid. Closure of this noise transmission flanking path, both at the shell penetration and again on entry to the control room provided multiple opportunities to seal off potentially compromising weak areas.

4 COMMISSIONING

The process of validating the performance of the chamber on completion was not a straightforward exercise. Due to the intense secrecy surrounding the engine development at that time, the client was reluctant to allow noise measurements to be made during live engine runs. Noise measurements, and particularly recordings, could be used to determine the V10 engine firing sequence, a closely guarded secret in the team at that time.

It was necessary, therefore, to use more standard sound insulation test methods, with high powered loudspeakers reproducing extremely high levels of a filtered white noise signal. Pink noise was not used, as the emphasis had to be on generating extreme levels of mid and high frequency, as per the design noise source. A filter was implemented, therefore, which provided the optimal compromise between simulating the F1 engine spectrum, and protecting the loudspeakers from damage. Reverberant source room noise levels in excess of 115 dB(A) were generated, using all of the loudspeaker units available, only one of which was damaged in the process. This enabled the level difference to be measured accurately, provided the rest of the facility was shut down to provide sufficient signal to noise ratio.

5 LESSONS LEARNED

A number of very valuable lessons were learned in predicting and then realizing such very high performance sound insulation in a very controlled way. The use of BS EN ISO 12354[1] predictive calculations in particular was refined during the process, and some of the pros and cons of commercial implementation packages were identified.

The most significant element in terms of client satisfaction was in delivering the performance predicted, while maintaining the requirements for direct observation, both visually and aurally. The key to this success was dependant on two factors:

i) Reducing noise intrusion from elsewhere in the facility to the control room to an absolute minimum, thereby maximizing the dynamic range over which the test engine could be heard below the threshold for hearing protection
ii) Including within the test cell design elements which provide variable acoustic performance, and which can be adjusted at commissioning to ‘fine tune’ the sound insulation realized in situ.

6 REFERENCES

1. BS EN 12354 Building Acoustics. Estimation of Acoustic Performance of Buildings from the Performance of Elements