

## NVH Development of the Ford 2.7L 4V-V6 Turbocharged Engine

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### ABSTRACT

A new turbocharged 60° 2.7L 4V-V6 gasoline engine has been developed by Ford Motor Company for both pickup trucks and car applications. This engine was code named “Nano” due to its compact size; it features a 4-valves DOHC valvetrain, a CGI cylinder block, an Aluminum ladder, an integrated exhaust manifold and twin turbochargers. The goal of this engine is to deliver 120HP/L, ULEV70 emission, fuel efficiency improvements and leadership level NVH.

This paper describes the upfront design and optimization process used for the NVH development of this engine. It showcases the use of analytical tools used to define the critical design features and discusses the NVH performance relative to competitive benchmarks.

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### INTRODUCTION

EcoBoost engines (i.e down sized and boosted engines) constitute one of the strategies used by Ford Motor Company to deliver engines with improved fuel economy and performance. However, this technology results in engines with extremely high power densities which constitute a big challenge to the NVH performance of the engine. In a highly competitive market, even though buyers are attracted by EcoBoost engines, there is an increased emphasis on vehicles with a high level of refinement. For this reason it is important to refine the design of the engine in order to deliver the NVH performance that meets the market expectations.

Recently Ford Motor Company added a 2.7L V6 engine to the family of its EcoBoost engines. This engine is shown in Fig. 1 and its specifications are depicted in Table 1. Not only the 2.7L V6 delivers an impressive 120 HP/L but its reduced size enables reduction of CO<sub>2</sub> and fuel consumption and improvement of crash and pedestrian impact.

The NVH goal for the 2.7L V6 engine was to design an EcoBoost engine that achieves NVH Leadership against all 6 cylinder engines. To meet this goal, the development approach was moved from a “Test-Find-Fix” process to “Design it Right First Time” process. This new process relies heavily on advanced CAE assessment methods [1] in order to lead the design of the key engine components and subsystems such as:

- A combustion system that generates low combustion pressure spectrums and a progressive increase in noise with increasing speed.

- The engine structure that provides a high level of noise attenuation and a low level of structural vibrations.
- The oil pump, vacuum pump, Fuel system and turbochargers to avoid potential unusual noises.

Table 1. Engine Specifications.

|                     |                                                                                                             |
|---------------------|-------------------------------------------------------------------------------------------------------------|
| Engine              | 2.7L 60° V6                                                                                                 |
| Torque <sup>†</sup> | 375 Ft Lbs at 3000 rpm                                                                                      |
| Power <sup>†</sup>  | 325 HP at 5750 rpm                                                                                          |
| Bore x Stroke       | 83 x 83 mm                                                                                                  |
| Bore Spacing        | 85 mm                                                                                                       |
| Valvetrain          | 24 Valves DOHC , Roller Finger Follower<br>Type Dual-Independent Cam Phasers<br>Chain driven (single chain) |
| Compression Ratio   | 10:1                                                                                                        |

<sup>†</sup> Achieved on 91 Ron Fuel, SAE net

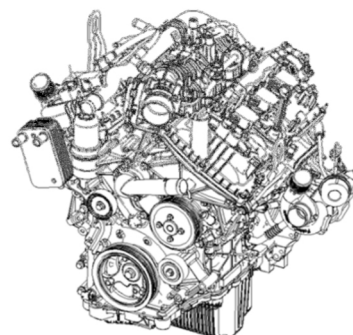


Figure 1. Ford 2.7L 4V V6 Twin Turbocharger.

After presenting the approach used for the NVH development of the 2.7L V6 engine, this paper showcases the use of analytical tools to drive the design of the bottom-end and top-end structures of this engine. Analytical case studies will also be presented to illustrate the design optimization of key components to eliminate unusual engine noises. This paper concludes with a discussion on the NVH performance of the 2.7L V6 relative to competitive V6 engines.

## DEVELOPMENT APPROACH

The NVH performance of an engine can be described by at least two attributes: (1) usual noises that include engine airborne and structure borne noises; the airborne noise is radiated by the engine components while the structure borne noise is due to vibrations at the powerplant mounts (2) unusual noises radiated by engine components that can be objectionable inside the vehicle.

Typically, the targets for airborne and structure borne noises are down cascaded from vehicle to engine to ensure that vehicle NVH targets are met and to adjust the NVH performance of other vehicle systems in case the engine exceeds one or both targets [2]. However, in the case of the 2.7L V6 engine, these targets are set at the leadership level of all 6 cylinder engines- PFI, DI, boosted and naturally aspirated V6 engines. This approach will ensure that the 2.7LV6 engine is a serious contender for many vehicle applications and that the targets are available during the early phase of engine development to assist in the selection of the engine architecture.

For an EcoBoost engine, under medium to heavy load, the airborne noise is mainly dominated by the combustion noise. For this reason, emphasis was on the design of a combustion system that delivers a low combustion pressure spectrum and on the design of the engine bottom-end components (i.e. cylinder block, oil pan and front cover) that deliver a high structural attenuation of the combustion noise. Even though mechanical and airflow noises are not dominant sources of noise, under medium to full load conditions, the engine top-end components (i.e. cylinder heads, valve covers and intake manifold) are designed to minimize the level of mechanical and flow noises.

On the other hand, to deliver the structure born noise target, emphasis was on reducing the low frequency excitations such as the 2<sup>nd</sup> order reciprocating couple, enabled by the small size of the pistons, and by designing a stout engine to transmission interface to increase the powerplant bending frequencies and avoid any resonance within the engine speed range.

The flip side of delivering very low level of airborne and structure borne noises is an increased sensitivity to the unusual noises. The noise masking level is so low that any knock, tick, pure tone, whine, buzz or whoosh noise, generated by one of the engine components, has a potential to become an issue at the vehicle level. For this reason, a list of potential NVH error states was identified and addressed during the development of the engine, as illustrated in the upcoming sections.

## ENGINE BOTTOM-END DESIGN

During the initial design stage, the focus was on defining the architecture of the engine's bottom-end that delivers both the airborne and the structure borne NVH targets. Several architectures, such as the one shown in Fig. 1, were considered including: deep skirt cylinder blocks, short skirt cylinder blocks with ladder frames, structural and non-structural oil pans. Also several materials were considered for the cylinder block and the oil pan.

For airborne NVH performance, deep skirt cylinder blocks with side bolts connecting the skirts to the main bearing caps (MBC) and composite oil pan are typically selected. For gas engines, aluminum is the material of choice for the cylinder blocks; these cylinder blocks have thick walls and bulkheads to carry the engine loads and deliver the NVH performance. A compact cylinder block design can be achieved with Iron or CGI materials but the heavy weight associated with these materials creates a fuel economy penalty.

For structure borne NVH performance, a stiff rear face of the engine is required to increase the powerplant bending frequency; typically, a deep skirt cylinder block with side connected MBC and an aluminum oil pan will satisfy this requirement.

In the case of the 2.7L engine, the concept level CAE analyses indicate that deep skirt CGI cylinder block provides the best NVH performance. However, due to weight constraint, a high skirt CGI block with aluminum ladder was investigated as a compromise between NVH and weight requirements. Figure 3 indicates that this architecture is good, for combustion transfer function, at high frequency but further improvements are required at low frequency. On the other hand, the aluminum ladder can be used as an interface to the transmission and allows for a composite oil pan to be used rather than a structural one which provides further airborne noise improvements due to the high damping of the composite pan.

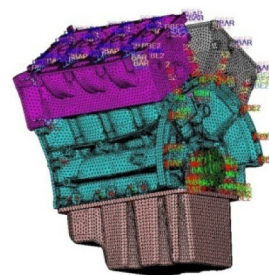


Figure 2. Initial Concept Design of the 2.7L Bottom-End

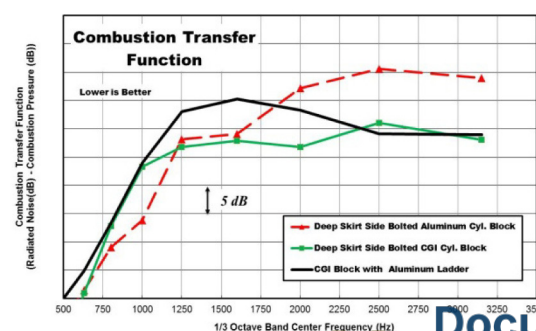


Figure 3. Combustion Transfer Function for Bottom-End