Automotive turbochargers aero acoustic noise source characterization:
VibeSys adoption for new psycho acoustic criteria applied on turbo aero noise

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• **Honeywell** Transportation Systems
  • New branding arriving soon...
  • Worldwide leader on **turbochargers** market
  • Growing trend in automotive **engine downsizing** for fuel economy & CO2 global emissions reduction

• **Turbocharger basics**
  • **Key element** of today & future powertrains for fuel economy & lower CO2 emissions
  • Thermal & kinetic energy from exhaust gas transformed into shaft/wheels assembly rotational speed
  • Provide oxygen to engine through compressed air
 Intro to Honeywell Transportation Systems & Vibro Acoustics

- Vibro Acoustics @ Honeywell
  - Noise & Vibration source
    - Model: Source / Path / Receiver
    - System approach: Turbo / Engine / Vehicle
  - Noise origins: product/process related
    - Rotor dynamic
    - Aerodynamic
    - Kinematic
    - Electromagnetic
  - Small rotating machinery
    - High rotation speed, mass flow & temperature
    - Operating condition are « Continuous transient » phases
• Acoustics of turbochargers ... Why?

• Acoustic requirements of car makers & automotive field
  • Comfort
  • Car maker brand image
  • Technical differentiation with competitors
Challenge & project scope

• Development of a new type of turbocharger product
  • Noise considered as **key element for customer adoption**
    • Potential « project killer »

• **New type of aero noise** source content
  • No robust CFD/Aero Acoustics simulation available yet
  • Existing data analysis methodology not enough to characterize this noise type

• **Short time frame** for investigations execution
  • Prototyping & testing

• Investigations generated huge amount of experimental data
  • **3 NVH test campaigns** on Turbo bench (Gas stand)
  • **30 days** of tests
  • **400 hours** of test cell running
  • **54 design configurations**
  • **2700 spectrums**
  • **65 Go** of data
Using VibeSys for NVH test data analysis & new psycho acoustic criteria

- nCode VibeSys used @ Honeywell as NVH experimental data **post processing software**
  - For Honeywell key & strategic project around a new type of product & aero noise source characterization
  - During development phase & huge turbo bench test campaigns

- nCode VibeSys main advantages
  - **Flexibility**
    - Customizable data analysis workflow quick & easy to built
    - New acoustic criteria built using glyphs assembly
  - **Efficiency**
    - VibeSys workflow re-usable on several test campaigns
    - Easy drag & drop use on a huge amount of experimental data
• Turbo test cell setup
  • Gas stand cell
    • Usual way for aero broad band noise source characterization
  • Turbo run using hot air/gas turbine side
  • Turbo operating points controlled (using several valves) with
    • Compressor mass flow (kg/s)
    • Compressor Pressure Ratio()
  • Anechoic ends added @ air inlet & outlet
    • To avoid reflected waves in ducts
  • Instrumentation
    • Turbo speed sensor (optical)
    • Accelerometer on turbo Center & Compressor Housings
    • Pulsation (dynamic pressure) sensors @ compressor inlet & outlet ducts

Using VibeSys for NVH test data analysis & new psycho acoustic criteria
Internal state of art for usual aero broad band noise source characterization
  - 3 Microphones Methodology for acoustic intensity assessment
    - Based on frequency domain analysis
  - Anechoic ends @ air inlet & outlet to avoid reflected waves
  - Assumption of planed wave propagation in duct (Ø 40 mm) for high wave length: valid < 4.5 kHz
  - Frequency bands average acoustic intensity on compressor map domain (Pressure ratio vs Mass flow)

✓ Good assessment for constant aero broad band noise source below 4.5 kHz
  - Done with internal code

❖ Not well adapted for
  - Tonal noise source
  - No constant (varying in time) noise source
  - Very high frequency noise source
Using VibeSys for NVH test data analysis & new psycho acoustic criteria

• First internal feedback & usual noise source evaluation did not match
  • Usual & internal aero noise source evaluation do not cover new noise content
  • New noise criteria required to improve understanding of relationship between product design & new noise source content

• Subjective (human perception) & objective (measurements) evaluations need to be taken into account
  • Criteria 1 : Fluctuation SDev Ratio
    • Based on Time domain analysis
    • Human perception : « Steam locomotive », no « safety » sound for usual compressor flow noise
  • Criteria 2 : Low frequency peak emergence
    • Based on Frequency domain analysis
    • Human perception : annoying whistling, captured by hears when peak frequency is below 2/3 kHz
Using VibeSys for NVH test data analysis & new psycho acoustic criteria

- Criteria 1: Fluctuation SDev Ratio
  - Based on time domain very low frequency **signal modulation**
    - Compressor outlet pulsation signal
    - Fluctuation effect during noise listening (« steam locomotive »)
  - Very low frequency (> 20 Hz) content magnitude
    - To see & detect the overall level modulation
  - **Ratio** b/w overall & very low frequency signal range
    - Standard deviation of magnitude for better spread description
    - Modulation detection with threshold value of 15%
    - Based & calibrated with several sound sample listening
  - **Fluctuation SDev Ratio**
    - Overall SDev / VeryLowFreq SDev

Sdev Ratio > 0.15

Sdev Ratio < 0.15
- **Criteria 2: Low frequency peak emergence**
  - Based on **frequency domain & spectrums**
    - Signal frequency content distribution
    - Peaks (more or less wide) emergence identification responsible to whistling feeling during signal listening
  - Focused on **peak emergence** below 2000 or 3000 Hz
    - Annoying & bad human perception even if overall noise level is low
    - Similar philosophy than tone to noise ratio applied on tonal noise
    - Tonal & wider peaks taken into account
  - **Low frequency peak emergence**
    - Step 1: running average (windows size of 600 Hz) to extract spectrum overall shape
    - Step 2: running average subtracted to spectrum itself, to keep only peaks and details of the spectrums
    - Step 3: Threshold detection applied on the remaining signal
    - Annoying peak considered when criteria > 8dB

Using VibeSys for NVH test data analysis & new psycho acoustic criteria
**Next steps**: Aero noise source levels criticality @ cabin level

- **1) Airborne Transfer Function** from compressor ducts to cabin
- **2) ‘Digital’ aero cabin noise sample** using noise captured on Turbo bench, and vehicle transfer function

**Vehicle tests & VibeSys features**

- (1) Static test on vehicle with white noise source & microphones @ cabin & compressor ducts level
- (1) Transfer function glyph used with vehicle test data to evaluate airborne noise transfer function
- (2) Custom FFT filter glyph used as transfer function to transform noise signal @ duct level to noise signal @ cabin level

**Final target**: Product optimization design for low noise

- Identify critical noise content & frequency bands @ cabin level, associated to product design parameters
Summary

Challenge

• New aero noise type characterization for a Honeywell key project, where internal state of art is not enough.

• Huge amount of experimental data in a short time frame from investigations.

Solution

• VibeSys flexibility: glyphs combination for new acoustic criteria building in phase with the new type of noise content.

• VibeSys efficiency: huge amount of experimental noise data quick & easy to handle.

Results and Next Steps

• 2 new acoustic criteria applied on a Design Of Experiments (> 50 design configuration ≈ 65 Go) for product design impact understanding.

• Acoustic criteria build quickly following subjective feedback of noise source evaluation & signal processing basics.

• Assess aero noise source criticality through compressor ducts to cabin airborne noise transfer function.

• Identify critical noise content & frequency bands, associated to product design parameters for design optimization.
More detail, including first validation using jury testing results