



Sound Quality A Consultant Perspective

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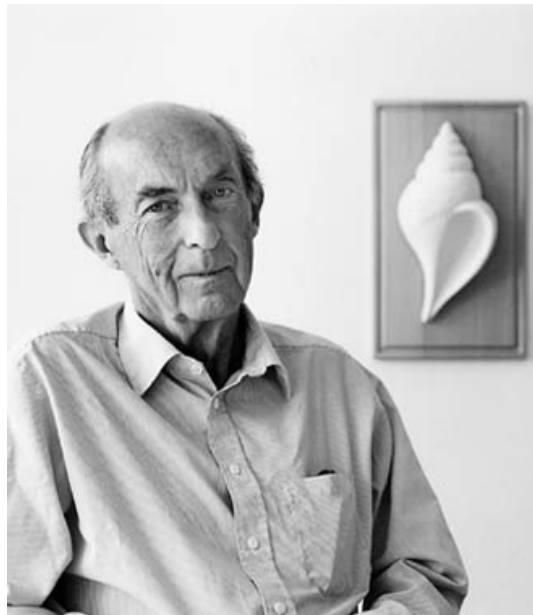
Presentation Outline



- Brief Company Presentation
- Sound Quality Generalities and Examples
 - Automotive Industry
 - Household Products
- Summary

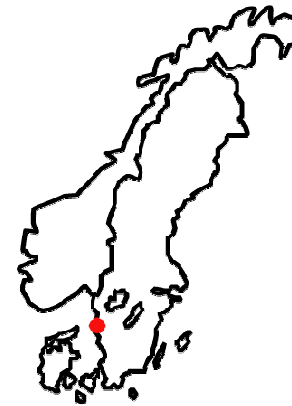


1956 - Ingemansson was founded



Stig Ingemansson (1921-1999)
The company founder

"I thought that there should be enough work in Sweden for at least one acoustician."





1950-1960: Jet aircrafts, cars and environment



Ground Vibration Test of a Jet aircraft.

Our first assignment for Saab, a "Transfer Path analysis".

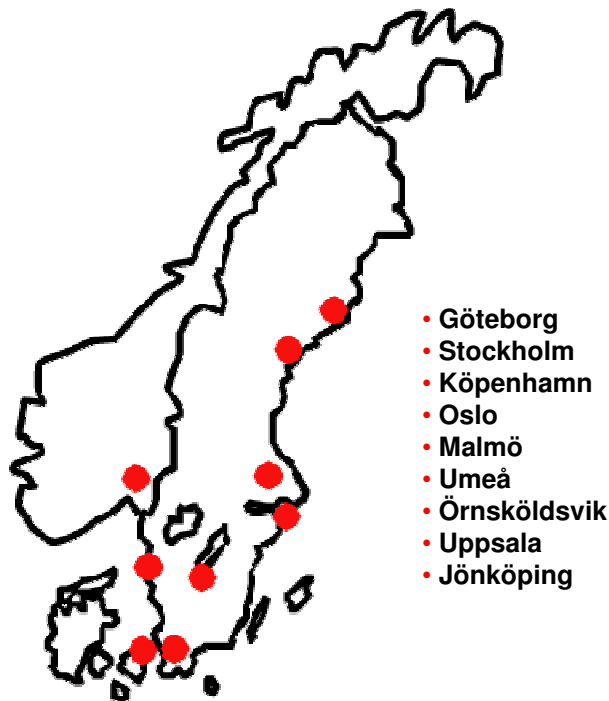


Sound environment testing.



Ingemansson today

Stig Ingemansson was right!!!



Ingemansson has become the leading expert in sound and vibration in Northern Europe with 140 employees in more than 8 offices.



The new owner ÅF(*)

Innovation by Experience

- The ÅF group is a leading name in technical consulting offering highly qualified services and solutions for process industries, infrastructure projects and the development of products and IT systems.
- The ÅF group has expertise founded on more than a century of experience and is one of the largest consulting company in Sweden with around 4000 employees.
- More information on www.afconsult.com

(*) Ångpanneförening: Steam Boiler Association



Business areas



Industry



Building



Automotive



Community



Product Engineering



Sound Quality and Automotive Industry

Generalities and Examples

- Drivers
- Definitions
- Requirements
- Approach



WHY is Sound and Vibration Comfort important for cars?

- **The perceived quality of the car is strongly influenced by the**
 - level of engine, road and wind noise
 - annoying noises, (e.g. brake squeal, squeaks, rattle, gear whine, harsh take-off noise etc)
 - unpleasant vibration at idle conditions
 - annoying vibration at driving conditions, e.g. engine shake, harsh transients, braking vibrations, ...
 - perceived quality of wanted sounds: controls, take-off “roar”, road feedback etc.
- **Immediately revealed by customer during the test drive before deciding to buy.**
- **Increasingly important for the image of car brands in prestige segments.**



Sound and Vibration attributes in cars

- **SQ is called Vehicle REFINEMENT and consists of improved:**
 - NVH (Noise-Vibration-Harshness)
 - Ride Quality (Rigid body motion relative to road)
 - Driveability (Responsiveness, Shunt-Shuffle, Power-hop etc)
- **SQ has been in focus for at least 30 years as a vital part of perceived product quality:**
 - More refined product in spite of a increased performance and **lower overall product cost**
 - Comparable V6 Ford or GM European products cost 75% 1999 compared to 1979 models.
 - They have about 20%-30% higher performance (peak power and torque)
 - They have more features

The Evolution Steps

- NVH has gone from reducing levels to designing sound quality:
 - **Step 1: Reduce intrusive noise levels**
 - Minimum refinement requirement for product to market (everyone are doing it!)
 - **Step 2: Improve the sound quality (no increase to product cost)**
 - Makes your brand more refined = More perceived value
 - Improves the perceived quality of your product = Competitiveness, better brand image, better margins
 - **Step 3: Design the sounds**
 - Makes the perception of your brand unique (e. g. BMW, Lexus, Porsche, Harley Davidson)
 - Improve the feedback sounds and sensation of powerful/relaxing vehicle



What is vehicle acoustics?

- Interior sound quality in priority order:
 - Passenger cars
 - Buses
 - Heavy trucks, off road and work vehicles
 - Military vehicles

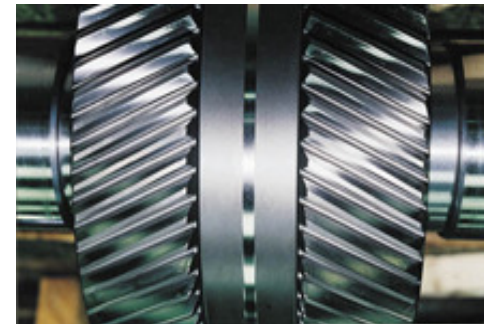
- External sound emission in priority order:
 - Trucks, buses, off road and work vehicles
 - Passenger cars
 - Military vehicles



Vehicle acoustics-vibrations (NVH)

Passenger cars:

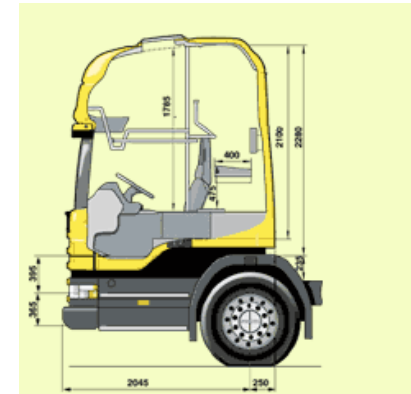
- Primarily problems with **interior sound comfort**:
 - Low frequency boom (e.g. 2nd order from 4-cyl. engines)
 - Road noise from road/tire interaction via suspension and body
 - Engine sound, - sound quality especially for diesel cars
 - Intake- and exhaust noise (level and quality)
 - Wind noise
 - Misc. auxiliaries (fans, power steering, electric motors, HVAC, etc)
 - Brake noise (Squeal, Groan etc.)
- **Vibrations**:
 - Idle-vibrations (steering wheel, seat etc)
 - Ride comfort
 - Unbalance of sources, shafts etc



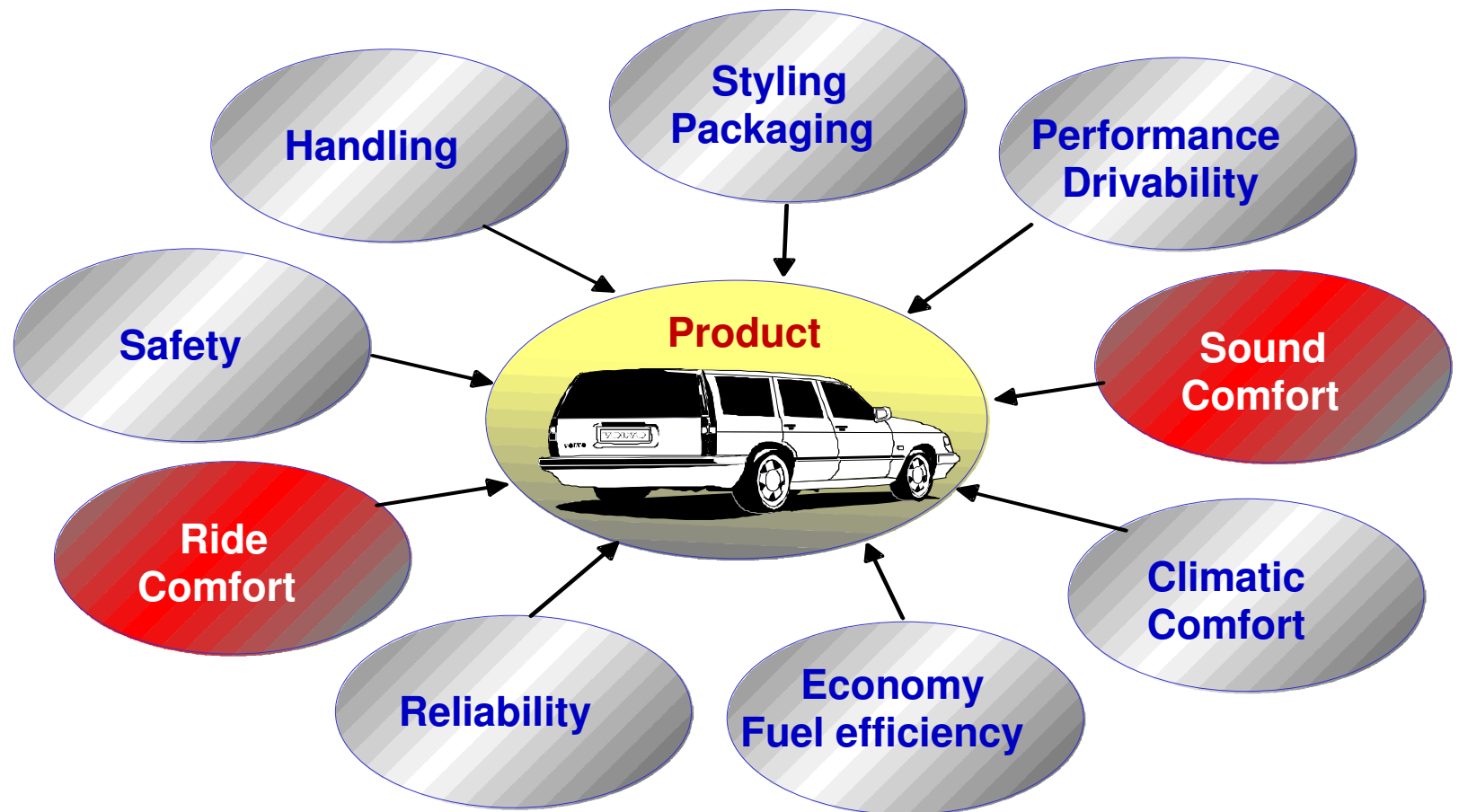
Vehicle acoustics-vibrations (NVH)

Trucks and Buses:

- Primarily problems with exterior noise levels (legal requirements)
 - Engine noise (diesel engines)
 - Cooling fans, exhaust-intake systems
 - Transmission noise radiation
 - Tyre noise (suppliers problem)
- Secondary is sound/vibration comfort in the cab/passenger compartment
 - Cab suspensions, structure borne sound transmission
 - Airborne sound isolation/absorption
 - Vibration isolation of drivers seat



The game of compromise !



NVH properties have to be balanced against other necessary product features, e. g. functionality

Summary: SQ in Cars

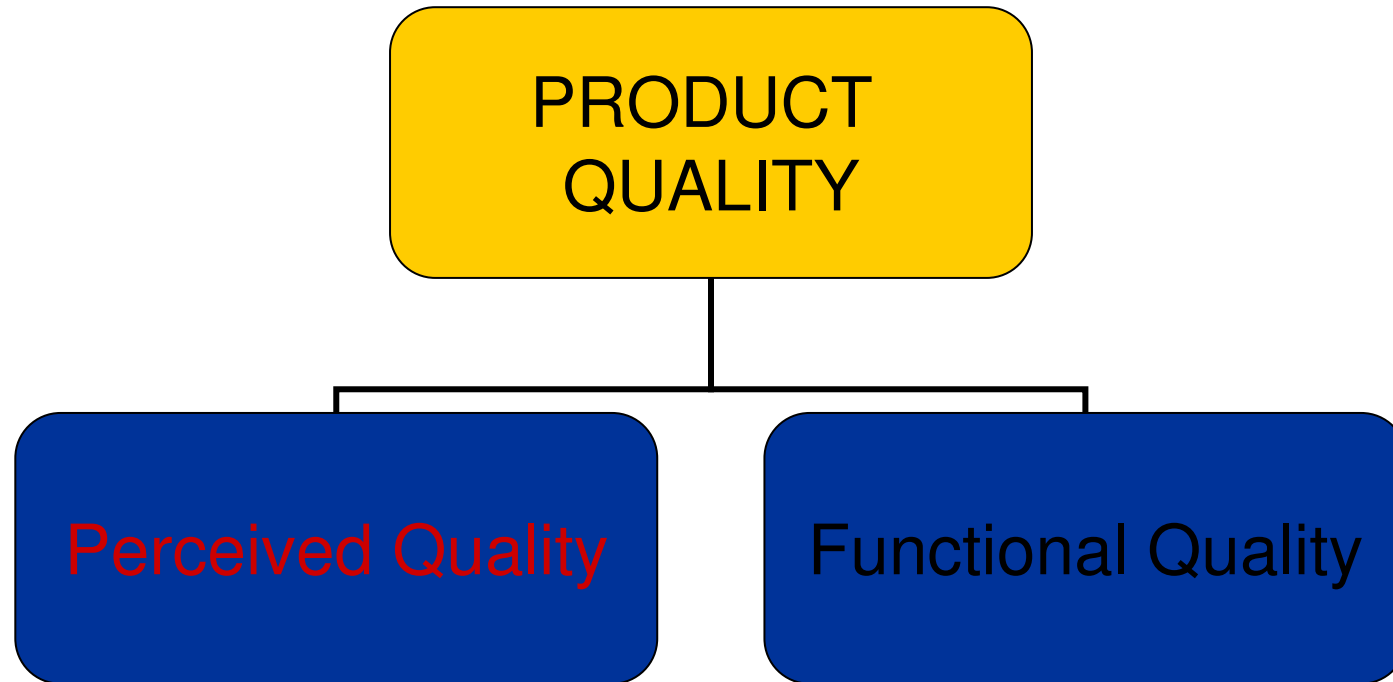
- **Sound quality gets increasing priority for interior sound design for passenger cars (most in the prestige segment). It includes:**
 - Correct balance between: road noise - engine noise - wind noise
 - No disturbing sound components (boom, beating, tonal noise, whine, squeak, squeal, rattle etc.)
 - Pleasing character for communicating sounds (acceleration noise, road contact, lever/knob response, starter motor etc)
 - Correct sound character to enhance the image of the car (sports car, limousine, sports-sedan etc)
- **It does not imply that the total sound *level* should be extremely low.**
- **Demand for other indicators than solely the dB(A) levels**

Sound Quality Generality

- Definitions
- SQ in Practice
- Evaluation Methods
- Applications

The QUALITY of the Product

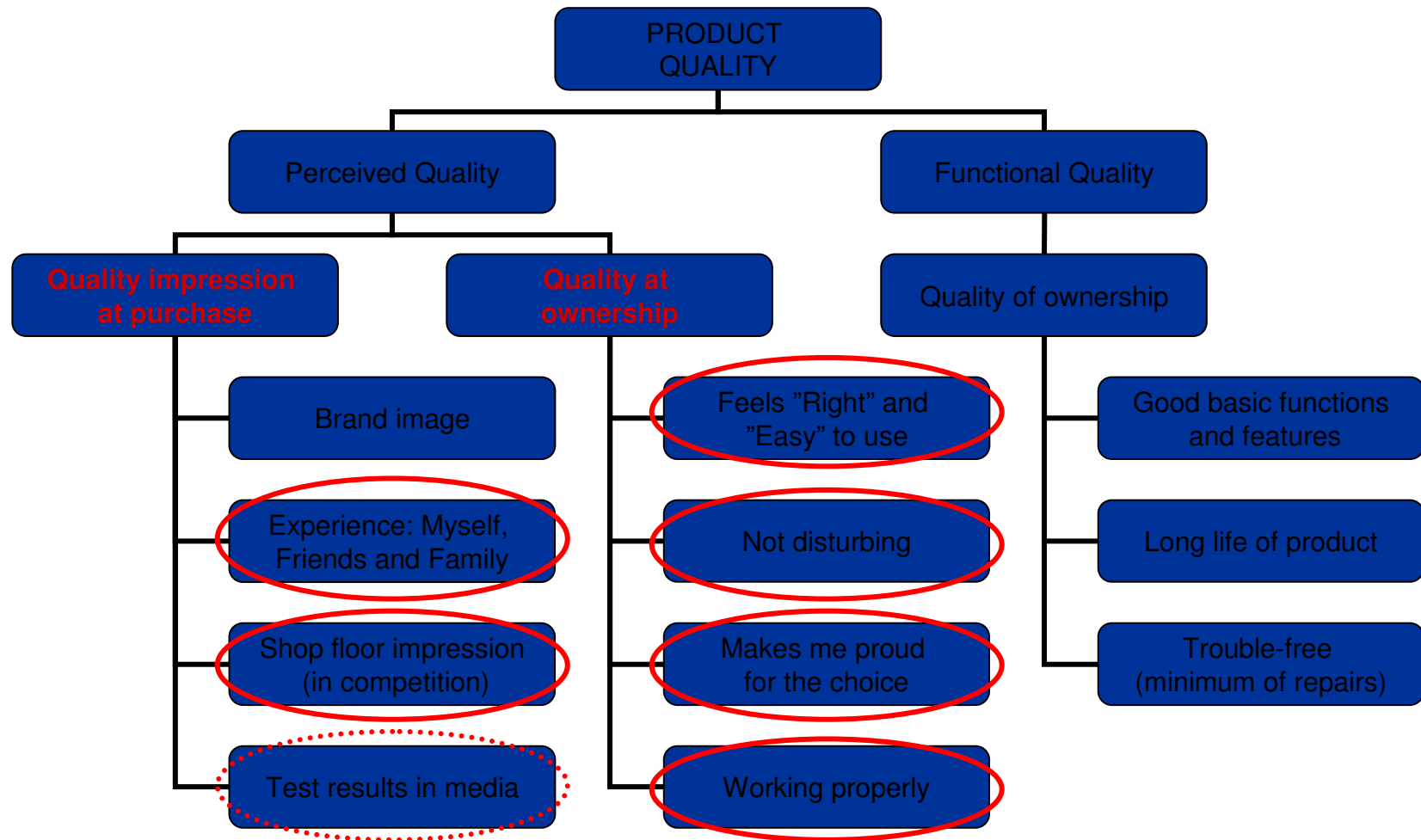
Quality is only partly defined by long and trouble-free ownership of a product:



Sound and Vibration Quality

1. An **important part of the Perceived Quality** (together with Brand Image, Visual Impression, Tactile impression, etc)
2. Also an **indicator** of Functional Quality: Indicates “solid” or “cheap” product Indicates OK or “something will break down soon” etc.
3. An **evolution of sound and vibration attributes**. Next step when the overall levels are sufficiently low: Especially for consumer products (cars, household products, leisure products, home electronics, personal computers, mobile phones etc.)

Sound Quality in Perspective



Sound Quality at Purchase

Quality impression at purchase

- **Previous experience:**
 - Functional quality
 - Quality impression (includes overall noise level (dBA) and sound quality)
- **Shop floor quality impression:**
 - Functions and features
 - *Feedback by sound (also Sound Quality impression)*
 - Visual and Tactile impression
 - Solidity, selection of materials, craftsmanship (determined also by Sound Quality for controls, lids, etc. Not necessarily consciously!) Feels "right" and "easy" to use: Good but not intrusive by sounds
- **Testing by Media:**
 - Mainly overall sound level reported (dBA)
 - Sound quality also judged more and more (especially for premium products)

Sound Quality at Ownership

Quality perception at ownership

- **Feels "right" and "easy" to use:**
 - Good but not intrusive feedback by sound
 - Good solid everyday quality impression (confirmed by sound quality)
- **Not disturbing:**
 - Low overall noise level (dBA)
 - Low transient noise levels
 - Good sound quality (comfortable, not intrusive)
- **Makes me proud:**
 - Looks and sounds QUALITY, "good judgment", "performance" and "I can afford"
- **Working properly:**
 - No unexpected or funny sounds
 - No false indications of possible breakdown

Subjective descriptors of sounds ...

| | | | | | | |
|--------|---------|----------|--------|---------|---------|---------|
| BANG | CHEEP | CRACKLE | GRUNT | PING | SCREECH | SQUEAL |
| BARK | CHIME | CRASH | GURGLE | POP | SCRUNCH | SQUISH |
| BEEP | CHIRP | CREAK | HISS | POW | SHRIEK | STAMP |
| BELLOW | CLACK | DRIP | HOOT | PULSING | SIZZLE | SWISH |
| BLARE | CLANK | DRUMMING | HOWL | PURR | SLAM | SWOOSH |
| BLAST | CLAP | FIZZ | HUM | RAP | SNAP | TAP |
| BLAT | CLATTER | GLUG | JINGLE | RATTLE | SNARL | TEARING |
| BLEAT | CLICK | GOBBLE | KNOCK | RING | SNORT | THROB |
| BONG | CLINK | GRINDING | MOAN | ROAR | SPLASH | THUD |
| BRAY | CLUCK | GROAN | MOO | RUMBLE | SPUTTER | THUNDER |
| BUZZ | CLUNCK | GROWL | MURMUR | RUSTLE | SQUAWK | TICK |
| CACKLE | CRACK | GRUMBLE | PEEP | SCREAM | SQUEAK | |

These descriptors are not easy to express in engineering terms !

Sound quality objectively evaluated

1. Loudness (how intrusive)

- dBA, loudness (ISO 532B), transient loudness, pure tone content, low frequency content, etc

2. Sound character

- Continuous sound
 - Frequency spectrum, spectrum balance, pitch
 - Noisiness, sharpness, tonality, roughness, impulsiveness, kurtosis, articulation index etc
- Transient sound
 - Multiple impacts (time.-frequency analysis with wavelets)
 - Energy spectrum, pitch

3. Time character

- Continuous sound
 - Time-varying loudness, fluctuating strength, beating, on/off etc.
- Transients
 - Number of occurrences/time unit, repeatability, etc.

4. Amenity Value

- Harmonicity, appropriateness (the pleasing aspects of the sound , no metric)

5. Information Content

- Identification, performance and condition of the product, appropriateness (no metric)

Correlation between Subjective and objective

- **Loudness (how intrusive)**

Correlation studies are found in literature but may have to be verified and usually adjusted for specific products

- **Sound character**

No general correlation exists except qualitative trends (especially for transients). Correlation between subjective scale and objective quantities has to be determined for each individual product and type of sound.

- **Time character**

Relevant for both continuous and transient sounds. Again no general correlation has been established. Has to be determined for each product group in each case.

Sound Quality in Practice

Final evaluation is still subjective

- Limited number of evaluators (cost reasons)
- Objective evaluation not trusted by management
- Top management evaluation has strong impact (trust in experts is low, when cost is involved)

Objective data is mainly used in product development by experts

- Very few fully reliable generic single-number quantities for continuous sounds (road, wind and powertrain)
- Taste and brand specific targets play a big role (not generic “good” quality)
- Transient sounds (door closure, controls etc) lack reliable single number quantities

SQ Evaluation for Benchmarking

- Competitor cars
 - Limited evaluation due to number of cars
 - SQ ratings given subjectively by 4-5 experts
 - Recordings of all SQ-related sounds
 - Rating matrix for each competitor
- Own cars
 - Extensive test drives and static car evaluation
 - SQ ratings given subjectively by 4-5 experts and 4-5 managers
 - Recordings of all SQ-related sounds
 - Rating matrix for each individual car and statistics (average, stand.dev)
 - Comparison of rating matrices, own cars-competitors
 - Deviation matrix from product planning targets

Quality Verification

Some objective metrics and methods correlate well with the subjective sound quality impression of shop floor specific transient sounds:

- Loudness (sone) of the transients– lower is better
- A-weighted peak amplitude for the sound pressure (loudness related) – lower is better
- Relative high frequency content (from the time-frequency analysis) - lower is better
- Decay time for the transients - shorter is better

Example 1: Door opening/closure sounds for cars



“Luxury”



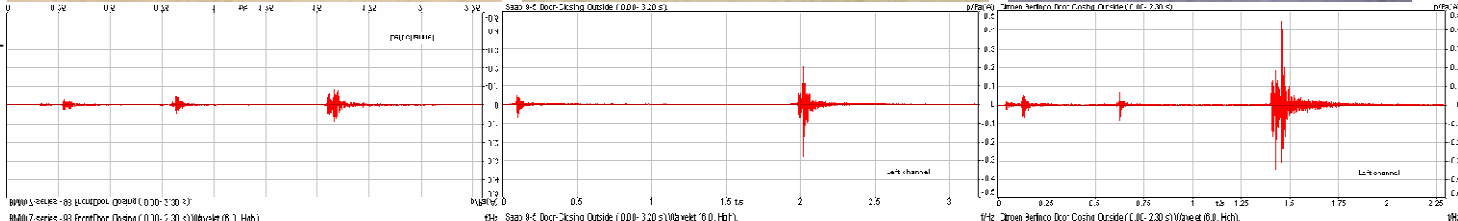
“Premium”



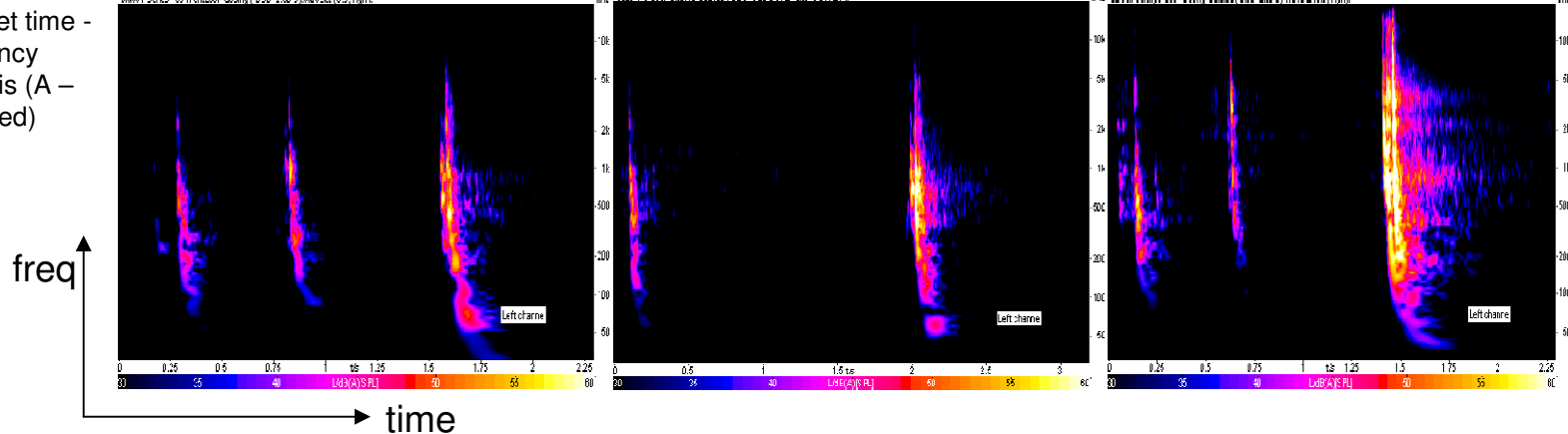
“Economy”



Time history (A-weighted)



Wavelet time - frequency analysis (A-weighted)



Example 2: Door opening/closure sounds for Dishwashers

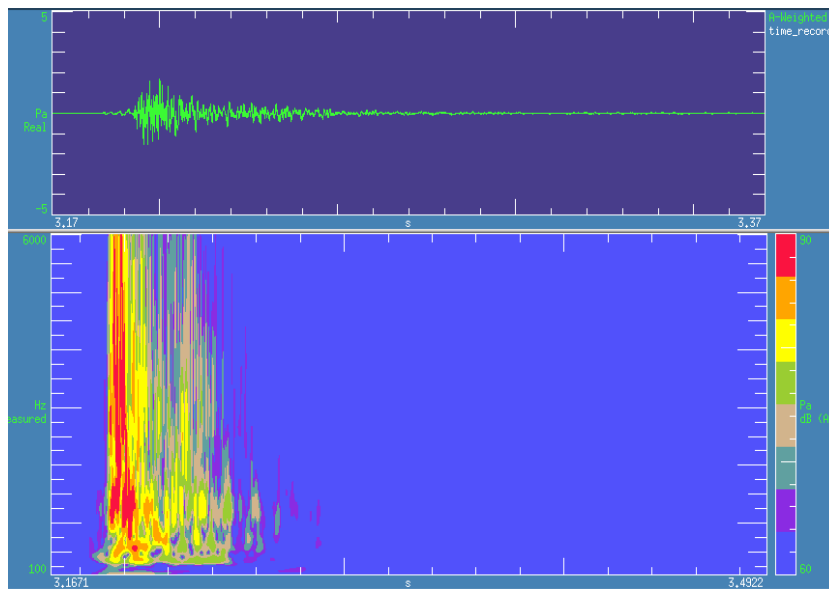


Typical Sounds at Shop Floor for Ovens

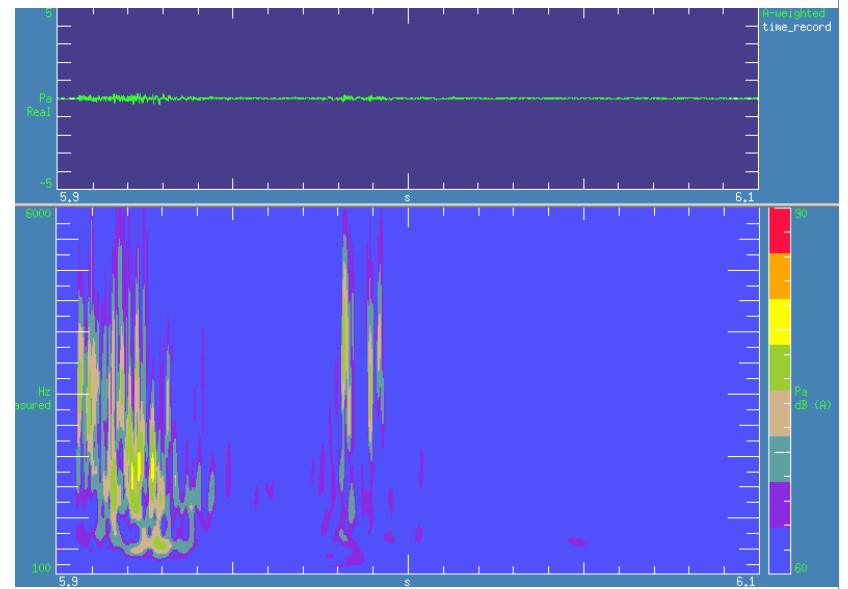
- 1. Door**
 - Opening
 - Closure
- 2. Knobs**
 - Turning
- 3. Buttons**
 - Pressing
- 4. Baking trays and structure**
 - Take out/in
- 5. Structure**
 - Knocking on the structure



Sound Analysis on Door Closure



Product A door closure. Time history and time-frequency (wavelet) plot



Product B door closure. Time history and time-frequency (wavelet) plot



Time on the X-axis - 0.2 s total time in all plots (also on next slide)
Frequency on the Y-axis of the color plot – 100 - 6000 Hz
SP amplitude on the Y-axis of the A-weighted time history plot - ± 5 Pa
SPL as colors in the color plot – 60-90 dBA

Guideline for Improved Sound Quality

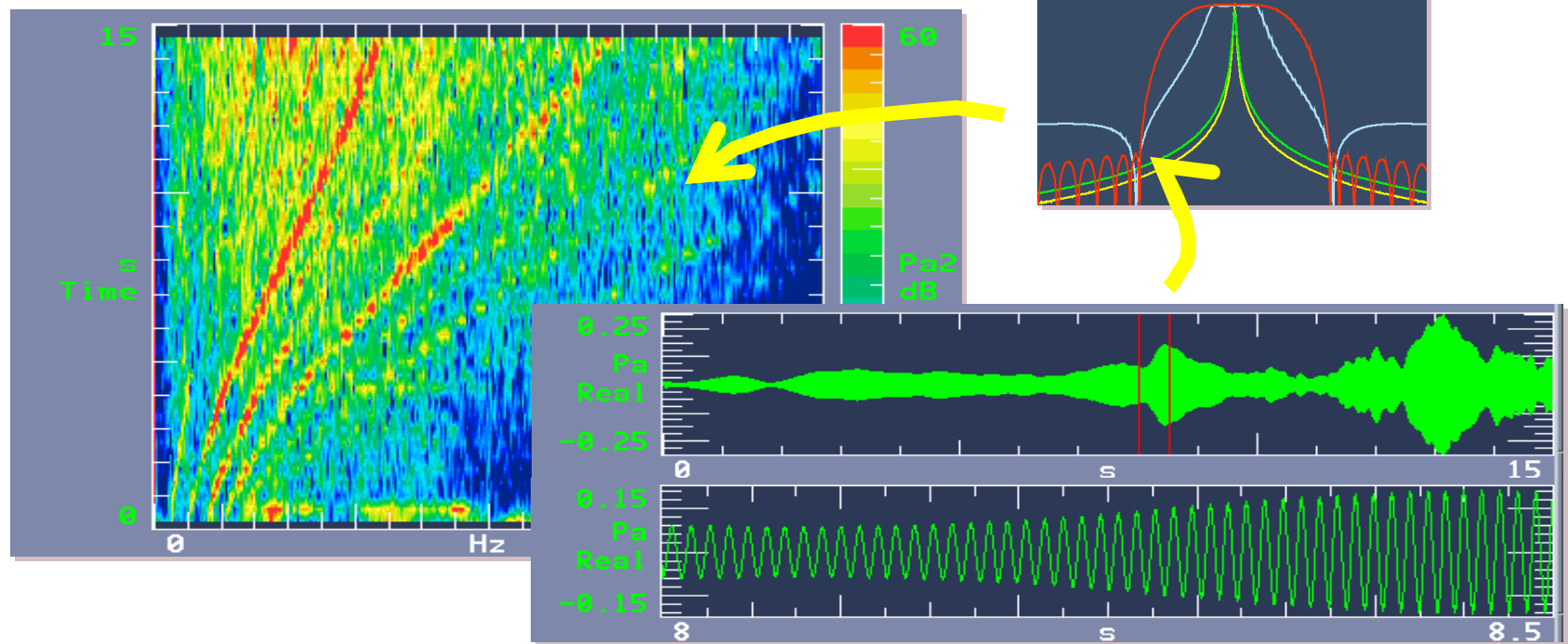
- Peak Loudness and Peak Amplitude - should generally be as low as possible but above reasonable level for good feedback if necessary
- High frequency components in the impulsive sounds that occur of shop floor shall be avoided, since they indicate “cheap”.
- General measures are to avoid fast contact forces
- Avoid unexpected sounds e.g. squeaks (friction forces), rattle
- Avoid reverberating components e.g. undamped springs
- A lot can be done by the design engineers just by playing around with the oven

Can sound quality be simulated or predicted?

- Subjective evaluation and determination of *target modifications* using signal processing of binaurally recorded sounds are "state-of-art"
- Subjective evaluation using "auralization" with a CAE-modelled vehicle requires:
 - Very good modelling of the sound generation for main sound sources
 - Very good modelling of the structural transmission system. Wide frequency region has to be covered for sufficiently high fidelity
 - Good acoustic model of the passenger compartment with corresponding frequency range

Sound Quality Analysis

You can use professional Sound Quality analysis systems to process your measurement signals to determine what improves your product sound.



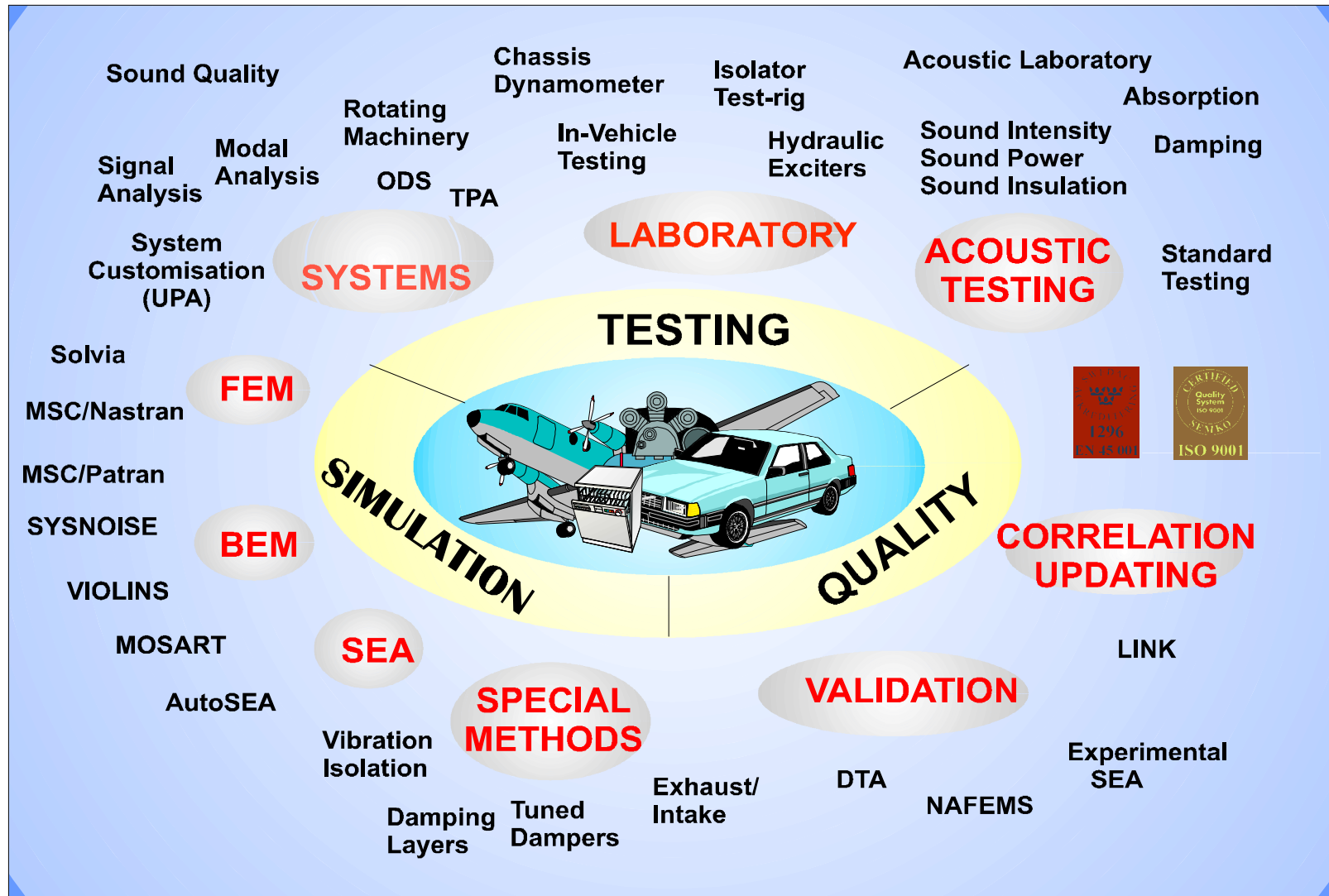
Before filtering



With order cut



Sound Quality in Perspective





Summary

- Sound Quality aspects become a key factor in the product development cycle.
- The perception of the quality of a product is to great extent related to sounds.
- Conventional acoustics and psychoacoustics have to be combined to achieve good results.
- There is a need for validated tools to evaluate sound quality.



ÅF Sound & Vibrations

