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SOURCE

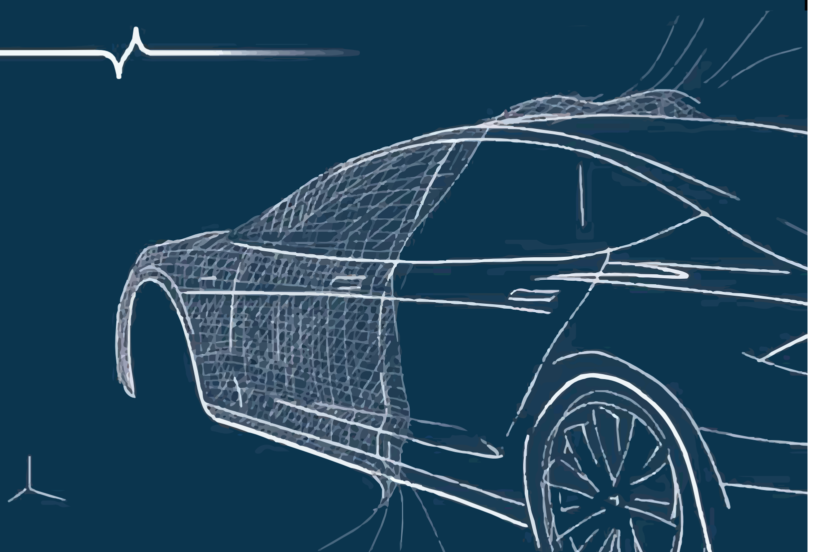
Software for source characterization and component TPA using Blocked Forces

VIBES' goal is to bring innovative engineering methodologies for NVH to the industry through intuitive software applications. With our DIRAC application, we successfully made the first step to fulfill our goals. With the release of SOURCE, we are proud to say we can now offer the full TPA proposition with the best solution in the market. In this magazine, we share how our background, our people and our vision on NVH all come together to define the product development and the work we do.

The automotive industry is making one of the largest transformations in history, with major challenges and changes as electrification, autonomous driving and a global crisis on top. New components, such as refrigerant compressors for battery cooling or new powertrain concepts, are challenging to work with – especially when travel restrictions and supply chain disruptions force a different way of working. Both automotive OEMs and their suppliers need to re-evaluate existing R&D processes in favor of agility and costs.
We propose, with our VIBES methodology, a fade between simulation and testing using our Virtual Point Transformation technique; building hybrid models which use best of both worlds. Source Characterization using Blocked Forces will lead to independent Targets for both suppliers and OEM. Combining our methods to what we call "Second time right". Second time because based on a first prototype at hand our test based techniques are able to reliably (and virtually) determine the required changes to achieve the envisioned (vehicle) vibration and sound characteristics. The Virtual Point transformation for example allows for measurement data to be used and re-used in a modular way, and new ISO standards ensure compatibility across partners in the industry.

The blocked force source characterization method (as part of the component-TPA approach) allows suppliers to measure actively vibrating components in their own facilities, while OEMs can make full-vehicle NVH predictions using this data. With VIBES, we have worked together with our clients for many years to implement all aspects of this and other TPA methods in consulting projects and in expert tools such as the Toolbox for MATLAB. With our DIRAC application, our customers can build test based model needed for Substructuring and accurate TPA analysis. With the release of SOURCE, we are proud to present a, first in market, software that embodies the full TPA proposition. When combined with DIRAC, we can offer our customers a UNIQUE solution covering every aspect of TPA, while saving valuable time and resources with a decline in the required number of prototype variants to get your targetted vibration and sound characteristics. Because we believe in an open ecosystem, open data standards are supported to ensure compatibility with existing ways of working.

In this magazine, we'll show you exactly why SOURCE is the next solution you are looking for.



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DEAR **READER,**

In the beginning of 2019 we released the first version of DIRAC, and we announced it by publishing the *DIRAC magazine*. Since then, VIBES has developed at a remarkable pace: within two years, DIRAC is being used by most of our clients, we opened a new office in Munich, we are serving our clients globally and most of all, we are releasing (again) a brand new, highly innovative software application: SOURCE. With SOURCE, we can characterize vibration sources and use this to predict interior noise, while making small adjustments or using multiple vehicle variants – all in a single, intuitive application.

I'm excited that our customers can now start to work with SOURCE. Years of effort and research preceded this, as Maarten van der Seijs highlights in his article ***The journey of SOURCE*** (page 8). As the CEO of *VIBES*, I'm proud of this journey and where it brought *VIBES* as a company.

The teamwork of VIBES plays a major part in where VIBES is now. Our team expanded over the past years in all dimensions: we added more functions, the existing teams grew and we expanded geographically. A personal note on the work at VIBES is shared by the stories of Mahmoud & Sander (A developers view, page 26) and Julie (Work hard, play hard - the Hyundai Motor Company case, page 28).

The development of SOURCE is actually the result of a partnership with Lightyear, an innovative Dutch company developing a revolutionary long-range solar electric vehicle. The article Lightyears of innovation (page 20) shares how this collaboration came to be and how it helped in the development and testing of SOURCE.

Our product portfolio now covers all aspects to implement the VIBES methodology: DIRAC for Virtual Point transfer-path measurements, SOURCE for source characterization and interior noise predictions, the Toolbox for MATLAB for Experimental DS, for advanced research purposes and custom consulting services to assist our clients in the implementation. As proud as we are on our full software suite, now we celebrate the release of SOURCE! We believe that SOURCE will become the new golden standard solution for TPA, and after reading this magazine, I'm convinced you'll be as enthusiastic as we are.

Yours sincerely,

Maarten van der Kooij
CEO VIBES.technology

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OUR **PARTNERS**

MathWorks · LIGHTYEAR · TUM Technische Universität München · UNIQ · MÜLLER-BBM VibroAkustik Systeme · MSC Software · ASAM MEMBER · TU Delft · Provincie Zuid Holland

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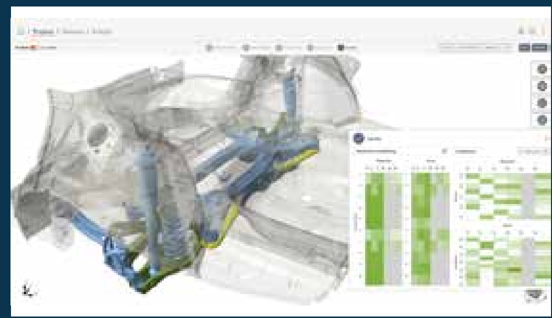
THE WHY **OF SOURCE**

Source characterization is at the heart of today's NVH analyses. From direct force measurements on a test rig to free velocity measurements, there are often several configurations to consider within an individual project. The book-keeping associated with keeping the force and response information straight between the various configurations quickly becomes unmanageable using simple tools like **MATLAB** and / or today's common NVH tools. And as more operational conditions are considered, the challenge of data management while maintaining an accurate solution only worsens. Furthermore our Virtual Point Transformation has shown vital to obtain robust / modulara source characterisations / **TPA** computations; as such **VIBES** software takes your development capabilities to a next level.

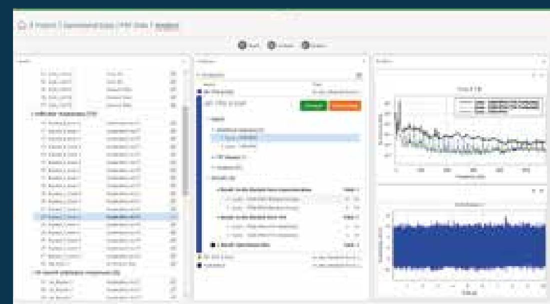
DIRAC **DESIGN OF EXPERIMENT**



DIRAC **VP FRF MEASUREMENTS**

PAK MKII **OPERATIONAL DATA ACQUISITION**

Enter **SOURCE**. **SOURCE** enables the engineer to seamlessly import operational and **FRF** data from the various test cases and keep track of the compatibility of the datasets. All of your many operational test runs can now be analyzed with ease, using intuitive plotting options to help visualize the data. Listen to what it will sound like inside the vehicle when your source component (compressor, steering system, etc) is combined with the noise transfer functions of a completely different vehicle. Understand which of the paths between your source and receiver contributes most to that annoying buzzing sound. It's all possible in **SOURCE**. And when combined with the VP technology in **DIRAC**, **SOURCE** works to provide you with not only blocked/interface forces but also the moments. By dealing with all the data management that could take days, **SOURCE** allows you to spend that extra time actually analyzing the data to gain engineering insights. In a similar way suppliers may use **SOURCE** to obtain Blocked Forces / Source descriptions which they can analyze and auralize.



SOURCE **FORCE CALCULATIONS, TPA AND PATH CONTRIBUTIONS**

WORKFLOW SOURCE. **SOURCE SOFTWARE FOR BLOCKED FORCE SOURCE CHARACTERIZATION AND TPA**

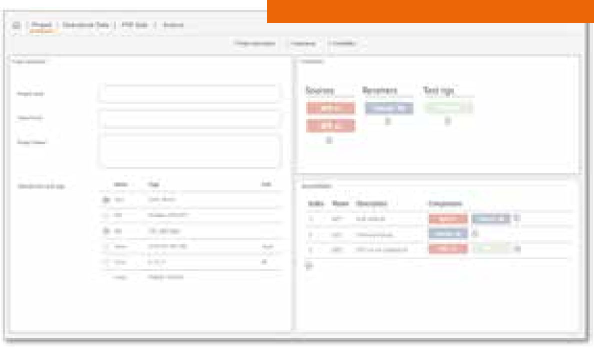
PROJECT DEFINITIONS

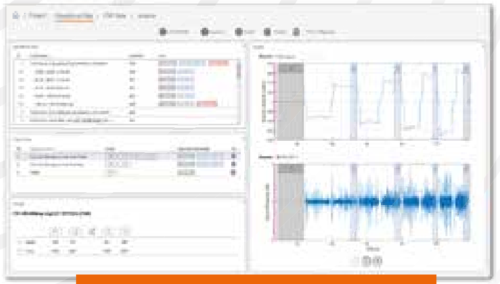
Components & Assemblies
Test assemblies are organized from combinations of components, such as full-vehicle assemblies, test-bench set-ups and active component variants. This way, SOURCE automatically understands which types of TPA to apply based on the available data.

Tags
Manage your operational conditions with custom tags, e.g. for load cases, speeds and on/off states. This way, SOURCE helps you to easily label and find the relevant data sections in larger projects.

Channel mapping
Channels from different datasets quickly become ambiguous and numerous. SOURCE handles channels in an innovative way by keeping a unique list of master channels. By assigning roles such as indicator, active/passive-side or on-board validation, relevant TPA methods are unlocked whenever possible.

SOURCE features a **unique project management workflow**, which lays out the basic organization for your project.





SOURCE is designed for **smart and intuitive data handling** and works with data from all popular data acquisition systems.

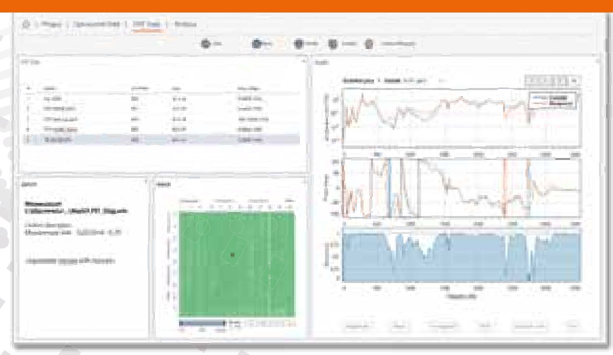
DATA HANDLING

Data import
Operational and FRF data is imported from popular data acquisition systems using ASAM-ODS (ATFX), or from DIRAC, MATLAB and Universal file format (UFF).

Powerful bulk data processing
SOURCE is optimized for handling large data batches. A quick analysis on a few datasets is computed with the same ease and performance as an extensive analysis over several tracking parameters.

Data quality checks
SOURCE comprises innovative tools to assess data integrity, such as the matrix viewer for FRF data, and Operational Deflection Shape (ODS) animations for operational measurements.

With all definitions and data in place, the calculation of the forces is a simple next step. **SOURCE supports different workflows**, think blocked & interface forces, two ISO standards and automatic & manual settings for the matrix inversion.



SOURCE CHARACTERIZATION

Blocked and interface forces
Combine several source descriptions, such as interface forces and blocked forces from a rigid test bench or in-situ measurement. Depending on available data, blocked forces can be converted into interface forces and vice-versa.

Advanced calculations
Employ mathematical techniques, such as regularization and truncation for matrix inversion. SOURCE uses optional noise and calibration measurements to automatically suggest optimal settings.

ISO-standard compliant
SOURCE and DIRAC are the perfect software solutions when combined together, for implementing standardized workflows as described in ISO/NWIP 21955 and ISO/CD 20270.

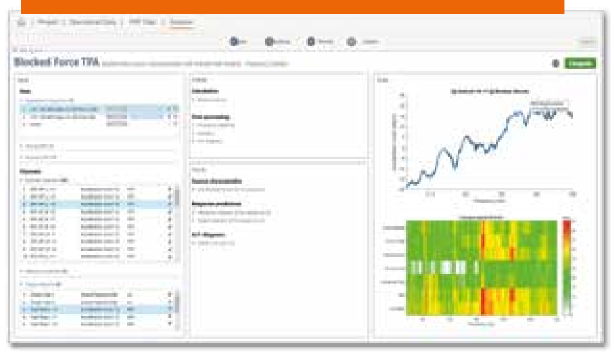
PREDICTION & AURALIZATION

Data Visualization
Use the advanced graphing capabilities to compare different settings, validate results or build your preferred personal evaluation dashboard.

Prediction & Optimization
Combine the obtained source descriptions with vehicle NTFs to make predictions of the interior noise. Optimize by changing NTFs or adjusting rubber bushing stiffnesses.

Auralization
Auralize the results to play back audio over your speakers or headphone. Export audio files to be shared with others or for playback in advanced sound evaluation studios.

Operational data and FRFs are combined to calculate blocked and interface forces. Combine the forces with (virtual-point transformed) FRFs and NTFs to make **TPA predictions** and evaluate different transfer paths.



MAARTEN VAN DER SEIJS

Maarten holds a PhD degree from the TU Delft on dynamic subsctructuring & TPA and as such is responsible for the technology within VIBES. Maarten co-founded VIBES when he came back to Delft from BMW in Munich, where he did his PhD research.

THE JOURNEY **OF SOURCE**

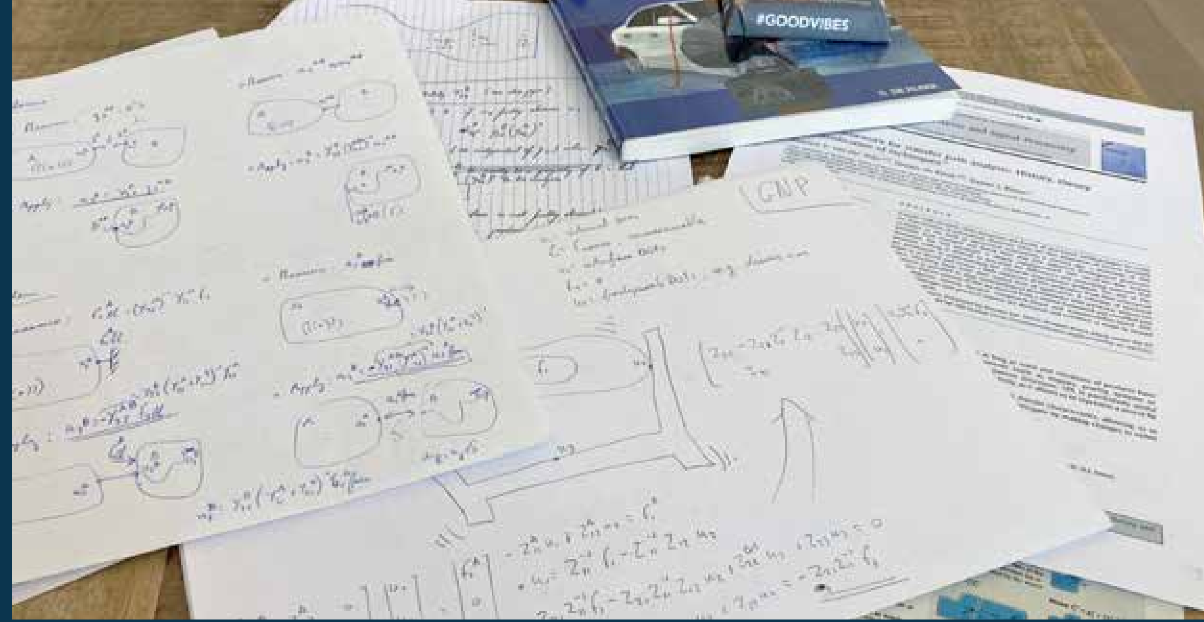
My first encounter with Transfer Path Analysis was during my PhD, co-organized by TU Delft, TU München and the BMW Group. I had always held a firm interest in the dynamics of structures, and to me the relevance was in the vibration modes, resonances and transfer functions (FRFs). Up until then, I never cared much for the excitation forces or vibration paths: the magic happens in the passive dynamics, I figured.

As part of the project I was told to find so-called "blocked forces" on a steering system, to be measured on a test bench, that would cause a similar response on the inside of a car. Standing under that car for the first time, I was wondering where I should put all these shakers to apply the blocked forces, and when that time would come, if I would have the slightest clue what I'd be doing.

Coming from the school of Daniel Rixen and Dennis de Klerk, I was quite familiar with the principles of Dynamic Substructuring, which seemed to have an explanation for just about anything that is structure-borne and linear. So, it did occur to me that blocked forces are just a special case of it, and that all these shakers are really not needed if you can just use FRF functions to predict the same response. However, both explanations didn't seem to resonate well in the round-table discussions about "TPA", which apparently I had become part of due to the nature of our activities. Clearly, that world of TPA was much bigger and needed diving into.

A unified approach

In the years to follow, we have explored numerous methods that loosely relate or refer to TPA. I've always felt that understanding Substructuring principles helps to see things more clearly, or at least more generic and structured than the TPA variants often got presented in their seminal papers. Seen through "substructuring glasses", most of the methods would come down to combinations of an active and passive subsystem, possibly some mounts and a well-chosen set of sensors or "degrees of freedom" with particular roles.



At the same time, we experimented with several test bench concepts to get to better blocked forces: rigid, flexible, with and without force sensors. We showed that key to all of this was my Virtual Point Transformation technique derived from Dennis' EMPC technique some years before. Indeed, it establishes the strict condition of a fully blocked interface, but also to actually have a common interface to transfer force descriptions between different assemblies. In a nice turn of events we ended up at an alternative derivation of a blocked force method better known as the *in-situ characterization* method by Andy Moorhouse et al. It turned out that *source characterization* was again another term for similar techniques.

We decided to unify these methods into a general framework, including as many methods as we could find. We chose to categorize them into the families of classic, component-based and transmissibility-based TPA, depending on the way the source was described. Since the start of VIBES technology in 2016, we got to work on many more large-scale TPA projects, on anything ranging from a coolant compressor to full-vehicle tire noise and often applying several methods from different families. Quite commonly we would use OTPA as a first quick-scan after measurement, blocked forces concepts for independent source characterization and classic-TPA interface forces to express path contributions. Using DIRAC for reliable FRF measurement in conjunction with our VIBES MATLAB Toolbox for the TPA calculations, a process arose which lent itself for re-application in other projects.

SOURCE: the software that speaks TPA

With the development of SOURCE we've taken this a step further: SOURCE not only provides the tools to process source characterization and our common TPA framework efficiently, we wanted to make the software such that it really *understands* TPA! To reach this, we have created software abstractions of TPA concepts, using the same semantics as they appear in the TPA framework. Now, SOURCE understands how combinations of subsystems and measurement channels lead to certain types of characterization, how active and passive-side vibrations need to be interpreted and how a noise floor measurement can be used to optimize the computation of blocked forces.

On top of that, we wanted to create an application that tackles some of the common obstacles of current-day analysis tools. SOURCE is optimized to handle large amounts of data efficiently, whether they are stored locally or on a network or cloud location. The user interface is streamlined, but not too restrictive, such that it also allows the user to try and apply new methods. SOURCE appeals to the engineer by being clear about what the datasets in terms of channels, length and representation. We have taken inspiration and combined principles from application we love, not only from NVH software but also MATLAB and Excel, audio & video editing workstations and big data analysis.

With the release of SOURCE we are proud to offer you this complete experience to TPA and are thrilled to continue building new tools to innovate NVH engineering!

SOURCE & **HOW IT IS USED BY ENGINEERS**

BY DENNIS DE KLERK,
expert in sound & vibration engineering & co-founder of VIBES

NVH software has been around for years and the most common used date back to the 80'ies. A lot of new developments took place since though and trying to keep up with them has had its impact on today's software usability, looks and bounded functionality.

Our roots date back to the early '00 where we ignited the development of Component based **TPA**, Blocked Force, Virtual Point Transformation and test based modeling for hybrid FEM simulation. Getting these advanced methods to industry is **VIBES**' mission and "bridging test and simulation" requires a new mind set. Therefore, over the past 4 year, **VIBES** developed a fundamentally new, ground up, software platform. It is with proud that we introduce to you **SOURCE**, the embodiment of all modern TPA methods known and much, much more all fitted in a modern look and feel and outstanding user experience. Combine **SOURCE** with our **DIRAC** software and lift your vehicle NVH engineering to new heights with huge time and cost savings.

Apart from sophisticated (Component based) analysis you may configure **SOURCE** to compute a whole batch thereof in one go. Setup N vehicles with M operational conditions with several different **TPA** methods and have **SOURCE** take care of all the data handling and computations. Data can be used from the local device itself and / or in the Cloud for a future oriented way of working. Bulk data analysis in minutes rather than days.

Last but not least you'll find our newly developed Stiffness Injection method in **SOURCE**. SI allows you to virtually simulate vehicle changes in your Component **TPA** analysis. Interested to find out more: please get in touch and we'll be happy to tell and show you more!

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THE VIBES METHODOLOGY

1 GET COMPONENT MODELS & SOURCE DESCRIPTION FROM TEST

Obtain models of the components in the most effective (time, accuracy) way, either test-based or through CAE.

SOURCE DESCRIPTION
Blocked Forces as an intrinsic property of the component

TEST-BASED FRF MODELS
Virtual Point FRFs measured with DIRAC

CAE-BASED FRF MODELS
FRFs from simulation software (e.g. Nastran)

2 BUILD UP A MODULAR SYSTEM

System assemblies are acquired from component models through dynamic substructuring. Changes in the components can be assessed on the global assembly.

FULL-VEHICLE MODEL
Coupling of models at the VirtualPoints with Dynamic Substructuring

3 MAKE PREDICTIONS & VIRTUAL ACOUSTIC PROTOTYPING

With component-based Transfer Path Analysis (TPA) methods, NVH-levels are predicted by combining the system model with a description of the active vibration source.

SIMULATION & PREDICTIONS
Use the source description with the full-vehicle FRF to predict, for example, sound pressure at the driver's ear

AURALIZATION

Listen to virtual component-vehicle combinations, based on a test bench measurement of a vibration source and a vehicle transfer function.

EVALUATE VEHICLE TARGETS

Predicted NVH-levels can be compared with set targets. Finetune or swap components and make new predictions without re-doing any measurements.

OPTIMIZE INDIVIDUAL PARTS

Optimize individual components and make new predictions for the full vehicle without re-doing any measurements.

THEORY BEHIND
SOURCE

SOURCE CHARACTERIZATION AND TPA FUNDAMENTALS

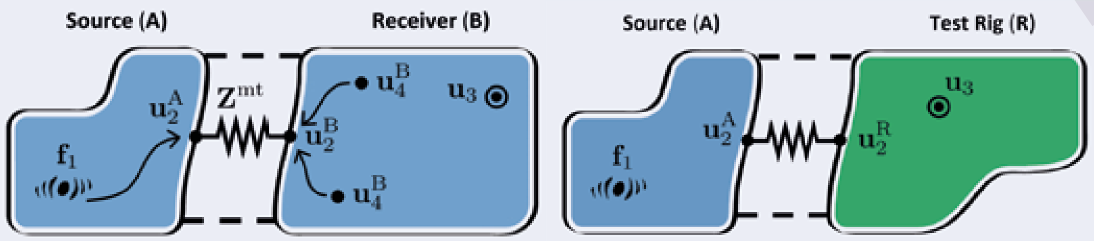
SOURCE is truly unique in the way it approaches TPA. In developing SOURCE, we sought for the best balance between flexibility in applying (new) methods and ease of use. These two are not easily combined. When using for instance the VIBES Toolbox for MATLAB, flexibility is certainly guaranteed but ease of use can be limited. Other software packages often provide streamlined approaches for TPA, but fall short in their ability to do "new things", such as combining source characterization variants and processing and combining dozens of operational conditions efficiently.

Based on the great variety of engineering case work at VIBES, we strongly believe that the TPA Framework provides the right set of tools and nomenclature to cover all different aspects of the extended TPA family. This is why we chose to build SOURCE on these very same fundaments. For instance: SOURCE understands how concepts such as *active-side interface forces, indicator responses and on-board validation channels* can be used to build up a blocked-force source characterization with integrated quality assessments. By defining test assemblies from several *source, receiver and test rig* subsystems, SOURCE will make it very easy to simulate for NVH in multiple vehicle variants in one go.

We strongly believe this is the best way for the application of today, being ready for future developments finding their way into SOURCE.

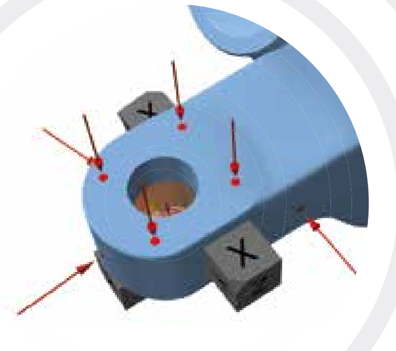
1 TPA FRAMEWORK

The typical transfer path problem is depicted in the figure on the left, where an actively vibrating subsystem (e.g. steering gear, compressor, etc.) transmits energy into a passive subsystem (e.g. the vehicle body). The figure on the right illustrates a test assembly with a component on a dedicated test rig. The most commonly-used types of degrees of freedom (DoF) are listed in the table. These simplified depictions lend themselves for a large amount of practical problems, from simple mechatronic component test benches to full-vehicle suspension studies with dozens of coupling points.



TPA FRAMEWORK: SUBSYSTEMS AND DEGREES OF FREEDOM

u	dynamic displacements/rotations
f	applied forces/moments
Y	Y admittance FRF or NTF matrix
$\mathbf{Z}^{mt}$	mount stiffness matrix
$\star^{AB}$	pertaining to the assembled system
$\star^{A}$	pertaining to the active source component
$\star^{B}$	pertaining to the passive receiver component
$\star^{R}$	pertaining to the test rig
$\star_1$	source excitation DoF
$\star_2$	interface DoF: active-side (A) or passive-side (B)
$\star_3$	receiver / target DoF
$\star_4$	indicator DoF (around the interface)
$\star_{ps}$	pseudo force DoF



Virtual Point

VIRTUAL POINTS IN SOURCE

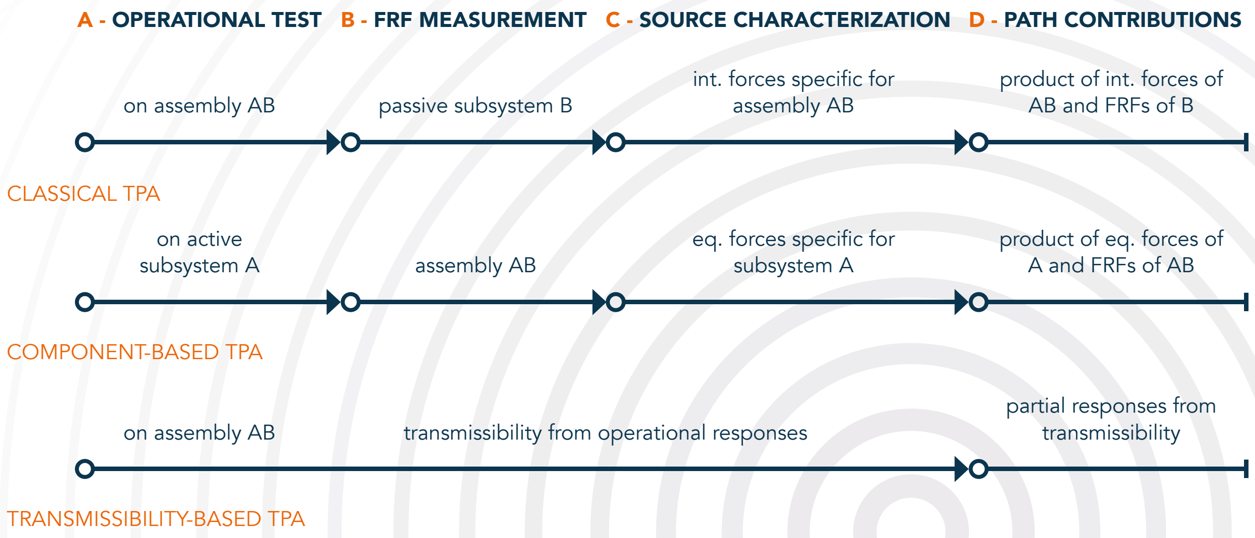
Many traditional TPA methods such as operational TPA and classic TPA are very much channel-oriented. One is mostly concerned with the input and output quantities that are measured on a structure – but often without exactly specifying where and in which direction exactly. This is one of the reasons why blocked force characterizations are hard to obtain properly, where a precise definition of the interfaces is instrumental.

SOURCE uses Virtual Point technology and substructuring concepts, proven in DIRAC and the VIBES Toolbox for MATLAB. Interfaces can be specified using virtual points, including rotation degrees of freedom when needed. This brings some unique advantages:

1. Virtual Points are aligned and positioned between different test assemblies, e.g. full vehicle, test bench and the active component. As such, results can easily be transferred from a test bench to the full vehicle.
2. With six DoF per interface, vehicle/component models can be built accurately in the mid and high frequency range where rotational DoF become more significant.
3. Mount stiffness calculations now incorporate all translations and rotations, easily expressed in cartesian frame or the local coordinate frame of the mount.

As the interfaces grow in complexity (bolts, welds, etc.), Virtual Points can be used to reduce the interface to the essential connecting nodes, choosing the right amount of degrees of freedom per connection. In practice, this means performing FRF testing around the interfaces in DIRAC to obtain the full virtual-point FRF matrix, with all the beneficial quality indicators. SOURCE adds another layer of indicators to express the validity of source characterizations.

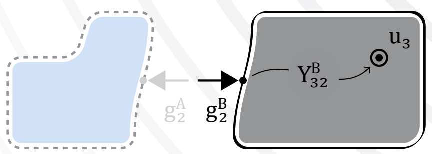
The organization of the modules in SOURCE closely aligns with the process of the TPA framework. SOURCE is designed to set up several analysis types quickly and cross-validate the results of methods from different TPA families. Intermediate results, such as force characterizations are all accessible as well. SOURCE can be used to apply any of the presented methods from the classical, component and transmissibility-based TPA families.



2 TPA METHODS IN SOURCE

Classical TPA

$u_3 = Y^B_{32}\, g^B_2$

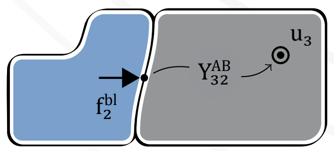


Transfer path analysis for existing products

- Source characterization: **interfaces forces (AB)**
- FRFs for prediction: **passive subsystem (B)**

Component TPA

$u_3 = Y^{AB}_{32}\, f^{bl}_2$

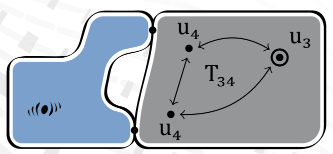


Independent forces → predict for new assemblies

- Source characterization: **blocked forces (A)**
- FRFs for prediction: **assembled system (AB)**
- Using **Dynamic Substructuring: A + B + C + ...**

Transmissibility TPA

$u_3 = T^{AB}_{34}\, u_4$



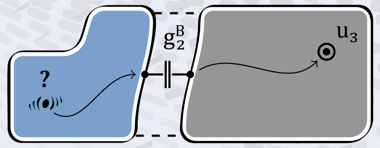
Transfer path ranking in existing products

- Source characterization: **indicator responses (AB)**
- FRFs for prediction: **operational transmissibility functions**

3 CLASSIC TPA

Direct Force

$g^B_2 = g^B_2$

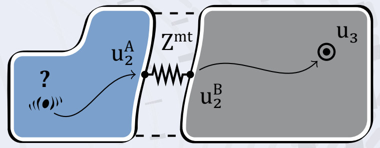


Measurement with force transducers

- Forces measured directly between active and passive structure
- Typically only in 3-DoF per coupling point

Mount Stiffness

$g^B_2 = Z^{mt}(u^A_2 - u^B_2)$

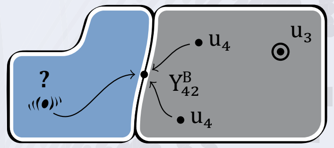


Accelerations before and after the mounts

- Uses the dynamic stiffness of the mount (up to 6-DoF)
- Forces calculated from the differential (virtual point) accelerations

Matrix Inverse

$g^B_2 = (Y^B_{42})^+ u_4$



Inversion of indicator responses with passive-side FRFs

- Uses the FRFs of the receiver (B) *without* the source component
- Forces calculated from (overdetermined) matrix inversion

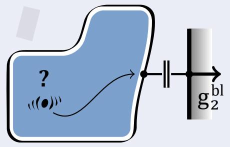
4 COMPONENT TPA

Blocked forces measured on a rigid test rig

- Forces measured between the active structure and a rigid boundary
- 3-DoF or up to 6-DoF using virtual point transformation

Blocked Force

$f^{bl}_2 = g^{bl}_2$

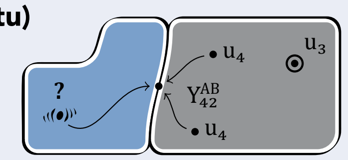


Inversion of indicator responses with assembly FRFs

- Uses the FRFs of the *full assembly* (AB) or *test assembly* (AR)
- Forces calculated from (overdetermined) matrix inversion
- Validation using blocked force quality indicators

Matrix Inverse (in-situ)

$f^{bl}_2 = (Y^{AB}_{42})^+ u_4$

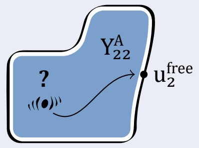


Acceleration measurement at the free interfaces

- Uses the FRFs of the active source component in free conditions
- Forces calculated from (overdetermined) matrix inversion

Free Velocity

$f^{bl}_2 = (Y^A_{22})^{-1} u^{free}_2$



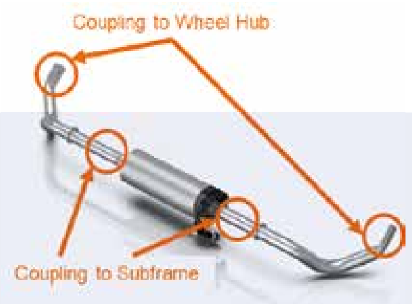
CASE **ELECTRIC ROLL CONTROL FOR ZF FRIEDRICHSHAFEN**

An insightful and successful project has been conducted with the German automotive supplier ZF from Friedrichshafen. In this project, an electro-mechanic roll-control (ERC) is the vibration source of interest. The ERC is built into high-class vehicles to increase the driving performance and comfort. In the future, we expect OEMs to be interested in the blocked forces of components like the ERC. It was therefore chosen to use this component as an example for general investigations regarding the applicability of component-based TPA approaches in practice.

Component

The ERC enhances the driver's comfort and safety through agile cornering and steering. It stabilizes the vehicle around the X-axis using an electric engine and a high-torque gear. As seen in Fig 11, the ERC is mounted to the vehicle at four connection points: two at the wheel hubs and two at the subframe. The ERC is connected directly to the wheel hubs while the subframe connections are isolated with rubber bushings.

From an NVH perspective, it is important that the driver does not experience any noise originating from this component. In some vehicles the ERC has caused a high-pitched sound from the electric engine, and in other vehicles rattling upon load changes from gear backlash. By characterizing the loads of the ERC with blocked forces, we should be able to predict this type of noise in new assemblies before actually building it into the assemblies.



Picture of the electric roll control by ZF. One can see the electric engine gear assembly in the center of the component. The four connections points are depicted by orange circles.

Goal

The main goal of this project is the blocked force characterization of the ERC at the four connection points.

The baseline set of forces includes three translational Degrees of Freedom (DoF) per coupling point, and the necessity of including rotational DoF was also investigated. The Virtual Point Transformation (VPT) is used to calculate the moments at the rotational DoF, while the blocked forces at the translational DoF are calculated both with and without the use of VPT. Thus, three approaches were considered:

1. **Six DoF interface with VPT**
2. **Three DoF interface with VPT**
3. **Three DoF interface without VPT**

The primary goal of this project was to validate the blocked force methodology for the ERC. Additionally, we wanted to provide the customer with insights into the quality of the obtained data from the vehicle or test bench. The final goal was to demonstrate the transferability of the blocked forces and prove that they are indeed an independent property of the source itself, as stated in the theory.

Blocked force determination

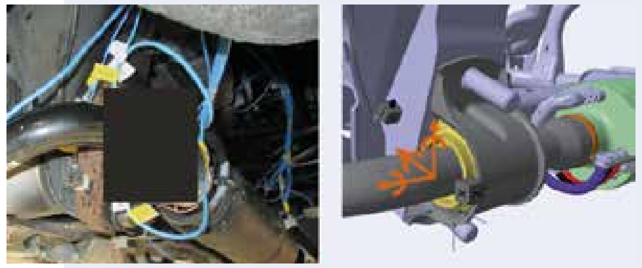
As no test bench was available, the blocked forces were determined using the in-situ method in the full vehicle. Two sets of measurements are needed to calculate the in-situ blocked forces:

1. FRF measurements of the full vehicle Y_{AB} (vehicle body + ERC) and (2) operational measurements with the same set-up of sensors.
2. Vehicle modifications were also made to demonstrate the transferability of the blocked forces, and thus the FRF and operational measurements were also repeated on the modified vehicle.

FRF measurements

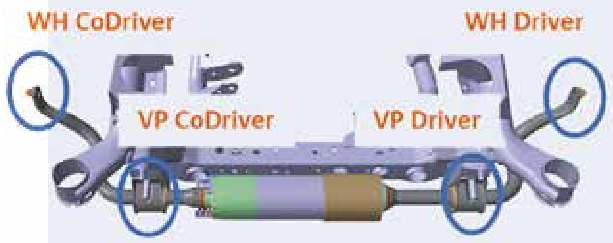
Full-vehicle FRF tests were performed with sensors in close proximity to each of the coupling points, along with some additional validation sensors and microphones inside the car. As mentioned, the ERC connects to the vehicle at two locations on the subframe and to both wheel hubs. As the wheel hub connections are ball joints which cannot transfer moments, it was decided to capture the forces at the wheel hub interfaces using only three DoF, while both three DoF and six DoF scenarios were considered at the subframe connection points.

Thus, three impacts were used to excite the three orthogonal directions at each wheel-hub connection point, and a single triaxial accelero-meter was used to capture the response (see Figure of the set-up). Where more DoF were desired at the subframe interfaces, additional impacts and sensors were needed. Six sensors were placed in close proximity to each of the connection points on the subframe: three on the active side (on the ERC) and three on the passive side (on the subframe). Transmission simulators were attached close to the connection points to allow proper sensor and impact positioning near these interfaces, with increased accuracy and accessibility of all six DoF. At each subframe connection point, 13 impacts were used to excite the system. As discussed in a following section, this set of impacts was then used in three different ways to calculate the various sets of blocked forces and moments.



The picture on the left shows a photo of the measurement set-up for one subframe connection point with a mount. The right picture shows the same set-up in DIRAC, including the VP defined for this connection point.

At each of the four connection points, a Virtual Point is defined in DIRAC. The Virtual Point is placed exactly at the ERC/vehicle interfaces where we will calculate the blocked forces. This figure shows the position of these VPs:



The ERC mounted to the subframe. The four virtual points are shown indicated by the blue circles.

To demonstrate blocked force transferability to a different vehicle, the vehicle was modified by mounting a seven-kilogram steel plate close to the subframe. With this addition, the dynamics in this region change drastically. The following figure shows a comparison between the FRFs of the original and modified vehicles. From this set of tests, one gets Y_{AB} and $Y_{AB,mod}$ for the full vehicle.

Operational measurements

The operational measurements are conducted with the same set of sensors to obtain u_4 and u_3. In total, we differ between three different operational cycles:

1. **Impacts on the housing of the ERC**
2. **Manual actuation of the ERC**
3. **Actuation of the ERC on a test track**

The first cycle is a very simple operational state obtained by exciting the housing of the ERC with an impact hammer. With this type of "operational" condition, the repeatability is high and you don't have to activate the ERC itself. The disadvantage is that this operational state is not representative of an actual operational state. The second operational state was the manual actuation of the ERC component. Using a remote control, one is able to drive the ERC from one extreme (minimum angle) to the other (maximum angle). The last and most realistic operational measurement was conducted on the test track by driving over rubber mats with different thicknesses. During these measurements, only the left wheels drove over the plates while the right wheels stayed on the road. This caused rolling of the vehicle around the X-axis and therefore an activation of the ERC. Cycles 1 and 2 were repeated with the modified vehicle to obtain $u_{4,\mathrm{mod}}$ and $u_{3,\mathrm{mod}}$.

The photo shows the test track for the one sided drive over of the rubber mats with different thicknesses.

Blocked force calculation

From the operational and FRF measurements, one gets the $u_{3,\mathrm{mod}}$ validation signal and the u_4 indicator responses in the frequency domain, and the FRFs from the connection points Y_{42}^{AB} and Y_{32}^{AB}, $Y_{32,\mathrm{mod}}^{AB}$ to the indicator and validation points for both, the modified and unmodified vehicle. Now all the required data is collected to calculate blocked forces and to make a transfer validation. The blocked forces in general are calculated as follows (without any regularization):

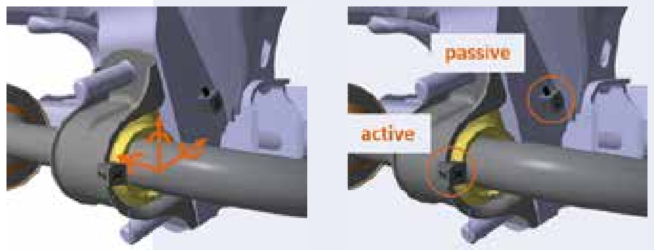
$$f_2^{bl} = (Y_{42}^{AB})^+ u_4 \quad (1)$$

As these blocked forces should be transferable to other assemblies, they can now be used to predict the responses $u_{3,\mathrm{mod}}^{pred}$ of the validation points in the modified vehicle using:

$$u_{3,\mathrm{mod}}^{pred} = Y_{32,\mathrm{mod}}^{AB} f_2^{bl} \quad (2)$$

These predictions are then compared to the measured signals. In this project, the validation points included a microphone at the driver's ear and a sensor on the seat rail.

As mentioned above, three different approaches were used to obtain blocked forces. For all cases, the wheel hub interfaces were described using 3-DoF Virtual Points on each side; this is reasonable as the ERC connects to the wheel hubs with a ball joint. The three cases instead focus on different descriptions of the forces/moments entering the body at the subframe interfaces.



Screenshots from DIRAC. The left shows the virtual point transformed approaches for 3-DoF and 6-DoF calculation. The right shows the approach where no virtual point transformation was used.

The first approach, which is generally recommended as it is the most complete, uses the Virtual Point Transformation to calculate blocked forces for six degrees of freedom at each interface. The second approach also uses the Virtual Point Transformation, but only includes the three translational degrees of freedom per interface. Figure 16 (left) shows the impacts and sensors that were used for both cases. The impacts on the crosses were transformed to the Virtual Point described using six DoF forces and moments (case 1) as well as three DoF forces (case 2). In both cases, all six sensors were retained in the FRF matrix to help identify the forces. The third approach also uses three DoF blocked forces to describe each interface, but this time without use of the Virtual Point Transformation. In this case, the DIRAC screenshot on the right shows the impacts and sensor on the subframe used in the blocked force calculation. From this figure, it already becomes apparent that using the Virtual Point with many impacts (left) could help to mitigate the measurement inaccuracies inherent with impact testing.

Results of application

Now we can apply all three sets of blocked forces obtained in the original vehicle to the FRFs of the modified vehicle and compare these predictions with the measured responses. Figure 17 shows a comparison of the measured and predicted responses at the seat rail during the second operational state. It is immediately apparent that the third case (yellow), where the Virtual Point Transformation was not used, performs much worse than the other two cases. At the lower frequencies, below 800 Hz, both the three- and six-DoF cases match the validation measurement well. Above 800 Hz we see the six-DoF case outperforming the three-DoF case, as rotations become more critical.

Takeaways

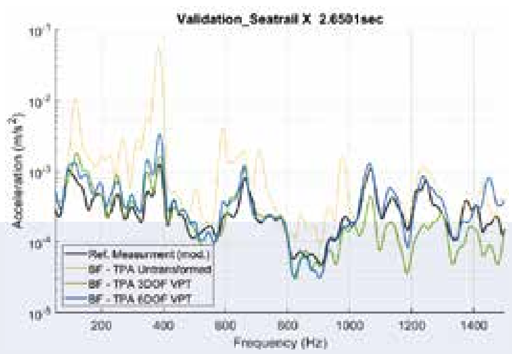
This study demonstrated several useful properties inherent to the blocked force methodology.

1. Blocked forces are transferable between different assemblies. While demonstrated using simple vehicle modifications here, these blocked forces could also be applied to other vehicles that use the ERC.

2. The Virtual Point Transformation greatly improves the quality of results, even when only three DoF are considered. This is likely because we average away the measurement inaccuracies inherent to impact testing.

3. Rotational DoF become important for getting accurate results at the higher frequencies. The Virtual Point Transformation enables us to accurately characterize the rotational DoF for better results at the higher frequencies. Note that the frequency at which rotations become important will vary for other components.

From these results, it is recommended to characterize the ERC using blocked forces and moments with six degrees of freedom per interface via the Virtual Point Transformation.



Application of the ERC blocked forces (calculated using three methods) to the modified vehicle, showing accurate prediction of the response at the seat rail using Virtual Points with six degrees of freedom per interface.

LIGHTYEARS **OF INNOVATION**

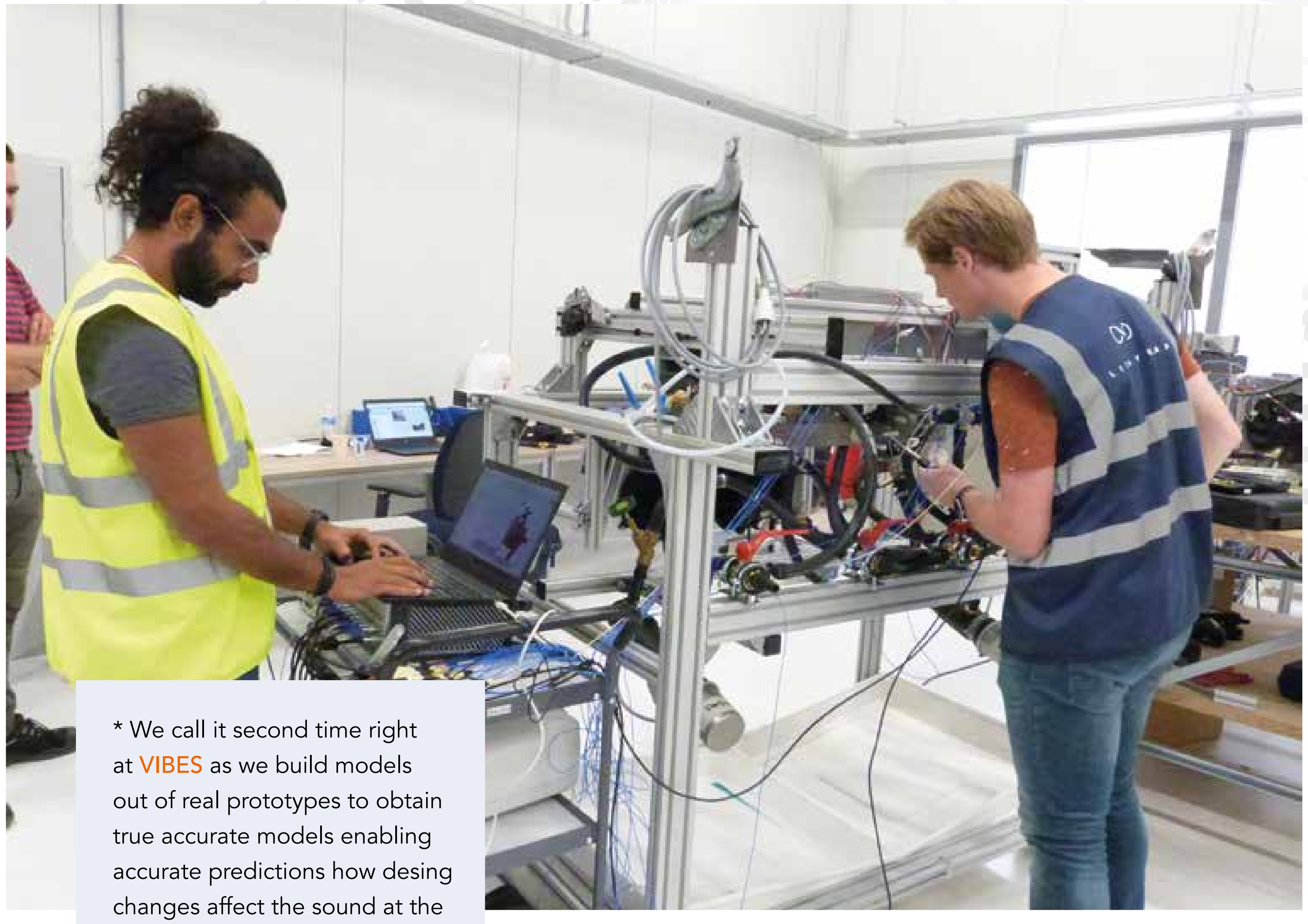
What happens when you combine a company developing revolutionary electric vehicles with a company that's moving to revolutionize the world of NVH testing and analysis? You get the partnership of Lightyear and VIBES. This collaboration, enabled by support from the RVO / Provincie Zuid-Holland (the Dutch government), helps Lightyear to develop vehicles with optimal NVH characteristics while VIBES develops relevant, validated software to perform the NVH analysis: SOURCE.

The first vehicle being designed by Lightyear, the Lightyear One, puts efficiency above all else; lightweight design, solar roof and hood, low aerodynamic drag, and in-wheel motors are some of the noteworthy features of this new electric vehicle. But with innovative design choices come potential NVH challenges. At VIBES, we believe in second (prototype) time right solutions*, and partnering with Lightyear gives us the perfect opportunity to showcase how our tools and methodology enable early insight into the NVH characteristics of vehicles. Specifically, through the development of SOURCE, we can help Lightyear understand the different contributors to the sound and vibration inside the Lightyear One from a very early stage in development.

And this is something we have already gotten started on. While there will be several potential noise and vibration sources, we wanted to start with something simple to demonstrate the complete process of testing and analysis needed for source characterization. Thus, in the first round of testing, we focused on source characterization of a coolant pump using blocked forces. These tests involved impact testing in DIRAC to get frequency response functions, as well as running a variety of different operational conditions and measuring accelerometer responses. These tests were loaded into SOURCE, which enabled us to calculate the blocked forces of the pump for all of the operational conditions. In this way, we were able to not only validate the blocked forces of the pump, but was also a great example of the functionality and useability of SOURCE. Now that we've determined the blocked forces from this component, we're ready to gather some more data to feed into SOURCE and also to take on some of the more complicated components, like the in-wheel motors. We expect that as soon as we're able to do some NVH testing of a complete prototype of the Lightyear One, Lightyear will truly be lightyears ahead of other automotive companies in their understanding of the NVH characteristics of the vehicle at this phase of development because of the implementation of the VIBES methodology and SOURCE.

Lightyear One

> “We can help Lightyear understand the different contributors to the sound and vibration inside the Lightyear One”



* We call it second time right at VIBES as we build models out of real prototypes to obtain true accurate models enabling accurate predictions how desing changes affect the sound at the driver's ears.

SOURCE CHARACTERIZATION **OF AN E-COMPRESSOR**

2020 has already been filled with exciting technological projects at VIBES, collaborating with several key players in the automotive industry in Europa and Asia. Most of these projects include source characterization using blocked forces. The goal of this study is to show the successful application of independent source characterization for an electric air cooling compressor (ELAC). We take several approaches to compute blocked forces and demonstrate the robustness of the characterization, achieved with our Virtual Point Transformation tech in DIRAC and SOURCE.

The component

Due to the lack of "masking noise" from a combustion engine in electric vehicles, the noise of auxiliary components is becoming a relevant topic. One of these components is the electric air cooling compressor (ELAC). In addition to temperature control of the vehicle interior, the ELAC also performs tasks such as cooling the battery and power electronics during operation and especially fast charging.

Throughout industry, one can observe different mounting concepts for e-compressors. In the presented case, the component is rigidly mounted with three connection points to a bracket. This bracket is again mounted with three rubber bushings to the E-drive.

The goal

The main goal is the characterization of the ELAC by a set of blocked forces, projected to the center of gravity (CoG) of the ELAC. For the calculations, a six degree of freedom (6DoF) Virtual Point (VP) is placed in the center of gravity. Two different methods were used to calculate the blocked forces, as will be discussed further on.

The determined forces were used for the synthesis of the structure-borne compressor noise at a structural response point and on the drivers ear. The goal of having two sets of blocked forces for the same operational states is to prove the transferability and overall robustness of the characterization.

Definitions

In this project, the following notations are used:
› **ERC** - denoted with **A**
› **Receiver** - denoted with **B**

Furthermore, the following technical notations are used:
› u_3 Response points;
› u_4 Indicator points;
› Y_{42}^{AB} FRFs of the ERC in free-free;
› Y_{42}^{AB} FRFs of full vehicle, ERC CoG to the indicators;
› Y_{32}^{AB} FRFs / NTFs of the full vehicle, from ERC CoG to the response points;
› f_2^{bl} Blocked forces / moments (6 DoF), in the CoG of the ERC.

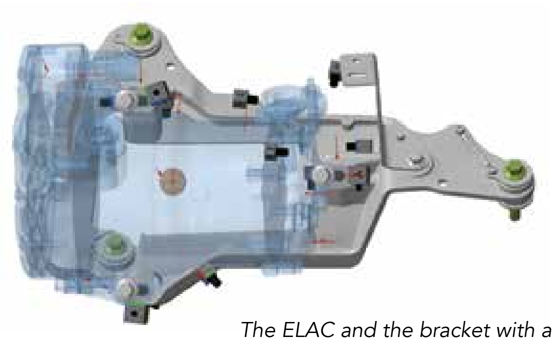
Technical approach

Because of the low frequency range of interest (0-500 Hz) the source description by blocked forces is sufficient to be derived in the CoG . The underlying assumption here is that the ELAC behaves as a rigid body in the frequency range of interest. This was verified by identifying the first eigenmode of the compressor. Secondly, it was verified by looking at the virtual point consistency. Another reason for describing the compressor in the CoG and not at the connection points is to avoid the amplification of measurement noise due to bad matrix conditioning and in order to hand-over the loads to the CAE department for their simulations. Here Transferablity is key as it enables one to determine blocked forces on component test benches which are truly independent of the test bench and hence can be used in the vehicle to produce accurate noise predictions. Among others, Virtual Point Technology show to be vital to guarantee a good Transferability of Source Characterization on Component test benches. The following two approaches will be used to determine blocked forces:

1. **ELAC mounted**: In-situ characterization using a matrix inversion procedure;
2. **ELAC freely suspended:** blocked forces calculated from 'free vibrations'.

For both applications, the virtual point transformation (VPT) will be used to express the blocked forces in the CoG. Next to that, the VPT ensures the transferability of the blocked forces, to the current vehicle or to another compressor / receiver combination.

The validation of the two sets of blocked forces will be done with a component TPA synthesis to a structural response point and to a microphone in the vehicle's interior.



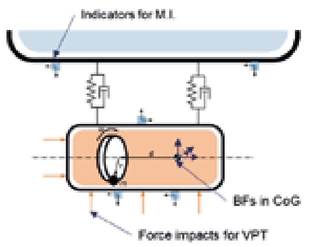
The ELAC and the bracket with a virtual point in the center of gravity.

ELAC mounted

The E-compressor is rigidly mounted onto a bracket, which is in turn resiliently mounted to the front electric motor. The E-motor is also resiliently mounted to the vehicle's body. To obtain blocked forces, operational measurements and FRF measurements are conducted with the same set of sensor positions. Two accelerometers per connection point on the bracket were used as indicator sensors for the matrix inversion. In addition to that, sensors on the seat rail and microphones at the driver's ear were used for validation.

Operational measurements were conducted for distinct constant speeds from 800 RPM up to 9000 RPM and for linear sweeps over the full range. The operational conditions were recorded at the sensor and microphone positions and later transformed into the frequency domain.

Next, an impact measurement was conducted for impact points on the compressor housing. These impacts are transformed into virtual point forces and moments in the center of gravity of the compressor. This yields the transfer function Y_{32}^{AB} from the center of gravity to the validation points and Y_{42}^{AB} to the indicator points on the bracket.



Schematic drawing of the ELAC mounted condition for the in-situ blocked force characterization.

The result

From the operational and FRF measurements, one gets the u_3 validation signal and the u_4 of the indicator sensors at the brackets in the frequency domain, and the FRFs from the CoG Y_{42}^{AB} and Y_{32}^{AB} to the indicator and validation points.

With these results, one can calculate the blocked forces and conduct an on-board validation.

The blocked forces are calculated as follows (no regularization was used):

$$f_2^{bl} = (Y_{42}^{AB})^+ u_4 \quad (1)$$

These forces can now be used to predict u_3^{pred} into to the validation points inside the car. These predictions can be compared to the measured signal. This procedure is called an on-board validation and produces typically good results.

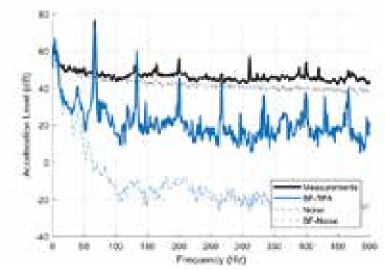
The following component TPA predictions are calculated:

$$u_3^{pred} = Y_{32}^{AB} f_2^{bl} \quad (2)$$

The predictions were validated at the driver's ear microphone and at a sensor at the seat rail.

The results in the figure below show that the first order of the compressor at 4000 RPM is dominant in the driver's cabin. One can observe that the blocked force prediction matches the first order quite well. With the blocked forces one can even predict below the noise floor.

As mentioned, the on-board validation typically produces quite good results. To further assess the transferability of the blocked forces, we determined an alternative set of blocked force under freely-suspended conditions and applied these to the vehicle FRF. The purpose is to prove the transferability of blocked forces.



The on-board validation for the seat rail sensor. The results are shown for the state at 4000 RPM.

ELAC freely suspended

For the freely suspended measurement, the ELAC was dismounted from the vehicle and suspended by rubber ropes. This time, six sensors are placed on the ELAC itself. Again, operational tests and FRF measurements were conducted with the same set of sensors. For the operational tests, the same operational states were recorded as in the mounted approach. For the FRF measurement the ELAC was turned off again and the impacts were placed on the housing of the ELAC.

With these results, one can calculate the blocked forces for the free condition. **The blocked forces are given by the following equation:**

$$f_2^{bl,free} = (Y_{22}^{A})^{-1} u_2^{free} \quad (3)$$

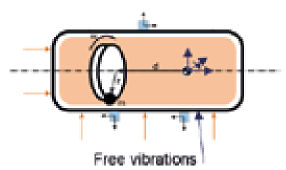
The result

As a result of the operational and the FRF measurements, one obtains the u_2^{free} of the indicator sensors in the frequency domain and the FRFs from the CoG Y_{22}^{A} to the indicator points.

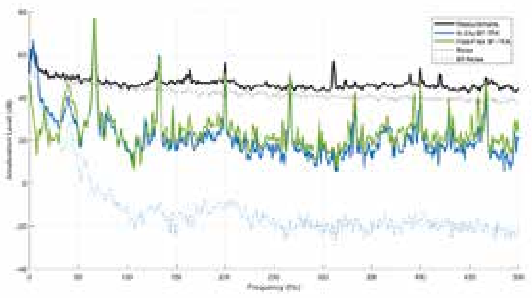
These forces can again be used to make a prediction to the validation points inside the car. These predictions can be compared to the measured signal and the predictions from the previous set of blocked forces. This procedure is called transfer validation and can prove the source independency of the blocked forces. **The prediction is calculated similarly:**

$$u_3^{pred,free} = Y_{32}^{AB} f_2^{bl,free} \quad (4)$$

The predictions were again validated at the driver's ear microphone and at the seat rail sensor. The figure below shows the comparison between the measured signal and the prediction from the blocked forces obtained from the free condition and the mounted condition.



Schematic display of the ELAC freely suspended condition for In-Situ blocked force characterization.



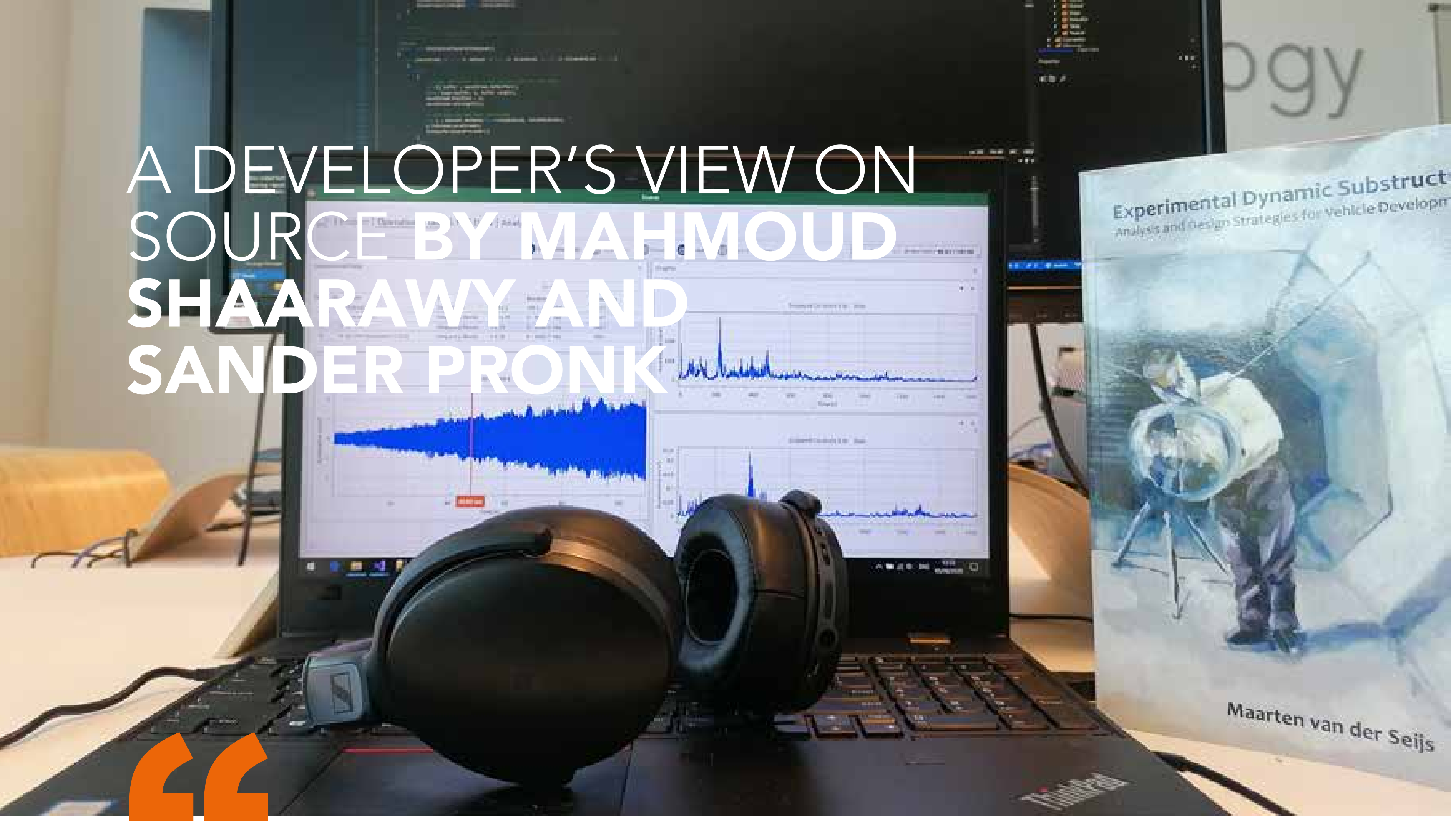
Comparison between the measured signal and the predictions from the blocked forces obtained from the freely suspended condition (green) and the mounted condition (blue).

The result

Both characterizations yield the same result, which means that the blocked forces are indeed independent of the testing conditions. This is even true for very different boundary conditions, meaning that the ELAC characterization is not affected by the mounting condition. It was also verified that the individual blocked forces show a high similarity between in-situ and freely suspended configuration. This finding gives the automotive OEM and supplier(s) freedom to choose the most effective characterization method.

What's next?

One powerful way to further use the identified blocked forces is the combination with transfer paths obtained from dynamic substructuring (DS). DS can be used to simulate modular transfer path models. Together with the blocked force source description, new isolation/packaging concepts for the compressor can be studied for new platforms and vehicles. This allows to create virtual acoustic prototypes of assemblies without the need to physically build them. Variants, for example different bushing stiffnesses, can be virtually exchanged and evaluated. This safes a lot of time and work in the development phase and could avoid late-phase troubleshooting.



A DEVELOPER'S VIEW ON SOURCE BY MAHMOUD SHAARAWY AND SANDER PRONK

In the summer of 2019, the VIBES development team set an ambitious goal: create a **SOURCE** proof of concept in an intensive development marathon. Since the team already had a lot of experience from the **DIRAC** development, we had confidence that our speed of development and decision-making process (from architectural to design decisions) was of such quality that we could realize this ambitious goal. As a result, this marathon resulted in the first proof of concept of **SOURCE** – which could be used for further internal and external discussions.

During the following winter period the development team focused her efforts on **DIRAC** and other products, to allow the full VIBES team to further define **SOURCE** as a product. This resulted in a concrete plan early 2020 to bring **SOURCE** to a version 1.0. But, just as the plan was in place and everyone was ready to kick-off, COVID-19 hit us all and left us with fresh challenges to deal with. Luckily, we already had all of our infrastructure and processes in the cloud: so with online team meetings and a good VIBES spirit, the COVID-19 did not stop us. To the contrary: we lived up to the challenge and regardless of the circumstances we kicked off the official 2nd development phase of **SOURCE**. Throughout the development of **SOURCE**, we realized that many of the required design aspects and modules had already been integrated in **DIRAC**. To deal with this, we decided to create a common repository that will have a shared codebase between the different products. With this common code-base, we challenged ourselves to standardize the behavior of components – which makes **SOURCE** much more intuitive and easier to use. But, it also posed the additional challenge of keeping **DIRAC** unaffected – a challenge we happily accepted.

While developing **SOURCE**, we always started from the viewpoint of the engineers that would use the application. Therefore, we adapted the "Think like a user" theory. We set the goal to optimize every component of the software. For example, while developing the graphing and the audio playback, we not only took into consideration the best practices from **DIRAC** and the Toolbox, but we included engineers in the decisions and we even put ourselves 'on the other side of the application' – by doing the analyses ourselves. Not all of the developers in the team have an NVH engineering background, and stepping into the world of TPA is not easy if you are unfamiliar with the terms and workflows. So, we worked closely together with the engineering team of VIBES during all development stages. By combining different disciplines in a single team, we ensured the quality and usability of the end-product.

With the input from the engineering team we realized that the true power of the application is in handling some advanced, but frequently occurring use-cases. Let us give some examples:

Firstly, adding data into **SOURCE** is fast, easy, and intuitive. As a user, one can simply drag 'n drop data files (e.g. MATLAB or ATFX) onto **SOURCE** and the data is automatically detected. Since the data files can contain lots of data, we decided to not actually load the data directly. Here we introduced the concept of Lazy Loading: data files are not kept in memory until the user actually needs them. This way we could achieve proper memory management, making **SOURCE** a blazingly fast application to work with.

Secondly, when so much data is involved it is easy to lose track of the data files you are using. Some users like to have their data files on a local disk underneath the project file, while others use a different approach – think of using data clouds for instance. To accommodate all the data storage standards and to cope with projects being moved and shared by employees, we came up with the idea of data repositories. By using repositories, users can easily relocate data or project files without having to relink all the individual input files.

Finally, one of the important aspects in TPA analysis is the management of all the different channels. The mapping of the channels between different measurements, and the correct settings for the type of channels (e.g. response and target channels) can be a tedious and error prone task. To eliminate mistakes and to keep track of the settings and mappings, we developed an innovative Channel Mapper concept. The Channel Mapper will really make a difference in the day-to-day use of **SOURCE**.

In conclusion, we enjoyed the journey and are proud of the result. The intuitive UI, the way large amounts of data are handled, the integration of the full TPA framework, and the way engineers are guided through the process all ensure outstanding results in no-time. We can proudly say that **SOURCE** really is the future product for all types of TPA analysis!

VIBES' dev team on Skype during the intelligent lock down.
Top left: Maarten van der Seijs. Top right: Henri Brinkhuis. Bottom: both authors of this article, left: Mahmoud Shaarawy and right: Sander Pronk.

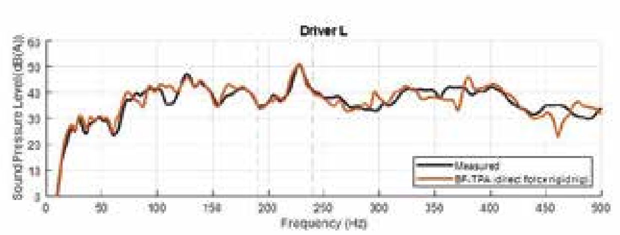
WORK HARD

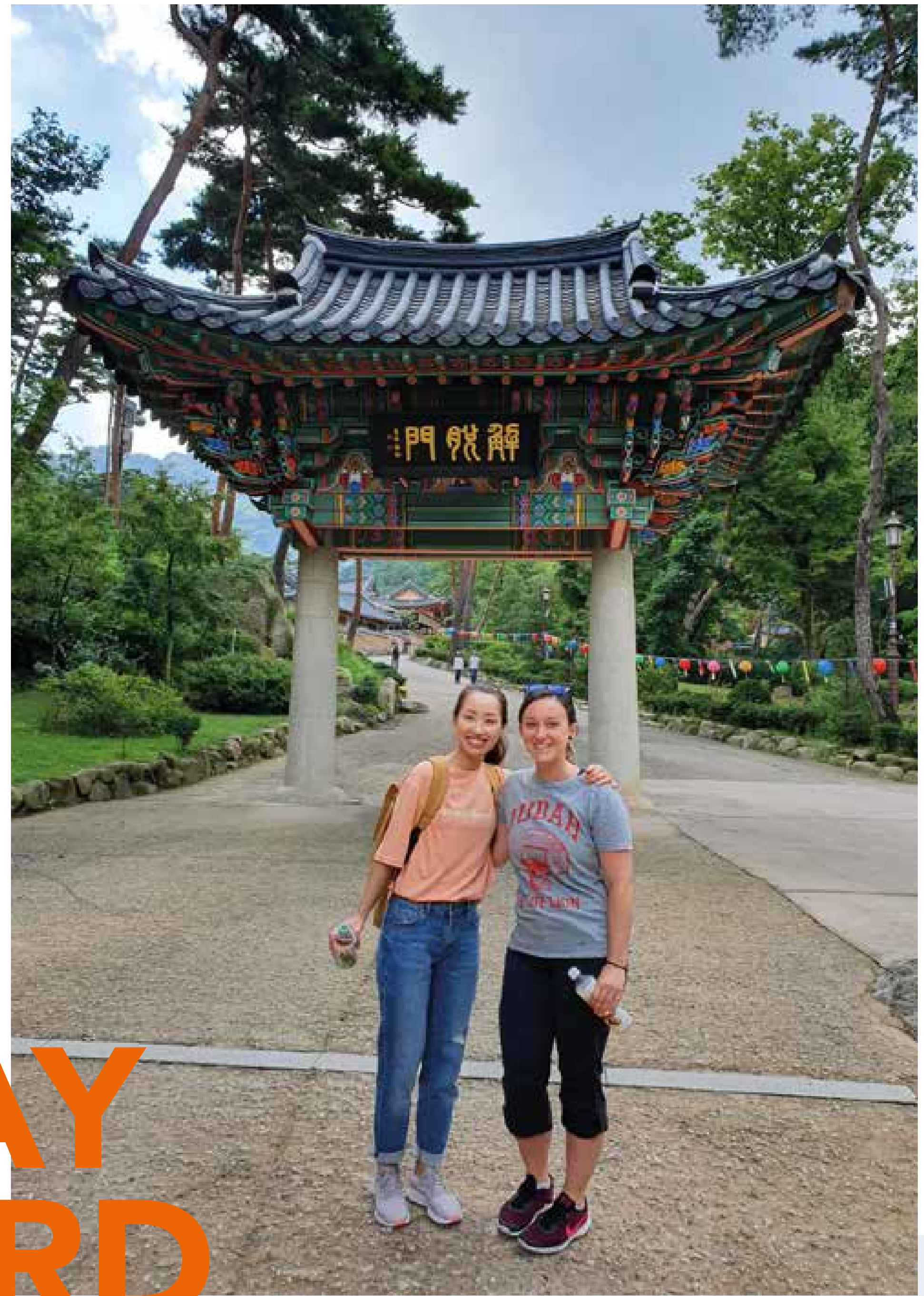
AN ENGINEERS VIEW ON THE HYUNDAI MOTOR COMPANY CASE BY JULIE HARVIE

Within the family of Transfer Path Analysis techniques, there are quite a few methods available to characterize source components. Depending on the specific problem at hand and available equipment, either blocked forces or interface forces can be used to describe the source characteristics, and there are multiple ways to derive either of these types of forces (and moments).

During a recent project in collaboration with the NVH Research Lab at Hyundai Motor Company in South Korea, we had the opportunity to execute a variety of these source characterization techniques to study tire road noise. Various configurations were tested, including a full vehicle, a vehicle with the suspension removed, a very rigid test rig, a softer test rig, and component-level tests to characterize the dynamic stiffness properties of the rubber bushings. This broad range of test data allowed us to determine the blocked forces in multiple ways (direct measurements and matrix inverse techniques). Additionally, the interface forces were calculated using several methods (matrix inverse, mount stiffness, conversion from blocked forces) enabling partial contribution analyses.

Combining such a broad range of data from different test configurations truly would not have been possible without the Virtual Point technology in **DIRAC**; this allowed us, for example, to easily apply the forces measured on the test rig to the full vehicle FRFs. Using this technology, we were able to validate all of the aforementioned source characterization methods. Particularly, the blocked forces measured on the rigid test rig could be directly applied to the vehicle FRFs and produced extremely accurate results up to higher frequencies (see figure), as Hyundai's test rig was designed to be very rigid. The results from this project give both us and the customer the confidence to employ any of these validated techniques in future projects.





PLAY HARD

Through our engineering consultation projects, we've gotten to see some amazing places in the world that we might not have gone to otherwise. Although **VIBES** is based in Europe, we've had a lot of enthusiastic customers in the automotive sector of Asia, and specifically in South Korea.

> While our Korean trips are usually filled with lots of NVH testing during the week-days, we get to spend the evenings and weekends getting to know the local culture.

From hiking in the Korean mountainside, to exploring the busy streets around Gangnam square, to mastering our chopsticks skills, we've really enjoyed the time we've gotten to spend in Korea. The locals really go out of their way to make foreigners such as ourselves feel welcome in their country. It's very much appreciated, especially when you're going on a culinary adventure after a long day of testing. We look forward to our next trip to Korea or wherever else the projects take us!

COMBINE SOURCE **WITH DIRAC**

The most effective solution and intuitive workflow for Blocked Forced calculations. Combine **SOURCE** and **DIRAC** and the entire workflow for Blocked Forces is covered from start to end. Both applications come with specific features perfectly suited to simplify the process of source characterization and response prediction.

Design of experiment ▸ Test preparation ▸ FRF-measurement ▸ FRF-matrix validation ▸ Oper. data validation ▸ Force calculation ▸ Result validation

CAD →

DIRAC
Design of experiment

→ **DIRAC**
VPT FRF Measurements

→ **MBBM PAK MKII**
Operational Data Acquisition

→ **SOURCE**
Includes quality indicators and improved matrix inversion insights, to increase the quality of the resulting forces incl. the VPT.

→ AFTX, UFF

DIRAC FLOW

PREPARE

Design of experiment

- Place sensors and impacts in 3D environment
- Define virtual points for compatibility with FE models

Align all involved parties

- DIRAC is used to define goals, design the experiment and inform measurement execution.
- Consistent way of describing measurements for an efficient modular R&D process

1

Import of CAD geometry

- Support for popular CAD formats
- High-performant 3D experience

High quality FRF testing

- Guided testing workflow
- Merging multiple impact hammers

2

MEASURE

Connect or import

- Measure live using your Müller-BBM MKII DAQ
- Import data from any other DAQ using ATFX

Real-time insights

- DIRAC helps spotting and fixing measurement errors
- Full flexibility to add impacts & change settings on the fly

ANALYZE

Matrix overviews

- All data in a single overview
- Choose between classic FRF coherence & magnitude and Virtual Point quality indicators

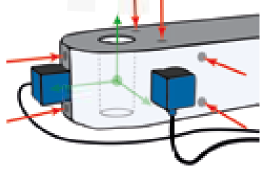
Quality indicators

- Virtual Point consistencies, reciprocity and passivity
- 3D mode shape animations

3

Virtual Point Transformation

- Unique in the market
- Rotational degrees of freedom
- True 6-DoF 'super-element' FRFs compatible with FE models



File formats

- Measurement setup (XLSX)
- FRF results (ATFX, UFF)
- Mode shapes (GIF)
- All-containing export (MATLAB)

4

EXPORT

Time-saving integration for further analysis

- VIBES' **SOURCE** for Blocked Forces and TPA
- **VIBES Toolbox for MATLAB** for Dynamic Substructuring

THE **BOARD**

VIBES.technology was founded by engineers at heart. A shared passion for structural engineering brought them together at Delft University of Technology. In 2016 **VIBES** emerged from their mission to enable experimental dynamic substructuring and modern **TPA** techniques for the engineering community. Nowadays, **VIBES** is a key player in today's innovative market, led by three technical experts.

Maarten van der Kooij
Chief Executive Officer
mvanderkooij@vibestechnology.com

THE **TEAM**

In the past years we have managed to build a great team. Not only have we brought together very enthusiastic people, we also created a good mix of theoretical know-ledge (engineering, C#-expertise, business development, marketing) and practical knowledge (PhD, prototyping, music, entrepreneurship, etc.). Together as a team we make sure we bring exciting, innovative engineering methodologies for NVH to the industry. And we love doing it! Read more about our team on **vibestechnology.com/team**.

Maarten van der Seijs
Technology
mvanderseijs@vibestechnology.com

THE **OFFICES**

Besides the HQ in Delft, we also operate from Munich - at the Tech Centre GATE. This way we can better serve our German and Austrian customers and be present in the heart of the German automotive industry.

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Other
14
15
3 Y
3 Z
Other
4 X
4 Y
4 Z
Excitation points →
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Acceleranc
10⁰
10⁻¹
10⁻²
0
1000
2000
3000
4000
5000