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Technical Engineering & Research in Acoustics

SEA-TEST Version Info

Summary

Presentation

InterAC Experimental SEA (ESEA) Software: SEA-XP/SEA-TEST has been evolving continuously for the last past ten years to fit with the complexity of industrial design. This software is mainly an evolution of early routines developed from 1991 by Dr. G. Borello to build SEA model of industrial engines. With the help of SEP (Société d'Etudes et de Propulsion) that has been designing the cryogenic rocket engine of Ariane 5, Vulcain, these routines have been turned progressively into a full operational software combining both acquisition and post-processing for a maximum of performance.

Starting from decomposition into subsystems of the system to be analyzed, **SEA-XP/SEA-TEST** solve the active power-balanced equations by measuring transfer acceleration and input power. More precisely the measured quantities are **FRF**'s (Frequency Response Functions) and input conductances as all accelerations are stored in FRF format and only the real part of the normalized input power/force^2 is used in the power equilibrium.

Here below, one of the first **SEA-XP/SEA-TEST** application where the experimental power balanced equations have been solved to build Vulcain hybrid SEA model. The analytical formulations where provided by the Dr. Borello's SEA software EARTHS, specifically designed to model the Vulcain and completed and validated by import of ESEA parameters.

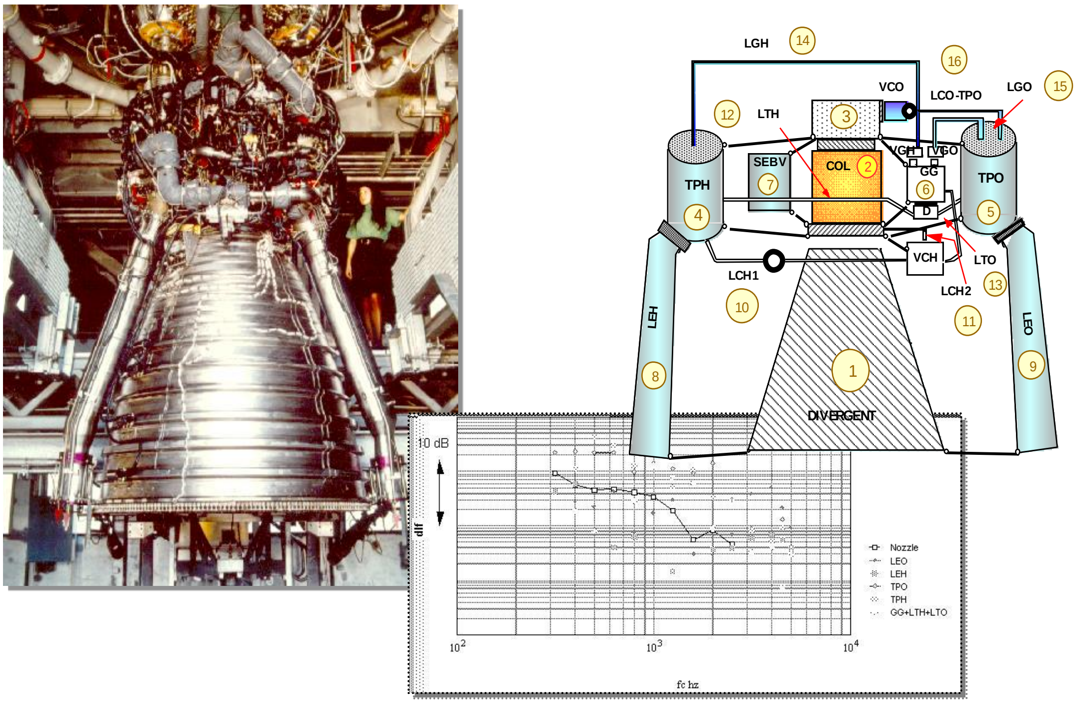

Figure 1: The SEA Vulcain model built in 91 with the help of original SEA-XP/SEA-TEST routines and related

Why Measuring DLF and CLF ?

Separating Internal and Coupling Losses

In most cases, the Damping Loss Factors (**DLF**) of industrial structures cannot be computed theoretically. They are also depending on the assembly and thus cannot be determined from individual tests.

More of it, simple tests such as decay rate measurement cannot provide good enough estimates of subsystem DLF. In fact the DLF of a subsystem in a coupled model is related to the power loss that is intrinsically dissipated within this subsystem and which is not related directly to the decay rate of its impulse response. The decay rate is only proportional to the total loss related to a given subsystem i.e. sum of the intrinsic power loss within this subsystem and to the power dissipated in the coupling (that escapes to the other coupled subsystems). Thus the decay rate includes information about both intrinsic power loss and coupling loss.

The power losses into the coupling between subsystems are characterized by the related Coupling Loss Factors (**CLF**).

The CLF level is depending upon the mechanical connection between subsystems.

To compute these coefficients in the high frequency domain, analytical SEA heavily relies on simplified hypothesis: ideal diffusion of energy, plane wave assumption, simple line or point connected junctions of homogeneous simple plates or shells. On real structures, junctions are far ahead in term of complexity.

ESEA, by measuring all transfer velocities and input conductances from a set of simple impact or acoustic tests, is able to identify both intrinsic DLF and the CLF between any subsystems. The subsystems must exhibit local modal behavior in the frequency range of interest for the inverse problem identification to be successful and is de facto a “high frequency measurement” technique.

SEA model of complex industrial machines can thus be built with the help of this technology.

Using the **SEA-XP/SEA-TEST** estimates of CLF, it is possible to tune simple adequate theoretical models of junctions in order to perform parametric changes and noise reduction analysis. As shown here below, powerful SEA models of complex systems such as the French High Speed Train (HST) were built with accuracy using hybridization of analytical and experimental loss factors.

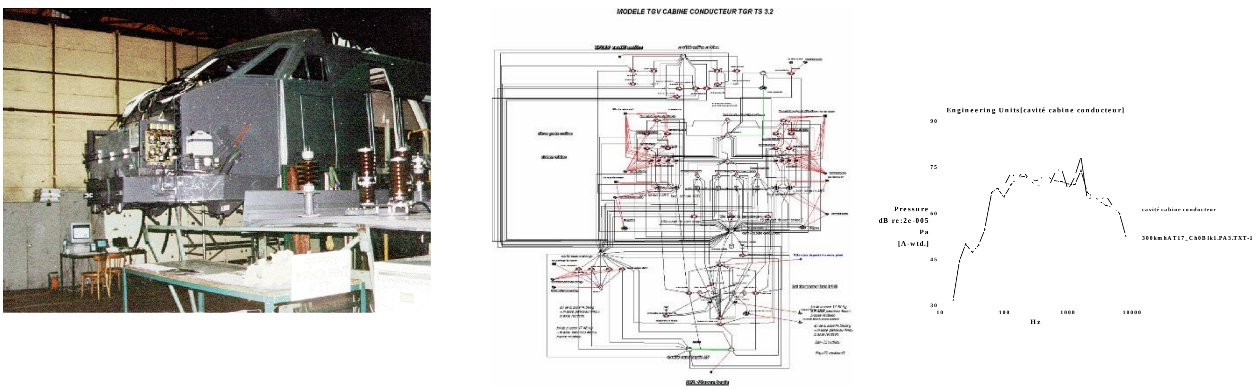

Figure 2: SEA model of the driver's cabin of French HST train for prediction of the airborne and structure-borne sound transmission (on the right prediction at 300 km/h and measurement in cabin)

In cooperation with Alstom, the French train manufacturer, many train vehicles (cabin or coaches) have been modeled using ESEA leading to fine understanding of system behavior.

Analyzing Subsystem Polymorphism

ESEA helps in understanding the polymorphism of subsystems (evolution of dynamical behaviour vs. frequency).

When applying experimental and analytical SEA to car modeling, it rapidly comes to an end that the frequency range of interest (100-2000 Hz) was very difficult to be successfully covered using only analytical description of subsystems.

Looking on the rear pillar shape of a car roof (Figure 3), it can be clearly seen that it is not easy to confine its SEA description in term of simple analytical beam or plate.

From ESEA, we learn about this subsystem by measuring both input conductance and CLF. It appears that this subsystem can be seen as SEA beam at low frequency and as SEA plate at higher frequency. The transition frequency domain just lies in the 800-1000 Hz.

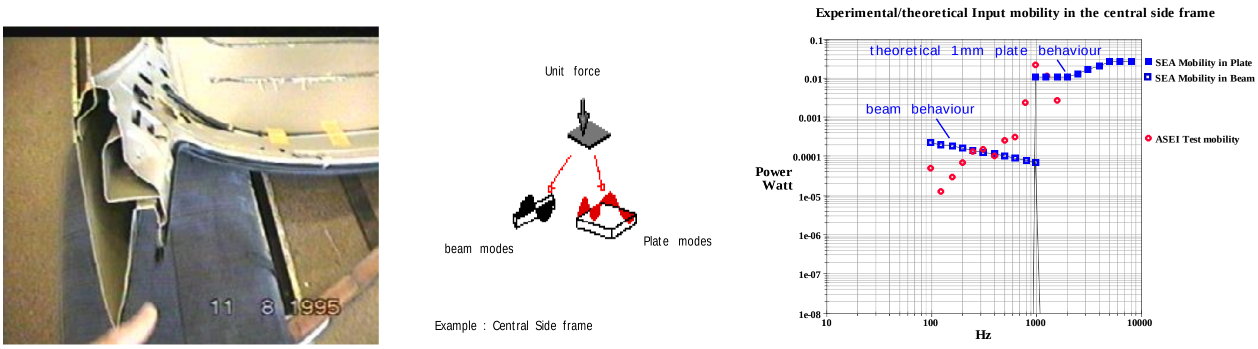

Figure 3: Analyzing subsystem polymorphism of car subsystem with ESEA

Most of the SEA subsystems of a car exhibit this dramatic change of dynamical behavior in this mid-frequency region, leading to difficulty in applying a "static" analytical description for each of them as required in commercial analytical SEA software.

ESEA was thus used to find "equivalent" SEA analytical representation that could fit to the observed dynamical behavior.

SEA Models for Non-Homogeneous Structures

ESEA is very useful to understand how non-homogeneous subsystems behave.

Non-homogeneous subsystems are characterized by some non-constant parameters that can vary within the subsystem domain: non-constant thickness, radius of curvature, material...

A car is typically made of many non-homogeneous subsystems.

Classical analytical SEA is ideal for homogeneous subsystems but how to derive an analytical representation of a shell with a non-constant radius of curvature as an example?

ESEA uses a multi-transducer approach to solve elegantly this problem.

In place of describing the subsystem by a single power balanced equation, referenced to a particular excitation (or to a particular transducer in reciprocal measurement), it uses as many power balanced equations as required with several reference excitation spread at various locations of the subsystem. Using more equations than unknowns in the solve process, it is possible to find a best-fitted experimental set of SEA parameters to characterized this non-homogeneous subsystem from the pseudo-inverse of the energy matrix (with a Singular Value Decomposition or **SVD** solver).

Non-homogeneous subsystems are also characterized by high variability of velocity when scanning the subsystem domain. All estimates of measured energy and power are thus affected by some variance depending upon subsystem complexity.

When simply inverting the transferred energy matrix once, some SEA parameters can be negative on output and not really representative of the real statistical behavior of the subsystem. A Monte-Carlo procedure has been introduced in the solve process to overcome SEA parameter dispersion:

- when recording the data, variance is computed for all inputs;
- when solving, the input data set is perturbed, following related variance of each of the input and the output set of SEA parameters is averaged with previous results obtained for another perturbation of the input data set;
- the solve process can be run in loops several thousand of time in order to derive statistic and variance on output; some solution sets that are obviously non-physical can thus be rejected from the averaged solution (i.e. SEA sets that incorporates too many negative CLF of DLF values);
- the SEA loss matrix final solution can be characterized by a performance index, providing confidence in the result.

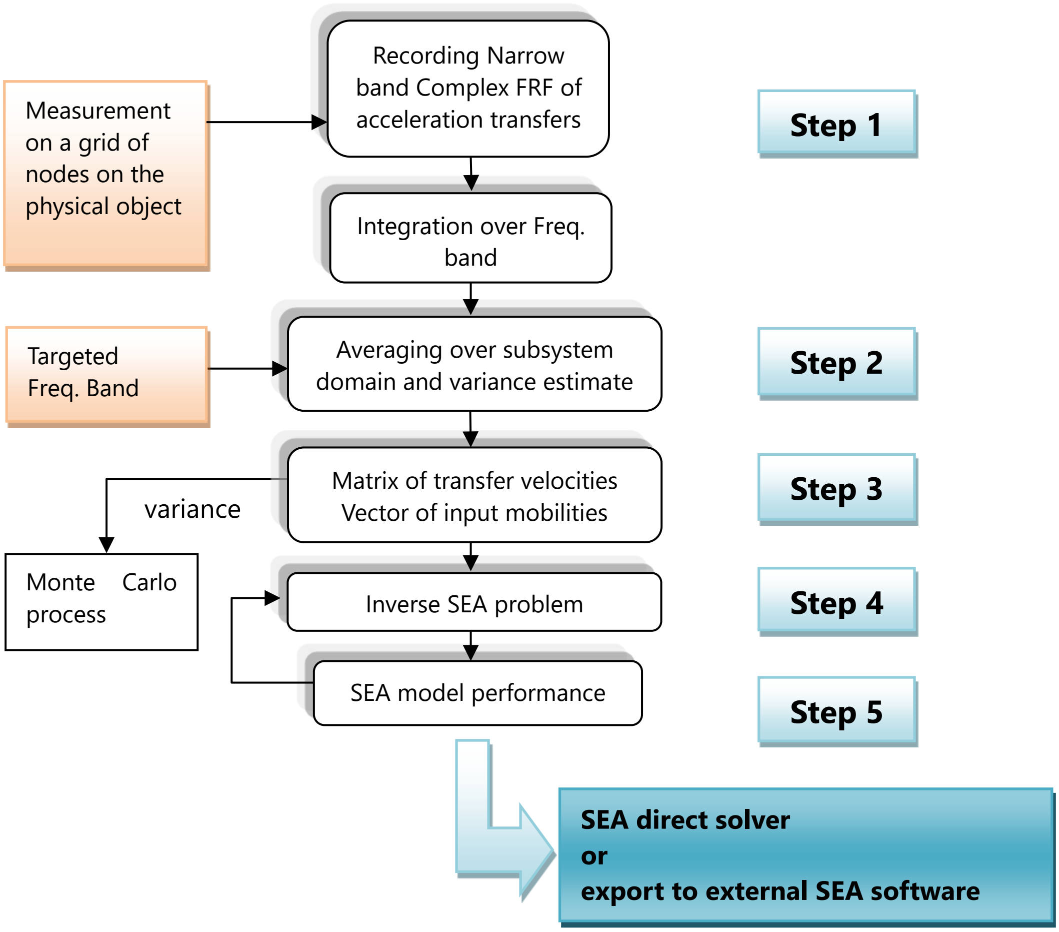

Figure 4: ESEA data flow

The velocity to energy conversion is performed through an "equivalent mass" term which is determined experimentally from the analysis of the decay rate of impulse responses of recorded FRF. This mass term is generally frequency-dependant as we deal with complex subsystems. The mass is nearly independent from frequency only for homogeneous simple systems. The use of equivalent mass in SEA is greatly improving dynamical behavior understanding and its computation does not require any additional measurement as it is fully automated in **SEA-XP/SEA-TEST**.

Acoustic and Structural Coupling

Most of the uncertainty in SEA models is contained in structural subsystems and **SEA-XP/SEA-TEST** was designed from the beginning to focus on structure borne sound transmission. Nevertheless, a full acoustic-to-structure analysis has been included in the software in the mid-nineties.

Within **SEA-XP/SEA-TEST**, the only difference between acoustic SEA subsystems and structural subsystems is the type of recorded data. Generally, pressure measurement is used for acoustics and acceleration for structures. In **SEA-XP/SEA-TEST**, the data type for acoustics is a FRF computed as "pressure signal /reference signal". When computing the mean squared transfer velocity from the FRF, the software automatically converts all acoustic FRF into velocity spectra, using an impedance term (the acoustic impedance) that is defined for each record.

After averaging into squared velocity, there is no more difference between cavity and structures in the data set.

Various problems can be addressed by ESEA, from pure cavity coupling to full vibroacoustic analysis.

Example 1: Sound radiation of a car at 7.5 m and analysis of the sensitivity of absorption changes in the cavities below bonnet
ESEA is used to determine optimal split of the acoustic space surrounding the engine, associated coupling apertures and intrinsic DLF values. The final model is a hybrid experimental-analytical SEA model able to reproduce within a few dB the noise radiated at 7.5 m outside the vehicle.

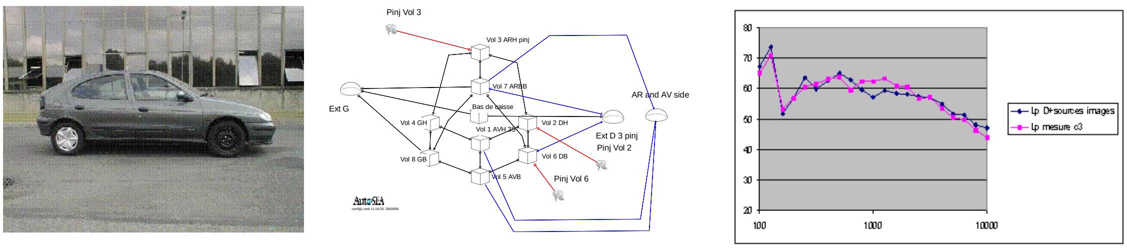

Figure 5: Prediction of sound radiation at 7.5m from the engine using hybrid SEA modeling and comparison of SEA predicted SPL (from engine radiated power) and measured SPL at 7.5 m

Example 2: Dashboard radiation
A full experimental model of a dashboard coupled with emitter and receiver cavities is created to analyze energy transmission paths between the two cavities and to predict the effects of changing trim configurations.

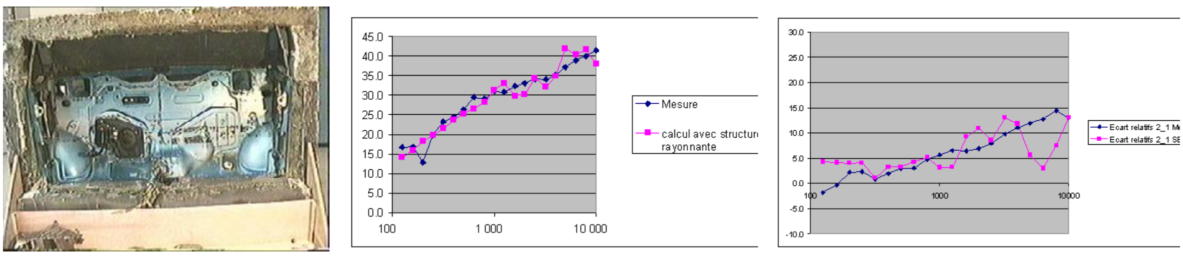

Figure 6: Prediction of dashboard transmission loss using ESEA model and comparison between relative changes predicted from the model and direct measurement for two different configurations

Exporting ESEA Model to Analytical SEA Software

ESEA is a good complement of analytical SEA software. Analytical prediction can be validated for all parameters and experimental description can be substituted to analytical one when the subsystem complexity is not suitable with the simple analytical libraries.

As an example, SEA+ subsystems computed parameters can be overridden by related imported spectra from ESEA provided by SEA-TEST/SEA-XP.

SEA-TEST/SEA-XP offers a bridge for connecting other analytical SEA software to ESEA (from AutoSEA 1 up to latest version of VA One). AutoSEA1.5 was the first version of AutoSEA that was supporting import of experimental SEA data.

InterAC and VASCI (former AutoSEA developer) have introduced a common way of exchanging data between the software using the Universal file format (UFF) and it is still the current way of transferring data from **SEA-XP/SEA-TEST** to VA One.

Review of SEA-TEST Evolution

Version 1.0 (October 2006)

- Experimental SEA with imported measurements

Version 2007-03 (August 2007)

Adding Functionalities

- AutoRev module and documentation

Bugs Fixed and Enhancements

Experimental SEA Menu All Simplified CLF

- Dialog box progress sometimes locked: fixed
- Some CLF are not correctly allocated in the matrix: fixed
- Text property dialog box not properly closed, disabling closing of Experimental SEA routine: fixed

Experimental SEA Menu Import from Model

- Frequency shift was sometimes observed in the imported data: changed in management of index and frequency choice: problem fixed

Graph Export to UNV or to Excel

- First frequency of frequency spectrum was different from other leading to miscomputation of frequency step when exporting (fixed)

Auto-Substructuration

- Cavities were not correctly detected in Auto-substructuration: fixed
  - Reference Correlation matrix algorithm revisited now with two options : fast clusterization and genetic

Edit Test Specimen

- All subsystems parameters, surface, volume and mass, initialized to 1
- Adding edition of test specimen properties in the project manager

Experimental SEA Solver

- Improvement of Loss matrix optimizer: performance index now computed by same routine, adding local global performance index and extra menu
- Import from model: now loss factors from subsystems with same name can be averaged between imported and targeted models
- New subsystem edition pane (parallel editing)
- Possible manual import of 1/3 octave spectrum in any item of the experimental SEA model

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Version 2007-04 (November 2007)

Adding Functionalities

- V_R protocol for non-homogeneous system and theory
- Creating geometry from FE exported data

Bugs Fixed and Enhancements

- Time reverberation in AutoRev

Version 2008-1 (April 2008)

Updating the user's guide to explain "reduced velocity" solve

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Version 2008-1.1 (July 2008)

- Change licensing protection from hasp key to license file
- AutoRev reverberation time analysis can be extended to very low frequency (limit 1 Hz)

Version 2008-2 (October 2008)

- Automated support is added for P/Q transfers, meaning that the post-processing will be entirely automatic up to SEA model creation, avoiding mistakes like using ill-defined masses
- Multiple file selection for importing file
- Improved dialog box for "Subsystem Property Characteristic" input
- Possibility to modify manually the sign of a particular FRF of the database using local right-button menu when selecting a record
- Updating the user-guide to give more practical details on how to measure power, full documentation on using P/Q transfer functions and overview of the various test protocols

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Version 2009 (October 2009)

- Import of time measurement in SEA-TEST project component data sheet to compute decay rate and equivalent mass from time history
- Wav import in AutoRev

Version 2011 (October 2011)

Update to LV Runtime Engine 2011

- Graphing options have been improved thanks to LV runtime engine 2011.

SEA-Experimental

- In SEA-Experimental, mass calculation of SVD compacted subsystem has been modified
Subsystem mass of compacted subsystems is now equal to the sum of masses of included subsystems. In previous version, subsystem mass of compacted subsystems was calculated as mean value of masses of included subsystems
- Upgrade of Export format to VA One (up to version 2010) for correct import of power and mass
- Graphing of reverberation time within Experimental SEA models has been added

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Version 2012 (October 2012)

- New functionalities added for importing UFF measurements (setting sign and selection). More options in SEA preferences
- New function for acoustic transfers added: Condensation of p/F transfer on references of a structural subsystem

- AutoRev: RT cursor algorithm improved to be more stable when using time history containing audible background noise

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Version 2013 (December 2013)

Update of all dependencies: LabVIEW 2013, Intel FORTRAN 2013, Net Framework 4
- New function : import Experimental SEA Model from SEA-XP
- New function : "swap CLF"
- Enhancement of function :"Create Geometry"
- Minor bugs fixed (export to dataset 58)

Version 2013.0.2 (July 2014)

Update of all dependencies: LabVIEW 2013 SP1f2, Intel FORTRAN 2013 SP1
- Damping Loss Factor computed from time computation changed DLF = 2.2 / (FC*TR)
- Temporary directory read from environment path “TMP_SEA_TEST” if found
- New subsystem compact (patch substructuration)

Bugs fixed
- Characters string exceed the location in the dialog “Show Properties” and in other dialogs box
- Mass import from text files in properties dialog
- Dialog box Properties cause a crash

Version 2016 (February 2016) Major Release

- **SEA-TEST 2016 is storing data using the same data engine than SEA+ (SQLite). Project files are saved with extension *.dbst.**

- **Previous SEA-TEST versions were saved with another file format with extension *.xea.**

- **Prior to open older project files in SEA-TEST 2016, you have to convert them from XEA to DBST format. SEA-TEST Data_Converter programme is installed with SEA-TEST 2016.**

- SEA-TEST interface is entirely re-written to fit new Windows operating system.

Version 2019 (July 2019)

Bug fixed :

- Data loss when importing measurements from UNV Files
- Correction of bug generated when importing large UNV file
- Minor bug fixed in the openGL GUI and subsystem creation

Improvement of the graph and Adding a power spectrum plot for temporal data the application and libraries have been adapted and updated:

- Net framework 4.6.2
- LabVIEW 2018
- Fortran 2019

Version 2021 (September 2021)

Bug fixed :

- When importing data, the selection was not taken into account, all spectra were systematically imported
- Minor Bugs

The application and libraries have been adapted and updated :

the code has been migrated to the net Framework 4.8 and Fortran 2020.4

Version 2024 (December 2023)

The application and libraries have been adapted and updated :

the code has been migrated to LabVIEW 2021 and Fortran 2023

Bug fixed :

- Minor Bugs