EMC MODEL BUILDING USING ANSA

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ABSTRACT – An useful software tool (ANSA-AMELET wrapper) created by Evektor within the HIRF-SE project (FP7 Research Programme of EU) extends the conventional application fields of ANSA to EMC modelling and simulations. The conference contribution will show, how an airplane EM model is built and meshed in the ANSA environment and then converted into the AMELET HDF data structure for EMC simulations by a plenty of useful 3D solvers integrated in the HIRF-SE framework.

TECHNICAL PAPER -

1. IN GENERAL

Problems of electromagnetic compatibility (EMC) are considered as a hidden threat in the aerospace industry. Some of them can be foreseen using simulations on digital mockups already before a materializing of the first aircraft prototype. Intensities of electric field E, magnetic field H and responses of these fields forced into aircraft wiring (voltages or currents) can be calculated using a plenty of computational electromagnetics (CEM) tools covering all the necessary spectrum of used frequencies (10 kHz-40 GHz) as well as airframe materials (classical metallic structures up to new nano-composites). If all the requirements of the EMC simulations are not realizable by any present advanced solver, an EMC computational toolbox is necessary for an effective exploitation of laborious deterministic models created by meshing of standard quality CAD geometries.

The above mentioned EMC toolbox is created within a continuance of the HIRF-SE collaborative research project (7-th Framework Programme of EC) where a common platform of the EM model data structure (AMELET-HDF) is established to match the data format for various EM solvers (both the existing and future ones) integrated in the HIRF-SE framework. Various types of full-wave 3D field calculators working in time as well as frequency domain are completed with asymptotic and stochastic solvers covering the microwave part of the required frequency spectrum and their output observables (E and H field intensities) are directly applicable to EM models of wiring for the above mentioned response calculations. As the HIRF-SE framework has integrated the unique advanced tool CRIPTE for calculations of these responses in airborne cable structures in their usual complexity, a wiring structure and geometry pre-processing with a traceability to cable design tools is useful.

Any successful simulation of EM field using the 3D solvers integrated in the framework strictly depends on a quality of a geometric model of the airframe and its mesh. It is sometimes tricky and difficult to create a complex high-fidelity EM model using a standard CAD geometry data. The universal pre-processor/mesher ANSA is well proven for this purpose when possibly used by more than 20 engineers in Evektor. As it became a standard "de-facto" and tool no. 1 for effective creation of simulating models, a direct output of the meshed geometries from ANSA to the HIRF-SE framework environment was very necessary for us. This data conversion module was recently created by Evektor within its participation in the HIRF-SE project as a part of the framework. The useful tool (called the ANSA-AMELET wrapper) extends the conventional application fields of ANSA to EMC models. The contribution will show, how an airplane EM model is built and meshed in the ANSA environment and then converted into the AMELET HDF data structure for EMC simulations by the tools integrated within the HIRF-SE framework. For the way of ANSA integration within the HIRF-SE Framework, see Figure 1.
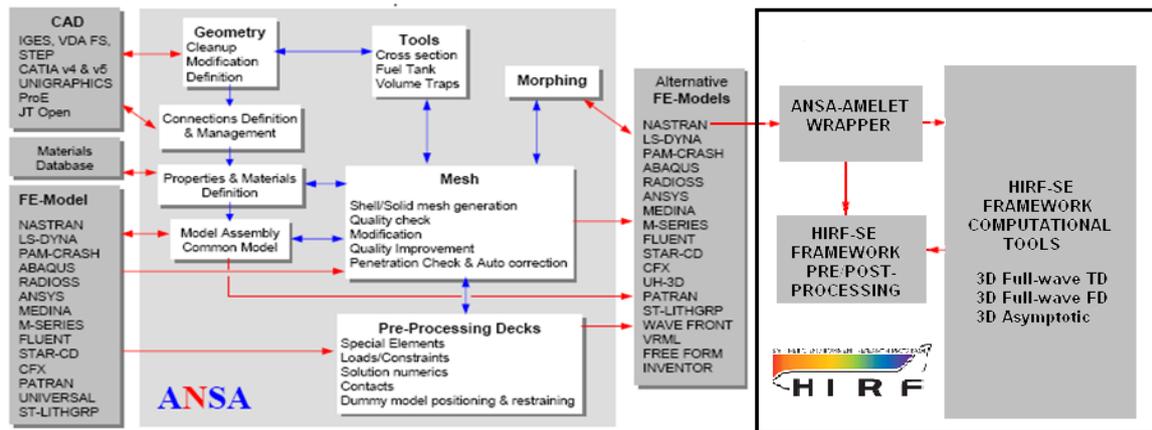
Figure 1 –   Universal pre-processor ANSA in CAE process flow and its opening into the HIRF-SE framework through the ANSA-AMELET wrapper.

As apparent in the Figure 1 and its left part taken from [1], ANSA is an universal environment, where airframe geometries and meshes are processed in their surface (shell) or volume (solid) versions. In addition to these usual applications (creating surface or volume mesh elements), geometries of cable bundle paths are defined and meshed using linear (1D) mesh elements. These linear elements are convenient for calculations of voltage or current sources, by means of which the wiring is stressed within the internal electromagnetic environment of the aircraft under test. When the geometries of the examined airframe and its internal cable bundles are fully defined and meshed, they are converted into the AMELET-HDF data structure and format as a common platform for the next processing within the HIRF-SE framework (see the right part of the figure).

The HIRF-SE framework has its own pre-processing and post-processing tools, by means of which a quality of the meshes transferred from ANSA can be checked, but it has also tools for pre-processing of cable bundle branching and cross-sectional structures, by means of which the data from ANSA are ideally completed i.a. for a creation of Multiconductor Transmission Line Network (MTLN) model of cable bundles using a data of cable design systems' outputs.

2. EMC MODEL OF AIRFRAME

A procedure of EMC model building using already created CAD models has some similarities with other kinds of digital prototyping models, but there are also differences caused by a different nature of physical phenomena and its description by a set of partial differential equations (for EMC it can be found e.g. at [5]). While the structural analysis or crash simulations are processing the models inside the solidity of the virtually tested object and Computational Fluid Dynamics (CFD) takes into considerations also flowing medium in its close proximity, the EM environment runs through the close as well as the far-distant environment and through the virtually tested object itself, if it is not made of perfect electric conductor (PEC), which is a hypothetic material used for simplifications of some EMC calculations.

In addition to the differences mentioned above, EM models are to be used in a very large spectrum of frequencies and wavelengths (10^4 – 10^{10} Hz and 10^4 – 10^{-3} m) and that is why the conception of an electric size of the object under test is established. If the ratio of an object dimension to the wavelength used for the object examination is much greater than 1, we are talking about an electrically large object and if this ratio is by much lower than 1, the object is called as electrically small one. If we consider an airframe with the fuselage length of 14 m and the wing span of 16 m (Evektor's twin-engine turboprop EV55), it appears as electrically small when examined at the frequency of 10 kHz (wavelength of 30 km), but electrically large, when using the frequency of 10 GHz (wavelength of 30 mm).

The conversions between frequencies and wavelengths each to other mentioned above were done provided that the EM wave propagates in vacuum (or air) according to the known equation

$$f = \frac{c}{l} \qquad \text{[Hz, m/s, m]} \qquad (1)$$

where f is a frequency in Hz, c is the light velocity in vacuum (300 000 000 m/s) and l is a wavelength in meters. However, the c can be quite different if the EM wave is propagated within other materials than air and its dependence on tensors of permittivity (ε) and permeability (μ) for the given material may be very distant from the known and transparent term

$$c = \frac{1}{\sqrt{\varepsilon\mu}}, \qquad \text{[m/s, F/m, H/m]} \qquad (2)$$

for air and vacuum. A complex nature of the above mentioned permittivity and permeability tensors in more dense materials than air is connected with different penetration depths of EM fields into these materials. The penetration depth is defined as the depth at which the intensity of the radiation inside the material falls to 1/e (about 37%) of its original value at (or more properly, just beneath) the surface [3].

If these penetration depths numerically approximated with skin depths [4] for all the more or less conductive materials usually used for airframe structures, they can be calculated according to the simple expression

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}, \qquad \text{[m, \Omega m, H/m]} \qquad (3)$$

where ρ is resistivity of the material (imaginary part of the ε tensor mentioned above) in Ωm, ω is angular frequency ($2\pi f$) and μ is absolute value of the permeability tensor in H/m for the considered material [4]. When using formula (3) for penetration depths of EM field in aluminum alloy, we get 1.2 mm for the frequency of 10 kHz and 1.2 μm for the frequency of 10 GHz. If we use for airframe structure carbon fibre composite (CFC) material with a much more resistivity, we get the penetration depths of 59 cm and 0.59 mm respectively.

The above mentioned electrical size of the test object is necessary to take into considerations not only when choosing a suitable size of elements for its meshing, but also at the initial phase of pre-processing when taking decisions, what details of the original structure in CAD are to be saved or omitted for the built up EMC model. For these decisions is important not only an electrical size of the details, but also their materials and appropriate penetration depths, when larger and radio-transparent details of the airframe can be omitted and more conductive smaller details of the airframe are to be saved in the final model.

Penetration depths are also important for a decision if a shell or solid structure is to be prepared for a meshing as EMC model and a division of the model into material domains. The specification of the material domains is a significant task carried out using ANSA during pre-processing and healing of the used CAD geometry before its meshing. An example of a complex structure with reference to its material and geometry composition is Evektor's EV55 (Figure 2).

Some of the nowadays used airframe materials have complex multilayer structures with addition of protective metallic foils and they have anisotropic and birefringent properties very remote from classical metallic structures. That's why material modelling tools are important parts of the HIRF-SE framework and they make possible a meaningful calculation of modern airframe internal EM environment.

These material modelling tools are submodules, by means of that a way of Maxwell equations' [5] solution is respected according to the selected solver to be used as a basic simulation tool. That means, if the main solver module is working in frequency domain (FD), the complex material is also modelled in frequency domain and if a time domain (TD) solver is used, the material model is prepared also for use in time domain. It has a connection with the multidimensionality of the electrical permittivity tensor (ε) which is usually approximated by an effective complex permittivity for a single frequency or by special pieces of a code to be used with time domain methods.

Figure 2 – Material diversity of EV55 airframe skin: basic metallic structure is yellow, CFC parts are brown, plexiglass windows' filling is blue and glass fibre composite (GFC) is green.

Representatives of the frequency domain (FD) full-wave computational tools integrated within the HIRF-SE framework are mostly based on the Method of Moments (MoM). When building the EMC models for a MoM solver, the airframe surface is meshed into planar patches (triangles or quads) with approximately the same dimensions. A maximum size as well as minimum size of the elements are defined using ANSA for automated meshing according to the maximum frequency to be applied on the EM model. An example of these meshes with the maximum element sizes of 500 mm, 200 mm and 80 mm for the maximum frequencies of 60 MHz, 200 MHz and 500 MHz respectively are shown by the Figure 3. A necessary time for processing of the models using the mentioned MoM-type solver is proportional to a number of frequencies as well as to a number of elements of the meshed model (20581, 41144 or 117048 respectively).
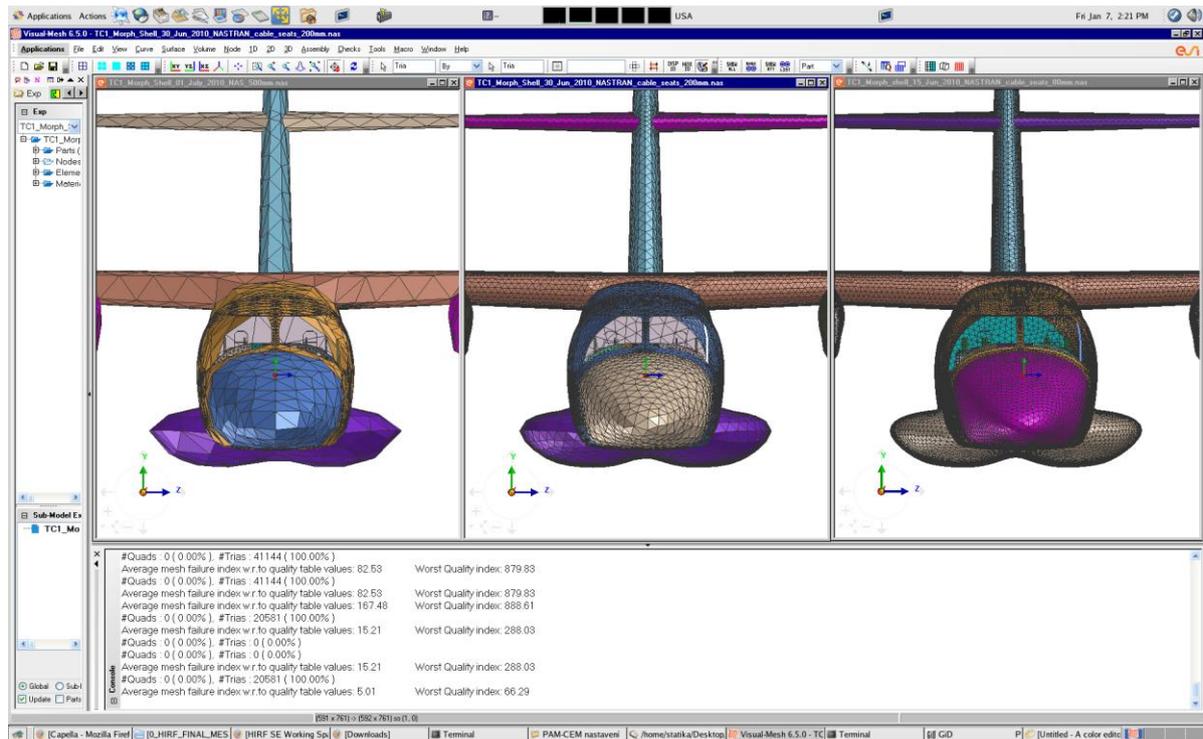
Figure 3 –   Examples of the EV55 model meshed by ANSA for a MoM-type solver with the requirements for maximum element sizes of 500 mm, 200 mm and 80 mm

The most typical representatives of the time domain (TD) computational tools in the framework are Finite Difference Time Domain (FDTD) solvers. This method requires a structured volume mesh of uniform cells, by means of which not only the airframe geometry, but also a limited part of the surrounding environment space is discretized and material properties (above mentioned ε and μ tensors) are specified for each the particular cell. This kind of mesh is also known as the stair-case as well as sugar-cube mesh or more expertly as the Yee lattice according to K. S. Yee, the originator of the FDTD method (firstly published in 1966). If the discrimination of the above mentioned FD solvers is naturally created by individual frequencies taken into consideration for simulations, the required frequency spectrum in its entirety in a form of an exciting pulse is used for simulations in the time domain. That's why the material modelling of complex multilayer structures requires a special approach coupled with FDTD sub-cell subroutines.
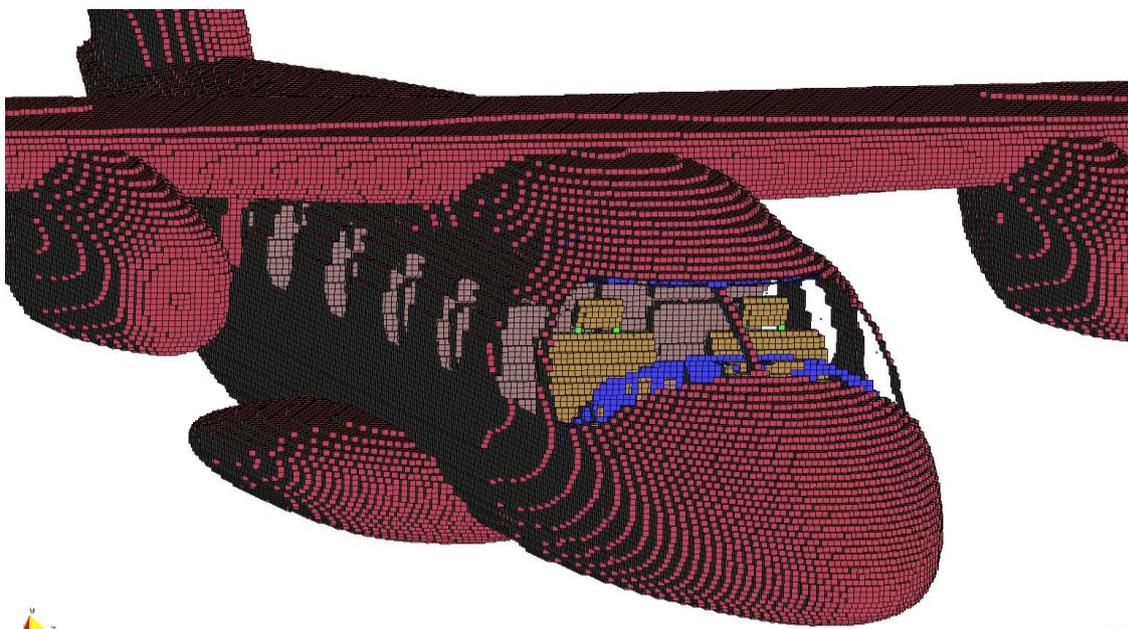
Figure 4 – An example of the EV55 model meshed for the FDTD-type solver with the element size of 30 mm (360233 elements).

An example of the EV55 simplified model expressed by Yee lattice is shown by the Figure 4. The EV55 simplified geometry is meshed with the element size of 30 mm which is applicable roughly up to the frequency of 1 GHz. This is corresponding with the basic rule of volume discretization for FDTD simulations, when the required element size of the meshed model is at least 1/10 of the minimum required wavelength. This mesh cannot be created directly using ANSA, but in addition to other valuable pre-processing and post-processing tools, the HIRF-SE framework has integrated the necessary FDTD mesher, which can process any high-quality unstructured surface mesh created by ANSA (or other meshing pre-processors) for the above mentioned Yee lattice.

Some our experience with the building of FDTD model and simplified composite materials' integration were already described in [6]. It was obtained when only one commercial tool (PAM-CEM) was available in Evektor for making the EM computational simulations. Even if an advanced tool for wiring responses' calculations (CRIPTE) had been already integrated with this tool, only limited possibilities were available for simulations of the airframe internal EM environment, by means of which the internal wiring is stressed. Now, when the HIRF-SE project is in progress, the high-frequency capabilities of EM field calculations are extended partly by asymptotic and stochastic solvers up to required 40 GHz and partly by applicability of various 3D solvers, by means of which simulations of new airframe materials and their combinations can be tested.

3. EMC MODEL OF WIRING AND EQUIPMENT

Even if electromagnetically vulnerable airborne equipment is the most probable victim of a severe electromagnetic environment, the cable bundles installed in the airframe play an important role in the equipment EM coupling to this environment. If any conductor becomes a source of electrical energy when situated in EM field, these sources may threaten a correct operation of airborne equipment or to destroy them in a severe EM environment if no protective precautions are done on the wiring and equipment connectors. That's why the wiring responses' calculations are the main goal of modelling and simulations in modern computational EMC.

The modelling of cables is a very specific task because of a considerable complexity of real aircraft installations. Any wiring, which is connecting the airborne equipment each to other in their installation locations, is realized by cable bundles that are branched into several cable segments. Each of the cable segments can include typically 50 up to 200 elementary conductors that can be single or twisted in pairs (triplets) and they can be unshielded, shielded or overbraided. All these conductors and their shields become sources of electrical energy if exposed to EM fields.

If these conductors create relatively complex cross-sectional structures, there was no software tool to manage the response calculations on them for a long time in the past. Former trials of modelling the cable bundles as single wires using the tools for antenna design failed and experimental testing of wiring responses using the first materialized aircraft prototype was only the reliable way, how to quantify the threats. This situation was recently changed, when a sufficient computational power is available and some formerly classified theoretical works of Dr. Carl E. Baum done during the cold war were cleared for public release [7]. The topological approach to the modelling of complex cable structures (described in [8]) was used for a development of the Multiconductor Transmission Line Network (MTLN) model. This model can be processed using the solver CRIPTE developed in the French aerospace research institute ONERA and responses of cable bundles exposed to EM field are calculable in their complexity now. The CRIPTE solver is also integrated within the HIRF-SE framework.

The MTLN model is based on a decomposition of complex cable bundle to junctions (corresponding to the cable extremities or branching nodes) and tubes (corresponding to the above mentioned cable segments). The junctions are connected by the tubes, by means of which a schematic topological network of the MTLN model is created. While the cross-sectional structures and lengths of appropriate bundle segments are defined by the tubes, the interconnections of individual wires in the bundle segments each to other are defined by the junctions.

If the modelled cable bundle is not stressed by an external EM field, an electrical energy corresponding to the normal cable signals is propagated in the form of incoming and outgoing waves in the tubes of this 1D network model. The propagation conditions of the waves on a tube are given by known scattering matrix of the tube, which can be established using the known cross-sectional structure of the corresponding modelled cable segment.

As soon as the cable bundle is exposed to EM fields, this situation is modelled by an implementation of current and/or voltage generators into the tubes of the MTLN model. Amplitudes corresponding to the appropriate generators are calculated from tangential electric fields that may come from any of 3D solvers mentioned above. Even if the solver CRIPTE itself calculates the wiring responses frequency by frequency, there is no problem to use frequency domain (FD) as well as time domain (TD) 3D solvers integrated in the HIRF-SE framework for these calculations.

When using a chaining of the CRIPTE MTLN solver with any of the 3D solvers integrated in the HIRF-SE framework, the cable bundle routes are only to be specified in the meshed model prepared for the selected 3D solver. These routes can be imported from the appropriate CAD model by ANSA and meshed by special linear CBAR (1D) elements.
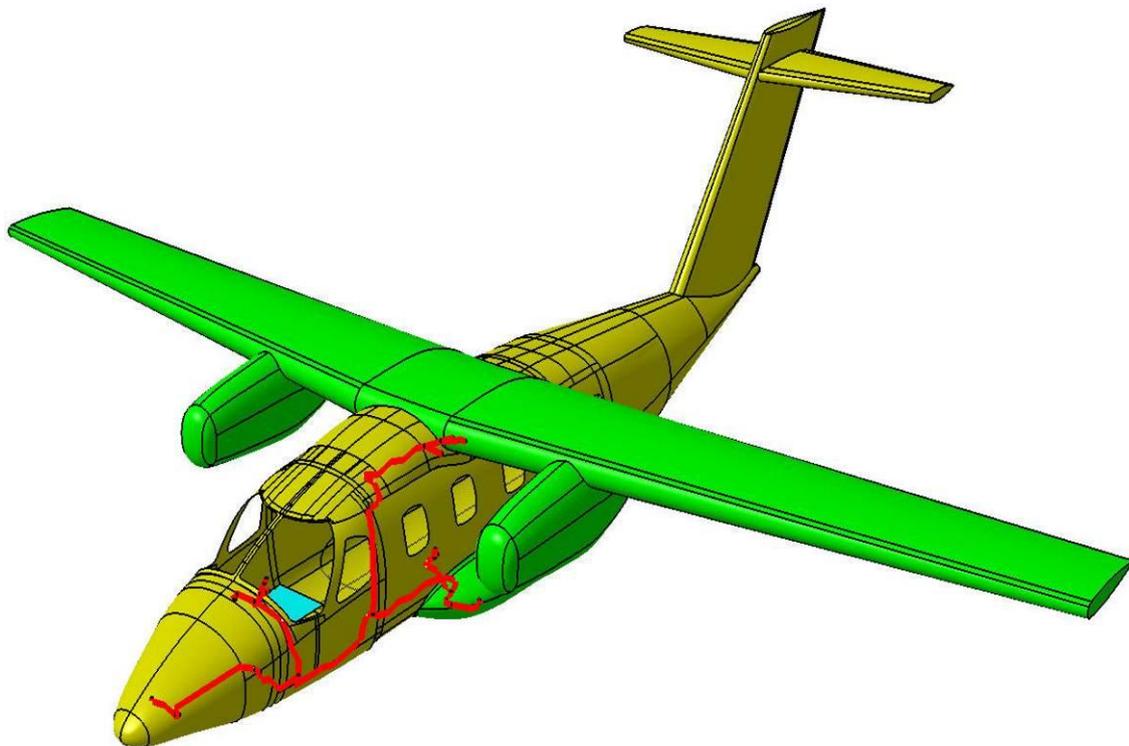
Figure 5 – Routes of a cable bundle (marked in red) inside the fuselage of the simplified EV55 geometry

Cable routes to be modelled for EM field responses' calculations using the CRIPTE solver are shown by the Figure 5. The data are imported from a CAD model created by CATIA together with individual bundle segments' specifications, i.e. defined parts of the routes between branching nodes (tubes in the MTLN model). These branching nodes are used for the junctions' identification (junctions in the MTLN model).

The cable bundle routes' meshed geometry is shown by the Figure 6. The linear mesh elements have the length of 30 mm (401 elements in total) and their coincidence with the individual tubes of the created MTLN model is provided by another piece of software added into the HIRF-SE framework by Evektor – the ProE/KABI-AMELET wrapper. This wrapper makes possible to create MTLN model of a complex cable bundle in HIRF-SE framework using a direct processing of a wiring design systems' output data.

The above mentioned cable route mesh is processed together with the already mentioned meshed airframe model when using a feasible TD or FD solver and tangential components of E-field distributed on these elements are calculated. If the fields along the cable route are known, stressing sources on the individual tubes of the MTLN model can be specified and the responses of the cable for EM environment can be obtained in any location along the cable bundle path for any individual conductor or shield of the modelled cable bundle using the CRIPTE solver.
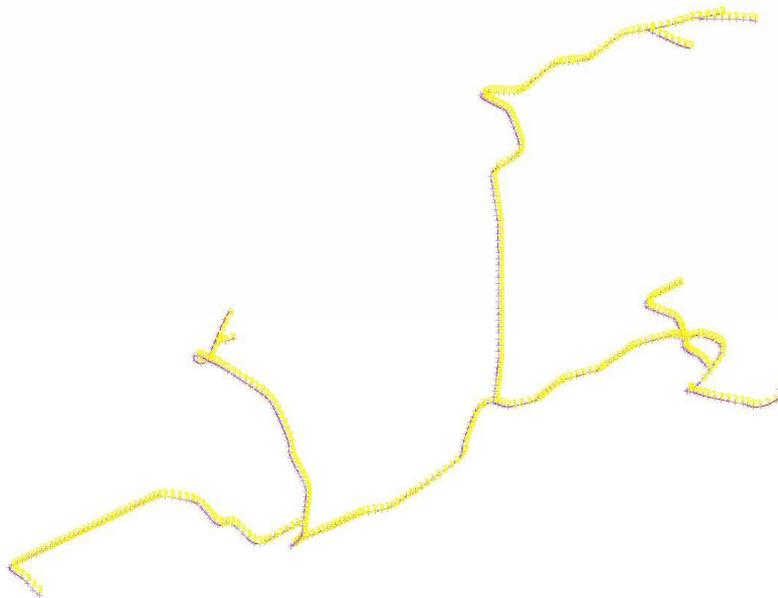
Figure 6 – Cable bundle routes of the EV55 meshed by ANSA to be used for calculations of the stressing sources' in MTLN model

The most interesting outputs of the CRIPTE solver are the responses of EM fields on the cable extremities in the planes of equipment connectors – that means a quantification of EM threat for the installed airborne equipment. This quantification is used to be usually expressed as a current in a conductor which is short-circuited to the airframe or an open-circuit voltage on this conductor. In addition, the HIRF-SE framework has integrated also tools for equipment input impedance modelling, by means of which the EM environment threats of the known airborne equipment can be evaluated more precisely. However, a description of these equipment modelling tools are quite out of the scope of this paper.

4. CONCLUSIONS

In this time, for the airframe internal EM environment calculations, the HIRF-SE framework integrates 6 TD (time domain) solvers, 6 FD (frequency domain) solvers and 2 asymptotic

solvers. All of them can process unstructured meshes created by ANSA either directly or through the integrated FDTD mesher, if the above mentioned structured Yee lattice is required. In addition, material modelling tools and material modelling library make possible an advanced interpretation of ε and μ tensors in their complexity for new materials in the frequency as well as time domain calculations.

The consequential modelling of a complex cable bundle as Multiconductor Transmission Line Network (MTLN) makes possible an advanced evaluation of EM environmental threats using the CRIPTE solver that can be chained with any of above mentioned time-domain or frequency-domain 3D solvers. The geometry of the cable route can be also created and meshed by ANSA and processed together with the airframe mesh by a suitably selected simulating solver. These useful combinations of various EM solvers are possible due their integration into the HIRF-SE framework with the common data exchange platform AMELET-HDF [9].

Even if the HIRF-SE framework has integrated its own suitable pre/post-processing and meshing tools, ANSA is a good and time-saving alternative for pre-processing and meshing of the models with a high geometric and material complexity to prepare them for EM simulations.

5. ACKNOWLEDGEMENT

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