A NEW TOOL FOR MULTIDISCIPLINARY CAE SIMULATIONS

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SUMMARY

One of the most challenging tasks in today’s simulations is the Multi Disciplinary Optimization (MDO) of a mechanical system.

Different specialty CAE tools are needed for structural assessment (FEA), fluid dynamics analysis (CFD), etc., each simulation code having its own specific requirements for modelling. Therefore one and the same numerical model can’t be generally used for a coupled simulation.

This paper introduces a modern software for coupled simulations that allows a seamless integration between different CAE tools through an interactive GUI and a robust interpolation engine.

The method is described and validated on Fluid Structure Interaction problems, a typical MDO application.

Keywords: Multi Disciplinary Optimization, Fluid Structure Interaction, Interpolation.

1: Introduction

The goal of MDO is to make engineers able of analyse and optimise complex physical phenomena, where more than one discipline is involved. This class of problem is very wide and it includes for example:

Workflow problems (Figure 1.a):

- Process simulation – Structural analysis: when it is necessary to pass the results of a process simulation like casting (Young’s modulus, density distribution) or stamping (Shell thickness, residual plastic strain distribution) to a FE model for structural assessment of the part;

- Thermal simulation – Structural analysis: to pass the results from a radiation / convection simulation code to a FE model for structural assessment.

Coupled problems (Figure 1.b):

- Fluid – Structure Interaction (FSI), where the structural response of a body under the action of fluid dynamic boundary conditions, has an influence on the calculation of the thermo-fluid-dynamic field and vice-versa;

- Thermal – Electromagnetism, when a thermal flow affects an electromagnetic field and vice-versa.

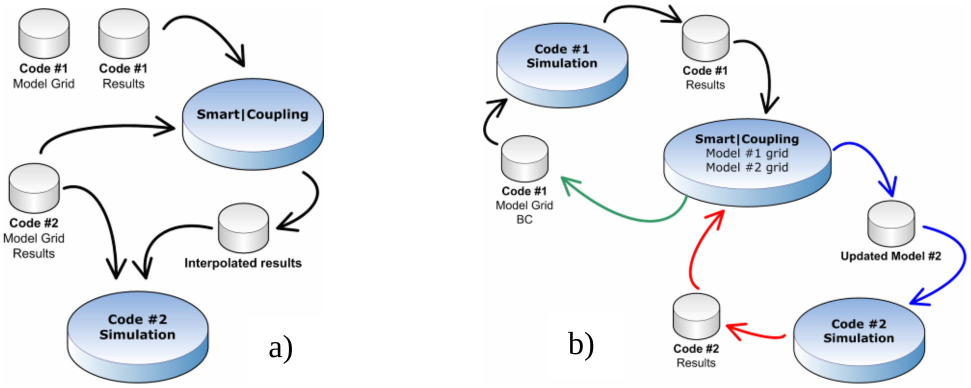

Figure 1: Data flow for MDO: a) Workflow problem, b) Coupled problem

While a workflow problem can be reduced to a simple –but often non trivial– data transfer between different software where the output of the first code is an input for the second, a coupled problem usually requires an actual interaction between the two physical domains, to predict a correct result.

The main problem for a practical and effective MDO is that, nowadays, only few simulation software are able to handle efficiently a fully coupled simulation, and usually they are applicable only under some modelling restrictions. On the other hand, the engineer can choose between many different good commercial tools, to explore each specific engineering field: CFD, FEA, EMAG, etc.

Practical MDO is then complicated, for few but relevant practical aspects, by the following distribution of "engineering competencies and resources":

- the hardware / operating system requirements of the codes may be different (RISC, IA32, IA64,Windows, Unix, Linux, etc.);
- the engineering skill and experience required for each discipline may be significantly different;
- different simulation software requires different modelling strategies (grid shape, density) and, in general, one and the same mesh can't actually be used for different disciplines.

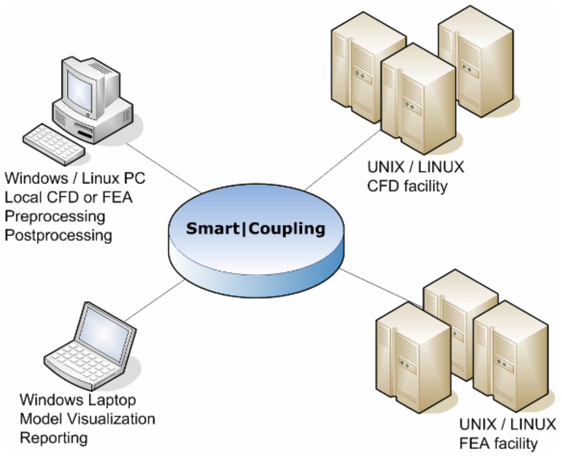

Figure 2: Example of typical CAE environment for MDO

The aim of this paper is to introduce new software, called Smart|Coupling, which enables MDO by means of interfacing different CAE software. The program provides engineers many tools for model import/export, multi-model matching, data interpolation, grid transformation and optimization.

The first part of the paper shows some of the basic functionalities of the program, describing the typical workflow for a data interpolation task over two different models.

Then, two case studies, where Smart|Coupling has been used for FSI simulations, are reported.

2: A Toolbox for MDO

The program Smart|Coupling has been developed using the FEMtools Framework [1] for model data storing and manipulation and the general purpose FEA solver NEiNastran [2] for specific algorithms like linear solution and data interpolation. This technical choice assures portability of the software across different OS (Windows, Linux, Unix) and state-of-art computing performance for the most demanding tasks.

The core of Smart|Coupling is its database where two models can be stored, viewed, modified and paired for multi disciplinary simulation. The typical workflow within Smart|Coupling is described in the following steps:

Step #1 - Multiple model import. The software can import two models with their results from different sources (CFD, FEA, Process, EMAG, etc.). During the import phase, the user can select the parts of the whole model that are actually subjected to interaction. Then, the engineer can view the model and check the imported results by means of graphic contour.

Step #2 - Model matching. The engineer can transform (scale, translate, rotate) one or both of the imported models (both grid and results) to fit the two grids in the space. This is useful because the two models may have different units: typical for FSI is to have the CFD model with length in meters and the FEA in millimetres. Doing the transformation of the model “a posteriori” doesn’t require the engineers to change their modelling strategies, thus reducing the impact for the MDO deployment on the existing CAE procedures.

Step #3 - Data interpolation. Once the pairing strategy has been decided, it is possible to transfer the result field from the source grid as a boundary condition to the destination one. This is done trough a 3D interpolation algorithm that allows a smooth transition of the result field across the two grids. The algorithm works on both volumetric grids and surfaces. The quality of the interpolated field can be shown graphically by means of contours, or quantitatively by means of checksum values and XY plots. For displacement interpolation on a volumetric grid, a pseudo-structural approach is used, as described by Xu and Accorsi [3].

Step #4 - Updated model export. The interpolated data is exported as a boundary condition for the next simulation software.

The workflow described above is less automated than other multi-code interfacing techniques available on the market, like MpCCI [4], but it has two main advantages over them:

- It doesn’t require any recompilation of the simulation code, because Smart|Coupling is an external standalone application. Any simulation code based on a geometrical mesh, on any platform, can be quickly and easily interfaced with this tool.

- Each run of the coupled simulation can be treated as a standard CFD or FEA run. It means that it doesn’t require any dedicated IT environment (hardware, software, network) and each simulation job can be driven using a load balancing tools like LSF, PBS, and Sun Grid Engine. This ensures a full compatibility of Smart|Coupling with industry standards and procedures.

3: Test Case No. 1: Airplane Wing

The first illustrative case presented is the data transfer between the fluid dynamics and the structural model of an airplane wing. The goals of the analysis were:

1. Interpolate the pressure field from the CFD model to the FEA one, to compute the static deformation of the wing;
2. Interpolate the displacement field from the FEA model to the CFD one, to update the grid of the wing.

Figure 3 shows the two models, with different mesh density and topology:

- CFD grid: 18,681 triangular cells;
- FEA grid: 533 quad elements.

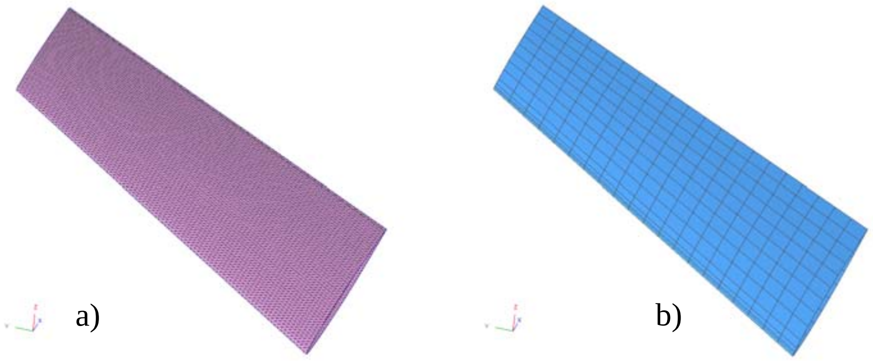

Figure 3: a) CFD model and b) FEA model of the wing

Figures 4 and 5 show the pressure distribution interpolated over the finite element model. It may be noticed that the interpolated field is generally well matching the source contour, but it is possible to identify local areas (mainly along the leading edge) where there are little differences between the two contours. This is mainly due to the coarseness of the destination (FEA) mesh that is not fine enough to catch gradients. The same behaviour emerges when comparing the resulting forces and moments on the two models (Table 1). The checksum evidences a large relative error only for X and Y components, while the Z resultant has a relative error lower than 2%. This ensures that the effect of aerodynamic loads has been correctly translated to the destination model.

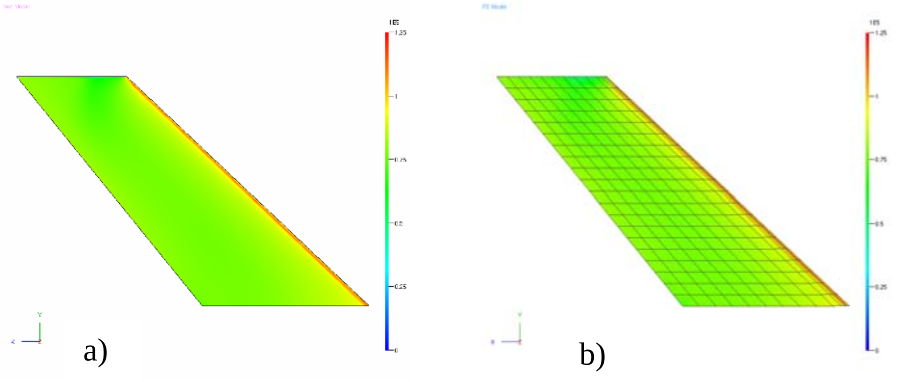

Figure 4: **Pressure distribution on a) CFD model, b) FEA model – bottom view**

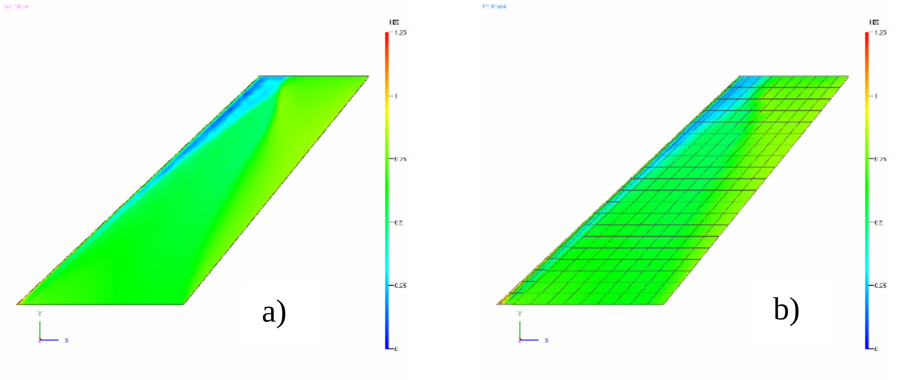

Figure 5: **Pressure distribution on a) CFD model, b) FEA model – top view**

	Fx [N]	*Fy [N]*	*Fz [N]*	*Mx [Nm]*	*My [Nm]*	*Mz [Nm]*
CFD load resultant	-9.60E+00	-5.41E+02	6.66E+03	2.39E+00	-3.56E+00	-2.45E-02
FEA load resultant	3.69E+00	-5.74E+02	6.56E+03	2.33E+00	-3.47E+00	-6.37E-02
Difference	-1.33E+01	3.38E+01	9.79E+01	5.99E-02	-8.74E-02	3.92E-02
Relative error [%]	-138.	6.25	-1.47	-2.51	-2.45	160.

Table 1 – Comparison of load resultant on CFD and FEA model

Once the pressure load has been interpolated, it has been used as an applied load for a FE simulation (in this case done by using NEiNastran as a solver).

The resulting displacement field was then imported inside Smart|Coupling in order to interpolate it over the CFD model. Figure 6 shows the comparison between the deformed shapes and Table 2 reports a numerical checksum performed by using two common correlation indexes for static deformation: the Displacement Assurance Criterion (DAC) and the Displacements Scale Factor (DSF) [5]. Both assure a perfect correlation between the two models.

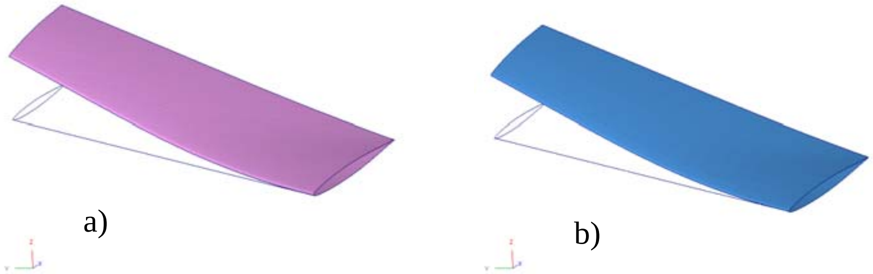

Figure 6: **Deformed shape on a) CFD model, b) FEA model**

Correlation Index	*Value*
DAC	100%
DSF	1.00

Table 2 – Correlation analysis between CFD and FEA model deformations

4: Test Case No. 2: Racing Car Rear Wing

The second case shown here is the coupling between the CFD model (Fluent) and the FEA mesh (Nastran) of the rear wing of a racing car. The aim of this analysis was to apply the pressure distribution calculated by Fluent to the structural model and then update the whole CFD volume grid, using the static displacements calculated by Nastran. Figure 7 shows the two models; the reader can appreciate inner stiffeners inside the main and the flap of the FE model that are removed before the interpolation phase. Furthermore, some parts of the structural geometry, like the end plate, have been modelled with a single layer of shell elements, while the same component has been modelled as a thin volume for the CFD simulation.

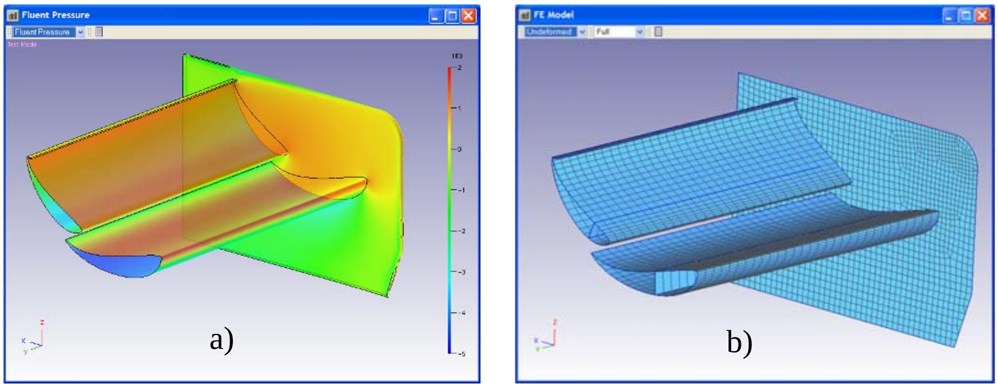

Figure 7: Racing car rear wing a) CFD model and results, b) FEA model

Also in this case, Smart|Coupling has been used for the interpolation of the pressure loads over the structural model. Table 3 summarizes the comparison between the load resultants calculated on the original (CFD) and interpolated (FEA) models. The relative error is less than 2%.

	Fx [N]	*Fy [N]*	*Fz [N]*	*Mx [Nmm]*	*My [Nmm*	*Mz [Nmm*
CFD load resultant	1.94E+08	0.00E+00	-6.67E+08	1.64E+08	2.47E+09	4.98E+07
FEA load resultant	1.91E+08	0.00E+00	-6.68E+08	1.64E+08	2.47E+09	4.89E+07
Difference	3.51E+06	0.00E+00	1.45E+06	-3.30E+05	-3.21E+06	8.75E+05
Relative error [%]	-1.81	0.00	0.21	0.20	0.13	-1.76

Table 3 – Comparison of load resultant on CFD and FEA model

The static displacement of the rear wing assembly under the interpolated loadings has been computed with NEiNastran and then interpolated over the CFD model. Figure 8 shows the deformed shape of the CFD and the FEA models, while Table 4 reports the correlation indexes between the two shapes.

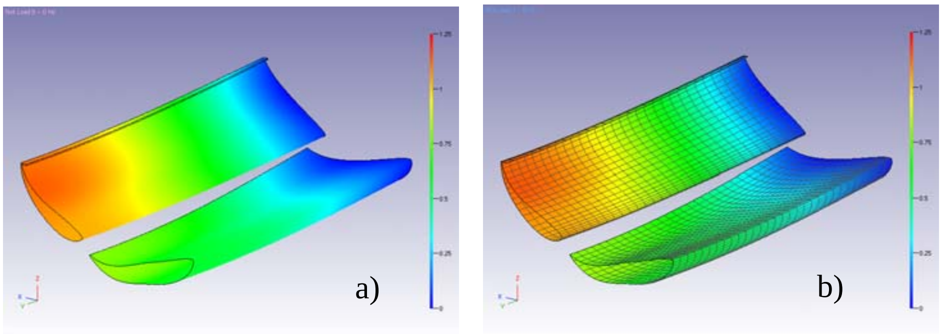

Figure 8: **Deformed shape on a) CFD model, b) FEA model**

Correlation Index	*Value*
DAC	100%
DSF	1.00

Table 4 – Correlation analysis between CFD and FEA model deformations

Finally, the displacement interpolated over the wet surfaces of the wing has been used to transform the whole volumetric fluid grid. Figure 9 shows, as an example of the grid deformation, the displacement along the X axis on the symmetry plane of the CFD model.

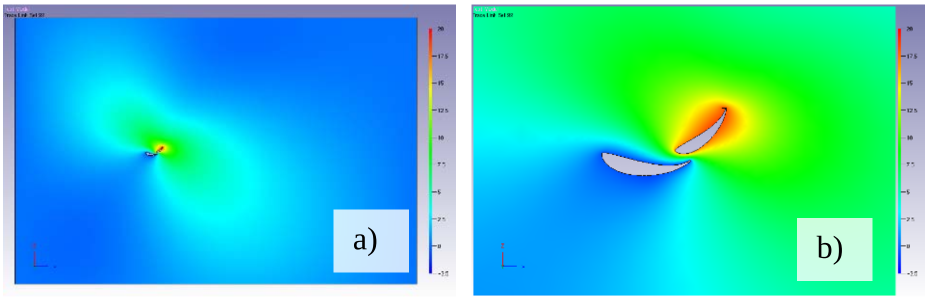

Figure 9: **Deformed symmetry plane: a) side view, b) detail**

5: Conclusion

A new tool for Multidisciplinary Design Optimization based on 3D data interpolation over incongruent grids has been shown. The method has been validated comparing the interpolated results with the source data.

With the proposed method engineers can overlap and compare different mathematical grids, transfer data and results between the models and thus improve the way they use their simulation software without changing the tools or the procedures they are confident with.

REFERENCES

1. FEMTOOLS – FEMtools Programmer’s Manual, Dynamic Design Solutions, Leuven, BE 2004
2. NEiNASTRAN – NEiNastran Reference Manual Version 8.4, Noran Engineering Inc., Westminster, USA, 2004
3. Xu Z, Accorsi M, Finite element mesh update methods for fluid–structure interaction simulations. Finite Elements in Analysis and Design No.40 , pp1259–1269, 2004
4. MpCCI – MpCCI Technical Reference. Fraunhofer SCAI, 2004
5. FEMTOOLS – FEMtools Theoretical Manual, Dynamic Design Solutions, Leuven, BE 2004
6. SAMAREH, J AM BATHIA K G – A unified approach to modelling multidisciplinary interactions – AIAA-2000-4704
7. GUPTA, K K, STARS – An Integrated, Multidisciplinary, Finite-Element, Structural, Fluids, Aeroelastic, and Aeroservoelastic Analysis Computer Program. NASA Technical Memorandum 4795, 1997
8. HAACK, C, WINTERGERSTE, T – Fluid-structural interactions in industrial applications by CFD / FEM coupling. NAFEMS International Journal of CFD case studies, Vol 3, pp. 61- 81, 2001