



Title:

**Computer Aided Design Tool for GT Ventilation System Ductworks**

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Introduction:

The proper design of a ventilation system (VS) is an important requirement in the Gas Turbine (GT) and energy production industry in general [9]. In fact, ventilation systems are designed to provide a continuous source of cooling air [5] so as to: remove heat and maintain the air temperature in the compartment below the operating limit; prevent the accumulation of hazardous gases; preserve a constant and uniform airflow through the ducts, independently from the environmental conditions; avoid accidental dust and sand contamination in gas turbines, especially when these are located in regions prone to sandstorm conditions.

When compared to typical Heating, Ventilating and Air Conditioning (HVAC) systems, the design of VSs results particularly challenging since many requirements, generally involving different engineering aspects such as fluid-dynamic, acoustic and structural, have to be fulfilled.

Generally speaking, a VS is composed by a number of elements such as linear ducts, expansion joints, transition duct sections, elbows, outlets to the atmosphere, supports, saddles and brackets. Shape and dimensions of these elements may significantly vary depending on the kind of application. Basically, the elements may have circular/oval or rectangular/square section. In the first case, they are manufactured by employing calendaring process followed by welding. Otherwise, the component is realized by cutting and welding metal sheets [6, 11]. Elements are coupled by using bolted flanges or welded joints in order to obtain the entire VS ductwork.

The VS design process generally starts from the plant layout definition taking into account a number of design parameters such as location, environmental characteristics, typology of installation (indoor/outdoor), site elevation etc. The plant layout process ends with technical drawing of the proposed system including: the typology of ducts components (e.g. main duct, branch ducts, expansion ducts and auxiliary components) and the position within the layout of each specific component (with a set of draft dimensions). The subsequent step consists of the fluid-dynamic dimensioning of each component, with particular reference to duct sections (length, cross sections, etc.); a proper dimensioning guarantees the required flow rate by minimizing friction and pressure losses [4]. Due to the complexity of GT systems, the above mentioned fluid-dynamic dimensioning may be carried out by using 3D CFD analysis [8, 9]; consequently, a simplified 3D model of the ducts need to be obtained by using 3D CAD modelers. Often an iterative procedure is required to determine the duct dimensioning better satisfying design specifications. Once the duct sections are defined, the VS has to be structurally assessed to withstand, with the appropriate safety factors, all possible combinations of mechanical, environmental (i.e. snow and wind) and thermal loads to which it is subjected. Structural design requires the definition of materials, the dimensioning of the thickness of each duct component (comprising the coupling flanges) and the positioning and dimensioning of stiffeners. As a consequence, usually the structural design phase leads to the creation of a more

detailed 3D model, to be used in subsequent FE simulations. The final VS ductwork is obtained after an iterative procedure where the design is possibly changed several times based on the FE results. Only at the end of this iterative procedure, the manufacturing drawings are realized.

According to the above mentioned process, the design of a new ductwork is a lengthy and tedious process, often requiring weeks to refine a single design concept followed by additional time to physically realize it [2]. Moreover, when dealing with structural design, the typical approach followed by main worldwide GT manufacturing companies is to outsource the phases of 3D modelling, FE analysis and manufacturing. As a consequence, a number of SMEs (typically) specialized in this kind of work are involved in the VS design process. In practice, their task consists in repeating the modeling and FE analysis steps several times whenever a new VS has to be produced.

Since the need for greater competitiveness in a global market has increased pressures on companies to reduce design cycles and time-to-market [2], speeding-up even a single step of the complex VS design process is today a crucial issue. Keeping the above objective in mind, the present paper proposes a CAD-based tool, implemented in a commercial 3D CAD software package (SolidWorks), supporting and partly automating the complex structural design process. By integrating into a comprehensive and easy to use tool both the design of VS components, their assembly and the subsequent FE analysis, it is possible to reduce the time-to-market of a new system and, at the same time, to avoid the necessity of outsourcing structural analysis. The solution suggested in this work consists of the design and implementation of a SolidWorks add-in, called *DuctWorks*, developed by using C# programming language. The choice of SolidWorks as preferred CAD software is mainly due to the fact that it is a low cost 3D modelling software featuring an easy to use FE modeler and solver and the availability of a SDK (Software Development Kit) [3, 7, 10].

Differently from commercial tools such as, for instance, *SolidWorks Routing*, the tool is specifically thought keeping in mind the necessity of performing a final structural assessment, which is of utmost importance given the considerable dimensions and stresses this kind of VS are subject to in the specific field of GT and energy production industry.

In detail, such an add-in consists of: 1) a database of custom-designed parametric archetypes (templates) covering the most used components in VS ductworks; 2) an interface to manage/modify the archetypes and to easily assemble the components; 3) an interface to allow (even non expert) users to simulate the structural behavior in FE environment (i.e. SolidWorks Simulation) taking into account the most common loading conditions.

#### Archetypes Database:

A database of the common components typically making up VS ductworks has been developed by preliminary analyzing a set of VS projects from a company working in Oil and Gas field. Despite the complexity of VS, consisting of a great number of different components with different shapes and dimensions, it is possible to classify such components into a limited number of categories. In fact, often 15-20 categories are sufficient to fully describe the entire set of modules composing a VS. By way of example, into a branch of the VS it is possible to use many straight ducts characterized by different sections, lengths and stiffeners (elements necessary to improve the stiffness of the module); however, the geometry of such a duct is clearly the same. Analogous considerations can be made when referring to other components (e.g. curved ducts and outlet ducts). Accordingly, it is possible to define a set of archetypes (i.e. parametric models) covering all the possible modules composing a typical VS. Consequently, the following eight duct components have been built: Straight (Fig. 1a); Elbow TypeA (Fig. 1b); Elbow TypeB (Fig. 1c); Curved (Fig. 1d); Transition (Fig. 1e); Offset (Fig. 1f); Three Way (Fig. 1g); Outlet (Fig. 1h).

Even if the geometry of the eight archetypes is considerably different, they share some common characteristics: 1) flanges are manufactured by using L-shaped bars; 2) when the area of a duct "face" exceeds 0.8 m<sup>2</sup> one or more stiffeners are added to strengthen structural behavior; 3) thickness is always greater than 3 mm; 4) component material is steel.

Consequently, each archetype is defined by a set of parameters taking into account not only geometrical properties but also the presence of stiffeners (number and dimensions) and the structure made of L-shaped flanges. With the aim of keeping FE simulation time as short as possible, the eight ducts have been modeled using surfaces instead of solid, so that shell elements, which are well known to be the best solution for FE simulation of thin-walled structures [1], can be used. This also entails the possibility of directly performing the FE simulation on the resulting 3D model without the need of any

model updating process, which proves to be an extremely useful feature of the tool especially considering that the design process is often iterative. In Fig. 2 the parametric archetypes populating the database are shown.

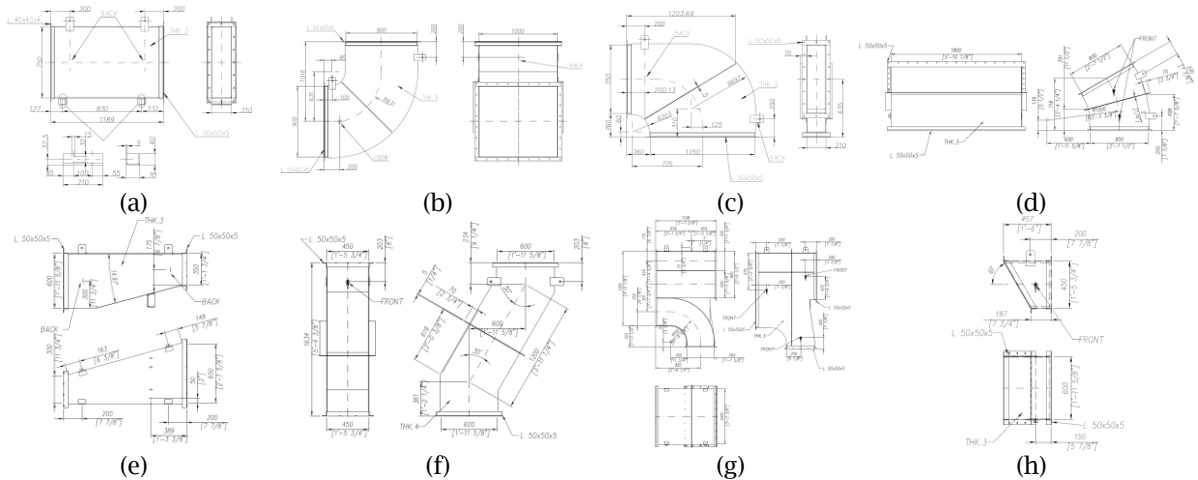


Fig. 1: Archetypal components of the ventilation system selected for the definition of database.

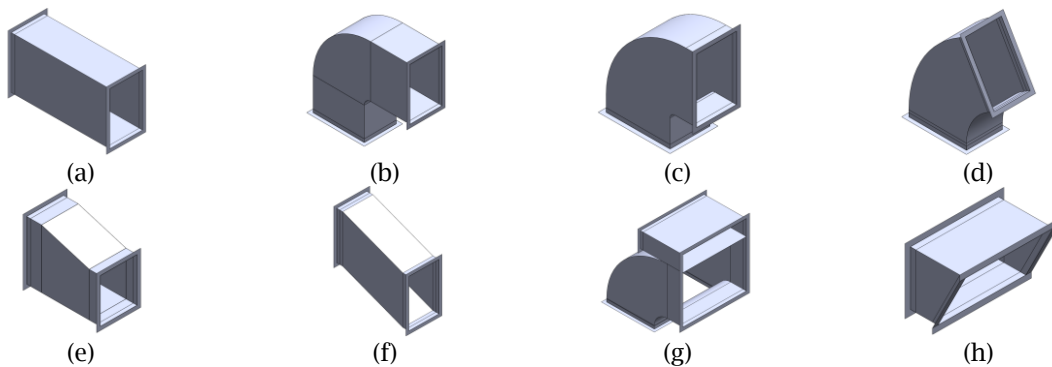


Fig. 2: Parametrized archetypes populating the database.

#### Management, Modification and Assembly of Archetypes:

The SolidWorks API SDK allowed the development (using C#) of a design tool in the form of an add-in called *DuctWorks* to allow management, modification and assembly of the archetypes. Using such tool, the entire VS ductwork (or one of its branches) can be easily modelled by means of a step-by-step procedure. In analogy with the SolidWorks Toolbox (used to manage bolts, screws, washers, nuts, bearings, etc.), *DuctWorks* makes the archetype database available to the users (see Fig. 3a). Each component can be used “as is” or customized by modifying its dimensions, number of stiffeners, flange typology to meet specific design requirements. In fact, after dragging and dropping the first desired component, a *Property Manager*, referred to the selected component is displayed in the corresponding tab (to the left side of the graphic area) enabling the user to possibly modify all the model parameters. Moreover, the designed tool checks the consistency of user-defined dimensions and suggests to insert one or more stiffeners in case the area of one of the metal sheets exceeds  $0.8 \text{ m}^2$  (see Fig. 3b). Only after the element is properly modelled, the following ones can be inserted; the tool automatically recognizes if a previous element has already been defined, so that it allows, not only to dimension the new one (using its Property manager), but also to insert all the necessary mates to correctly assemble the two elements. This procedure can be repeated until the entire VS ductwork (or one of its branches) is designed (see Fig. 4a).

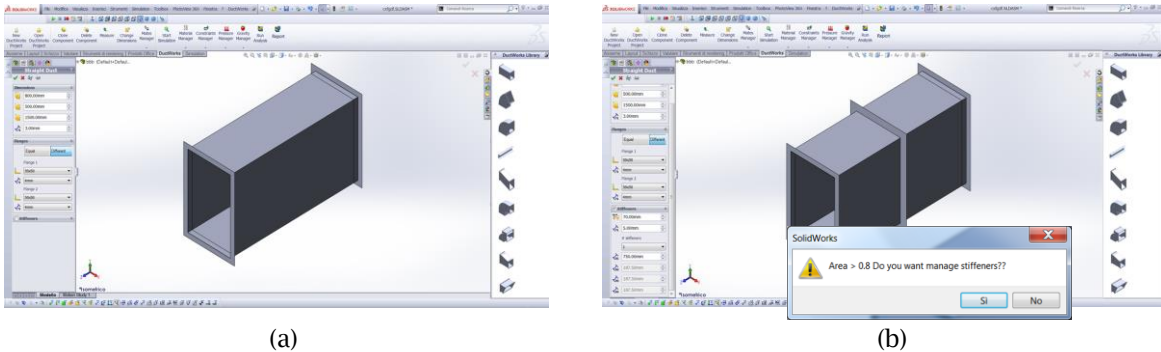


Fig. 3: *DuctWorks* add-in: a) archetype database on the right and Property Manager on the left of the graphics area; b) a pop-up menu suggesting to insert one or more stiffeners in case the area of one of the metal sheets exceeds  $0.8 \text{ m}^2$ .

It is worth to be mentioned that the database can be updated by adding more models under the obvious condition that, for each added archetype, a set of parameters fully describing it is provided.

#### FE Analysis Tool:

Differently from other commercial tools, in addition to CAD modelling wizard, *DuctWorks* directly provides a toolbar for carrying out a step-by-step FE simulation taking into account a variety of load types without the need of updating in any way the starting geometric model (i.e. converting solid parts into surface ones for instance by extracting mid surfaces).

In particular, the designed graphical user interface makes available to the final users only the essential commands to set up and run the FE simulation on this type of ducts. For instance, the user is allowed to limit the choice of loads only to pressure (so as to consider the duct internal gas pressure or the external loads due to snow and wind) and gravity. Moreover, the pushbutton to start the FE analysis is activated only after the user has properly set materials, loads and constraints.

The guided and easy to use FE part of the tool is a considerable improvement with respect to other available commercial tools and is achievable only thanks to the careful geometric modeling phase carried out during archetype development mentioned before.

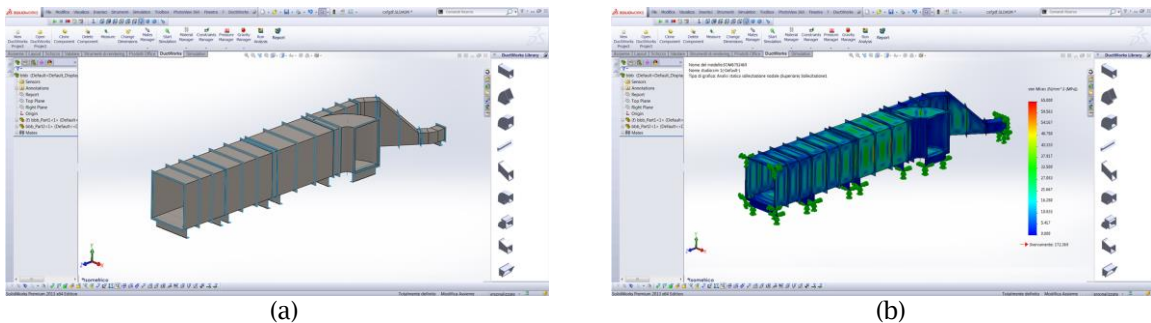


Fig. 4: a) Assembly of a VS branch designed with *DuctWorks* and b) Von Mises stress map simulated in SolidWorks Simulation.

By following the described procedure, even a non-expert user is able to straightforwardly simulate the structural behavior of the VS ductwork. The outputs of this analysis are the Von Mises stress map, the total displacement map and the displacements along the three orthogonal directions (X, Y, Z) (see Fig. 4b).

#### Results and Conclusions:

The present work proposes a novel tool, called *DuctWorks*, providing a CAD/FEM solution to designers of VS ductwork (specifically devised for the GT sector and energy production industry). The tool operates within the SolidWorks platform and relies on the construction of a database of archetypes.

The tool allows to speed-up the modelling and modification of ductwork components and assemblies as well as to provide a semi-automatic and intuitive FE analysis environment which directly operates on the geometry coming out from the modeling phase (differently from other commercial solutions such as SolidWorks Routing).

To evaluate the effectiveness of the designed tool, a number of case studies have been analyzed. More in particular, a set of six already designed and verified VS ductworks have been considered and have been re-modelled and simulated by using the proposed tool. The FE simulation results obtained using *DuctWorks* have been, then, compared with the ones previously obtained following the traditional design process. A mean error of approximately 5% (1.5 MPa) in terms of maximum values of Von Mises stresses and 7% error (0.4 mm) in terms of maximum values of total displacement can be observed. These values are more than acceptable given the specific application, even more considering that two simulations are here compared and that a typical CAD user (not particularly skilled) is able to complete the entire process in only a fraction (typically 15%) of the time commonly spent on this kind of work.

Finally, it is worth to be mentioned that the system can be updated by adding more models under the condition that, for each added archetype, the correspondent rules for its property setting manager is also defined.

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