

PARAMETRIC MODELLING SYSTEM OF GAS TURBINE COMBUSTOR

Xi Chen, Hongtao Zheng, Gang Pan, Xiangyu Jia

Original scientific paper

In the numerical simulation research of gas turbine combustor, there are plenty repetitive operations such as modelling and meshing. Parametric design idea is about simplifying it. This paper establishes a parametric modelling system of gas turbine combustor, mainly for the flame tube components, which includes parametric modelling and simple mesh generation. Taking a swirler as example, this paper introduces the parametric modelling system in detail. It also shows that the database contains different swirler and flame tube structure types. The system is designed under the UG secondary development platform, based on graphics template of parametric design method. The parametric modelling system has good practicability and universality, only takes a few minutes to update a model, and can update the database anytime to add new structure types. It is a utility for aid of both combustion chamber design and performance optimization research work.

Keywords: combustor, gas turbine, parametric modelling, secondary development

Parametarski sustav modeliranja komore izgaranja plinske turbine

Izvorni znanstveni članak

U istraživanju numeričke simulacije komore izgaranja plinske turbine postoji niz ponavljajućih operacija kao što su modeliranje i umrežavanje. Ideja je parametarskog projekta da se to pojednostavi. U ovom se radu predstavlja parametarski sustav modeliranja komore izgaranja plinske turbine, uglavnom za sastavnice plamene cijevi, a to uključuje parametarsko modeliranje i stvaranje mreže. Na primjeru vrtložne komore, u radu se detaljno predstavlja parametarski sustav modeliranja. Također se pokazuje da se u bazi podataka nalaze različiti tipovi konstrukcije vrtložne komore i plamene cijevi. Sustav je projektiran prema UG platformi sekundarnog razvoja, temeljenoj na grafičkoj šablonoj metodi parametarskog projektiranja. Parametarski sustav modeliranja je lako primjenjiv i univerzalan, potrebno je svega nekoliko minuta da se model ažurira, a baza podataka može se ažurirati bilo kada i dodati nove tipove konstrukcije. To je probitak i za projektiranje komore izgaranja i za istraživački rad na optimalizaciji postupka.

Cljučne riječi: komora izgaranja, parametarsko modeliranje, plinska turbina, sekundarni razvoj

1 Introduction

Computer Aided Design-Computer Aided Engineering (CAD-CAE) tech can save both design period and economic costs, so aerospace, aviation[1], machinery[2] and many other industries[3] are adopting this approach for structure design and optimization. But the CAD-CAE method requires frequent structure adjustment of geometric model. Every change will repeat the process of modelling generating meshes and simulating, most of which is repeated and wasting manpower cost and time cost. Parametric design idea is to solve this problem: Cancel the repetitive progress, control the geometry modelling and generate meshes by changing parameters, update the structure automatically. The parametric modelling method has been applied in some simple geometric structures or standard parts, such as gears, shafts and fans. But a gas turbine combustor chamber has an extremely complicated geometric structure, massive sizes and control variables. These are all unfavourable factors for parametric modelling. So how to realize the parametric modelling system of combustor chamber is a problem urgently needed to solve.

In the literature, Tangirala [4] proposed a parametric simulation method about gas turbine combustor aerothermal analysis. Malecki [5] also used the parametric idea in a comparative analysis of different dilution holes influence on combustor outlet temperature field. Motsamai [6] had the similar research. The Advanced Combustion Tools, mentioned by Lai [7], is a detailed analysis design tool based on Computer Fluid Dynamics (CFD) and parameterization. This ACT can be used for diagnosis design and development of the DC-type and reflux type cylindrical combustion chamber. However, these gas turbine parametric

researches all have limitations. They all have limited research objects, aim on one single parameter and optimize it to obtain the best performance of the combustion chamber. The parametric theory [8, 9] is just applied in the simulation process, not in geometry modelling and mesh generation.

The parametric modelling ideas were first formally mentioned by Samareh [10], who presented five features a perfect modelling and meshing system should have, but so far there is not any parametric system to fit the standards perfectly [11]. Tangirala presented a modular approach only for some Single-tube combustors. Pegemanyfar [12] also presented a design tool, which was for the combustion chamber preliminary design, driven by the EXCEL database and generated by the NX Unigraphics (UG) software. All these researches simplified the process of the numerical simulation study in some way. But when it concerned the parametric geometry modelling and mesh generation, there were still plenty of problems. Dawes [13, 14] wanted to find a general method to generate meshes for CAD models automatically. They did develop some semiautomatic tools, although these tools depended on a lot of practical experiences.

Researchers of Chinese Academy of Sciences [15] (RCS) and Nanjing University of Aeronautics and Astronautics [16, 17] (NUAA) both have used parametric idea in their study. The NUAA researchers' study has gone further. They mainly used the secondary development of UG software, compiled data conversion program in UG/Open GRIP language, had original software interface window. But it read a large number of coordinate points during the modelling process, which brought a very complicated program. In order to solve this problem, they simplified the combustor chamber

configuration a lot. Under this situation, the parametric system cannot have commonality and will have limited controllable parameters.

There are several ways to build a geometry using parameters. One way is writing code to build geometry and generate meshes directly, which is used in the research of NUAA. As mentioned above, this method has some disadvantages. It will be complex and hard to realize if the structures have multiple parameters changed. Another approach is to use existing software secondary development platform, which is also the method used in this paper. The parametric structures are designed and operated on the secondary development platform of UG® software. We use a graphics template-based parametric design method [18] to realize the combustor parametric modelling and combine the Gambit software to generate meshes. This method shares many characteristics, such as strong generality, easy to be realized and convenience to be used. It is a simple and intuitive way to control the parameters of the geometry and mesh sizes of the combustor, to build the structures and generate the mesh automatically. It will simplify the process of design and optimization of the gas turbine combustion chamber, shorten the preparatory time of the combustor numerical study, make establishment of combustor geometry model faster and more convenient. It has great significance in the combustion chamber geometric design, not to mention saving plenty of time for the performance prediction research of the combustion chamber flow field.

2 Parametric modelling

The combustor model is a complex structure which has plenty of parameters. Every time modifying the model we will re-enter hundreds of dimensions. It is not only error-prone but also uneasy to achieve. Using templates modelling can avoid these problems. It also allows users to preview the three-dimensional model visually through reading the template model, which is very convenient to modify some parameters. Therefore, this paper uses this graphics-template-based parametric design method. Basically, the idea is modifying the features of the graphics template by changing the characteristics parameters: first, obtain characteristic parameters; second, change the parameters' value to the one you designed; then, update the model. The parameter changes will reflect on the geometry in the software window. The process is quite simple and clear, as seen in Fig. 1.

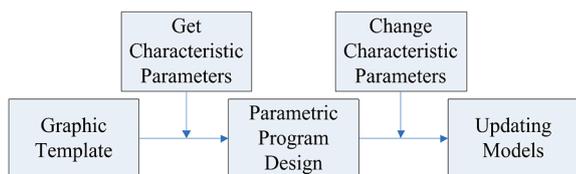


Figure 1 Parametric design idea

Specific implementation process can be summarized as follows:

Step 1, create graphics template files. In this paper this step means to create a basic model of the combustion

chamber. It will be the basis of all the following parametric design about this type of combustor.

Step 2, create a parameter expression. An expression is a powerful tool for parameterized editing. Modifying the parameters of expression can easily update the model features. And even can use the expressions of a specific component as a variable quantity, to change this part into a new component with a similar topology.

Step 3, customize the menu. Designing the menu according to the parameters required changes, also can add some pictures annotations or other details. It can adjust as needed.

Step 4, write the dialog callback function. Obtain the design parameters from the dialog box. Modify the expression values of geometric parameters. Update the model. And ultimately achieve the purpose of the model modify.

Take the axial single-stage swirler as an example to introduce the parametric modeling process in detail as follows.

2.1 Graphic template file creation

In the UG operation interface, create an axial single-stage swirler with holes shown in Fig. 2. And then establish the list of expressions for all parameters used during the process, some of these parameter variables are listed in Tab. 1, for subsequent parametric modelling modified used.

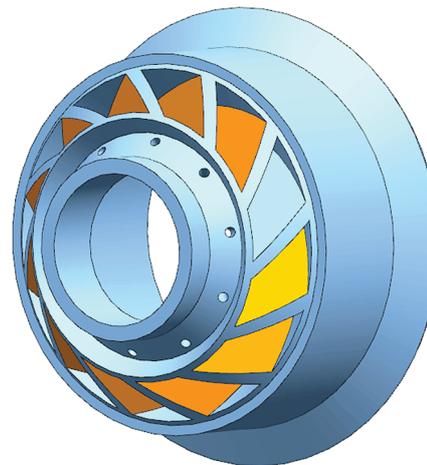


Figure 2 Axial single-stage swirler graphics templates

Table 1 Expressions of parameter variables

Parameter names	Variables	Initial parameter values
Blade number	Np	12
Blade deflection	a	45°
Blade thickness	h7	2 mm
Hole number	Nr	10 mm
Hole radius	Rr	2 mm
Inner radius of the swirler	ds1	15 mm
Blade array angle	apr	360/Np
Constraint size	h8	0,5*h7
Blade array number	n	Np - 1

2.2 Window menu design

This uses UG/Open Menu Script tools to design the window menu. It contains both the swirler types and the

combustor types. In the swirler menu, there is single-stage swirler and dual-stage swirler, axial swirler and radial swirler. In the combustor menu, there is annular combustor and can annular combustor, straight-flow combustor and counter-flow combustor. All the parametric modeling customs drop down menus ensure the users find the wanted structures quickly. The program statements of the axial single-stage swirler menu are as follows:

```

"TOP_MENU"
"CASCADE_BUTTON MENU_xlq"
"LABEL Swirler" // Customize the first grade menu.
"MENU MENU_xlq"
"CASCADE_BUTTON xlq_class1"
    
```

```

"LABEL Single-stage Swirler" // Customize the
second grade menu.
"MENU xlq_class1"
"BUTTON xlq_class1_k"
"LABEL Axial Single-stage Swirler with Holes" //
Customize the third grade menu.
"ACTIONS xlq_class1_k.dlg"
    
```

In the above program statements, CASCADE_BUTTON statement defines the first grade menu option, BUTTON statement defines second grade menu buttons, and ACTIONS statement defines the behavior of clicking the button. The effect of the final presentation customized menu is shown in Fig. 3.

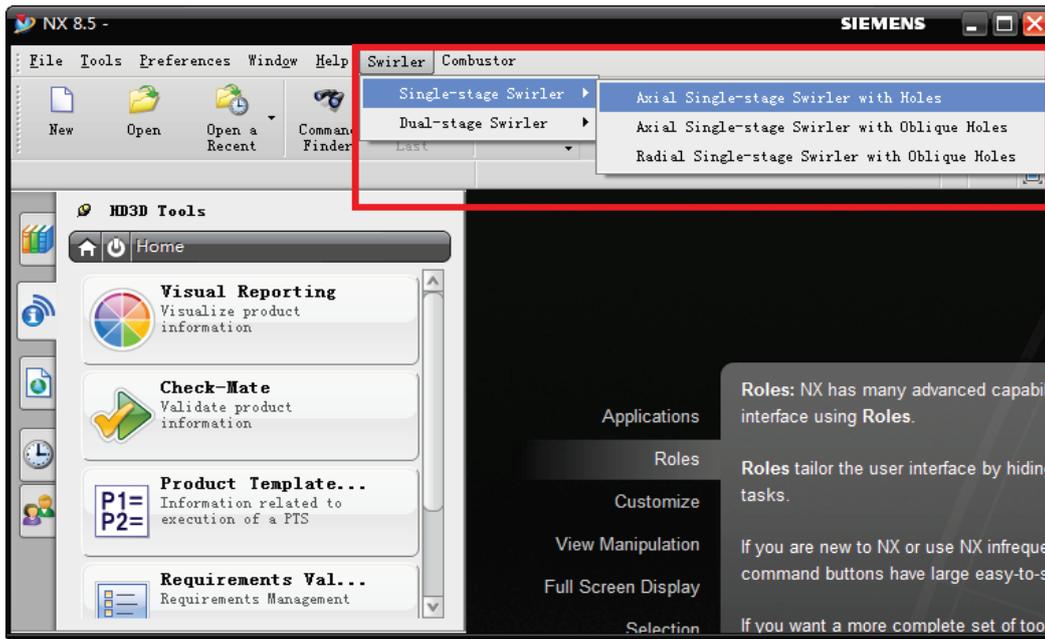


Figure 3 Customized window menus

2.3 Dialog design

Using UG/Open UIStyler designs the swirler dialog shown in Fig. 4. It allows visualization design. According to users' need, execute different behaviors. In this axial single-stage swirler example, there are three parts in the dialog zone: a picture to show the general structure, a list containing the chosen parameters and operation button to read the swirler geometric template file. It also needs to define the file path of the picture and the data type.

Every parameter must have an identifier in order to be recognized and value assignment when executing the program. For example: for the embedded image of the axial single-stage swirler, define its identifier as "XLQ_CLASS1_K_BITMAP_0"; for the parameter "Blade Number", define its identifier as "XLQ_CLASS1_K_NP"; for the button "Import the Swirler Model", define its identifier as "XLQ_CLASS1_K_ACTION_READMODEL" and so on.

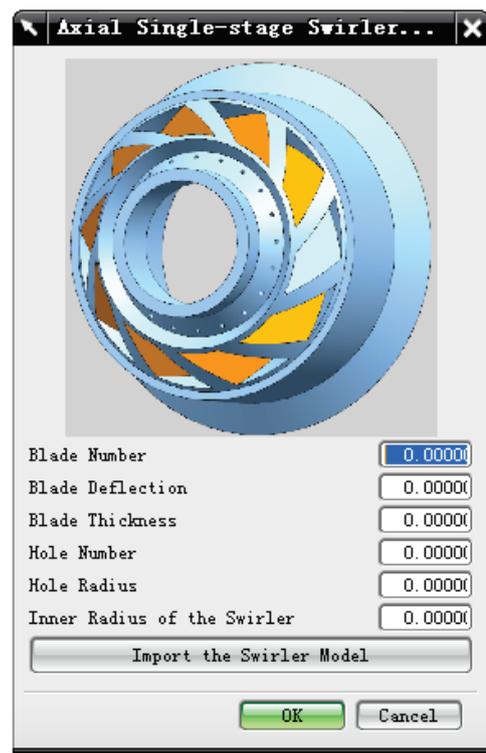


Figure 4 Dialog of the axial single-stage swirler

2.3 Data transferring

It is important to achieve the data transfer between the parameter value of the dialog and the expression value of the graphic template model. So how to edit the program is the key point. For example, the parameter blade number “Blade Number”, the key program statements to achieve data transfer process are as follows:

```

.....
UF_STYLER_item_value_type_t data[6];
data[0].item_attr=UF_STYLER_VALUE;
data[0].item_id=XLQ_CLASS1_K_NP;
UF_STYLER_ask_value(dialog_id,&data[0]);
Np=data[0].value.real;
.....
sprintf(exps_string[0],”Np=%f”,Np);//Modify the
value of the expression
for(int j=0;j<6;j++)
{
    UF_MODL_edit_exp(exps_string[j]);
    UF_MODL_update();
} //Update Model
.....
UF_MODL_eval_exp(“Np”,&arExpValue[0]);
data_set.item_attr=UF_STYLER_VALUE;
data_set.item_id=XLQ_CLASS1_K_NP;
data_set.value.real=arExpValue[0];
UF_STYLER_set_value(dialog_id,&data_set);
UF_STYLER_free_value(&data_set);
.....
    
```

3 Mesh generations

Consider Gambit software can automatically record log files. Or users can create, modify and edit the log file by their own, and then run the log file to reproduce all the meshing operations, thereby eliminating plenty of repeated work and a lot of artificial time. In the log file, adding variables, arrays, transition statements, looping statements, functions, macros and other programming languages means adding different operations. The log file will control Gambit to finish specified action. For a single-stage swirler, the structure is relatively simple, the size differences between parameters are no more than two magnitudes. Therefore the volume mesh operations can give reasonable mesh results:

Importing STEP file using InterOp translator version 12// the program statement of importing model

Import step “G:\gambit\Swirl cup.stp” no edges no faces scale 1 heal tolerant

Volume mesh “volume.1” tetrahedral size 1// the program statement of mesh generation

Open Gambit software. Execute the Run Journal operation under the File list to import the log file. The mesh generated result is as Fig. 6. The total mesh number is 368 737.

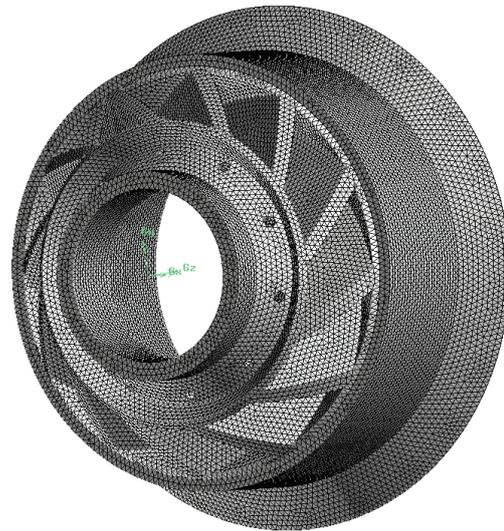


Figure 5 Mesh generation results

4 Results

After creating a graphic template file and finishing the various operations and parametric design process, it will be easily and quickly to generate a series of new swirler models based on this structure graphic template with different parameter values. Users can control the blade parameters or the inlet holes parameters or other parameters through the dialog window in this case.

4.1 Parametric modelling process

This parametric modelling system of gas turbine combustor is intuitive and easy to use, even for people who are not experts of CAD or modelling. As in Fig. 6, the process is quite clear.

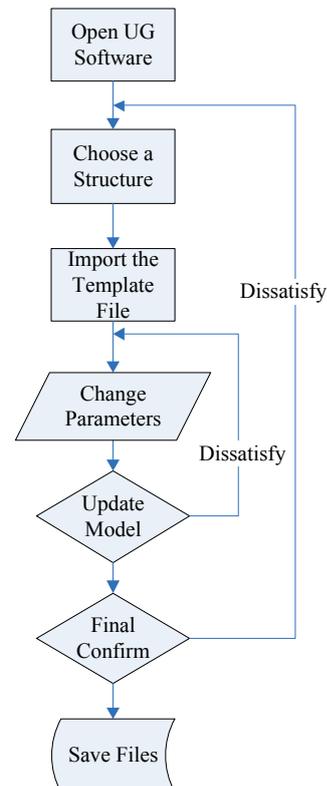
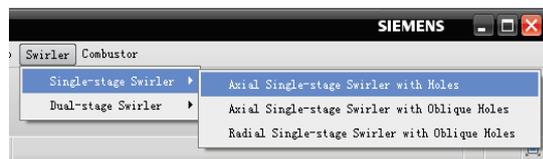
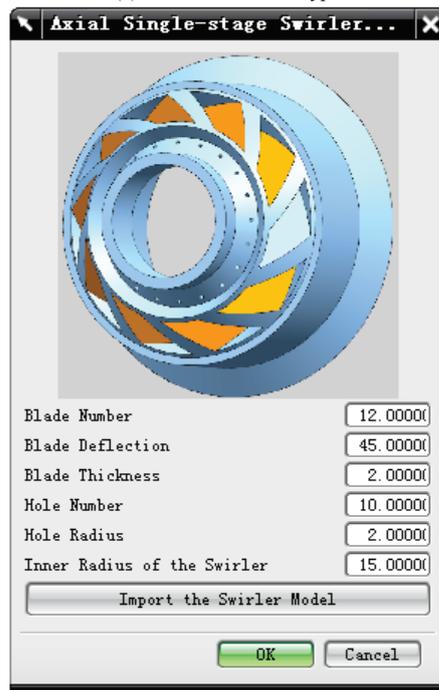


Figure 6 Process of generating geometry

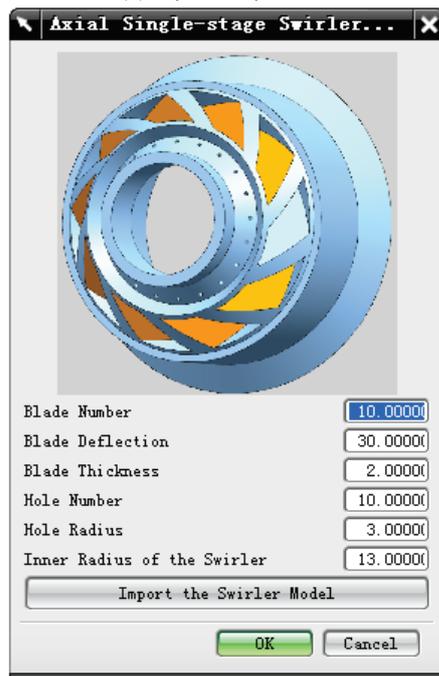
Take the graphic template file “Axial Single-stage Swirler with Holes” for example. First open the UG software, find the “Axial Single-stage Swirler with Holes” structure under the “Swirler” menu (Fig. 7a). Then the swirler dialog comes out, click the “Import the Swirler Model” button (Fig. 7b). Change any parameters you want, then click the “OK” button (Fig. 7c). Fig. 7 shows each step of this modelling process.



(a) Choose Structure Type



(b) Import Template File



(c) Change parameters

Figure 7 Pictures of each step

It still allows users to readjust the model structure or change other parameters after the new swirler is generated. When the new swirler has been generated but not saved, its key parameters are available in the dialog window. Open the dialog users can directly see the current parameters' value and modify these values. Then press the OK button, update the model structure. Fig. 8 shows two different swirlers with different parameters based on one same graphic template file. Fig. 8a is the geometry with parameters of Fig. 7b. Fig. 8b is the geometry with parameters of Fig. 7c.

(a) $N_p=12$ $R_r=2$ $ds_1=15$ $a=45^\circ$ (b) $N_p=10$ $R_r=3$ $ds_1=13$ $a=30^\circ$

Figure 8 Swirlers with Different Parameters

4.2 Structure database

This parametric system is available to offer more comprehensive of swirlers and combustors quickly. The more comprehensive graphic template files the database covers, the more structure types it involves. Each time update the database, add a new parametric structure, we only need to create a graph template file for this new structure, and follow the above procedure and modify the characterization data. It will complete the parametric design for this type of structural design. For now the swirlers and combustors of this system are classified as Fig. 9. Fig. 10 shows the exact structure types of the current graphic template. The database of this parametric system can be constantly updated in use.

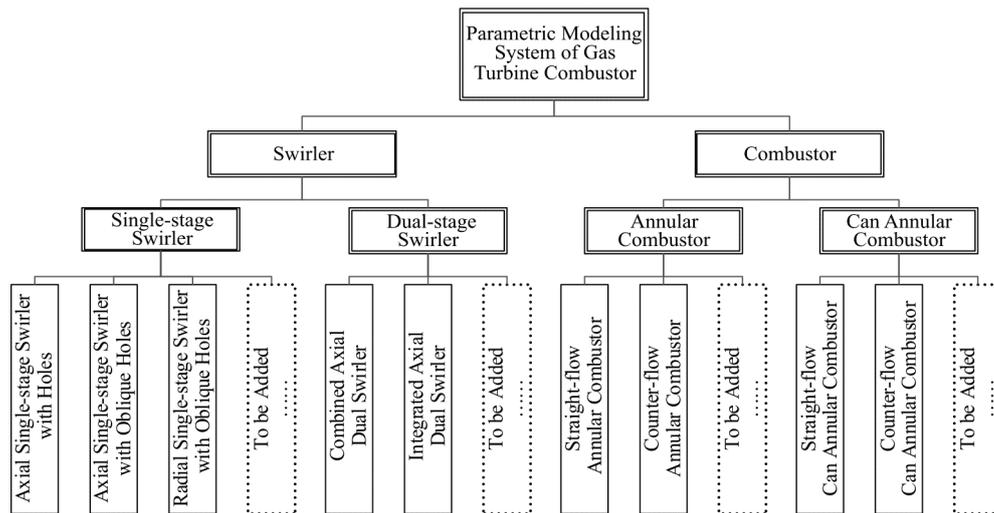


Figure 9 Structure database

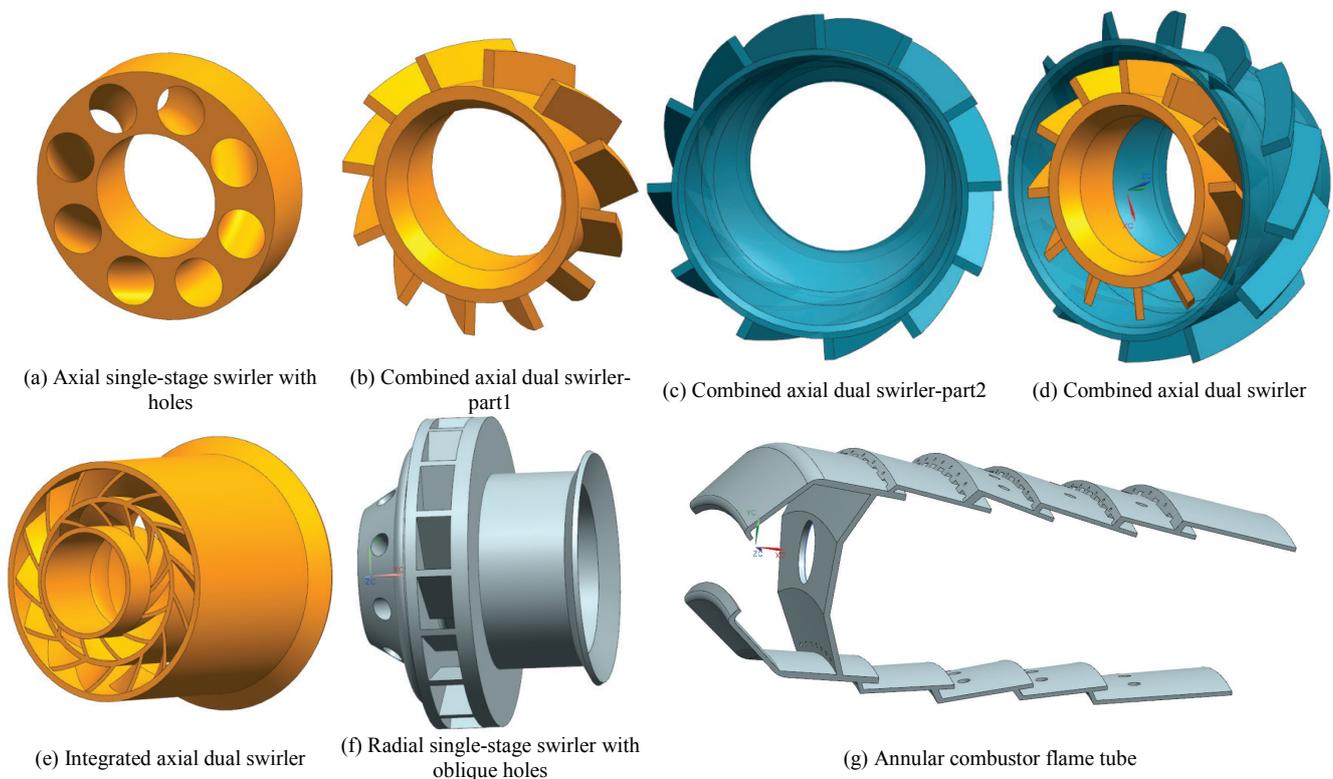


Figure 10 Different dtructure templates

4.3 Comparison

Tab. 2 is the comparison of ordinary modelling method and parametric modelling method using the system in this paper. This comparison results are running under the computer hardware of Intel® Core™ i5 CPU and 4,00 GB RAM. The basic geometric model software is NX Unigraphics 8.0. The statistical time of both modelling methods is from opening the software to saving the final structure files. Different people may need different time on building the same structure using ordinary method, but the partial differences are minor. Data in Tab. 2 is the statistical results of the authors' laboratory. The parametric modelling method using parametric system of this paper saves over 99 % time comparing to the ordinary method.

Table 2 Time comparison

Objects	Radial single-stage swirler with oblique holes	Straight-flow annular combustor
Ordinary modelling method	3 hours	12 hours
Parametric modelling method	27 seconds	150 seconds
Saving time	99,75 %	99,65 %

5 Conclusions

Through this instance can be drawn: the combustor parametric modelling system studied in this article can quickly generate geometry model and meshes that fits the numerical simulation requirement. Thus this system greatly saves the preparatory time of the numerical study,

provides convenience for structure improvement and performance optimization researches. Although creating graphic template files and realizing data transferring will cost slightly longer time than the normal modelling process, once the template is finished, the time of changing parameters and updating models can be approximated negligible.

Overall, this combustor parametric modelling system is a utility designed tool to assist the combustion chamber design and performance researches. The advantages of this parametric modelling system are: it allows multiple parameters to modify simultaneously; its database contains a variety of model templates; its database can be constantly expanding, and the method is quite simple; using log files is convenient; the program statements are easy to learn and so on. But there is still a lot work to do in the further research: enhance geometrical parameters relevance; improve mesh quality; perfect data transfer; decrease the error rates of some complicated structures and so on. These are all the focus of future research.

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Authors' addresses

Xi Chen

College of Power and Energy Engineering,
Harbin Engineering University,
Harbin Heilongjiang 150001, China
E-mail: chenxi05313@126.com

Hongtao Zheng

Professor at the Harbin Engineering University
College of Power and Energy Engineering,
Harbin Engineering University,
Harbin Heilongjiang 150001, China
E-mail: zhenghongtao9000@163.com

Gang Pan

College of Power and Energy Engineering,
Harbin Engineering University,
Harbin Heilongjiang 150001, China
E-mail: markpg0808@gmail.com

Xiangyu Jia

College of Power and Energy Engineering,
Harbin Engineering University,
Harbin Heilongjiang 150001, China
E-mail: jiaxiangyu2012@sina.com