

## Combustor design and performance prediction based on parametric model

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**Abstract:** By combining the three-dimensional model software and grid generation software, the combustor parametric model and high quality and high speed gridding in the full flow field has been realized. Based on the research of the parametric modeling, an optimizing design, CFD analysis and performance prediction of the combustor have been accomplished, and the rule of the combustor performance variation with structural parameters was presented. The results show that the combustor capability has no significant change with the radial swirler parameters and the primary holes area. The combustor capability has significant change with position and profile of the primary holes and dilution holes, and the combustor outlet temperature profile and emission change greatly when the total hole area of the burner inner liner changes. The parametric model method is helpful to provide a fast design method for the aero-engine combustor design.

**Key words:** parametric model; parametric design; combustor design; combustor performance; performance prediction

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The aero-engine combustor has complicated structure, complicated geometry characteristics and highly complicated inside flow. The process of simulation and analysis is complicated and expensive from gridding to modeling. The combustion simulation process (including geometric modeling, mesh generation and boundary conditions design) can be finished automatically with the help of parametric modeling. This will help to shorten the period from CAD (computer aided design) to simulation, promote the design efficiency and accelerate the application of CFD method to the design of combustor<sup>[1]</sup>.

The parametric modeling method was originally proposed by Tangirala. The CAD/CAE (computer aided engineering) software package and parameterized master model were used; the

inner flow field grid of combustor was generated quickly; the CFD simulation was given and the design and analysis period of aero-engine combustor was shortened. The CAD/CAE software packages were combined with grid generation software by Malecki. The combustor grid with the full flow region was generated by parametric modeling method, and the CFD simulation and analysis were given<sup>[2-3]</sup>.

The combustion gas turbine researchers abroad are turning to develop the parametric modeling and CFD simulation method, such as ACC (advanced combustion code) of General Electric Company, ACT (advanced combustion tools) of Honeywell. In ACT, the combustor capability can be analyzed rapidly according to the given information of fuel nozzle, combustor geo-

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metric modelling of CAD and the engine cycle process. In ACT, the traditional geometric model, grid generation, physics model, boundary condition, initial condition, convergence criterion, criterion and the post-treatment were integrated together and assembly-line fashion was adopted. In ACT, some key characteristics were used to shorten the design period and improve the computation credible degree. The initial spray boundary condition was measured by high gas-pressurized spraying instrument, and geometric model and grid were generated automatically with the help of macro instruction which was changed as the combustor characteristic. The parameters are specified simplified and standardized by the preprocessor, and the simulation results are graphical displayed and analyzed by the post-processor<sup>[4-16]</sup>.

The parametric control method through some combustor characteristic was investigated in this paper. Based on the research of parametric modeling, different parameter control ways were taken by different combustor characteristics. The parameter driving technology was used in the combustor reform design; the interface of three-dimensional model software UG and grid generation software ICEM (integrated computer engineering and manufacturing) were used to generate grid conveniently; the CFD software Fluent was used to simulate the combustion process, and the efficiency of reform design was increased greatly. Optimal design of combustor model, CFD analysis and performance prediction were exerted. The change regularity of the combustor performance with the change of structure parameters were exerted; the efficiency of design was increased; a rapid way of combustor reform design was provided.

## 1 Parametric modeling method

Parametric design maintains the characteristic connection automatically by classifying the geometry constraint and dimensional constraint, ensuring the unification and effectiveness of the modified model. Parametric design saves the de-

sign parameter by the way of expression form, and builds the parameter driving. There are two operation types. One is the dimensional constraint where the shape feature is constrained by dimensional constraint, and the other is orientation constraint where the feature is constrained by orientation constraint.

The parametric design can be combined with the characteristic modeling; the characteristic can be used as a vehicle of parameter; the geometric figure of parts can be created by characteristics operation; the characteristic parameters of size and shape can be adjusted according to the customer requirements, and the required design can be got.

### 1.1 Research object

In this paper, the computational domain is from the inlet of diffuser to the inlet of turbine. Passing the prefixed diffuser, the combustor inlet air is slowed down and pressurized, which is divided into three parts. The first part gets into the combustor inside channel; the second part gets into the combustor outside channel; the third part gets into the burner inner liner head gas channel. Passing the double reverse swirler, the burner inner liner head gas gets into combustion zone. In the combustor head, the fuel was injected as conical shape, sputtered on the venturimeter; the good initial spray was realized, and got ready for high efficiency combustion. Passing the main combustion hole, dilution hole and film cooling hole, the inside and outside channel gas gets into the burner inner liner, realizes the combustion organization, temperature field adjustment and the burner inner liner wall cooling. The profile drawing of combustor is given as shown in Fig. 1.

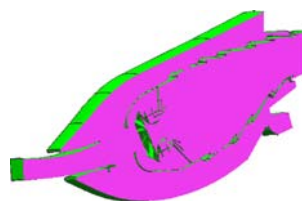


Fig. 1 Profile drawing of combustor

## 1.2 Procedure of parametric modeling

Parametric modeling is aiming at the characteristic. The characteristic is a group of information collection related to the description of parts which include a great quantity of design intentions of the designer. The general characteristics can be divided into the shape characteristics, accuracy characteristics, material characteristics, technical characteristics and assembly characteristics. Parametric modeling researches mainly the relations of forming characteristics and geometric characteristics, gets the parametric collection which can drive the model. For the aero-engine combustor, the ideal parametric modeling procedure is given as shown in Fig. 2.

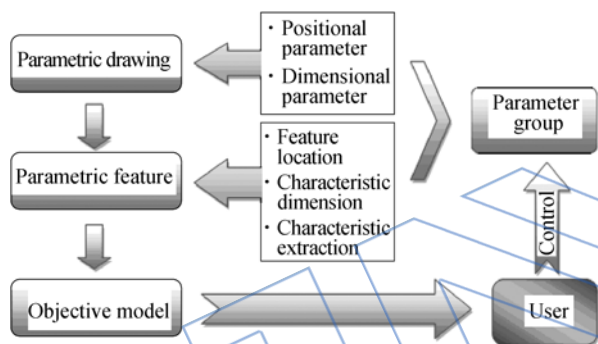


Fig. 2 Parametric modeling procedure

For an existing combustor research process, the involving changed parameters are composed of two parts as follow.

1) The swirler; including the swirler radial inlet area, the swirl number, as shown in Fig. 3.

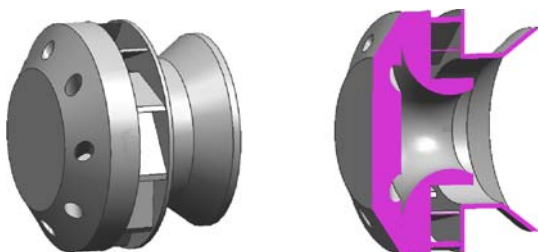


Fig. 3 Structural drawing of swirler

2) The burnerinnerliner; including the film cooling area (the width of film slot), the main combustion hole area and the location (axial direction), the dilution hole area and the location

(axial direction and circumferential direction), as shown in Fig. 4.

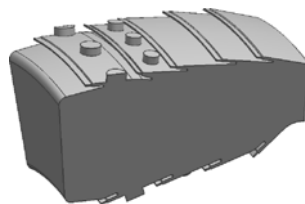


Fig. 4 Structural drawing of burnerinnerliner

## 1.3 Parametric control of combustor

Parametric modeling tools include the expressional editor, the visual editor, the geometry object link tool and the electronic form.

In the process of swirler modification, the parameters which need to be revised are the swirler radial inlet area (including the width of radial blade  $b$ , the outlet internal diameter  $R_1$ , the outlet external diameter  $R_2$ ), the swirl number of the radial swirler. So the parameter driving can be used for the swirler parameters, as shown in Fig. 5. For the no changed external form part, the fixed constraint was used. When part parameter need to be changed, only the ac-

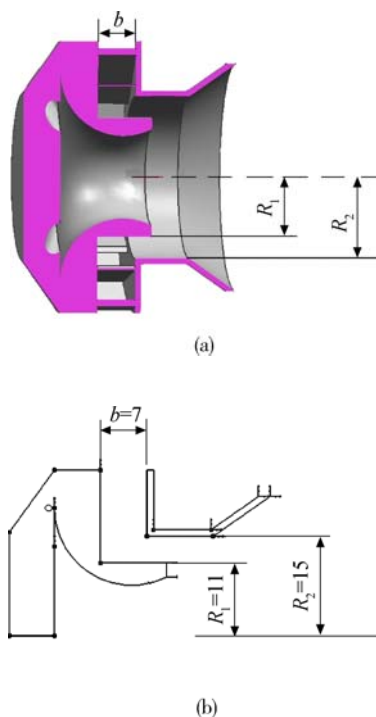


Fig. 5 Corresponding parameters of swirler  
(unit:mm)

cordingly characteristics will be changed.

In the process of burnerinnerliner modification, the main parameters effecting the combustion performance will be researched, such as the main combustion hole area and location (axial direction), the dilution hole area and location (axial direction and circumferential direction).

So the parameter driving used for the burnerinnerliner are the main combustion hole, dilution hole diameter  $d$ , the distance from the main combustion hole spindle to the last burnerinnerliner lip  $s$ , the dilution hole circumference profiles angle  $\alpha$ . The parameter driving can be used for the swirler parameters, and the driving parameters are given as shown in Fig. 6.

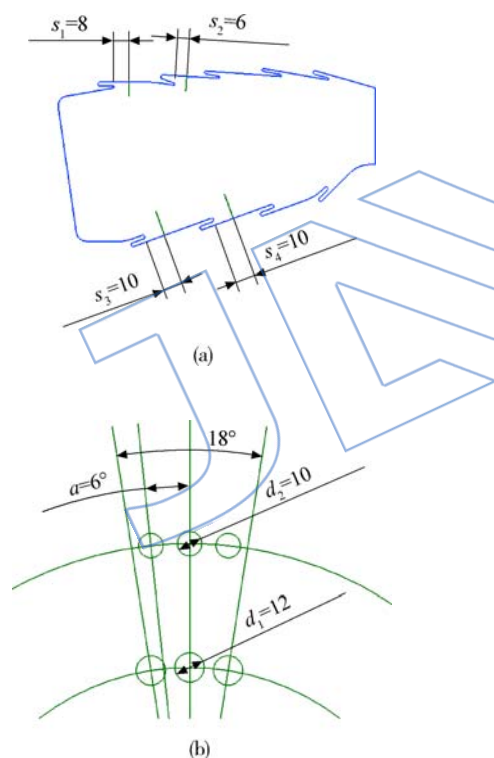


Fig. 6 Corresponding parameters of burnerinnerliner  
(unit:mm)

#### 1.4 Connection of parametric modeling with grid generation

The parametric modeling process is a process of building the parameterized geometric control model. But geometric model can not be used in combustion simulation directly, only the geometric model of the mesh generation can be identified

and be used by the CFD software. So the connection between the process of geometry modeling and grid generation is an important step in CFD simulation. The traditional method is building the geometric model in the modeling software UG. With the help of format transformation, the UG model can be transformed into geometric file which can be identified by the grid generation software ICEM CFD, then the family definition and mesh size will be set up by the grid generation software ICEM CFD.

It is obvious that the method is hard in the process of reform design, especially of the reform design in small range. There are too much repetitive work and the reform design efficiency will be affected greatly.

All the times, the researchers hope to find a way to generate grids automatically, realize the grids generation semi-automatically or automatically. In this paper, the replay technology was used where the operation process was appointed, and according to the operation process command, the grids of geometry models were generated automatically by the software. Replay technology can be used to record part or whole operation order and characteristic parameter when the grids were generated, and the information can be saved into a replay script file. When the geometric size of the model was changed, the grids of new model were generated according to the saved operation order and characteristic parameter.

The replay process concerns about topological analysis of the geometric object, different families of grid size and grid generation were set. So the technology is applicable to treat the model of similar procedure, especially the model of rarely changed geometric dimensions and the model of rarely changed characteristics. The reasonable application of replay would help for the grids generation when the CFD simulation was carried out, and the time of modeling and grids generation was reduced.

Computing grid is shown in Fig. 7.

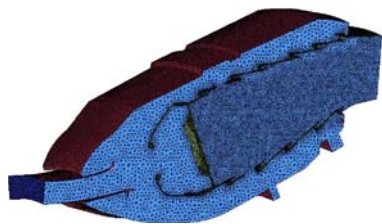


Fig. 7 Schematic diagram of computing grid

## 2 Mathematical model

### 2.1 Physical model

In this paper, the turbulent model of realizable  $k-\epsilon$ , spray model of DDM (discrete drop model), combustion model of PDF (probability density function), radiation model of DO (discrete ordinates), thermal-mechanical NO<sub>x</sub> emission model were used for simulation, and the CFD software was the FLUENT 6.3. In Ref. [17], the numerical calculation results were compared with the experimental results of a single annular combustor, and the model was verified to be reliable. In this paper, the same model was used; the combustor capability was analyzed for different combustor structures; suggestions were given for the combustor reform design.

### 2.2 Boundary conditions

When the boundary conditions were setup,

the inlet boundary conditions and outlet boundary conditions of different combustors were the same, and the boundary conditions were set up in Table 1 and Table 2. The periodic boundary conditions were used for the side fluid area, and the reference pressure point was set at the inlet of diffuser.

Table 1 Inlet boundary conditions

| Mass flow/<br>(kg/s) | Temperature/<br>K | Turbulent<br>intensity/% | Viscosity<br>ratio/% |
|----------------------|-------------------|--------------------------|----------------------|
| 3.125                | 862               | 10                       | 10                   |

Table 2 Outlet boundary conditions (unit: kg/s)

| Outside | Burner | Inside 1 | Inside 2 |
|---------|--------|----------|----------|
| 0.156   | 2.732  | 0.094    | 0.14     |

## 3 Combustor performance of different schemes

### 3.1 Reform design scheme

Reform design scheme is shown in Table 3.

### 3.2 Outlet temperature profile

The combustor OTDF (outlet temperature distribution factor) was given in Fig. 8.

The combustor outlet RTDF (radial temper-

Table 3 Reform design scheme

| Scheme number | Scheme content                                                    |
|---------------|-------------------------------------------------------------------|
| 1             | Prototype, standard scheme                                        |
| 2             | The main combustion hole area increasing 10%                      |
| 3             | The main combustion hole area increasing 20%                      |
| 4             | Radial swirler area increasing 20%, swirl number no change        |
| 5             | Radial swirler area increasing 40%, swirl number no change        |
| 6             | Radial swirler swirl number decreasing 16%, area no change        |
| 7             | Radial swirler swirl number increasing 25%, area no change        |
| 8             | The main combustion hole backward 7 mm                            |
| 9             | Dilution hole forward 7 mm, circumferential change                |
| 10            | Total hole area increasing 14%                                    |
| 11            | Total hole area increasing 23%, dilution hole forward             |
| 12            | Based on scheme 10, dilution hole forward, circumferential change |

ature distribution factor) was given in Fig. 9.

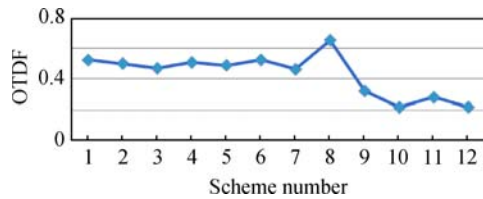


Fig. 8 OTDF of different combustors

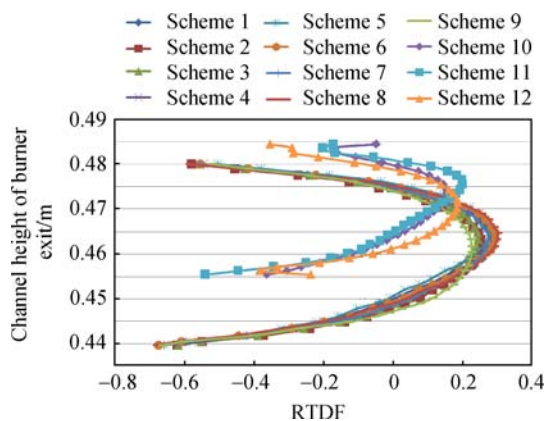


Fig. 9 RTDF of different combustors

### 3.3 Total pressure recovery coefficient

The combustor total pressure recovery coefficient was given in Fig. 10.

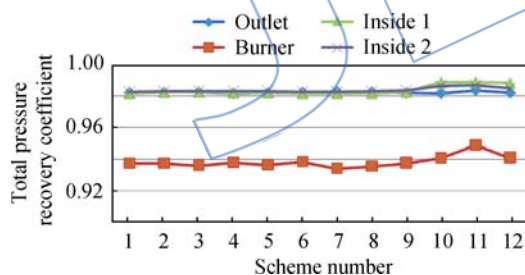


Fig. 10 Total pressure recovery coefficient of different combustors

### 3.4 Pollution emission

The combustor outlet pollution emission of CO and NOx was given in Fig. 11.

The simulation results comparison of different combustor schemes appeared that, the combustor capability had no significant change with the radial swirler parameters and the main combustion hole area. The combustor capability had significant change with the main combustion hole position, dilution hole position and profile.

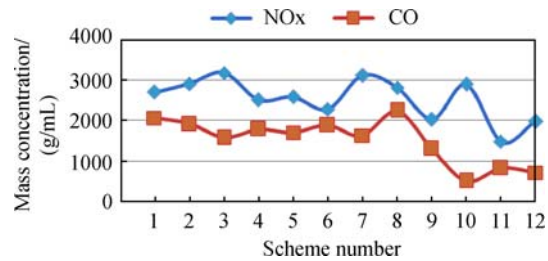


Fig. 11 CO and NOx emission of different combustors

When the position and profile of the main combustion hole and dilution hole changed, the aerodynamic characteristics of the combustor changed greatly, and the combustor outlet temperature profile changed greatly, so the combustor capability had significant change. As the total hole area of the burner inner liner changed, the combustor outlet temperature profile and pollution emission changed greatly. Better combustor performance can be got through adjusting the total hole area of the burner inner liner, dilution hole position and profile. The parametric modeling method can be used in the process of combustor optimization design.

## 4 Conclusions

Through the analysis and comparison of the simulation results of parametric modeling method, automatic grid generation method, simulation and series design of combustor, some conclusions can be got as follows:

1) Combined the advanced grid generation software, the parametric modeling method can increase the reform design efficiency of combustor, and be used in the process of combustor series design and optimization design.

2) Within limits range, the combustor capability had no significant change when the radial swirler parameters and the main combustion hole area were changed. The combustor capability had significant change when the main combustion hole position, dilution hole position and profile were changed.

3) Better combustor performance can be got through adjusting the total hole area of the burner inner liner, dilution hole position and profile. The parametric modeling method can be used in

the process of combustor optimization design.

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