

面向对象的航空发动机性能仿真程序 设计方法研究

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【摘要】 本文提出了一种用于建立扩展性强、灵活可靠的航空发动机性能仿真方法。通过建立一个面向对象的航空发动机基本类库(或称为航空发动机应用程序框架),针对不同的研究目的或不同类型的航空发动机,能够非常方便可靠地建立起高效专用的发动机性能仿真程序。本文提出了在仿真程序中建立异常处理机制以方便仿真软件的调试和提高它的可靠性。本文在该框架的基础上建立了某双轴涡扇发动机的性能仿真模型和某涡轴发动机的性能仿真模型,揭示了该框架的灵活性和专用性。

关键词: 航空发动机 性能 仿真 程序设计

分类号: V 231

1 前 言

在航空发动机的研制发展过程中,不可能建立一个适合于航空发展又固定不变的航空发动机仿真模型,工程技术人员需要根据研究的需要随时调整发动机的仿真模型。然而,由于航空发动机本身非常复杂,每次都重新建立一个既准确又适合于研究目的模型是一件工作量很大的工作。近十年来,软件技术取得了革命性的进展。本文的目的就是利用这些进展,研究一个好的航空发动机性能程序设计工具,使得工程技术人员可以从繁琐、复杂而且可靠性低的底层编程工作中解脱出来,把更多的精力投入到有关航空发动机的研究中去。

2 面向对象的发动机仿真模型的框架结构

在建模以前,首先进行了以下几个方面的工作。第一,分析航空发动机仿真模型的应用范围;第二,分析航空发动机的工作原理、仿真算法及各部件之间的气动和机械关联;第三,对航空发动机的各个部件的功能、工作原理及仿真算法进行分析并归类;第四,对计算要用到的气动热力性质计算公式进行分析归类。

通过以上分析,本文采用了建立MFC扩展库的方式来设计该软件系统——即建立一个航空发动机基本类库而不是一个具体的发动机对象。该类库的基本结构如图1所示。类名以及成员变量和成员函数都按照标准Visual C++语言的命名约定方法进行命名。

可以把航空发动机看成一个由不同状态的工质、部件及控制律构成的抽象机械。部件又分为转动、非转动和机械传递部件三大类。根据Coad提出的面向对象系统的分析与设计方法^[1],可以得出航空发动机性能仿真领域的部件对象模块(图1)并进一步得到相应的类及与之相关

的属性和方法。

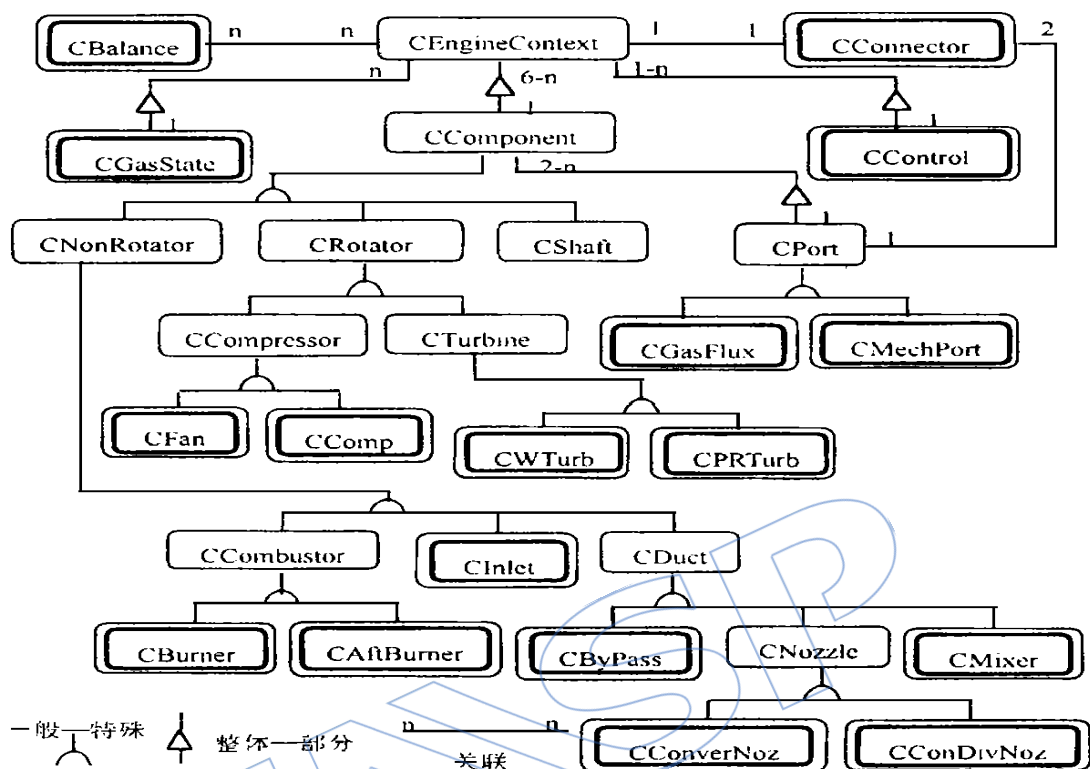


图1 航空发动机性能仿真问题域部件对象模块

为了满足仿真的需要还需添加一些辅助的类如 CCompMap 类、CCalInfo 类、CSolver 类等。CCompMap 类包括了读写数表、插值等基本功能; CCalInfo 类包含了异常处理方法; CSolver 类汇集了求解非线性方程组的解法。这样的结构符合灵活方便、高效专用的要求。

根据分析得出的类结构和内容, 就可以建立起航空发动机基本类库, 并用动态链接库的方式进行发布。开发人员就可以直接使用类库中的类所提供的方法和属性编写应用程序, 也可以通过继承和重载来方便、灵活、可靠地完成基本类库的扩展。

3 航空发动机部件对象的实现

各个类都封装了自己的属性和方法, 这样的结构有利于用来描述有着不同要求的具体部件。对于不同的部件, 只需要用已有的方法进行合乎逻辑的组合, 这使得模拟具体部件工作过程的类方法变得非常简单。比如模拟风扇的 Run() 方法:

```
... //执行运算
InitCal(Pi, Ti, PNC, WA, WA c, CNC);
pGasState- > ThComp(m - dPR, m - dEff, Ti, Hi, Si, Pi);
pGasState- > CalResult(Po, To, Ho, So);
SurgeMargin(WA c, CNC);
Work = WA * (Ho - Hi);
... //运算结束
```

类的应用也非常简单,如下所示:

```
...
m - strM apN ame = "GFan";
CFan * pFan = new CFan(pEngine, m - strM apN ame);
pFan -> Run();
...
```

这时,就可以模拟具体发动机部件的计算了。

4 部件对象之间通信的实现

在部件对象模型中,要模拟实际部件的所有机械和气动热力或化学等过程。为了满足扩展灵活的要求,部件必须是完全自我包容的控制体^[2],并假设这些过程都是在一个控制体中完成,部件间的所有质量和能量的交换都是通过控制体表面的“端口”进行,如图 2 所示。图中,大方块表示控制体,小方块表示端口,箭头表示连接器。

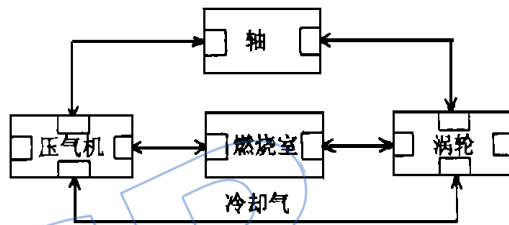


图 2 部件间的数据交换模型

CPort 类有两个派生类 CMechPort 和 CGasFlux。CMechPort 表示存在着机械联系的部件的机械端口,CGasFlux 表示存在着气动联系的气路端口。这两个类负责从部件中获取数据及把连接器传来的数据传递给部件。Connector 类是为了实现端口间通信而设计的,用于实现部件间数据交换的类方法。

5 异常处理和仿真实现

在软件开发中应该非常重视异常处理,每一种成功的软件包括编程语言内部都建立有比较完整的异常处理机制。要对像航空发动机这样复杂的机械的建立一个灵活可靠、开放扩展的仿真系统,也必须建立一套完整的异常处理机制。在本文的应用程序框架的第二层类中,建立了 CCalInfo 类用以收集航空发动机仿真模型计算过程中导致计算失败的各种可能因素,并且采用了不同的处理方法处理不同的信息。比如:

```
...
CCalInfo * pInfo = new CCalInfo(); //创建异常信息对象
...
pInfo -> ShowInfo(m - pCaller, strErrMsg); //致命错误,显示错误信息并退出运算
...
pInfo -> SaveInfo(m - pCaller, strErrMsg); //有可能导致计算失败,存储信息继续运算
...
```

在仿真模型的 Debug 版本中,该类收集到的信息可以精确定位到具体部件对象的代码行。这样就极大地方便了应用程序的调试,提高了应用程序的可靠性。

简言之,航空发动机的仿真就是求解非线性方程组。先用上述部件对象对不同要求或不同类型的发动机流程进行描述,然后从 CSolver 类选取解算方法,即可实现航空发动机的仿真。

6 实例和结论

本文在这个框架的基础上建立了某双轴涡扇混排发动机的性能仿真模型和某型由燃气发生器和自由涡轮构成的涡轴发动机的性能仿真模型, 仿真了涡扇发动机的动态过程和涡轴发动机的速度高度特性, 结果如图 3 和图 4 所示。

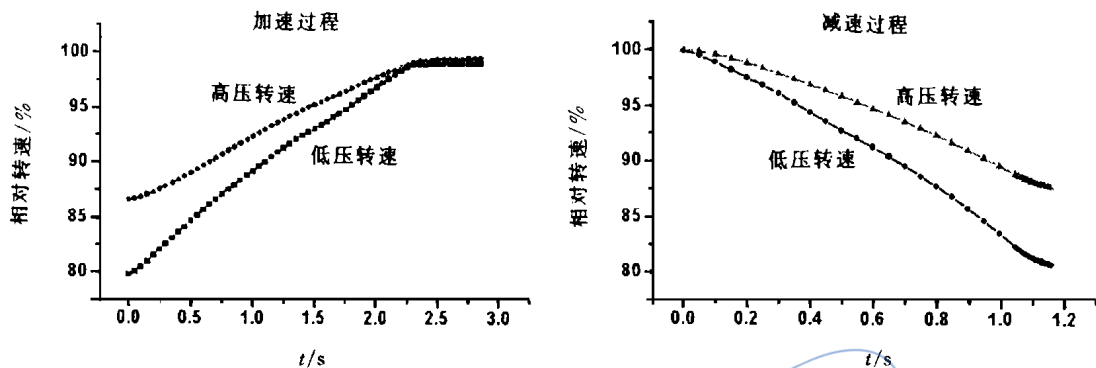


图 3 涡轮风扇发动机动态过程

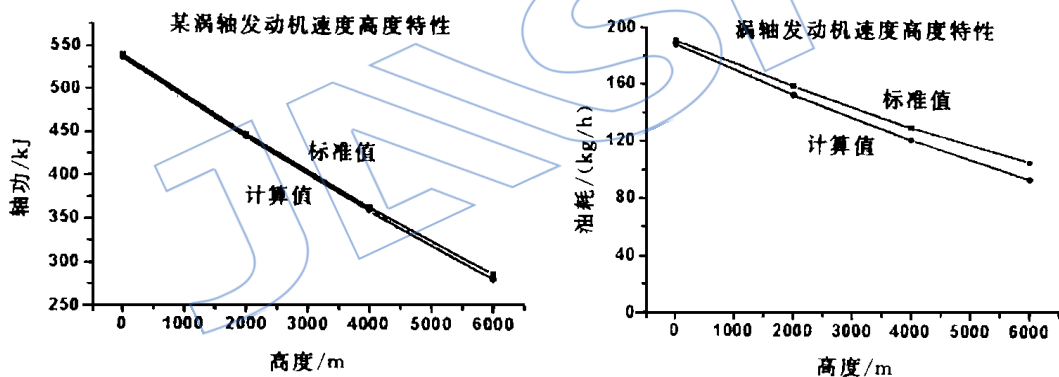


图 4 涡轴发动机速度高度特性

由此可以提出了一种用于建立扩展性强、灵活可靠的航空发动机性能仿真方法, 能够非常方便可靠地建立起高效专用的发动机性能仿真程序。异常处理机制的引入方便了仿真软件的调试并提高软件的可靠性。实例表明应用程序框架扩展灵活、高效专用。

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cesses. Radiography can hardly resolve the spray cloud, but it is capable of recording the full jet structure and allows to determine the intact core. As examples some liquid jet radiographs have been taken at different fluid pressures and nozzles. The point of cylindrical jet disintegration and the point of annular jet coalescence shift to the nozzle orifice with increasing pre-pressure.

Key Words liquid jet Breaking Atomization X-ray Experiments

A METHOD FOR CONSTRUCTING TWO- DIMENSIONAL DELAUNAY TRIANGULATION OF COMBUSTOR FLUID

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ABSTRACT A method is presented here for constructing two- dimensional Delaunay triangulation with a new automatic point creation technique. This technique is based on the idea of advancing- front method to achieve good geometry flexibility. The main steps are as follows: The initial triangulation is generated first, according to the given border set. In the initial triangulation usually there are lots of triangles with very small minimum angles which will seriously decrease computational accuracy. The new nodes are introduced with advancing- front method, and added into the existing mesh according to Bowyer- Watson algorithm simultaneously. The procedure is repeated until no more improvement of the grid can be achieved by inserting the new nodes. Its application to triangulating combustor fluid shows that the resulted grids have great regularity and boundary quality.

Key Words Combustion chambers Flow fields Calculations Grids

A STUDY OF COMPUTER AIDED TESTING TECHNIQUE FOR AEROENGINE

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ABSTRACT A system engineering method for development of the Computer Aided Testing (CAT) technique was discussed in the light of a comprehensive review of CAT technique, and investigation of CAT Systems. The application of digital filtering to the Aeroengine Test was also introduced. The focus was put on the achievements of multi- signal acquisition, processing and displaying according to Virtual Instrument conception. The necessity and trend of a man- machine harmonious information environment development with supporting of database system in the aeroengine Test field were considered.

Key Words Computer aided experiment Aeroengine Digital filtering methods

A STUDY OF OBJECT- ORIENTED APPROACH FOR AEROENGINE PERFORMANCE SIMULATION

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ABSTRACT This paper discusses how to create an extensible, flexible, reliable

aeroengine simulation program. An effective aeroengine simulation program on the basis of object-oriented aeroengine fundamental class library (an aeroengine application framework), can be easily built for a specified type of aeroengine or a specified intention of study, an Exception handlers are integrated to the framework to make the debug of the simulation software easy and improve its reliability. A two-spool turbofan engine and a turbo shaft engine simulation programs are provided as examples to illustrate the flexibility and specificity of the framework

Key Words Aeroengine Performance Simulation Programming

A STUDY ON SYSTEM RESPONSE FOR LIQUID PROPELLANT STAGED COMBUSTION CYCLE ROCKET ENGINE

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ABSTRACT A feeding system of a pump-fed Liquid Propellant Staged Combustion Cycle Rocket Engine (LPSCCRE) is taken as a research object. Its system physical model is constructed, and its nonlinear mathematical model is established. The nonlinear dynamic response of LPSCCRE is simulated with adaptive Runge-Kutta algorithm on the conditions of parameter variation and working regime regulation in wide range. Comparison of the obtained results with the test data shows that: The mathematical model is quite valid and calculation method meets the simulation requirements.

Key Words Liquid propellant rocket engine Mathematical model
Dynamic characteristic

LEAK FAULT DETECTION OF LIQUID ROCKET ENGINE BASED ON K-L INFORMATION DISTANCE

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ABSTRACT The leak of Liquid Rocket Engine (LRE) is very common and dangerous. It is important to research a fast and effective approach for leak detection. In accordance to the measured monitor state parameters of LRE, the AR model is established and the time series analysis is completed. K-L information distance is taken as discriminant function to detect the leak fault of LRE. The simulation results show the leak fault detection algorithm is feasible.

Key Words Liquid propellant rocket engine Leakage Time series Analysis
Measuring