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Research of Model-based Aeroengine Control System Design Structure and Workflow

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Abstract

The control system of aeroengine design is a complex system engineering including many procedure of different subsystems. To improve the efficiency of aeroengine control system design and reduce the cost and development period of research procedure, model-based aeroengine control system design method can be used for integrating systems, collaborative design and optimizing design. Model-based aeroengine control system design workflow consists of the phases from analysis of system requirements to semi-physics simulation verification. The management approach and design procedure can help to separate the whole design workflow into different sub-phases which can help to scheme the concurrent design procedure of complex control system in order to improve the efficiency of aeroengine design and optimize the performance of aeroengine control system.

Keywords: Control system of Aeroengine, Simulation, Model-based, Simulation Design Structure;

1. Introduction

Aeroengine control system design is a complex system engineering, concluding engine design, hydraulic system design, electronic system design, control system design, communicational signal process, pneumatic system design and so on which an integrated and coordinated system design method is needed\cite{1}. Since the computer aided design is widely and continuously used in different engineering areas, with its help, the efficiency of system design in
various phases has been increased obviously, however, there are also some key problems during design procedure, subsystem design of each phase is not closed linked which causes lowering integrated capabilities of different subsystem design departments[2]. The problems during initial design phase cannot be found because of lower integration and this will increase the design cost. Contemporarily, in the area of automobile industry, model-based modeling method is widely used by the automobile designers to design the automobile system, especially the control system and electronic system which can help automobile designer to solve the coupling problems of collaborative design. Therefore, model-based design method can also be used to solve the lowering integration, poor interaction between C code used in controller and simulation model and complexity of iterative design during aeroengine control system design.

Currently, model-based design method is very popular in industry. Model is a mathematical description of physical systems, an identified executing criterion. Model-based design is based on object-oriented modeling method and mathematical calculating process method continuing to update subsystem models and coupling model of the whole systems in order to ensure high cooperation of different phases of design process. Model-based design can help system designer to run quick design cycle and get information feedback rapidly. Complete control algorithm model can be translated into C code automatically by special tools.

Model-based design method can be divided into several sub-phases during design process,
1. Analysis of Physical System Demand
2. Demonstration of System Model Target
3. Plan Top System Model Design
4. Detail System Model Design
5. Building models
6. Verification of Subsystem Model
7. Verification of Integrated System Model
8. Verification of Hardware-in-Loop Simulation
9. Verification of Semi-physical simulation
10. Verification of integrated hardware and software system of aeroengine

The 10 sub-phases during aeroengine control system design is not independent, there are several iterative design processes between different sub-phases in order to ensure to find and correct the problems of initial design phase. The following parts are the description of model-based control system design method.

2. Model-based Aeroengine Control System Design Workflow

During the design process of aeroengine, the whole design process can be divided into three parts, including phase of design, phase of building models and phase of system verification. In different sub-phases of design procedure, object-oriented management method is used for task distribution. In Fig 1, design workflow of the whole procedure is shown.
3. Design phase

In the design phase, it contains system analysis of demand, demonstration of system model target, plan top system model design and detailed system model design. In the phase of analysis of system demand, physical system analysis is needed and physical system need to be separated into different sub-systems by object-oriented method. During the stage of target validation of system model, the target of system model needs to be compared with physical system demand and should be ultimately determined after several iterative analysis and comparison. In the phase of top system model design, based on system model target, the system model should be separated into several subsystem models, including hydraulic system, mechanical system, electronic system, control system, fuel & pipe system and so on. Then the interface protocols should be built to design the interfaces of different subsystem models [3]. The procedure scheme contains co-simulation approach which the top system model composes, the variables of interface data flow, key parameters and control algorithms of controllers, parameters and characters of actuators, experimental way of HIL(Hardware-in-Loop) simulation and scheme of semi-physical simulation. In Fig 2, model design workflow in design phase is shown.

4. Building models phase

During building models, subsystem models should be built and interfaces of each subsystem model should be designed based on the scheme of detail system model design. Currently, engine models are built by M language or C, C++ language and models are often designed by mathematical procedure oriented modeling method which can be transported into a form that can be directly used in HIL and semi-physical simulation[4].

During this procedure, engine model should be designed to satisfy real-time instantaneity and engine model also need to be reduced order in common. After engine models are transported into the form or dynamic linking library which Matlab\Simulink can identify and call, Matlab\Simulink can integrate control system model, executing actuator model and engine model for the integrated system simulation.

Executing actuator model can be built by object-oriented modeling method and models are often built by AMESim, EASY5 and so on. Multi-body system dynamics model of mechanical system can often be built by Adams, LMS Motion to calculate the kinematics and dynamics performances. Hydraulic system and fuel system models can often provide interfaces of control signals and displacement, velocity and force with control system models and mechanical system models.

Control system models can be created by Matlab\Simulink or C code. Also this model can be used for integrating into the whole system and to predict the control logic and optimize the parameters during the verification of
integrated system model. Key technology needs to be developed to transport the control system model into C code which can be used in controller during HIL and Semi-physical simulation [5].

The interface of different subsystem models can be designed based on the relationships of physical linking of different subsystems. Bond graph theory is used for different subsystems coupling into top system model. The information of interface contains unified variable names, variable units and fixed communication time step. In Fig 3, scheme and workflow of modeling after design phase are shown.

5. System verification phase

Verification phase contains verification of subsystem model, integrated system model, hardware-in-loop simulation, semi-physical simulation and integrated hardware and software system of aeroengine. Because of object-oriented modeling method, subsystem models need to be tested and verified by their own subsystem designers. In multi-condition of specified system input, output and key parameters of system models should be compared with experimental data to verify the availability of subsystem models. When the subsystem models were verified by experimental results, models can be packaged into a special form and upload into serves by a model management system and these models can be used for new system design in the future, shown in Fig.4. Then the element models can be used in the detail system model design phase. Also models can be updated if it is optimized.
During verification of integrated system model, top system model integrates different subsystem models by various coupling method to predict and optimize the performances of the whole system in off-line simulation. Also, control system model can be optimized and engine model can be tested and reduced order in order to be used in HIL and semi-physical simulation [6].

During hard-in-loop simulation, control system model can transport into C code directly which hardware can identify. Actuator models can be transported into a special transfer function model which output and input are specified or a special mathematical relationship by neural network. The mathematical model and engine model integrate to be used in DSP for HIL simulation.

During semi-physical system, controller used the C code of control logic tested in the HIL simulation. Semi-physical experiment equipment replaces the actuator model and engine model of HIL simulation is also used. Performances of engine accessories are tested and analyzed in semi-physical systems.

In verification of integrated hardware and software system of aeroengine, software and actuator mechanism of control system of aeroengine need to be integrated to tested in order to validate function of the control system [7].

6. Iteration and improvement

During model-based design procedure, if test result of each sub-phase of system verification phase is not accord with simulation target, the detailed design scheme need to be re-improved. This design procedure is called iteration. Iteration means models are not according with its simulation target and need to be improved. If test result of each sub-phase of system verification phase is verified to satisfy the simulation target, systems can be improved and optimized by simulation result. This procedure is called improvement. Improvement means demand of system analysis is according to models and it can be improved and optimized based on model analysis [8].

7. Management of elements during design procedure

During model-based design procedure, a management system is designed to arrange modeling procedure and store design reports, models and dynamic linking libraries of algorithms. Management system based on client-server structure is a platform which can manage models and simulation data. Also, the information of the models and simulation data can be checked and shared through the client. First, models and simulation data need to be packaged into a special form that the management system can identify and all the information of them can be written into XML file. Client can upload the packaged models to the virtual warehouse in server[9]. Server gets the information of models and simulation data from the XML file and then records it into database. Meantime, element information of models or simulation data can be sent into SVN in order to get the corresponding version number which will be recorded into database through the server. Client can be used to check the models and data’s information through the database [10] [11], such as shown in Fig 5.

Fig 4 Model Management System in the Workflow
8. Summary

Model-based aeroengine control system design method can be used for aeroengine control system design. During design phase, system modeling scheme and simulation method need to be decided. System demand needs to be affirmed to accord with simulation target. In modeling phase, based on detailed design method, off-line simulation model need to be built by object-oriented modeling method. Then in the test phase, integrated system modeling simulation, HIL simulation and semi-physical simulation can be used for verifying models and optimizing systems.
Fig 6 Receiving version number from XML file

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