Advanced Engineering Informatics 29 (2015) 1110–1125

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Automated generation of multiphysics simulation models to support multidisciplinary design optimization

Fengnian Tian *, Mark Voskuijl

Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands

ARTICLE INFO

Article history:
Received 17 August 2014
Received in revised form 11 July 2015
Accepted 18 July 2015
Available online 8 September 2015

Keywords:
Multiphysics simulation model
Knowledge based engineering
Multidisciplinary design optimization
Multirotor UAV

ABSTRACT

To ensure a consistent design representation for serving multidisciplinary analysis, this research study proposes an *intelligent modeling system* to automatically generate *multiphysics simulation models* to support multidisciplinary design optimization processes by using a knowledge based engineering approach. A key element of this system is a *multiphysics information model* (MIM), which integrates the design and simulation knowledge from multiple engineering domains. The *intelligent modeling system* defines classes with attributes to represent various aspects of physical entities. Moreover, it uses functions to capture the non-physical information, such as control architecture, simulation test maneuvers and simulation procedures. The challenge of system coupling and the interactions among the disciplines are taken into account during the process of knowledge acquisition. Depending on the domain requirements, the *intelligent modeling system* extracts the required knowledge from the MIM and uses this first to instantiate submodels and second to construct the *multiphysics simulation model* by combining all submodels. The objective of this research is to reduce the time and effort for modeling complex systems and to provide a consistent and concurrent design environment to support multidisciplinary design optimization. The development of an unstable and unmanned aerial vehicle, a multirotor UAV, is selected as test case. The *intelligent modeling system* is demonstrated by modeling thirty-thousand multirotor UAV designs with different topologies and by ensuring the automatic development of a consistent control system dedicated for each individual design. Moreover, the resulting *multiphysics simulation model* of the multirotor UAV is validated by comparing with the flight data of an actual quadrotor UAV. The results show that the *multiphysics simulation model* matches test data well and indicate that high fidelity models can be generated with the automatic model generation process.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The development of complex systems, such as road vehicles and aircraft, is a highly multidisciplinary task which involves dynamics, aerodynamics, propulsion, structures, thermal and electronic control system. Therefore, *multidisciplinary design optimization* (MDO) has been proposed. MDO is a field of engineering that focuses on the use of numerical optimization for the design of systems that involve a number of disciplines or subsystems [1]. It has been utilized when the performance of a multidisciplinary system is driven not only by the performance of the individual disciplines but also by their interactions [1]. A large amount of research has been performed in the field of MDO over the last decades and there is a clear increase in the use of MDO by industry.

In order to support MDO, analysis tools from different domains are required, as well as *multiphysics simulation models* capable of simulating the performance and behavior of the overall integrated design. However, the modeling of a complex engineering across multiple domains is a difficult task. First of all, because the physical systems can be very complex, it costs much time and effort to set up the simulation models in one domain, let alone a *multiphysics simulation model* which requires information from many disciplines. Second, more and more analysis tools require high fidelity geometric information, along with other configuration parameters, such as *computational fluid dynamics* (CFD) or *finite element method* (FEM). This requirement aggravates the difficulty of modeling complex systems. Delays in a single discipline, for example caused by manually tuning the control system, may slow down the whole MDO process. Third, all simulation models should be consistent with each other through the whole MDO framework. When the top-level configuration of the target design is changed, all simulation models should be synchronously updated. It can be expected

* Corresponding author.
E-mail addresses: f.tian@tudelft.nl (F. Tian), m.voskuijl@tudelft.nl (M. Voskuijl).

http://dx.doi.org/10.1016/j.aei.2015.07.004
1474-0346/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

Roman symbols

Δn_p	rotor speed change as a result of a roll command input (rad/s)
Δn_q	rotor speed change as a result of a pitch command input (rad/s)
Δn_r	rotor speed change as a result of a yaw command input (rad/s)
Δn_w	rotor speed change as a result of an altitude command input (rad/s)
$\mathbf{A}$	system matrix (–)
$\mathbf{B}$	input matrix (–)
C_i	cost of component i (\$)
$f(x)$	objective function (–)
$fitness(x)$	fitness function (–)
g	gravitational acceleration (m/s^2)
$g(x)$	constraints (–)
K_i	control system gain (–)
p	body axis roll rate (rad/s)
q	body axis pitch rate (rad/s)
r	body axis yaw rate (rad/s)
$rank(x)$	ranking function (–)
T	thrust (N)
u_x	speed command in longitudinal direction (–)
w	vertical velocity in body axis (m/s)
W_i	weight of component i (kg)
x_k	decision variables (–)

that this process will be repeated many times during the period of product development, which is a time consuming effort and prone to errors.

This research study proposes an *intelligent modeling system* to automatically generate *multiphysics simulation models* to support the MDO process by using the *knowledge based engineering* (KBE) approach. A key element of this system is a *multiphysics information model* (MIM), which integrates the design and simulation knowledge from multiple engineering domains. The MIM defines classes with attributes to represent various characteristics of physical entities. Moreover, it uses functions to capture the non-physical information, such as control architecture, simulation test maneuvers and simulation procedures. Depending on the requirements for the *multiphysics simulation model*, the *intelligent modeling system* extracts the required knowledge from the MIM and uses this first to instantiate submodels and second to construct the overall *multiphysics simulation model* by combining all submodels. Moreover, the resulting *multiphysics simulation model* not only includes a design representation of the physical systems but also the information for configuring the simulation environment. The objective of this research is to reduce the time and efforts for modeling complex systems and to provide a consistent design environment to support MDO.

The paper is organized as follows. Initially, a review of model generation methods to support MDO is given in Section 2. These methods are compared to the traditional design process and to the MIM proposed in this research study. Next, details of the method are presented in Section 3. Then, the suitability of the new approach is evaluated by automatically generating *multiphysics simulation models* of a large number of multirotor UAVs design with different topologies in Section 4. Subsequently, the resulting *multiphysics simulation model* is validated by comparison with flight test results of an actual quadrotor UAV (see Section 5). The *intelligent modeling system* is also tested to support a complete design optimization for the multirotor UAVs with significant configuration differences. A discussion of the results and the associated conclusions are given in Sections 6 and 7, respectively.

2. Related work

In order to support MDO for complex engineering systems, a different design representation must be created for each separate disciplinary analysis. Through a literature review, it has been found that the different design representations typically evolve when new requirements emerge during the design and analysis process.

Modeling the physical systems across multiple domains is required for the MDO process. The common practice for designing robots, airplanes and ground vehicles is a sequential approach, where the mechanical subsystems are designed prior to other subsystems [2]. Nevertheless, as a complex system, the mechanical design cannot be optimized without taking into account its influence upon other subsystems, like the controls [3]. Therefore, various modeling methods for supporting mechatronic design, which is a multidisciplinary approach are proposed in the literature.

As can be seen in Fig. 1, mathematic equations are the most direct way to describe the physical system across multiple domains. For example, He and McPhee [2] use equations to model the dynamics of a half-vehicle. A *genetic algorithm* (GA) is applied to simultaneously optimize relevant parameters for the dynamic model and control systems. Moreover, da Silva et al. [4] represent the dynamics behavior of a pick-and-place assembly robot using flexible multibody dynamics. The flexible multibody system is modeled using mathematical equations. Control system design is based on these equations as well. Furthermore, other researchers use an evaluation model called *mechatronic design quotient* (MDQ) to facilitate decision-making in the design process [5]. It is claimed that the controller design issues and parameters are treated simultaneously with other physical issues and parameters [5]. However, if the complex systems are modeled by mathematical equations, it is not straightforward to see the physical meaning behind them.

Bond graphs were proposed by Paynter [6] at 1959. The bond graph approach starts by taking into account the energy flows between the ports of the (actual and conceptual) components of an engineering system instead of establishing and reformulating mathematical equations [7]. The advantage of the bond graph methodology is that the complex engineering (mechatronic) system can be represented in a compact and explicit way. Margolis and Shim [8] apply the bond graph methodology to generate a four-wheel, non-linear vehicle dynamics simulation model with electrically controlled brakes and steering as well as stability control at each suspension corner. Submodels are first modeled and then assembled into a computable overall model. Moreover, Granda [9] explored the bond graph technique and developed a software tool, named as *computer aided modeling program with graphical input* (CAMP-G), to create state space models for serving simulations in MATLAB Simulink. Commercial software packages, like 20-sim, also support the domain independent bond graph notation for modeling dynamic systems [10].

Subsequently, *model-based system engineering* (MBSE) is widely accepted as a useful approach for designing complex systems [11].

Download English Version:

https://daneshyari.com/en/article/241976

Download Persian Version:

https://daneshyari.com/article/241976

Daneshyari.com