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Uncertainty Quantification of Store-Separation Simulation Due to Ejector Modeling using a Monte Carlo Approach with Kriging Model

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Abstract. Precise calculation of the trajectory of store separation is critical in assessing whether the store can be released safely. Store ejection is the initial stage of the releasing process and any uncertainty introduced at this stage will propagate through the whole trajectory. In this work, the impact of the uncertainties in ejector modeling on the simulation of a generic store separation is investigated by using a Monte-Carlo-based approach. To reduce the extremely large computation cost resulted from the direct use CFD in Monte Carlo simulation, the CFD solutions are represented by a time-dependent Kriging model, which is constructed at each time step by using the samples from the URANS simulations. The stochastic outputs, including the distribution of probability density function, expected value and 95% confidence interval of store separation trajectory, are obtained by the Monte Carlo simulations. The sensitivity analysis is also carried out by using the Monte-Carlo-based method to determine the most significant variables in ejector modeling, which affect the output uncertainty. Our results show that ejector modeling is one of the main uncertainty sources of store separation simulation and the approximation in ejector modeling can cause a significant deviation, especially in the angular displacement.

AMS subject classifications: 65E05, 76M12

Key words: Uncertainty quantification, Monte Carlo simulation, Kriging surrogate model, store separation.

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1 Introduction

Store separation is a common problem encountered in the field of aerospace, such as the releases of ammunition, external fuel tank, capsules, bombs, missiles, etc. The studies of store separation are required before a new aircraft goes into service, or an old aircraft undergoes substantial modifications or needs to be certified to carry and employ new stores [1]. From an aerodynamic point of view, store separation is an unsteady flow problem involving moving-boundaries. Traditionally, there are three approaches to investigate the store separation: flight test, wind tunnel test and computational fluid dynamics (CFD) simulation. The flight test of a store separation is the most direct approach, but it is also the most dangerous and costly one. Currently, it is only used as a means of final verification. Therefore, the study of the safety of store separation mainly relies on the ground wind-tunnel test and CFD simulation. In the wind-tunnel test, the Captive Trajectory System (CTS) and the free-flight method are the two most commonly used technologies. However, it is often found that the wind-tunnel test for some store-separation problems is prohibitively difficult. In addition, as fairly small scale models have to be used in the wind-tunnel tests, in many cases the wind-tunnel predictions do not match the flight test results [1]. Over the past decades, a great progress has been made in CFD simulations of store separation. Many methods have been developed to deal with the moving boundaries in store separation, such as Cartesian grid, deforming grid, overset grid and so on [2, 35]. CFD has become a crucial technology for the study of store separation and it can alleviate the requirement of wind tunnel test. Because of its low-cost and high efficiency, CFD has been playing a more and more important role in the safety prediction of store separation. In many cases, the separation-safety margin is determined directly by CFD simulations as the flight test and wind tunnel test can't be conducted at all. Therefore, the reliability of store separation simulation is very important to the flight safety.

The model used in CFD simulation is only an abstraction of the realities and it is an approximate representation of a complex system. It often utilizes a large number of modeling parameters. The value of these parameters may be approximately determined through fitting the model predictions with the calibration data obtained from laboratory experiments. The model-predicted performance often deviates at certain levels. As a result, uncertainty always exists in the CFD results [8, 34, 36]. As a method of evaluation on confidence level of experimental measurement, uncertainty quantification (UQ) is also an important and basic work of numerical simulation. Many studies have been carried out to assess the impact of uncertainties on CFD simulations. Liu et al. [6] investigated aerodynamic uncertainties due to the smooth-geometry deviation from the original shape, which typically arise in the manufacture process. Bose et al. [7] performed uncertainty analysis for the prediction of a laminar convective heating in a moderate Mars atmospheric entry condition using a CFD code. The uncertainties due to the statistical variations of a total of 130 CFD input parameters were investigated and the quantitative contribution of uncertainties in key modeling parameters to the final heat flux uncer-