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A CFD STUDY OF COMPLEX MISSILE AND STORE CONFIGURATIONS IN RELATIVE MOTION

By

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A CFD STUDY OF COMPLEX MISSILE AND STORE CONFIGURATIONS IN RELATIVE MOTION

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§.1 Introduction

An investigation was conducted from May 16, 1990 to August 31, 1994 on the development of computational fluid dynamics (CFD) methodologies for complex missiles and the store separation problem. These flowfields involved multiple-component configurations, where at least one of the objects was engaged in relative motion. The two most important issues that had to be addressed were: (i) the *unsteadiness* of the flowfields (time-accurate and efficient CFD algorithms for the unsteady equations), and (ii) the generation of *grid systems* which would permit multiple and moving bodies in the computational domain (dynamic domain decomposition).

The study produced two competing and promising methodologies, and their proof-of-concept cases, which have been reported in the open literature:

1) Unsteady solutions on *dynamic, overlapped grids*, which may also be perceived as moving, locally-structured grids
2) Unsteady solutions on *dynamic, unstructured grids.*

After providing a background for the topic, only a very brief overview of the research supported under NAG-1-1150 is given in **§.2**. However, the details are available in the technical publications listed in **§.3**. and sampled by cover pages in **§.4**.

§.2 Overview

In order to simplify the engineering analyses, the "*steady flow past a stationary object*" assumption is often used. Depending on the particular problem in question, this may be a reasonable approach. However, it becomes not only difficult to decide on the assumed freestream flow velocity but it also renders unacceptable results, if the problem being solved involves a *multicomponent configuration with at least one of the components engaged in a motion different than the other components*. In other words, the moving boundaries and aerodynamic interference introduce non-negligible effects for problems, such as those encountered in the following applications:

> the rotation of an aircraft propeller, motion of wing flaps, rotor-stator interaction in turbomachines, separation of multistage-rocket components, separation of booster tanks from the space shuttle, and separation of stores from military aircraft. The present research has been directed to the last application.

In approaching a problem of this type, there are at least four *levels of assumptions* that can be made for the flowfield and solid-surface interaction:

(I) The component that is engaged in a relative motion is assumed to be *instantaneously frozen*.

(II) *All* components are assumed to be engaged in the *same rigid-body motion*, and the complete computational grid wrapped around the configuration is assigned this motion during the analysis. This requires unsteady and dynamic-grid calculations.

(III) Each component is assigned *its own rigid-body motion* and unsteady computations are performed for these dynamic objects. However, the rigid-body motion of each component is either known or assumed to be known so that they can be *prescribed* as givens to the computations. Such calculations require remeshing the computational domain as the components move relative to each other or assigning each component its own grid, which moves with the component and communicate with the other component grids.

(IV) For the type of problems, where the rigid-body motion of each component is neither known a priori nor can it be easily guessed, because it is determined by the instantaneous flowfield, that is, *aerodynamically determined*, the aforementioned levels of assumptions may be rather compromising. Then, the capability to handle the problems of category (III) needs to be coupled with the solution to the *governing equations of rigid-body dynamics*.

The objective of the present research project has been to develop the methodologies for the problems of categories (iii) and (iv).

Initially, the hybrid domain decomposition (HDD) techniques, developed for steady flows past multicomponent but static objects,[1] were studied. By developing dynamic communication protocols between the subgrids at their interfaces, and assigning each component its own subgrid, the kinematic domain domain decomposition (KDD) was introduced.[2,3] Another advantage of the method was the ability to decompose the kinematics of a complex rigid-body motion into simpler motions; for example, a combined pitching-plunging motion was recovered from the pitching of a subgrid fixed on another subgrid which engaged in a plunging motion only.

Within a moving subdomain, the flow equations were solved after transforming into a stationary computational domain using the time-dependent metrics of the time-dependent, generalized, curvilinear coordinates. Also, all the dependent variables were converted to their absolute values in the fixed frame of reference before they were communicated to their neighbor subdomains. Then, the method was extended to three-dimensional flowfields and demonstrated using a proof-of-concept case: an ogive cylinder oscillating in the proximity of a flat plate.[4]

During these developments, the present research team was invited to participate in a "benchmarking" exercise organized by USAF Wright Laboratories' Armament Directorate, Eglin AFB, FL: the transonic flowfield about a finned store carried under a delta wing via a pylon was successfully simulated using the present HDD methodology.[5]

Along with the numerous advantages of the developed HDD methodology and its dynamic extension, KDD, some of the disadvantages were also recognized; in particular, the difficulty of generating overlapped grids when the clearings between the components were exceedingly small, and sometimes the excessive man-hours involved in generating the composite grids. Hence, a totally different approach was planned as a competing technology, namely, the *unstructured grids*. Note that although the subdomains of the HDD were structured grids, the composite grid was not. Therefore, it might be viewed as a "locally structured" grid. If the subdomain grids were taken to the limit such that each one consisted of only one cell, an unstructured grid would be obtained. With this frame of thinking, a series of assessment studies were conducted to compare the two approaches.[6,7]

So far, the investigation had produced methodologies for the problems of category (III) as classified above. To solve the problems where the rigid-body motion was "aerodynamically determined" (that is, category (IV)), Eulerian equations of dynamics were considered. Given the force and moment fields from the integration of the flowfield equations, the Eulerian dynamics equations were solved to obtain the translation and rotation of the objects in six degrees-of-freedom (6 DOF). This "trajectory" code was then coupled with the developed CFD codes, both the KDD code[8] and the unstructured code.[9]

First the 6-DOF trajectory code was validated, then the coupled codes were demonstrated using 2-D proof-of-concept flow cases. An important contribution along with the unstructured approach was the development of the "adaptive window" concept, where the motion of an object was tracked and the grid adaptation to accommodate the new position was performed within the window containing the object.

The KDD approach was then extended to solve for 3-D flowfields involving 6-DOF relative motions. At this point the computational package consisted of three modules: composite KDD grid module, CFD module, and the trajectory module. Then, it was demonstrated by simulating the unsteady flowfield and computing the trajectory of a store separating from its carriage position.[10]

One of the important concerns in this practice was the temporal accuracy of the method, which was further complicated due to the time-dependent transfer of information amongst the moving subdomain grids. This point was further studied[11] using 2-D cases including the well-known shock tube problem (Riemann problem) to assess the some of the uncertainties associated with the present method.

Since this research project was motivated by the store separation problem, another aspect of internal store carriage was studied: the aeroacoustic environment of a cavity (a store bay). The unsteady, structured CFD method was used to simulate the flowfield and the aeroacoustic field of a 2-D cavity.[12] Then, two suppression devices and their effects on the cavity acoustics were computed and compared with experimental data. Although the comparisons were acceptable for engineering purposes, it was concluded that higher-order methods to integrate the flow equations and better spectral methods for the time series analysis were needed[13].

However, neither this "computational aeroacoustics" study nor the extension of the unsteady unstructured method to 3-D could be completed prior to the closing of the grant NAG-1-1150. These topics are currently being studied under another grant, NAG-1-1499.

Before closing this summary, another important contribution of the grant NAG-1-1150 should be expressed. As a grant of a research project conducted by an academic team, it has also provided the financial support, either partially (along with the grant NAG-1-1499) or fully, to two Ph.D. students,[14,15] two Master's students,[16,17] and only briefly, to two post-doctoral research associates (Drs. K. Fouladi and E. Oktay).

Finally, it should be pointed out that the CFD codes CFL3D[18] (for *unsteady flows past stationary objects*), VISCC[19] (for *unsteady flows past stationary objects*), and USM3D[20] (for *steady flows past stationary objects*) were used as the starting methods for the present investigation.

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10. Yen, G.W., and Baysal, O., “Prediction of Store Separation Trajectory Using Dynamic Overlapped Grids,” will be submitted to *Journal of Spacecraft and Rockets*,. **(support under NAG-1-1150)**

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§.4. Cover pages of sample publications

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