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Validation of a near-body and off-body grid partitioning methodology for aircraft aerodynamic performance prediction

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ABSTRACT

This article describes a methodology based on overset grid techniques that enables the mesh generation process for aircraft configurations to be simplified and shortened. It is based on the key-concept of partitioning the computational domain: the near-body areas are meshed by a set of body-fitted structured grids while the off-body domain is treated with an automated Cartesian grid method. This state-of-the-art combination allows a complex geometry to be considered as the sum of simple elements such as fuselage, wing, winglets, or tailplanes. As a consequence, the ONERA approach exhibits several decisive advantages: easiness, flexibility, rapid implementation, Cartesian grid adaptation. In order to apply and validate the overall methodology, a well-known configuration, the NASA Common Research Model, has been chosen. It is an open geometry representative of current wide-body commercial aircraft which has been used in the international AIAA Drag Prediction Workshops. In this paper, the complete meshing procedure is described. Then, for near-field and far-field drag as well as for local analyses, the results obtained with this new overset strategy are compared to the data produced by the common point-matched Drag Prediction Workshop grids and a very satisfactory agreement is observed. Moreover, some advantages of Cartesian grid adaptation are highlighted.

1. Introduction

COMPUTATIONAL Fluid Dynamics (CFD) has successfully grown over the past decades, in particular for aircraft design. Since Reynolds-averaged Navier–Stokes (RANS) simulations are nowadays performed within an acceptable time frame, configurations that are simulated tend to become more and more complex, involving bodies in relative motion or with geometrical details. Thus, the mesh generation process for industrial configurations still remains challenging; it is time-consuming and requires very specific skills.

For that matter, overset grid methods, also known as Chimera approaches [1], have been used for many years in the CFD community as a means to reduce the mesh generation effort, in particular for structured grids [2,3]. Then, Cartesian grids have been introduced within the overset grid framework in order to mesh the off-body domain, whereas near-body regions can be meshed by overlapping or abutting body-fitted grids extending to a relatively short distance from body surfaces [4–7]. Once the near-body and off-body domains are meshed, the overset grid assembly can be performed prior to the RANS calculation using packages such as Pegasus [8], Pundit [9], Suggar++ [10], and Cassiopée, or directly within the solver (Overflow [11], *elsA* [12,13]). At ONERA, a Cartesian grid generation module has been implemented in the in-house software Cassiopée [14,15], enabling the refinement of the Cartesian mesh to be adapted locally to near-body grid density levels. Cassiopée (CFD Advanced Set of Services In an Open Python EnvironmEnt) is a set of Python modules providing functions for preparing and post-processing CFD computations.

In the present study, this near-body/off-body mesh partitioning of the computational volume is used and a specific method of ONERA is applied: each element of the aircraft configuration (fuselage, wing, tail) is meshed separately with the commercial software Pointwise [16]; then, off-body Cartesian grids and overset grid assembly are obtained using respectively the octree approach and the module Connector [17,18] available in Cassiopée. All these tools used together allow satisfactory meshes to be generated and then the necessary pre-processing to be performed within a short

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time frame. Furthermore, along the whole CFD procedure, from the meshing step to the post-processing, only the CGNS format is used, which clearly simplifies the user work.

Recently, several studies have been successfully carried out with this ONERA meshing method [19–21]. In order to demonstrate its capabilities in this article, the NASA Common Research Model (CRM) used in the latest international Drag Prediction Workshops (DPW) of AIAA has been chosen [22]. The CRM is an open geometry representative of current wide-body commercial aircraft [23], for which a wealth of experimental and numerical data is available. This configuration has been deeply studied at ONERA [24–26] in the framework of DPW-4 (San Antonio, 2009) and DPW-5 (New Orleans, 2012) which was focused on a deep grid convergence study.

The paper is organized as follows: first, the CRM geometry is briefly described. Then, the reference grids and results from DPW will be shown; they will be used for comparison purposes. The near-body and Cartesian off-body grid method of ONERA will be explained and the associated grids will be shown. In a dedicated section, the CFD software used for the RANS computations and post-processing will be presented. Finally, the results obtained by this innovative meshing strategy will be analyzed and some numerical considerations involving multigrid techniques and grid adaptation will be addressed.

2. The CRM as a multi-element configuration

2.1. CRM geometry

The Drag prediction Workshop series was initiated in 2001 by a working group of the AIAA Applied Aerodynamics Technical Committee. The objective was to assess the state-of-the-art computational methods as practical aerodynamic tools for aircraft drag and moment predictions. Over the years, it has provided an impartial forum for evaluating the effectiveness of existing CFD codes and modeling techniques using Navier–Stokes solvers. In the context of DPW-4 and DPW-5 studies, the CRM wing-body (WB) configuration has respectively been used either with a Horizontal Tail Plane (HTP) or without. This relevant geometry was designed by a NASA/Boeing Technical Working Group. As a result, the CRM has the following characteristics: conventional low-wing configuration, possible nacelle/pylon installation, design Mach number (*Ma*) of 0.85, fuselage representative of a wide/body commercial aircraft. The reference geometry is defined by mean-aerodynamic chord $c = 7.00532$ m, reference surface area $Sref = 383.68956$ m^2 (full-model), half-span $b/2 = 29.38145$ m, aspect ratio $AR = 9.0$, and a moment center of coordinates $Xref = 33.67786$ m, $Yref = 0.0$ m, and $Zref = 4.51993$ m. In this study, the HTP setting is always 0°. The complete configuration is shown in Fig. 1.

As it can be noticed, the CRM exhibited in Fig. 1 has a Vertical Tail Plane (VTP). The VTP geometry has not been provided by the DPW Committee: it has been designed by the Applied Aerodynamics Department of ONERA. Indeed, with the authorization of NASA, the ONERA is planning to carry out test campaigns using its own CRM model. This configuration will be used as a reference model for the largest ONERA wind tunnel (S1). In this context, the design of a VTP has been completed and the Computer-Aided Design (CAD) geometry of this new element was recently shared with NASA.

In Fig. 1, it can be observed that the original CRM geometry already includes a functional area on the upper part of the rear fuselage which perfectly corresponds to the location of a VTP. This hollow partly compensates the volume effect of the vertical tail on the fuselage, thus mitigating local drag rise and flow separation risk. The VTP planform defined at ONERA has the following

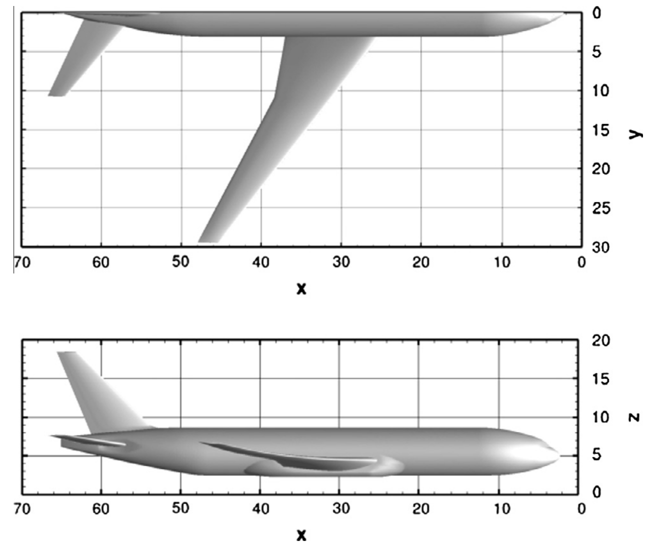

Fig. 1. The common research model (in meters).

characteristics: projected surface of 56 m^2, a root chord of 7.935 m, a tip chord of 2.576 m, a leading edge sweep angle of 44.5°, and a trailing edge sweep angle of 22.2°. As a consequence, the VTP is about 10 m high. Once the planform has been set, a NACA-64A011 airfoil exhibiting 13.42% of relative thickness has been chosen to generate the three-dimensional (3D) shape. This airfoil is considered as suitable for such purposes, having a maximum thickness close to the mid chord.

2.2. CRM element by element

All the CRM elements (fuselage, wing, HTP at 0°, VTP) mentioned in the former paragraph will be used in this paper. As said previously, these basic pieces will be meshed independently. To illustrate this approach, Fig. 2 exhibits the CRM breakdown: each element is considered separately. Moreover, as it can be noticed, for meshing purposes, a part of the fuselage surface will be used in order to build the near-body grids of the other elements.

3. Reference grids and data

In order to compare and validate the results obtained with the ONERA meshing approach presented in this article, some reference grids and data are required. As mentioned in the introduction, the literature focusing on the CRM is abundant. In the framework of the Drag Prediction Workshops, many grids and results have been made available for all the DPW community.

Concerning grids, the family of point-matched multiblock meshes provided by the DPW-5 Committee for the CRM wing-body configuration will be used [27]. These structured grids have produced consistent results and relatively good agreement with the National Transonic Facility (NTF) experimental data [25]. The different characteristics of these meshes are indicated in Table 1.

Y^+ is the normalized first cell height (average). Sizes of these grids range from 638,976 to 138,018,816 cells, exhibiting a grid size ratio of 216. They are O-type grids obtained by an hyperbolic mesh generation tool starting from a discretization of the surfaces (see Fig. 3). They are made of 5 structured blocks. Grid quality, i.e. grid spacing, stretching ratio and grid orthogonality, is well controlled using this mesh generation method. The height of the first cell next to the wall varies from $Y^+ = 2.00$ for the tiny grid to $Y^+ = 0.33$ for the super-fine mesh. The mesh extent is greater than