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CFD Platforms: an Introduction to Onera's Softwares

This second issue of Aerospace Lab is dedicated to Computational Fluid Dynamics (CFD). The objective is to develop platforms for our industrial partners, as well as for our own research. This activity started at Onera in the late sixties, when the first computers became available. A dramatic progress in CFD has been achieved since the beginning, due to both a continuous increase in computer power and the development of advanced algorithms. Thus, CFD has become an essential tool for industry, both for performance prediction and for design purposes, and one of Onera's missions is to provide industry with the most advanced platforms. CFD is a multidisciplinary activity, since skills in physics, applied mathematics, informatics and aeronautical engineering are needed. This will be detailed in this issue, where the "elsA" and "CEDRE" platforms, dedicated respectively to aerodynamics and propulsion, are presented in detail.

Review of the physics underlying the numerical methods

Fluid motion is fully described by the Navier-Stokes equations, which express the conservation of mass, momentum, energy and, if necessary, chemical species. Although these equations are well known, their solution in practical applications is beyond the scope of present and foreseeable computers. Models are thus required to account for different physical phenomena. For non-reactive flows, the transition to turbulence, as well as at least part of the turbulent motion are to be modeled [1].

When dealing with reactive flows, models are also required for the source terms, which arise from the chemical reactions appearing in the species mass balance equations. For laminar flows, Arrhenius laws are simply used, whereas for turbulent flows, different models have been developed in order to treat diffusion flames, premixed flames, or intermediate situations [2]. For these flows, thermodynamic properties also have to be accurately computed [3].

In propulsion systems, different phase flows are present. The different models for the special case of gas-particle flows, which are of major importance in the aerospace context, are described in [4].

Radiative flux and power must be calculated in many applications using CFD, such as predictions of pollutant emissions and service life of aeroengine combustors, the design of thermal protection systems and the ignition of solid propellant rocket motors, the design of spacecraft heat shields for atmospheric (re-)entries, etc. In such configurations, media are composed of gases (combustion products or plasma) and particles (soot, alumina, water droplets). Since the use of a line-by-line approach is not possible for industrial configurations, radiative properties are computed by means of approximate band models, which are presented in [5].

Mathematical aspects

The Navier-Stokes equations associated with the different turbulence models must be discretized on meshes to be solved. Onera CFD platforms are based on a finite volume approach. Structured or unstructured meshes can be used, depending on the type of application. Three types of discretization techniques are presented in [6].

After space discretization, a system of ordinary differential equations is obtained. A very large number of iterative methods are available in the literature. A presentation of the two main methods implemented in elsA (LU Relaxation) or CEDRE (GMRES resolution) is made in [7]. The convergence acceleration techniques based on multigrid methods for block-structured grids, which have been used at Onera for many years, are also presented. A dual time-stepping approach, in which a steady state with respect to the dual time is approximately reached at each physical time-step, is described for unsteady flow calculations.

Many design problems of industrial interest can be formulated mathematically as finite-dimensional optimizations, through discretization and parameterization of the shape of the object of interest. Hence, a good knowledge of global and local optimization algorithms is important to aerodynamic design engineers. The classical algorithms that are currently used at Onera for aerodynamic shape optimization are presented. In addition, many local optimization algorithms require the gradient of the functions of interest with respect to the design parameters. The different ways to compute those derivatives - often called "sensitivities" - are also described in [8].

Most real configurations involve different physics. This is the case, for example, of aeroelasticity. Different coupling techniques are presented in [9].

Softwares architecture

The development of the elsA platform for complex external and internal flow aerodynamics and multidisciplinary applications was initiated at Onera in 1997. The multi-purpose feature of elsA allows the sharing of many common CFD features for a wide range of aerospace applications: aircraft, helicopters, turbo machinery, missiles, launchers, etc. The elsA software is based on an Object-Oriented design method and on an Object-Oriented implementation, based on three programming languages: C++, Fortran and Python. The strategy for interoperability is based on a component approach, which relies on standard interfaces for the CFD simulation components [10].

CEDRE® is a multi-physics platform for general unstructured grids, for both research and industrial applications, in the fields of energetics and propulsion. The software architecture follows a multi-domain, multi-solver approach. Different solvers are considered for each physical system: gas phase, dispersed phase, thermal fields in solids and radiation. These solvers share the CEDRE architecture and libraries, and can be either coupled to perform a multi-physics computation, or operated alone [11].

Various applications that can be computed using Onera's platforms

The different applications presented in [12] underline the capabilities of the elsA software to compute the flow around different aircraft, such as airplanes, helicopters and missiles. The aerodynamics of propellers, compressors and turbines is also addressed. Examples include performance prediction and shape optimization. Examples including aeroelasticity and thermal effects are also described.

A selection of recent CEDRE applications in the aerospace field are presented in [13] to illustrate various functionalities of the platform. These applications have been selected to cover a wide range of applications in the field of aerothermodynamics and combustion. Many of them are "multi-physics", in the sense that they are based on the coupling of independent solvers for, respectively, gas flow, condensed phase transport, solid conduction, radiation, etc. Some of them include an external coupling to other codes.

Even though impressive results have already been achieved with CFD, we are still far from computing an aircraft or an engine in their entire utilization domain accurately and at an affordable cost. To achieve this goal, further advances are needed in the topics listed above. Therefore, for at least several decades, experiments will still be needed to complement CFD. The "numerical wind tunnel" is not for tomorrow...

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