Ricerca
Fluid Dynamics Specialist
Porto Ricerca News
The CFD Newsletter
November-December 2005

Two Approaches To CFD: Costs and Benefits

Abstract

This paper presents a comparison of two of the most used methods in the computational fluidodynamics field: the panel code for the solution of the Laplace equation and the code for the solution of the RANS equations (Reynolds Average Navier-Stokes).We will show that the panel code, in its latest formulation (wake relaxation and iterative coupling of boundary layer) is a more efficient and less expensive tool than the RANS code.

Introduction and History of CFD

CFD begins in the aerospace industry in the early 70's when the industry develops computers better able to sustain a greater amount of computations. At the time, the panel codes are the only solution to the equation of mass conservation, and therefore fit for computers of limited power. VSAERO is the first code of this kind on the market. It has been conceived from the beginning with wake relaxation and iteratively coupled to a boundary level integral. The first codes for the solution of Eulero equations are related to the increment of computational power, of RAM and mass memory. During the mid 80's with the first simple turbolence models, the RANS equations enter the computational mode.Since then, the number of solutors of Navier-Stokes equations has been increasing-from Jameson Schemes to the Vp-wind TVD as well as the turbolence models (today we can perform a direct simulation of Reynolds efforts. What ususally is not being considered is that during all this time panel codes and Navier Stokes solutors have evolved as well, and have developed more accurate manipulations of the wake, including the possibility to simulate base separations: more efficient codes for computation of integral boundary layer have also been developed, together with simulation of jet propulsion and manouvres, thanks to the coupling to codes for computation of 6 degrees of freedom.It is well known that panel codes require nowdays less computational time than RANS codes: what may not be so apparent is that the panel codes, if completed with the above tools, are often more accurate and efficient than the RANS.

Features and applications of the two methods

The characteristics of the RANS codes are well known.They offer the possibility to solve any type of continous fluid, but the amount of time and costs required are both quite high. In fact, the complexity of the software requires a specific post-graduate training, often abroad, and therefore these costs are justifed only for those activities that require the use of these tools. This is the case of simulations of: the inside fluidodynamics of plants, combustion or explosive fenomena, very dense fluxes, and fusion processes.
La CFD nasce nell'ambito della industria aerospaziale

The original applications of CFD include highly separated fluxes as a consequence of an extreme manouvre attitude in trans-supersonic regime.
The applications also include the fluxes developed in hypersonic regime. The panel codes and particularly VSAERO yield reliable results, that correlate excellently to the experiment if applied to fluxes around bodies of aerodynamic shape and that are characterized by a moderately attached or detached boundary layer. Furthermore thanks to comprimibility corrections the panel codes are able to simulate currents where moderate effects of comprimibility are present. The advantages offered by the panel codes are many, among which the reduced computation times by generation of a system of linear equations that can easily be solved by modern computers. Another advantage is a shorter training time needed, and the possibility to employ less qualified and therefore less expensive personnell, as well as less requirements for hardware. All that is needed when using the panel codes, is an average computer set up, avoiding purchase of expensive work stations

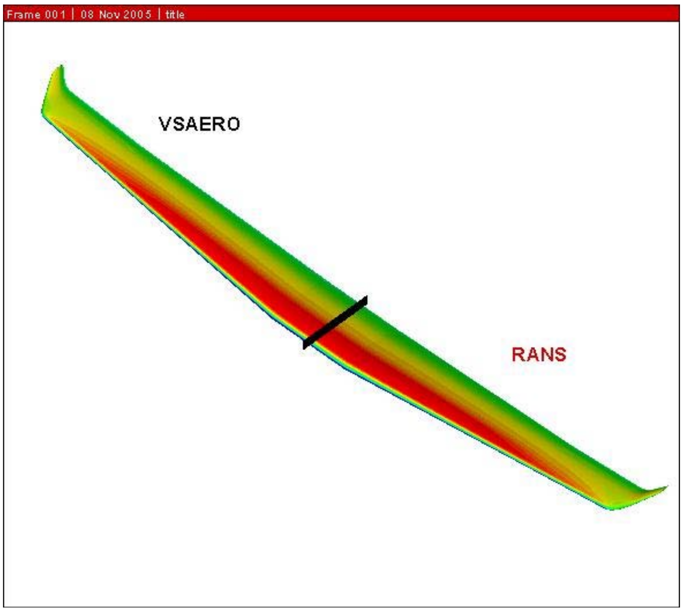

Fig 1-wing+winglet; Identical superficial mesh 10 800 panels

Comparison

We have compared the panel code VSAERO to the RANS solutor NSAERO (by AMI Inc ,USA- distributed in Italy by Porto Ricerca snc).Four areas have been considered: preparation and control of computational models, viscous computation, system economicity, efficacy of project loop.

Preparation and Control

The codes for solution of RANS equations have also been defined end-volume codes, since the preparation of the model also include the air volume surrounding the body: the volume must extend to the aerodynamic infinite that is far enough from the body to simulate an undisturbed flux. When using the panel codes, it is enough to model the body surface while there is no need to model the surrounding fluid, with a drastic decrease of the time of preparation of the model, especially when it is complex. A good example is the simulation of an isolated wing. For the expert user, with a clear understanding of each aspect of the procedure including the shape of the computation mesh (topology), the generation and control of the model need at least 90 minutes. If we use about 1.000.000 knots, computation time per each updated CPU is equal to 8 hours. The same process with the panel code takes 5 minutes for model generation (600 panels) and 25 seconds for the simulation, yielding very competitive results. In the example above, in the same amount of time needed for a RANS solution, the panel codes can produce around 100 geometries. Another major problem that is often underestimated is the study of the independence of mesh result. It is clear that a study as the above-needing a large number of computations-is better performed with the panel codes, due to the speed of execution. On top, it is possible to use a multitude of panels, that is impossible to do with the RANS solutors.

Viscous Computation

The discretization of the boundary layer is a basic issue when using the RANS solutors.Even if today it is a common practice to use wall functions, thus avoiding the modeling of the flux next to the wall, in order to achieve an accurate result it is always necessary to model the laminar substrate correctly. The latter further complicates the computation, besides the need to check the correctness of the values of characteristic parameters (Y+) with at least one trial computation, especially when multi-equations turbolence models are used. Last, when using RANS codes, we are facing the problem of univocity of results. Beside the problem of solution convergence –in same cases the solution, even if slowly, continues to evolve and obtaining a stable solution can take a long time-there is a problem of univocity of result with the same mesh, upon variation of the turbolence model. It is no news that a k-epsilon model, a Baldwin-Barth or Spalart-Allmaras model, applied to the same grid upon a geometry that develops a separation bubble, yield quite different results. The lack of experimental data can cause serious hardship to the user.

System Economicity

It is well known that the RANS codes request very updated hardware, CPU, RAM and HD. The CPU must be the latest version to reduce computation times. The RAM must be maximized for the need to model each detail of the cosidered body. The need reflects in the amount of cells to be used, currently we can speak of an average of 6 million cells , and in same areas we can reach 25 million.

Each code requires from ½ megabyte to 2 per cell, depending on the solutor, so the Ram is widely used. The hard disk, given the amount of information per computation must be quite large, each computation needs 100Mb and therefore it is necessary to analyze 30 configurations to enable the user to file during the design project.

With the panel codes , an average CPU is enough to guarantee an excellent analysis. In order to compute a detailed geomentry(18 000 panels), 1 Gigabyte of RAM is sufficient, and 10 free gigabytes on the hard disk allow to perform a whole design and file it on the hard disk upon completino.

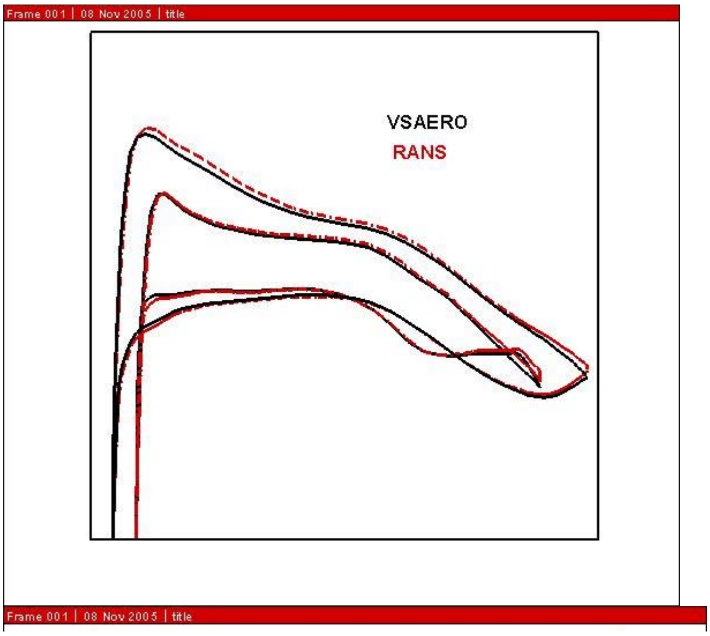

Fig.2 Distribution of pression along the wing cords

Efficacy of project loop 1

One of the main characteristics that a design tool must possess is the capacity to modify geometries quickly. Most of the RANS solutors should be considered tools of analysis -because of the long time required for computation-and they do not allow modifications of geometries that must be performed using external routines or CAD softwares-and expert designers, or using grid generators with parametric capacities e.g.GRIDGEN by Pointwise Inc. However, this requires preparation of complex scripts for automatic regeneration of the mesh, not easy to implement. VSAEROallows to work on the geometry by directly modifying the input file, having inside interpolation routines and an organization of the data base that allows geometric transformations such as rotations, traslations, scaling, all on different hierarchical levels of geometries. For example, it is possibile to quickly study variations of plants, sections with respect to one or more axis, reciprocal positioning in different parts of geometry, and rotation of mobile parts.

Efficacy of project loop 2

Another characteristics of the design tool that is utmost appreciated by the designer(a professional who doesn't just define a functioning shape, but the best possible shape), is the stability of numbers representing the performance assigned to each modification. In the case of the RANS codes, applied to geometries that develop separated fluxes in ares of no interest to the design, to obtain costant values identifying the performance,is certainly a complex issue It is therefore an hazard to compare the different geometries, unless comparison criteria are used that filter results oscillations. In the case of VSAERO the possibility to simulate separated areas that are not included in the project, even with approximation,and to verify convergences for the part of geometry of interest, allows to eliminate result uncertainty.

Quantification

In order to support what has been said until now, we will consider a standard example for the aerospace world: a complete aircraft modeled by the average user (with at least 1 model experience). Times of generation of the model can be quantified in:

-20 working days for the **RANS** model of 2.5 million cells; 5 days for preparation of the same model using the **panel code** (18000)

-preparation of input does not have any impact to time expenditure

5 days of computation on each CPU for the **RANS,** 4 hours for the panel code.

Applying the different costs as per in *table 2* where

-training costs have not been considered for the human resources

-only the cost of 1 single licence has been considered for RANS (computation on single CPU)

-the hardware taken into consideration are the latest set up for the RANS solutor, and an intermediate hardware for VSAERO, depreciated over a 3 years period.

The graph below (Fig 3)clearly shows that a computation using the RANS code is 5 times more expensive than with a panel code

Costo Orario in Euro	Navier Stokes	VSAERO
Risorse Umane	30.00	30.00
Software	15.71	16.00
Hardware	0.70	0.50

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Conclusions

Is is evident that the panel codes represent a very useful design tool, now and in the future, and a strategic choice when designing attached or moderately separated fluxes, and moderately comprimable or not-comprimable fluxes.