Automatic Prediction of laminar/turbulent transition in an unstructured Finite Element Navier-Stokes Solver.

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With the rising fuel costs and environmental requirements getting more stringent, aircraft manufacturers are investigating the potential of new technologies in aircraft design to address this trend. Integrating transition from laminar to turbulent regimes in CFD solver is one of the major problems these last decades. Taking it into account will allow in a first time to accurately predict friction drag and in a second time through laminar design to reduce significantly the aircraft drag (In theory around 15% of drag reduction could be reached). In free-flight conditions (low external turbulence and noise levels, good surface quality) the transition is said to be natural and is determined by an identified mechanism. External disturbances or small average surface roughness will activate a phenomenon called receptivity [1]. Receptivity creates modes in the boundary layer (noted B.L.) which are characterised by their frequencies and wavelengths. Two kinds of disturbances can lead to this natural transition: the Tollmien-Schlichting (noted T.S.) waves linked to the longitudinal velocity profile and amplified by a positive pressure gradient, or the crossflow (C.F.) instabilities generated by the crossflow velocity profile. These disturbances will be amplified in the streamwise direction until they reach a critical amplitude and trigger the transition to turbulence. The natural transition can be determined using semi empirical criteria based on the integral values of the B.L. For instance, Onera developed the AHD criterion for T.S. induced transition [2], the C1 criteria [2] for CF induced transition and a more sophisticated transition prediction tool called the database method [3] able to predict transition onset due to both T.S. or C.F. amplification.
This paper presents the state-of-the-art of the transition prediction numerical chain which has been developed at Dassault-Aviation (noted D.A.) during the last two years in the RANS solver AETHER [4]. This includes the transition criteria listed above. Two strategies for transition location estimations exist. First, AETHER is coupled with the Onera B.L. code 3c3d [5]. Second, the transition location is computed by using directly the RANS velocity profiles. Both methods were preliminarily tested in subsonic and transonic conditions for a laminar airfoil of a generic future Falcon business jet.
Dealing with the first strategy, the first step was to make an efficient data transfer between the solvers AETHER and 3c3d. The velocity field at the B.L edge is extracted using entropy variation along the normal to the surface. A B.L. computation is then performed and transition criteria (AHD, C1 or Database method) are applied to B.L. velocity profiles. Even though this strategy is restricted to attached flow, the convenience of using a B.L. code allows to reduce significantly the number of nodes in the near wall region, which has obviously a positive effect on CFD computing time.

Applying the first strategy, the preliminary computations have shown a discontinuity in the pressure coefficient distribution corresponding to transition location. This numerical artefact was due to the sharp transition between laminar and turbulent flows and could artificially freeze the transition position. This has been overcome by developing a strategy using an intermittency function noted γ (ex: Arnal & Coustols [6]) which drives the effective viscosity term μ_{eff}. The intermittency function has multiple advantages: it smoothes the numerical artefact, improves the convergence of the computation and matches better the physics itself.
The second strategy consists in using directly the N.S. velocity profiles to calculate the transition location. It also allows us to anticipate for the future coupling of AETHER with an exact stability solver instead of the database method. Besides, short-circuiting boundary layer computation and applying directly transition criteria on N.S. velocity profiles will allow addressing transition process in separation bubble [7].
In order to directly apply the transition criteria onto N.S velocity profiles it is absolutely necessary to have a good mesh quality to determine correctly the gradient and inflexion points of B.L. velocity profiles. Presently, there are three possible methods available at D.A.

- The first method is to uniformly refine the mesh in the B.L. by decreasing the first-layer thickness. This method has the tendency to over refine the turbulent B.L. by far.
- The second method uses a variable first-layer thickness. It needs an accurate estimation of the boundary layer thickness. If the natural transition locations between two coupled iterations are too far away from one another, the mesh cannot be re-used. Nonetheless, the problem of over refining turbulent B.L. is solved.
- The third method consists in using higher order finite elements [8] for AETHER RANS computations. By keeping the same degree of freedom as in the lower order method, it has been shown that the use of P2 elements seemed to be promising.

The paper will include comparison between the two strategies. Convergence problem as well as optimization of meshes for laminar/turbulent transition prediction will be discussed. Moreover, the presentation will include results on a Falcon generic business jet in flight subsonic and transonic conditions.

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