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LAMINAR-TURBULENT TRANSITION MODELLING IN CFD: LIMITATIONS, ALTERNATIVES AND NEW APPROACHES

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ABSTRACT

With the vision of the virtual aircraft [1] and the concepts of qualification by analysis (QbA) and certification by analysis (CbA) [2] laminar-turbulent transition modelling in computational fluid dynamics (CFD) has become a topic of much ongoing research. Available transition models are being implemented in many CFD codes which often form part of large multi-disciplinary simulation environments. The results obtained with these models are the basis of verification and validation activities presented and discussed on workshops and conference special sessions.

For achieving the goals within the virtual aircraft vision the simulation results predicted by a model must be of reliable accuracy and also its technical application in a code must be reliable. In addition, all major transition mechanisms and related effects must be covered over a wide range of flow conditions. For existing models the physical and technical limitations must be known, the application range must be extended or alternative approaches have to be developed and new fields of application, for example, hybrid-laminar flow control (HLFC) or scale-resolving simulations (SRS), have to be tackled.

Besides approaches which take into account the non-local nature of transition prediction models based on, for example, correlation-based transition criteria or e^N methods, requiring integral boundary-layer data and/or integration paths [3], PDE-based methods have been developed which can make use of the same numerical algorithms as the Reynolds-averaged Navier-Stokes (RANS) equations and, thus, comply with the requirements of unstructured flow solvers and can fully exploit the advantages of massive parallelization.

Prominent examples of this latter model class are local-correlation models, as the γ-Re_θ model [4], the amplification factor transport (AFT) model [5] or the physics-based laminar kinetic energy approach [6],[7]. The γ-Re_θ model has been adopted in many CFD codes, including commercial, research organisation and academic codes and was extended to cover crossflow transition [8],[9] that was not contained in the original model formulation.

All these models suffer from specific limitations and/or deficiencies and a number of approaches have been developed to overcome them. The γ-Re_θ model has been reduced to different γ models [10],[11], the crossflow extensions for the γ-Re_θ model were coupled to other models [12],[13], and the AFT concept was extended to a band of tracked frequencies and to crossflow transition [14]. In addition, transition models are being coupled to SRS methods such as hybrid RANS-LES methods (HRLM) [15],[16].

An accurate description of the transitional zone, the intermittency region, is also of importance [17], all the more, it may cover an extended region as, for instance, on laminar airfoils. The modification of the mean flow by instabilities such as stationary crossflow of Klebanoff mode is also of interest in turbomachinery applications where wall-thermal exchange is important. In the same way, the influence of wall temperature (de-icing, wall cooling of turbine blades [18]) should be taken into account in CFD computations.

The transition prediction in hypersonic flows also appears as a challenging topic [19].

This Minisymposium addresses the current and future challenges of CFD transition modelling approaches and emphasizes the recent status of known model limitation, current developments to overcome them, and emerging new approaches and application regimes. The Minisymposium should/would cover the following aspects:

- Application limitations of current transition modelling approaches/techniques
  - ***Physical limitations:*** Where do *state-of-the-art* approaches fail? How do they fail? What is needed to fill the gaps? …
    - Missing transition mechanisms in specific models
    - Limited application range (e.g. with regard to the Reynolds number, …)
    - Specific transition-related physical phenomena requiring special treatment (e.g. laminar separation bubbles, …)
    - Description of the intermittency region
    - Influence of mean flow distortion (by crossflow waves, Klebanoff streaks) on modal instabilities
  - ***Numerical limitations:*** In which situations are current transition modelling approaches not reliably applicable from a technical point of view?
    - Robustness
    - Application effort (e.g. grid requirements, computing costs, ...)
    - Ease of use, user friendliness, user acceptance
    - …
- New and alternative approaches: Which ways are gone to overcome the limitations?
  - Alternative concepts or extension of existing concepts
  - Alternative model formulations:
    - Additional transition mechanisms (e.g. separation induced transition, by-pass transition, attachment-line transition/contamination, relaminarization, …)
    - Different/extended/refined formulation of the equations
  - Roughness effects (streamwise and crossflow transition)
  - …
- Hybrid Laminar Flow Control: Current *state-of-the-art* with regard to HLFC
  - Which methods/approaches are applied?
  - Validation of transition with suction (streamwise and crossflow transition)

    - …
- Scale-resolving simulation (HRLM, SAS) with laminar-turbulent transition: Current *state-of-the-art* with regard to SRS?
    - Which methods/approaches are applied?
    - Validation
    - …
- PSE in CFD solvers: Current *state-of-the-art*
    - Which methods/approaches are applied?
    - Validation
    - …

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