CFD SIMULATION OF DEEP STALL CONDITION ON THE SWEPTBACK WING

Peter GAŠPAROVIČ[1]

Abstract: *A deep stall, a dangerous flight condition, affects aircraft with certain sweptback wing designs. The paper presents preliminary phase in exploring the deep stall condition by CFD (Computational Fluid Dynamics) methods. The preliminary phase should verify the ability of CFD methods to confirm existing experimental data of the sweep and taper parameter combinations of the wing. The same methodology could be then used to explore the effect of the next parameter, wing twist, on deep stall condition.*

Keywords: *deep stall, pitch-up tendency, sweptback wing, CFD*

1. INTRODUCTION

Deep stall requires stable longitudinal trim point beyond the stall [1]. Such condition may be caused by normal action of longitudinal control, but the interest into the deep stall is motivated by different scenario when the same position of controls correspond to two stable trim attitudes – the first, intended, attitude (unstalled) and the second attitude which is beyond the stall. After exceeding the angle of attack beyond the zero pitching moment, the aircraft exhibit pitch-up tendency toward the second stable trim attitude (fig. 1). The most dangerous is the case when the deep stall condition exists even with the full nose-down controls, when the longitudinal controls are insufficient to nose the airplane down to an unstalled attitude. Such condition is also called locked-in deep stall [1, p. 209].

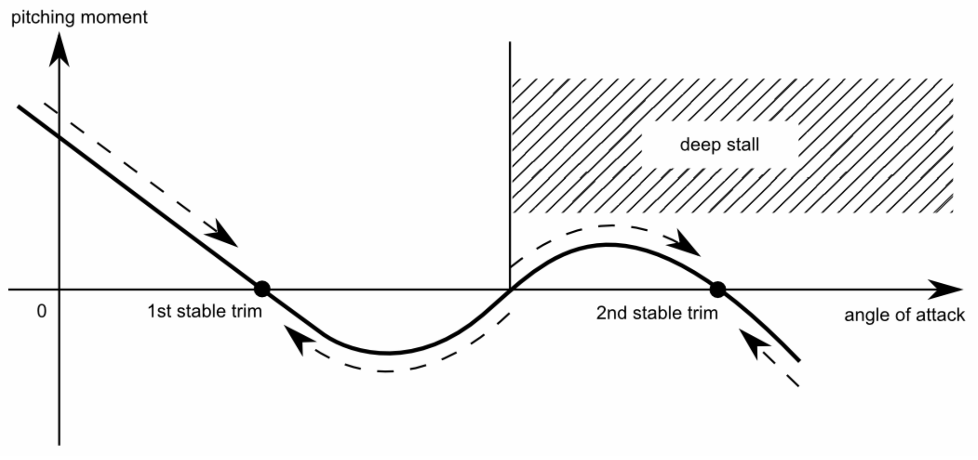

Figure 1 Pitching moment curve with the deep stall behaviour

The most known causes of deep stall condition are:

- pitch-up tendency at the stall of some sweptback shapes of the wing
- tip stall of sweptback wing in combination with T-tail surfaces (e.g. Tu-154 – see fig. 2)
- leading edge extensions (LEX) in modern fighters (e.g. F-16)

We restrict our interest only to the first cause (important for the design of tailless aircraft). The normal behaviour of wing section (or infinite wing) at stall is sudden pitch-down about aerodynamic centre (a.c.), i.e. highly negative pitching moment (in respect to the right wing lateral axis). Negative increment of pitching moment with the angle of attack (a.o.a.) has stabilizing effect on flight attitude. Some shapes of the sweptback wing lack this tendency and some others exhibit opposite behaviour – pitch-up tendency. Pitch-up tendency with increasing a.o.a. has destabilizing effect. Two NACA reports mapped the stable and unstable regions of two parameters of the sweptback wing – aspect ratio

---

[1] - Ing.; e-mail: pgasparovic@gmail.com, Faculty of Aeronautics, TUKE, Rampova 7, Kosice, SLOVAKIA, phone: +421 918 717 445

(AR), and sweep angle at quarter chord of the wing ($\Lambda_{c/4}$). The latter – NACA Report 1339 [2], added the third parameter – taper (λ).

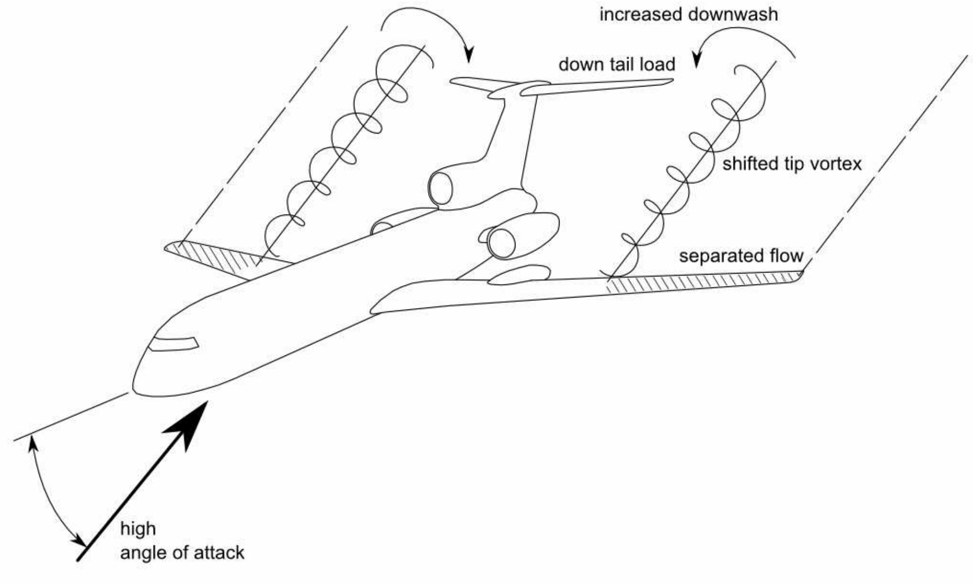

Figure 2 Deep stall of the T-tail configurations

The pitch-up tendency is usually alleviated by properly sized tail surfaces, but tailless aircraft don't have this possibility. Longitudinal controls of tailless aircraft have small moment arm (in comparison with the moment arm of classic tail surfaces), and simple calculation shows, that small arm is insufficient for decreasing pitch-up tendency (fig. 3).

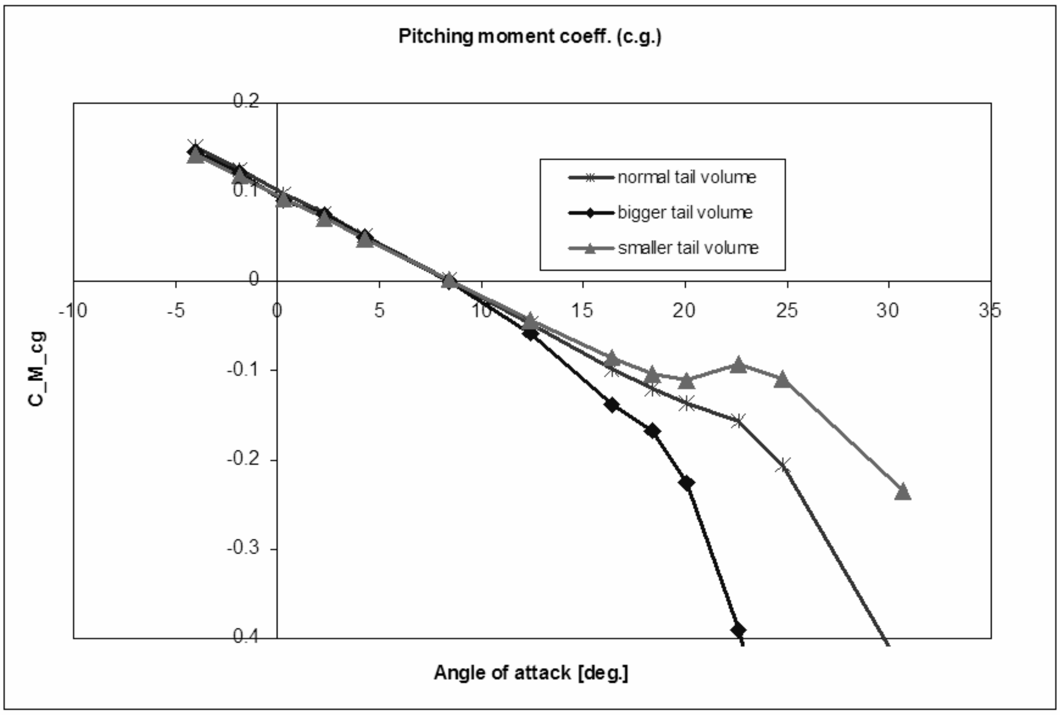

Figure 3 Effect of tail surface and arm (volume) on the shape of pitch curve

There are other ways of elimination of pitch-up tendency of sweptback wing. One of them is wing twist. Wing twist is another parameter of the shape of the wing which could be added to systematic investigation of stable and unstable shapes of sweptback wing. Contrary to the latest published investigation [2] which was based on older experimental results (till the year 1957), the more efficient way of performing such investigation in present time would be by means of the Computational Fluid Dynamics (CFD) analysis. At first, it is needed to verify, that CFD method is able to reproduce the same results as experimental data, which the investigation is based on. One of the sources are tunnel measurement published in NACA report 572 [3]. It contains measurement of three sweptback configuration, and one of them is unstable configuration named “airfoil 24-30-0”.

2. DESCRIPTION OF CFD SOLUTION

Geometric model was based on the common parameters of all configuration (aspect ratio, taper, dihedral). The sweep angle at the quarter chord ($\Lambda_{c/4}$) was chosen 26.57° ($\tan \Lambda_{c/4} = 0.5$). Resulting shape of the model is on fig. 4.

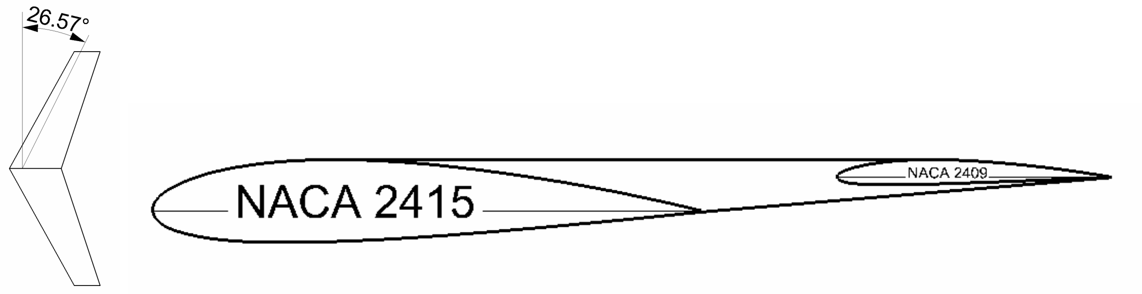

Figure 4 Geometric model of the wing analysed by CFD

Structured mesh was created by ICEM CFD software. The volume between outer surface of the wing and exterior surface (separated by distance of 15 root chords) is divided to 4 hexa-blocks with O-topology, connected outside the span of the wing to another 4-hexa-blocks which together with the central hexa-block abut to wing tip flat surface (see fig. 5). The resulting mesh contains 484 000 hexahedrons, and the cells adjacent to surface wing achieve $y^{+}_{max}=0.6$.

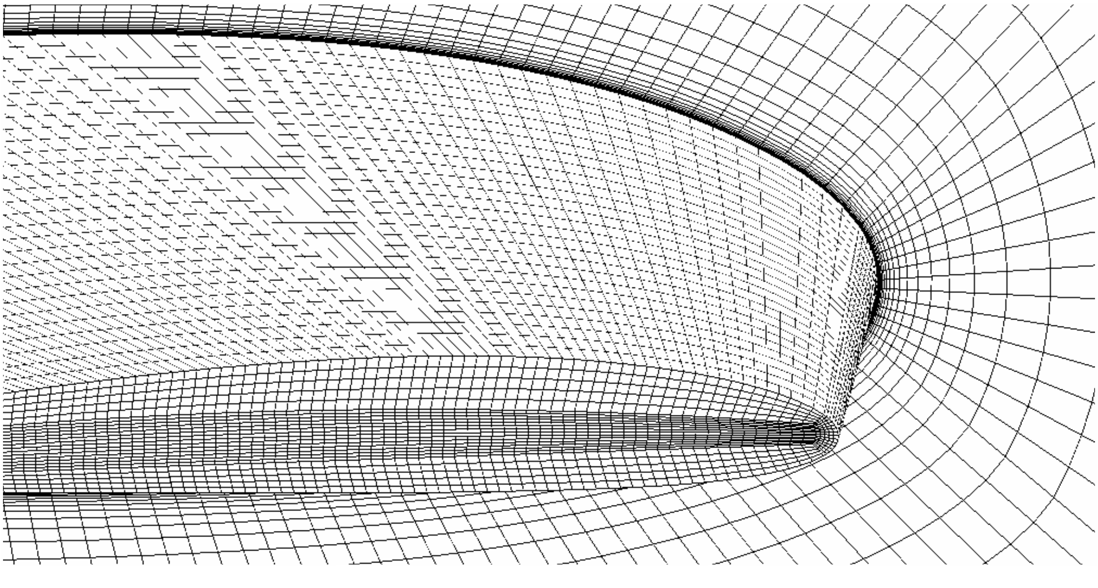

Figure 5 Structured CFD mesh with O-topology

CFD computation was performed with Ansys CFX. The physical model was: incompressible, turbulence model k-omega SST with gamma-theta transition of boundary layer. Convergence of the solution was monitored by integral parameter (pitching moment), and solution was stopped approximately after 100 iterations and 4 hours of CPU time (Intel P4) at each of 9 runs (correspond to 9 angles of attack which were investigated).

3. RESULTS AND DISCUSSION

Pitch moment coefficient curve calculated by CFD is shown on fig. 6 together with the experimental results. Although the geometry of CFD case and geometry of experimental case are not exactly the same, the CFD results show very similar pitch-up tendency as the experimental data. Moreover the details of the surface flow gained from CFD results (fig. 7) provide insights on the cause of the changes of pitching moment at various a.o.a. Therefore, the CFD method can be successfully applied to investigation of the effect of wing twist on pitch-up characteristics of sweepback wing.

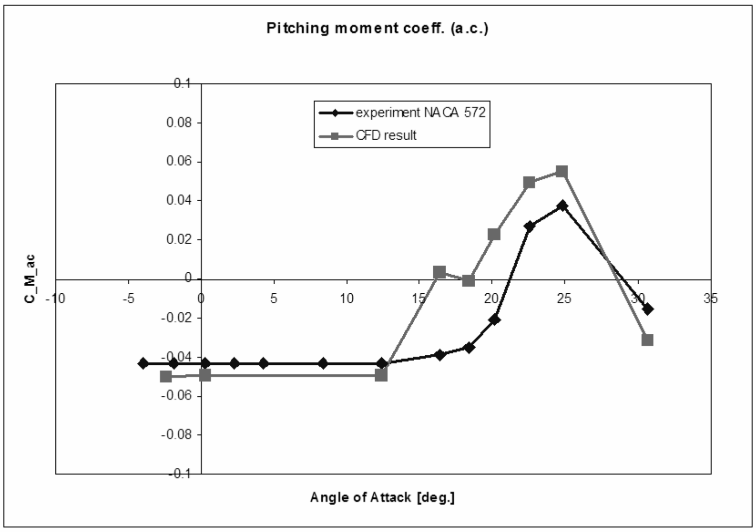

Figure 6 Comparison of experimental and CFD results

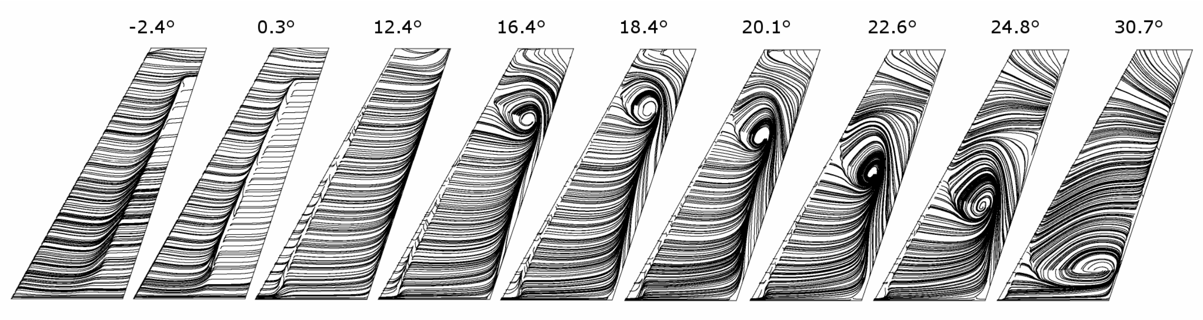

Figure 7 CFD calculated development of surface flow and separation with the angle of attack

REFERENCES

1. Abzug, M. J. and Larrabee, E. E.: *A Airplane Stability and Control.* Cambridge University Press, 2002. 414 p. ISBN 0521809924
2. Furlong, G. C. and Mchugh, J. G.: A summary and analysis of the low-speed longitudinal characteristics of swept wings at high Reynolds number, NACA Technical Report 1339, 1957. 150 p.
3. Anderson, R. F.: Determination of the characteristics of tapered wings, NACA Technical Report 572, 1936. 20 p.

Reviewer: Assoc. Prof. Ing. Dušan Neštrák, CSc., Dusan.Nestrak@tuke.sk, Faculty of Aeronautics, TUKE, Rampova 7, Kosice, SLOVAKIA, phone: 0918 400 580