Validation of Unsteady CFD Solver with Experimental Data of Biconvex Airfoil at Supercritical Conditions

Hritam Nath[a] and Chaphalkar Aaditya Nitin[b*]

[a]Scientist/Engineer-SC,CFDD/ADSG/AERO,VSSC,Thiruvananthapuram, India

[b]Scientist/Engineer-SF,CFDD/ADSG/AERO,VSSC,Thiruvananthapuram, India

1. INTRODUCTION & OBJECTIVE

PraVaHa (Parallel RANS Solver for Aerospace Vehicle Aerothermodynamic Analysis) is the finite-volume CFD solver developed by Vikram Sarabhai Space Centre - ISRO, with the vision of creating an indigenous CFD solver at par with commercial codes, while catering to ISRO's specific requirements of aerodynamic analyses. It solves the Reynolds Averaged Navier Stokes (RANS) equations on unstructured, solve-to-wall type body-fitted meshes for 3D, 2D and axisymmetric simulations in subsonic to hypersonic regime – with multi-core functionality for usage in High Performance Computing clusters.

As a part of development, it is crucial to validate the solver's performance in unsteady simulations against experimental results. One such case is identified from the NASA report in Ref. [1], where supercritical flow over an 18% thick biconvex circular-arc airfoil has been investigated experimentally, over a range of freestream Mach numbers, angles of attack and Reynolds' numbers. In this paper, we have considered only Mach number variation.

2. METHODS OF ANALYSIS

- The simulations have been run on VSSC's PF HPC facility, using the unsteady (URANS) mode of PraVaHa utilizing a dual time-stepping approach - the inner loops with an implicit scheme (SGS) and local time-stepping while the outer loops (time-accurate) with Euler explicit scheme and global time-stepping.
- Simulations are run with 80 inner iterations for each global timestep, with a CFL of 50 (for inner iterations) and under-relaxation parameter of 0.95 with second-order accuracy and SST k-ω turbulence model. Grid convergence and timestep convergence have been validated.
- Every Mach number case has been initialized with the limit cycle solution of the previous one with small increment (~0.005) to mimic the slow increment ($\partial M_\infty/\partial t = 0.001$) in the experiments. 40 initial flow-through times based on chord length have been discarded to eliminate initial transients.

3. RESULTS AND/OR HIGHLIGHTS OF IMPORTANT POINTS

- The comparison between CFD and experiments in fig 1 shows the periodic shock-movement at **M 0.76, Re = 11e+06** over a time period. Shock-induced BL separation can be observed.
- Surface pressure fluctuations ($\Delta p/p_0$), C_p on upper surface, shock location (x_{SH}/c) and reduced frequency of pressure fluctuations ($\bar{f} = \pi f c/U_\infty$) have been extracted.
- Unsteadiness persists even at M 0.80 while experimentally flow was observed to become steady at ~0.778.
- $\bar{f}$ varies almost linearly from 0.475 at Mach 0.745 to 0.465 at Mach 0.775, while from CFD it is almost constant at 0.50 over Mach 0.745 to 0.778.

4. CONCLUSIONS

- In general the separated flow and the associated shock location are captured (Fig. [1]).
- PraVaHa predicted the onset of unsteadiness reasonably well (**M 0.745 vs 0.76 in experiments**). The same was observed to be between 0.73 and 0.74 in 5 different CFD codes in Ref. [3].
- Frequency of flow oscillation is also predicted within 7%.
- Pressure fluctuations beyond x/c=0.5 are not captured well in CFD (Fig. [2]) – will be further discussed in the full paper.

5. REFERENCES

[1] John B. McDevitt, "Supercritical Flow About a Thick Circular-Arc Airfoil"- NASA-TM-78549 19790008629.

[2] McDevitt *et. al.*, "Transonic Flow about a Thick Circular-Arc Airfoil" – AIAA Vol 14 No 5, May 1976.
[3] Bradford et. al, "Evaluation of Flow Solver Accuracy using Five Simple Unsteady Validation Cases" – AIAA, AIAA-2011-0029.

Hritam Nath, hn00india@gmail.com : Chaphalkar Aaditya Nitin, aaditya.chaphalkar@gmail.com

---

* Communicating Author: Second Author Name and email id.

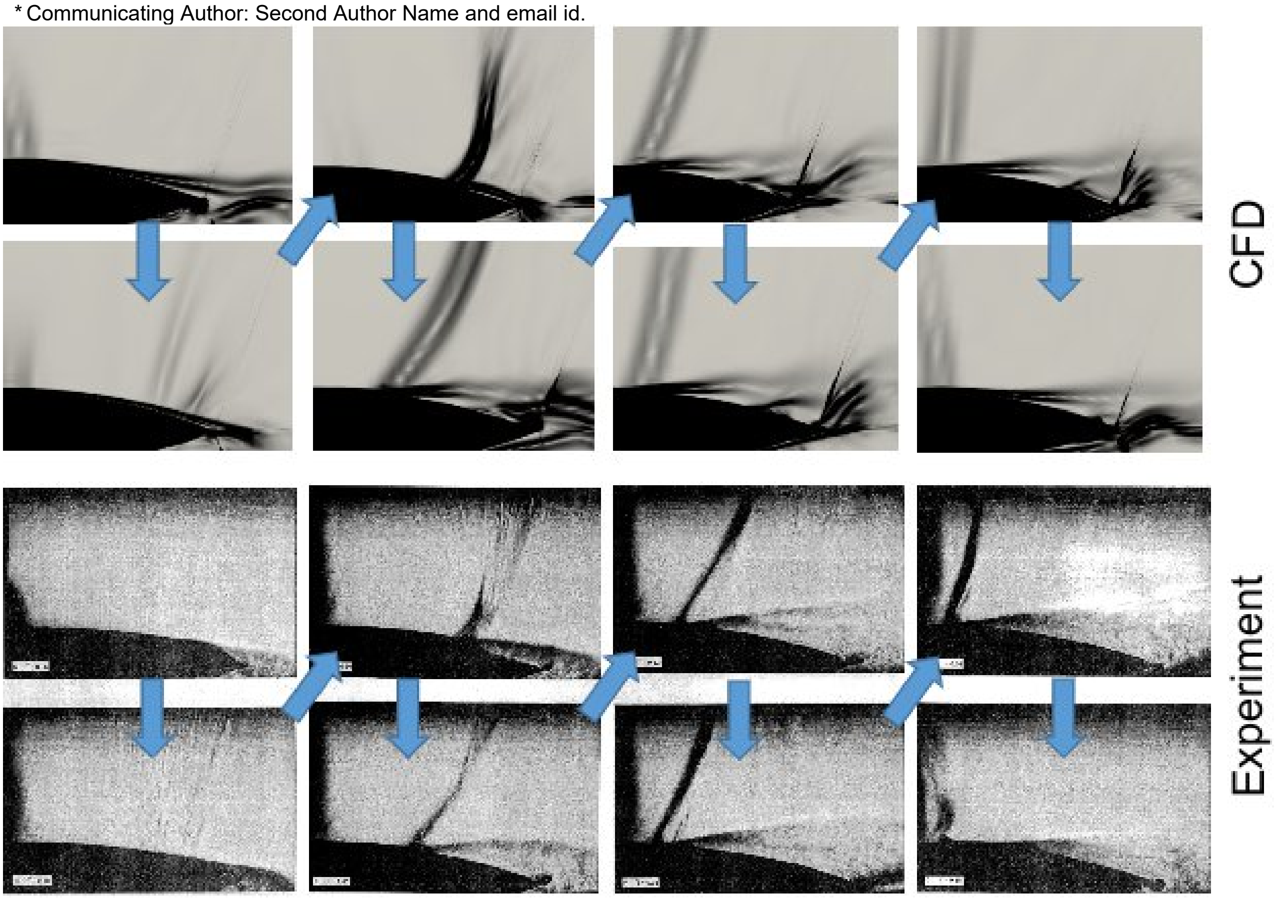

Figure 1: Shadowgraph Comparison at M_∞=0.76, Re=11e+06 near Trailing Edge

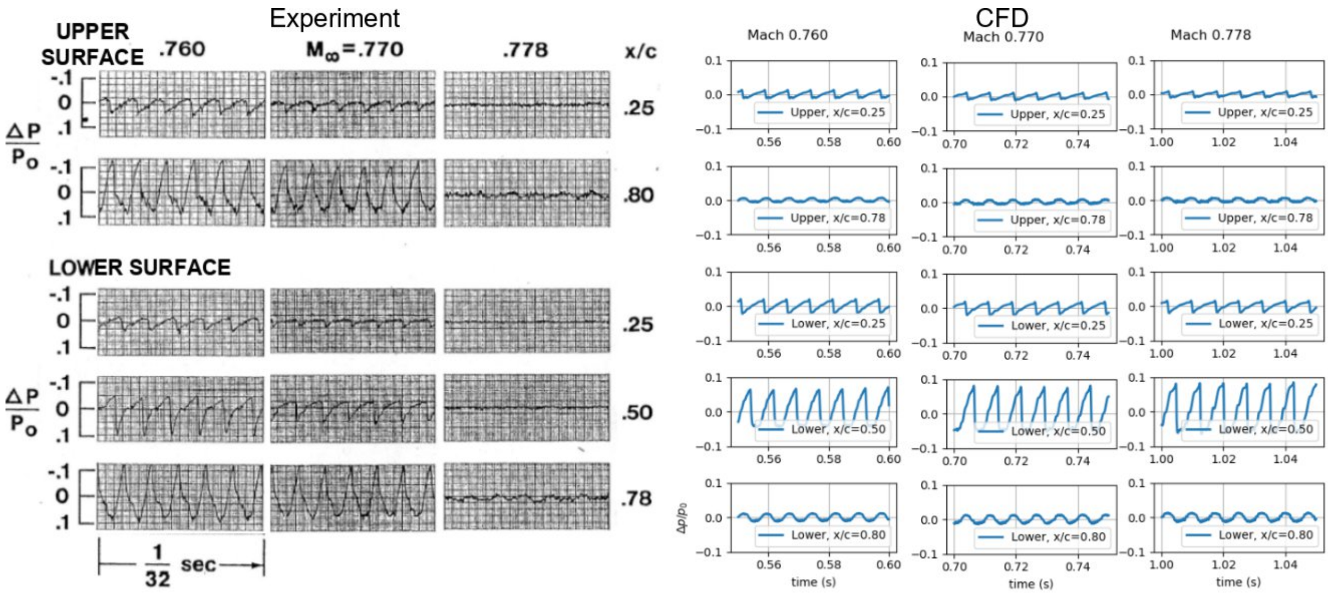

Figure 2: Pressure Fluctuation Comparison