Analysis of Low-Speed Stall Aerodynamics of a Swept Wing with Seamless Flaps

Trong T. Bui
NASA Armstrong Flight Research Center
Edwards, California 93523

¹Aerospace Engineer, Aerodynamics and Propulsion Branch
Presentation outline

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  • CFD strategy for generating wing lift curves

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ACTE aircraft description

• NASA GIII Tail No. 804:
  • Subsonic Research Aircraft (SCRAT) – Extensively instrumented for subsonic jetliner-class flight research
  • Adaptive Compliant Trailing Edge (ACTE) – Conventional GIII flaps replaced by experimental compliant ACTE flaps
STAR-CCM+ CFD Methodology

• Implicit, coupled steady flow solver with perfect gas air model
• 2nd-order spatial discretization with Hybrid Gauss-LSQ reconstruction
• Roe FDS with Venkatakrishnan limiter
• Symmetry plane used for half-wing CFD simulations
  • No aircraft fuselage
  • No landing gear
• Mesh sizes range from medium (39 to 50 million cells) to fine (61 to 76 million cells)
• Spalart-Allmaras one-equation turbulence model
• Low-y+ wall treatment without wall function
  • Typical near-wall y+ values around 0.2, ranges from 0.05 at TE to 0.4 at LE
  • 19 (medium) and 23 (fine) prism layers were used within a normal distance of approximately 2.2 inches from the wall
• Overset meshing required for ground-effect CFD simulations
Overset mesh strategy for ground effect analysis
CFD strategy for generating wing lift curves

1. Start the AoA sweep with a CFD simulation of the wing at a small initial AoA value
2. After the lower AoA-value solution converges, increase the AoA to the next higher value
3. Restart the new higher AoA simulation from the previous converged lower AoA solution
4. Repeat steps 2 and 3 above until wing lift is lost indicating wing stall has been reached
5. Repeat step 4 from the last maximum lift solution, but with an AoA increment that is half as large as the previous AoA increment
6. Repeat step 5 above keep decreasing the AoA increment until the desired tolerance of AoA increment is reached

- With large values of AoA increment or large values of initial AoA, premature CFD wing stall occurred
- Starting AoA increment value was 2 deg
- Last AoA increment value was 0.5 deg
- Therefore, our stall solution is within 0.5-deg AoA tolerance
- We could use even smaller AoA increment if necessary
CFD grid convergence results – free air

The graph shows the lift coefficient ratio ($C_{L}/C_{L_{max}}$) as a function of angle of attack (deg.). The lines represent different angles of attack and grid resolutions:

- **Clean wing (medium)**
- **N2-deg ACTE (medium)**
- **15-deg ACTE (medium)**
- **30-deg ACTE (medium)**
- **Clean wing (fine)**
- **N2-deg ACTE (fine)**
- **15-deg ACTE (fine)**
- **30-deg ACTE (fine)**

The graph indicates that as the angle of attack increases, the lift coefficient ratio decreases, with different trends observed for medium and fine grid resolutions.
CFD grid convergence results – ground effect

The image shows a graph plotting the Lift Coefficient Ratio ($C_L/C_{L_{\text{max}}}$) against the Angle of Attack (deg.) for different flap configurations. The graph includes lines and markers for:
- Clean wing flap (medium)
- 15-deg ACTE flap (medium)
- 30-deg ACTE flap (medium)
- Clean wing flap (fine)
- 15-deg ACTE flap (fine)
- 30-deg ACTE flap (fine)
ACTE CFD Wing Stall Results

The diagram illustrates the lift coefficient ratio ($C_L/C_{L_{\text{max}}}$) versus angle of attack (in degrees) for different conditions:

- **Clean wing ground effect**: Blue solid line.
- **15-deg ACTE flap ground effect**: Green dashed line.
- **30-deg ACTE flap ground effect**: Red dashed line.
- **Clean wing free air**: Blue dotted line.
- **15-deg ACTE flap free air**: Green dotted line.
- **30-deg ACTE flap free air**: Red dotted line.

The data shows how the lift coefficient changes with varying angles of attack under different configurations and environmental conditions.
a. Clean wing, AoA = 13 deg

b. 15-deg ACTE, AoA = 12.5 deg

c. 30-deg ACTE, AoA = 12.5 deg
Conclusions

• Grid-independent CFD results were obtained from the STAR-CCM+ code for the ACTE wing stall aerodynamics

• The 15- and 30-deg ACTE wings are predicted to stall at earlier angle of attack values than the clean wing. The negative 2-deg ACTE wing stalls at approximately the same angle of attack value as the clean wing

• Ground effect is predicted to decrease the stall angle of attack for all wings

• Ground effect is predicted to decrease the maximum lift coefficient for all wings

• Higher ACTE flap deflections are predicted to have less lift increase in ground effect than the clean wing

• Large flow separation region is predicted to occur directly above the ACTE flap and is responsible for the earlier wing stall