

Angle-of-Attack Sweep with Mesh Adaptation for High-Lift Configurations

Aravind Balan², Stephen L. Wood, Michael A. Park, W. Kyle Anderson
and Kevin E. Jacobson
Computational Aerosciences Branch
NASA Langley Research Center

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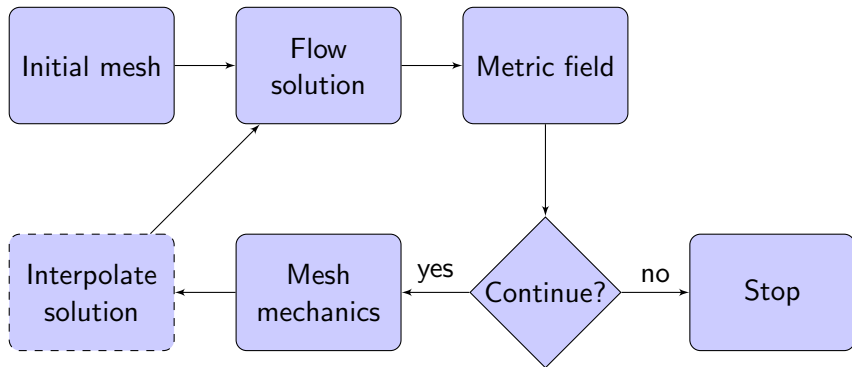
²Currently Asst. Professor at Indian Institute of Technology Bombay, India

Motivation

- RANS solvers have been the workhorse for turbulent CFD simulations
- Still a major challenge to simulate high-lift flows with sufficient accuracy
- Manually generated meshes may give insufficient mesh resolution near complex flow features
- Automated mesh adaptation has matured for adaptive simulations for complex geometries.³
- Adapts the mesh iteratively to control discretization errors, thereby resolving critical flow features

³F. Alauzet and A. Loseille. A Decade of Progress on Anisotropic Mesh Adaptation for Computational Fluid Dynamics, Computer-Aided Design, 2016

Mesh adaptation cycle



Mesh adaptation cycle components

- Flow solver: FUN3D-SFE⁴
- Metric field: Multiscale metric field⁵
- Mesh mechanics: *refine*⁶
 - ▶ Geometry access: EGADS⁷

⁴W. Kyle Anderson, James. C. Newmann, and Steve L. Karman. Stabilized Finite Elements in FUN3D, Journal of Aircraft, 2018

⁵A. Loseille et al. Achievement of Global Second Order Mesh Convergence for Discontinuous Flows with Adapted Unstructured Meshes, AIAA Paper 2007-4186, 2007

⁶M. A. Park and D. L. Darmofal. Parallel Anisotropic Tetrahedral Adaptation, AIAA Paper 2008-917, 2008

⁷R. Haimes and M. Drela. On The Construction of Aircraft Conceptual Geometry for High-Fidelity Analysis and Design, AIAA Paper 2012-683, 2012

Alpha continuation

- High-lift configurations at high angle-of-attack (α) may give multiple RANS solutions on same mesh⁸
- Alpha continuation can be done to avoid low-lift solutions⁹

⁸D. S. Kamenetskiy, et al., Numerical Evidence of Multiple Solutions for the Reynolds-Averaged Navier-Stokes Equations, AIAA Journal, 2014

⁹T. Michal et al., Anisotropic Adaptive Mesh Results for the Third High Lift Prediction Workshop, AIAA Paper 2018-1257, 2018

Approach

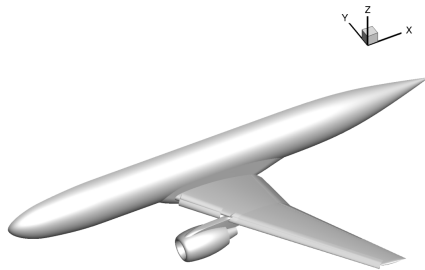
- Our approach: Alpha continuation + Mesh adaptation
 - ▶ Start with a low alpha on a coarse mesh, do mesh adaptations keeping the mesh size the same
 - ▶ During the process, interpolate the solution from the previous mesh
 - ▶ After certain adaptations, increase alpha by a step-size and continue the process
 - ▶ For those angles-of-attack of interest, do further mesh adaptation to larger meshes

Test Cases

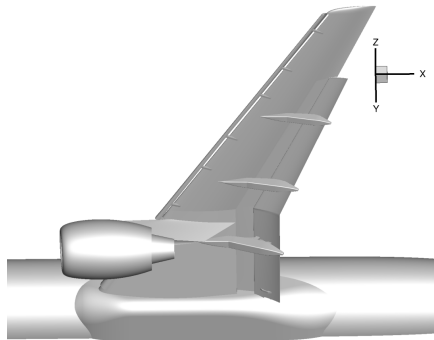
1. High-Lift JAXA Standard Model (JAXA-JSM)

- Test case from 3rd AIAA CFD High-Lift Prediction Workshop
- Flow conditions: $M=0.172$, $Re=1.93$ million
- RANS, SA-neg turbulence model

High-Lift JAXA-JSM



(a) Full view



(b) Wing

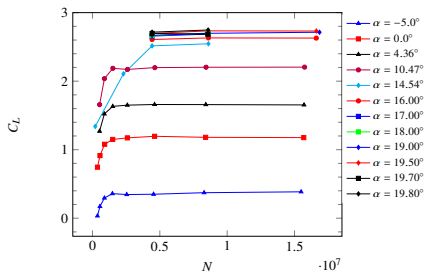
High-Lift JAXA-JSM

Approach

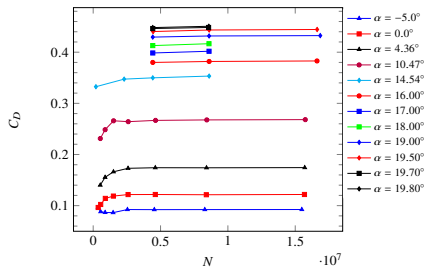
- For $\alpha = -5.0^\circ, 0.0^\circ, 4.36^\circ, 10.47^\circ, 14.54^\circ$, initialization using freestream values
- For $\alpha > 14.54^\circ$, alpha continuation is done, on 4 million vertices mesh, with 0.25° as the step size
- For those angles-of-attack of interest, further adaptations are done to larger meshes
- Starting from a post-stall solution, a reverse alpha continuation is also done, and observed a hysteresis loop

High-Lift JAXA-JSM

Mesh convergence study



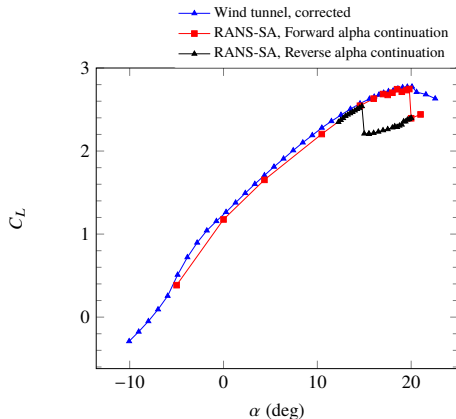
(c) Lift coefficient vs. No. of vertices



(d) Drag coefficient vs. No. of vertices

High-Lift JAXA-JSM

Final mesh adapted values

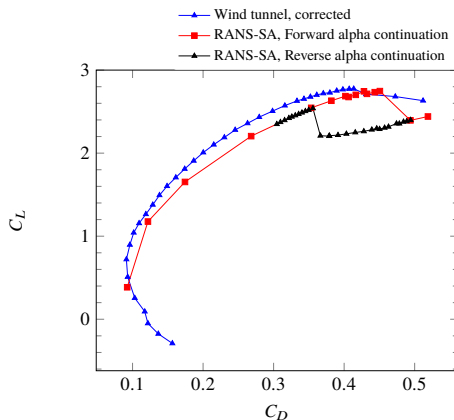


CFD: $C_{L,max} = 2.747$ at $\alpha = 19.80^\circ$

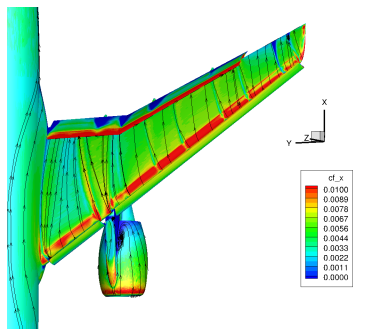
Exp: $C_{L,max} = 2.775$ at $\alpha = 20.09^\circ$

High-Lift JAXA-JSM

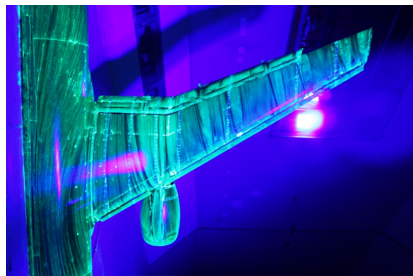
Final mesh adapted values



High-Lift JAXA-JSM

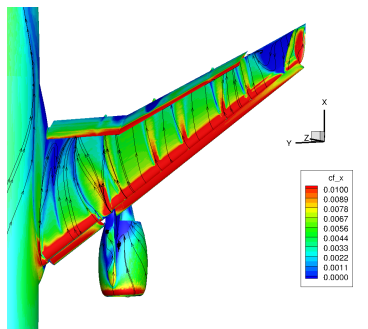


(e) Skin friction at 4.36°

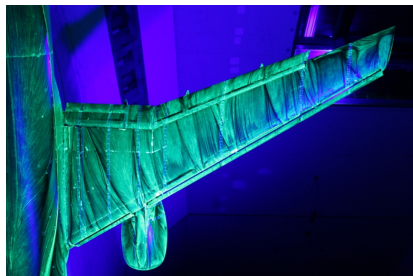


(f) Oil flow image at 4.36°

High-Lift JAXA-JSM



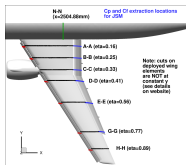
(g) Skin friction at 18.50°



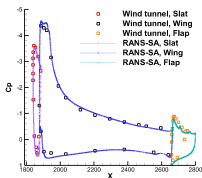
(h) Oil flow image at 18.59°

High-Lift JAXA-JSM

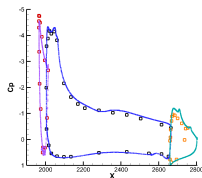
C_p at $\alpha = 18.50^\circ$



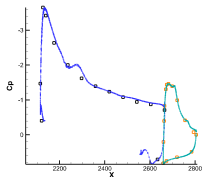
(i) C_p extraction locations



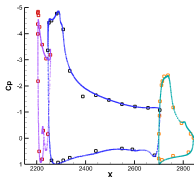
(j) A-A section



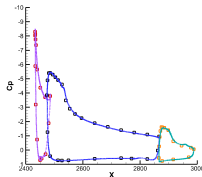
(k) B-B section



(l) C-C section



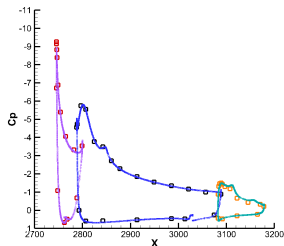
(m) D-D section



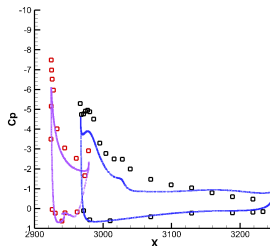
(n) E-E section

High-Lift JAXA-JSM

C_p at $\alpha = 18.50^\circ$



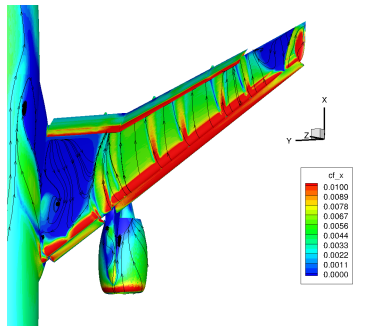
(o) G-G section



(p) H-H section

High-Lift JAXA-JSM

After the stall



(q) Skin friction at 20.00°



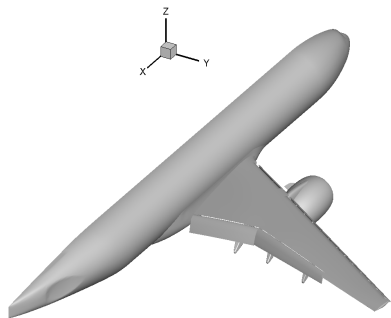
(r) Oil flow image at 21.57°

Test Cases

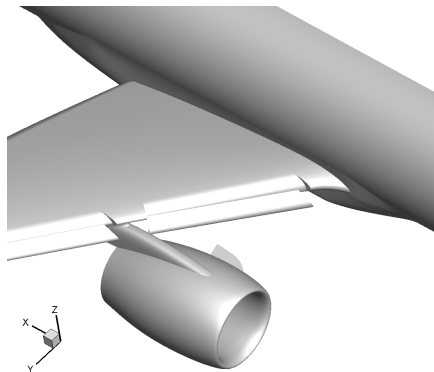
2. High-Lift Common Research Model (CRM-HL)

- Test case from 4th AIAA CFD High-Lift Prediction Workshop
- Nominal $40^\circ/37^\circ$ flap deflection setting
- Flow conditions: $M=0.2$, $Re=5.49$ million
- RANS, SA-neg turbulence model

High-Lift Common Research Model (CRM-HL)



(s) Full Geometry



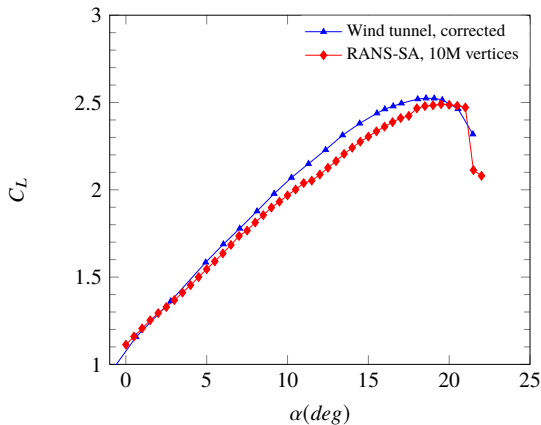
(t) Geometry near Nacelle

High-Lift Common Research Model (CRM-HL)

Alpha continuation from 0°

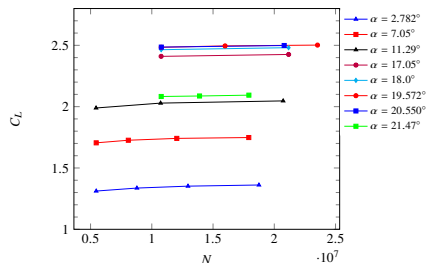
Meshes of 10 million vertices

Step size = 0.5°

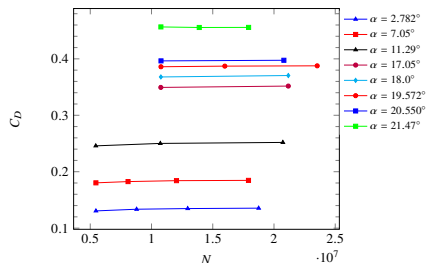


High-Lift Common Research Model (CRM-HL)

Mesh convergence study



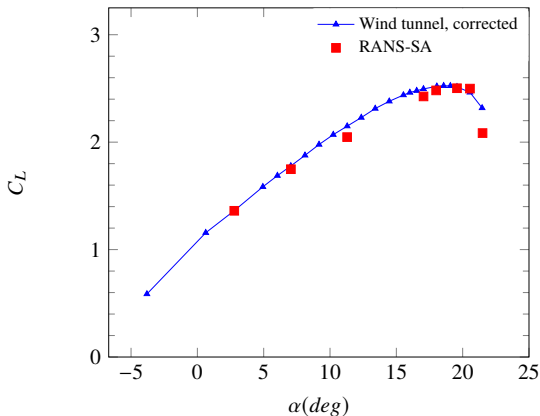
(u) Lift coefficient vs. No. of Vertices



(v) Drag coefficient vs. No. of Vertices

High-Lift Common Research Model (CRM-HL)

Final mesh adapted values



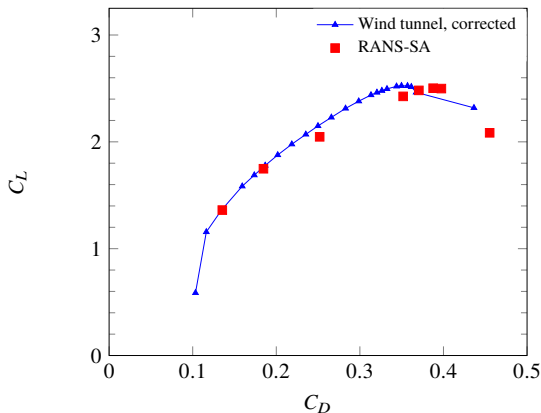
CFD: $C_{L,max} = 2.50$ at $\alpha = 19.57^\circ$

Exp : $C_{L,max} = 2.52$ at $\alpha = 18.57^\circ$

High-Lift Common Research Model (CRM-HL)

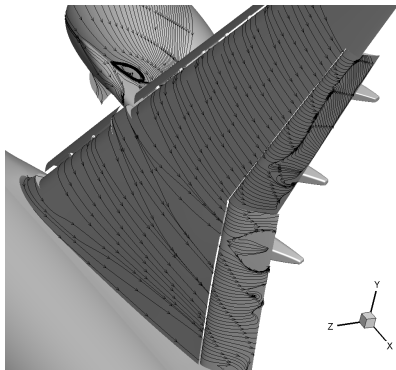
Final mesh adapted values

C_L vs. C_D

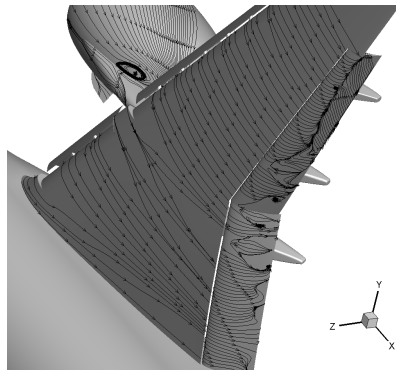


High-Lift Common Research Model (CRM-HL)

Streamlines at $\alpha = 7.05^\circ$



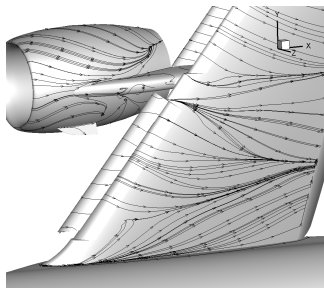
(w) Adapted mesh



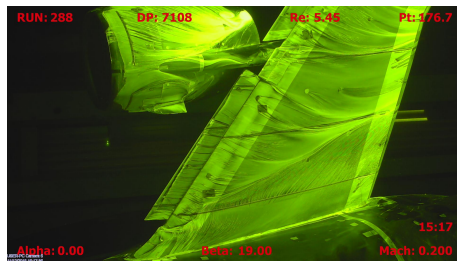
(x) Workshop mesh (30M)

High-Lift Common Research Model (CRM-HL)

Streamlines and Oil flow at $\alpha = 20.550^\circ$



(y) Adapted mesh



(z) Oil flow image

Summary

- Alpha continuation and mesh adaptation for JAXA-JSM and CRM-HL models
- Further mesh adaptation to larger meshes for angles-of-attack of interest
- Final mesh converged C_L values agreed fairly well with wind-tunnel until stall, and thereafter a sudden drop
- Overall flow patterns, using streamlines and skin frictions, looked consistent with oil-flow images
- For both models, the stall seem to have occurred due to massive flow separation near the wing-root, which is consistent with the experiments.

Future Work

Next Steps

- Different turbulence models: SA-QCR, SA-RC-QCR, etc
- Adjoint-based RANS error estimators and metric fields

Acknowledgment

Acknowledgment

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