HeldenMesh Grids

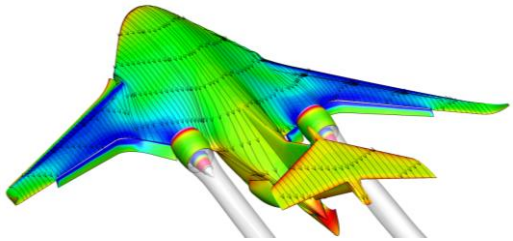
Effect of Slat Bracket Shape on RANS CFD Simulations for Case 1

Andrew Wick Rick Hooker

Slat Bracket Shape Effect

Helden Aerospace

- The current HLPW wind tunnel bracket shapes are difficult for RANS
  - Accuracy: Pizza slice separation on wing upper surface which is not observed in testing are caused by brackets
  - Residual convergence: some solvers have trouble converging to machine zero when the brackets are present, but others don't.
    - Many factors contribute: grid, condition, FE vs. FV, other solver schemes

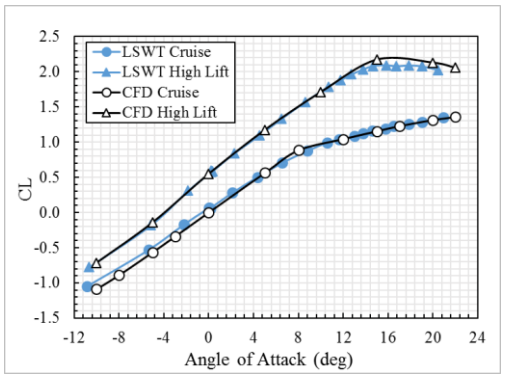


Hybrid Wing Body Conceptual Design
Model w/ Flaps and Slats (no brackets)
*AIAA 2014-1285

- Big Picture: How are aircraft high lift systems designed? (Lockheed)
  - **Conceptual design phase:** slat brackets are usually not defined. Slat and flaps hang out in space. Engineers vary gap, overhang, angle, etc to get best RANS-based performance predictions without brackets
    - The "no bracket" geometry becomes the nominal baseline case
    - These are often the performance estimates that size the airplane
  - **Preliminary design phase:** wind tunnel testing. Model needs WT brackets!
  - **Detailed design phase:** slat tracks and actuation are only considered once the wing and slats designs are finalized and the loads are known. Ideally, CFD analysis is used to verify the final actuators do not impact performance (CLmax)

HWB LSWT Powered WT Model
*AIAA 2017-0100

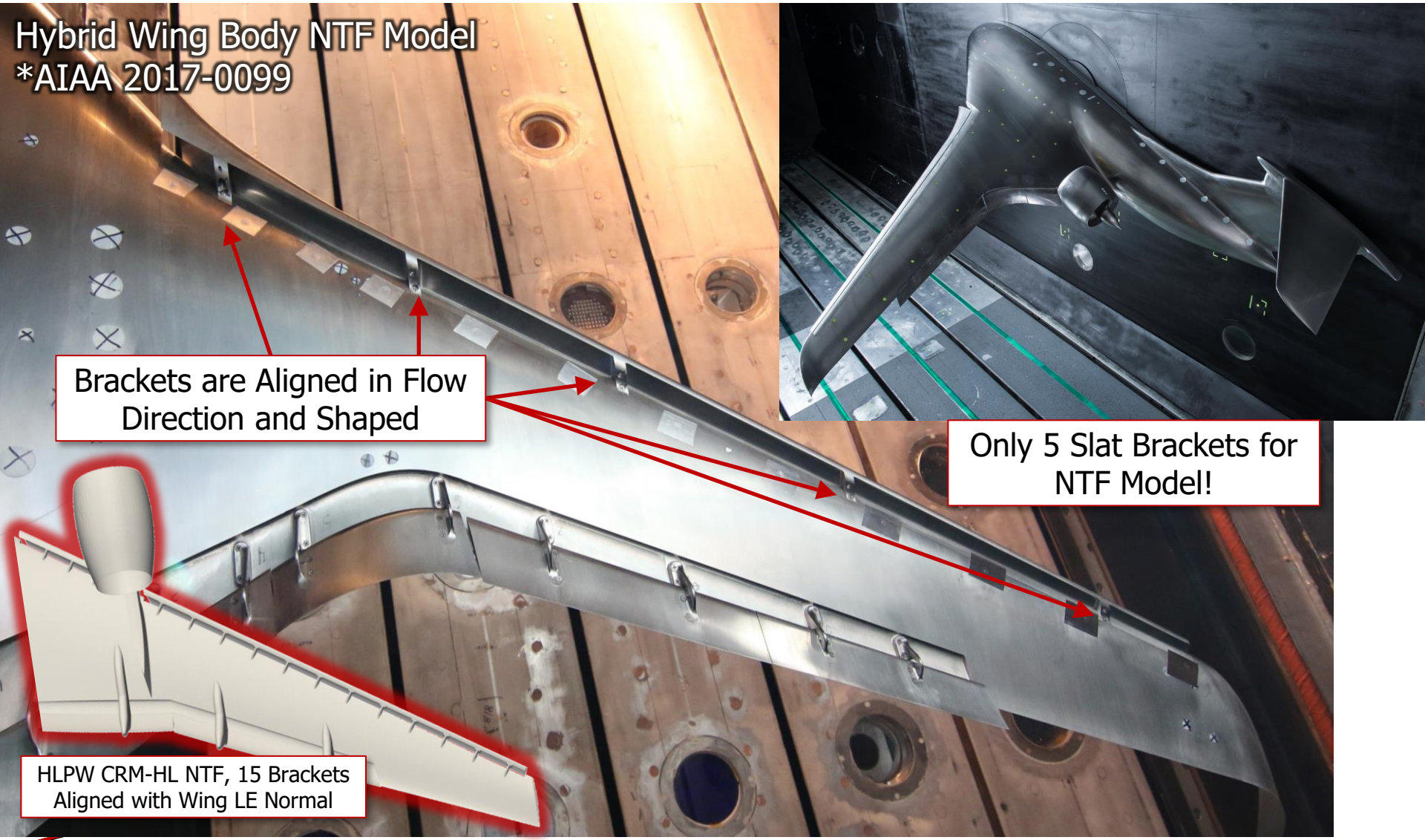
- How should wind tunnel model slat brackets be designed?
  - 1. Replicate typical full scale # brackets, but sized by wind tunnel constraints -> leads to current CRM HL designs
  - 2. Go through bracket design effort and get performance as close to the no bracket case as possible (fewer brackets, stream aligned, aerodynamic cross section) -> naturally leads to more RANS friendly designs.



RANS matches Test Data. No Pizza Sep!

NTF-HL Model Designed for Minimal Impact on Performance

Helden Aerospace



Wind Tunnel Brackets Can be Designed for Minimal Impact

Slat WT Brackets vs. Slat Tracks

Helden Aerospace

HLPW5 Case 2.4

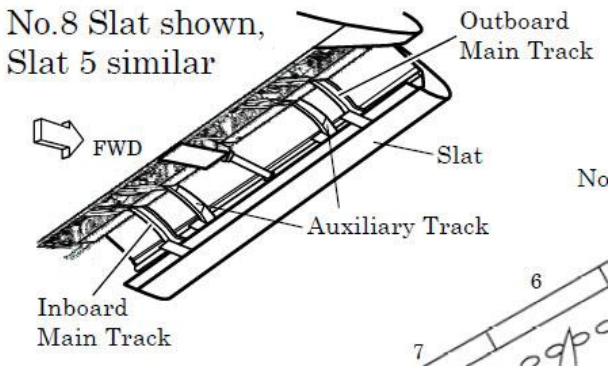
HLPW6 Case 1

B-777

B-727

B-747

B-737



http://www.b737.org.uk/slat-track-ad.htm

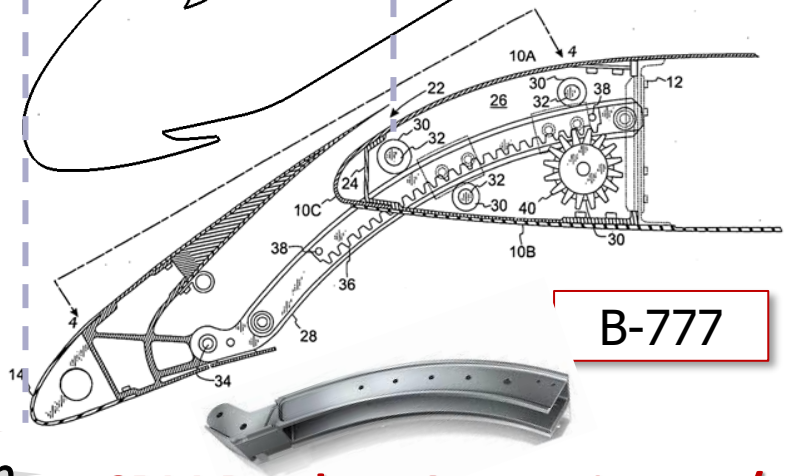
Lots of Different Bracket Shapes / Cross Sections on Actual Aircraft

Slat WT Brackets vs. Slat Tracks

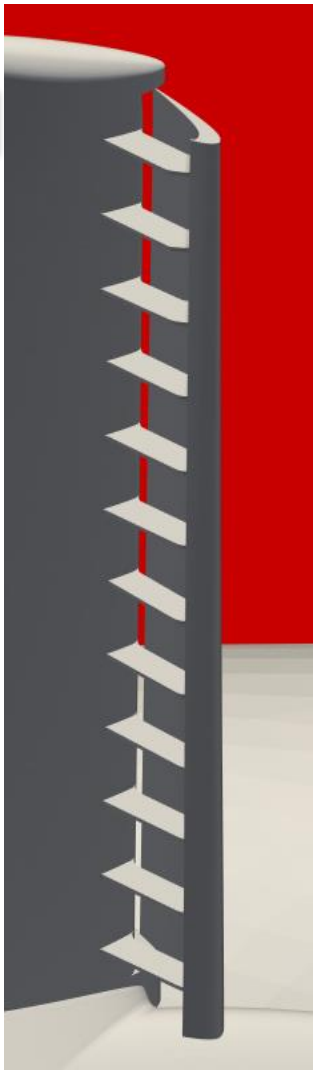
Helden Aerospace

HLPW6 Case 1

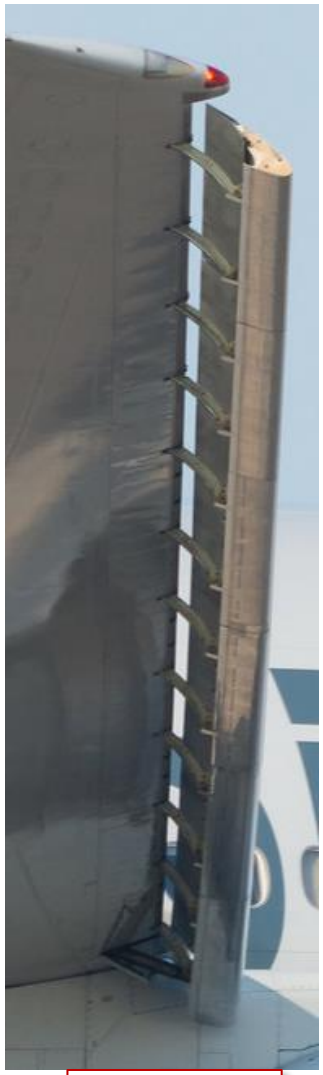
HLPW5 Case 2.4
(Middle Bracket)



B-777



HLPW5 Case 2.4



B-777

CRM Brackets Appear Larger / Chunkier Than Actual Slat Tracks

Case 1: No Brackets

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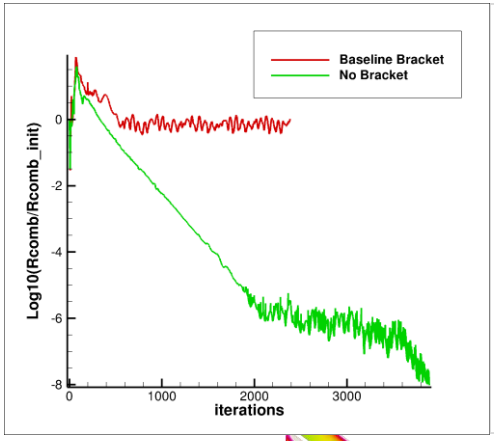
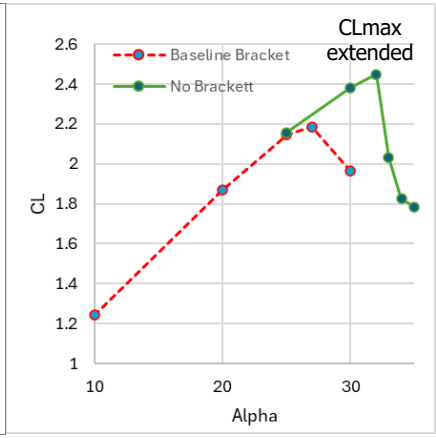
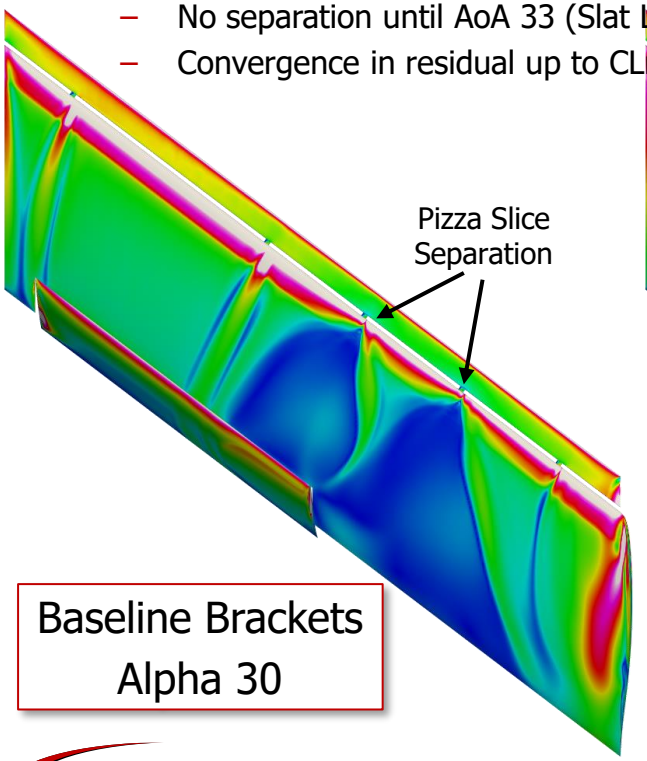
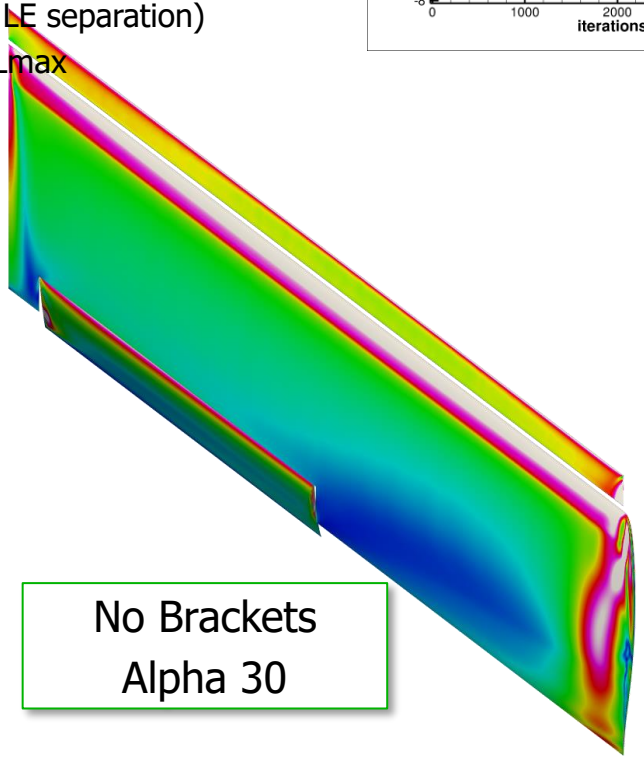
- HeldenMesh, USM3DME used for meshing/CFD
  - Series 3, D level fixed mesh spacing + wake sources
  - ~40M cells for each bracket variation
- Baseline bracket design impact on RANS
  - Residual convergence difficulties with HANIM
  - Pizza Slices on wing upper surface at AoA 30
- No bracket impact on RANS
  - No separation until AoA 33 (Slat LE separation)
  - Convergence in residual up to CLmax



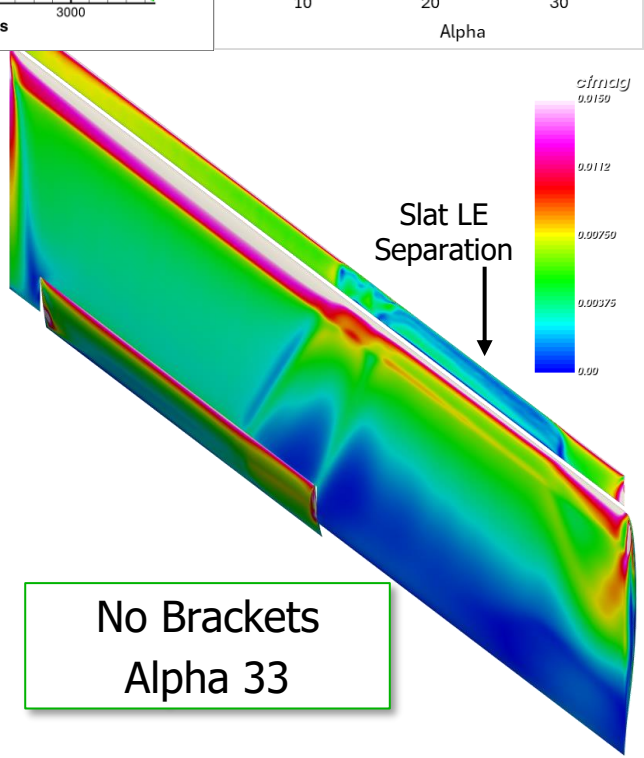




Baseline Brackets
Alpha 30



No Brackets
Alpha 30



No Brackets
Alpha 33

No Bracket = Solution Convergence and no Pizza

Bracket Design Effort (1/2)

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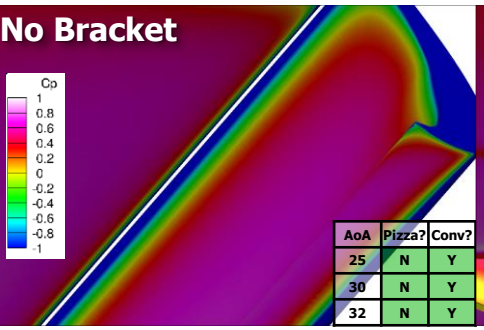
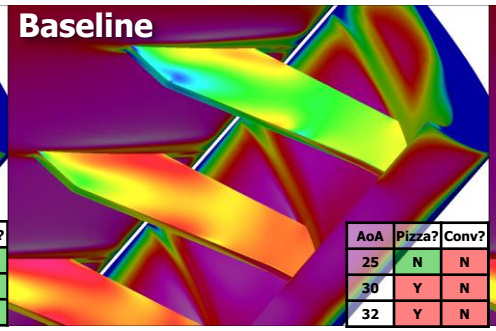
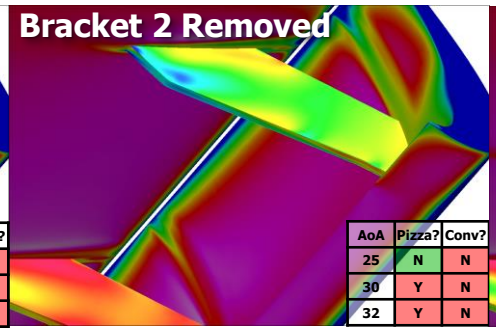


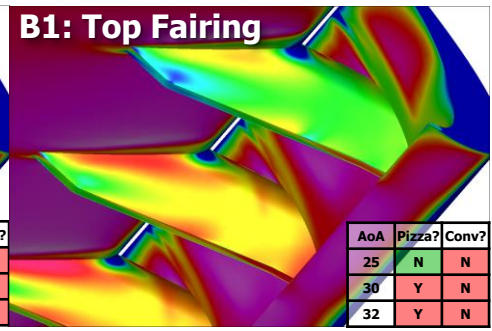
AoA	Pizza?	Conv?
25	N	Y
30	N	Y
32	N	Y



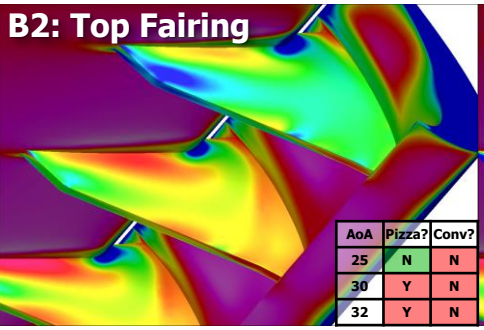
AoA	Pizza?	Conv?
25	N	N
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
25	N	N
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
25	N	N
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
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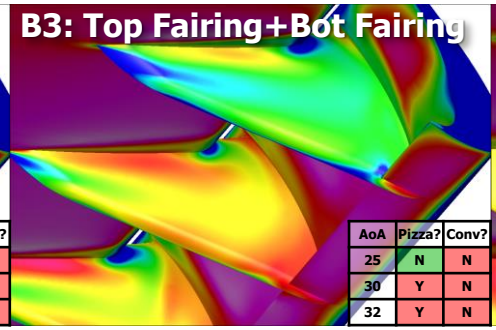
30	Y	N
32	Y	N



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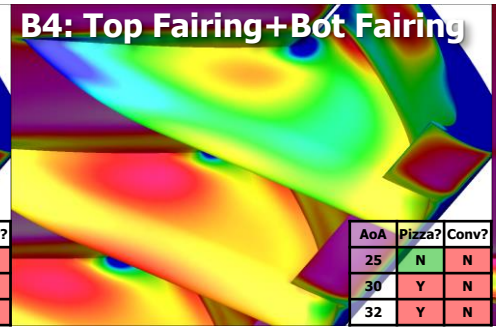
32	Y	N



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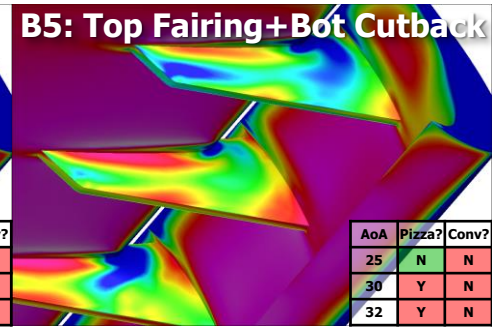
32	Y	N



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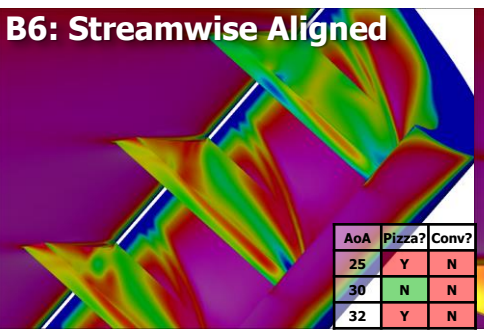
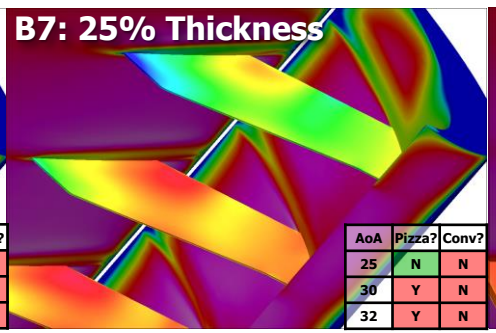
32	Y	N



AoA	Pizza?	Conv?
25	Y	N
30	N	N
32	Y	N



AoA	Pizza?	Conv?
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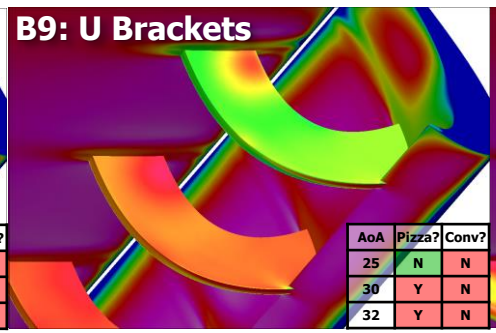
30	Y	N
32	Y	N



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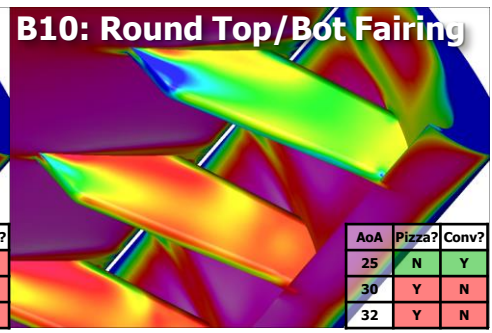

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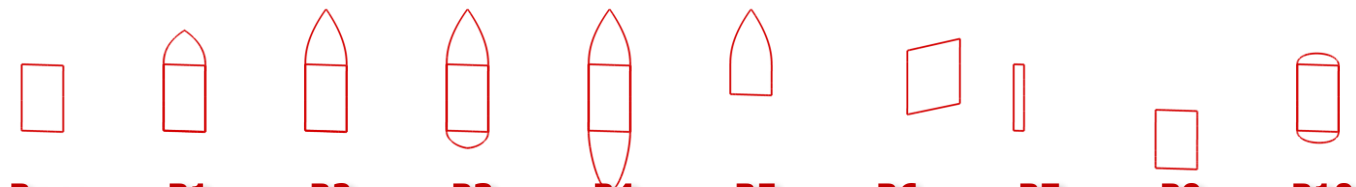
Cross Sections of Brackets:



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Bracket Design Effort (2/2)

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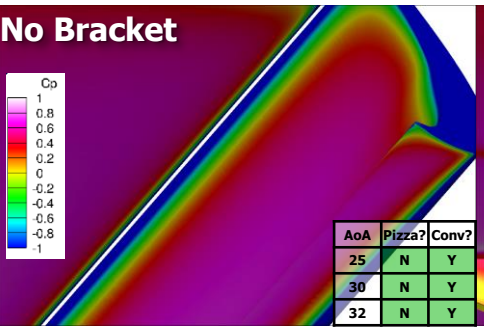
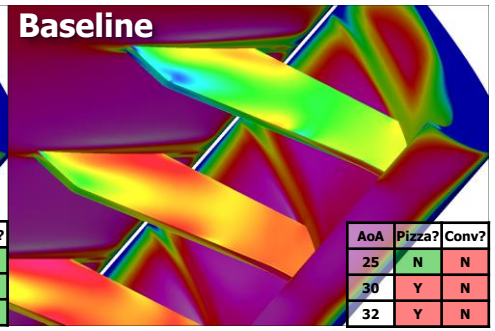
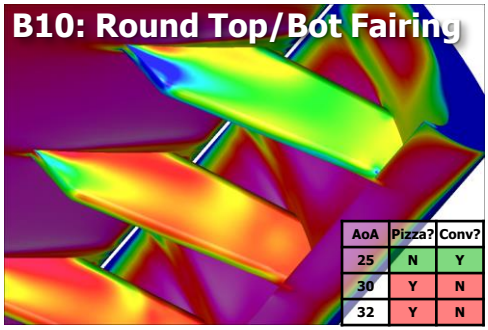


AoA	Pizza?	Conv?
25	N	Y
30	N	Y
32	N	Y



AoA	Pizza?	Conv?
25	N	N
30	Y	N
32	Y	N



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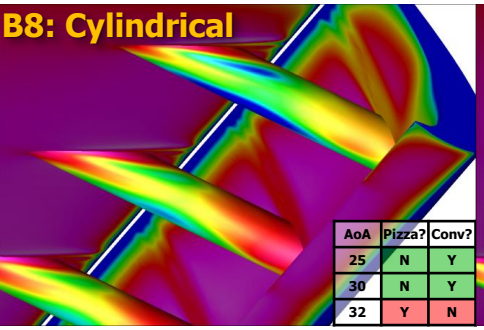
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
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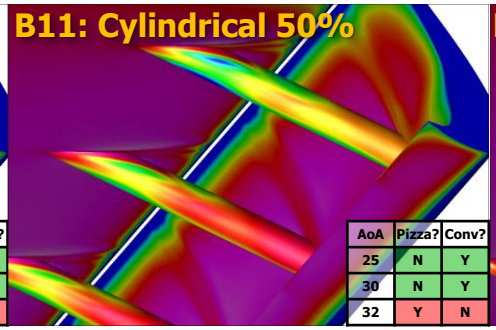
30	N	Y
32	Y	N



AoA	Pizza?	Conv?
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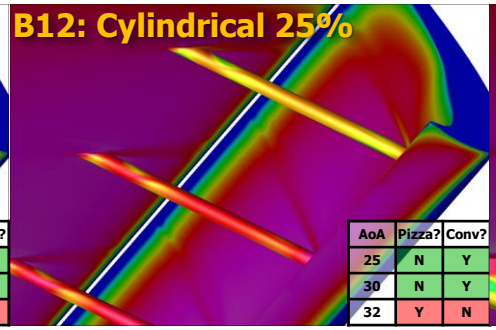
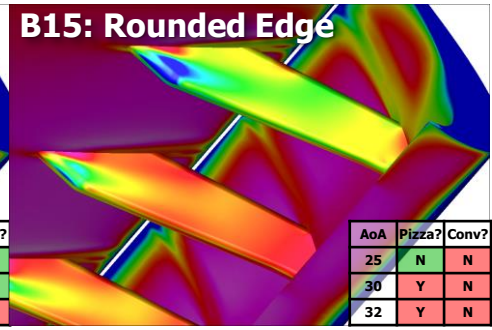
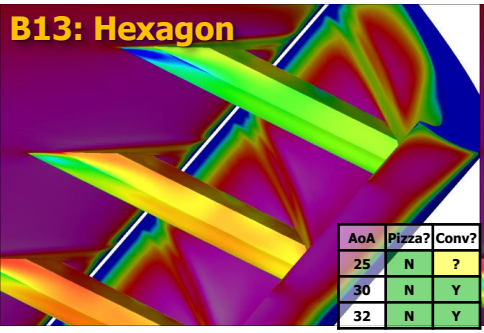


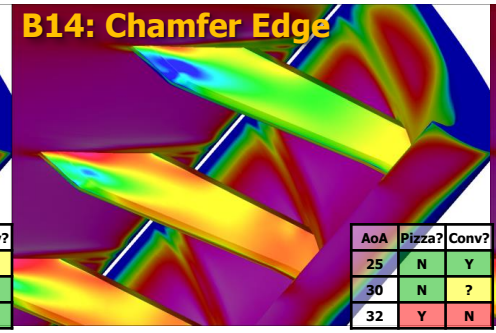
AoA	Pizza?	Conv?
25	N	Y
30	N	Y
32	Y	N



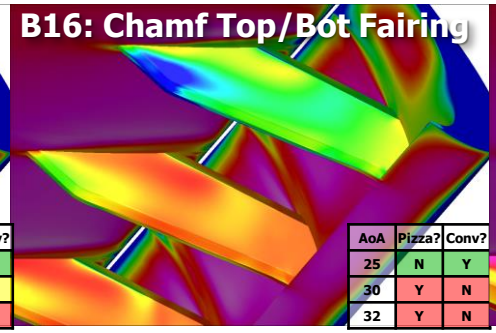
AoA	Pizza?	Conv?
25	N	N
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
25	N	?
30	N	Y
32	N	Y



AoA	Pizza?	Conv?
25	N	Y
30	N	?
32	Y	N



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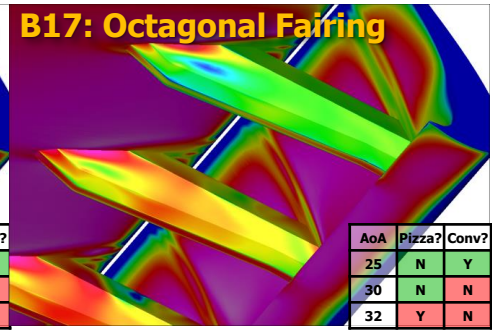
25	N	Y
30	Y	N
32	Y	N



AoA	Pizza?	Conv?
25	N	Y
30	N	N
32	Y	N

Cross Sections of Brackets:

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Bracket Study Summary

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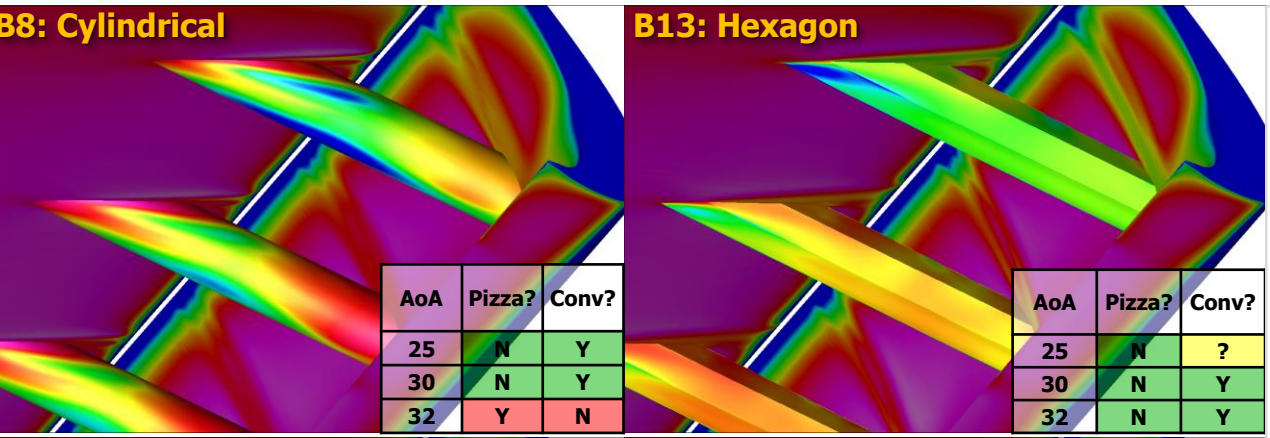
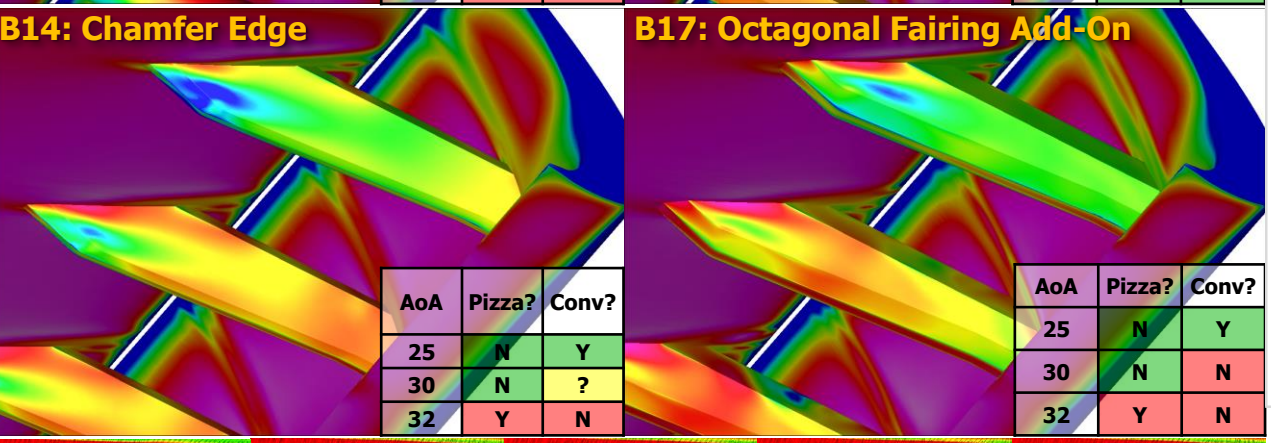
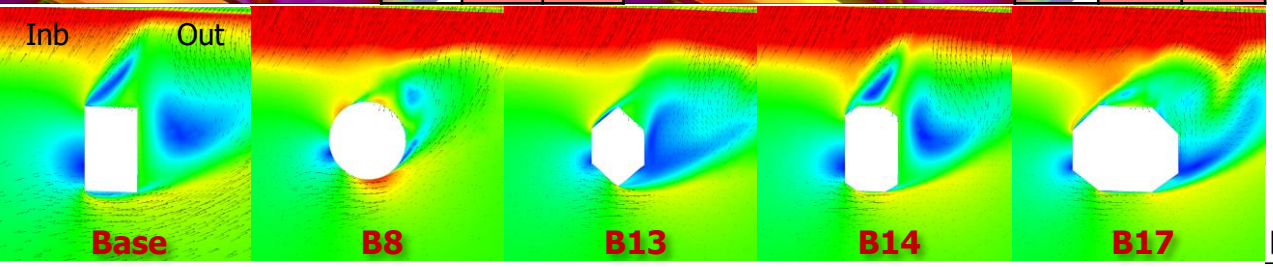
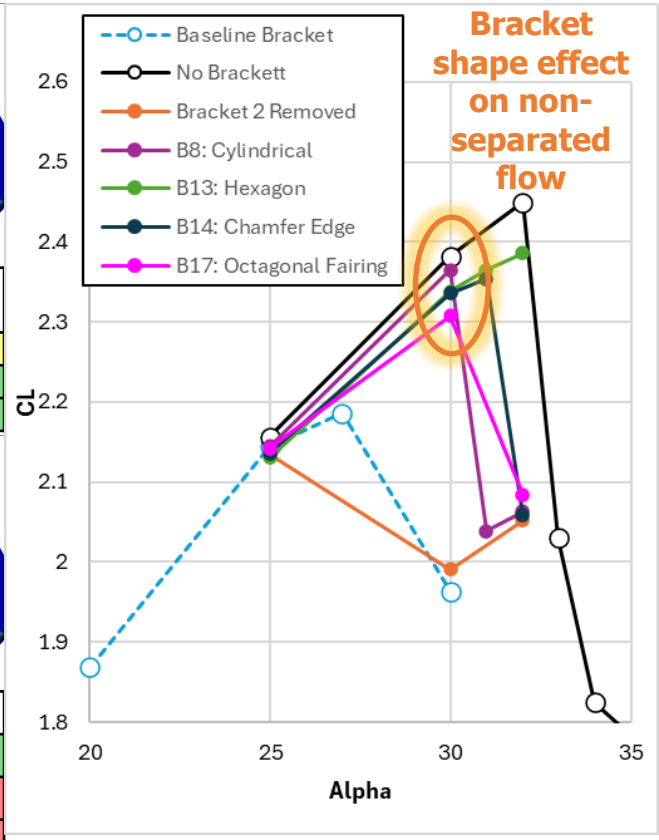
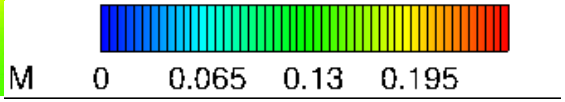








Cross Sections of Brackets:



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Bracket Shape Can Improve Convergence and Reduce Pizza Sep

Bracket Study Conclusions

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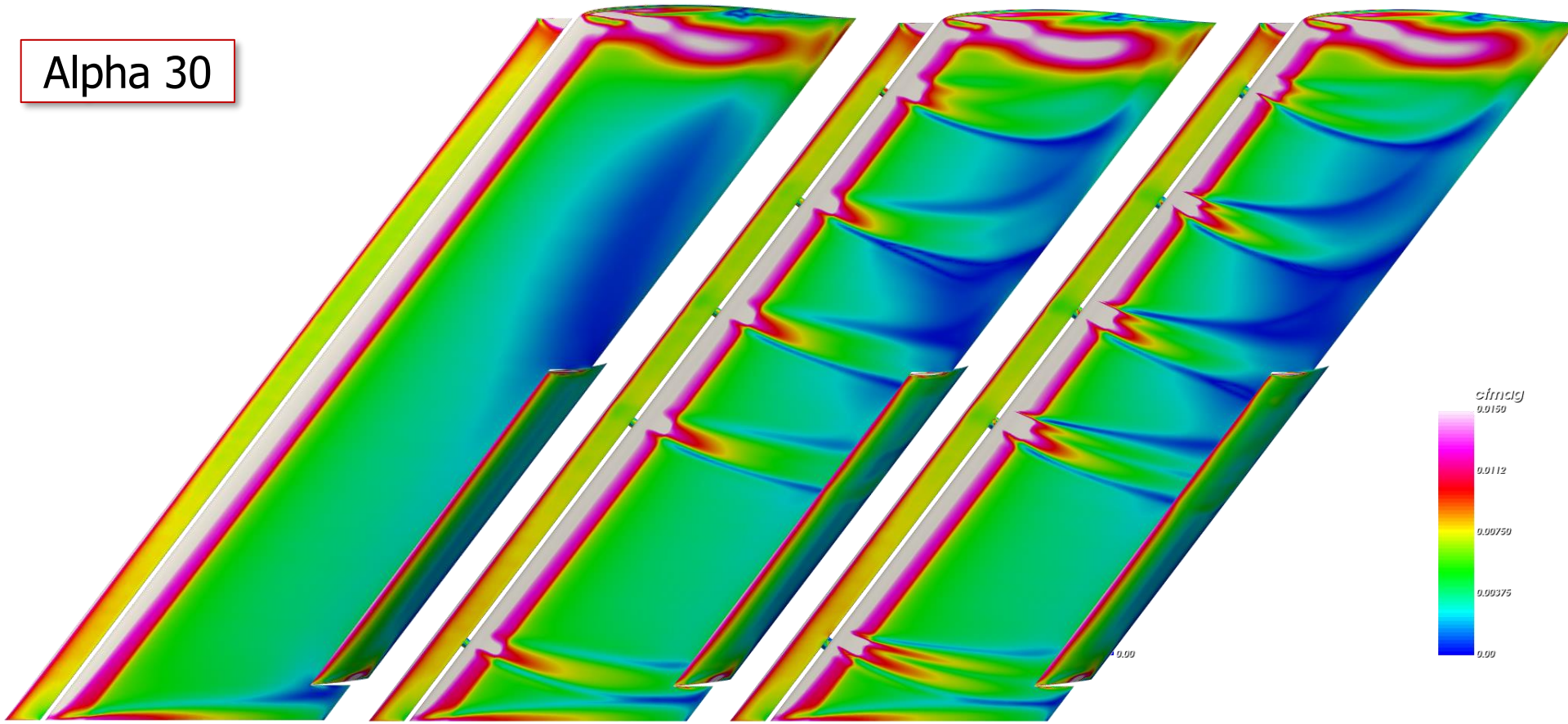
Alpha 30



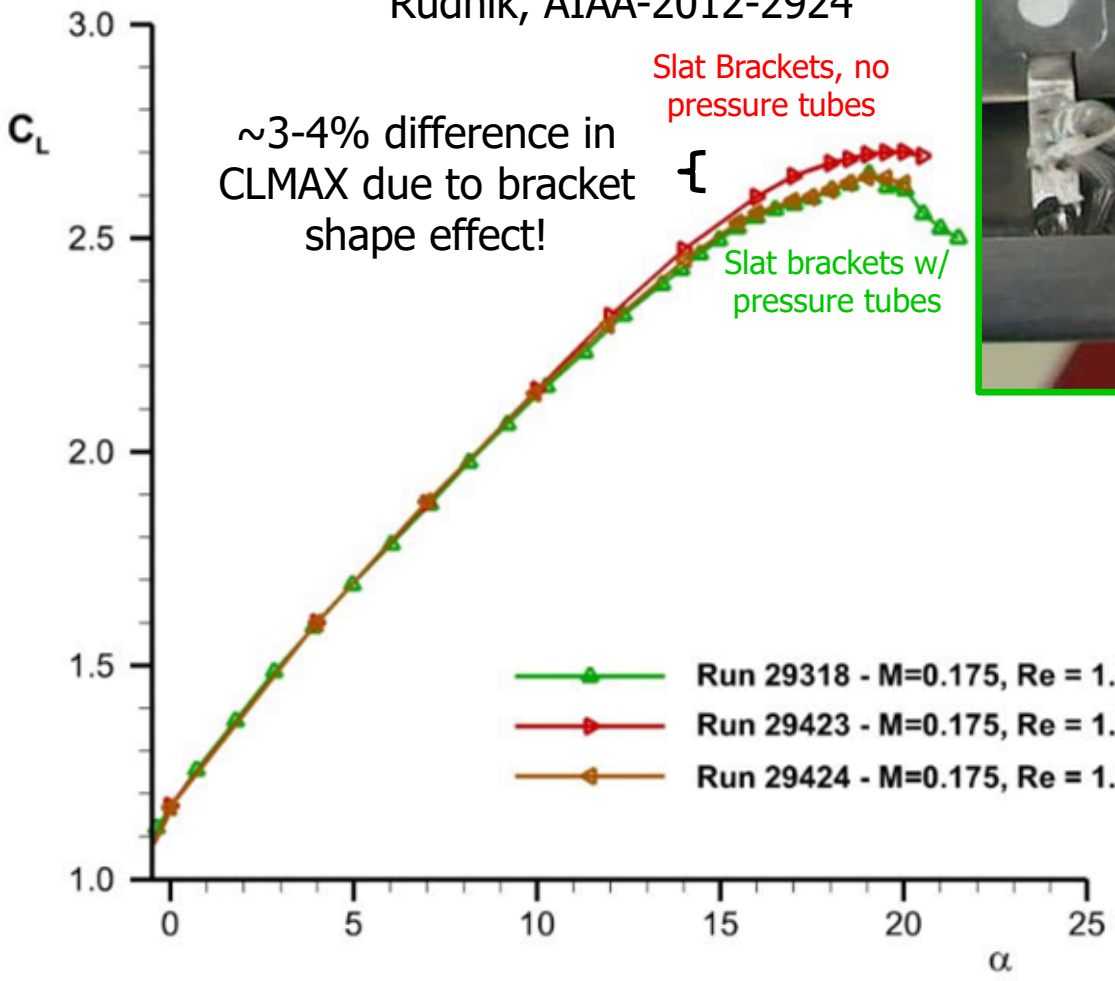
No Bracket	B8: Cylinder	B17: Octagonal Fairing
CL 2.382	CL 2.365	CL 2.307

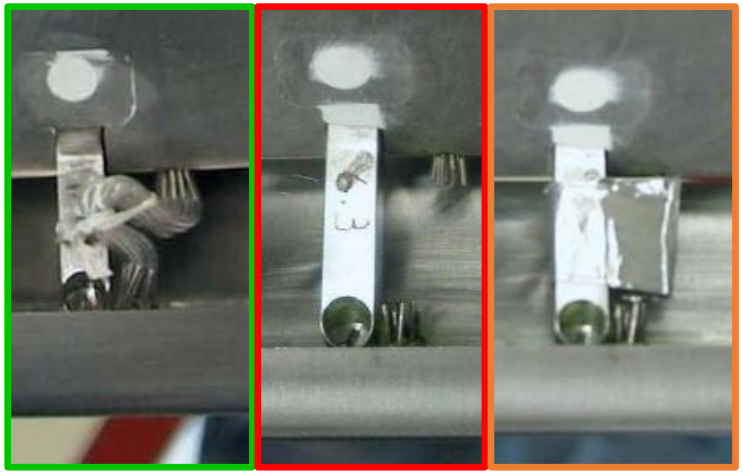
Bracket Shape Also Has Effect on CL for Attached Flows Near CLMAX

HLPW 2 – DLR Geometry

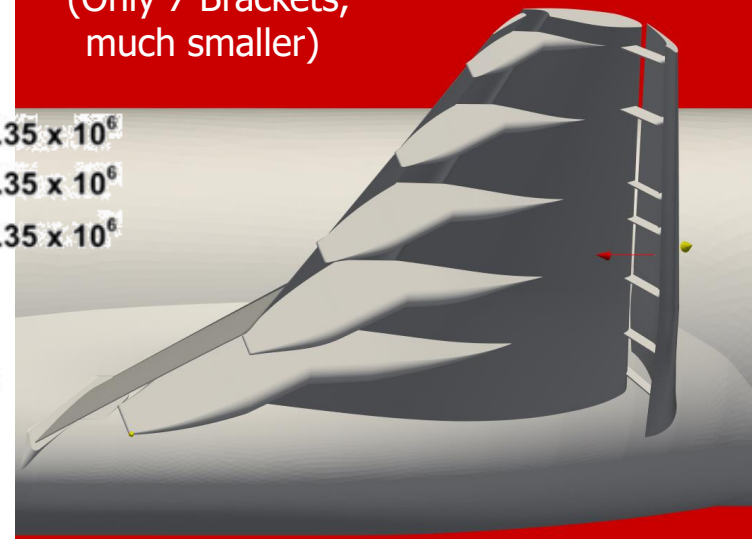
Helden Aerospace

Rudnik, AIAA-2012-2924





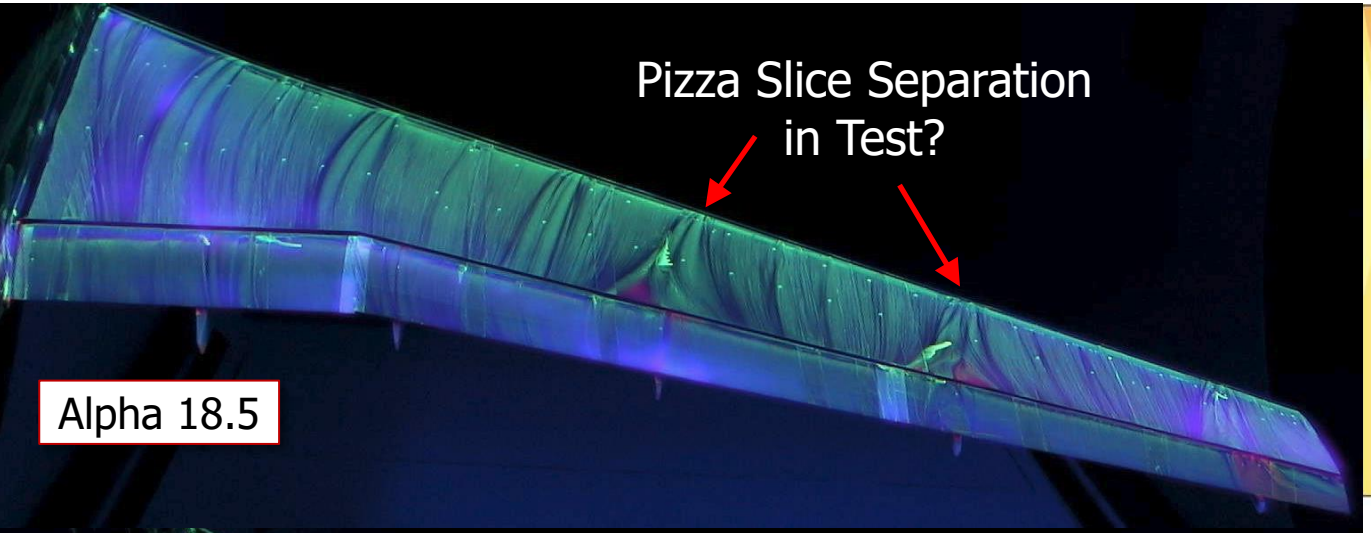
DLR F11 Geometry (Only 7 Brackets, much smaller)

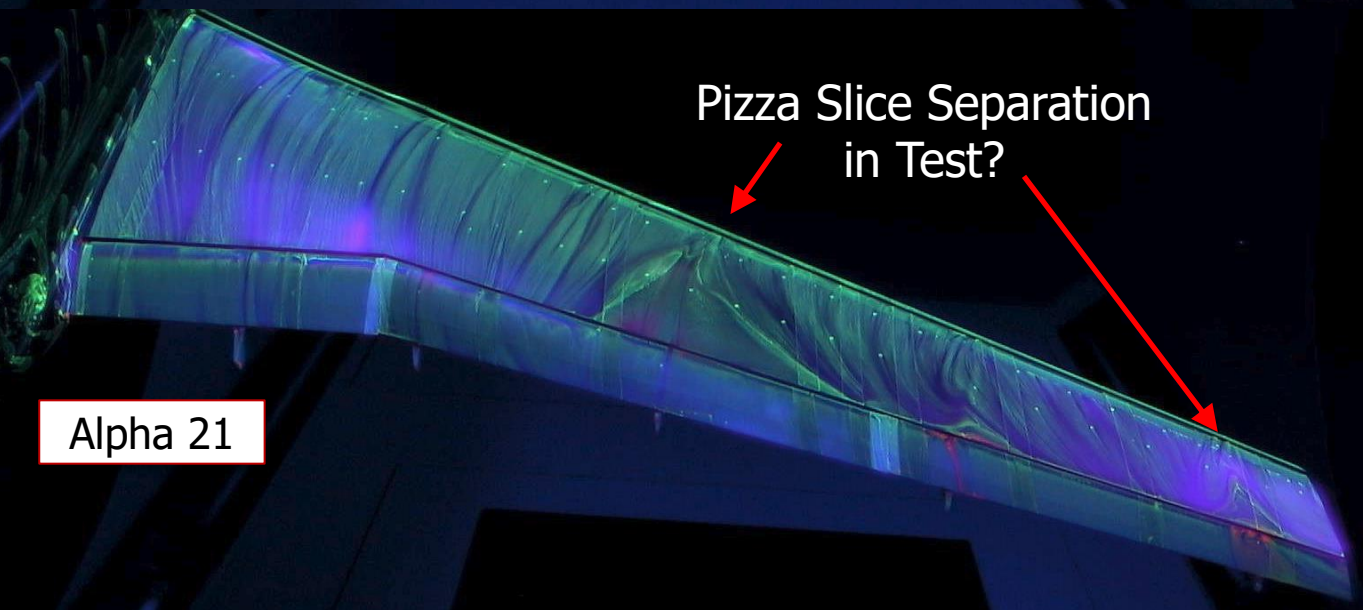


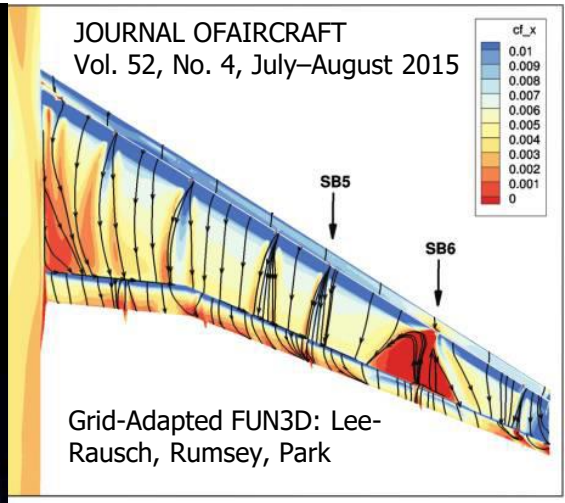
HLPW2 WT Test Data Showed Influence of Slat Bracket Shape

HLPW 2 – DLR Geometry

Helden Aerospace







"In my opinion, pizza separation probably was an issue for RANS in HLPW2, but there was no collection of surface streamlines back then, so it's hard to pin it down for all of the collective results. We just weren't on the lookout for that. However, some participants' papers probably showed it." –Chris Rumsey (May 2026)

How would we do on this case today?

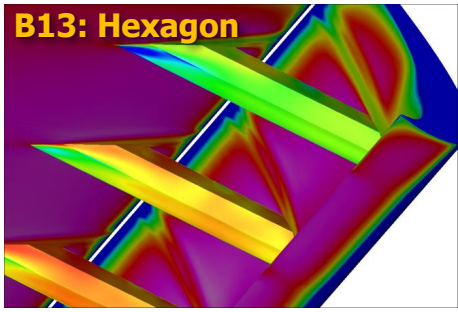
Bracket Study Conclusions

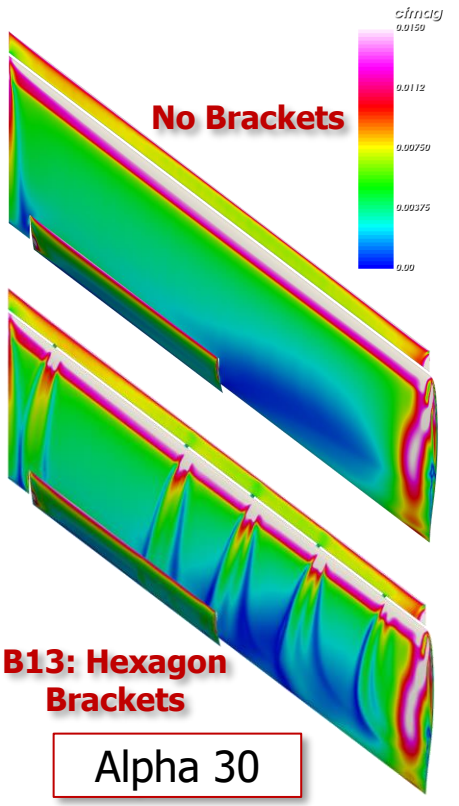
Helden Aerospace

- Some minor adjustments to the bracket shape can result in improved RANS simulations with no pizza and improved residual convergence
  - Cylindrical cross section
  - Hexagon cross section
  - Chamfering on sharp edges of existing brackets.
  - Fairings can be added to the sides of the existing brackets.
  - These changes might also improve CLmax on the test data.

- The "No Bracket" Case is still useful to study, even if it can't be tested
  - Simulates the nominal performance of the high lift system. It's what we designed!
  - In the aircraft design process, most pre-test RANS CFD probably doesn't even model slat brackets. These are the performance estimates that size the aircraft!
  - Easier to simulate with RANS. Free of pizza and convergence issues.
  - For HLPW5 Case 2, RANS simulations without brackets matched the test data

- Where do we go next on this topic?
  - Look at Case 1 with alternate bracket shape (with or without test data)
  - Look at Case 1 with no brackets
  - Revisit HLPW2: What effect do the smaller brackets have on our scatter between participants? How do we compare to a case that actually shows pizza-like separation as the stall mechanism?
  - There was a 10% CRM test with alternate "aero" and "acoustic" brackets from NASA Langley that may be interesting…





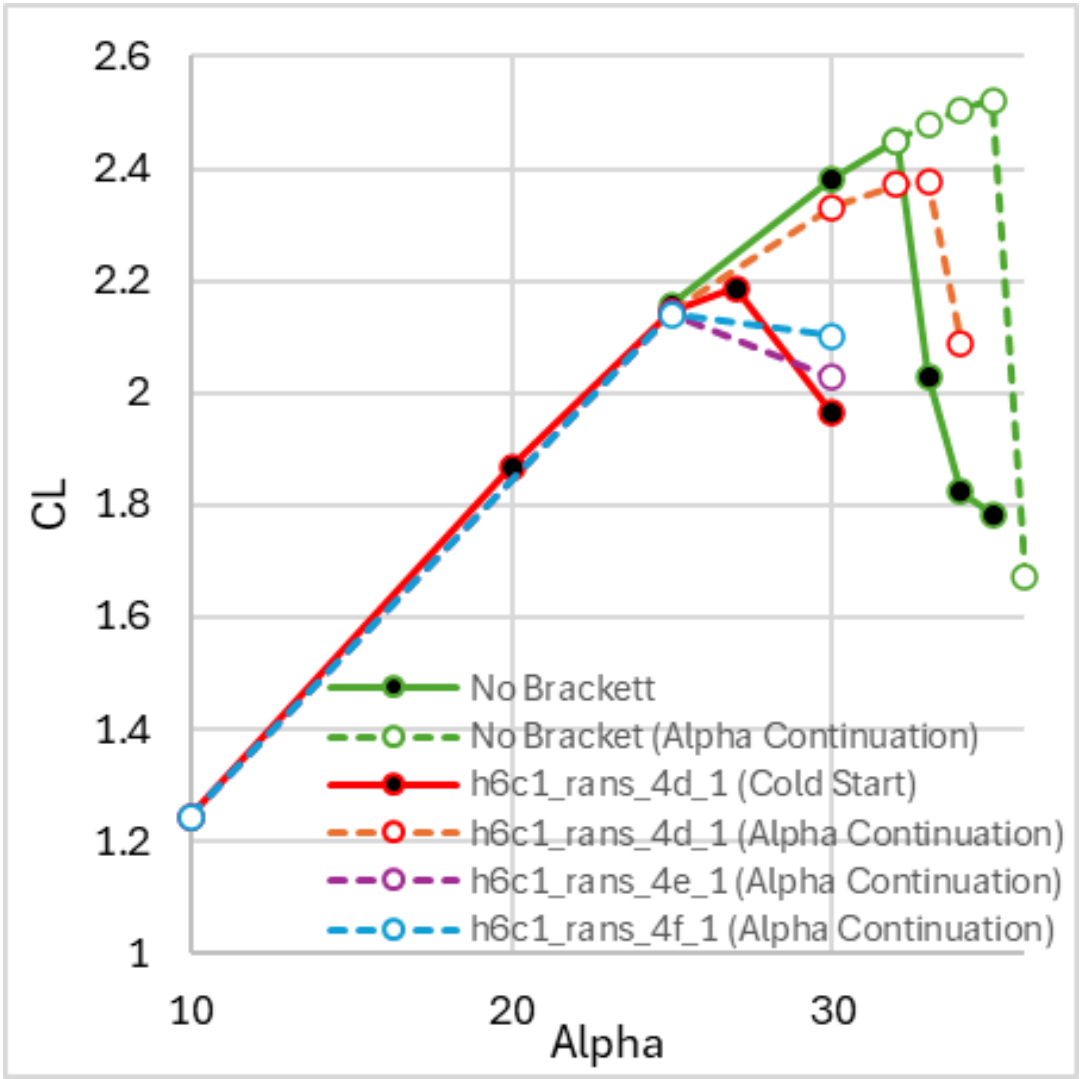
Backup

Helden Aerospace

Effect of Alpha Continuation

Helden Aerospace

- Effect of using alpha continuation was explored. Alpha 30 simulation was restarted from the pizza-free Alpha 25 deg solution
- Alpha continuation delays stall by 3 deg AoA for the no bracket simulation
  - Clmax at Alpha 32 -> Clmax to Alpha 35
- For the medium mesh (4D), alpha continuation can be used to get pizza-free solutions at alpha 30
- Finer mesh resolution (4E, 4F) leads to development of pizza separation
- Explorations were also made using heldenadapt to create adapted meshes which were tailored to the pizza-free Alpha 30 simulation. These simulations all led to pizza separation eventually forming
  - Alpha continuation used to simulate alpha 25 deg then restarted at alpha 30. As mesh was refined, pizza eventually formed

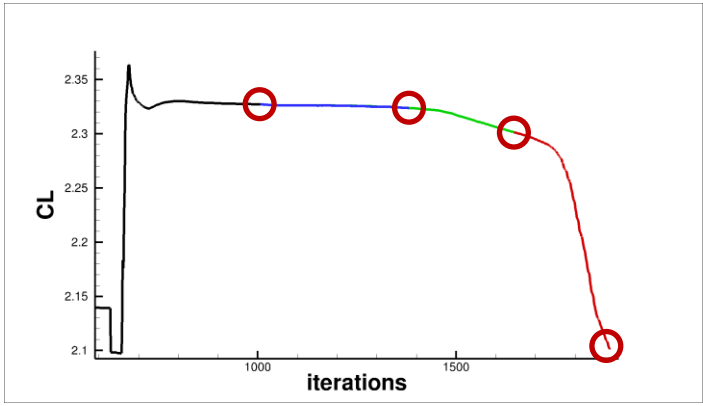


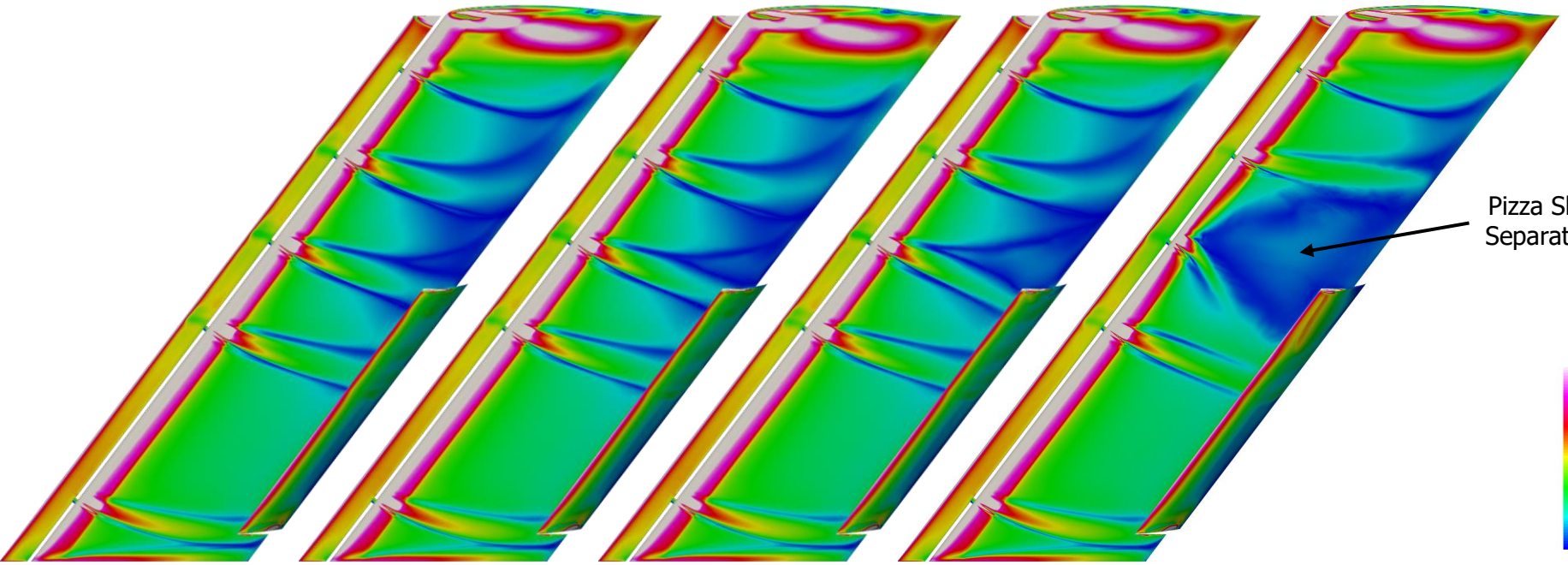
Alpha Continuation Not Enough to Prevent Pizza

Bracket Study

Helden Aerospace

- h6c1_rans_4f_1 mesh (323M cells) was used to study development of the Pizza Separation at Alpha 30
- Solution was restarted from alpha 25 solution up to 30 deg
- Flow is initially pizza free. Then the 3rd bracket wake begins to widen at the trailing edge and eventually separates.





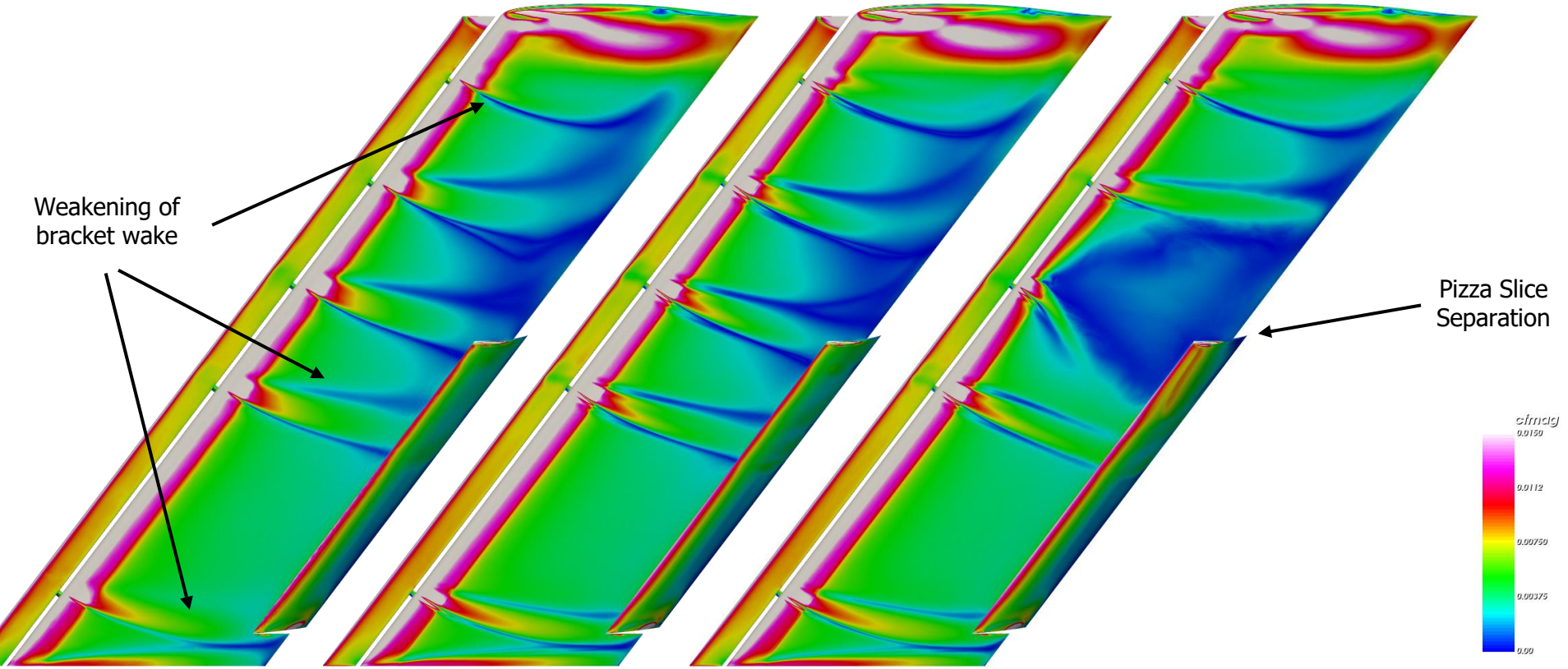
1007 Iter | 1382 Iter | 1646 Iter | 1887 Iter

Pizza Separation Develops from the Trailing Edge

Bracket Study

Helden Aerospace

- Alpha 30 Comparison of Bracket Shape Effect on Bracket Wakes
- B13 solution is grid converged using heldenadapt



Bracket Shape Affects Upper Skin Friction Patterns