Unstructured Grid High Lift Aerodynamic Prediction

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HiLiftPW-1: 1st AIAA CFD High Lift Prediction Workshop

Sponsored by the Applied Aerodynamics Technical Committee

Chicago, IL, USA

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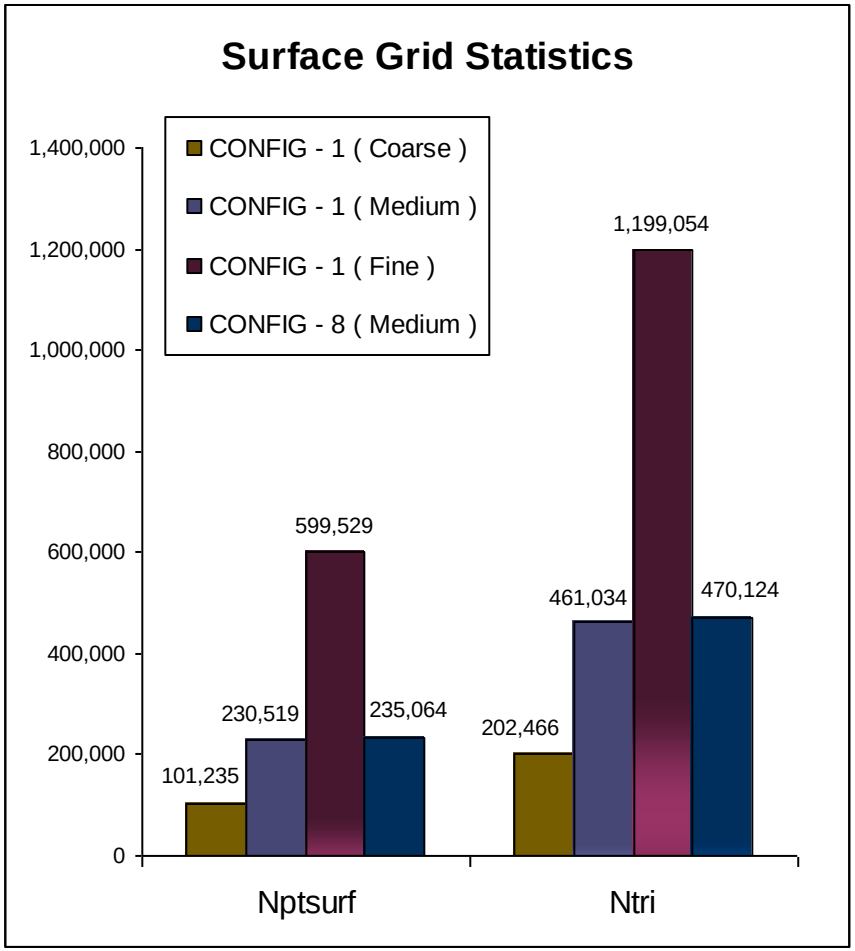
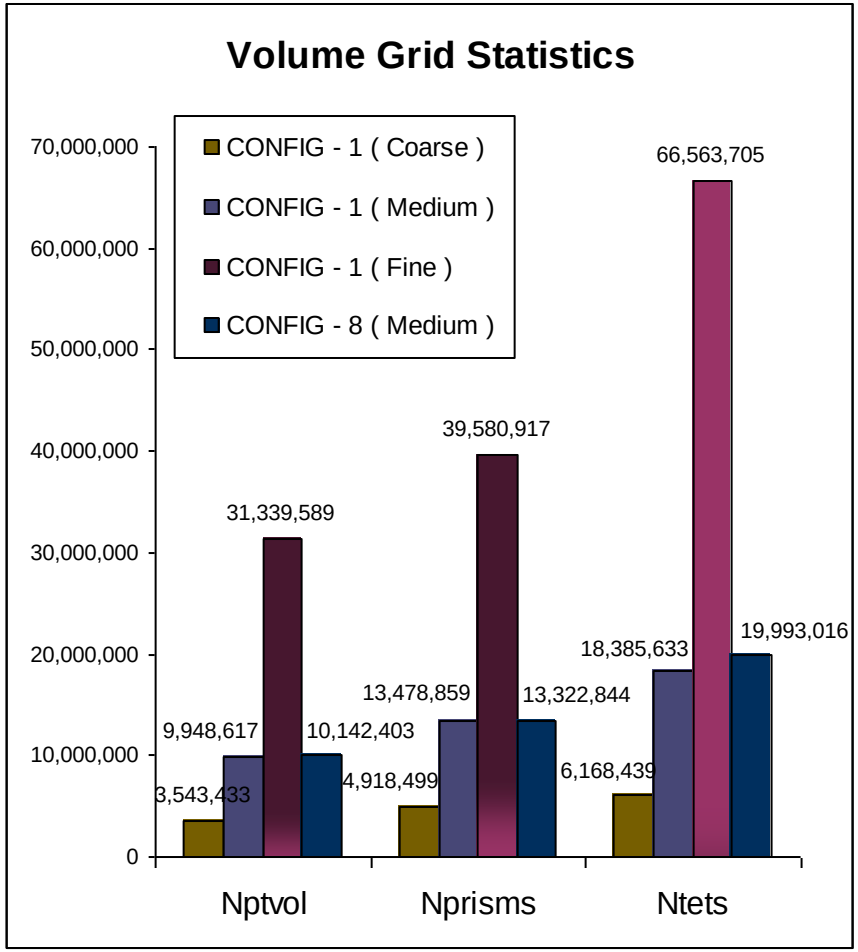
- **Grid Generation tools used**
  - Gridtool & Vgrid (version 4.1)
    - *Ref: TetrUSS (S.Pirzadeh, J. Samareh, N.Frink et al., NASA Langley)*
    - *Self Generated Grids*
- **CFD solver**
  - NSU3D (Unstructured, hybrid grid RANS solver, with SA Turbulence)
    - *Ref: Scientific Simulations (D. Mavriplis)*
    - *Surface grids composed of highly stretched triangulations*
    - *Prismatic cells in boundary layer region*
    - *Tetrahedral cells in flow domain outside of boundary layer*
- **HiLiftPW-1 cases analyzed**
  - CONFIG-1 (Slat 30, Flap 25): Coarse, Medium & Fine grids
  - CONFIG-8 (Slat 30, Flap 20): Medium grid


Surface Grid Statistics
CONFIG - 1 (Coarse)
CONFIG - 1 (Medium)
CONFIG - 1 (Fine)
CONFIG - 8 (Medium)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
101,235
230,519
599,529
235,064
202,466
461,034
1,199,054
470,124
Nptsurf
Ntri

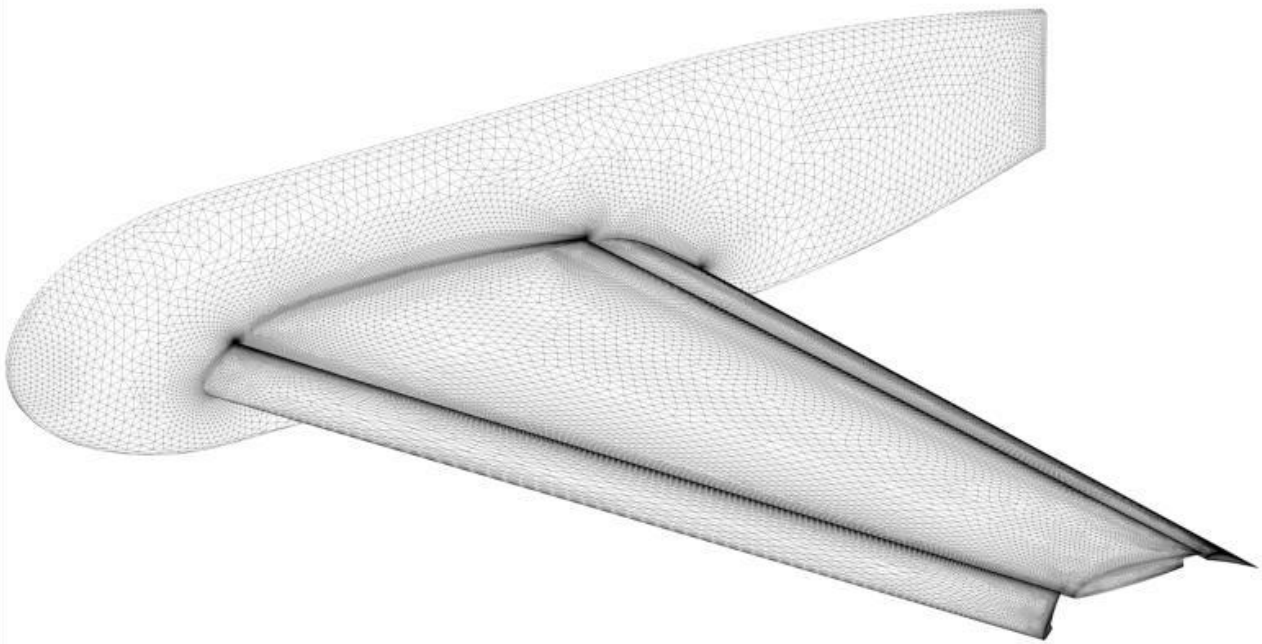

Volume Grid Statistics
CONFIG - 1 (Coarse)
CONFIG - 1 (Medium)
CONFIG - 1 (Fine)
CONFIG - 8 (Medium)
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
3,543,433
9,948,617
31,339,589
10,142,403
4,918,499
13,478,859
39,580,917
13,322,844
6,168,439
18,385,633
66,563,705
19,993,016
Nptvol
Nprisms
Ntets

HiLiftPW-1: NASA Trap Wing Test Case
CONFIG-1 - Slat 30, Flap 25

Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0

COARSE Grid : Npt_surface = 101,325; Ntri_surface = 202,466; Nnodes = 3,543,433; Nprisms = 4,918,499; Ntets = 6,168,439

Mach = 0.2, Alpha = 6.0, Re (MAC) = 4.3 million



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HiLiftPW-1

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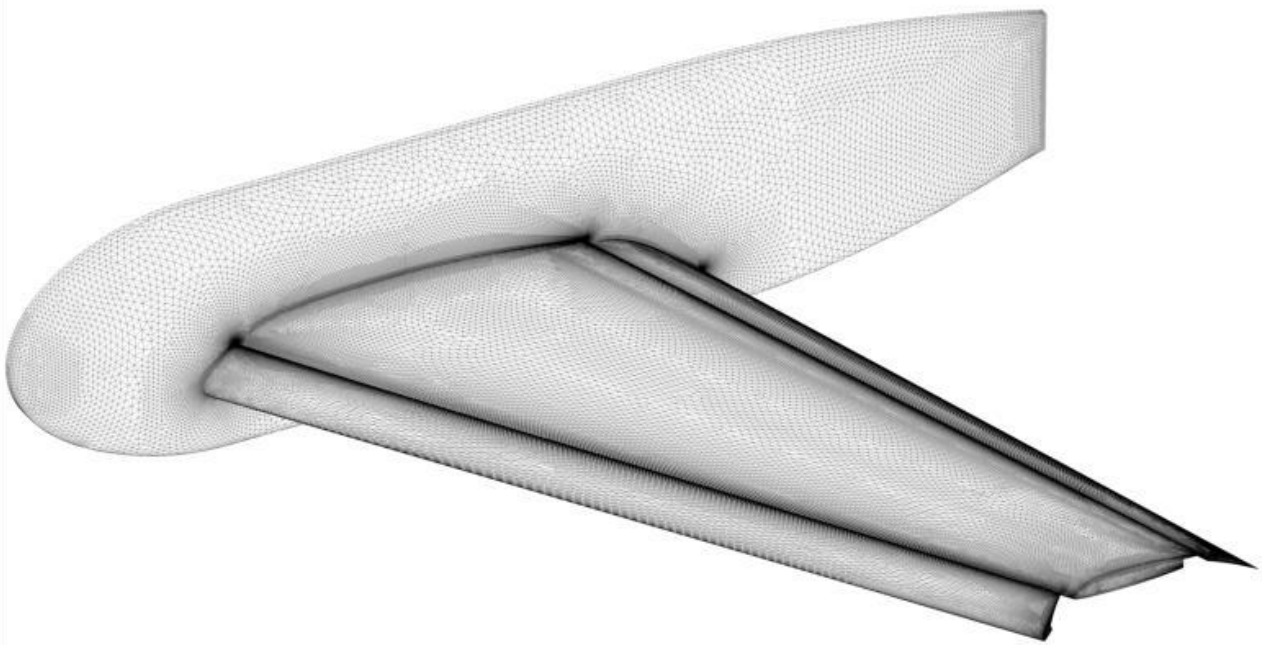
Xref = 34.342, Yref = -0.95, Zref = 0.0

MEDIUM Grid : Npt_surface = 230,519; Ntri_surface = 461,034; Nnodes = 9,948,617; Nprisms = 13,478,859; Ntets = 18,358,633

Mach = 0.2, Alpha = 6.0, Re (MAC) = 4.3 million



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HiLiftPW-1

HiLiftPW-1: NASA Trap Wing Test Case
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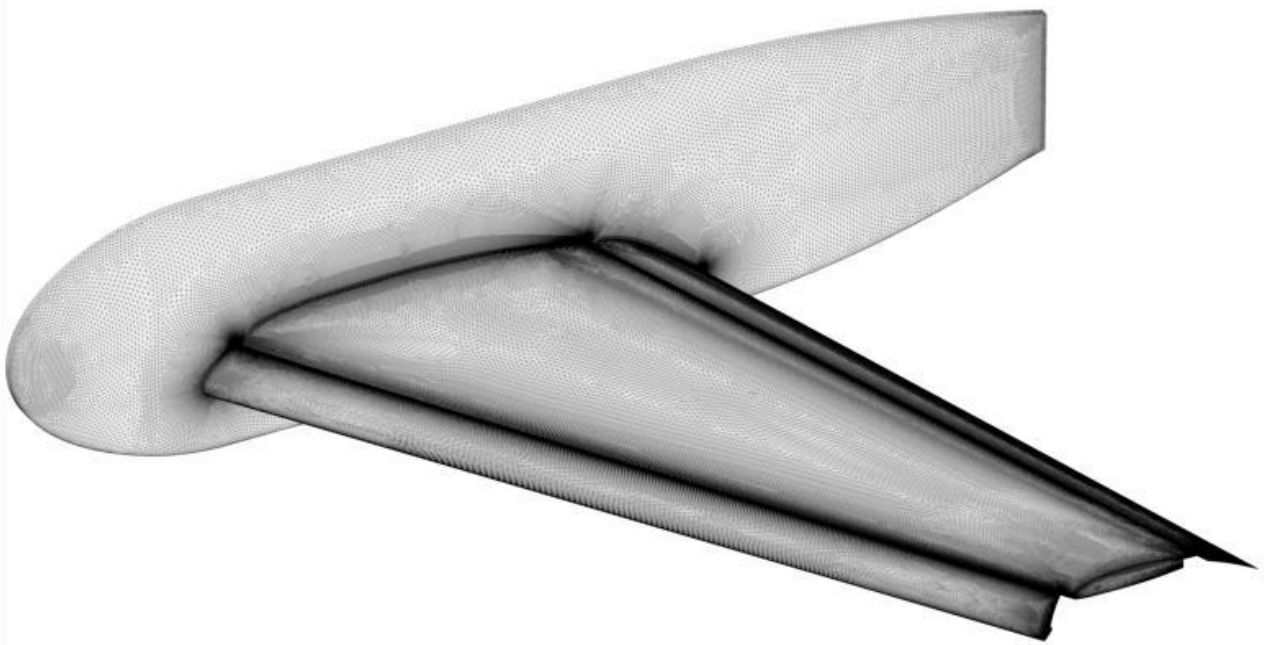
Xref = 34.342, Yref = -0.95, Zref = 0.0

FINE Grid : Npt_surface = 599,529; Ntri_surface = 1,199,054; Nnodes = 31,339,589; Nprisms = 39,580,917; Ntets = 66,563,705

Mach = 0.2, Alpha = 13.0, Re (MAC) = 4.3 million



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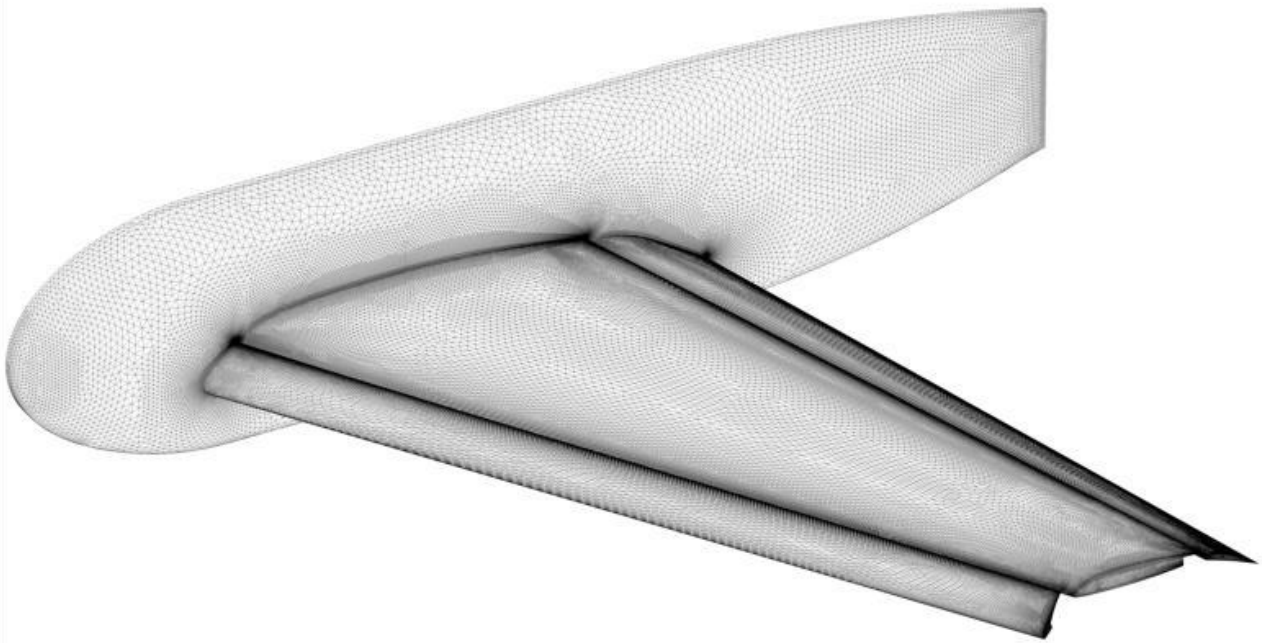
HiLiftPW-1: NASA Trap Wing Test Case
CONFIG-8 - Slat 30, Flap 20

Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0

MEDIUM Grid : Npt_surface = 235,064; Ntri_surface = 470,124; Nnodes = 10,142,403; Nprisms = 13,322,844; Ntets = 19,993,016

Mach = 0.2, Alpha = 6.0, Re (MAC) = 4.3 million



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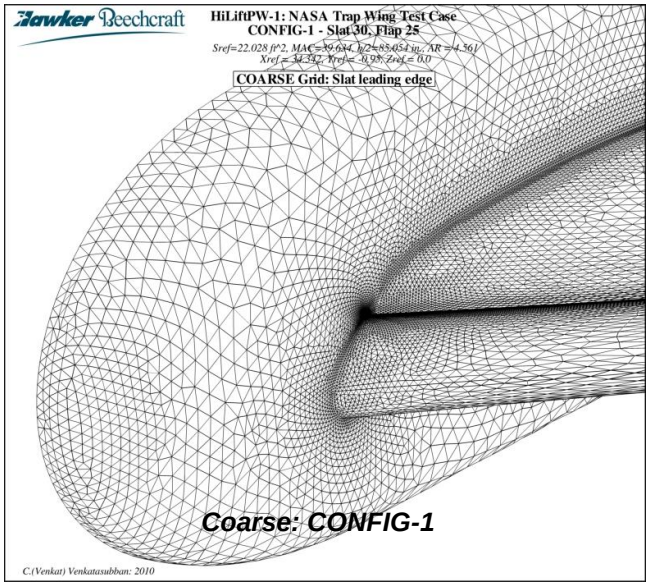
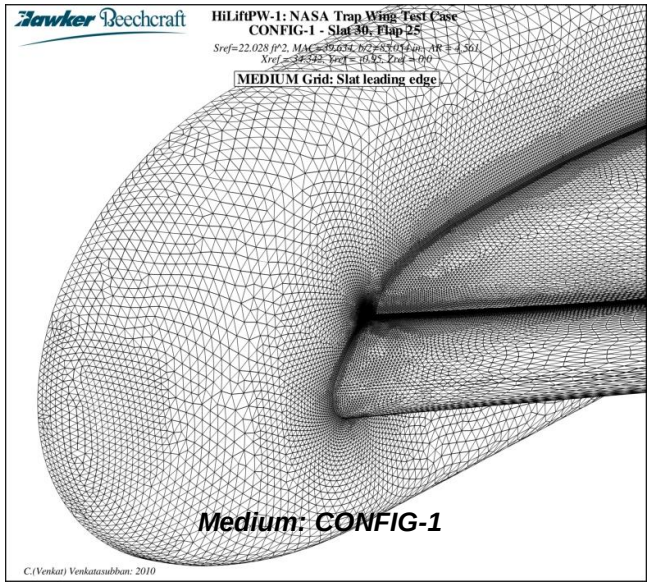
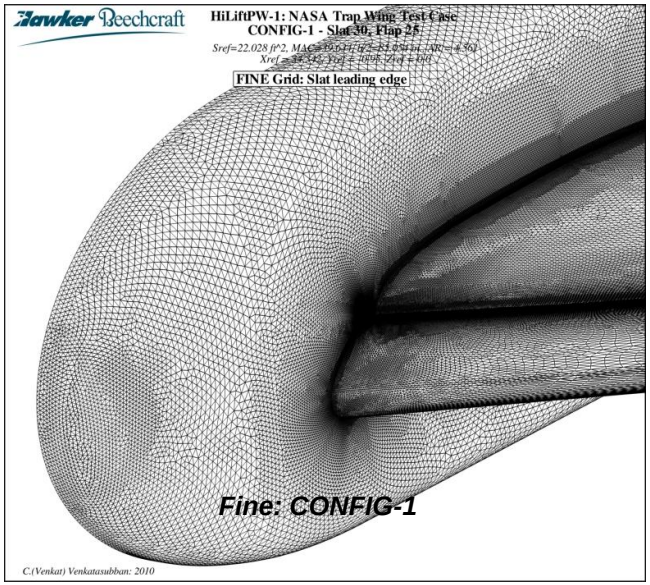
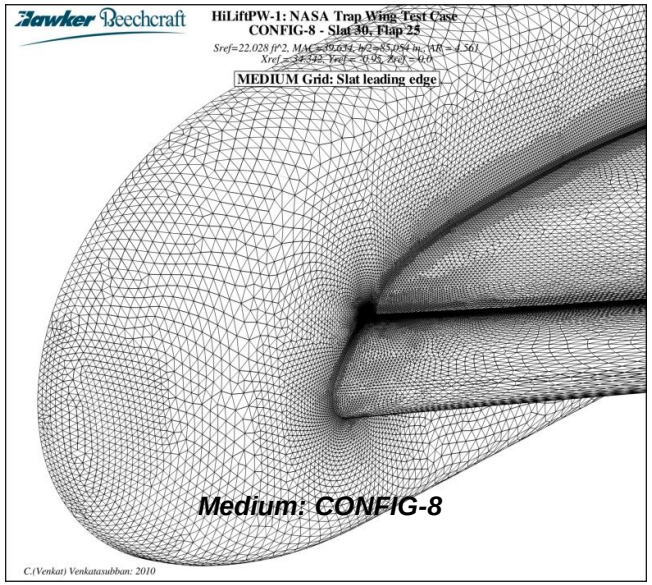
HiLiftPW-1





Nose & slat root





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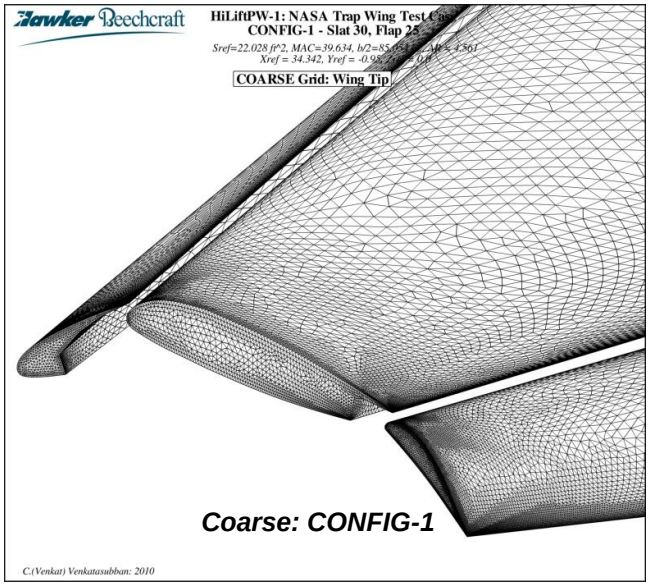
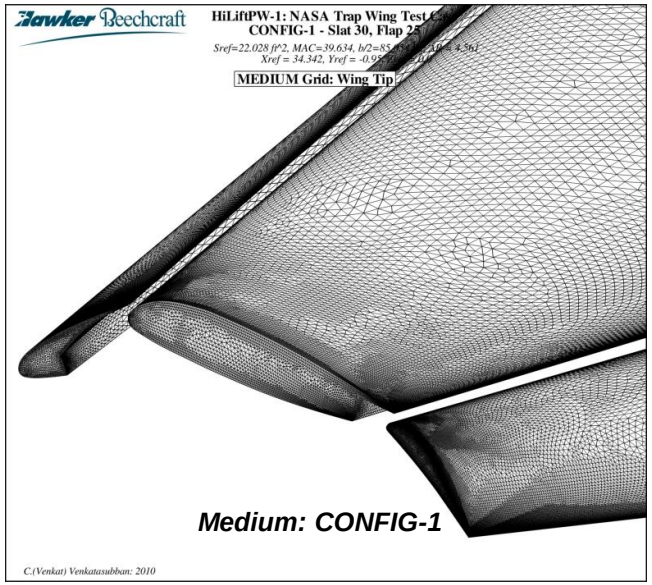
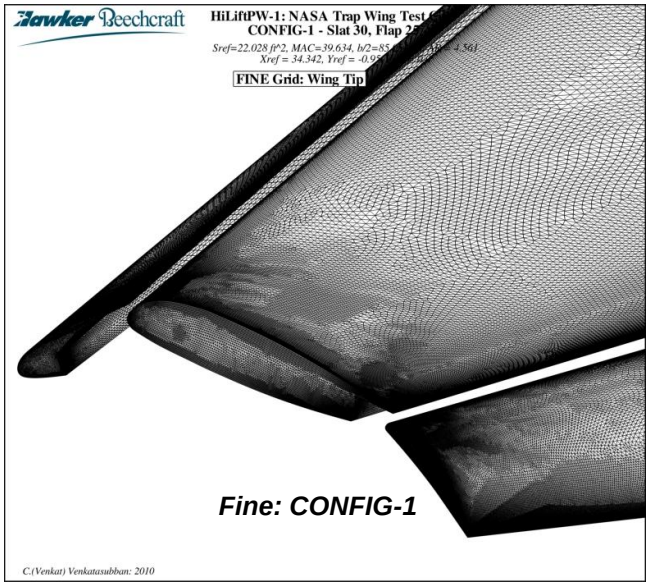
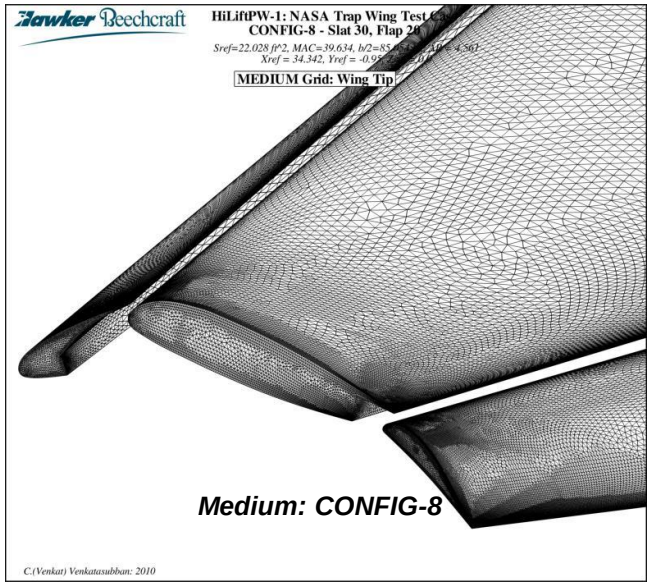


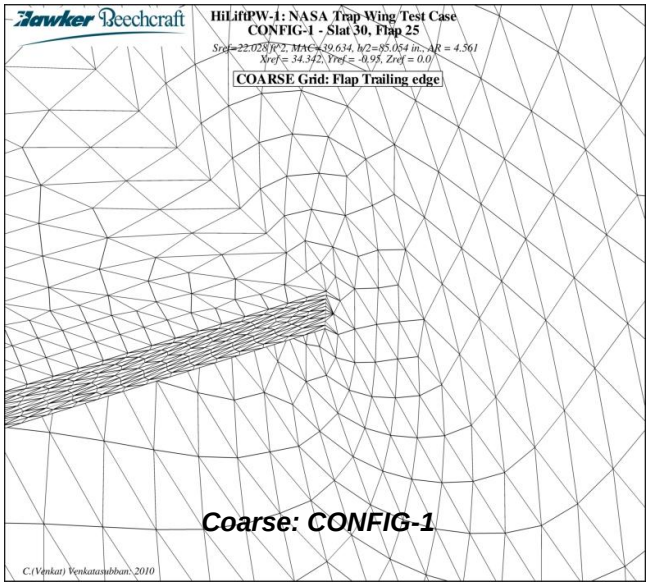


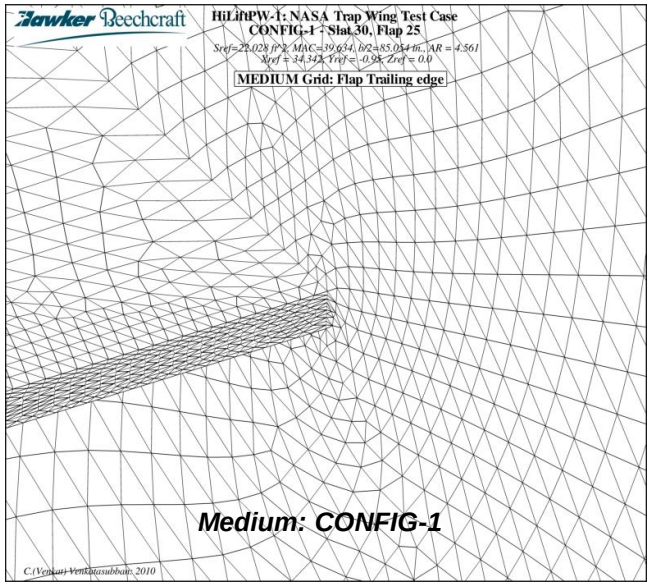
Wing Tip



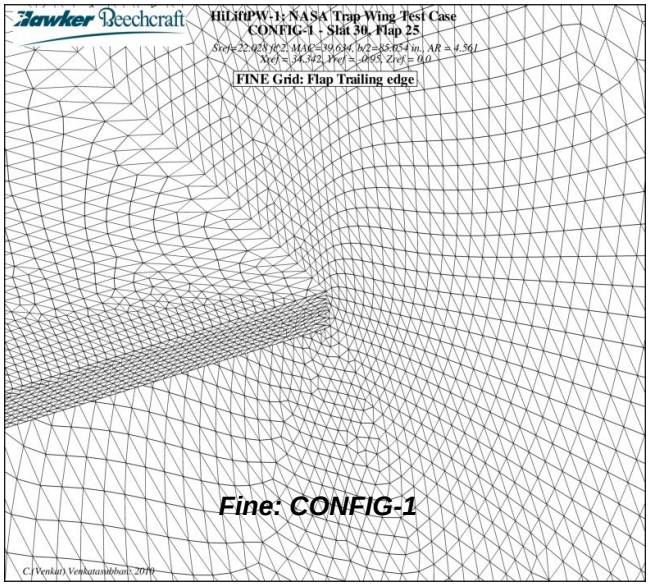


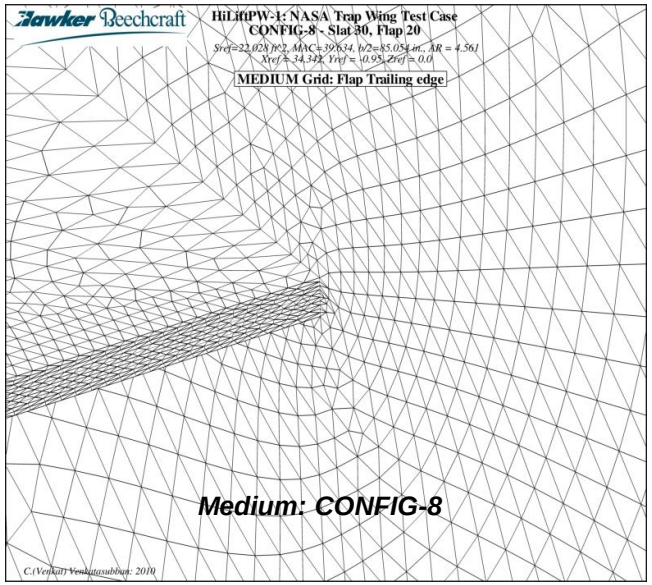
HiLiftPW-1





10 cells across trailing edges





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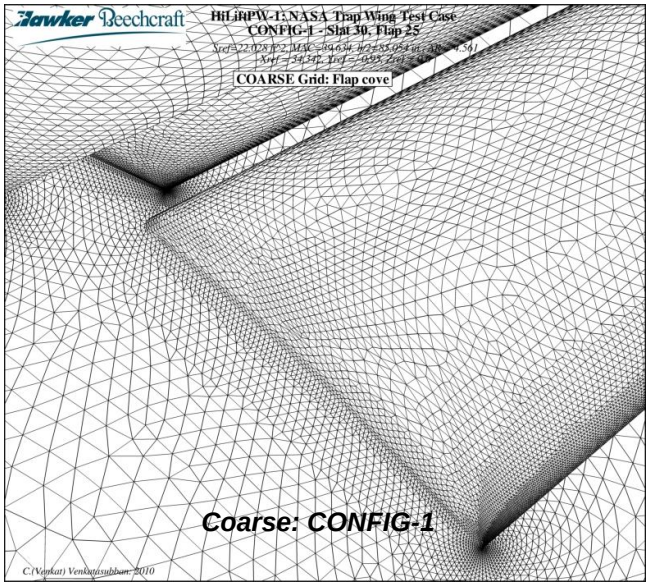
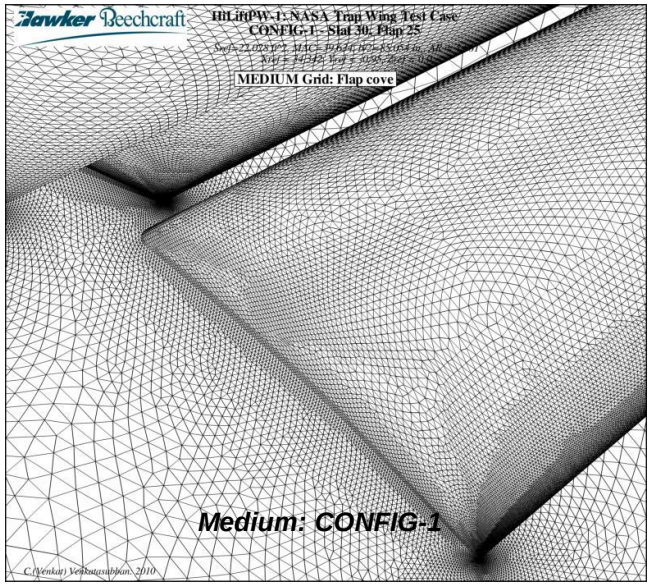
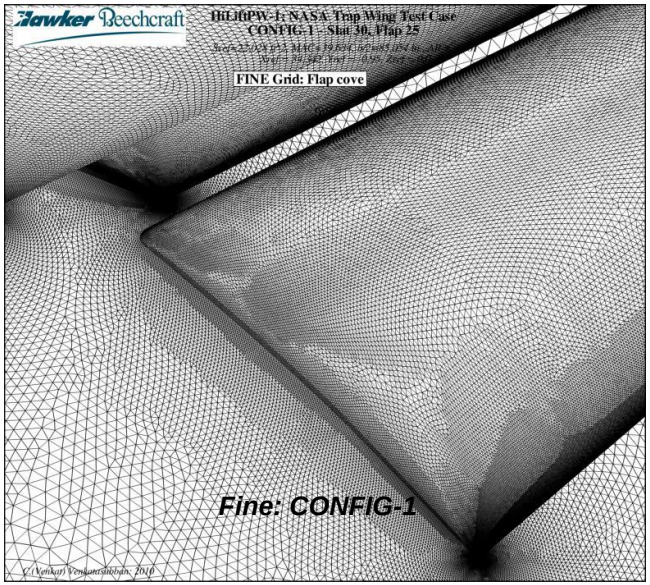
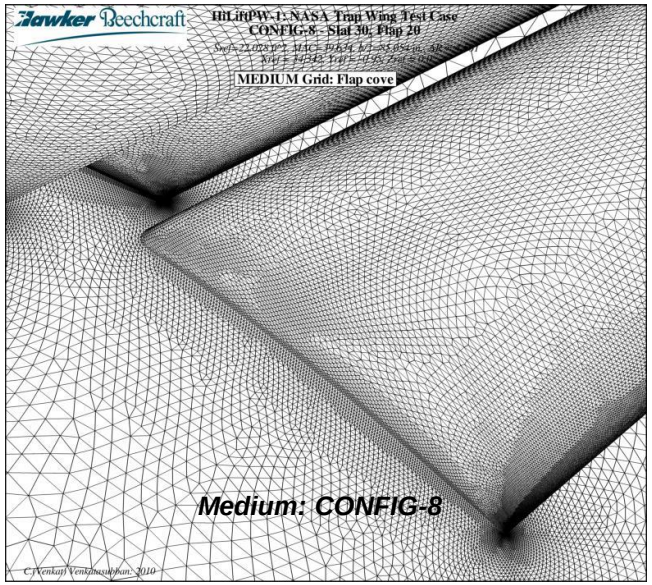




Flap cove





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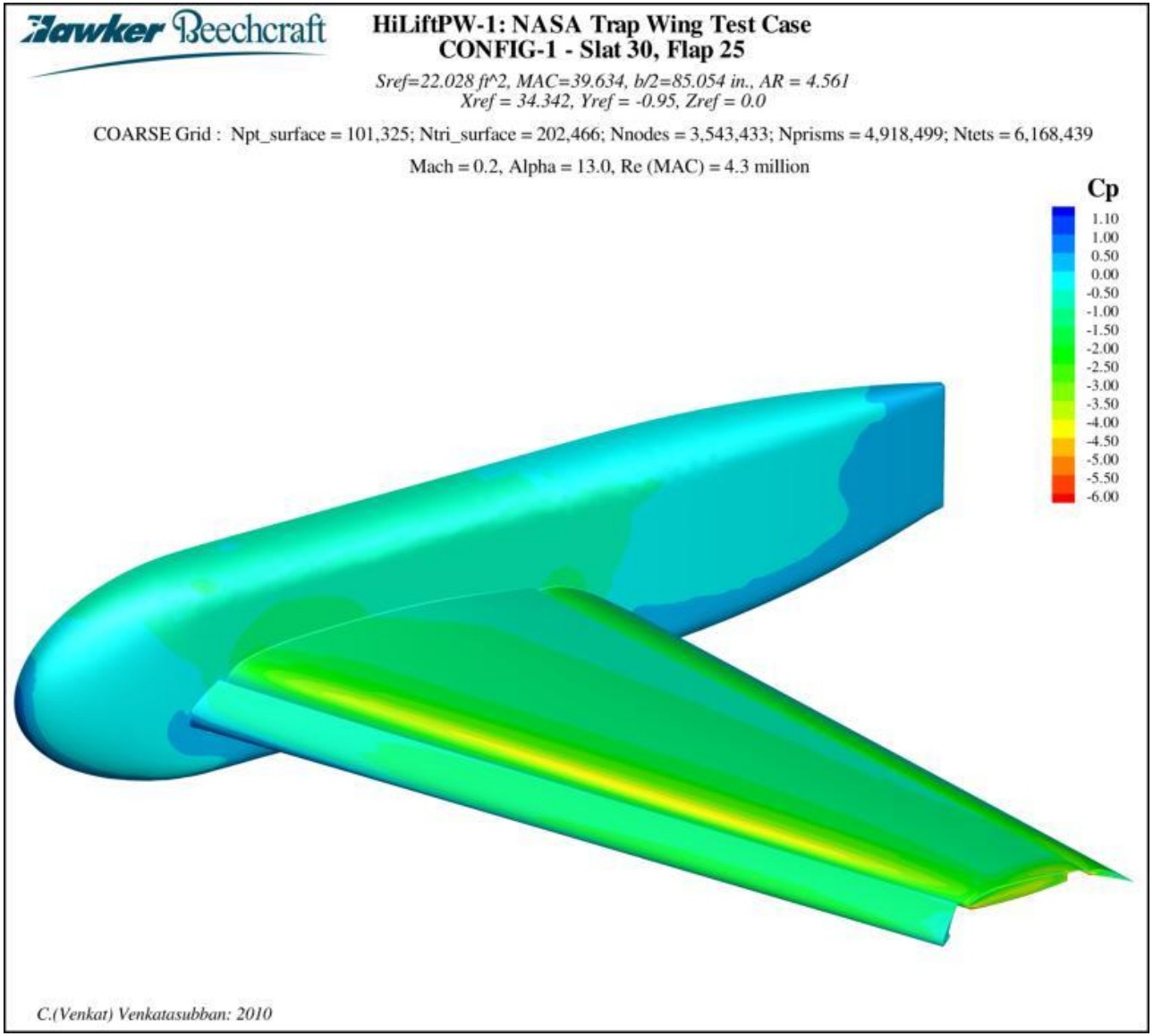
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Mach = 0.2, Alpha = 13.0, Re (MAC) = 4.3 million
Cp
1.10
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
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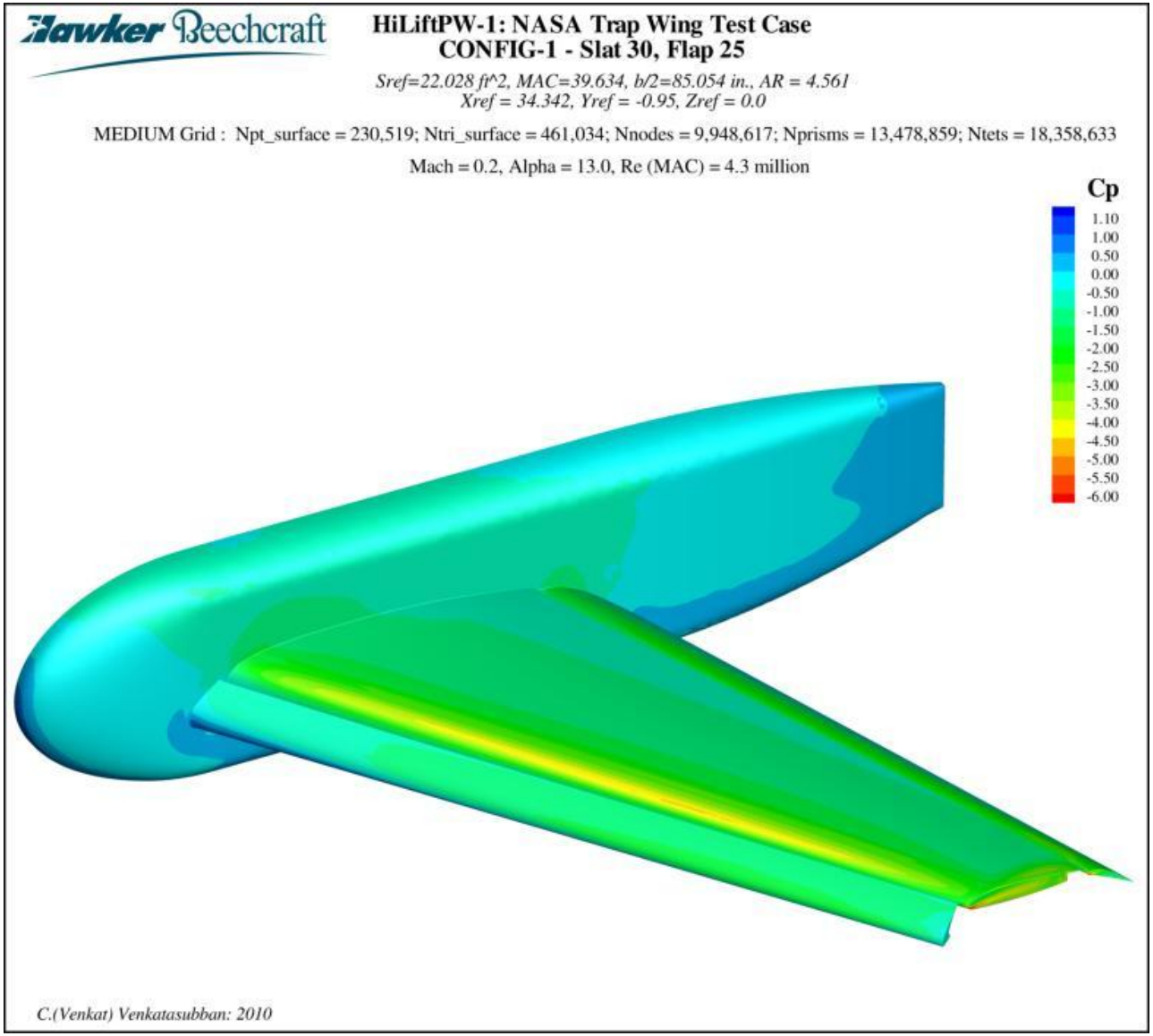
HiLiftPW-1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Mach = 0.2, Alpha = 13.0, Re (MAC) = 4.3 million
Cp
1.10
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
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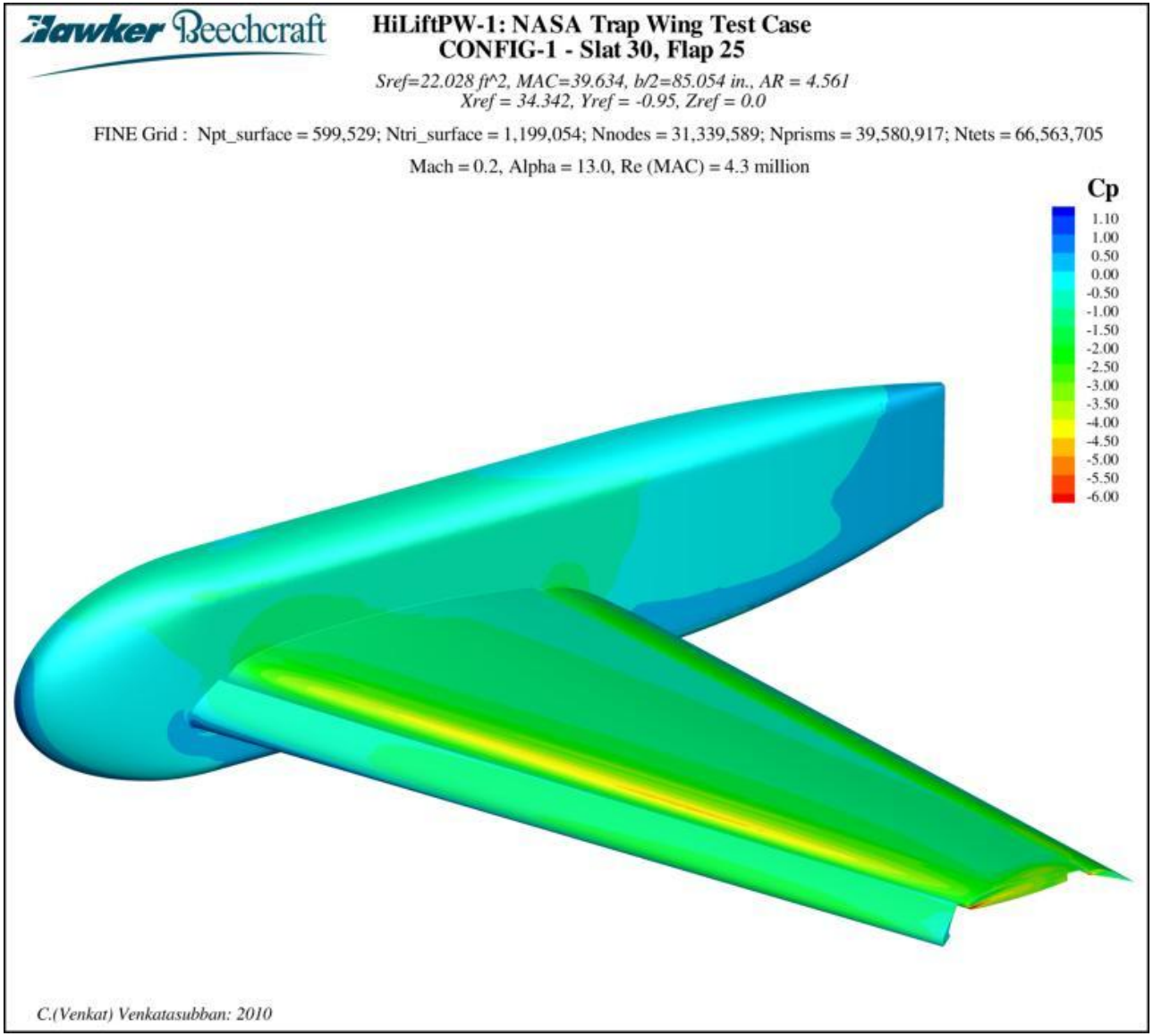
HiLiftPW-1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FINE Grid : Npt_surface = 599,529; Ntri_surface = 1,199,054; Nnodes = 31,339,589; Nprisms = 39,580,917; Ntets = 66,563,705
Mach = 0.2, Alpha = 13.0, Re (MAC) = 4.3 million
Cp
1.10
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
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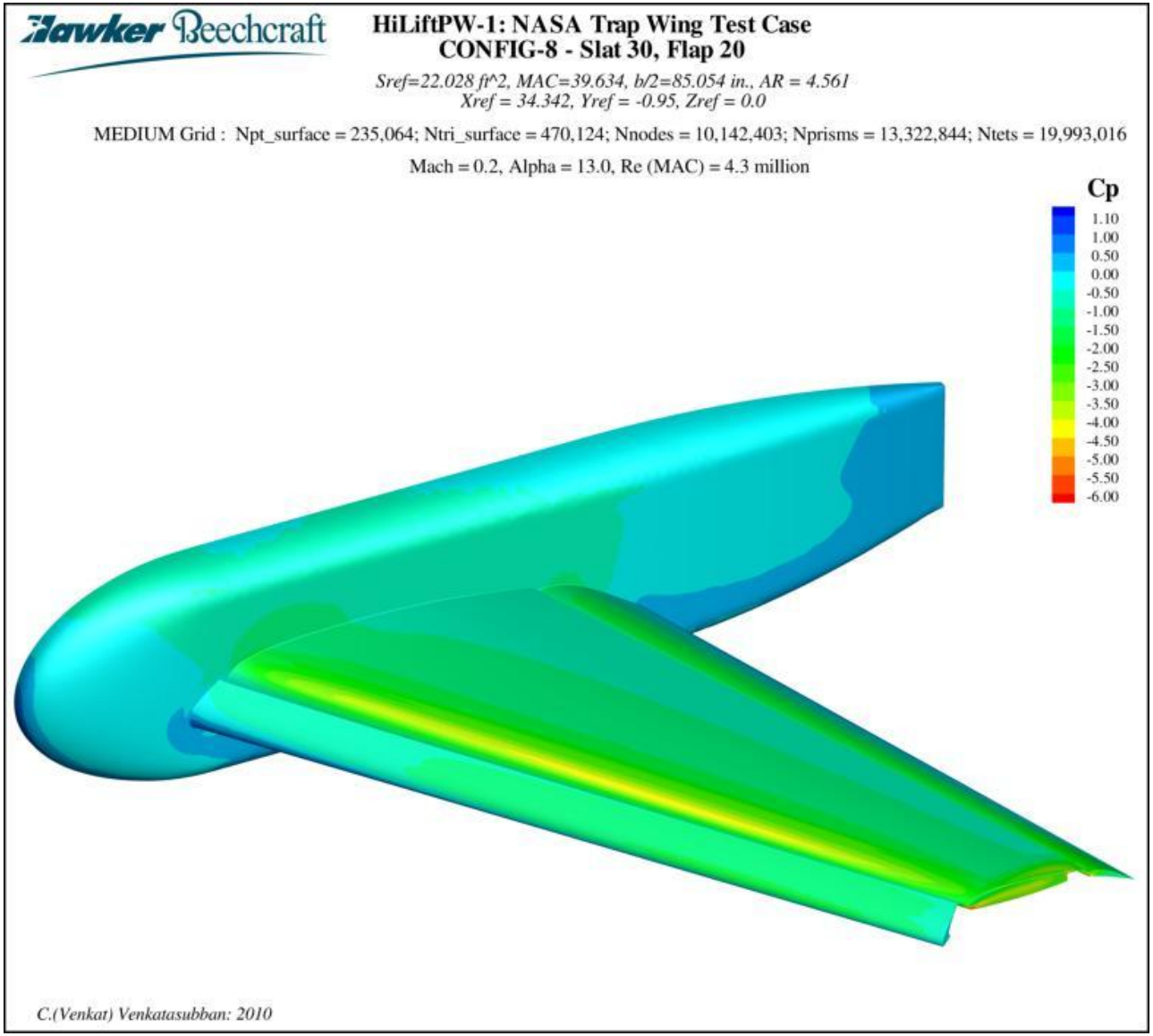
HiLiftPW-1


HiLiftPW-1: NASA Trap Wing Test Case
CONFIG-8 - Slat 30, Flap 20
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 235,064; Ntri_surface = 470,124; Nnodes = 10,142,403; Nprisms = 13,322,844; Ntets = 19,993,016
Mach = 0.2, Alpha = 13.0, Re (MAC) = 4.3 million
Cp
1.10
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
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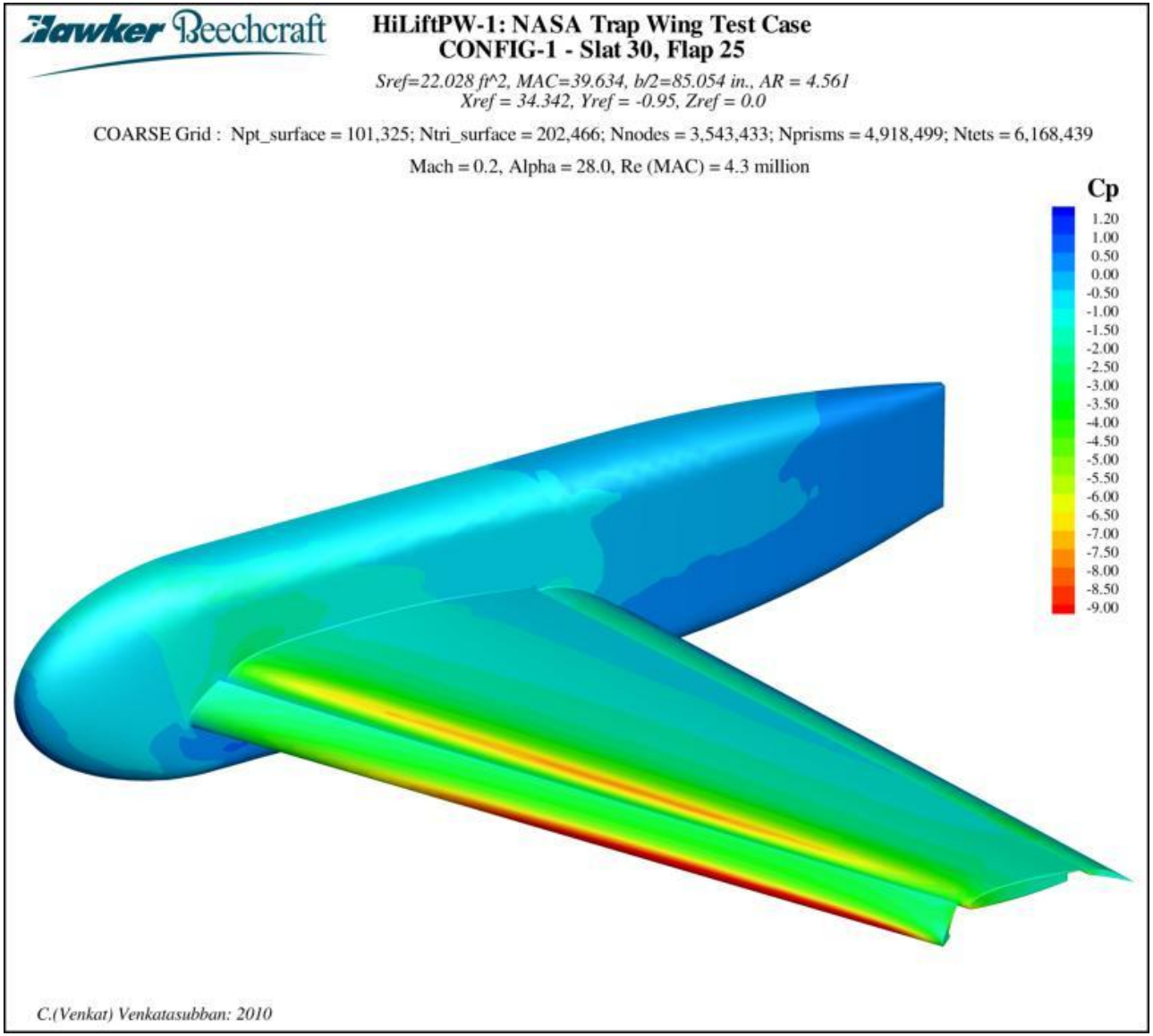
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Cp
1.20
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
-6.50
-7.00
-7.50
-8.00
-8.50
-9.00
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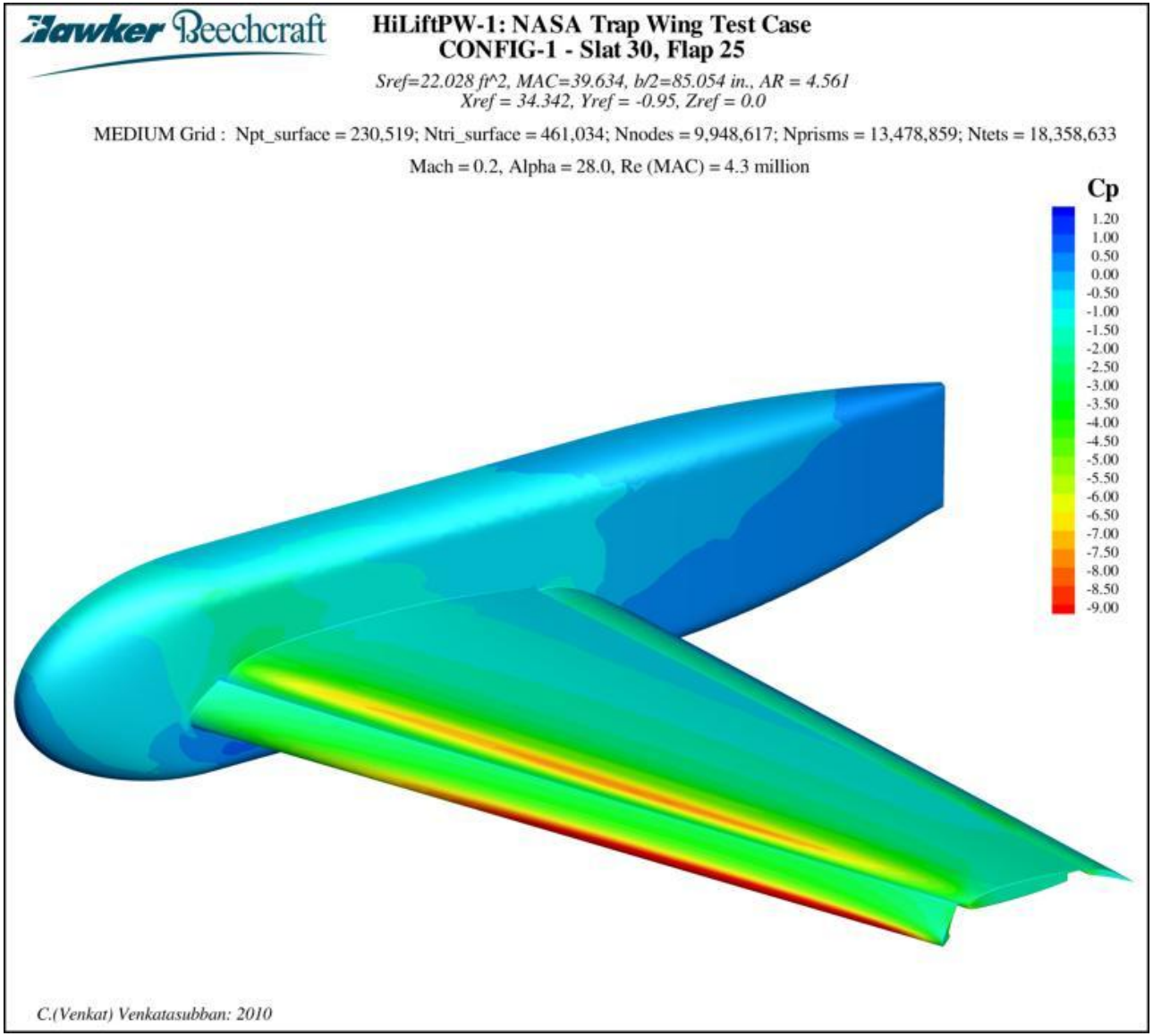
HiLiftPW-1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Mach = 0.2, Alpha = 28.0, Re (MAC) = 4.3 million
Cp
1.20
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
-6.50
-7.00
-7.50
-8.00
-8.50
-9.00
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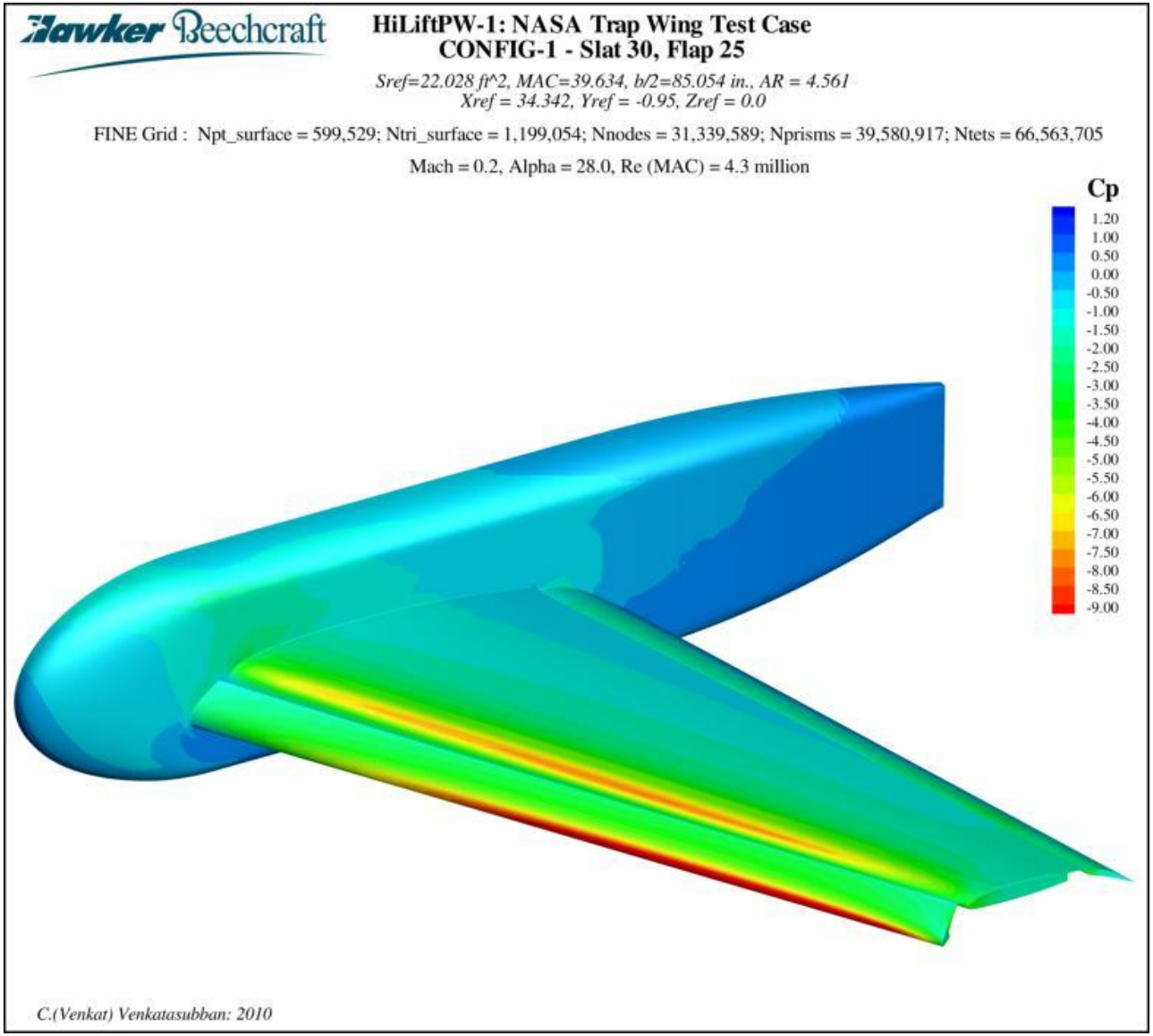
HiLiftPW-1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Mach = 0.2, Alpha = 28.0, Re (MAC) = 4.3 million
Cp
1.20
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
-6.50
-7.00
-7.50
-8.00
-8.50
-9.00
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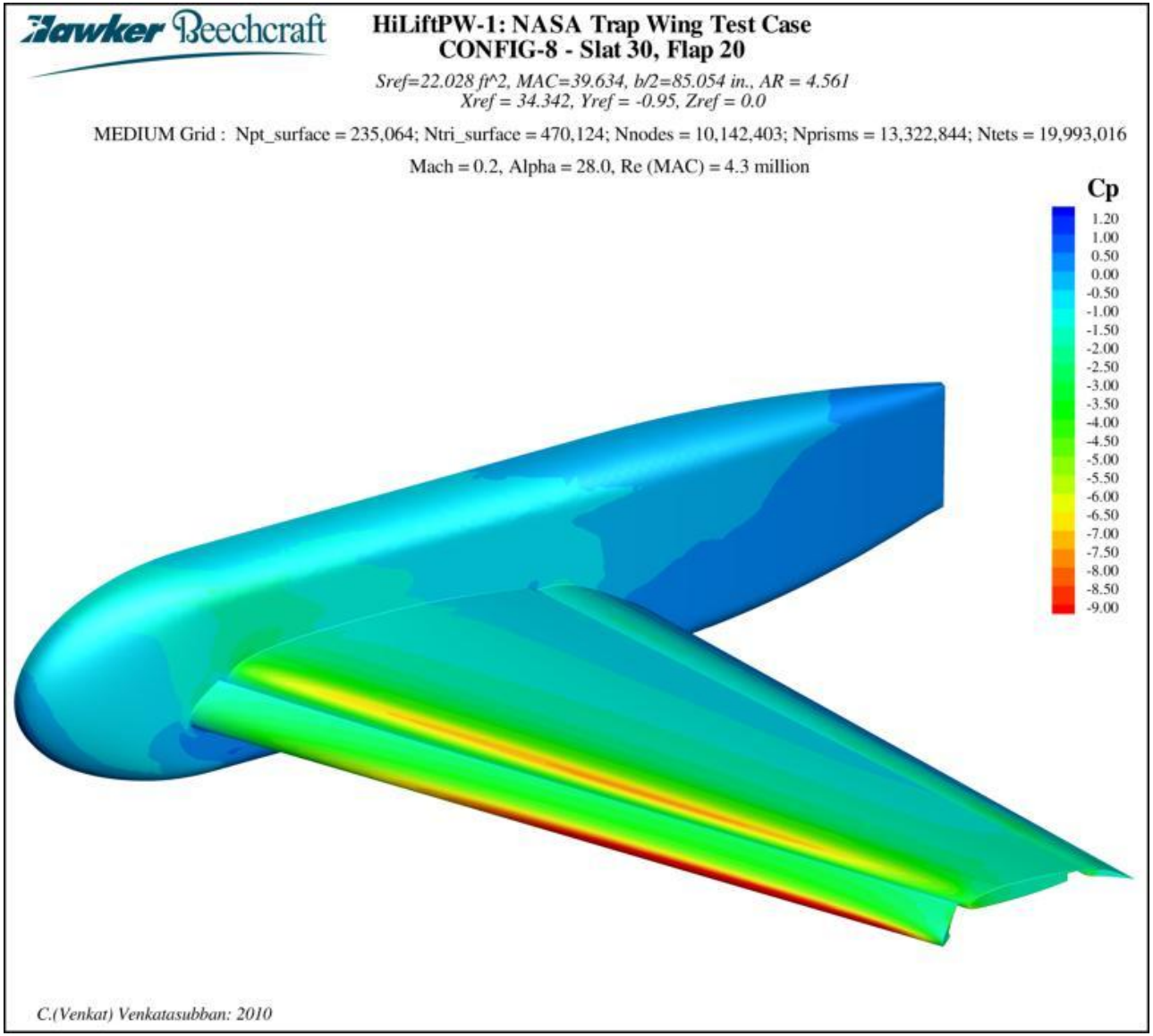
HiLiftPW-1


HiLiftPW-1: NASA Trap Wing Test Case
CONFIG-8 - Slat 30, Flap 20
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
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Mach = 0.2, Alpha = 28.0, Re (MAC) = 4.3 million
Cp
1.20
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
-6.50
-7.00
-7.50
-8.00
-8.50
-9.00
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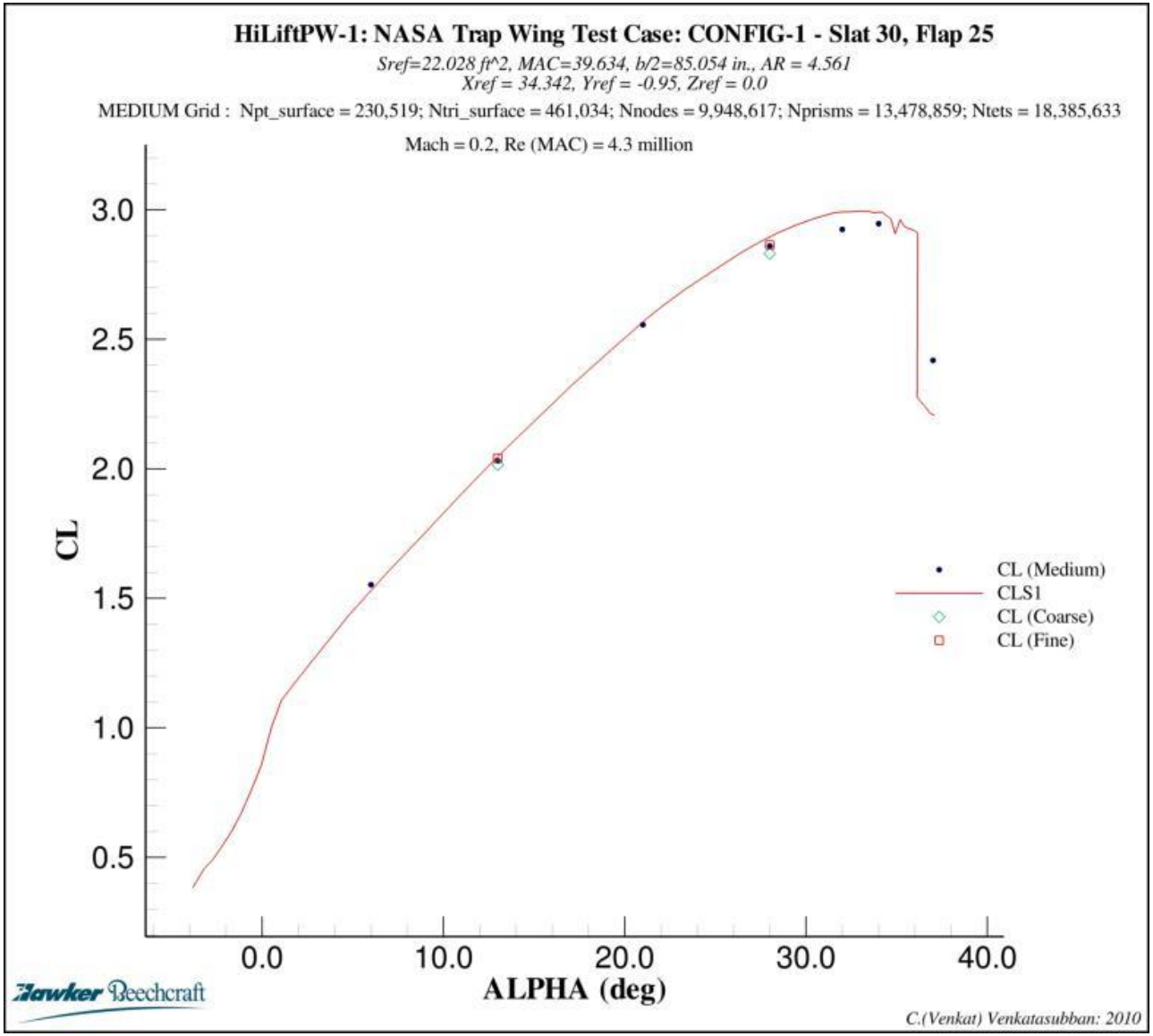
HiLiftPW-1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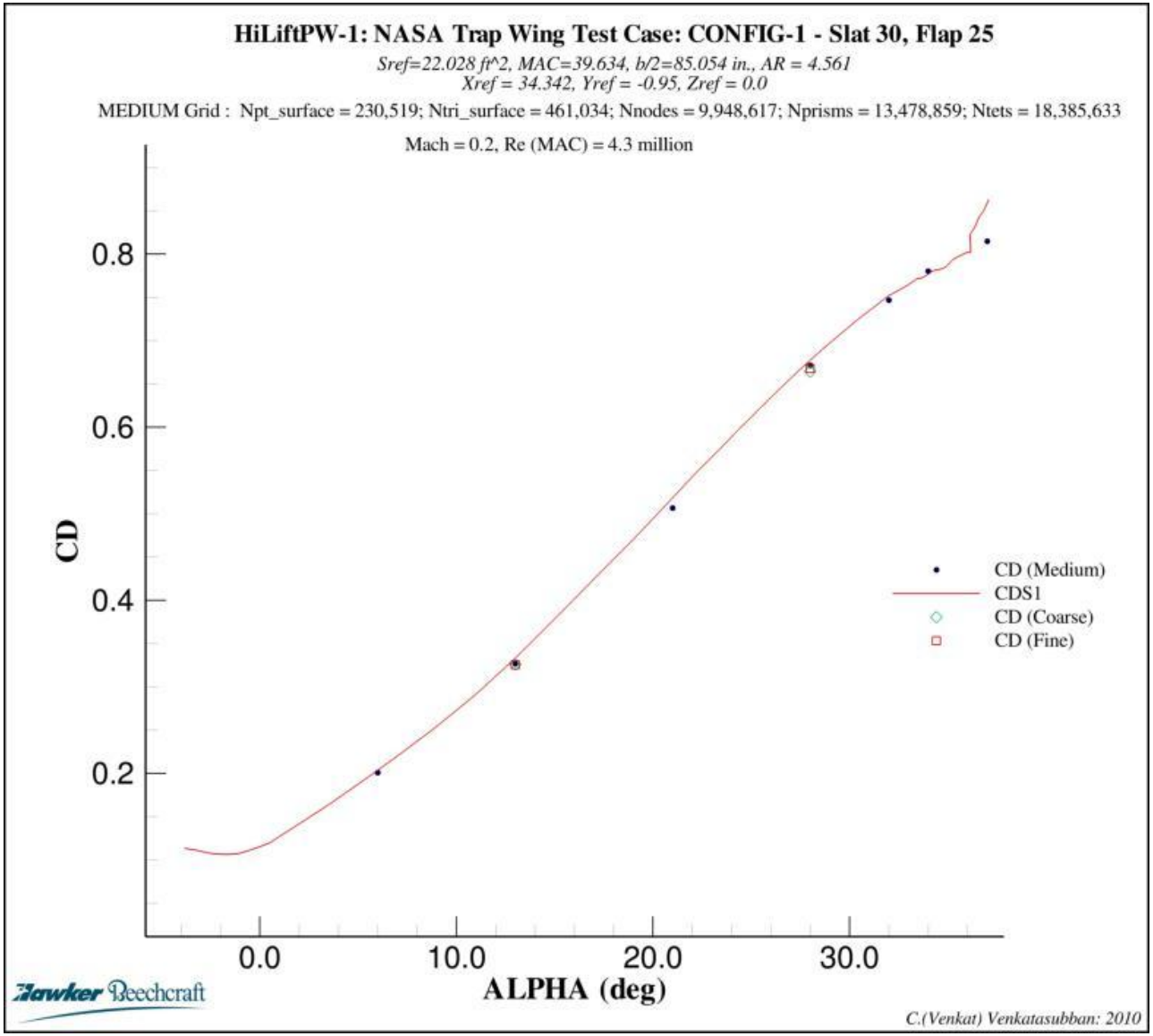
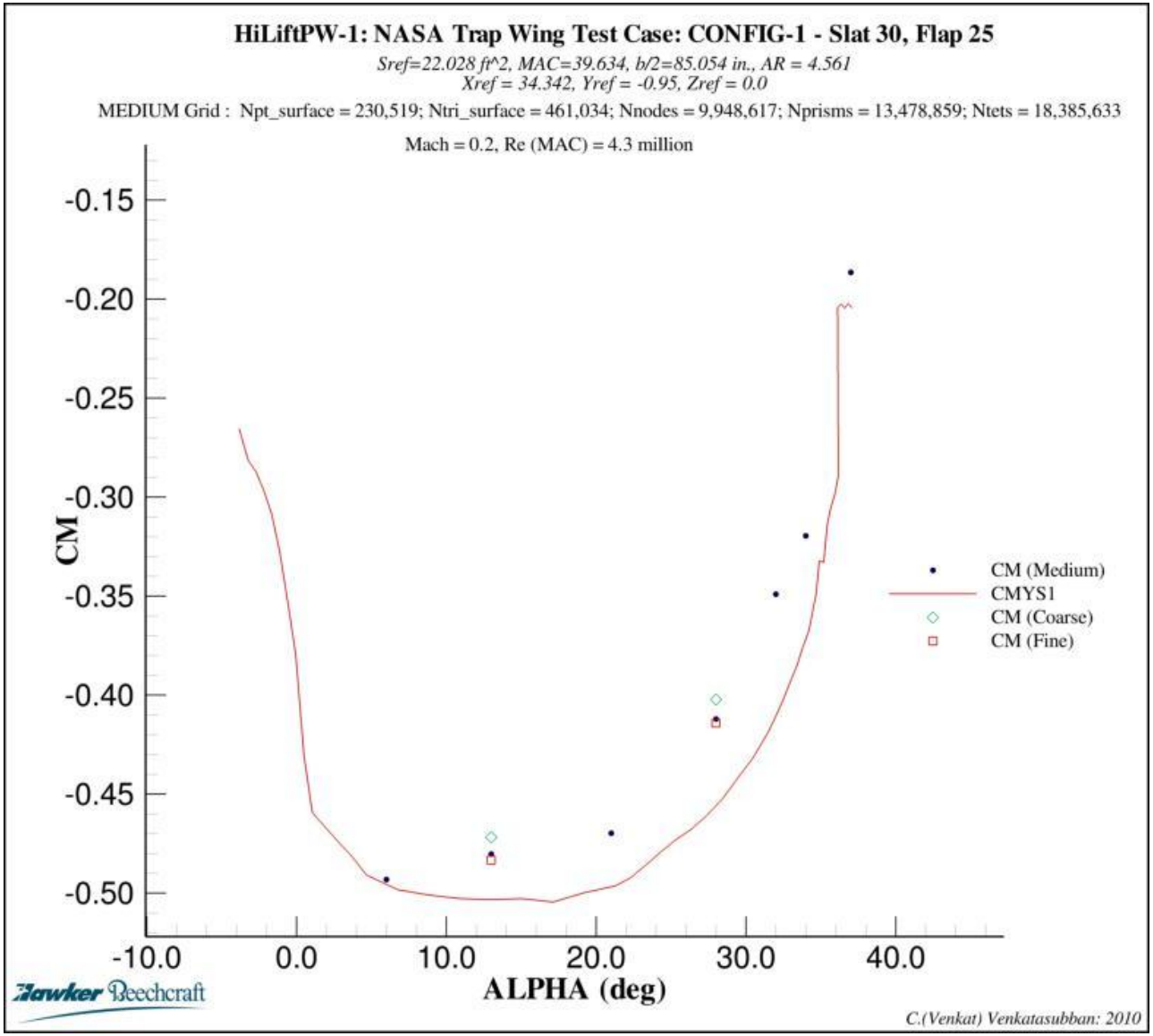
Mach = 0.2, Re (MAC) = 4.3 million
CL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10.0
20.0
30.0
40.0
ALPHA (deg)
CL (Medium)
CLS1
CL (Coarse)
CL (Fine)
C.(Venkat) Venkatasubban: 2010

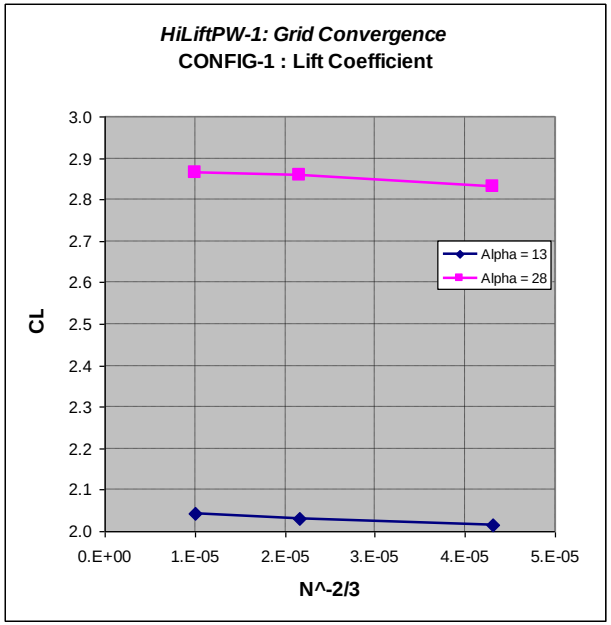
HiLiftPW-1

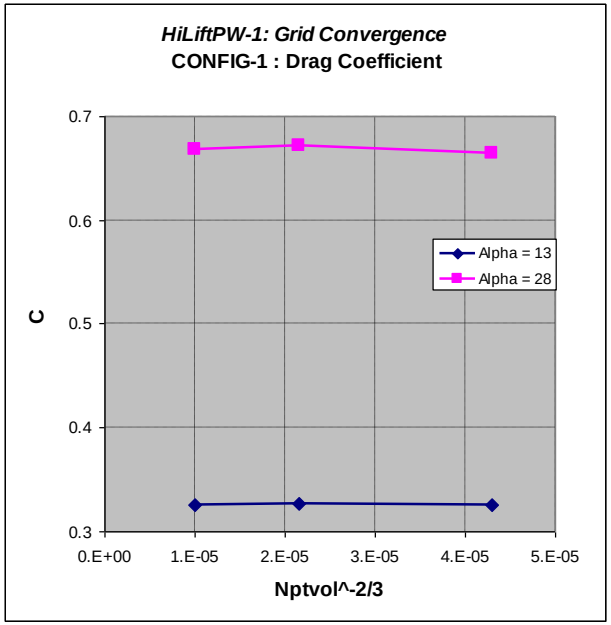

HiLiftPW-1: NASA Trap Wing Test Case: CONFIG-1 - Slat 30, Flap 25
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 230,519; Ntri_surface = 461,034; Nnodes = 9,948,617; Nprisms = 13,478,859; Ntets = 18,385,633
Mach = 0.2, Re (MAC) = 4.3 million
CD
0.8
0.6
0.4
0.2
0.0
10.0
20.0
30.0
ALPHA (deg)
CD (Medium)
CDS1
CD (Coarse)
CD (Fine)
C.(Venkat) Venkatasubban: 2010

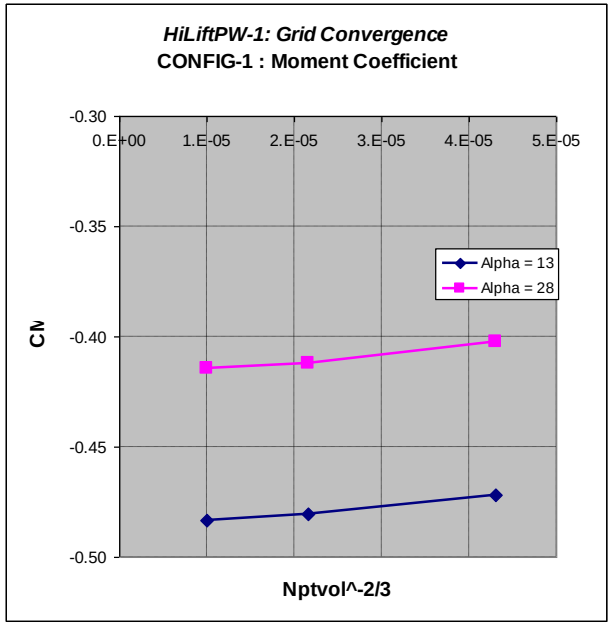
HiLiftPW-1

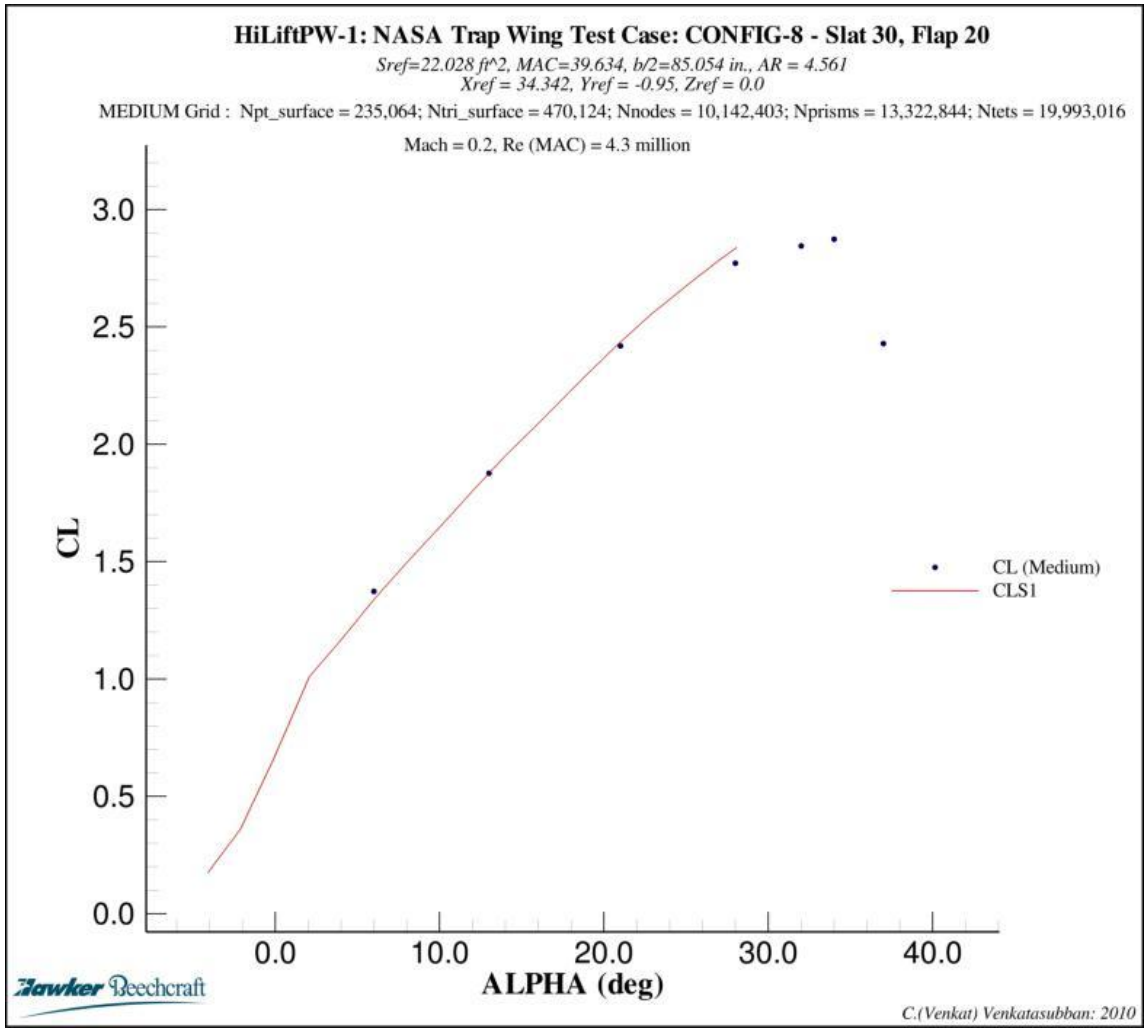

HiLiftPW-1: NASA Trap Wing Test Case: CONFIG-1 - Slat 30, Flap 25
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 230,519; Ntri_surface = 461,034; Nnodes = 9,948,617; Nprisms = 13,478,859; Ntets = 18,385,633
Mach = 0.2, Re (MAC) = 4.3 million
CM
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
-10.0
0.0
10.0
20.0
30.0
40.0
ALPHA (deg)
CM (Medium)
CMYS1
CM (Coarse)
CM (Fine)
C.(Venkat) Venkatasubban: 2010

- **Grid Convergence**

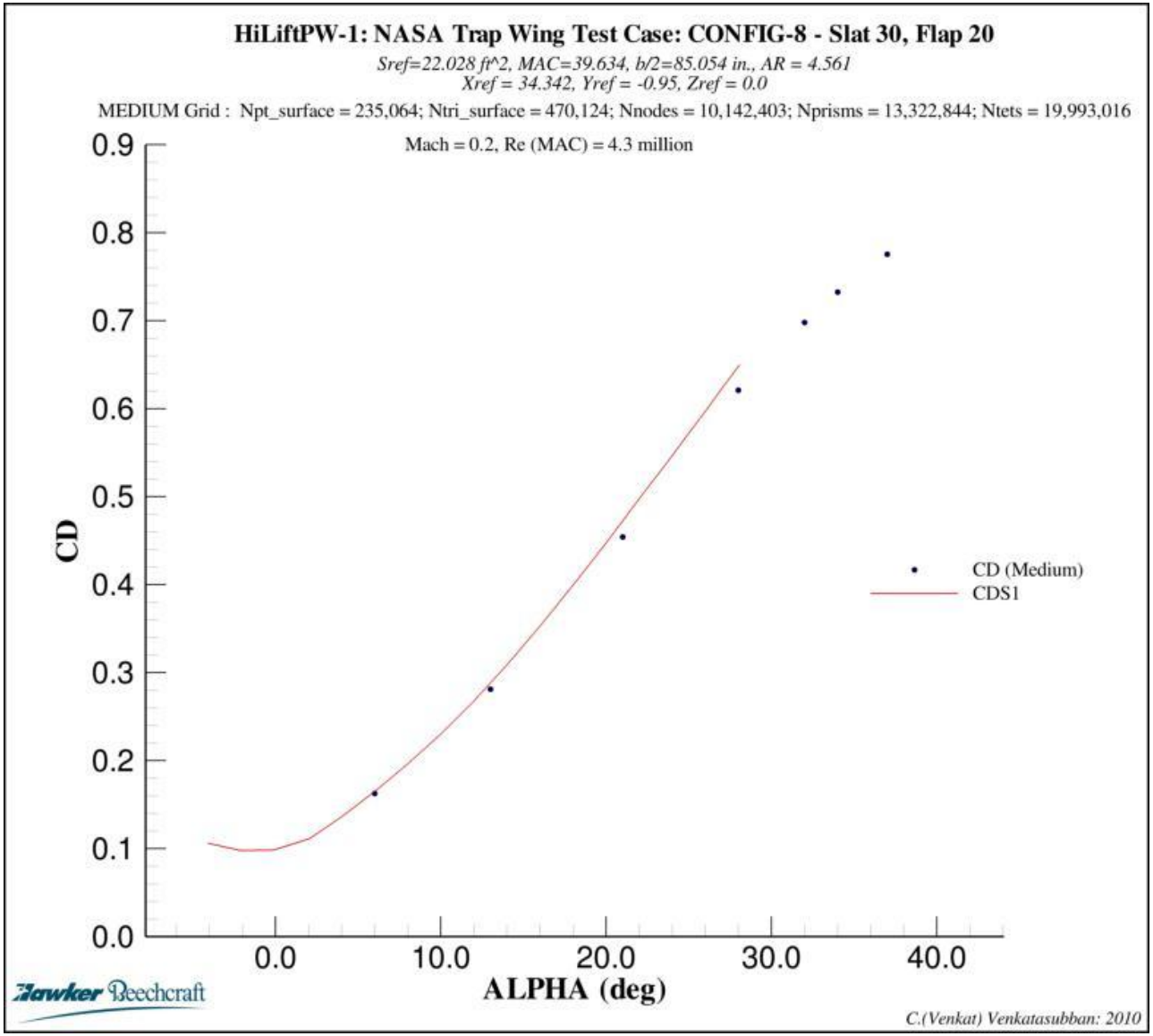




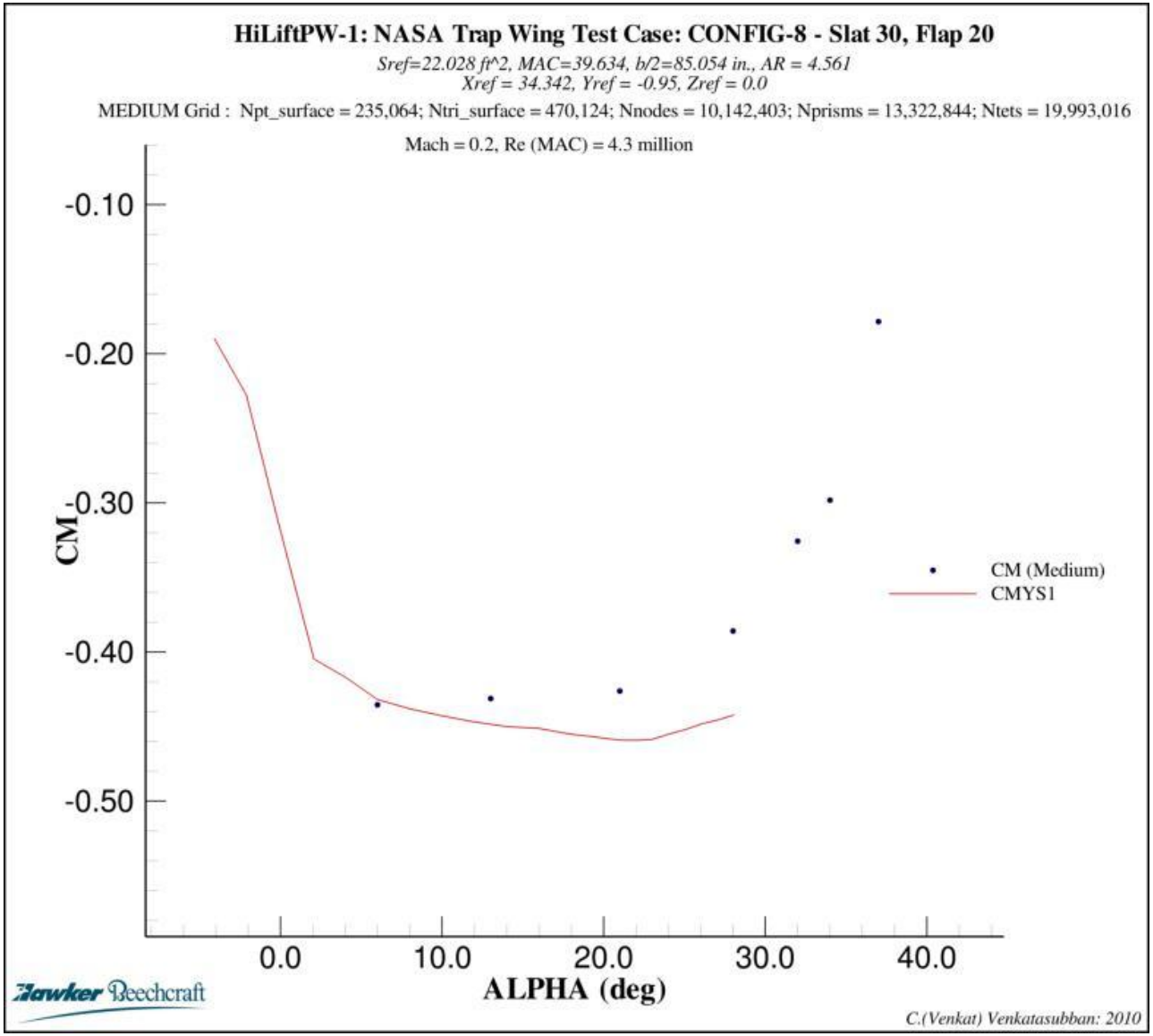



HiLiftPW-1: NASA Trap Wing Test Case: CONFIG-8 - Slat 30, Flap 20
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 235,064; Ntri_surface = 470,124; Nnodes = 10,142,403; Nprisms = 13,322,844; Ntets = 19,993,016
Mach = 0.2, Re (MAC) = 4.3 million
CL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
10.0
20.0
30.0
40.0
ALPHA (deg)
CL (Medium)
CLS1
C.(Venkat) Venkatasubban: 2010

HiLiftPW-1

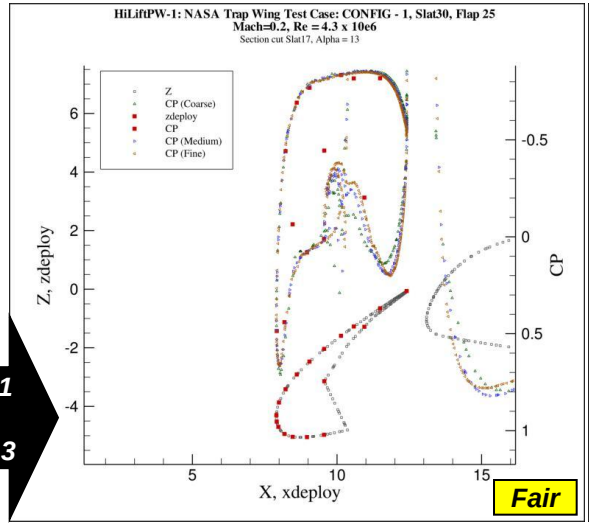

HiLiftPW-1: NASA Trap Wing Test Case: CONFIG-8 - Slat 30, Flap 20
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 235,064; Ntri_surface = 470,124; Nnodes = 10,142,403; Nprisms = 13,322,844; Ntets = 19,993,016
Mach = 0.2, Re (MAC) = 4.3 million
CD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.0
10.0
20.0
30.0
40.0
ALPHA (deg)
CD (Medium)
CDS1
C.(Venkat) Venkatasubban: 2010

HiLiftPW-1

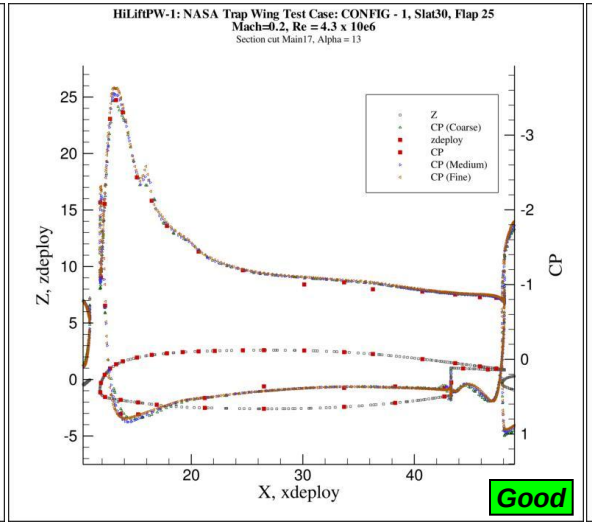

HiLiftPW-1: NASA Trap Wing Test Case: CONFIG-8 - Slat 30, Flap 20
Sref=22.028 ft^2, MAC=39.634, b/2=85.054 in., AR = 4.561
Xref = 34.342, Yref = -0.95, Zref = 0.0
MEDIUM Grid : Npt_surface = 235,064; Ntri_surface = 470,124; Nnodes = 10,142,403; Nprisms = 13,322,844; Ntets = 19,993,016
Mach = 0.2, Re (MAC) = 4.3 million
-0.10
-0.20
-0.30
-0.40
-0.50
CM
0.0
10.0
20.0
30.0
40.0
ALPHA (deg)
CM (Medium)
CMYS1
C.(Venkat) Venkatasubban: 2010

HiLiftPW-1

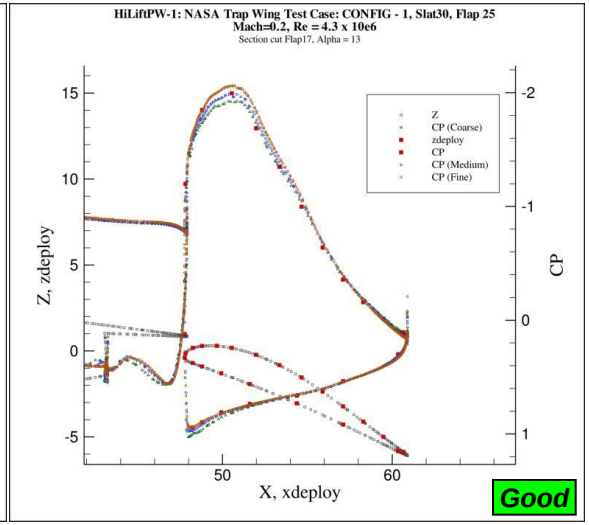
CONFIG-1
Cut 17
Alpha = 13



Fair

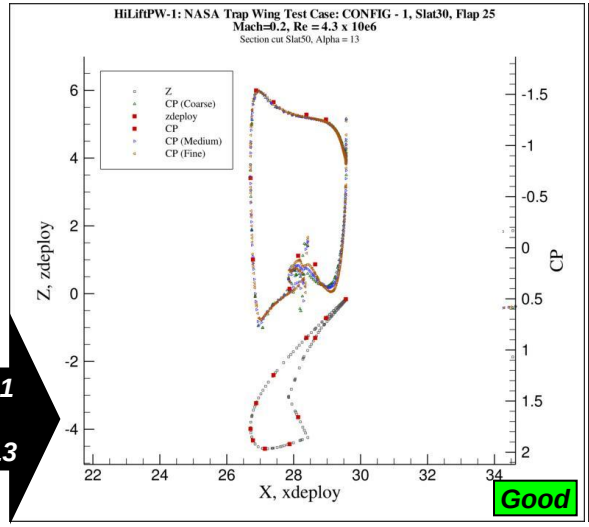


Good

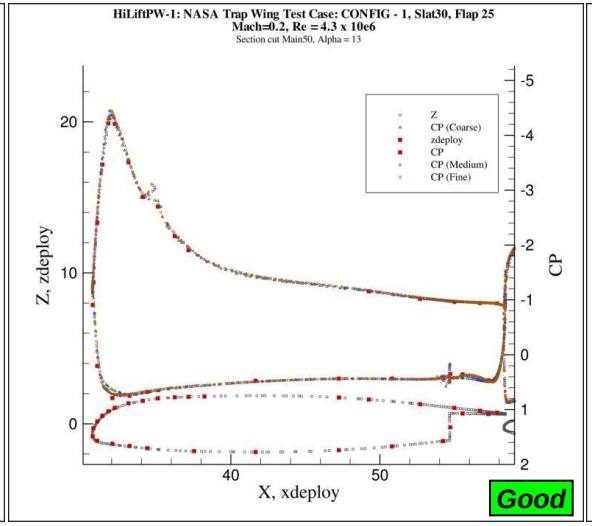


Good

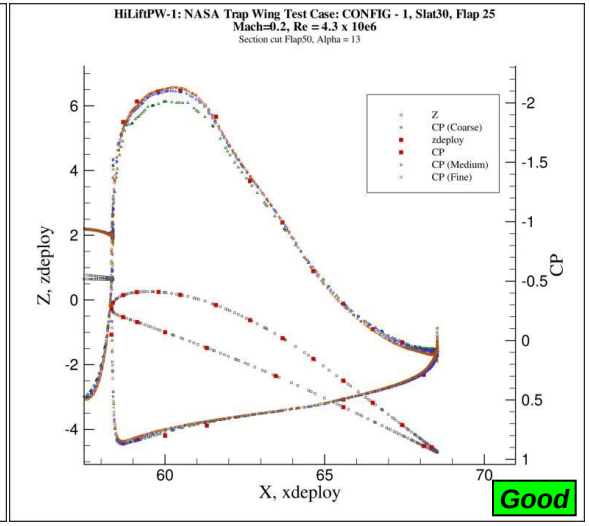
CONFIG-1
Cut 50
Alpha = 13



Good



Good

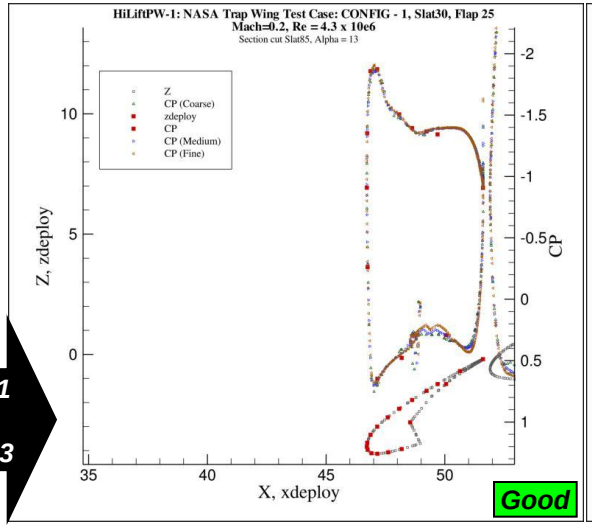


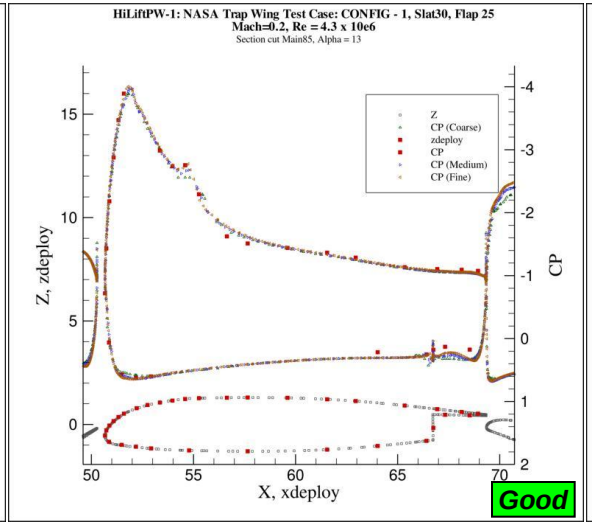
Good

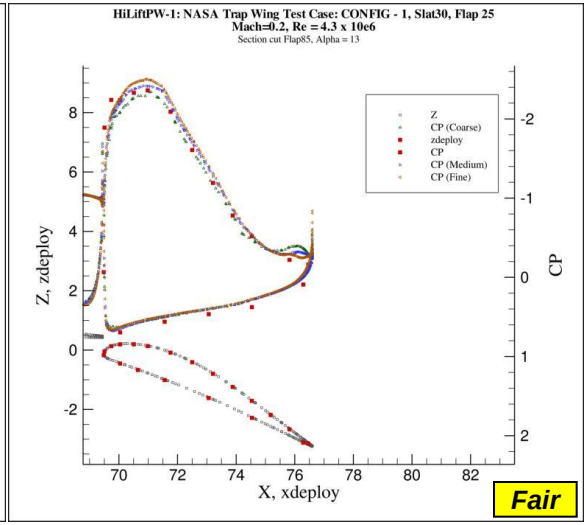
HiLiftPW-1

Hawker Beechcraft

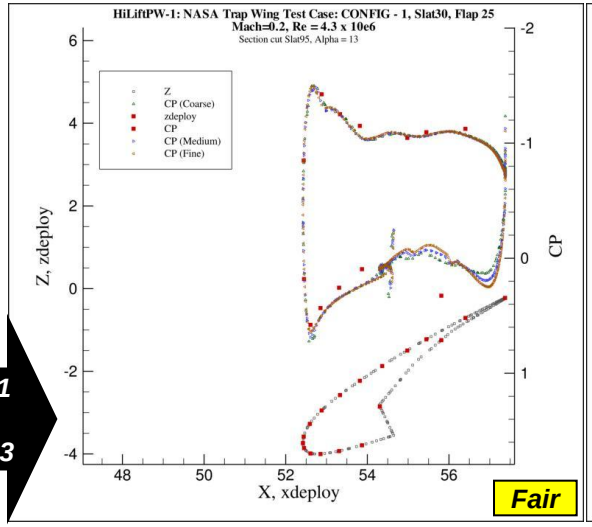
CONFIG-1
Cut 85
Alpha = 13

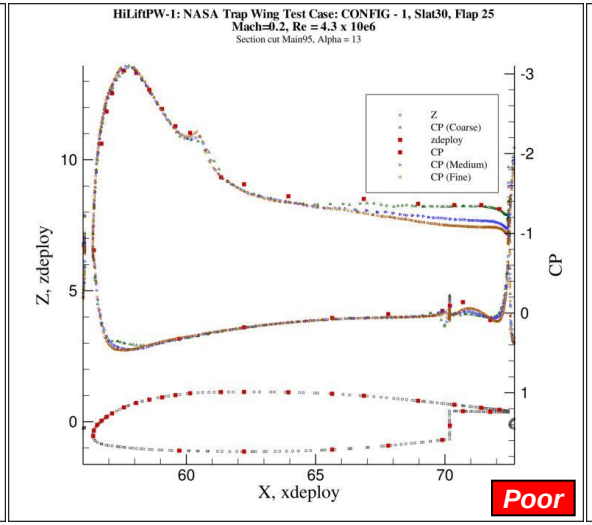


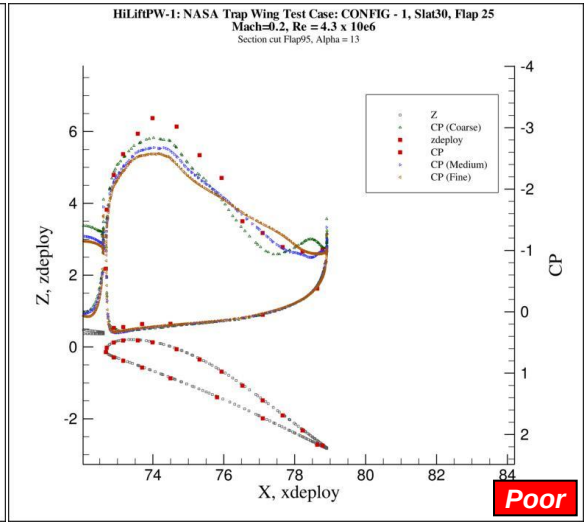




CONFIG-1
Cut 95
Alpha = 13

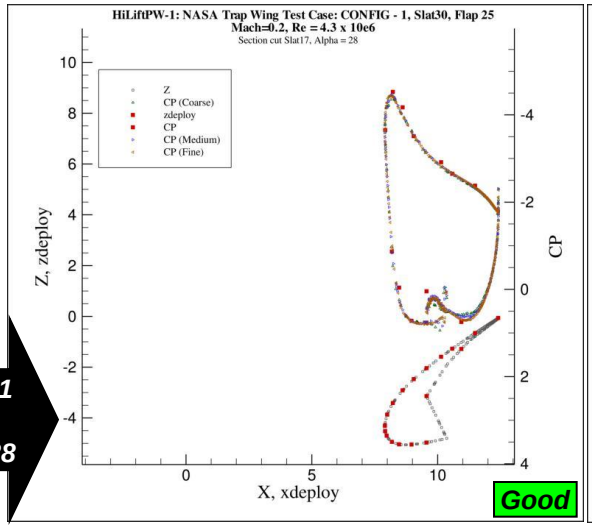


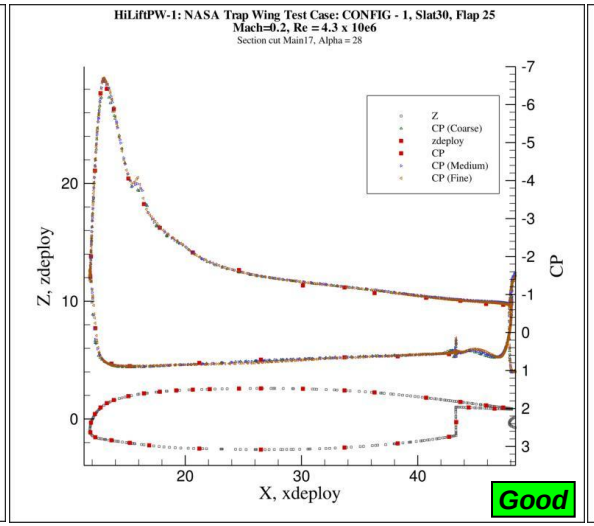


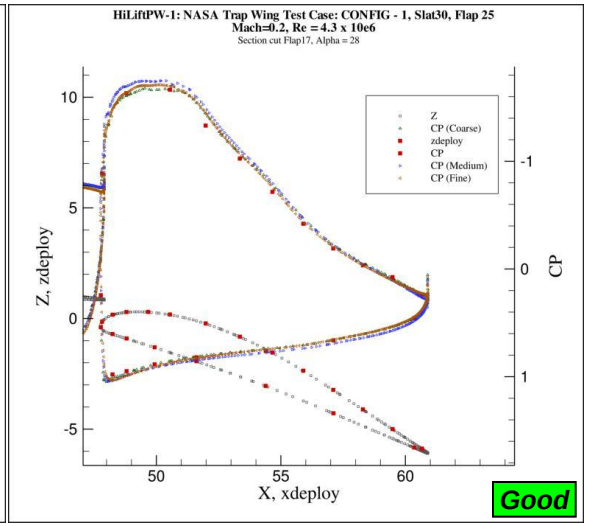


HiLiftPW-1

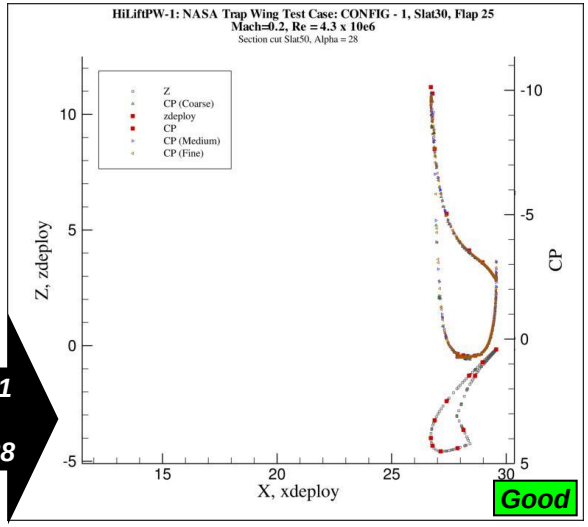
CONFIG-1
Cut 17
Alpha = 28

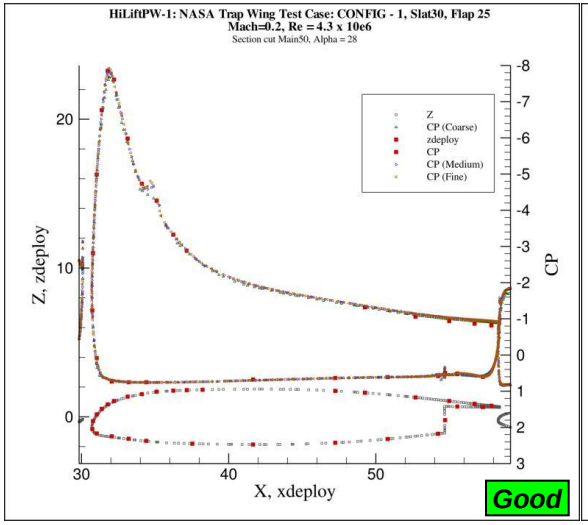


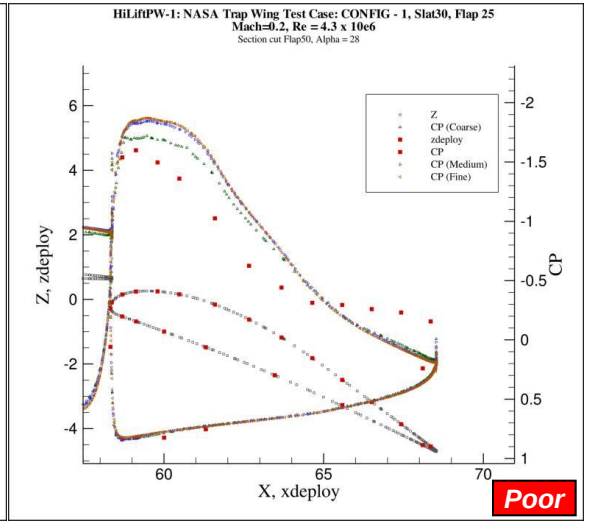




CONFIG-1
Cut 50
Alpha = 28



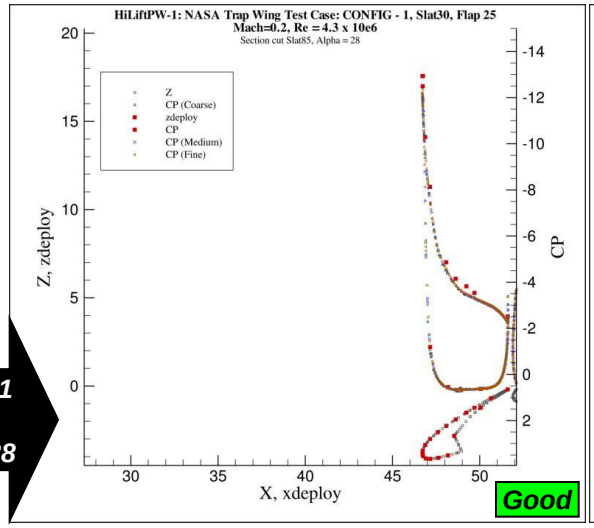


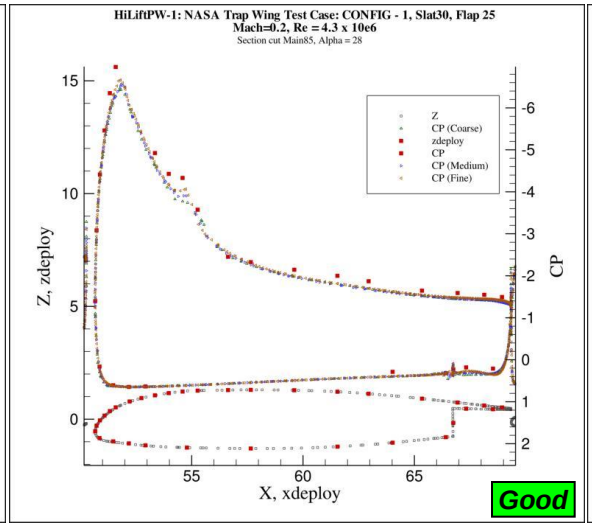


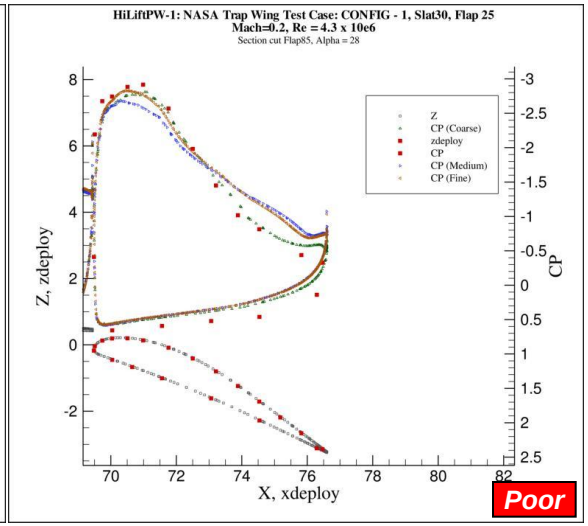
HiLiftPW-1

Hawker Beechcraft

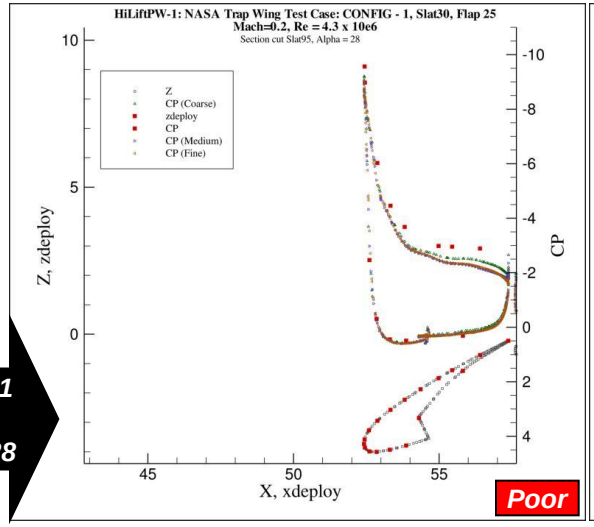
CONFIG-1
Cut 85
Alpha = 28

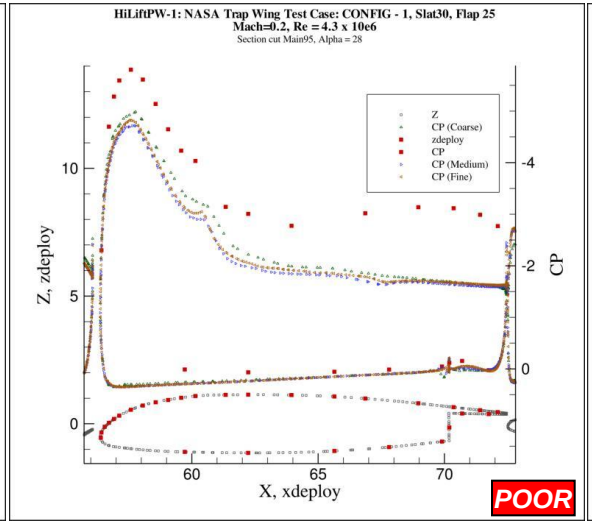


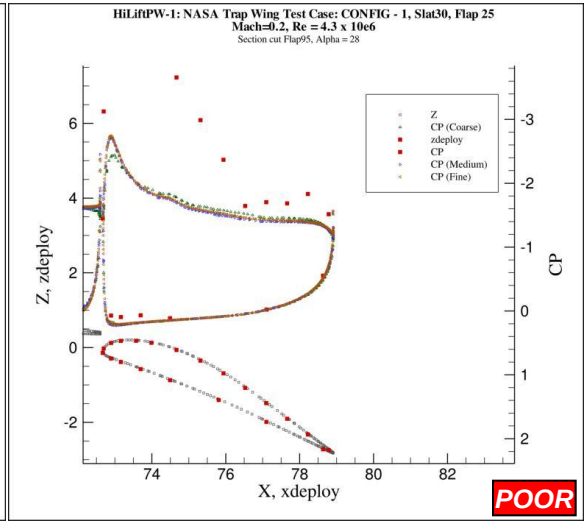




CONFIG-1
Cut 95
Alpha = 28

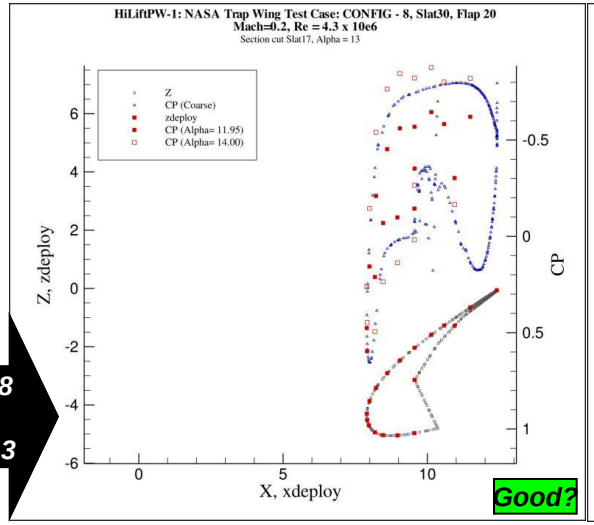


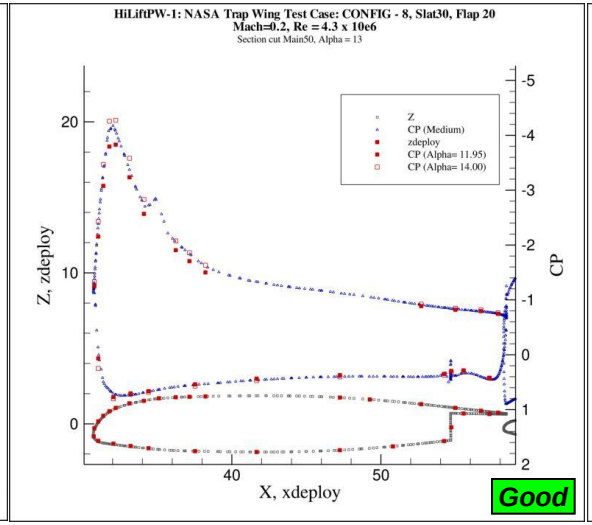


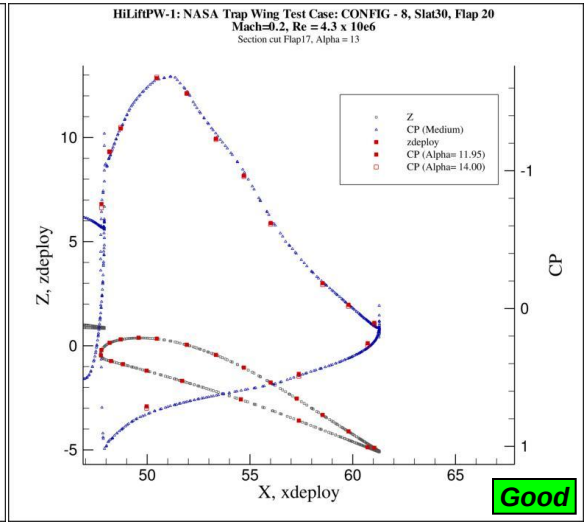


HiLiftPW-1

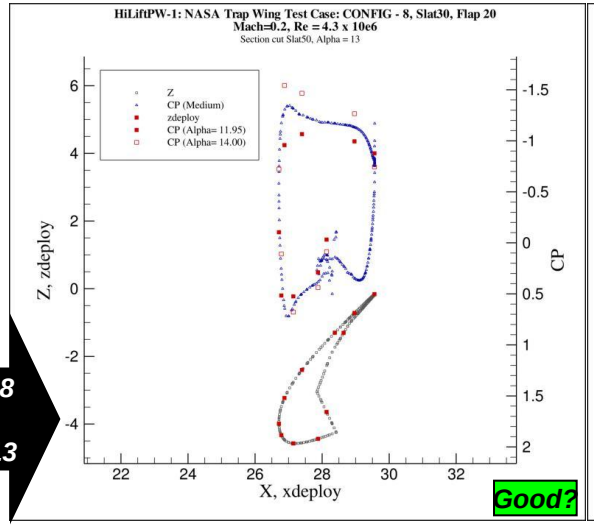
CONFIG-8
Cut 17
Alpha = 13

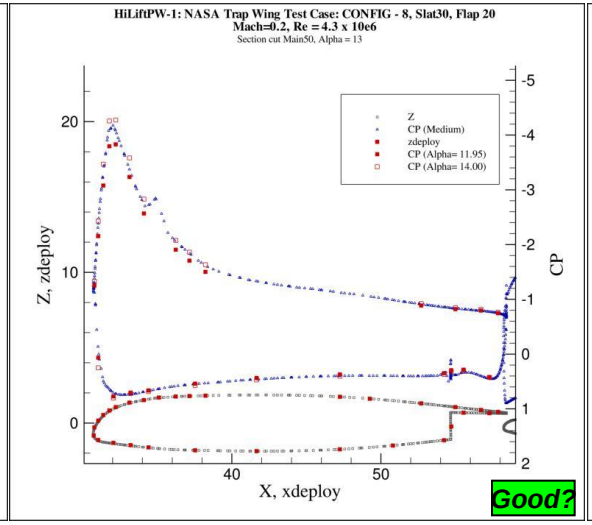


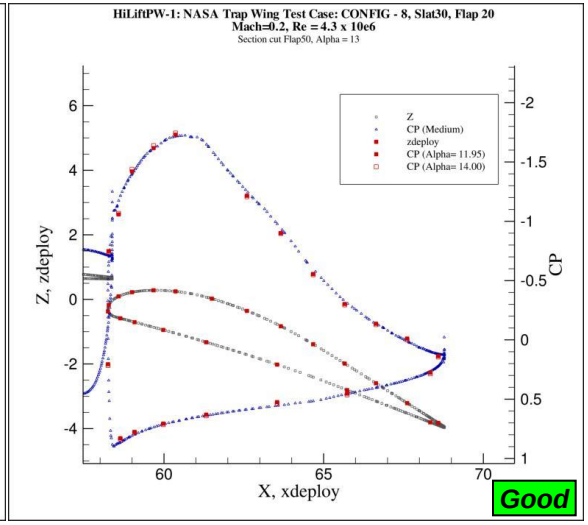




CONFIG-8
Cut 50
Alpha = 13

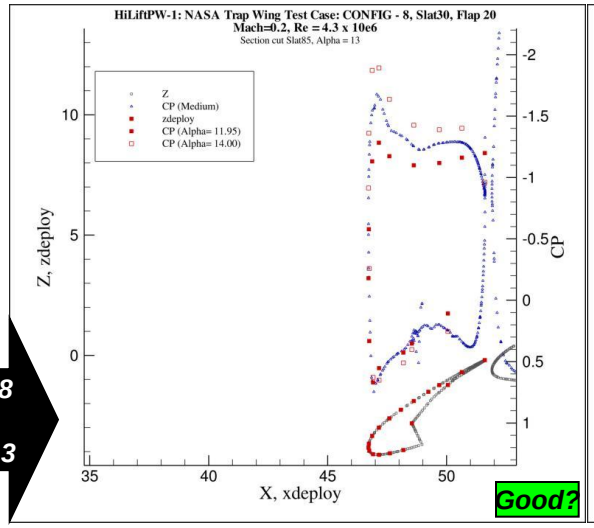




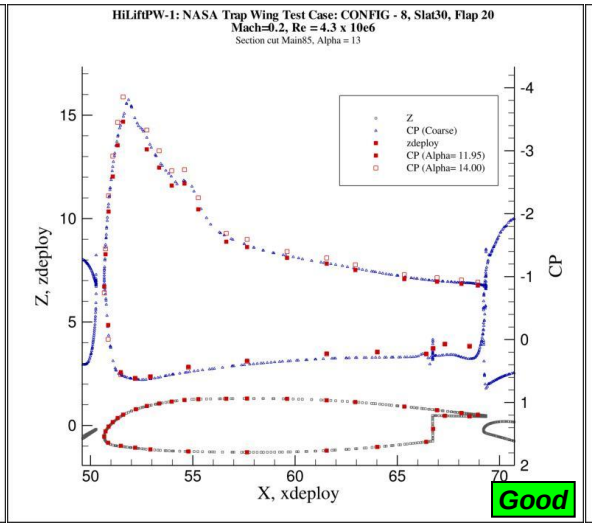


HiLiftPW-1

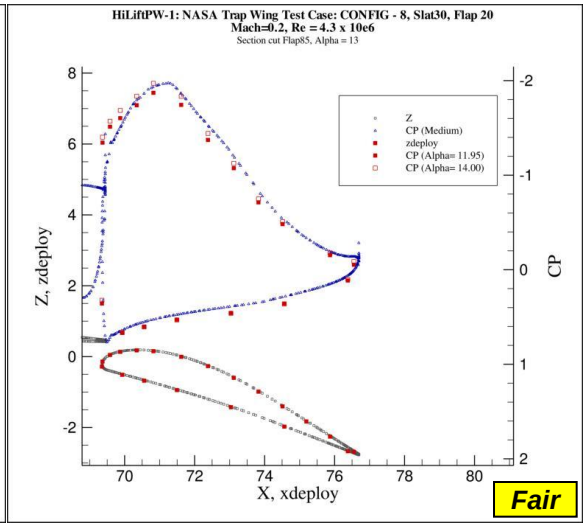
CONFIG-8
Cut 85
Alpha = 13



Good?

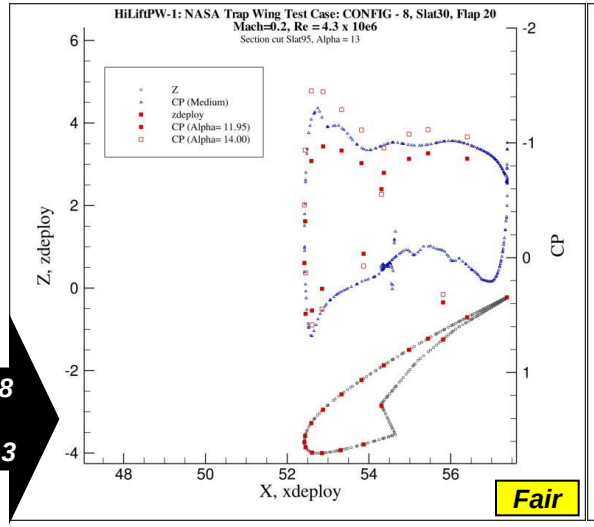


Good

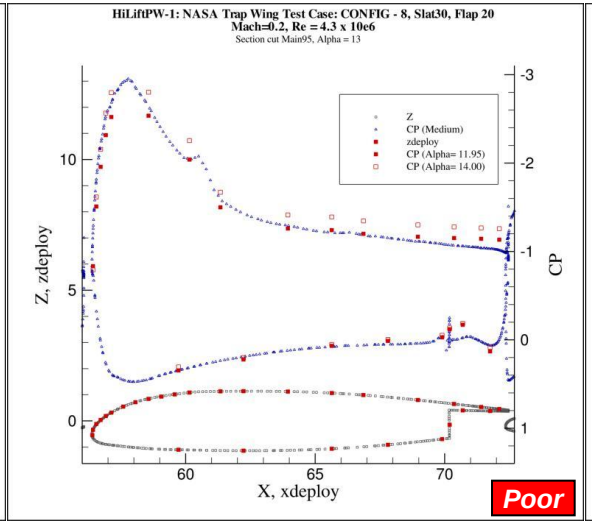


Fair

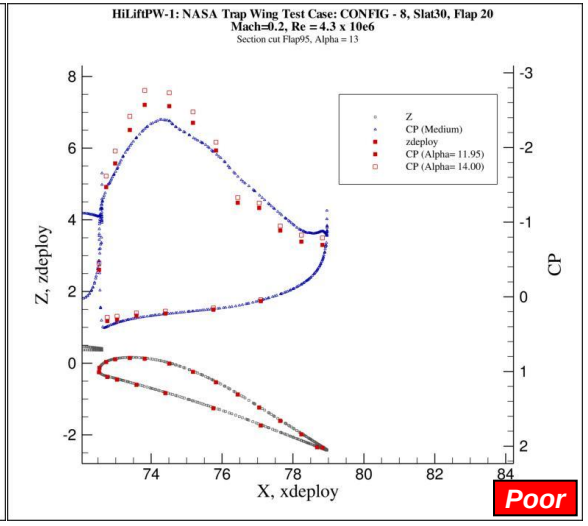
CONFIG-8
Cut 95
Alpha = 13



Fair



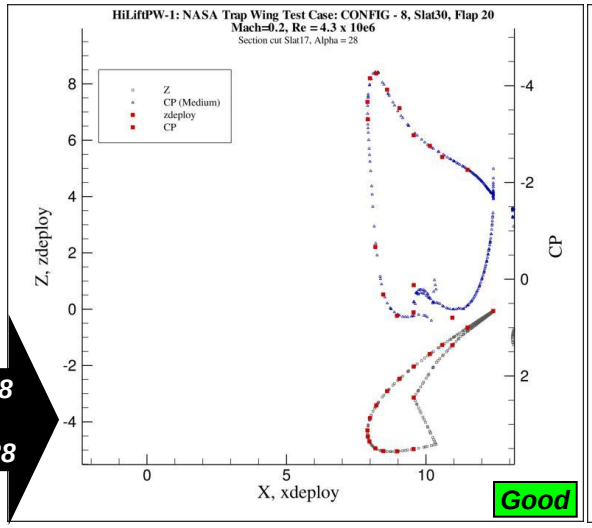
Poor



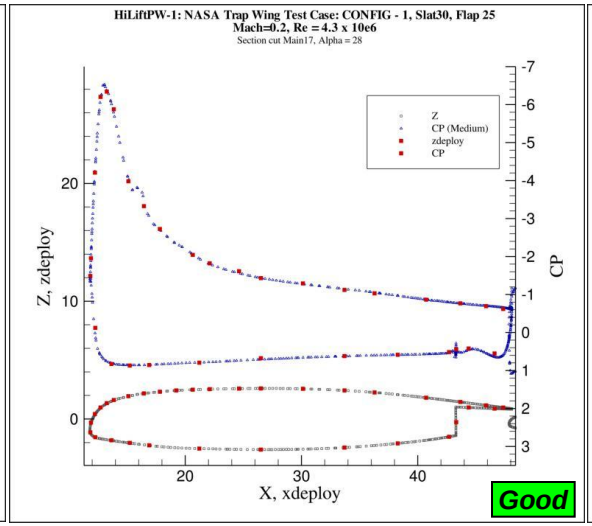
Poor

HiLiftPW-1

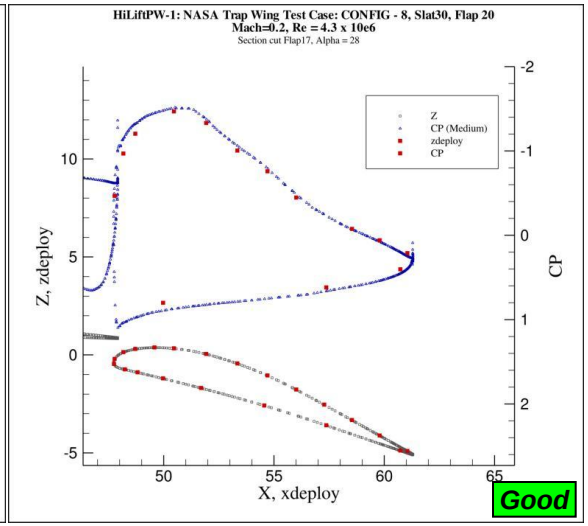
CONFIG-8
Cut 17
Alpha = 28



Good

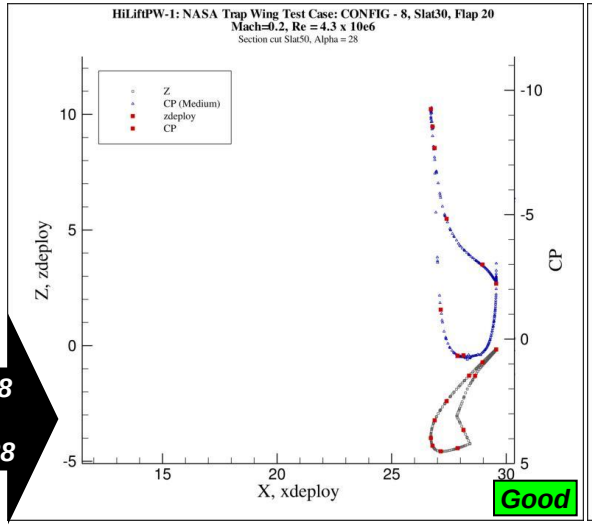


Good

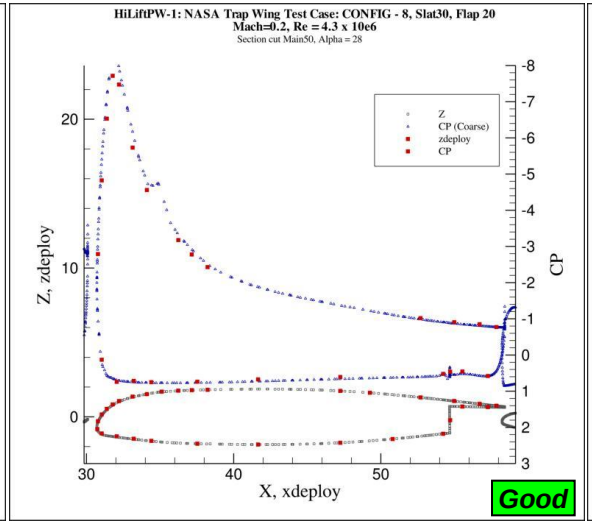


Good

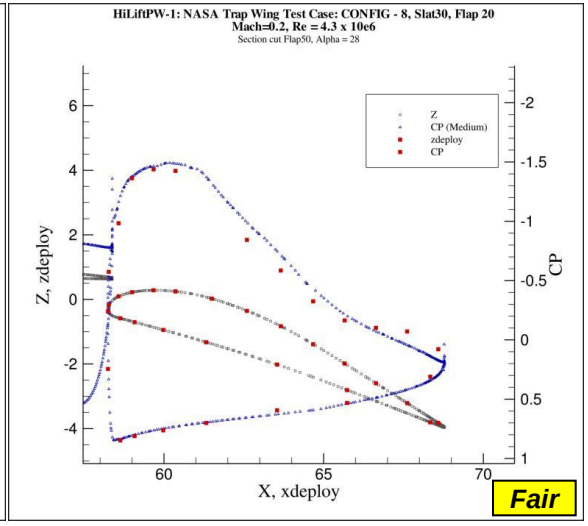
CONFIG-8
Cut 50
Alpha = 28



Good



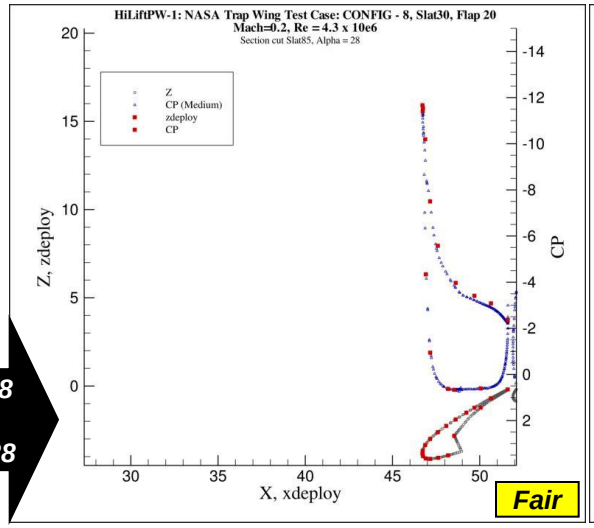
Good

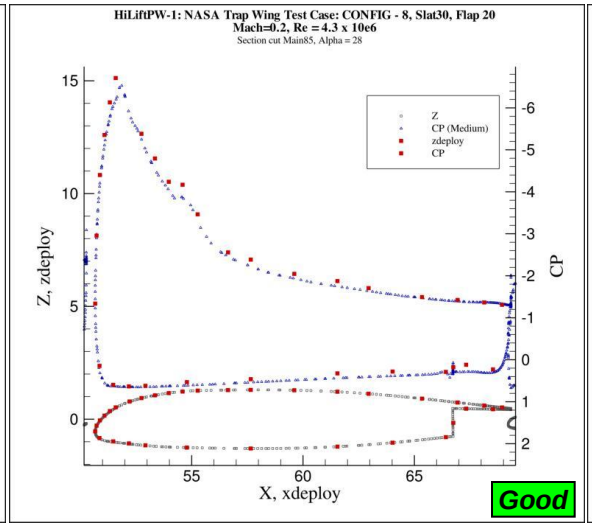


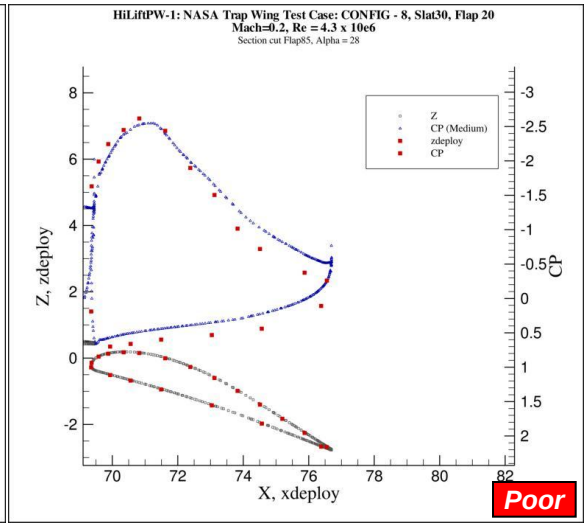
Fair

HiLiftPW-1

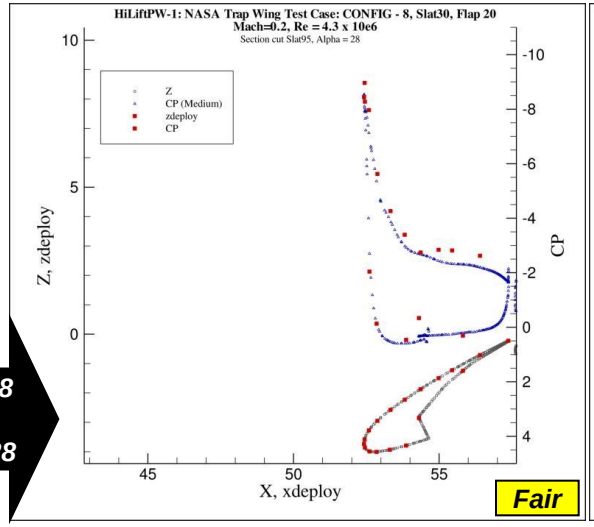
CONFIG-8
Cut 85
Alpha = 28

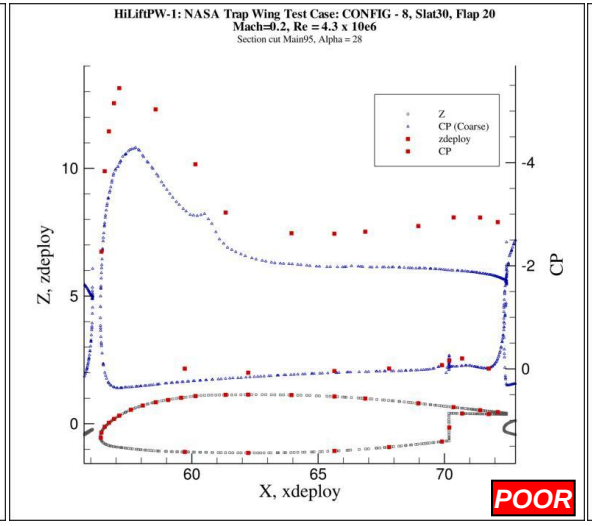


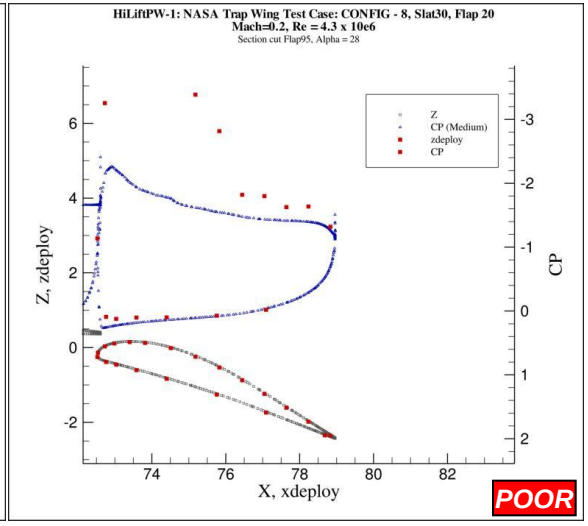




CONFIG-8
Cut 95
Alpha = 28







- **Surface Pressure Summary (CONFIG-1: Slat 30, Flap 25)**

Alpha = 13

Section Cut	Slat	Main	Flap
17	Fair	Good	Good
50	Good	Good	Good
85	Good	Good	Fair
95	Fair	Poor	Poor

Alpha = 28

Section Cut	Slat	Main	Flap
17	Good	Good	Good
50	Good	Good	Poor
85	Good	Good	Poor
95	Poor	POOR	POOR

Slat to Main to Flap: Good to Poor, but never Poor to Good!

- **Surface Pressure Summary (CONFIG-8: Slat 30, Flap 20)**

Alpha = 13

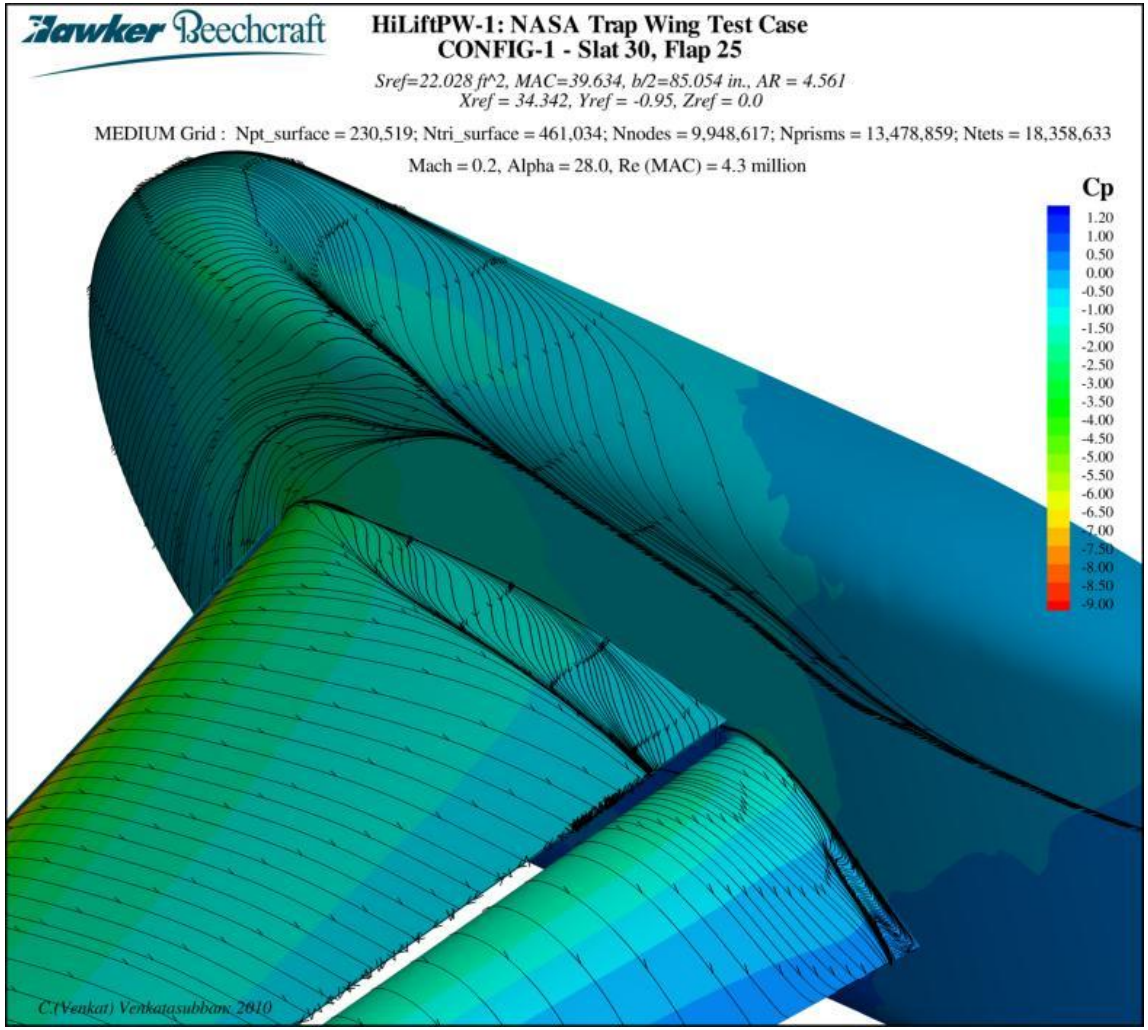
Section Cut	Slat	Main	Flap
17	Good?	Good	Good
50	Good?	Good?	Good
85	Good?	Good	Fair
95	Fair	Poor	Poor

Alpha = 28

Section Cut	Slat	Main	Flap
17	Good	Good	Good
50	Good	Good	Fair
85	Fair	Good	Poor
95	Fair	POOR	POOR

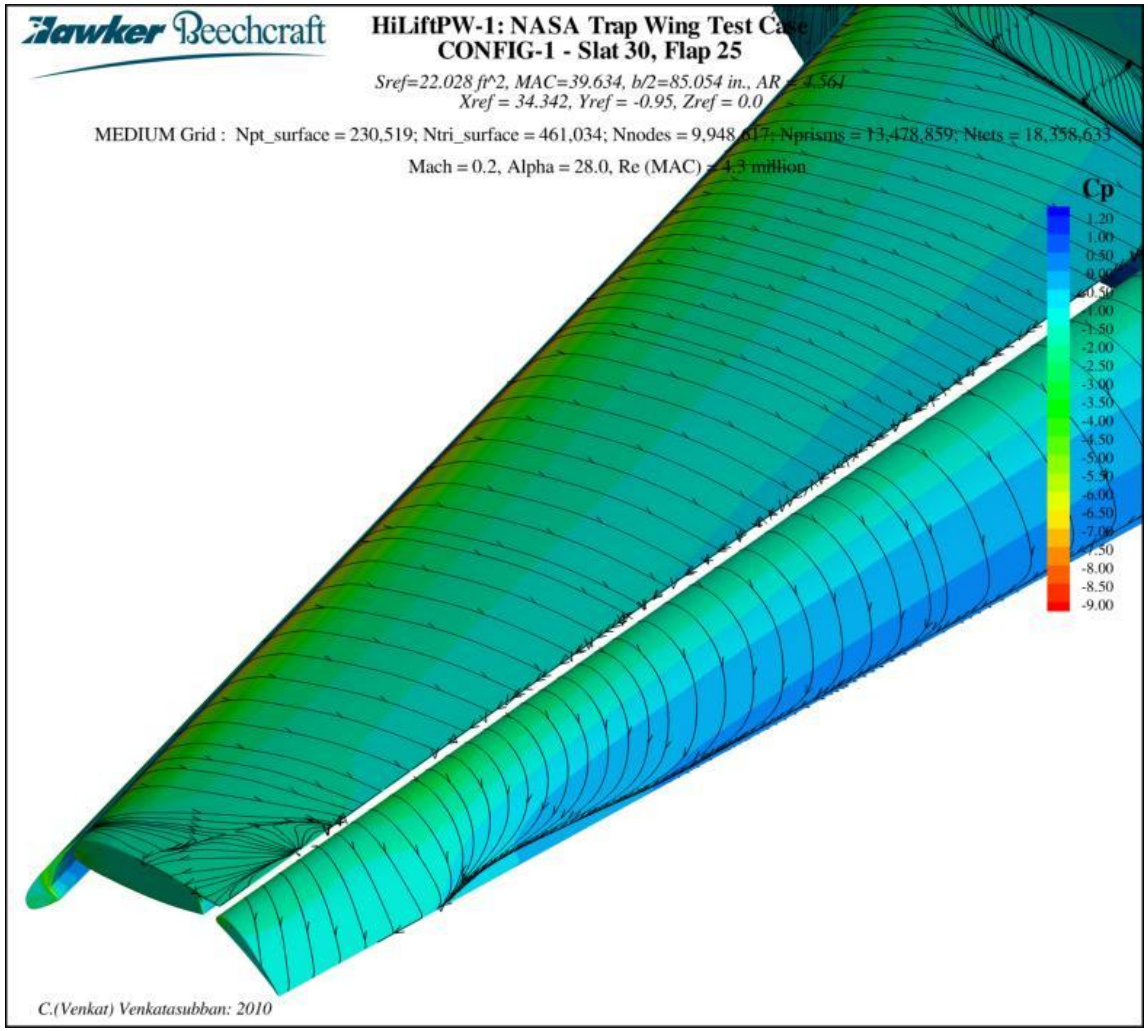
Slat to Main to Flap: Good to Poor but never Poor to Good!

- **Skin Friction Contours (Alpha=28, CONFIG1, Medium)**

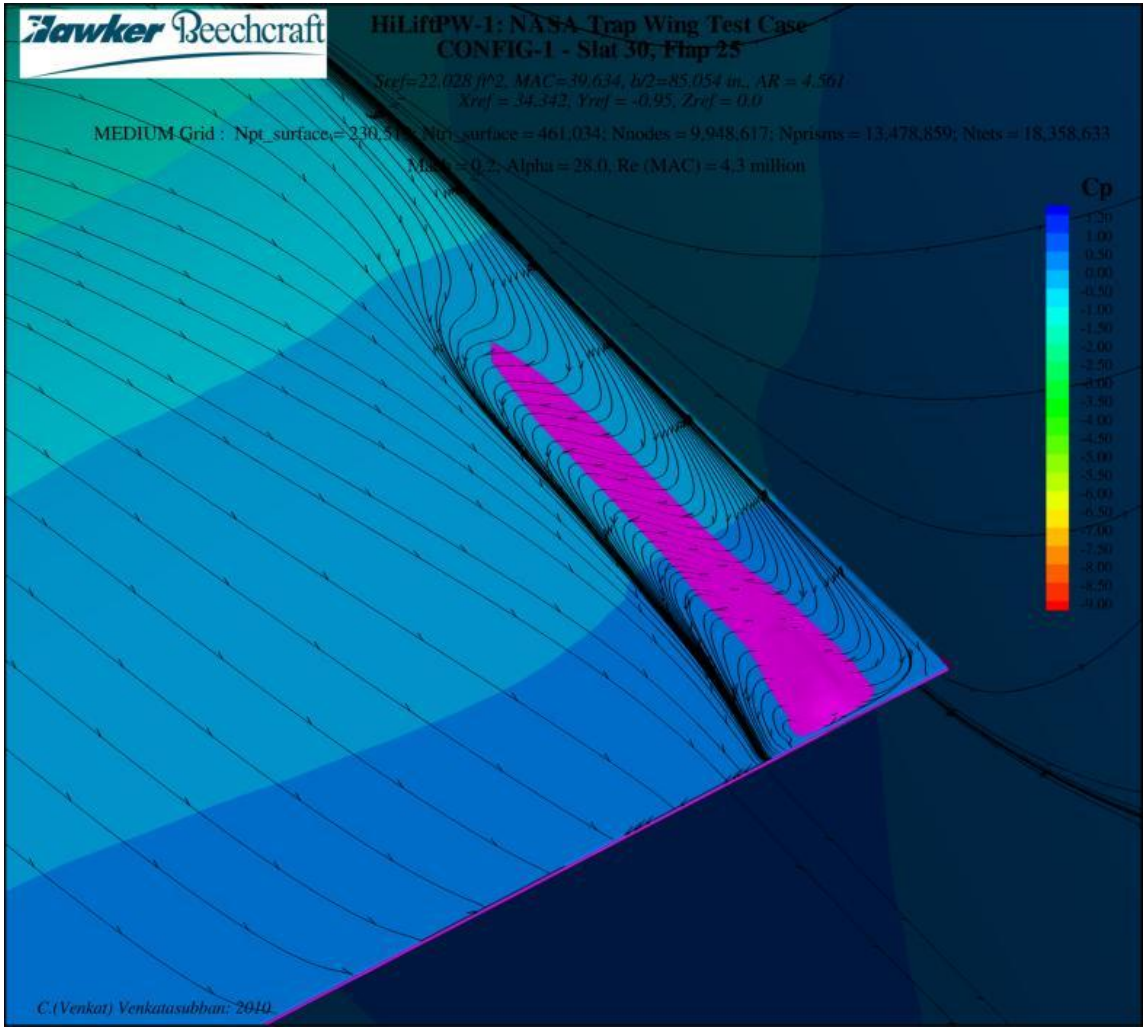


Vortical flow separation structures at wing and flap root

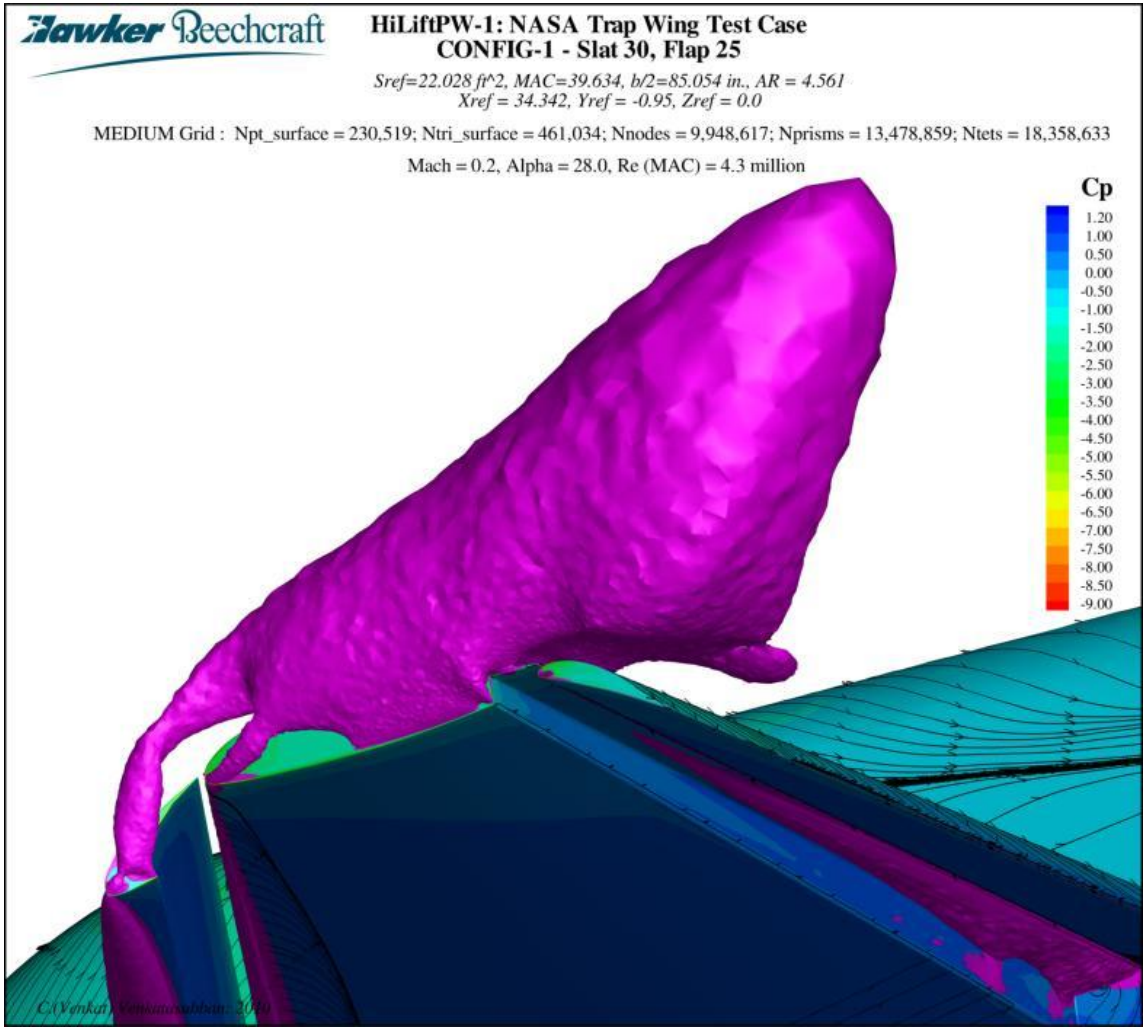
- **Skin Friction Contours (Alpha=28, CONFIG1, Medium)**



- **Wing root separation surfaces (Alpha=28, CONFIG1, Medium)**

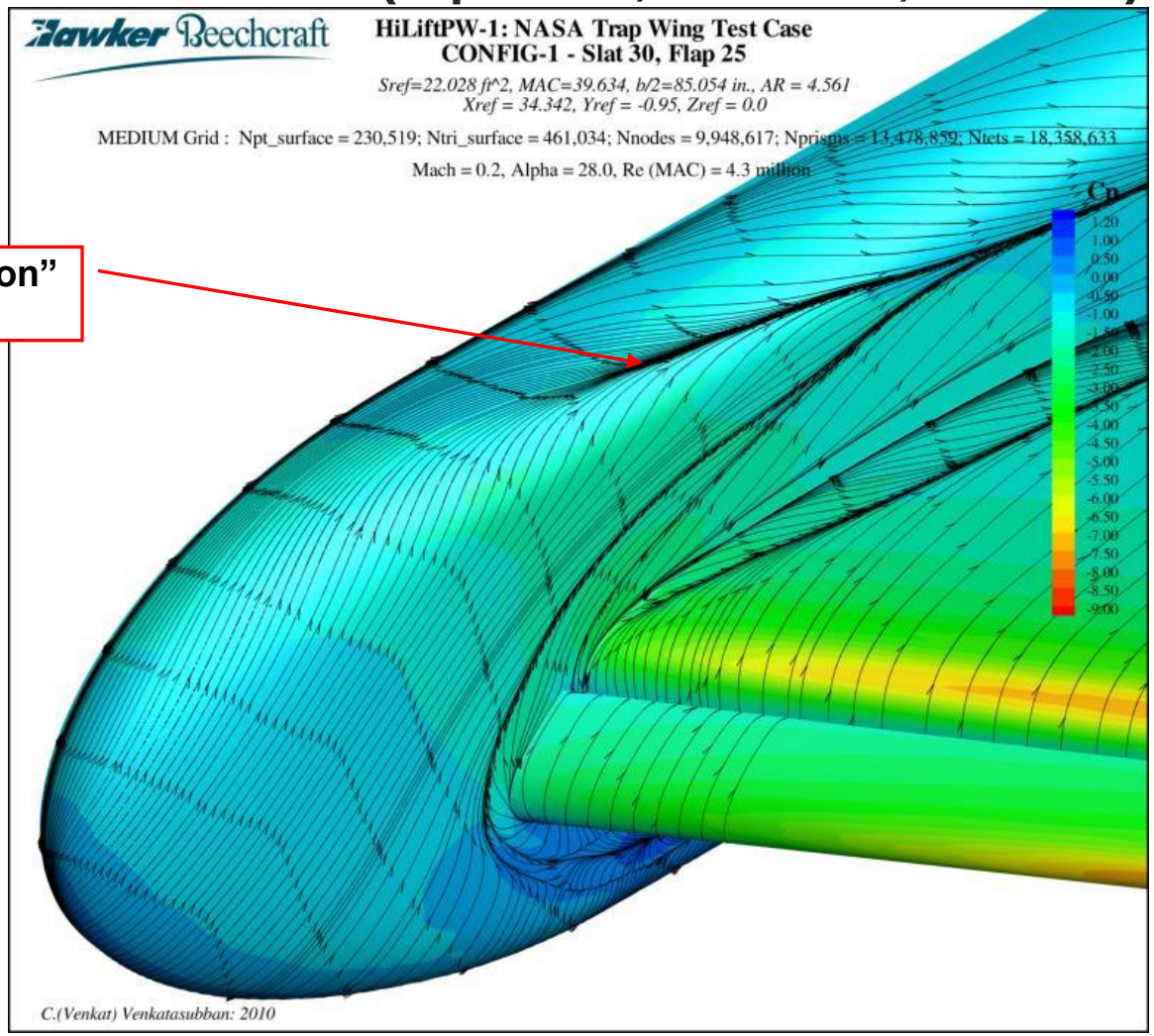


- **Wing tip separation surfaces (Alpha=28, CONFIG1, Medium)**



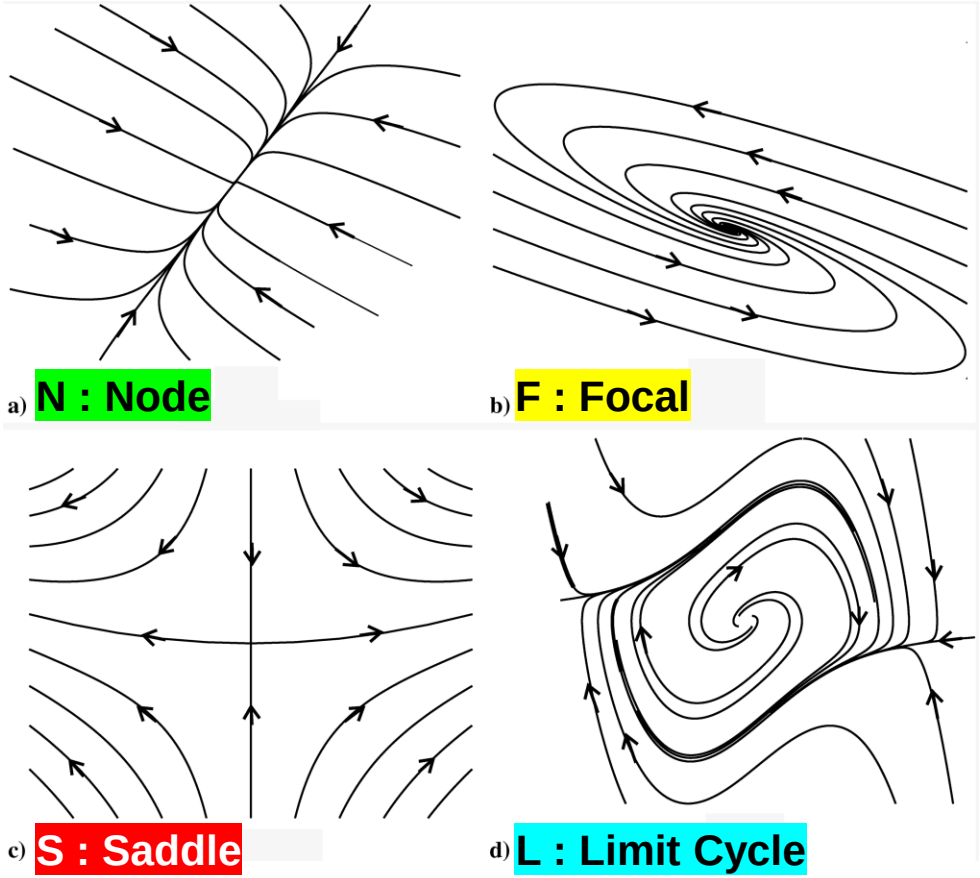
- **Skin Friction Contours (Alpha=28, CONFIG1, Medium)**

"Open Separation"
Wang 1974



Ref: K.C.Wang; Boundary layer over a blunt body at high incidence; Proc. of the Royal Soc. London., 1974

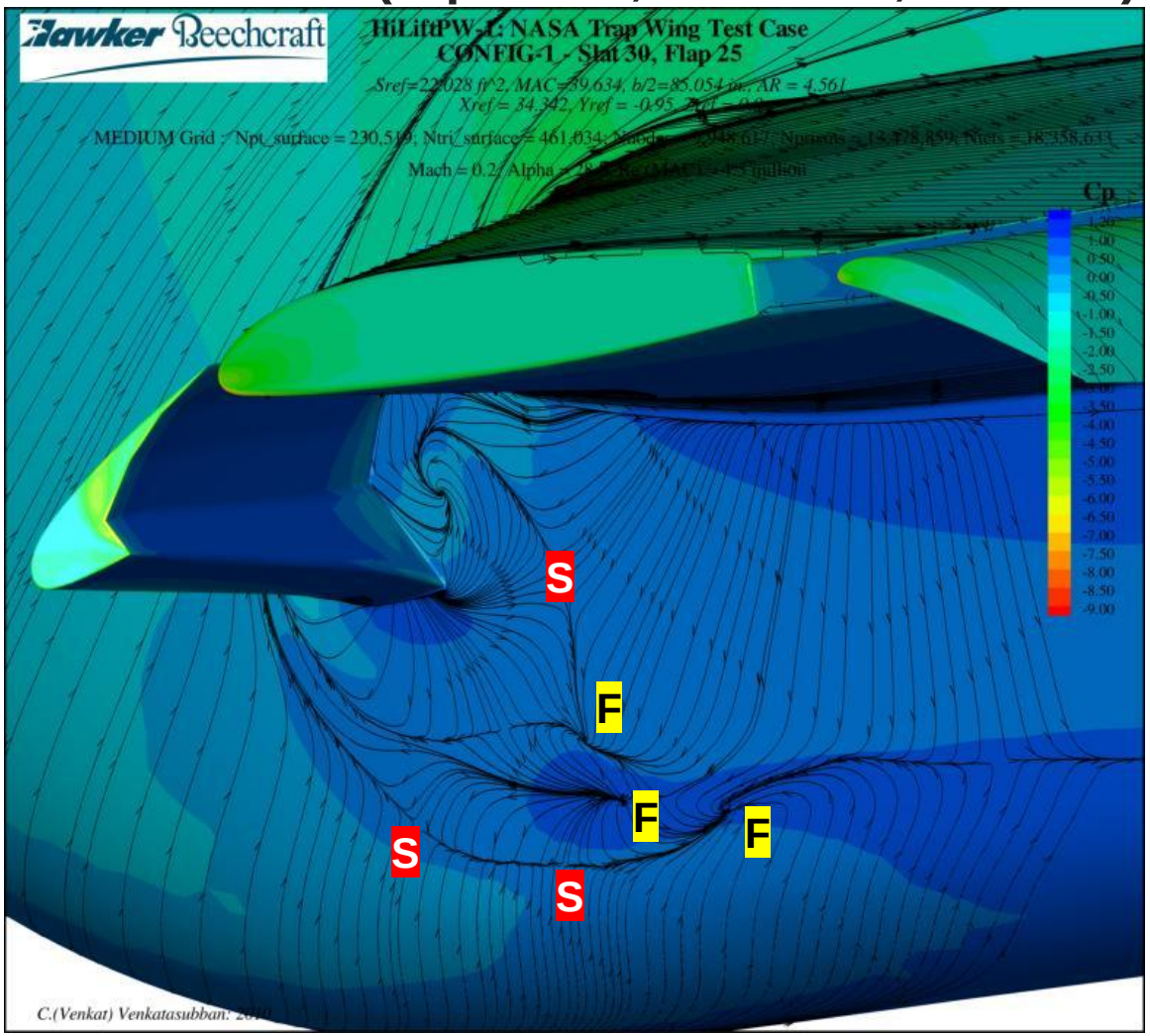
- **Exact theory of 3D flow separation**
  - A.Surana, O.Grunberg & G.Haller (J. Fluid Mech. 2006, *vol. 564, pp. 57-103*).
    - Only <u>4 possible surface separation patterns</u> from nonlinear dynamic systems theory



- **Skin Friction Contours (Alpha=28, CONFIG1, Medium)**

S : Saddle

F: Focal



Ref: Exact theory of 3D flow separation; Surana, Grunberg & Haller (Journal of Fluid Mechanics, 2006)

- **Summary & Conclusions**
  - Force Coefficients
    - CONFIG-1 Lift & Drag
      - good comparison with experimental results up to stall incidence
      - grid refinement shows minimal effect from coarse to medium grids
    - CONFIG-8 Lift & Drag
      - good comparison with experimental results (despite issues with chordwise load distribution on flap)
    - CONFIG-1 & CONFIG-8 Moments
      - Fair to poor comparison with experimental results
  - Pressure plots
    - CONFIG-1
      - Comparisons are good to fair up to section 85 (to section 50 for Alpha=28)
      - Comparisons deteriorate after section 95
    - CONFIG-8
      - Comparisons are good to fair up to section 85
      - Comparisons deteriorate after section 95 (from section 85 on flap)