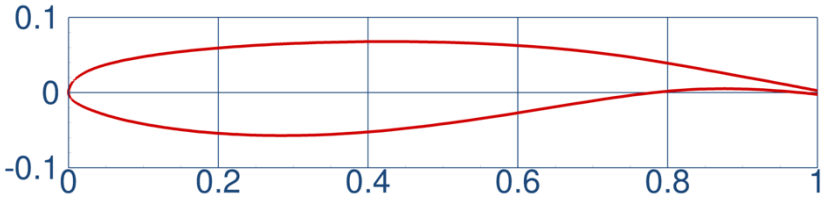
DPW-8/AePW-4
Test Case Summary
Scatter Reduction Working Group

Ben Rider
Marshall Galbraith

Test Cases: Scatter Reduction Working Group

- **Test Case 1a: ONERA OAT15A Airfoil (Transonic 2D)**
  - Purpose: Workshop-wide assessment of current state of scatter
- **Test Case 1b: Joukowski Airfoil (Subsonic 2D)**
  - Purpose: "Simple" case allowing detailed code verification
- **Test Case 1c: ONERA OAT15A Airfoil (Transonic 2D)**
  - Purpose: Determine reduction of scatter with lessons from above
- **Test Case 1d/1e: DPW-III Wing 1/Wing 2 (Transonic 3D, Drag Increment)**
  - Purpose: Evaluate absolute ***and*** incremental scatter compared to DPW-III (2006)
- **Test Case 2a/2b: NASA CRM Wing/Body (Transonic 3D)**
  - Purpose: Evaluate today's scatter compared to DPW-VII (2022)

Test Case 1a: Workshop-Wide Validation



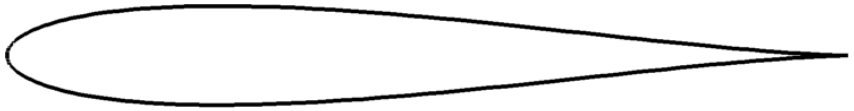
ONERA OAT15A Transonic Airfoil

- **Validation of steady CFD analysis, required**
- **Users are encouraged to employ best practices**
- **Settings**
  - Steady CFD (e.g., RANS)
  - Prefer some version of SA, multiple turbulence models can be submitted
  - Purely 2D simulations (one cell wide)
- **Grids**
  - Six-member RANS grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
  - Committee-supplied grid is one cell wide with a 230mm chord (same as experiment) and follows RANS best practices
- **Conditions**
  - Mach 0.73, Re_c=3m (based on chord length), T_{static}= 271 K (487.8 R)
  - Alpha: 1.36, 1.50, 2.50, 3.00, 3.10

Jaquin, et al. "Experimental Study of Shock Oscillation over a Transonic Supercritical Profiles." AIAA Journal, Vol. 47, No. 9, 2009. Pages 1985-1994.

Test Case 1b: Joukowski Airfoil

- **Validation of steady CFD analysis, required**
  - https://github.com/Drag-Prediction-Workshop/DPW8-Scatter/blob/main/TestCase1b/Joukowski.pdf
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
    - Characteristic Farfield (***1000 chords away***)
    - Use periodic boundary conditions for sidewall boundary conditions
  - Converge residuals to machine precision (~1e-10)



- **Grids**
  - Committee-supplied grid family
- **Conditions**

Mach	Re_c	T_{static}	α	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.15	6×10^6	520.0 R	0.0°	1.4	0.72	0.9	3

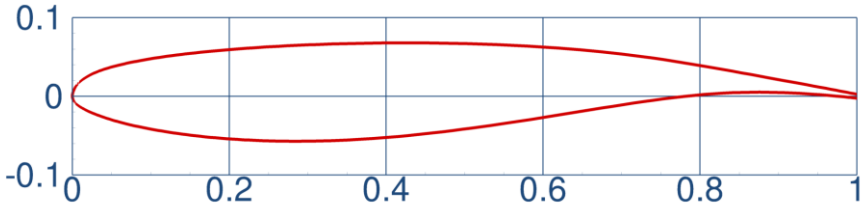
- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\ R \quad S = 198.6°\ R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

Test Case 1c: ONERA OAT15A Airfoil

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
    - Characteristic Farfield (***1000 chords away***)
    - Use periodic boundary conditions for sidewall boundary conditions
  - Converge residuals to machine precision (~1e-10)



ONERA OAT15A Transonic Airfoil

- **Grids**
  - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
- **Conditions**

Mach	Re_c	T_{static}	α	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.73	3×10^6	271 K (487.8 R)	1.5°	1.4	0.72	0.9	3

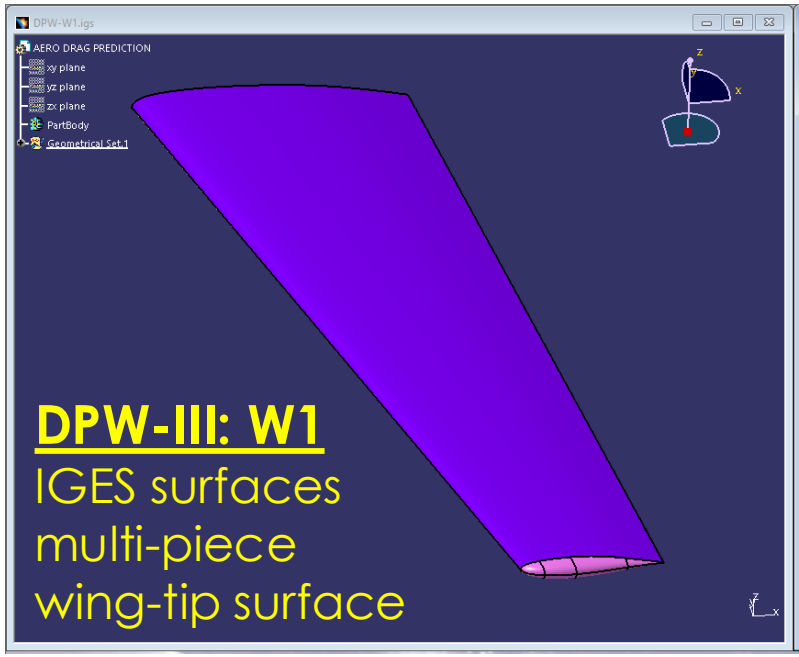
- **Sutherland's Law**

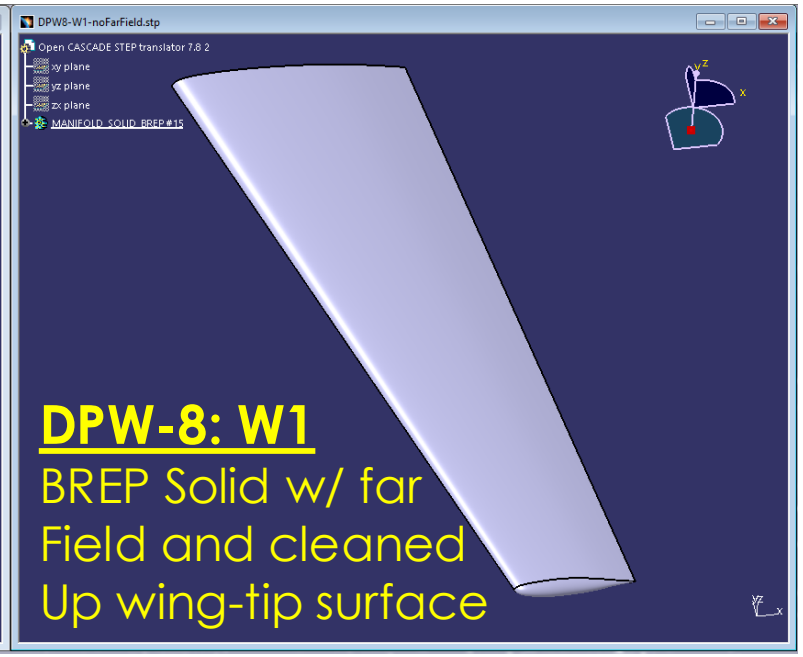
$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\ R \quad S = 198.6°\ R$$

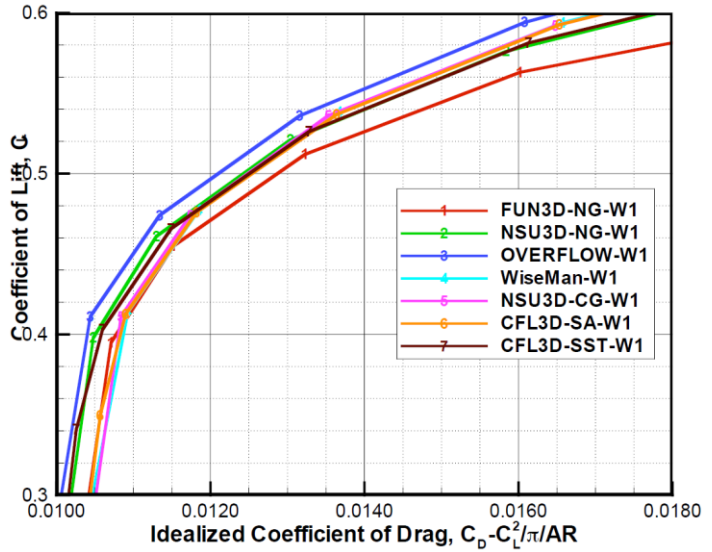
$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

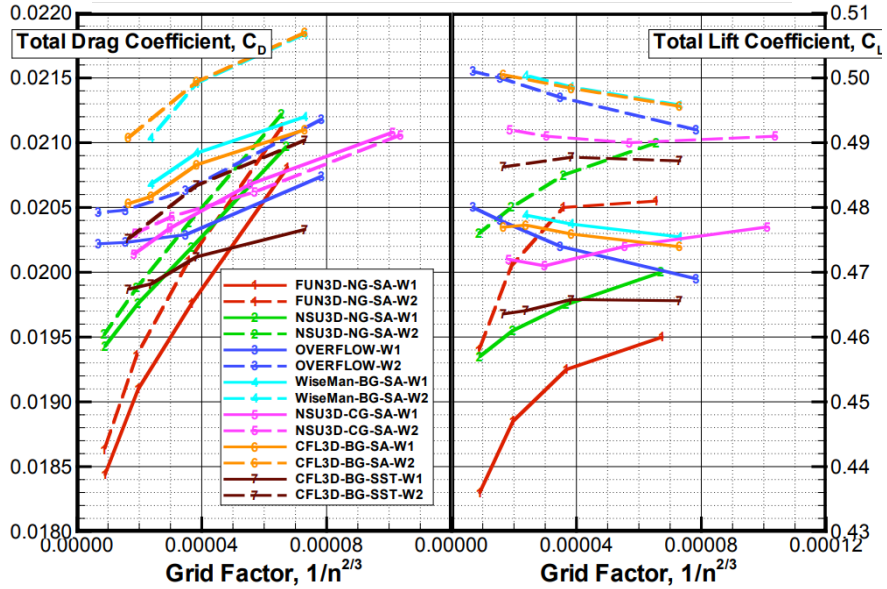
Test Case 1d/1e: DPWIII W1/W2 (+20 years)

- **DPW-III: Wing-Only Test Case**
  - W1 & W2, including incremental comparison
- **DPW-8: Scatter WG**
  - Revisit Wing Only cases to measure the progress over 20 years



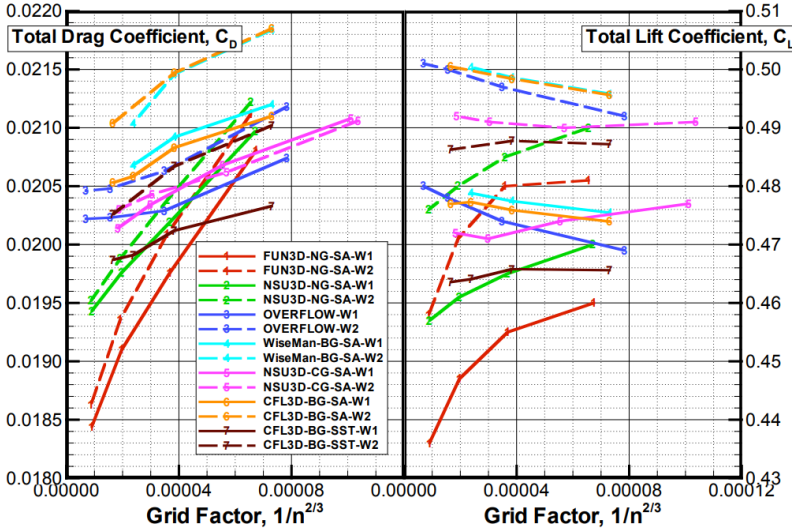






Test Case 1d: DPW-III W1/W2 (+20 years)

- **Grid Convergence Verification of steady CFD analysis at Mach=0.76: α = 0.5°**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: *https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_3***
  - DPW-III W1 wing-only geometry (with symmetry plane)
    - (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
    - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable



https://www.aiaa-dpw.org/Workshop3/presentations/S9-Zickhur-Case2-Summary.pdf

- **Reference Units**

Sref (semi-span grid)	Cref	Semispan	Moment Center
225.0 sq.in	7.7778 in	30.0 in	(6.0726, 0.0, 0.0)

- **Conditions**

Mach	Re_c	α	T_{static} (120.33° F)	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.76	5×10^6	0.50°	580.0 R | 322.22 K	1.4	0.72	0.90	3

- **Sutherland's Law**

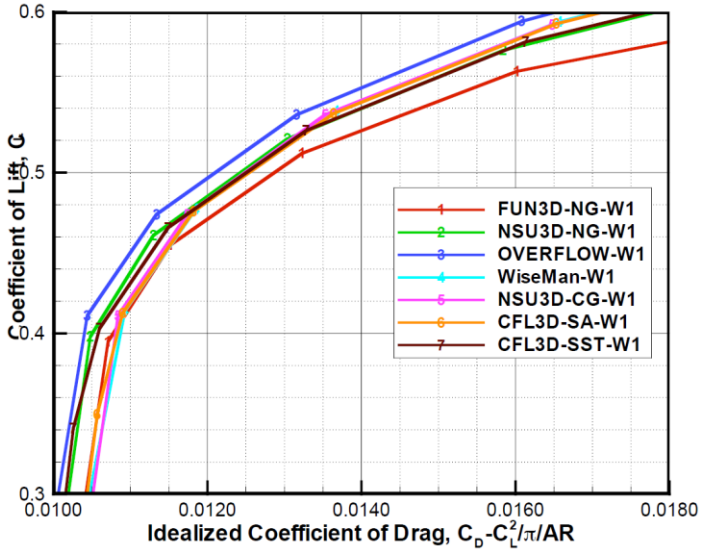
$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\,R \quad S = 198.6°\,R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

Cut	Eta	Y (inch)
1	0.026	-0.7874
2	0.157	-4.7244
3	0.289	-8.6614
4	0.420	-12.5984
5	0.551	-16.5354
6	0.682	-20.4724
7	0.814	-24.4094
8	0.945	-28.3464

Test Case 1e: DPW-III W1/W2 Polar (+20 years)

- **Drag Polar at Mach=0.76: α = [-1.0, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0]**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: *https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_3***
  - DPW-III W1 wing-only geometry (with symmetry plane)
    - Use finest affordable mesh (Recommend at least L3:**Medium**)
    - α = [-1.0°, 0.0°, 0.5°, 1.0°, 1.5°, 2.0°, 2.5°, 3.0°]
  - Encourage use of committee-supplied grids; user-generated grids are acceptable



https://www.aiaa-dpw.org/Workshop3/presentations/S9-Zickhur-Case2-Summary.pdf

- **Reference Units**

Sref (semi-span grid)	Cref	Semispan	Moment Center
225.0 sq.in	7.7778 in	30.0 in	(6.0726, 0.0, 0.0)

- **Conditions**

Mach	Re_c	α	T_{static} (120.33° F)	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.76	5×10^6		580.0 R | 322.22 K	1.4	0.72	0.90	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\,R \quad S = 198.6°\,R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

Cut	Eta	Y (inch)
1	0.026	-0.7874
2	0.157	-4.7244
3	0.289	-8.6614
4	0.420	-12.5984
5	0.551	-16.5354
6	0.682	-20.4724
7	0.814	-24.4094
8	0.945	-28.3464

Test Case 2a: Wing/Body Cruise

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: *https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2***
  - NASA CRM geometry including deformed wing matching condition
    - (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
    - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable

Comparison Data
NTF197: r44,r51,r53
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

- **Reference Units**

Sref (semi-span grid)	Cref	Semispan	Moment Center
297360.0 sq.in	275.8 in	1156.75 in	(1325.90, 0.00, 177.95)

Revision History:
v2: Cref (278.5in → 275.8in)
v3: T_{static} (120° F → 100 ° F)

- **Conditions**

Mach	Re_c	α	T_{static} (100° F)	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.85	5×10^6	2.50°	559.67 R | 310.928 K	1.4	0.72	0.90	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\,R \quad S = 198.6°\,R \quad \frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

Test Case 2b: Wing/Body Polar

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
    - QCR is critical to side-of-body at higher AOA – ***Recommend adding QCR2000***
  - Converge residuals to machine precision (~1e-10)
- **Grids: *https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2***
  - NASA CRM geometry including deformed wing matching condition
    - Grid density representative of standard analysis (i.e. L3:**M**edium)
- **Reference Units**
- **Conditions**
- **Sutherland's Law**

Comparison Data
NTF197: r44,r51,r53
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

Revision History:
v1: Recommend inclusion of QCR2000

Cut	Eta	Y (inch)
1	0.1050	121.459
2	0.1150	133.026
3	0.1250	144.594
4	0.1306	151.074
5	0.2009	232.444
6	0.2828	327.074
7	0.3430	396.765
8	0.3700	427.998
9	0.3971	459.370
10	0.5024	581.148
11	0.6028	697.333
12	0.7268	840.704
13	0.8456	978.148
14	0.9500	1098.926
15	0.9700	1122.048
16	0.9900	1145.183

Sref (semi-span grid)	Cref	Semispan	Moment Center
297360.0 sq.in	275.8 in	1156.75 in	(1325.90, 0.00, 177.95)

Mach	Re_c	T_{static} (100° F)	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.85	5×10^6	559.67 R | 310.928 K	1.4	0.72	0.90	3
Polar Conditions	α = [2.50°, 2.75°, 3.00°, 3.25°, 3.50°, 3.75°, 4.00°, 4.25°]					

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\ s} \quad T_0 = 491.6°\ R \quad S = 198.6°\ R \quad \frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{ref}}{T/T_{ref} + S/T_{ref}}\right)$$

Questions?

Geometry/Grid Far Field Details

NASA CRM (Full Scale)
MAC = 275.8"
Semispan = 1156.75"

AIAA

DPW8

DPW8: HeldenMesh (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-55160.0	55160.0	55160.0	200.0	~ 47.7
Y (inch)	0.0	55160.0	55160.0	200.0	~ 47.7
Z (inch)	-55160.0	55160.0	55160.0	200.0	~ 47.7

https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2/Helden_Grids.REV00/

DPW8: Cadence (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-115582.5	118237.9	116910.2	~ 424.2	~ 101.1
Y (inch)	0.0	116834.7	116834.7	~ 423.9	~ 101.0
Z (inch)	-115584.0	116018.1	115801.1	~ 420.2	~ 100.1

https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2/Cadence_Grids.REV00/

DPW7

DPW7: iges files (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-22440.9,	23838.6	23139.75	~ 84.0	~ 20.0
Y (inch)	0.0	35433.1	35433.1	~ 128.6	~ 30.6
Z (inch)	-23405.5	23838.6	23838.6	~ 86.5	~ 20.6

https://aiaa-dpw.larc.nasa.gov/Workshop7/Geometry/2021-03-02_Version_01/DPW7geometries.zip

DPW7: Vassberg (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-30328.203	32996.560	31662.382	~ 114.8	~ 27.4
Y (inch)	0.0	31664.519	31664.519	~ 114.8	~ 27.4
Z (inch)	-31449.638	31865.992	31657.815	~ 114.8	~ 27.4

https://dpw.larc.nasa.gov/DPW7/Vassberg_Grids.REV00/

DPW7: JAXA (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (MAC)	-413.890	424.690	419.290	~ 419.3	~ 100
Y (MAC)	0.0	419.349	419.349	~ 419.3	~ 100
Z (MAC)	-418.675	420.005	419.340	~ 419.3	~ 100

https://dpw.larc.nasa.gov/DPW7/JAXA_Grids.REV00/

DPW7: NLR (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (m)	-2949.98	3050.00	2999.99	~ 428.2	~ 102.1
Y (m)	0.0	3000.00	3000.00	~ 428.2	~ 102.1
Z (m)	-2995.1	3004.99	3000.05	~ 428.2	~ 102.1

https://dpw.larc.nasa.gov/DPW7/NLR_Grids.REV00/DPW7-NLR-grids/

DPW7: DLR (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (m)	-570.0	630.0	1200.0	~ 171.3	~ 40.9
Y (m)	0.0	900.0	900.0	~ 128.5	~ 30.6
Z (m)	-594.5	605.5	1200.0	~ 171.3	~ 40.9

https://dpw.larc.nasa.gov/DPW7/DLR_Grids.REV00/

DPW7: GGNS (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-22400.0	22400.0	22400.0	~ 81.2	~19.4
Y (inch)	0.0	22400.0	22400.0	~ 81.2	~19.4
Z (inch)	-22400.0	22400.0	22400.0	~ 81.2	~19.4

Adapted grids (not publicly released)