

Summary of the Second AIAA Stability and Control Prediction Workshop

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This paper documents the setup, execution, and findings of the Second Stability and Control Prediction Workshop (S&CPW2) held at the AIAA SciTech 2025 Forum. The workshop focused on prediction of static and dynamic stability derivatives for the Common Research Model (CRM) at subsonic flight conditions. The static workshop test cases were composed of angle-of-attack and angle-of-sideslip sweeps; the dynamic test cases included roll, pitch, and yaw sinusoidal forced oscillations. Seven organizations submitted computational fluid dynamics (CFD) results to the workshop using a variety of approaches. Wind-tunnel data collected in the NASA Langley 12-Foot Low-Speed Tunnel for a 2.4% scale version of the CRM served as a blind basis of comparison for the CFD predictions. The workshop findings indicate that additional collaborative efforts are needed to help establish best practices for accurate prediction of dynamic stability derivatives.

Nomenclature

A	=	oscillation amplitude, rad or deg
b	=	wingspan, ft
C_N, C_A, C_Y	=	normal, axial, and side force coefficients
C_L, C_D	=	lift and drag coefficients
C_l, C_m, C_n	=	rolling, pitching, and yawing moment coefficients
$\bar{c}$	=	mean aerodynamic chord, ft
F_x, F_y, F_z	=	body-axis aerodynamic forces, lbf
f_r	=	reduced frequency
M	=	Mach number
M_x, M_y, M_z	=	body-axis aerodynamic moments, ft·lbf
p, q, r	=	body-axis roll, pitch, and yaw rate, rad/s or deg/s
Re	=	Reynolds number
S	=	wing reference area, ft ²
T_a	=	air temperature, °R
V	=	freestream velocity, ft/s
α	=	angle of attack, rad or deg
β	=	angle of sideslip, rad or deg
ϕ, θ, ψ	=	Euler roll, pitch, and yaw angles, rad or deg
ω	=	oscillation frequency, rad/s

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I. Introduction

THE Stability and Control Prediction Workshop (S&CPW) series strives to establish best practices for prediction of stability and control (S&C) derivatives using computational fluid dynamics (CFD) and assess the current limitations of CFD methods when these best practices are applied. The workshops are intended to provide an impartial forum for evaluating the effectiveness of existing CFD codes and modeling techniques, as well as to identify areas in need of additional research and development. The workshops are open to participants worldwide and efforts are made to ensure adequate representation from industry, academia, and government laboratories.

Recent S&CPW-related activities are briefly highlighted to provide context for the present work. In 2020, a paper published by several members of the AIAA Applied Aerodynamics (APA) Technical Committee Stability and Control Prediction Discussion Group sought to capture the current state-of-the-art in S&C predictions [1]. The paper served as a basis to pursue S&C prediction workshops to assess and advance S&C prediction techniques. The first AIAA S&CPW (S&CPW1) was held at the AIAA SciTech 2021 Forum and focused on prediction of static stability derivatives at transonic conditions for the Common Research Model (CRM) [2]. Twelve participant groups submitted results to the workshop and six different CFD codes were represented. The CFD results were compared to previously unpublished wind-tunnel data provided by ONERA, the French Aerospace Lab. The results from S&CPW1 were formally documented as a part of special sessions at the AIAA SciTech 2022 Forum in a summary paper [2] and papers from a subset of the participants [3–7]. A special session at the AIAA AVIATION 2023 Forum, referred to as “S&CPW 1.5,” examined a two-dimensional wing and tail section of the CRM to investigate differences in longitudinal static stability derivative predictions seen in S&CPW1 [8–11].

The second AIAA S&CPW (S&CPW2), held at the AIAA SciTech 2025 Forum in cross-listed APA and Atmospheric Flight Mechanics (AFM) Technical Sessions, focused on the prediction of static and dynamic stability derivatives for the CRM. The primary distinguishing attribute of S&CPW2 relative to previous S&CPW efforts was an emphasis on prediction of dynamic stability derivatives. This paper summarizes the results from S&CPW2, and is presented as a part of a special session at the AIAA SciTech 2026 Forum alongside papers from three S&CPW2 participant groups [12–14].

The paper is organized as follows: Section II describes the model geometry, computational meshes, and reference quantities. The workshop test cases are presented in Sec. III, followed by an overview of the wind-tunnel testing supporting the workshop in Sec. IV. The stability derivative calculation approaches are outlined in Sec. V. Comparisons of the workshop CFD predictions and wind-tunnel data are presented in Sec. VI. Section VII documents lessons learned and Sec. VIII summarizes the overall conclusions from the workshop.

II. Geometry and Reference Quantities

The CRM is a generic twin-engine transport aircraft configuration with a transonic supercritical wing. The vehicle was designed to provide geometry and experimental data for CFD validation workshops [15–17]. Initial efforts focused on aerodynamic performance prediction rather than stability and control studies. Consequently, the original version of the CRM did not include a vertical tail and lacked testing with nonzero sideslip. ONERA later built and tested a version of the CRM that included a vertical tail design [18, 19]. Wind-tunnel data collected for the CRM configuration including the vertical tail were used to support S&CPW1 [2].

The CRM configuration used for S&CPW2 wind-tunnel testing and CFD predictions is the same outer mold line as the geometry from the Fourth Drag Prediction Workshop (DPW4) [20], with addition of the ONERA-designed vertical tail; the model did not include engine nacelles or pylons. Figure 1 shows the outer mold line geometry used for S&CPW2. Figures 1a-1c include the wind-tunnel sting used for static and roll oscillation testing, pitch oscillation testing, and yaw oscillation testing. Figure 1d shows the clean (sting-free) geometry.

Common unstructured workshop meshes were provided by the Air Force Life Cycle Management Center (AFLCMC) and Bihle using HeldenMesh and Pointwise mesh generation tools, respectively. Attributes of the S&CPW2 meshes are summarized in Table 1. Figure 2 shows an example mesh from AFLCMC. Although these meshes were provided, participants were permitted to use their own mesh generation methods. Participants were encouraged to report results using at least three meshes of increasing resolution to provide a mesh-independence study. The turbulence models selection was left open to the workshop participants, but for Reynolds-Averaged Navier-Stokes (RANS) methods, the negative Spalart-Allmaras (SA-neg) model was recommended.

Full-scale model geometry was used for prediction with wingspan $b = 192.8$ ft, mean aerodynamic chord $\bar{c} = 22.98$ ft, and wing reference area $S = 4130$ ft². The moment reference center was located at $x = 110.5$ ft, $y = 0$ ft, $z = 14.83$ ft, in a body-axis coordinate system with x positive backward, y positive through the right wing, and z positive upward. Although the prediction geometry was full-scale, the Reynolds number (with $\bar{c}$ as the reference length), Mach number,

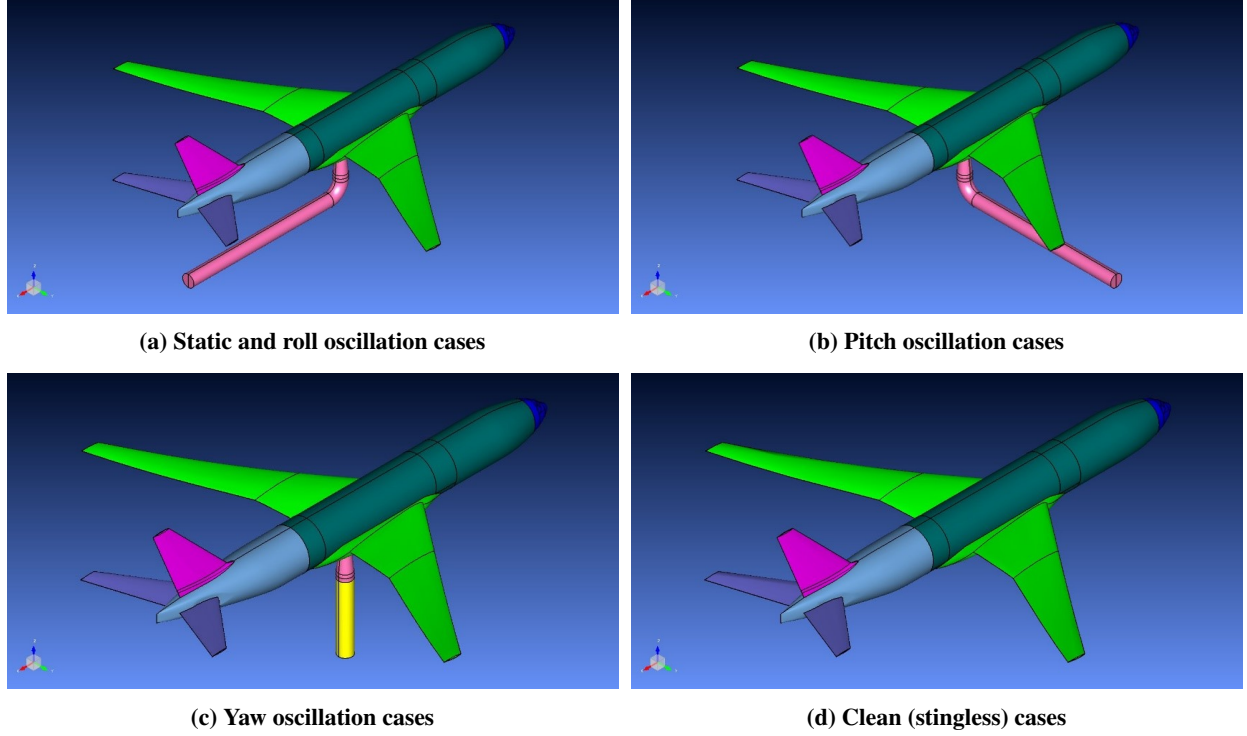


Fig. 1 CRM geometry used for S&CPW2. (Credit: AFLCMC)

Table 1 S&CPW2 computational mesh characteristics

Mesh Type	Nodes	Cells
AFLCMC Mesh A	~3.4M	~10M
AFLCMC Mesh B	~6.7M	~22M
AFLCMC Mesh C	~16M	~60M
AFLCMC Mesh D	~49M	~210M
Bihrlle (fine)	~30M	~72M

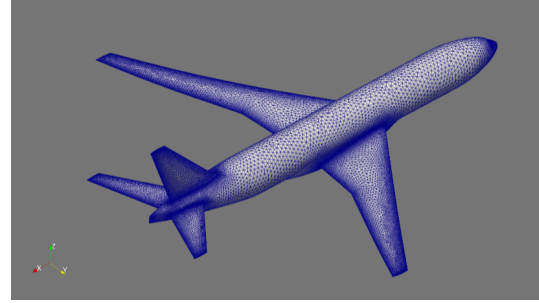


Fig. 2 Example S&CPW2 mesh. (Credit: AFLCMC)

air temperature, and reduced frequency were set to match the wind-tunnel conditions.

The reported force and moment coefficients in the body axes are defined as

- normal force coefficient: $C_N = \frac{F_z}{qS}$
- axial force coefficient: $C_A = \frac{F_x}{qS}$
- side force coefficient: $C_Y = \frac{F_y}{qS}$
- pitching moment coefficient (positive nose up): $C_m = \frac{M_y}{qS\bar{c}}$
- rolling moment coefficient (positive right wing down): $C_l = \frac{-M_x}{qSb}$
- yawing moment coefficient (positive nose to starboard): $C_n = \frac{-M_z}{qSb}$

The force and moment coefficients are labeled in Fig. 3. Static results are also presented in the form of the lift coefficient

$$C_L = C_N \cos \alpha - C_A \sin \alpha \quad (1)$$

and drag coefficient:

$$C_D = C_A \cos \alpha + C_N \sin \alpha \quad (2)$$

The force accounting included only the CRM model surfaces (i.e., excluding the wind-tunnel sting) to calculate the force and moment coefficients.

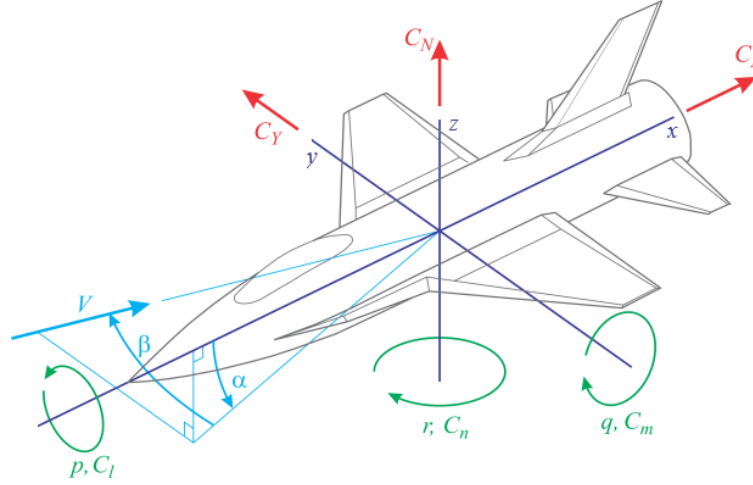


Fig. 3 Definition and orientation of axes, airflow angles, angular velocity components, and force and moment coefficients (diagram adapted from Ref. [21]).

Angle of attack (α) is defined as positive nose up and angle of sideslip (β) is defined as positive nose to port. The Euler orientation angle conversions are pitch angle (θ) positive nose up, roll angle (ϕ) positive right wing down, and yaw angle (ψ) positive nose to starboard.

III. Test Cases

This section summarizes the S&CPW2 test cases. Static test cases were composed of angle-of-attack and angle-of-sideslip sweeps. Dynamic test cases were composed of pitch, roll, and yaw sinusoidal forced oscillations. Participants were also encouraged to use alternative methods to determine stability and control derivatives.

A. Test Case 1

Test Case 1 focused on static stability derivative predictions for the CRM with the wind-tunnel sting by executing static α and β sweeps. The freestream conditions were a Mach number of 0.052, a Reynolds number of 200,000, and a temperature of 518 °R. Test Case 1a was an α sweep at zero sideslip with α settings of

$$\alpha = [-5, \mathbf{0}, 2, \mathbf{4}, 6, \mathbf{8}, 10, \mathbf{12}, 14, \mathbf{16}, 18, \mathbf{20}, 22, 24, 26, 28, 30, 35, 40, 45] \text{ deg} \quad (3)$$

where **bold** numbers indicate required values and numbers in standard font indicate optional values. Test Case 1b and 1c were β sweeps at $\alpha = 0$ deg and $\alpha = 4$ deg, respectively, with β settings of

$$\beta = [-\mathbf{10}, -8, -\mathbf{4}, -2, \mathbf{0}, 2, \mathbf{4}, 8, \mathbf{10}] \text{ deg} \quad (4)$$

with **bold** numbers again indicating required values. The CRM geometry for Test Cases 1a-1c included the fuselage, wing, horizontal tail, vertical tail, and sting. Test Case 1d was an α sweep with the same conditions as Test Case 1a, except with the horizontal and vertical tails removed from the model. Test Cases 1a and 1c were designated as required, whereas Test Cases 1b and 1d were specified to be optional.

For each data point, participants were asked to submit final values, or time averages, for all force and moment coefficients. Furthermore, for each sub-case, participants were asked to report static stability derivative estimates. For longitudinal cases (1a and 1d), participants reported longitudinal static stability derivatives C_{N_α} and C_{m_α} at $\alpha = 4$ deg. For lateral-directional cases (1b and 1c), participants reported lateral-directional stability derivatives C_{Y_β} , C_{l_β} , and C_{n_β} , at $\alpha = 0$ deg and $\alpha = 4$ deg, respectively, with zero sideslip. Test Case 1 is summarized in Table 2.

Table 2 Summary of Test Case 1 ($M = 0.052$; $Re = 200,000$; $T_a = 518^\circ\text{R}$)

Case	Type	Priority	Configuration	α , deg	β , deg	Stability Derivatives
1a	α sweep	required	including tails	Eq. (3)	0	$C_{N_\alpha}, C_{m_\alpha}$
1b	β sweep	optional	including tails	0	Eq. (4)	$C_{Y_\beta}, C_{l_\beta}, C_{n_\beta}$
1c	β sweep	required	including tails	4	Eq. (4)	$C_{Y_\beta}, C_{l_\beta}, C_{n_\beta}$
1d	α sweep	optional	no tails	Eq. (3)	0	$C_{N_\alpha}, C_{m_\alpha}$

B. Test Case 2

Test Case 2 focused on dynamic stability derivative predictions by executing single-frequency sinusoidal forced oscillations. The CRM geometry included the fuselage, wing, horizontal tail, vertical tail, and wind-tunnel sting for the particular oscillation axis. The freestream conditions were a Mach number of 0.0358, a Reynolds number of 140,000, and a temperature of 518 °R. The nominal air-flow angles for the forced oscillations were $\alpha_o = 3$ deg and $\beta_o = 0$ deg. Test Cases 2a, 2b, and 2c included sinusoidal oscillations in pitch, roll, and yaw angles, respectively, with an oscillation amplitude of $A = 5$ deg about the reference model orientation. The reduced frequencies for the pitch case were

$$f_r = \frac{\omega \bar{c}}{2V} = [\mathbf{0.04}, 0.06, 0.08, 0.10] \quad (5)$$

and the reduced frequencies for the roll and yaw cases were

$$f_r = \frac{\omega b}{2V} = [0.2, \mathbf{0.4}, 0.6, 0.8] \quad (6)$$

with **bold** numbers indicating the required reduced frequency values. For the full-scale model, the corresponding oscillation frequencies $f = \omega/2\pi$ for pitch are

$$f = [\mathbf{0.0222}, 0.0332, 0.0443, 0.0554] \text{ Hz} \quad (7)$$

and for roll and yaw are

$$f = [0.0132, \mathbf{0.0264}, 0.0396, 0.0528] \text{ Hz} \quad (8)$$

For each oscillation case, participants were asked to submit time histories of the force and moment coefficients, as well as orientation angles. The time histories were requested to include at least three full converged oscillation cycles. Additionally, for each sub-case, participants were asked to report the following dynamic stability derivative estimates at $\alpha = 3$ deg and $\beta = 0$ deg: C_{N_q} and C_{m_q} for pitch oscillations, C_{l_p} and C_{n_p} for roll oscillations, C_{l_r} and C_{n_r} for yaw oscillations. Test Case 2 is summarized in Table 3.

Table 3 Summary of Test Case 2 ($\alpha_o = 3$ deg; $\beta_o = 0$ deg; $M = 0.0358$; $Re = 140,000$; $T_a = 518^\circ\text{R}$)

Case	Type	Angle Range, deg	Required f_r	Optional f_r	Stability Derivatives
2a	pitch oscillation	$-5 \leq \Delta\theta \leq +5$	0.04	0.06, 0.08, 0.10	C_{N_q}, C_{m_q}
2b	roll oscillation	$-5 \leq \Delta\phi \leq +5$	0.4	0.2, 0.6, 0.8	C_{l_p}, C_{n_p}
2c	yaw oscillation	$-5 \leq \Delta\psi \leq +5$	0.4	0.2, 0.6, 0.8	C_{l_r}, C_{n_r}

C. Test Cases 3-5

Test Case 3 was to employ alternative methods, such as custom training maneuvers, to determine static and dynamic stability derivatives at $\alpha = 3$ deg and $\beta = 0$ deg. Test Cases 4 and 5 were to repeat Test Cases 1 and 2, respectively, without the wind-tunnel sting. Test Cases 3-5 were deemed to be optional.

IV. Wind-Tunnel Testing

The static and dynamic wind-tunnel data serving as a source of comparison for S&CPW2 were collected in the 12-Foot Low-Speed Tunnel at NASA Langley Research Center. The facility is an atmospheric pressure tunnel with a 12-ft-wide and 12-ft-high octagonal cross-section and 15-ft test section length. Dynamic pressures are achievable up to 7 lbf/ft², which corresponds to a freestream velocity of approximately 77 ft/s at standard sea level conditions. The air is pulled through the tunnel by a 6-blade, 15.8-ft diameter fan. A schematic of the wind tunnel is shown in Fig. 4. The CRM data were collected as a part of check standard testing executed in preparation for moving the legacy dynamic test rigs to the new Flight Dynamics Research Facility (FDRF) [22].

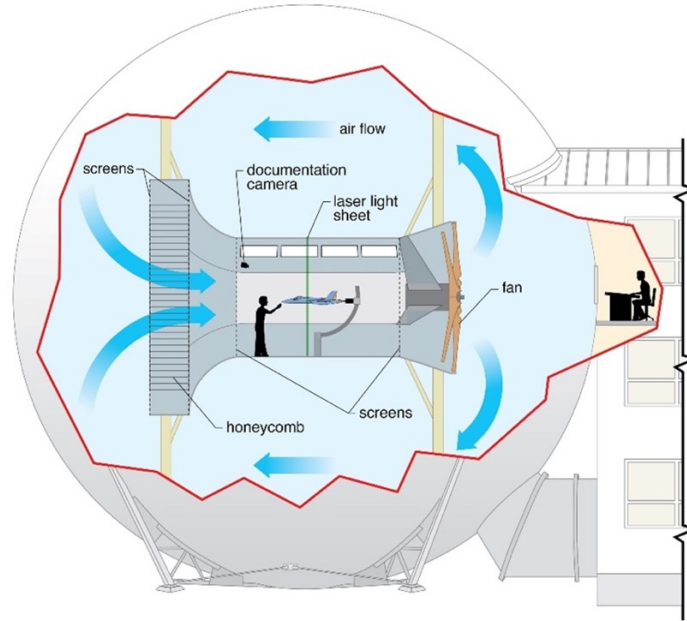


Fig. 4 Schematic of the NASA Langley 12-Foot Low-Speed Tunnel. (Credit: NASA)

The 2.4%-scale CRM check standard wind-tunnel model was fabricated using a polycarbonate rapid prototyping technique. This fabrication technique provided an accurate replication of the geometric details while meeting the stringent and challenging mass properties targets required for dynamic testing. The wind-tunnel model wingspan is $b = 4.627$ ft, the mean aerodynamic chord is $\bar{c} = 0.552$ ft, and the reference area is $S = 2.379$ ft², with a total model weight of 15.85 lb. The CFD and wind-tunnel model reference geometry parameters are compared in Table 4. A photo of the CRM wind-tunnel model is shown in Fig. 5. Figure 6 shows the model mounted in the 12-Foot LST in the roll, pitch, and yaw forced oscillation configurations. Figures 7 and 8 provide the as-built CRM check standard model geometry differences relative to the computer model and the model surface roughness measurements, respectively.

Table 4 CFD and wind-tunnel model reference geometry

	CFD	Wind Tunnel
Model scale	100%	2.4%
Wingspan (b), ft	192.8	4.627
Mean aerodynamic chord ($\bar{c}$), ft	22.98	0.552
Wing reference area (S), ft ²	4130	2.379



Fig. 5 CRM check standard model photograph. (Credit: NASA)



(a) Static and roll oscillation configuration (b) Pitch oscillation configuration (c) Yaw oscillation configuration

Fig. 6 CRM mounted in the 12-Foot Low-Speed Tunnel in each test configuration. (Credit: NASA)

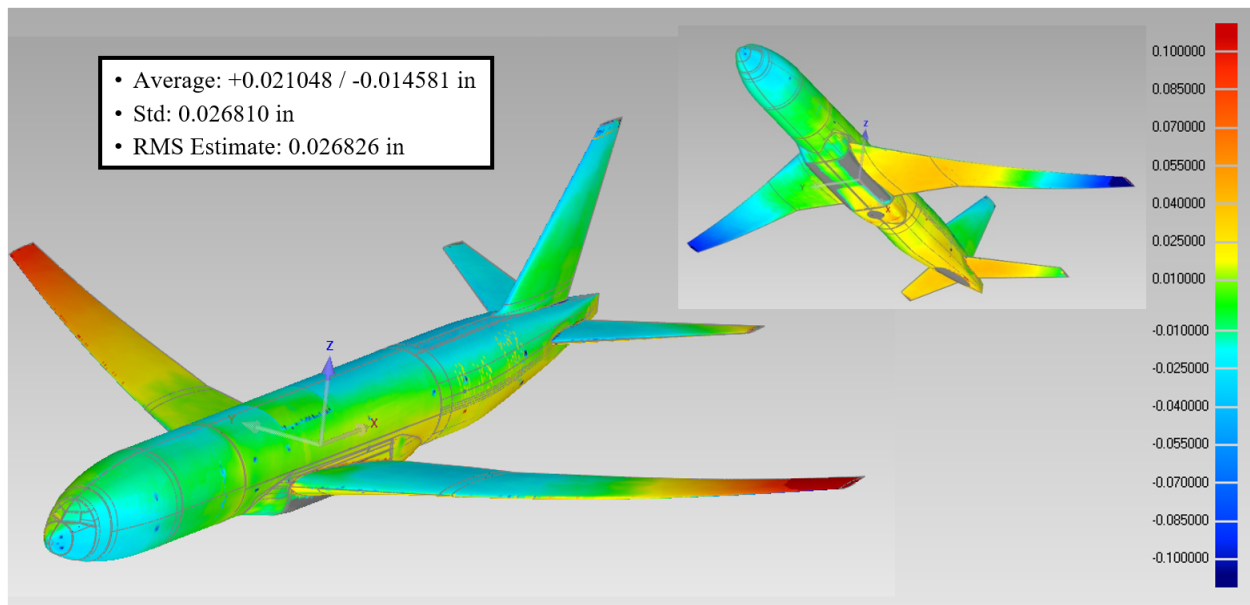


Fig. 7 As-built CRM check standard model geometry differences in inches. (Credit: NASA)

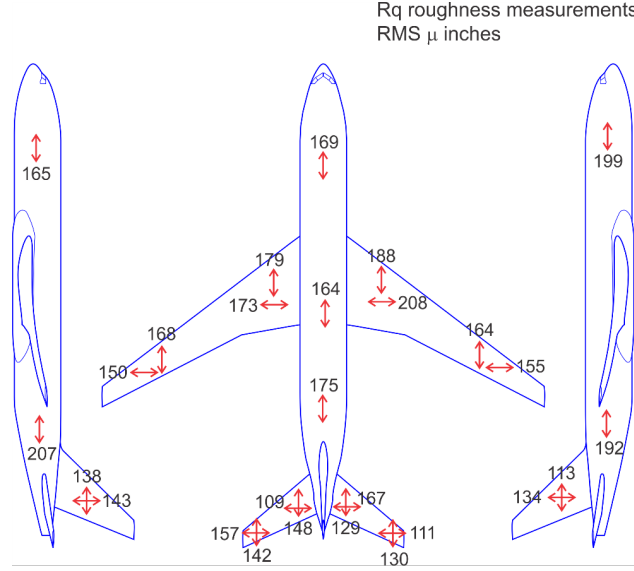


Fig. 8 As-built CRM check standard model surface roughness. (Credit: NASA)

Flow angularity and blockage corrections were applied to the wind-tunnel data. The flow angularity correction, determined by testing the model mounted in an upright and inverted orientation, was determined to be a 0.26 deg upwash correction. The blockage correction applied to the dynamic pressure was calculated as

$$\bar{q}_c = \bar{q}_u \left(1 + \frac{1}{4} \frac{A_F}{A_T} \right)^2 \quad (9)$$

where $\bar{q}_c$ is the corrected dynamic pressure, $\bar{q}_u$ is the uncorrected dynamic pressure, A_F is the model/support frontal area, and A_T the tunnel cross-section area [23]. The blockage ratio A_F/A_T variation with model position is displayed in Fig. 9 for each test configuration.

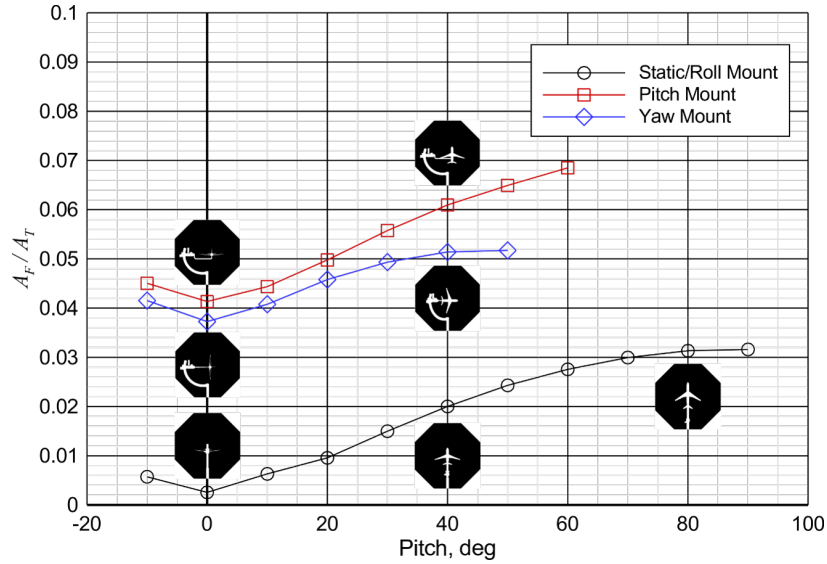


Fig. 9 Model blockage ratio variation with pitch angle in each CRM mounting configuration. (Credit: NASA)

Model deformation and wall corrections were not applied to the wind-tunnel data. Model deformation was not expected to have a substantial effect on the final stability derivatives. Wall corrections were assessed but were found to

be within the measurement noise of the facility given that the model wingspan was 39% of the test section width.

The wind-tunnel data were used for a blind comparison to CFD predictions for S&CPW2. The data were withheld from workshop participants providing CFD predictions and were not publicly released until the wind-tunnel testing presentation given at S&CPW2 in January 2025 [24]. The static sweep and dynamic one-cycle average wind-tunnel data are available in a spreadsheet stored alongside the S&CPW2 wind-tunnel testing presentation on the NASA Technical Report Server (NTRS).*

V. Stability Derivative Calculation Approach

After collecting wind-tunnel or CFD data, additional steps are required to determine the stability derivatives. Although workshop participants were given the flexibility to select their stability derivative calculation approach, common methods were applied to all submitted workshop sweep and time history data. Common data processing methods were applied to remove variation in stability derivative predictions from the data post-processing approach, thereby attempting to isolate differences in stability derivatives to the CFD solution methodology.

A. Static Stability Derivatives

The static stability derivatives were determined from α and β sweeps. Two common methods were applied to all workshop data: the central difference approximation and differentiation of a local polynomial fit. The central difference approximation used the two data points neighboring the operating point. For example, to calculate C_{m_α} about the i th data point, the central difference approximation is:

$$C_{m_\alpha} = \frac{C_m(i+1) - C_m(i-1)}{\alpha(i+1) - \alpha(i-1)} \quad (10)$$

The second method involves fitting a polynomial to data points around the operating point and then evaluating the value of the analytical derivative of the polynomial fit at the operating point. For example, for pitching moment, the polynomial fit could be

$$C_m(\alpha) = c_2\alpha^2 + c_1\alpha + c_0 \quad (11)$$

and the associated C_{m_α} estimate at the operating point α_o would be

$$C_{m_\alpha} = 2c_2\alpha_o + c_1 \quad (12)$$

The polynomial order was adjusted up to third order based on the character of the particular response and the polynomial was fit over data spanning ± 4 deg around the operating point.

B. Dynamic Stability Derivatives

The dynamic stability derivatives were determined from the data collected during roll, pitch, and yaw forced oscillation tests. Two common methods were applied to all workshop data: the integration method and the specific point method. These dynamic stability derivative calculation approaches follow the methods described in Ref. [21], which provides additional details on each approach.

Because angular velocity and airflow angle rates are correlated in forced oscillation motion, the presented dynamic stability derivatives represent their combined damping effects [25]. For example, in pitch forced oscillations, pitch rate q and angle-of-attack rate $\dot{\alpha}$ are coupled; for pitching moment, the combined derivative is:

$$\bar{C}_{m_q} = C_{m_q} + C_{m_{\dot{\alpha}}} \quad (13)$$

Similarly, combined dynamic derivatives are obtained from roll and yaw forced oscillations, such as:

$$\bar{C}_{l_p} = C_{l_p} + C_{l_{\dot{\beta}}} \sin \alpha \quad (14)$$

$$\bar{C}_{n_r} = C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha \quad (15)$$

Alternative forced motions, such as plunging, are required to isolate the angular velocity and airflow angle rate effects. For the rest of this paper, the over-bar notation ($\bar{}$) on the combined dynamic derivatives is omitted for simplicity, but all presented results represent combined dynamic derivatives [e.g., C_{m_q} is understood to represent $\bar{C}_{m_q}$ from Eq. (13)].

*Information available online at <https://ntrs.nasa.gov/citations/20240016282> [retrieved 16 November 2025].

To calculate the dynamic derivatives, first, a one cycle average was computed from the time history data. Because of the different data attributes and model scale between the wind-tunnel and CFD data, the data processing approaches prior to averaging were slightly different. For the wind-tunnel data, a sixth-order, digital, low-pass, Butterworth filter with a cutoff frequency of 4 Hz was applied to all measured signals sampled at 50 Hz over 40 full oscillation cycles. The wind-tunnel data averaging process is reflected in a pitch oscillation hysteresis loop example shown in Fig. 10, where 40 full oscillation cycles are converted into a 1-cycle average and standard deviation. For the submitted CFD data, the data were resampled to a uniform 5 Hz sample rate and a zero-phase-shift, sixth-order, digital, low-pass, Butterworth filter with a cutoff frequency five times the oscillation frequency was applied. Initial transients were removed, if applicable, and the data were trimmed to only include full cycles for analysis.

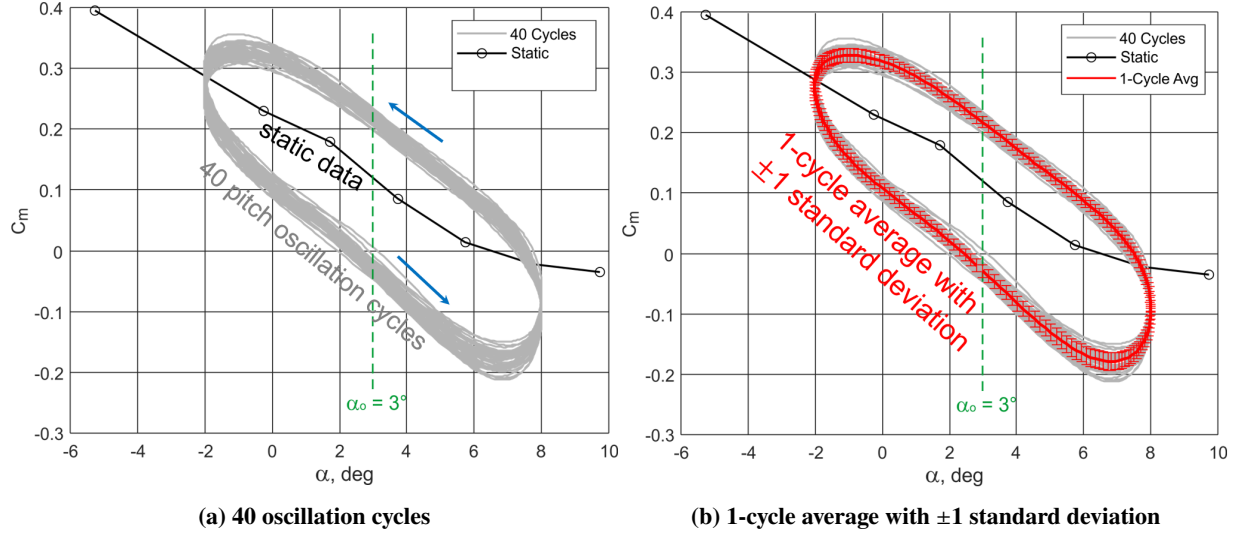


Fig. 10 Example of wind-tunnel forced oscillation data processing for C_m in a pitch oscillation.

The integration method, as its name suggests, integrates the measurements over a complete oscillation cycle. For example, C_{m_q} is calculated as

$$C_{m_q}(\alpha_o) = \frac{4V}{\bar{c}\omega AT} \int_0^T C_m(t) \cos(\omega t) dt \quad (16)$$

where T is the oscillation period. The integration method is a traditional approach that was advantageous for use with legacy analog data systems. However, it requires assuming a linear model (i.e., an elliptical hysteresis loop, as is shown in Fig. 11), limiting its use in nonlinear aerodynamic regions [21].

The specific point method uses only the data at the crossing points through the nominal orientation angle value where angular rate is at its maximum absolute value and angular acceleration is zero. For example, C_{m_q} is calculated as

$$C_{m_q}(\alpha_o) = \frac{V}{\bar{c}A\omega} [C_m(q_{max}) - C_m(q_{min})] \quad (17)$$

where only $C_m(q_{max})$ and $C_m(q_{min})$ crossing point data, annotated in the example hysteresis loop shown in Fig. 11, are used in the calculation. Therefore, the specific point method is more robust to non-elliptical hysteresis loops and, accordingly, is preferred in nonlinear aerodynamic regions [21].

The integration method and the specific point method are both presented to quantify the impact of calculation approaches and their assumptions on the final S&CPW2 dynamic stability derivative results. Both methods yield the same dynamic stability derivative estimates for an elliptical hysteresis loop resulting from a linear model; however, it is important to note that the current recommended forced oscillation data processing best practice is to use the specific point method because of its robustness to aerodynamic nonlinearities and consequent non-elliptical hysteresis loops. The authors strongly recommend application of the specific point method as the preferred forced oscillation dynamic stability derivative calculation approach.

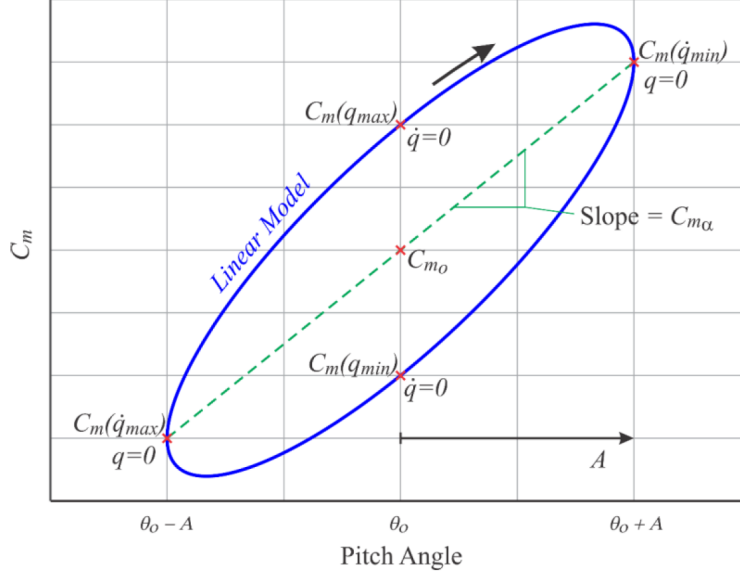


Fig. 11 Example linear model hysteresis loop for pitching moment (Ref. [21]).

VI. Results

This section presents a comparison of wind-tunnel and CFD results from S&CPW2. Due to limited CFD submissions for optional test cases, the focus herein is placed on required cases where all seven participant CFD solutions were available. The required test cases include an α sweep (Case 1a) and a β sweep at non-zero α (Case 1c), as well as pitch, roll, and yaw forced oscillations at a single reduced frequency (Case 2a-2c). The optional test cases allow for investigation of a β sweep at zero α (Case 1b), a tail-free α sweep (Case 1d), reduced frequency effects (Case 2 using optional reduced frequencies), alternative solution methods (Case 3), and sting effects (Case 4 and 5). The limited optional test case submissions were included as backup slides in the S&CPW2 summary presentation given at the AIAA SciTech 2025 Forum [26], which is available on NTRS.[†]

The list of S&CPW2 participants is given in Table 5. The participant identification numbers have been removed for public dissemination of this paper to respect the preferences of certain participant groups. CFD results were submitted by seven different organizations, representing four different codes: FlightStream, FUN3D, Kestrel, and STAR-CCM+. The participant groups worked independently, but a “mini-workshop” was held a few months before the actual workshop where preliminary CFD solution results were compared. This was done to allow for diagnosis and resolution of setup discrepancies before the final submission deadline. As noted previously, the wind-tunnel data provided by NASA Langley were not publicly disseminated nor shown to CFD participants until the actual workshop, after the CFD solutions were finalized.

In the forthcoming figures, the wind-tunnel data and derived parameters are compared to CFD results from each participant. The participant solutions are labeled by the assigned participant identification number for the workshop—001 through 007. Certain participants elected to submit multiple solutions for each test case, varying the mesh resolution, turbulence model, and/or time step size. To facilitate easier viewing of the data from all participants, one dataset was selected per participant for the comparison figures. The selected dataset was determined based on the best judgment of the authors, for example, by observing the convergence of results among different solutions provided by the participant. Distinguishing information (e.g., mesh resolution level) is provided in the plot legends to indicate to participants which of their datasets is shown, but this information will be ambiguous to the outside reader. For the mesh resolution level, all solutions were renamed to have “A” be the coarsest mesh, or only submitted mesh, and all subsequent letters “B,” “C,” and “D” indicate increasing mesh fineness.

[†]Information available online at <https://ntrs.nasa.gov/citations/20240016445> [retrieved 16 November 2025].

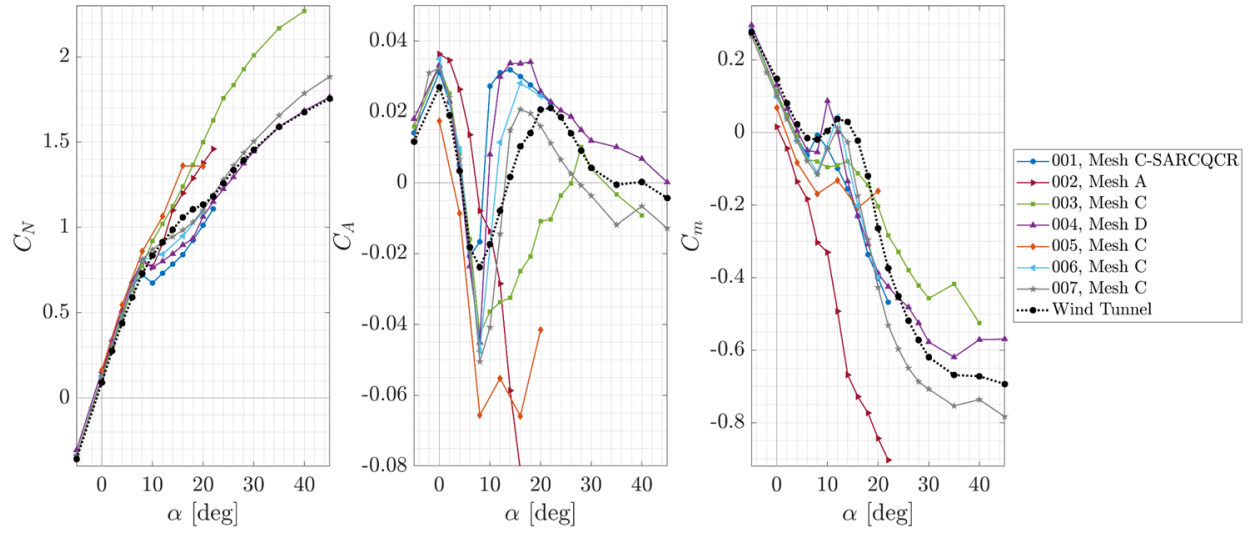
Table 5 S&CPW2 participants

Participant Name(s)	Organization	Method
Dan Vicroy, Benjamin Simmons	Adaptive Aerospace Group, NASA Langley	Wind Tunnel
Daniel Enriquez	Altair Engineering	FlightStream
Wei Liao, Collin Strassburger	Bihrl Applied Research	FUN3D
Kelly Laffin, Steven Klausmeyer	Textron Aviation	FUN3D
Andrew Lofthouse, William Vogel	Air Force Life Cycle Management Center	Kestrel
Mehdi Ghoreyshi, Pooneh Aref	U.S. Air Force Academy	Kestrel
Seung Yoo	NASA Armstrong	STAR-CCM+
Zhuoneng Li, Andrea Da Ronch, Xupeng Sui	University of Southampton	STAR-CCM+

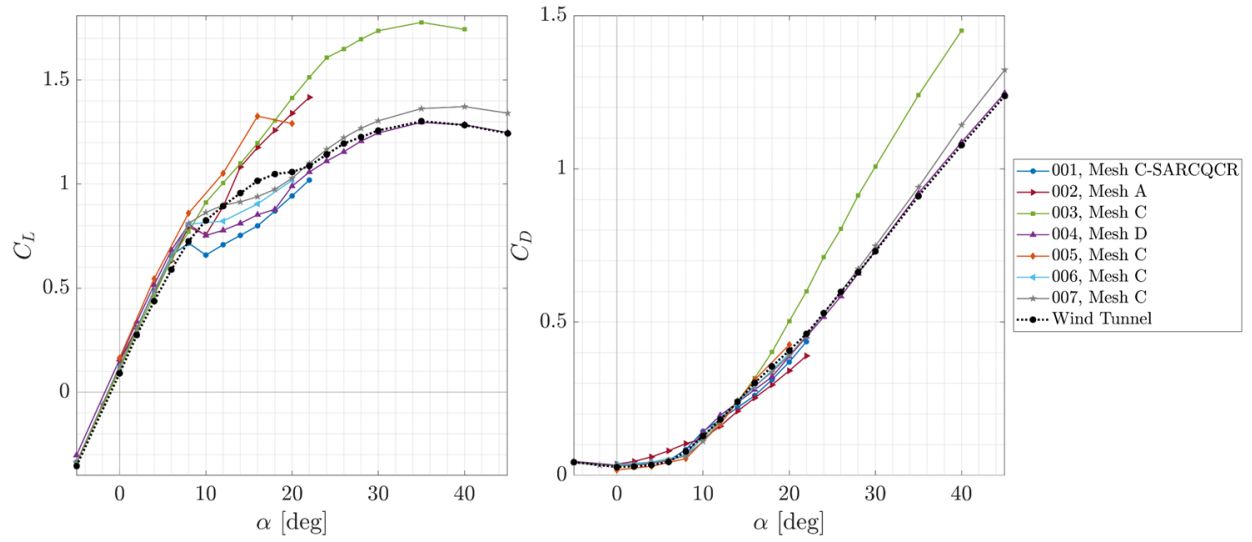
Note: Participant identification numbers have been removed for public dissemination of this paper. Participants are not ordered by their identification number in this table.

A. Case 1a: Angle-of-Attack Sweep and Longitudinal Static Stability Derivatives

The comparisons of results for Case 1a are shown in Figs. 12-15. Figures 12-14 show the α sweeps from each CFD participant compared to wind-tunnel data, where each sequential figure progressively reduces the displayed α range to clarify differences at lower angles of attack. Figure 12 shows all required and optional data available ($-5 \leq \alpha \leq +45$) deg, Figure 13 shows the required α data range ($0 \leq \alpha \leq +20$ deg), and Figure 14 shows low- α data ($0 \leq \alpha \leq +8$ deg) near the stability derivative reference point of $\alpha = 4$ deg. In these figures, C_N , C_A , C_m , C_L , and C_D are plotted against α . The CFD and wind-tunnel data generally exhibit reasonably close agreement in value and slope at low α values, with increasing differences evident near and beyond stall.

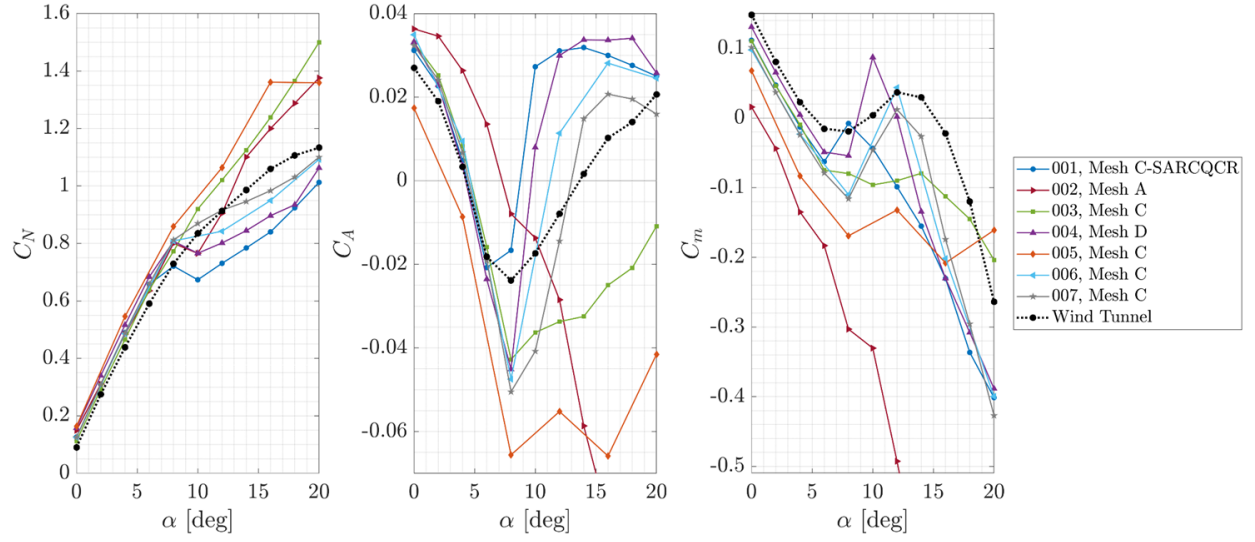


(a) C_N , C_A , and C_m versus α

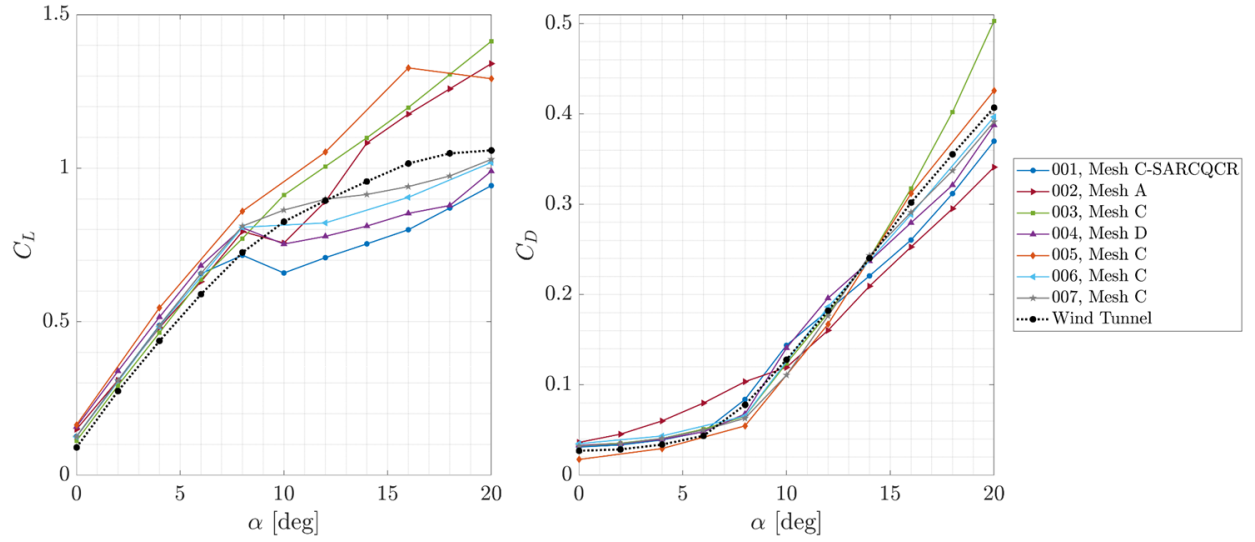


(b) C_L and C_D versus α

Fig. 12 Comparison of CFD and wind-tunnel α sweeps including all data ($-5 \leq \alpha \leq +45$ deg).

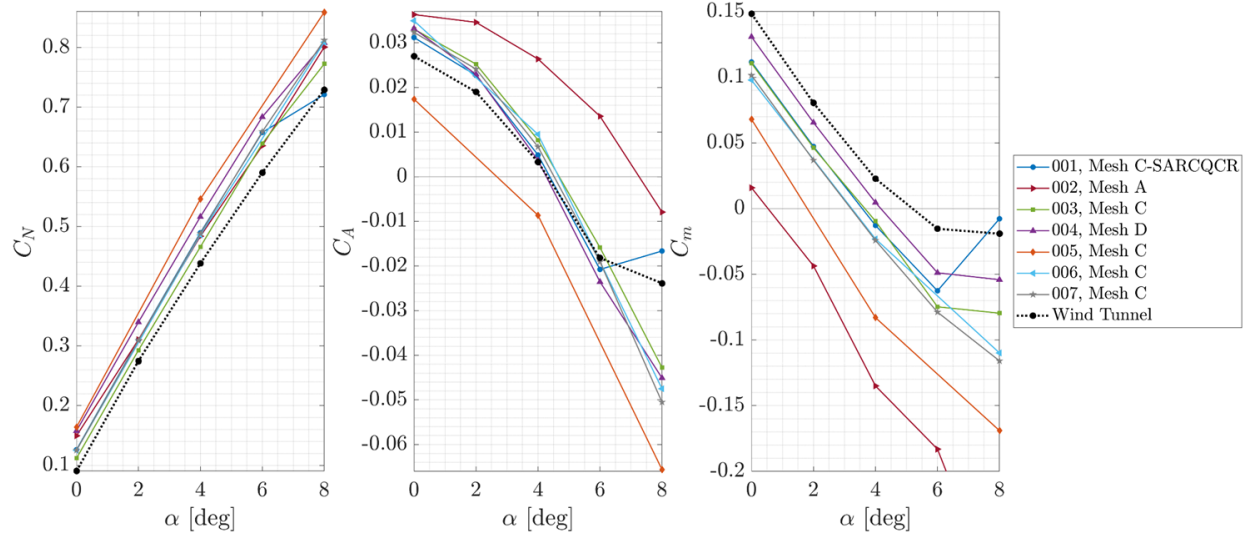


(a) C_N , C_A , and C_m versus α

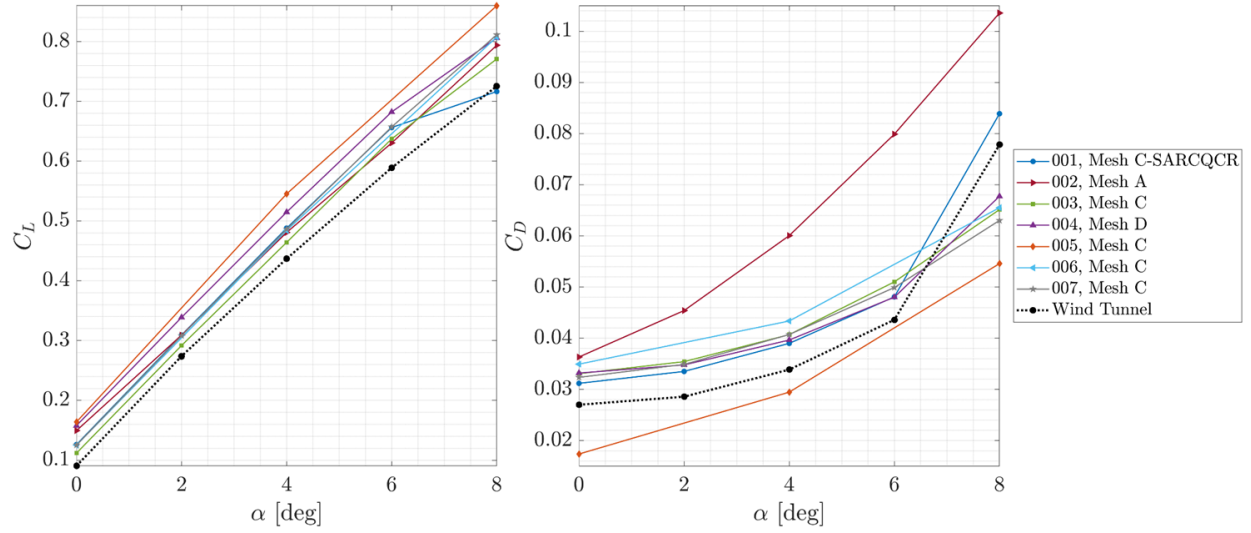


(b) C_L and C_D versus α

Fig. 13 Comparison of CFD and wind-tunnel α sweeps including only required data ($0 \leq \alpha \leq +20$ deg).



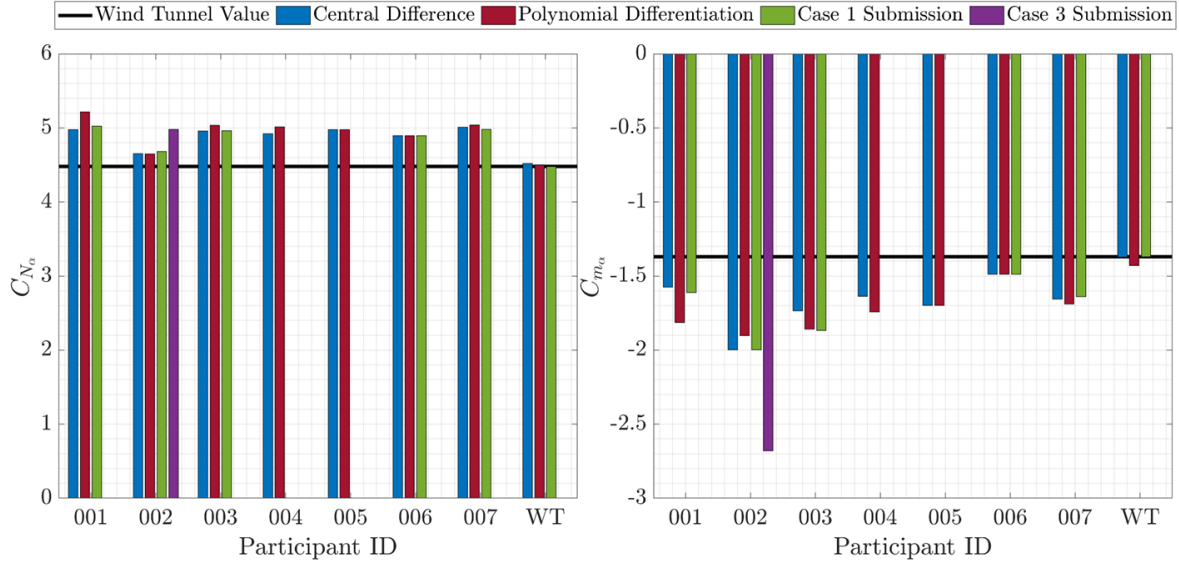
(a) C_N , C_A , and C_m versus α



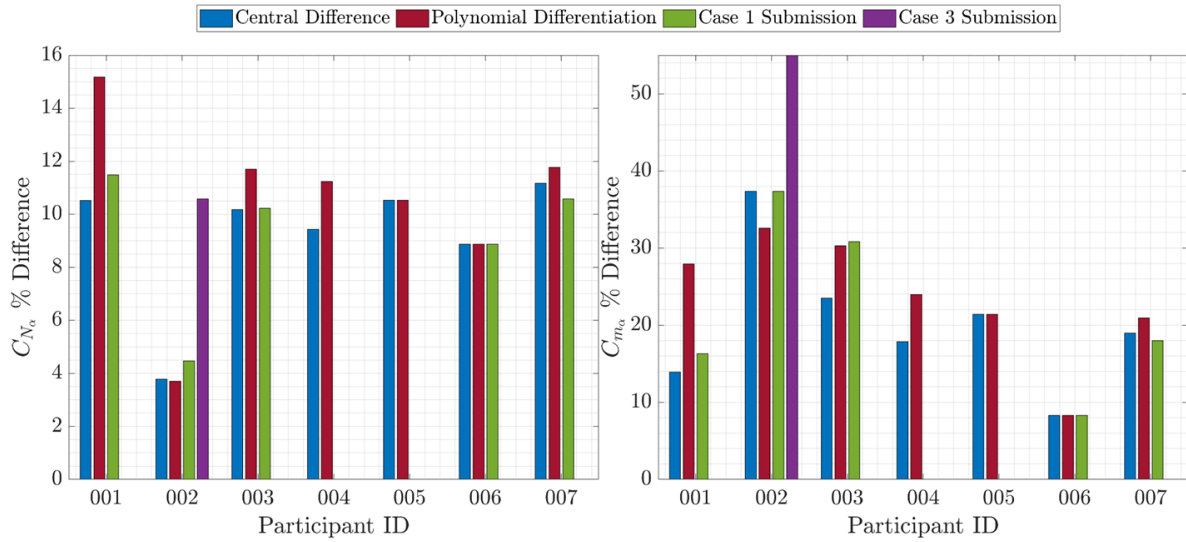
(b) C_L and C_D versus α

Fig. 14 Comparison of CFD and wind-tunnel α sweeps including only low- α data ($0 \leq \alpha \leq +8$ deg).

Figure 15 shows a comparison of the static stability derivatives calculated at $\alpha = 4$ deg (Fig. 15a), as well as the corresponding percent difference between CFD and wind-tunnel derived values (Fig. 15b). The “Central Difference” and “Polynomial Differentiation” legend entries indicate the stability derivatives calculated using the data processing methods discussed in Sec. V.A applied uniformly to each submitted α sweep. The “Case 1 Submission” and “Case 3 Submission” legend entries indicate the stability derivative estimates calculated by workshop participants, if they were provided. The solid black line is the wind-tunnel derived value provided as the “Case 1 Submission.” The C_{N_α} estimates match reasonably well, with the CFD-derived estimates tending to be slightly larger than the wind-tunnel derived estimates, with most percent differences roughly near 10%. More variation is seen in the C_{m_α} estimates, where the CFD-derived estimates have larger-magnitude negative values compared to the wind-tunnel derived estimates. The percent differences between CFD and wind-tunnel derived estimates for the uniform calculation methods vary from 8% to 38%.



(a) CFD and wind-tunnel derived stability derivative estimates



(b) Percent difference between CFD and wind-tunnel derived stability derivatives

Fig. 15 Comparison of longitudinal static stability derivatives C_{N_α} and C_{m_α} at $\alpha = 4$ deg.

B. Case 1c: Angle-of-Sideslip Sweep and Lateral-Directional Static Stability Derivatives

The comparisons of results for Case 1c are shown in Figs. 16-17. Figure 16 shows the C_Y , C_l , and C_n against β for each CFD submission and the wind-tunnel data at $\alpha = 4$ deg. The general trends between the CFD and wind-tunnel data are comparable; however, with slight slope differences evident that lead to differences in the stability derivatives. Figure 17 shows the corresponding calculated stability derivatives at $\beta = 0$ deg and the percent difference between CFD and wind-tunnel derived values. The interpretation of the legend is identical to the description given in the previous subsection (Sec. VI.A). For $C_{Y\beta}$, most CFD-derived estimates have a lower-magnitude negative value compared to the wind-tunnel data, with percent differences varying from 2% to 28% for the uniformly applied calculation methods. The CFD-derived $C_{l\beta}$ estimates have smaller negative values compared to the corresponding wind-tunnel derived estimates, with the percent difference varying from approximately 7% to 26%. $C_{n\beta}$ estimates derived from CFD generally have a smaller positive value compared to the wind-tunnel derived estimate, with percent differences varying from near zero to approximately 44% for the uniform calculation techniques.

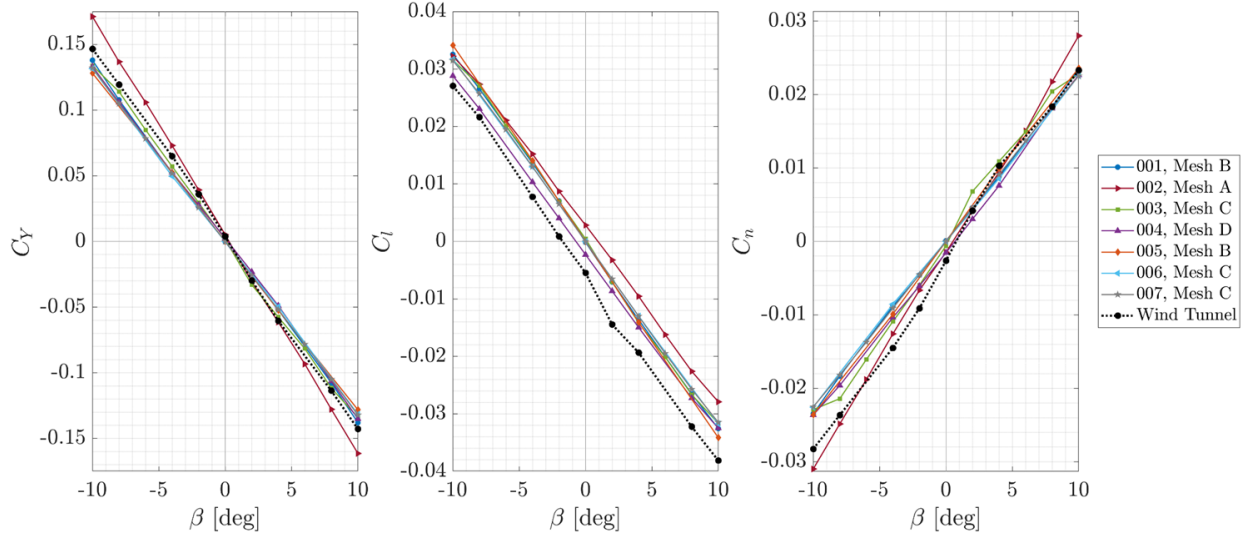
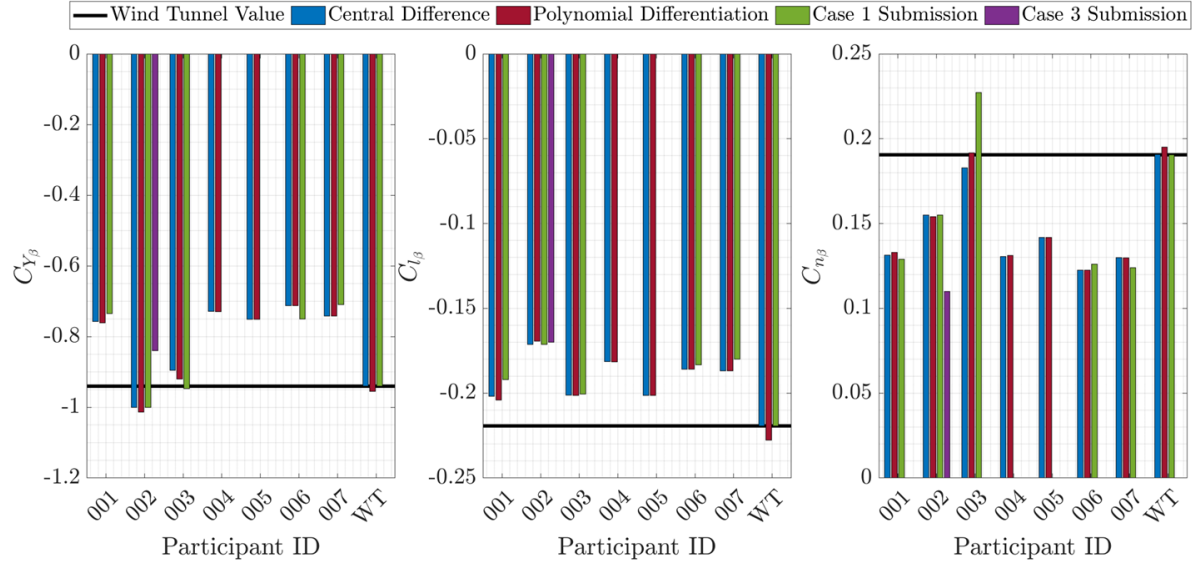
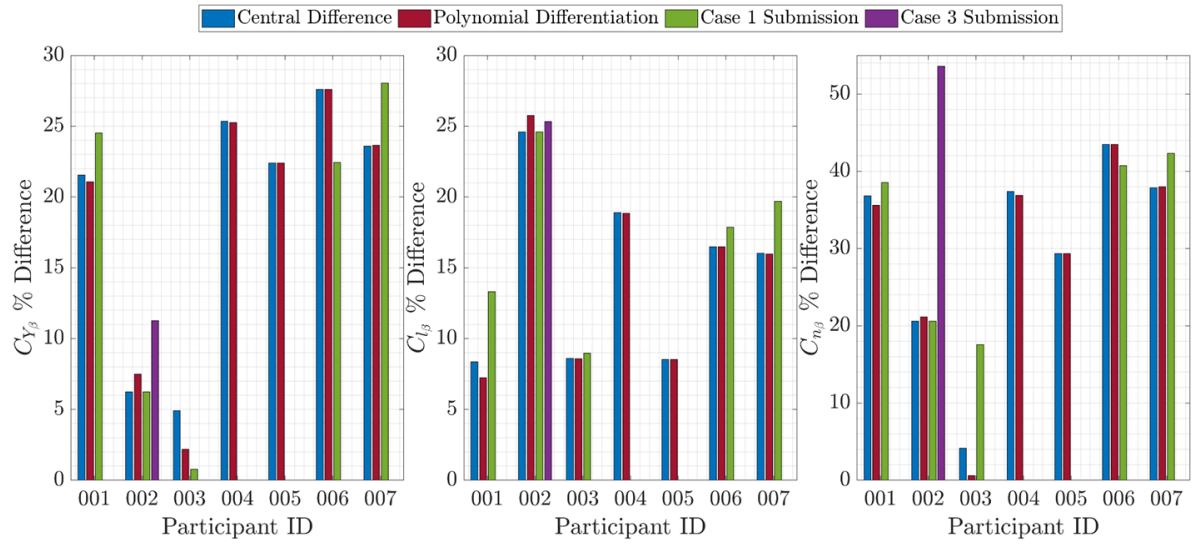


Fig. 16 Comparison of CFD and wind-tunnel β sweeps displaying C_Y , C_l , and C_n versus β .



(a) CFD and wind-tunnel derived stability derivative estimates

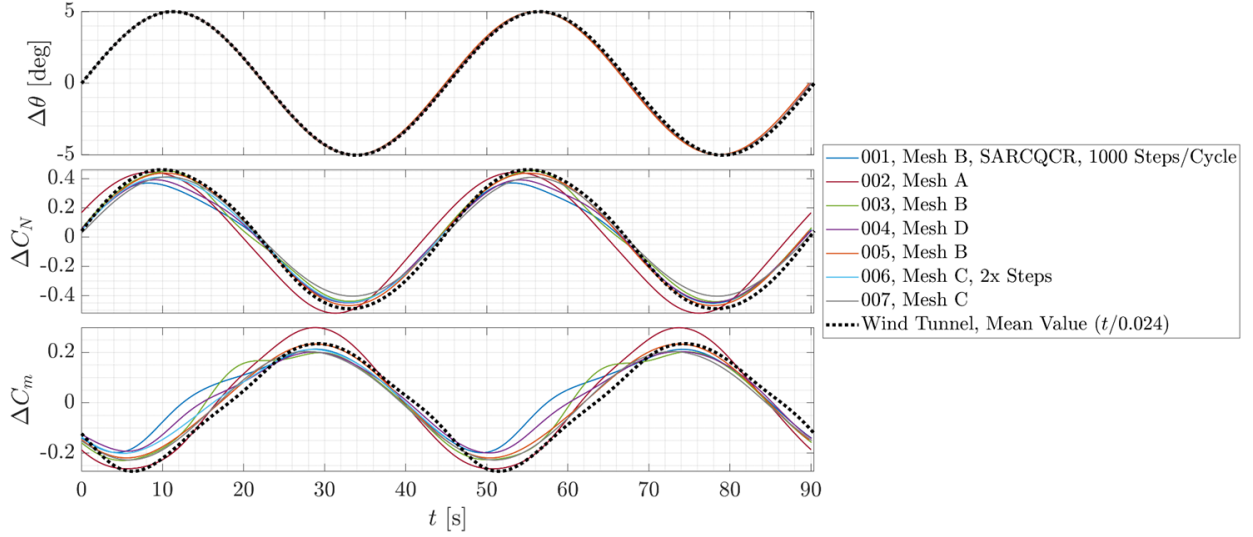


(b) Percent difference between CFD and wind-tunnel derived stability derivatives

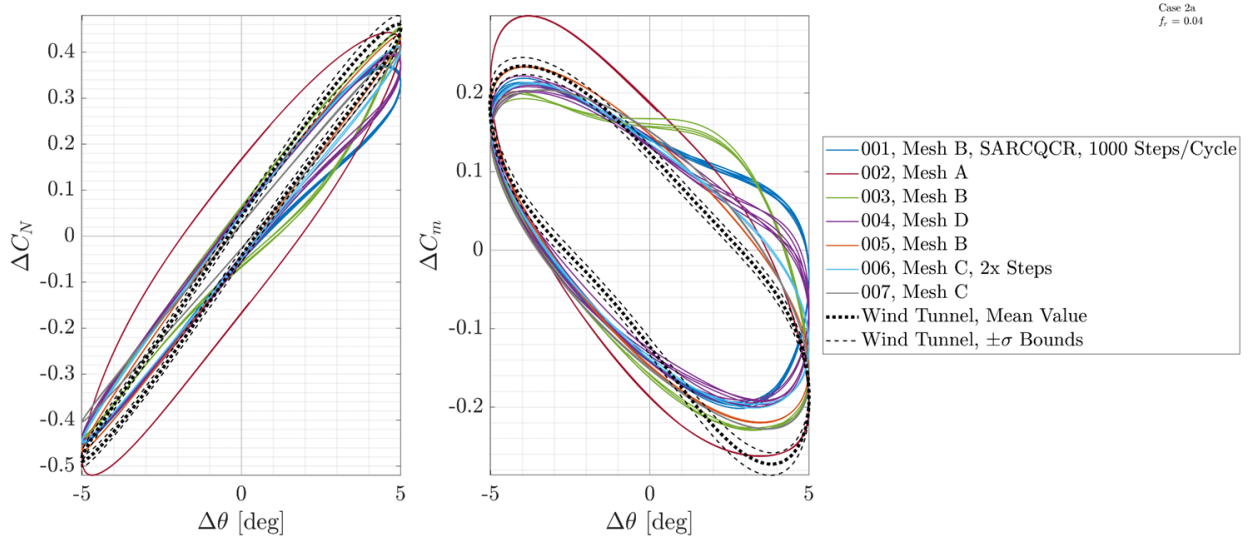
Fig. 17 Comparison of lateral-directional static stability derivatives C_{Y_β} , C_{l_β} , and C_{n_β} at $\alpha = 4$ deg and $\beta = 0$ deg.

C. Case 2a: Pitch Oscillations and Dynamic Stability Derivatives

The comparisons of CFD and wind-tunnel results for Case 2a are shown in Figs. 18-19. Time histories for $\Delta\theta$, ΔC_N , and ΔC_m are displayed in Fig. 18a, where “ Δ ” denotes a perturbation from the corresponding reference value. Two converged, smoothed CFD oscillation cycles are shown for each participant, along with the repeated one-cycle average from the wind-tunnel data. The full-scale CFD and 2.4%-scale wind-tunnel forced oscillations matched reduced frequency to directly compare aerodynamic damping characteristics. This makes the oscillation frequency of CFD solutions different from the wind-tunnel oscillation frequency by a factor of 0.024; therefore, to directly compare CFD and wind-tunnel time histories, the wind-tunnel time variable was divided by 0.024. The corresponding hysteresis loops showing ΔC_N and ΔC_m variation with $\Delta\theta$ are shown in Fig. 18b. All converged, completed cycles of the CFD data are shown, along with the wind-tunnel one-cycle average value and one standard deviation bounds. The general trends of the CFD and wind-tunnel data are fairly similar but the varying hysteresis loop shapes indicate different aerodynamic damping predictions.



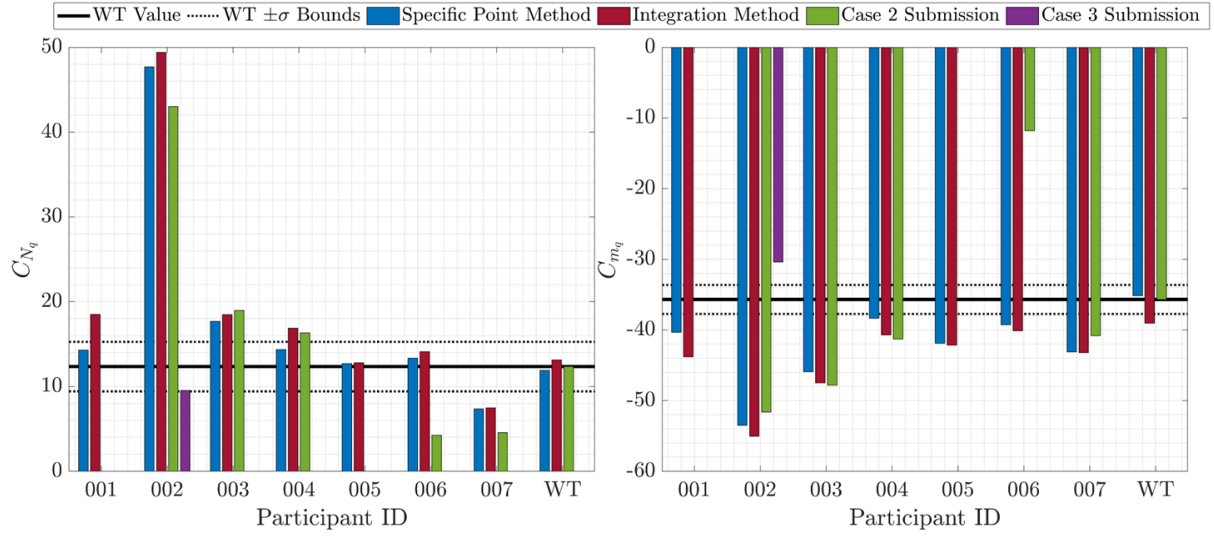
(a) Time histories for $\Delta\theta$, ΔC_N , and ΔC_m



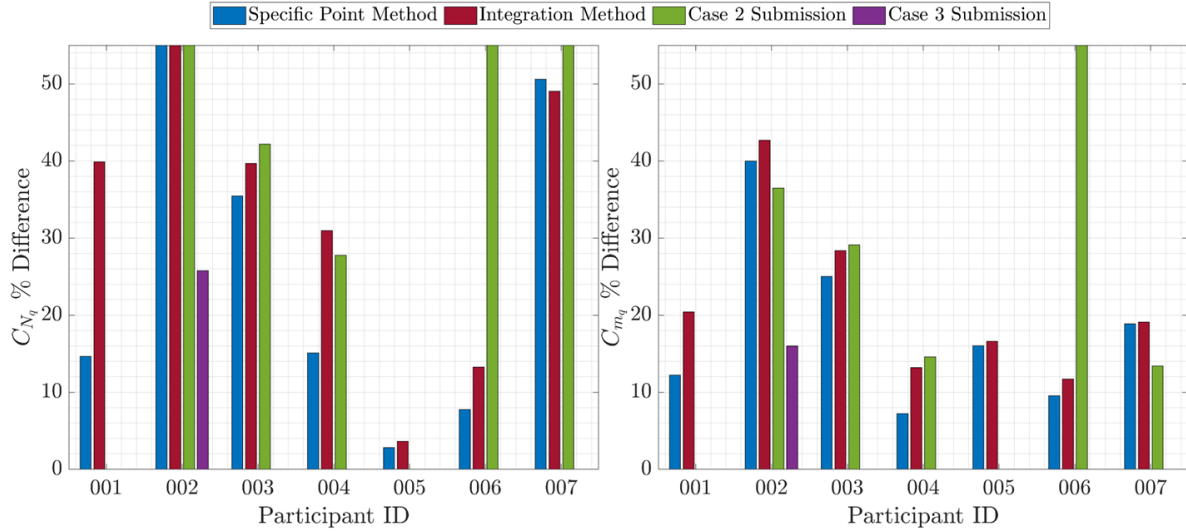
(b) Hysteresis loops: ΔC_N and ΔC_m versus $\Delta\theta$

Fig. 18 Comparison of CFD and wind-tunnel pitch forced oscillations.

Figure 19 shows the comparison of pitch dynamic stability derivatives calculated at $\alpha_o = 3$ deg (Fig. 19a), as well as the corresponding percent difference between CFD and wind-tunnel derived values (Fig. 19b). The “Specific Point Method” and “Integration Method” legend entries indicate the stability derivatives calculated using the data processing methods discussed in Sec. V.B applied uniformly to each pitch oscillation dataset. The “Case 2 Submission” and “Case 3 Submission” legend entries indicate the stability derivative estimates calculated by workshop participants, if they were provided. The solid black line is the wind-tunnel derived value provided as the “Case 2 Submission,” along with dotted black lines that give one standard deviation bounds. A majority of the CFD-derived C_{N_q} estimates have larger positive values compared to the wind-tunnel derived estimates. The corresponding percent differences vary from approximately 3% to over 50%, with four CFD specific-point estimates falling within the wind-tunnel estimate one standard deviation bounds. For C_{m_q} , the CFD-derived estimates generally have a larger-magnitude negative value compared to the wind-tunnel derived estimates. The percent differences between CFD and wind-tunnel derived estimates for the uniform calculation methods vary from approximately 7% to 42%.



(a) CFD and wind-tunnel derived stability derivative estimates

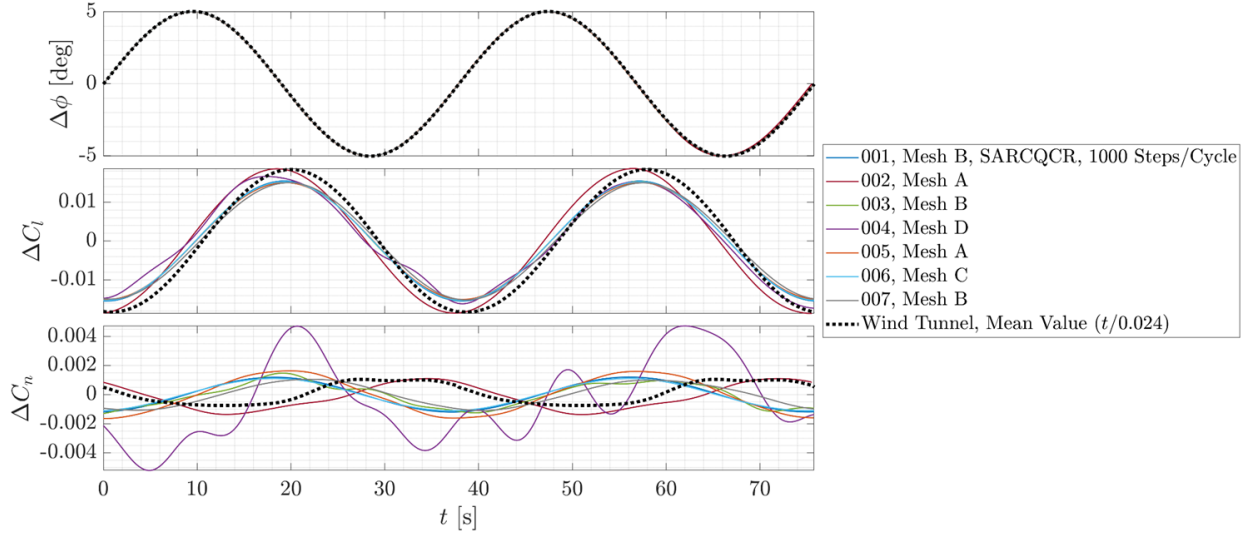


(b) Percent difference between CFD and wind-tunnel derived stability derivatives

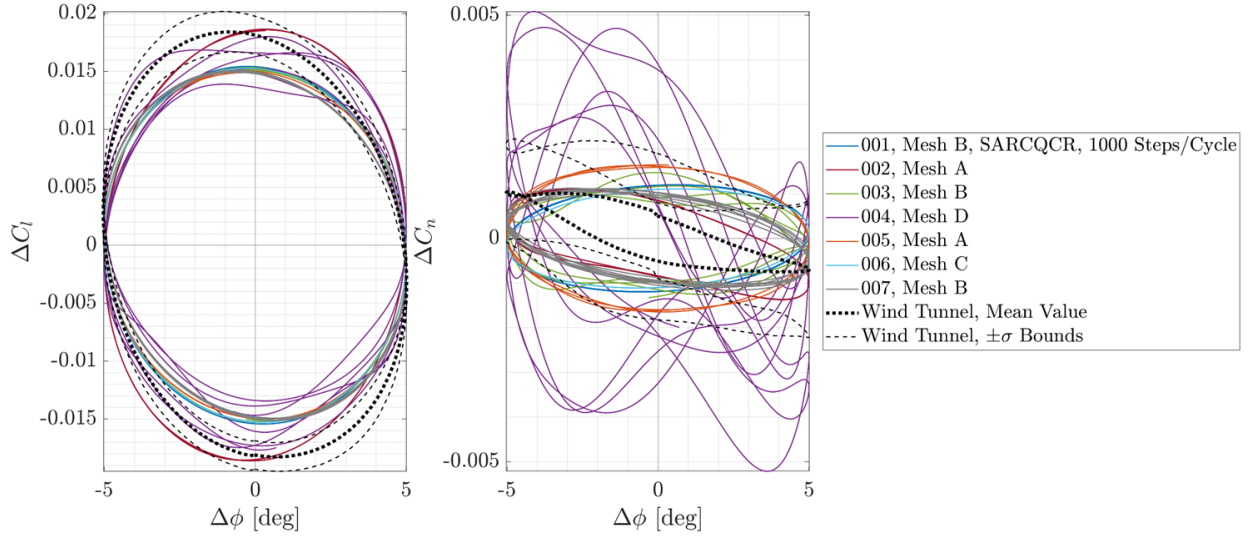
Fig. 19 Comparison of pitch dynamic stability derivatives C_{N_q} and C_{m_q} at $\alpha_o = 3$ deg and $\beta_o = 0$ deg.

D. Case 2b: Roll Oscillations and Dynamic Stability Derivatives

The comparisons of results for Case 2b are shown in Figs. 20-22. Time histories for $\Delta\phi$, ΔC_l , and ΔC_n are displayed in Fig. 20a. The corresponding hysteresis loops for ΔC_l and ΔC_n variation with $\Delta\phi$ are shown in Fig. 20b. Furthermore, to aid in viewing the ΔC_n data, Fig. 21 shows the same plots with the “004” solution removed. The data display methodology emulates the discussion from the previous subsection (Sec. VI.C). For ΔC_l , the dominant coefficient for roll oscillations, the CFD and wind-tunnel hysteresis loops appear to be decently close. More variation between datasets is observed in the ΔC_n data, as is also reflected by the larger uncertainty bounds for the wind-tunnel data.

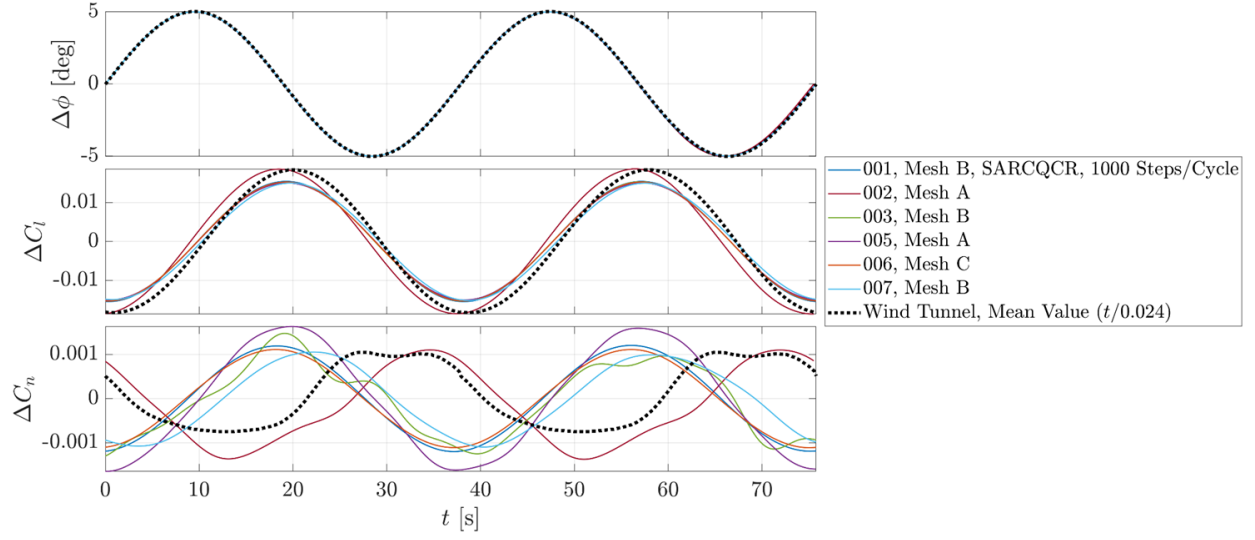


(a) Time histories for $\Delta\phi$, ΔC_l , and ΔC_n

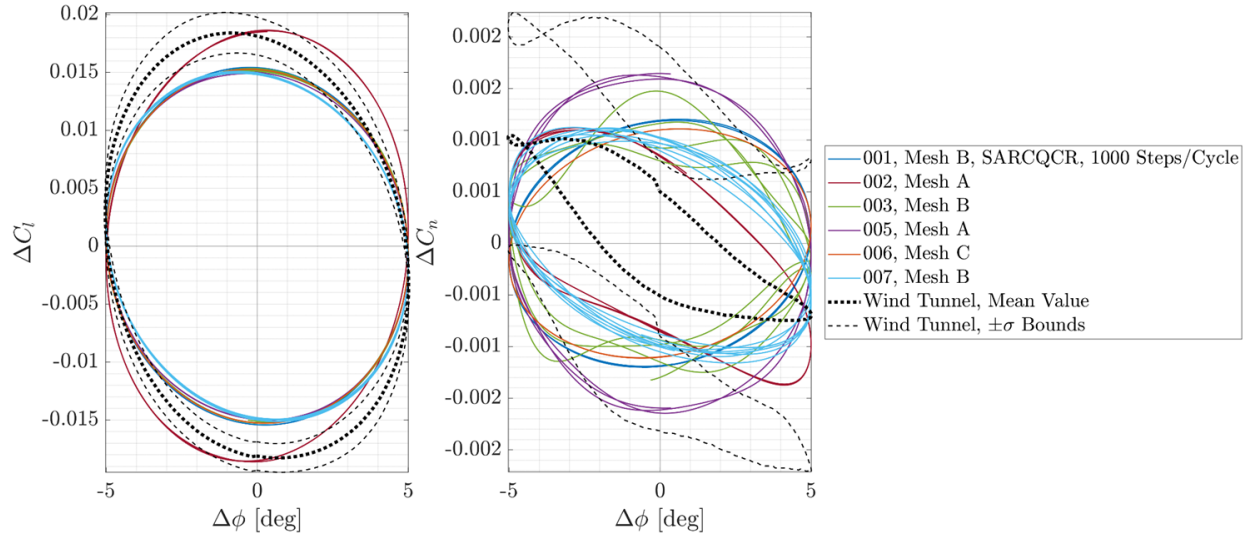


(b) Hysteresis loops: ΔC_l and ΔC_n versus $\Delta\phi$

Fig. 20 Comparison of CFD and wind-tunnel roll forced oscillations.



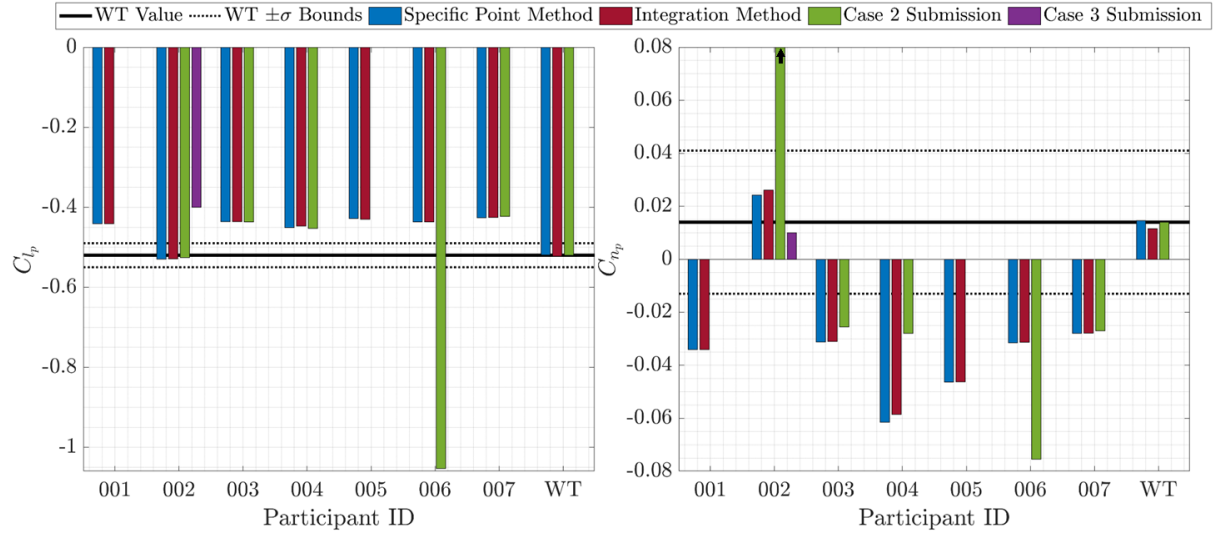
(a) Time histories for $\Delta\phi$, ΔC_l , and ΔC_n



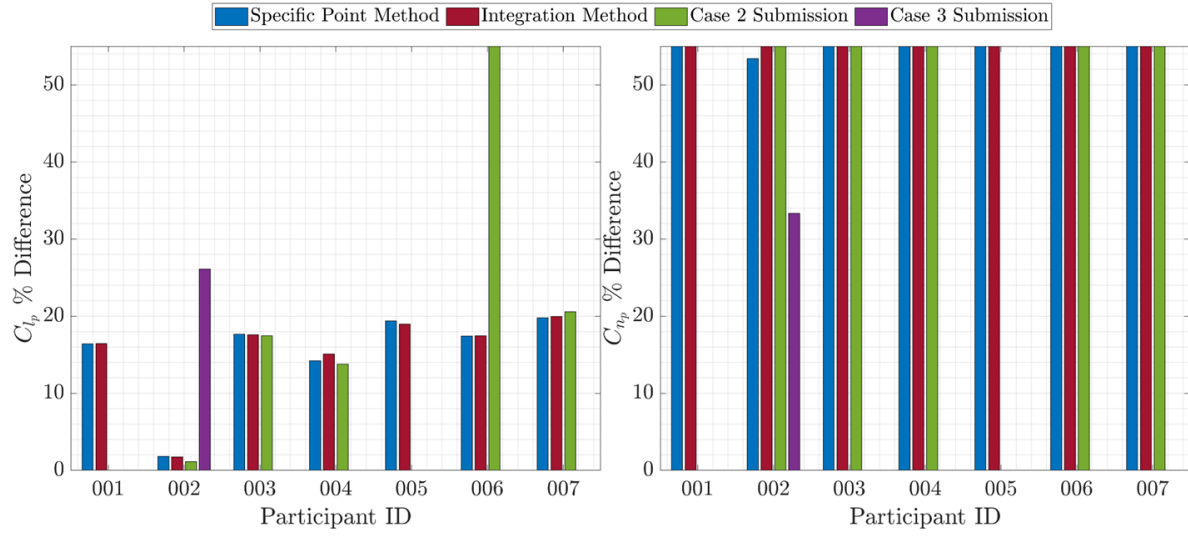
(b) Hysteresis loops: ΔC_l and ΔC_n versus $\Delta\phi$

Fig. 21 Comparison of CFD and wind-tunnel roll forced oscillations (ID 004 removed).

Figure 22 shows a comparison of the roll dynamic stability derivatives calculated at $\alpha_o = 3$ deg and $\beta_o = 0$ deg (Fig. 22a), as well as the corresponding percent difference between CFD and wind-tunnel derived values (Fig. 22b). For C_{l_p} , the CFD-derived estimates are mostly lower-magnitude negative values compared to the wind-tunnel derived estimates. The percent differences for the common data processing techniques range from 2% to 20%. For C_{n_p} , all but one CFD-derived solution has a different sign compared to the wind-tunnel derived estimate; accordingly, the percent differences are high.



(a) CFD and wind-tunnel derived stability derivative estimates

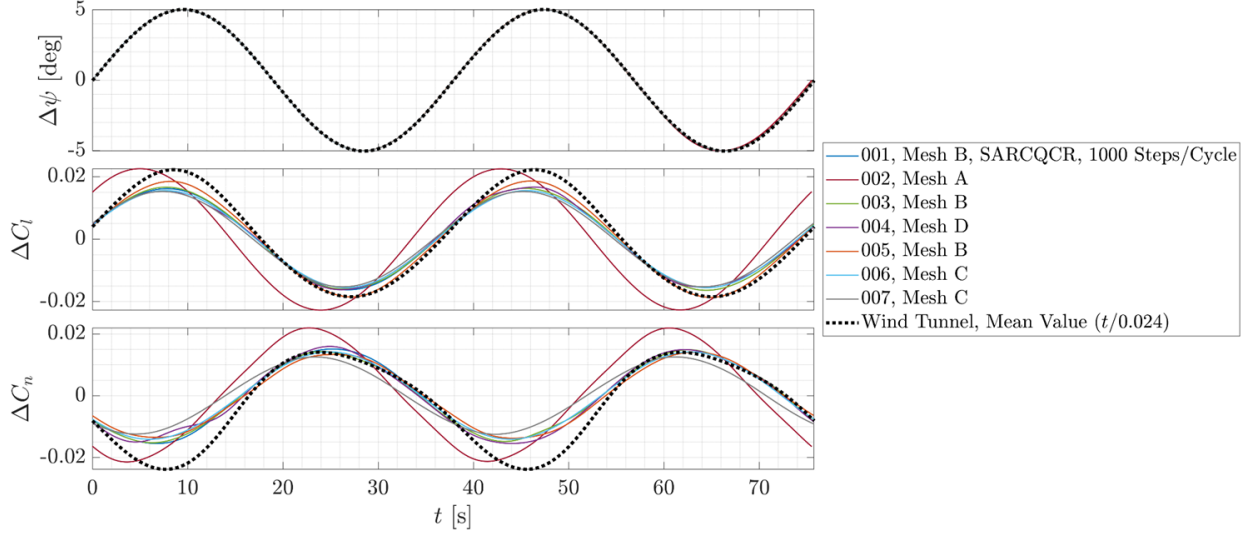


(b) Percent difference between CFD and wind-tunnel derived stability derivatives

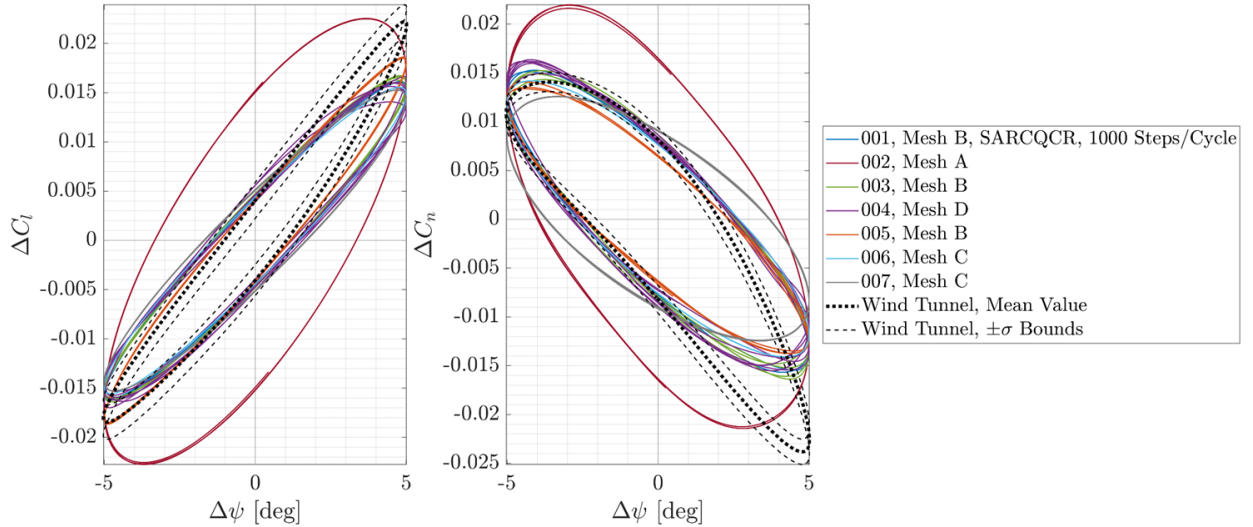
Fig. 22 Comparison of roll dynamic stability derivatives C_{l_p} and C_{n_p} at $\alpha_o = 3$ deg and $\beta_o = 0$ deg.

E. Case 2c: Yaw Oscillations and Dynamic Stability Derivatives

The comparisons of results for Case 2c are shown in Figs. 23-24. Time histories for $\Delta\psi$, ΔC_l , and ΔC_n are displayed in Fig. 23a. The corresponding hysteresis loops for ΔC_l and ΔC_n variation with $\Delta\psi$ are shown in Fig. 23b. The data display methodology again reflects the discussion given in Sec. VI.C. The ΔC_l and ΔC_n values at crossing points for most CFD predictions and the wind-tunnel values align well, indicating similar damping predictions about the reference condition.



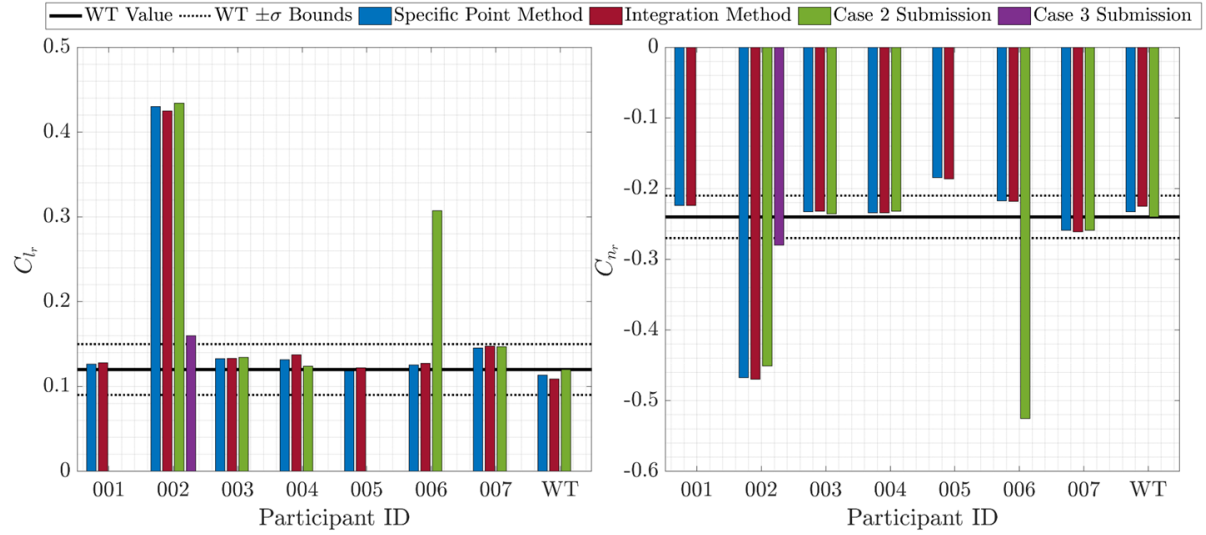
(a) Time histories for $\Delta\psi$, ΔC_l , and ΔC_n



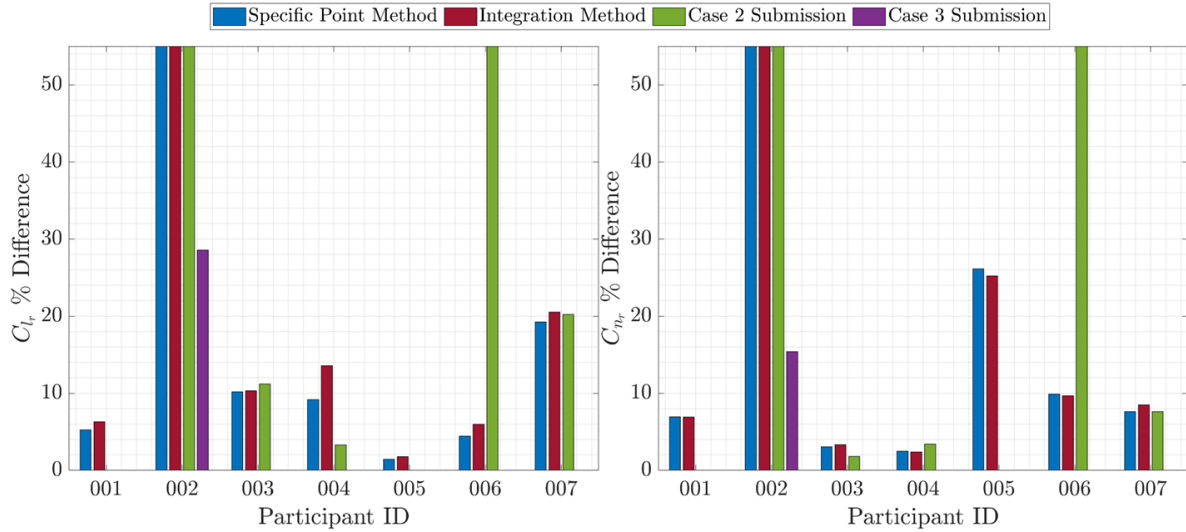
(b) Hysteresis loops: ΔC_l and ΔC_n versus $\Delta\psi$

Fig. 23 Comparison of CFD and wind-tunnel yaw forced oscillations.

Figure 24 shows a comparison of the yaw dynamic stability derivatives calculated at $\alpha_o = 3$ deg and $\beta_o = 0$ deg (Fig. 24a), as well as the corresponding percent difference between CFD and wind-tunnel derived values (Fig. 24b). For both C_{l_r} and C_{n_r} , a majority of the CFD-derived estimates are near the wind-tunnel derivative estimates within one wind-tunnel estimate standard deviation. For the uniformly applied calculation methods, a majority of the percent differences are approximately 10% or lower, with a couple of higher percent differences for each derivative. In general, compared to the pitch and roll cases, the yaw dynamic stability derivative estimates from CFD and wind-tunnel data appear to be the most consistent.



(a) CFD and wind-tunnel derived stability derivative estimates



(b) Percent difference between CFD and wind-tunnel derived stability derivatives

Fig. 24 Comparison of yaw dynamic stability derivatives C_{l_r} and C_{n_r} at $\alpha_o = 3$ deg and $\beta_o = 0$ deg.

VII. Lessons Learned

This section documents certain lessons learned from S&CPW2. Several lessons learned result from the fact that forced oscillations and dynamic stability derivative determination techniques are less commonly applied in the aerodynamic prediction community. These lessons learned are meant only constructively to help improve the execution of future workshops (the lessons learned are not intended to be critical of the organizing committee and/or participants).

- Including additional cycles in the CFD data submissions would have aided forced oscillation data processing. The requested three converged cycles assumed “low noise” data; however, many of the CFD solutions exhibited noise character reminiscent of wind-tunnel data, which requires a larger number of oscillation cycles to obtain adequate results. Therefore, in cases where CFD exhibits wind-tunnel-like noise characteristics, the number of oscillation cycles should be increased, especially where there is variability in smoothed, converged hysteresis loops. Although including additional cycles will improve dynamic derivative estimation, the expense of running

additional cycles may be prohibitive due to the high computational expense.

- Particularly for the dynamic test cases, the CFD solution methodology specifications were left too broad. Some participants explored different approaches, which is appreciated, but it was difficult to deduce concrete insights to inform the community. In other words, different codes, solver settings, meshes, turbulence models, time steps, etc. among different groups made it difficult to glean overall strategies to improve the consistency among CFD results from the workshop. A major takeaway from this study is that more research is needed to identify dynamic CFD simulation best practices to achieve more reliable dynamic stability derivative prediction results. Further exploration of different solution approaches should be encouraged and examined with more structure.
- For dynamic stability derivative predictions, some participants elected to submit only time histories (i.e., not submit dynamic stability derivative predictions) due to uncertainty regarding how to properly compute dynamic stability derivatives from forced oscillation data. In other cases, participants submitted dynamic stability derivative estimates, but there was a large difference between the submitted value and the value computed by the workshop organizers using the common data processing methods discussed in Sec. V.B. This highlights the need for additional training in dynamic stability derivative computation within the community and the fact that dynamic stability derivative predictions can substantially vary depending on the forced oscillation post-processing techniques. In addition to the need for establishment of best practices in the CFD solution methodology, measures to improve consistency in dynamic stability derivative computation are also important. Furthermore, additional guidelines are desired for the expected and necessary accuracy of dynamic derivative predictions, where higher uncertainties are likely acceptable compared to static and control derivatives.
- Certain CFD solvers experienced difficulties due to the low subsonic reference flight conditions used in S&CPW2 to match the available wind-tunnel test conditions. It is uncertain if these CFD solver challenges had an impact on the accuracy of the final CFD solutions.
- Holding a pre-workshop comparison study among participants (i.e., the “mini-workshop”) was critical to improve the quality of the final workshop results. This meeting allowed for diagnosis of setup discrepancies that were mostly able to be resolved before the final workshop submissions were due.
- It would have been helpful to provide an example of the expected data character (general shape, magnitude, sign) with the original test case description document. This would have likely helped to avoid solution issues found at the mini-workshop.
- Although common data submission files were provided, issues with the submitted data format resulted in a significant additional data processing burden. Providing a way for participants to verify the consistency of their data format before submission would have helped to mitigate this issue.
- Although a data file submission name and information format was provided, additional documentation structure would have helped with the post-processing of all workshop data. For example, including a common format for participant ID, case, mesh level, frequency, time steps, and turbulence models, would have made batch workshop data post-processing easier.

VIII. Concluding Remarks

S&CPW2 provided an opportunity to compare CFD solutions from different government, industry, and academic institutions alongside low-speed static and dynamic CRM wind-tunnel data that were released during the workshop. The workshop was held at the AIAA SciTech 2025 Forum and included seven participants submitting CFD results, with four different CFD codes represented. The workshop test cases included static angle-of-attack and angle-of-sideslip sweeps, as well as pitch, roll, and yaw sinusoidal force oscillations. These data were used to compute static and dynamic stability derivatives. Workshop participants were encouraged to use their preferred methods to compute stability derivatives, but common post-processing methods for derivative computation were also uniformly applied to the submitted data. Compared to S&CPW1, the primary new attribute of S&CPW2 was its focus on dynamic stability derivative prediction.

CFD results from each participant were compared to wind-tunnel data. This included a comparison of data points for static cases, as well as time histories and hysteresis loops for dynamic forced oscillation cases. Bar charts were subsequently presented to compare the static and dynamic stability derivative estimates computed using multiple methods. Although the CFD and wind-tunnel derived stability derivatives were close in some cases, in general, closer agreement among all results remains an important objective. Particularly for dynamic cases, additional work is needed

to establish best practices for obtaining consistent and repeatable results, as well as to form guidelines for the desired and required prediction accuracy.

The general trajectory for the S&CPW series started with static stability derivative prediction in S&CPW1 and then shifted to a focus on dynamic stability derivative prediction at S&CPW2. The original planned next step was to progress to control derivative predictions at a future S&CPW3; however, the results from S&CPW2 indicate that additional study is needed for refinement of results and establishment of best practices for dynamic stability derivative prediction. Future S&CPW activities focusing on dynamic forced motions and dynamic stability derivative predictions are recommended as a next step for the S&CPW series.

Acknowledgments

The authors gratefully acknowledge the significant contributions of the S&CPW2 participants (Table 5) and the S&CPW2 organizing committee:

- Andrew Lofthouse, Air Force Life Cycle Management Center
- Benjamin Simmons, NASA Langley Research Center
- Dan Vicroy, Adaptive Aerospace Group, Inc.
- William Vogel, Air Force Life Cycle Management Center
- Norman Princen, The Boeing Company
- Adam Clark, The Boeing Company
- Brett Johnson, The Boeing Company
- Matthew Prior, General Atomics – ASI
- Steve Klausmeyer, Textron Aviation
- Kelly Laffin, Textron Aviation
- Charlie Harrison, Gulfstream Aerospace Corporation

The dedicated efforts of these individuals were instrumental to the success of the workshop. Furthermore, support for S&CPW2 from the AIAA Stability and Control Prediction Discussion Group, Applied Aerodynamics Technical Committee, and Atmospheric Flight Mechanics Technical Committee is greatly appreciated.

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