AIAA G-129-2012

Guide

Nomenclature and Axis Systems for Aerodynamic Wind Tunnel Testing

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Guide

Nomenclature and Axis Systems for Aerodynamic Wind Tunnel Testing

Sponsored by

American Institute of Aeronautics and Astronautics

Approved March 2012

Abstract

This guide is intended to increase the understanding of test nomenclature and axis systems between wind tunnel facilities throughout the world. Facilities should consider fully adopting the nomenclature in this Guide. At a minimum, it is recommended that this Guide be used as a reference for nomenclature between facilities.

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Foreword

Wind tunnel test data nomenclature may be ambiguous and is quite often a source of confusion between wind tunnel test facilities. Using a parameter incorrectly could result in bad wind tunnel data with damaging consequences.

The Ground Testing Technical Committee (GTTC) of the American Institute of Aeronautics and Astronautics (AIAA) was asked to sponsor a working group on test nomenclature. After approval, the Test Nomenclature Working Group was formed under the operating structure of the GTTC. This nomenclature standard is limited to steady-state wind tunnel testing involving forces and pressures for the broader wind tunnel testing community.

This guide is intended to increase the understanding of test nomenclature and axis systems between wind tunnel facilities throughout the world. Facilities should consider fully adopting the nomenclature in this guide. At a minimum, it is recommended that this nomenclature guide be used as a reference for nomenclature between facilities.

Some of the benefits that may be achieved by using a standard set of nomenclature for testing are

- increased customer understanding
- increased portability of experimental data
- increased usefulness of archived data
- increased workforce flexibility
- reduced data system development and support costs

During the initial meeting, an invitation list was developed for prospective organizations to join the working group representing several wind tunnel facilities, wind tunnel customer organizations, and academia. A standard is more effective when it is accepted at inception by a broad spectrum of participating organizations.

The following officers and members have provided dedicated support, contributions, and leadership to the AIAA/GTTC Test Nomenclature Working Group; their efforts have resulted in the development of this Guide:

David Cahill, Chair	ATA/Arnold Engineering Development Center
Pete Wilcox, Co-Chair	The Boeing Company
Clifford Obara, Secretary	NASA Langley Research Center
Max Amaya	NASA Ames Research Center
Nancy Andersen	Lockheed Martin Space Systems
Allen Arrington	Sierra Lobo Inc., NASA Glenn Research Center
John Henfling	Sandia National Laboratories
Frank Jackson	ATA/Arnold Engineering Development Center
Mark Melanson	Lockheed Martin Aeronautics Company
Joe Patrick	Lockheed Martin Aeronautics Company
Juergen Quest	European Transonic Wind Tunnel
Don Saxer	Calspan (now at NASA Langley Research Center)
Nick Verhaagen	Delft University of Technology
Julien Weiss	University of Québec

The following individuals are also acknowledged for their contributions:

Jean Bianco	NASA Headquarters
Guy Kemmerly	NASA Langley Research Center
Frank Kmak	NASA Ames Research Center

In addition, NASA Ames Research Center, the NASA Glenn Research Center, and the Arnold Engineering and Development Center provided their internal nomenclature toward the development of this standard.

The GTTC consensus body approved this document in November 2011. The consensus body submitted this document to the AIAA Standards Executive Council (SEC) for their review in January 2012. The AIAA Standards Executive Council (Wilson Felder, Vice President) accepted the document for publication in March 2012.

The AIAA Standards Procedures dictates that all approved Standards, Recommended Practices, and Guides are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any AIAA standards publication and no commitment to conform to or be guided by standards reports. In formulating, revising, and approving standards publications, the committees on standards will not consider patents that may apply to the subject matter. Prospective users of the publications are responsible for protecting themselves against liability for infringement of patents or copyright or both.

1 Scope

This document provides a recommended test nomenclature for steady-state wind tunnel testing involving force, moment, and pressure data. This guide may be used as a translator (Rosetta stone) between different facilities and customers. The use of this document will enhance the understanding and communication between customers and facilities in the wind tunnel testing community.

A major focus throughout this process has been to achieve a balance between too much or too little detail in the nomenclature parameters and definitions. When the names become too long, it is no longer nomenclature, but a full description of the item. The best nomenclature is immediately understood with no need to look it up. It is recognized that for this guide to be fully adopted, it must be easy to use and understand.

1.1 Purpose

Test nomenclature ambiguity can be a source of confusion, error, and inefficiency. While wind tunnel facilities measure many of the same physical quantities and apply similar corrections to their data, no two facilities and customers use the same set of nomenclature. This presents difficulties for facilities with multiple customers and customers who test at multiple facilities. This sometimes leads to serious confusion, especially when a variable ends up with the same name but a different meaning. Finally, wind tunnel operation often requires the transfer of staff between facilities, which would be greatly facilitated by common nomenclature at each facility.

1.2 Constraints

For each parameter addressed, a standard name is defined for use by data reduction, display, and storage devices. The computer names are limited to fourteen characters with no distinction made between upper and lower case. Only standard letters, numbers, and the underscore character are allowed (no symbols or Greek letters); subscripts and superscripts are not allowed. The meaning, unit of measure, and sign convention are defined for each parameter as well as a recommended name for publication. The standard units for each parameter are defined for the International System, SI, and the English system. Units are not defined for the publication parameters since it is typically done in the publication.

The following groups of testing parameters are included in this recommended nomenclature:

Test Section Conditions;

Model Axis Systems and Attitude;

Dimensional References; and

Pressures, Forces, Moments, and their Coefficients.

1.3 Naming Convention

The parameter names consist of a base name and a four-character suffix, which provides information about the parameter. The base name is a commonly used, and thus recognizable, name for the specific parameter. The suffix begins with an underscore character to set it apart from the base name.

The remaining three characters begin with an “S” to identify and associate the parameter with this AIAA Wind Tunnel Nomenclature standard. An “X” in this position instead of an “S” indicates that a change was made to the parameter requiring the user to seek further guidance.

The next character in the suffix defines the parameter group. For example, all parameters describing the empty test section flow field have an “F” in this position.

The last character of the parameter name defines the system of units. “I” indicates that the SI convention is used, “E” indicates that English units are presented, and “C” indicates that the parameter is non-dimensional.

The previous statements result in the formulation of the following suffix for all standard parameters:

_Sxy

Where: _S identifies the nomenclature as part of this recommended standard

x is the group descriptor

- A Angles
- C Coordinate systems
- F Flow field (empty test section at model location)
- G Geometry - lengths, areas, and weight
- L Loads - forces, moments and their coefficients
- P Pressures and their coefficients

y is the units descriptor

- I SI units
- E English units
- C Common to English and SI units

For example, the extension "_SFE" would be attached to all tunnel flow condition parameters using English units. Therefore, the nomenclature name for the freestream dynamic pressure (q) in English units is Q_SFE.

1.4 Balance or Parameter Number

Some parameters are associated with the balances that are used during a wind tunnel test. These parameters have an n following the base name representing the balance number. For example, on a test with two balances, THETABALn_SAC would have the names THETABAL1_SAC and THETABAL2_SAC representing the balance pitch angle for balance 1 and 2, respectively.

Other parameters that need additional identification are associated with pressure measurements. Pressure measurements are split into two groups, model surface pressures and other model or test-related pressures such as base and tunnel wall pressures. The model surface pressures are identified by an array (indicated by () in the name), which can be an array of single numbers, an array of two numbers indicating row and pressure number, or any other array type. The second group of parameters have an x following the parameter base name. An example would be PBASEx_SPE where PBASE1_SPE and PBASE2_SPE represent base pressures 1 and 2, respectively.

1.5 Corrections

Calculations, equations, or other details describing tares and corrections (i.e., tunnel wall corrections and weight tares) are not provided because they tend to be facility dependent. Rather, "fully corrected" in this document indicates that the facility has applied all corrections that they typically provide. Wall pressure coefficients are normalized by an uncorrected q; model pressure coefficients and force and moment coefficients by a corrected q, which is defined by the facility.

There are three defined levels of corrections described in this document; uncorrected, corrected for base and cavity pressures, and corrected for all facility specified adjustments.

Parameters containing U_Sxy are uncorrected. The subscript u is used in the publication names.

Parameters containing BC_Sxy are corrected for base/cavity pressures only. The subscript bc is used in the publication names.

Parameters not containing the above include all corrections normally provided by the facility (i.e., Q_SFE is the fully corrected tunnel dynamic pressure).

1.6 Applicable Documents

The following documents and standards were used as a source or guide for the development of this standard nomenclature.

Document 1: AIAA-R-093-2003 “Calibration of Subsonic and Transonic Wind Tunnels.”

Document 2: AIAA-R-091-2003 “Calibration and Use of Internal Strain-Gage Balances with Application to Wind Tunnel Testing.”

Document 3: NOLR 1241 “Compilation of Aerodynamic Nomenclature and Axes Systems.” (This document has been used as a source for the development of the axis systems and angles.)

Document 4: AIAA-R-004-1992 “Atmospheric and Space Flight Vehicle Coordinate Systems.”

2 Test Section Conditions

The most basic set of nomenclature are used to describe the test section operating conditions. The primary parameters are the pressures (total, static, and dynamic), temperatures (total and static), Mach number or airspeed and Reynolds number. These conditions can be measured from facility instrumentation, determined from calibration relationships or calculated. The nomenclature for the test section conditions is based on the terms used in the wind tunnel calibration recommended practices document (Reference 1). A summary of the terms included as part of the test section conditions nomenclature is listed at the end of this section (see Table 1).

Although these are the most basic set of parameters used during a wind tunnel test, they are also some of the most important. The test section operating conditions are the basis for setting the test matrix and are used in the analysis of test data. It is of vital importance to understand how these parameters are determined and to understand what each means. In order to compare test data between facilities, it is critical that the definitions of the parameters describing the operation are understood. Ideally, the parameters used to describe the test section operating conditions should be consistent from facility to facility.

The methodologies for determining a given parameter may vary between facilities, but the final understanding of the parameter will be the same. For example, consider the calibration of a subsonic wind tunnel. In order to fully define the test section operation conditions, two pressures and a temperature are needed. However, three pressures are available (total, static, and dynamic). A facility has its pick of measuring total, static, or differential pressure (total – static), as shown in Figure 1. Also, the hardware used to measure the pressures could vary between facilities (rakes of pressure probes, static pressure taps, or combinations thereof).

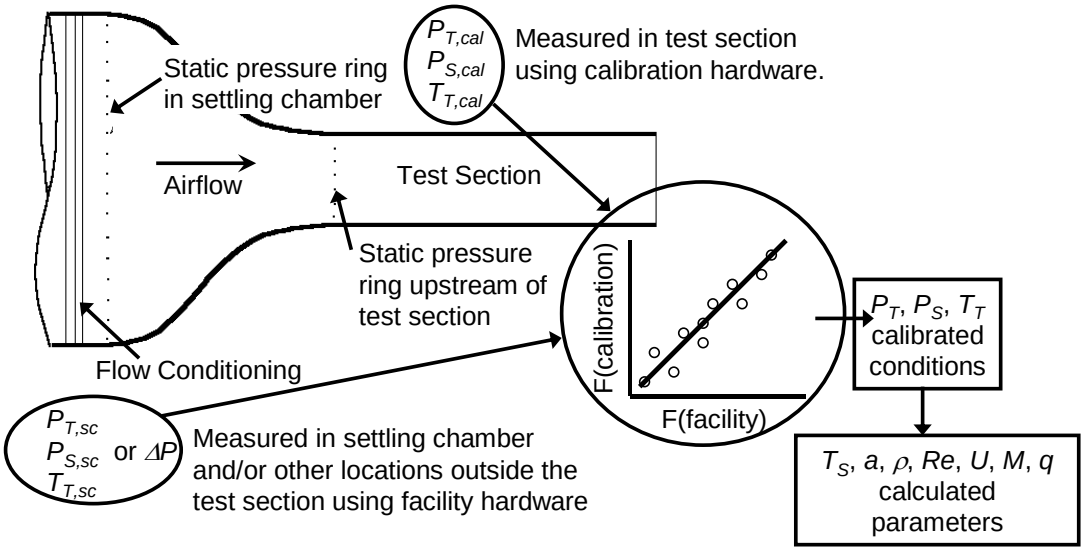


Figure 1 — Arrangement of measurements for monitoring operating conditions in a subsonic wind tunnel using a pair of static pressure rings

Figure 1 shows the classic method for calibrating a subsonic wind tunnel using two sets of static pressure taps at different locations in the tunnel. The upstream set of rings or taps measures the pressure in the settling chamber that will be similar to the total pressure. The downstream set of taps is just upstream of the test section and provides an indication of the static pressure. Calibration curves are developed using the pressures measured by the static pressure rings and measurements made in the test section. The calibration curves are used during customer testing to determine the actual test section pressures

(calibration curves will also be developed for total temperature and perhaps Mach number or airspeed). Once the calibrated test section conditions are determined, all other pertinent parameters can be calculated. As mentioned, other hardware can be used to calibrate a subsonic wind tunnel (and different hardware is used in the transonic and supersonic regimes), but the general philosophy will remain the same.

The resulting set of conditions is referred to as the test section operating conditions and specific parameters are identified using the subscript "ts." For example, the calibrated test section total pressure will be designated as $P_{T,ts}$. Similarly, the test section Mach number and dynamic pressure are given as M_{ts} and q_{ts}, respectively.

These results represent the flow properties at some reference location in the test section defined by the facility, typically some location on the model such as the nose or moment reference center. The results now represent the "facility final corrected" values or the facilities "best answer." The type of correction applied to these results is again completely facility dependent.

Facility final corrected refers to a few tunnel condition parameters (M, Q, P_s, U, for example) that may have various corrections applied. The corrections applied will vary by facility. For example, consider Mach number, M_{ts}. In some facilities, M_{ts} is the calibrated Mach number (Reference 1). Other facilities apply corrections for wall effects and/or buoyancy to the calibrated value and consider this the test section value. It was decided to use the same symbol for Mach number regardless of the level of corrections. This was done to maintain consistency with Reference 1 and to allow facilities to continue to use these widely implemented symbols. It is therefore the responsibility of the person using the data to understand the corrections that have been made to the test sections conditions.

Although different methods are used to determine the test section conditions depending on the facility, the relationship between the flow properties are ultimately defined by compressible flow equations. A good source for these equations can be found in Reference 2. For completeness, the primary constants used in the compressible flow equations were also listed as part of the standard nomenclature (gas constant, R, ratio of specific heats, γ, etc.). The dew point temperature and specific humidity are also included as part of the test section conditions parameters since these terms are monitored and used to correct static pressure and Mach number.

The final set of terms included as part of the test section conditions are the integrated up flow and side flow, $\theta_{FA,ts}$ and $\psi_{FA,ts}$, respectively. These terms are used to correct the model angle of attack and angle of yaw. The integrated up flow and side flow are normally determined on a test-by-test basis since their magnitudes are generally dependent on the portion of the tunnel flow which impacts the model and the model area. The up flow is generally determined by calculating the value needed to collapse the $C_{NF,bu}$ versus α_s curves obtained from upright and inverted α_s sweeps over a small α_s range. The side flow is determined in a similar manner using $C_{SF,bu}$ and β_s. When necessary (i.e., the model cannot be rolled) the flow angles can also be determined from the tunnel flow characterization data. Additional information is contained in Reference 1.

Table 1 — Test section conditions nomenclature

Computer Name	Description	Units	Publication Name
PS_SFE, I	Test section Static pressure. Facility final corrected value	Psia, kPa	$P_{S,ts}$
PT_SFE, I	Total pressure	Psia, kPa	$P_{T,ts}$
Q_SFE, I	Dynamic Pressure. Facility final corrected value	Psia, kPa	q_{ts}
TT_SFE, I	Total temperature	R, K	$T_{T,ts}$
RE_SFE, I	Reynolds Number /length x E-06	Millions ft^{-1} Millions m^{-1}	Re_{ts}
RHO_SFE, I	Density	slugs ft^{-3} kg m^{-3}	ρ_{ts}
M_SFC	Mach number, facility final corrected value		M_{ts}
TDP_SFE, I	Dew point temperature	R, K	$T_{DP,ts}$
MU_SFE, I	Viscosity	slugs ft^{-1} sec^{-1} kg m^{-1} sec^{-1}	μ_{ts}
U_SFE, I	Velocity, facility final corrected value	ft sec^{-1} m sec^{-1}	U_{ts}
UX_SFE, I UY_SFE, I UZ_SFE, I	Rectangular components of the tunnel flow velocity vector (U_{ts}) in the body axis system x-, y-, and z-directions, respectively	ft sec^{-1} m sec^{-1}	u_{ts},v_{ts},w_{ts}
THETAFA_SFC	Model integrated up flow angle, angle from the projection of the relative wind vector in the gravity axis x-z plane to the gravity x-axis	deg	$\theta_{FA,ts}$
PSIFA_SFC	Model integrated side flow angle, angle from the projection of the relative wind vector in the gravity axis x-y plane to the gravity x-axis	deg	$\psi_{FA,ts}$
TS_SFE, I	Static temperature	R, K	$T_{S,ts}$
SH_SFC	Specific humidity. Ratio of the mass of water in the air to the total mass of the air.		SH_{ts}
GAMMA_SFC	Specific heat ratio		γ_{ts}
R_SFE, I	Gas constant	ft^2 sec^{-2} R^{-1}, m^2 sec^{-2} K^{-1}	R
A_SFE, I	Speed of sound	ft sec^{-1} m sec^{-1}	a_{ts}

3 Model Axis Systems and Attitude

3.1 Axis Systems

The axis systems commonly used for describing the model attitude and/or aerodynamic coefficient data are described here. The axis systems are required in order to provide data commensurate with the type of model (i.e., aircraft, missile) being tested and the subsequent data analysis (simulation) requirements. Figure 2, which depicts the various axis systems (except for the gravity axis system), is provided to show the relationship of the axis systems. Note that all of the axis systems presented are right-handed orthogonal axis systems. Reference 3 was used in the development of this section.

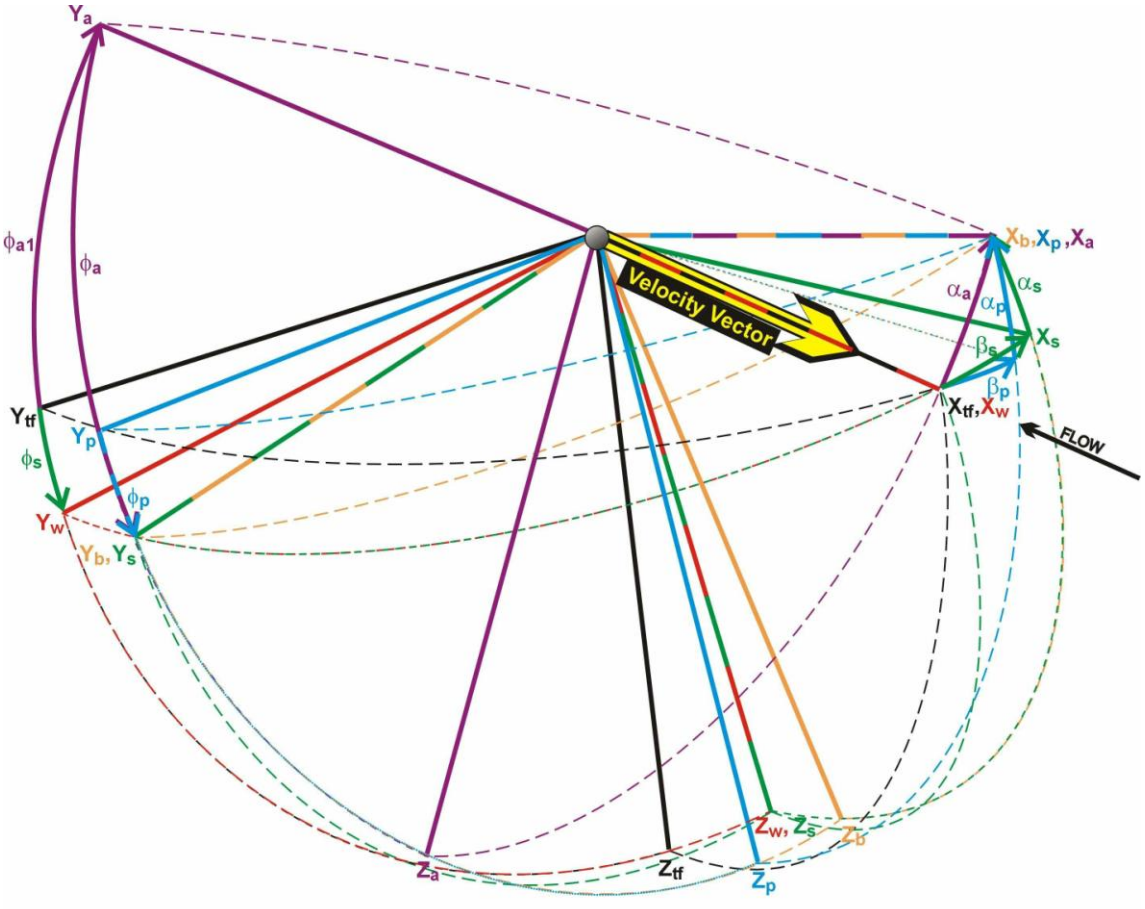


Figure 2 — All axis systems

3.2 Gravity Axis System

The gravity axis system is an Earth fixed axis system, which has its z-direction, aligned with the gravity vector. The origin is located at the model moment reference center. The axes are X_g, Y_g, and Z_g and are defined in Table 2.

3.3 Tunnel Flow Axis System

The tunnel flow axis system is a flow-oriented axis system that has its x-axis aligned with the total velocity vector and its origin at the model moment reference center. The orientation of the tunnel flow axis system is described by the rotations $-\theta_{FA,ts}$ and $-\psi_{FA,ts}$ about the gravity axis system y- and z-axes, respectively. The axes are X_{tf}, Y_{tf}, and Z_{tf} and are defined in Table 2.

3.4 Body, Stability, and Wind Axis Systems

These axis systems are primarily used with an aircraft model. The origins of the systems are located at the model moment reference center. The orientation of the axis systems is determined through a roll-yaw-pitch series of rotations. Begin with all three axis systems coincident with the tunnel flow axis system. Then roll all three axis systems through the angle ϕ_s about the tunnel flow x-axis. Next, the body and stability axis systems are yawed, by $-\beta_s$, about the wind z-axis (note that β_s = –yaw angle). Finally the body axis system is pitched, by α_s, about the stability y-axis. A graphical depiction of the orientations and rotations of the tunnel flow, wind, stability, and body axis systems is shown in Figure 3. The axes for the body, stability, and wind axis systems are respectively; X_b, Y_b, Z_b; X_s, Y_s, Z_s; and X_w, Y_w, Z_w and are defined in Table 2.

3.5 Aeroballistic Axis System

In a wind tunnel, a model may be positioned using the aeroballistic axis system angles by rotating through a roll-pitch-roll sequence and the origin of the system is located at the model moment reference center. The orientation of the aeroballistic axis system is described in relation to the tunnel flow and body axis systems. Begin with the body and aeroballistic axis systems coincident with the tunnel flow axis system. Then roll the body and aeroballistic axis systems through the angle ϕ_{a1} about the tunnel flow x-axis. Next, pitch the body and aeroballistic axis systems through the angle α_a about the aeroballistic y-axis. Finally, the body axis system is rolled through the angle ϕ_a about the aeroballistic x-axis. A graphical depiction of the orientation and rotations of the aeroballistic axis system to the tunnel flow and body axis systems is shown in Figure 4. The aeroballistic axes are X_a, Y_a, and Z_a and are defined in Table 2.

The aeroballistic axis system was most likely developed for use with bodies of revolution since the system allows for only positive values of α_a. This is unique to the aeroballistic axis system and provides for an interesting phenomenon. As the model is pitched through zero α_a the axis system instantaneously rotates 180 degrees about its x-axis to keep the aeroballistic z-axis in the correct orientation. At the same instant, the body axis system must also rotate 180 degrees about its x-axis in order to maintain the same value of ϕ_a.

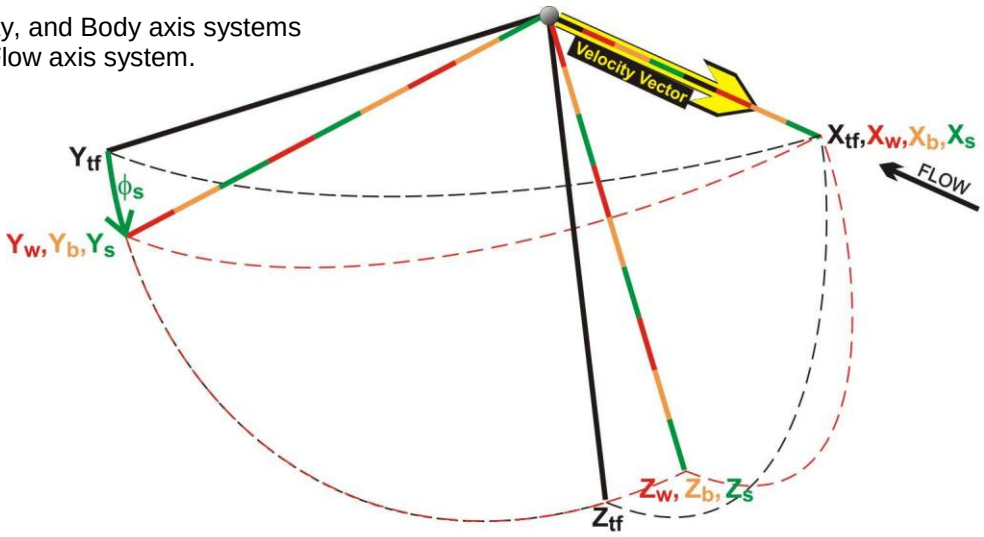
3.6 Missile Axis System

To position the model using the missile axis system, a yaw-pitch-roll sequence of rotations must be undertaken. As for the other axis systems, the origin of the missile axis system is located at the model moment reference center (MRC). The orientation of the missile axis system is described in relation to the tunnel flow and body axis systems. Begin with the body and missile axis systems coincident with the tunnel flow axis system. Then yaw the missile and body axis systems through the angle $-\beta_p$ about the tunnel flow z-axis. Next, pitch the missile and body axis system by α_p about the missile y-axis. Finally, roll the body axis system by ϕ_p about the missile axis x-axis. A graphical depiction of the orientation and rotations of the missile axis system to the tunnel flow and body axis systems is shown in Figure 5. The missile axes are X_p, Y_p, and Z_p and are defined in Table 2.

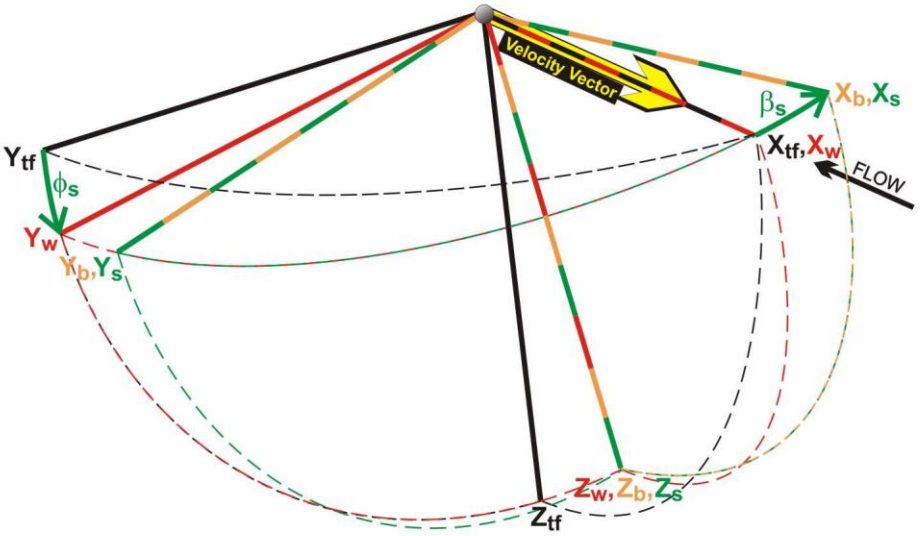
As described, the missile axis system rotates with the model through yaw and pitch rotations only. This makes the body and missile axes coincident when ϕ_s and ϕ_p are both equal to zero. This feature has led to the missile axis system being called the “non-rolling body axis system.”

Begin with the Wind, Stability, and Body axis systems coincident with the Tunnel Flow axis system.

First, **roll** the Wind, Stability, and Body axis systems about the Tunnel Flow X-axis by ϕ_s.



Next, **yaw** the Stability and Body axis systems about the Wind z-axis by β_s. (-yaw rotation shown)



Finally, **pitch** the Body axis system about the Stability y-axis by α_s.

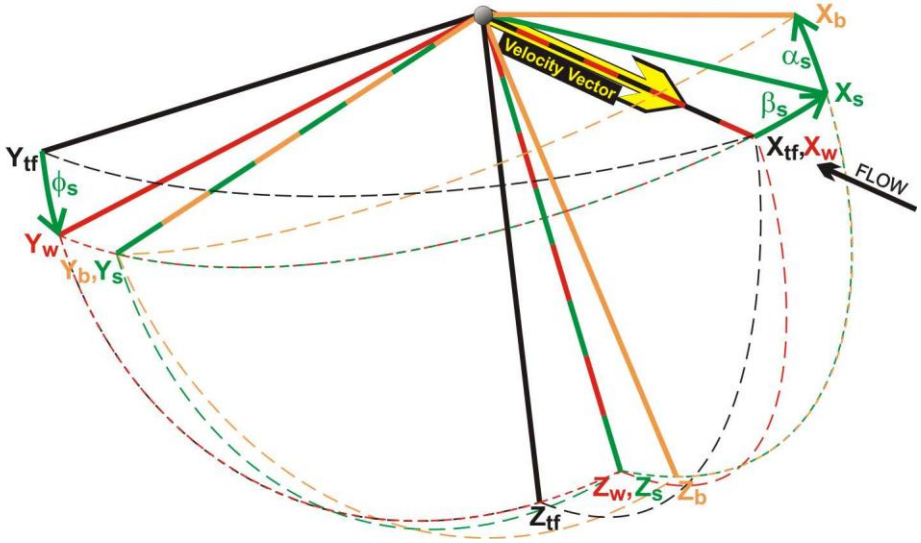


Figure 3 — Tunnel flow, body, stability, and wind axis systems

Begin with the Aeroballistic and Body axis systems coincident with the Tunnel Flow axis system.

First, **roll** the Aeroballistic and Body axis systems about the Body X-axis by ϕ_{a1}. (- ϕ_{a1} rotation shown)

Next, **pitch** the Aeroballistic and Body axis systems about Body Y-axis by α_a.

Finally, **roll** the Body axis system about the Body X-axis by ϕ_a.

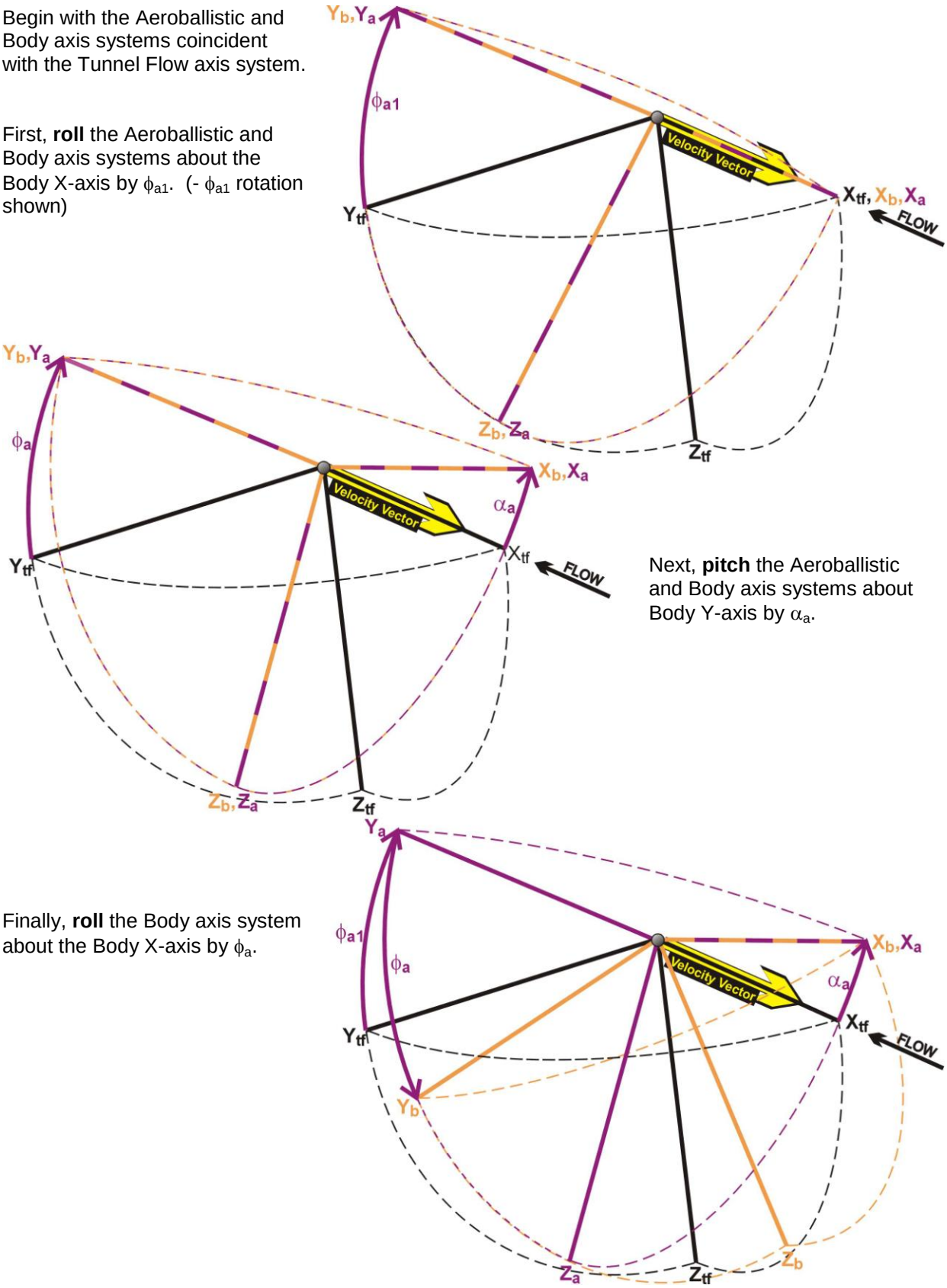


Figure 4 — Tunnel flow, body, and aeroballistic axis systems

Begin with the Missile and Body axis systems coincident with the Tunnel Flow axis system.

First, **yaw** the Missile and Body axis systems about the Body Z-axis by β_p. (– yaw rotation shown)

Next, **pitch** the Missile and Body axis systems about the Body Y-axis by α_p.

Finally, **roll** the Body axis system about the Body X-axis by ϕ_p.

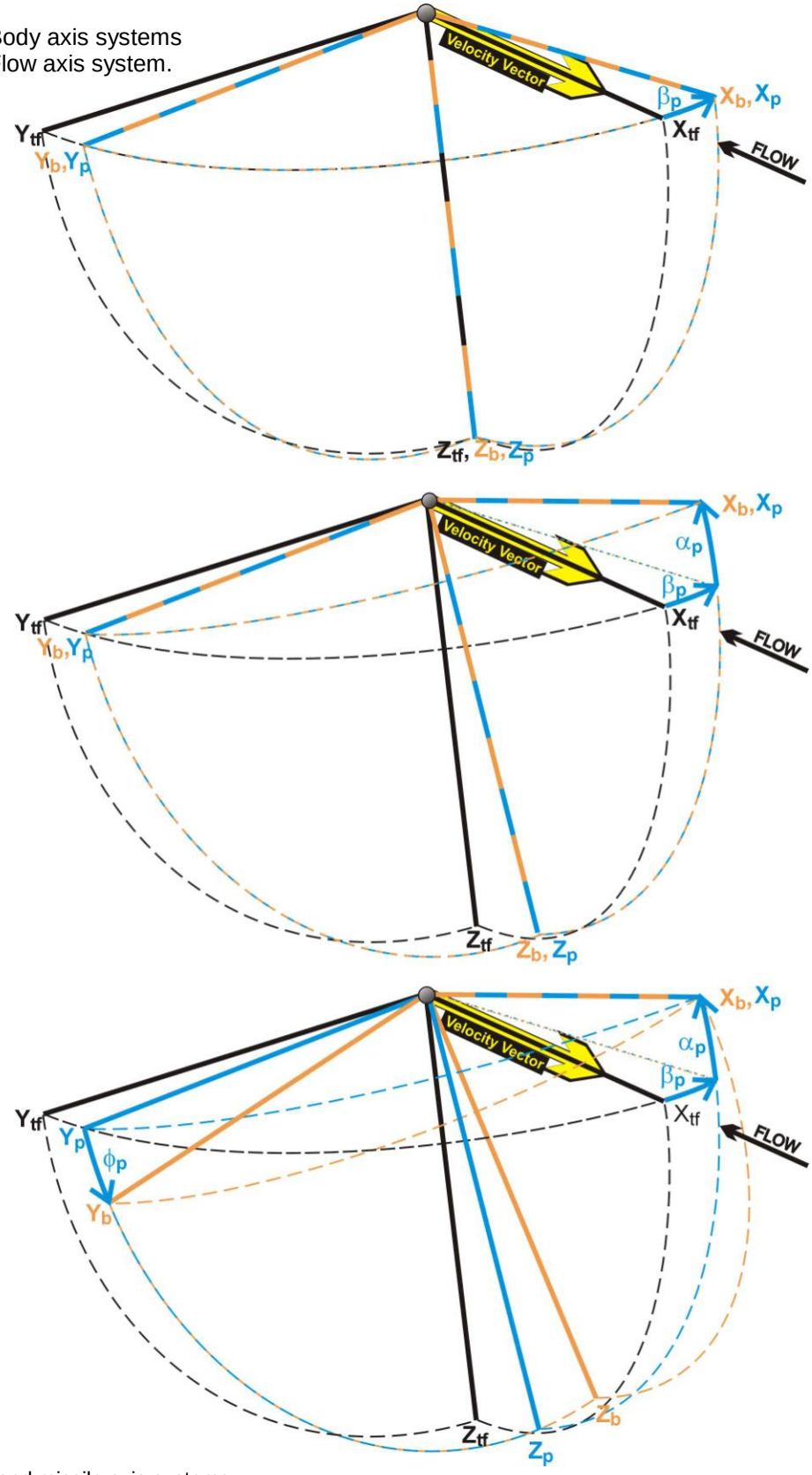


Figure 5 — Tunnel flow, body, and missile axis systems

3.7 Axis System Rotations

Before the model attitude angles for each axis system can be defined, the method used to determine the attitudes must be explained. The model attitudes are determined by a system of rotation angles that make up the model attitude angles. Typical of these angles are the sector (pitch and roll, pitch and yaw, etc.), sting installation, sting and balance deflections, balance to model alignment, and flow angles. This includes instances where the model attitude is measured by onboard instrumentation or with photogrametric methods, as these methods measure the attitude relative to some reference axis system, which must at least be rotated into the tunnel flow axis system. Each rotation of orthogonal axis systems is described by a pitch, yaw, or roll rotation. The equations for each of these rotations are listed below. An illustration is included to show the necessary sign conventions and the matrix derivations. The order in which the rotations are performed is important as is shown in Figure 6.

Pitch Rotation:

$$
\begin{aligned}
X' &= X\cos(\text{PITCH}) + Y(0) - Z\sin(\text{PITCH}) \\
Y' &= X(0) + Y(1) + Z(0) \\
Z' &= X\sin(\text{PITCH}) + Y(0) + Z\cos(\text{PITCH})
\end{aligned}
$$

$$
\left[M_{\text{PITCH}}\right] = \begin{bmatrix} \cos(\text{PITCH}) & 0 & -\sin(\text{PITCH}) \\ 0 & 1 & 0 \\ \sin(\text{PITCH}) & 0 & \cos(\text{PITCH}) \end{bmatrix}
$$

Yaw Rotation:

$$
\begin{aligned}
X' &= X\cos(\text{YAW}) + Y\sin(\text{YAW}) + Z(0) \\
Y' &= -X\sin(\text{YAW}) + Y\cos(\text{YAW}) + Z(0) \\
Z' &= X(0) + Y(0) + Z(1)
\end{aligned}
$$

$$
\left[M_{\text{YAW}}\right] = \begin{bmatrix} \cos(\text{YAW}) & \sin(\text{YAW}) & 0 \\ -\sin(\text{YAW}) & \cos(\text{YAW}) & 0 \\ 0 & 0 & 1 \end{bmatrix}
$$

Roll Rotation:

$$
\begin{aligned}
X' &= X(1) + Y(0) + Z(0) \\
Y' &= X(0) + Y\cos(\text{ROLL}) + Z\sin(\text{ROLL}) \\
Z' &= X(0) - Y\sin(\text{ROLL}) + Z\cos(\text{ROLL})
\end{aligned}
$$

$$
\left[M_{\text{ROLL}}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\text{ROLL}) & \sin(\text{ROLL}) \\ 0 & -\sin(\text{ROLL}) & \cos(\text{ROLL}) \end{bmatrix}
$$

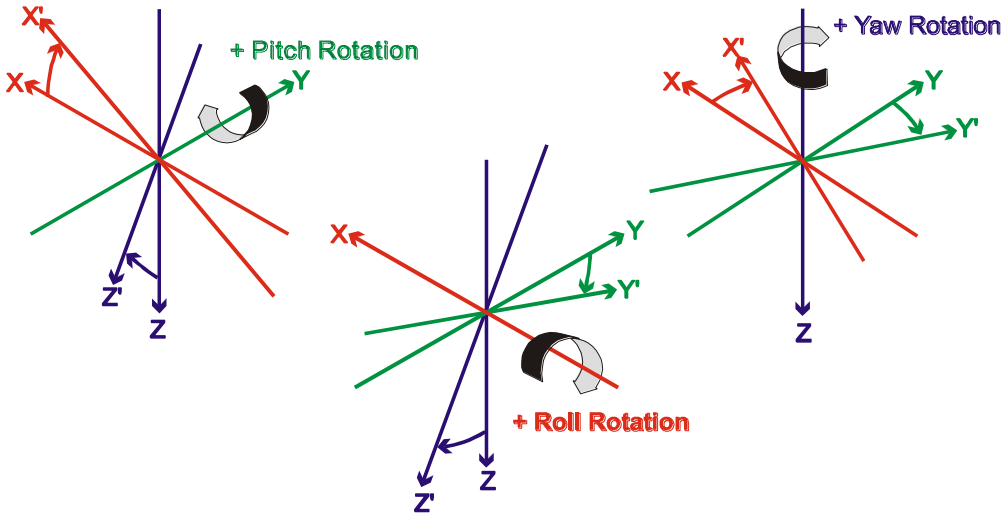


Figure 6 illustrates the effects of three rotation sequences each containing a 90 deg. pitch, 90 deg. yaw and -90 deg. roll rotation. In each rotation sequence the model starts in the same attitude. However, after making the three rotations the model ends in very different orientations.

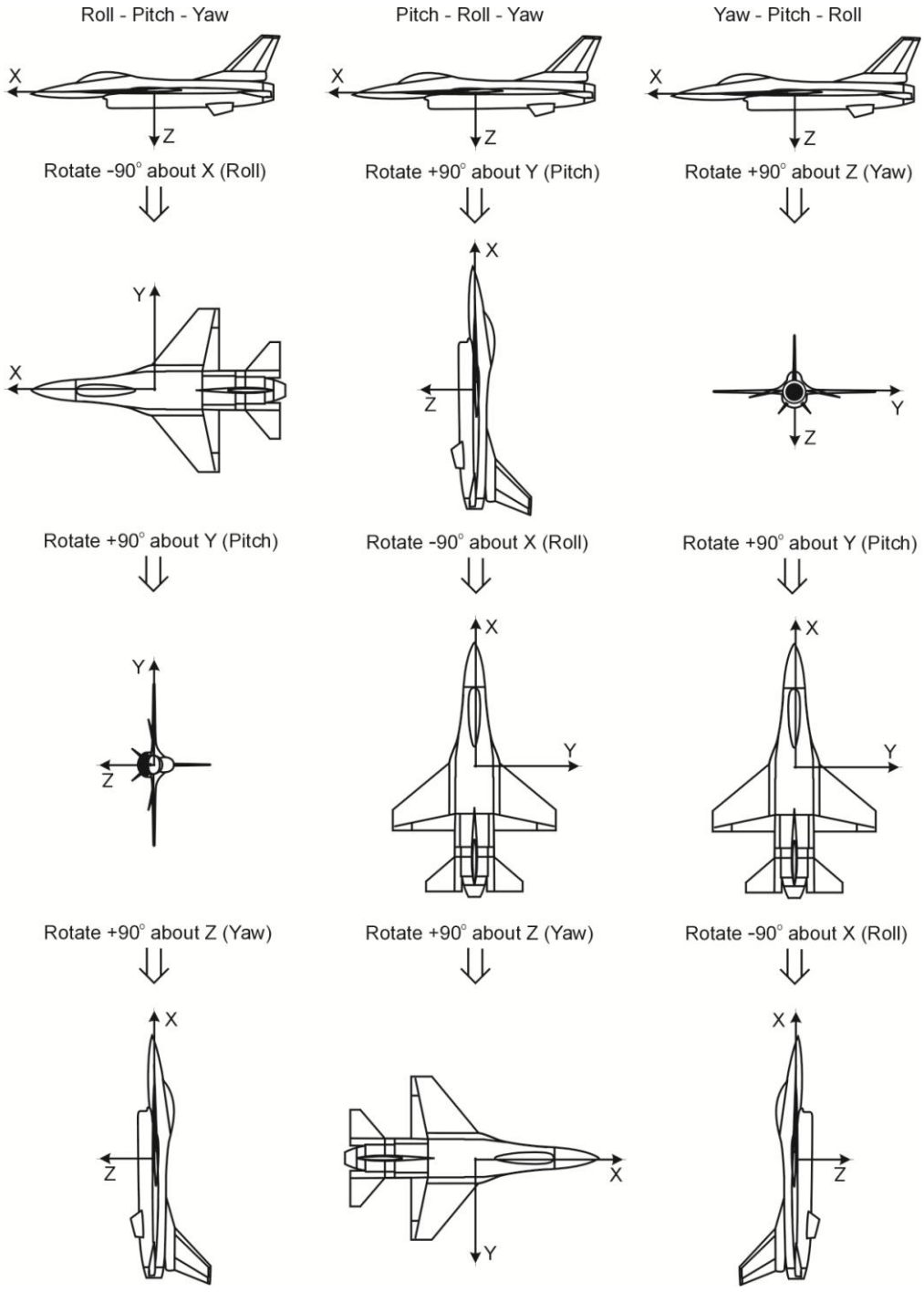


Figure 6 — Effect of rotation order

A typical axis system rotation that, for example, transforms a system of vectors from the balance axis system to the body axis system may be written as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{BODY} = \left(M_{\theta_{bal\text{-}m}} \right) \left(M_{\psi_{bal\text{-}m}} \right) \left(M_{\phi_{bal\text{-}m}} \right) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{BALANCE}$$

3.8 Model Attitude

The systems of model attitude angles are summarized below:

System	Rotation Order	Nomenclature
Stability	Roll-Yaw-Pitch	ϕ_s, $-\beta_s$, α_s
Missile	Yaw-Pitch-Roll	$-\beta_p$, α_p, ϕ_p
Aeroballistic	Roll-Pitch-Roll	ϕ_{a1}, α_a, ϕ_a

Because all of the model attitude angles are referenced to the tunnel flow axis system, the rotation sequences must all start with the model body axis aligned with the tunnel flow axis. For example, the typical matrix equations for the model attached to balance 1 may be written in the abbreviated matrix notation as follows:

$$\begin{bmatrix} M11, M12, M13 \\ M21, M22, M23 \\ M31, M32, M33 \end{bmatrix} = \left(M\ \theta_{bal\text{-}m}, \psi_{bal\text{-}m}, \phi_{bal\text{-}m}, \ldots, \theta_{FA,ts}, \psi_{FA,ts} \right) \quad (3.1)$$

Note that the previous sequence does not contain the facility model support system angles, deflection of the sting produced by its weight, sting installation angles, and sting/balance deflection angles, etc.

Matrix algebra operations require that the rotation matrices be placed in the equation from right to left in accordance with the order in which each rotation occurs. The flow angularities must generally be accounted for first because the tunnel flow axis must be rotated through these angles to be aligned with the system in which the model support mechanism angles are referenced (generally the gravity axis).

The terms M11 through M33 describe the orientation of the model in terms of the individual rotation angles. However, it should be noted that if the unit (normalized) velocity vector, $\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$, was multiplied by the right-hand side of Eq. (3.1), then the terms M11, M21, and M31 are the rectangular components of the unit velocity vector, $\left(\frac{u_{ts}}{U_{ts}} \right)$, $\left(\frac{v_{ts}}{U_{ts}} \right)$, and $\left(\frac{w_{ts}}{U_{ts}} \right)$, respectively. Because of this the M matrix is referred to as the Velocity Vector Component matrix.

3.9 Stability Axis System Angles

The stability, wind, and body axis systems all employ the stability axis system reference angles for describing the model attitude with respect to the total velocity vector. The model attitude is determined by rotating the model through a roll-yaw-pitch sequence. The roll, yaw, and pitch rotations are represented by the angles ϕ_s, $-\beta_s$, and α_s, respectively. However, the roll angle only orients the model relative to gravity and is of no aerodynamic importance in free flight or in the wind tunnel (assuming tunnel flow angles are properly accounted for). A vehicle's aerodynamic attitude is therefore totally described by the angles α_s and β_s.

In matrix form, the rotation sequence is:

$$\left[M_{\alpha_s}\right] \qquad \left[M_{-\beta_s}\right] \qquad \left[M_{\phi_s}\right]$$

Where

$$\left[M_{\alpha_s}\right] = \begin{bmatrix} \text{Cos}(\alpha_s) & 0 & -\text{Sin}(\alpha_s) \\ 0 & 1 & 0 \\ \text{Sin}(\alpha_s) & 0 & \text{Cos}(\alpha_s) \end{bmatrix} \tag{3.2}$$

$$\left[M_{-\beta_s}\right] = \begin{bmatrix} \text{Cos}(-\beta_s) & \text{Sin}(-\beta_s) & 0 \\ -\text{Sin}(-\beta_s) & \text{Cos}(-\beta_s) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.3}$$

$$\left[M_{\phi_s}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{Cos}(\phi_s) & \text{Sin}(\phi_s) \\ 0 & -\text{Sin}(\phi_s) & \text{Cos}(\phi_s) \end{bmatrix} \tag{3.4}$$

Multiplying these matrices together in the proper order results in the following matrix:

$$\left[M_{\alpha_s, -\beta_s, \phi_s}\right] = \begin{bmatrix} C(\alpha_s)C(\beta_s) & S(\alpha_s)S(\phi_s) - C(\alpha_s)S(\beta_s)C(\phi_s) & -C(\alpha_s)S(\beta_s)S(\phi_s) - S(\alpha_s)C(\phi_s) \\ S(\beta_s) & C(\beta_s)C(\phi_s) & C(\beta_s)s(\phi_s) \\ S(\alpha_s)C(\beta_s) & -S(\alpha_s)S(\beta_s)C(\phi_s) - C(\alpha_s)S(\phi_s) & C(\alpha_s)C(\phi_s) - S(\alpha_s)S(\beta_s)S(\phi_s) \end{bmatrix} \tag{3.5}$$

Where S( ) and C( ) represent the Sin( ) and Cos( ), respectively.

This matrix is the stability axis model attitude angle matrix. Because the Velocity Vector Component matrix and the model attitude angle matrix both describe the position of the model, they can be set equal to each other and used to derive the expressions required to calculate the model attitude angles. For two matrices to be equal, each term of one matrix must be equal to the corresponding term in the other matrix. These two 3x3 matrices yield the following nine equations:

$$M11 = \left(\frac{u_{ts}}{U_{ts}}\right) = \text{Cos}(\alpha_s)\,\text{Cos}(\beta_s) \tag{3.6}$$

$$M21 = \left(\frac{v_{ts}}{U_{ts}}\right) = \text{Sin}(\beta_s) \tag{3.7}$$

$$M31 = \left(\frac{w_{ts}}{U_{ts}}\right) = \text{Sin}(\alpha_s)\,\text{Cos}(\beta_s) \tag{3.8}$$

$$M12 = \text{Sin}(\alpha_s)\,\text{Sin}(\phi_s) - \text{Cos}(\alpha_s)\,\text{Sin}(\beta_s)\,\text{Cos}(\phi_s) \tag{3.9}$$

$$M22 = \text{Cos}(\beta_s)\,\text{Cos}(\phi_s) \tag{3.10}$$

$$M32 = -\,\text{Sin}(\alpha_s)\,\text{Sin}(\beta_s)\,\text{Cos}(\phi_s) - \text{Cos}(\alpha_s)\,\text{Sin}(\phi_s) \tag{3.11}$$

$$M13 = -\,\text{Cos}(\alpha_s)\,\text{Sin}(\beta_s)\,\text{Sin}(\phi_s) - \text{Sin}(\alpha_s)\,\text{Cos}(\phi_s) \tag{3.12}$$

$$M23 = \text{Cos}(\beta_s)\,\text{Sin}(\phi_s) \tag{3.13}$$

$$M33 = \text{Cos}(\alpha_s)\,\text{Cos}(\phi_s) - \text{Sin}(\alpha_s)\,\text{Sin}(\beta_s)\,\text{Sin}(\phi_s) \tag{3.14}$$

The results of solving these equations for ϕ_s, β_s, and α_s are:

$$\phi_s = \text{ATan2}\left(\frac{M23}{M22}\right) \tag{3.15}$$

$$\beta_s = \text{ASin}\left(\frac{v_{ts}}{U_{ts}}\right) \tag{3.16}$$

$$\text{IF } M22 / \text{Cos}(\phi_s) < 0;\ \beta_s = -\text{ASin}\left(\frac{v_{ts}}{U_{ts}}\right) + 180\left(\left(\frac{v_{ts}}{U_{ts}}\right) \Big/ \left|\left(\frac{v_{ts}}{U_{ts}}\right)\right|\right) \tag{3.17}$$

$$\alpha_s = \text{ATan2}\left(\frac{w_{ts}}{u_{ts}}\right) \tag{3.18}$$

Equation (3.17) is necessary because Equation (3.16) can only determine angles between ±90 deg. Equation (3.17) will provide the correct value and sign when $|\beta_s| > 90$ deg.

The equations make use of the double-argument inverse tangent function ATAN2. The ATAN2 function is used because it is always defined and determines the correct quadrant as well as the correct sign of the angle. The ATAN2 function is defined as:

X	Y	Quadrant	Resulting Function
+	+	1	ATAN(Y/X)
–	+	2	ATAN(Y/X) + 180
–	–	3	ATAN(Y/X) - 180
+	–	4	ATAN(Y/X)
0	+	+Y Axis	90 deg
0	–	–Y Axis	–90 deg
+	0	+X Axis	0 deg
–	0	–X Axis	180 deg
0	0	Origin	0 deg

3.10 Aeroballistic Axis System Angles

The model is positioned in the aeroballistic axis system through a roll, pitch, roll rotation sequence. These angles are defined to be ϕ_{a1}, α_a, and ϕ_a, respectively. The first roll angle, ϕ_{a1}, like the stability axis system roll angle, only orients the model pitch plane relative to gravity and is of no aerodynamic importance in free flight or in a wind tunnel (assuming tunnel flow angles are properly accounted for). A model's aerodynamic attitude is therefore totally described by two angles, α_a, and ϕ_a. It should be noted that the aerodynamic roll angle ϕ_a is undefined when the total angle of attack α_a is identically zero.

In matrix form the rotation sequence is:

$$\left[M_{\phi_a}\right] \qquad \left[M_{\alpha_a}\right] \qquad \left[M_{\phi_{a1}}\right]$$

Where:

$$\left[M_{\phi_a}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{Cos}(\phi_a) & \text{Sin}(\phi_a) \\ 0 & -\text{Sin}(\phi_a) & \text{Cos}(\phi_a) \end{bmatrix} \tag{3.19}$$

$$\left[M_{\alpha_a}\right] = \begin{bmatrix} \text{Cos}(\alpha_a) & 0 & -\text{Sin}(\alpha_a) \\ 0 & 1 & 0 \\ \text{Sin}(\alpha_a) & 0 & \text{Cos}(\alpha_a) \end{bmatrix} \tag{3.20}$$

$$\left[M_{\phi_{a1}}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{Cos}(\phi_{a1}) & \text{Sin}(\phi_{a1}) \\ 0 & -\text{Sin}(\phi_{a1}) & \text{Cos}(\phi_{a1}) \end{bmatrix} \tag{3.21}$$

Multiplying these matrices together in the proper order results in the following matrix:

$$\left[M_{\phi_a,\,\alpha_a,\,\phi_{a1}}\right] = \begin{bmatrix} \text{C}(\alpha_a) & \text{S}(\alpha_a)\text{S}(\phi_{a1}) & -\text{S}(\alpha_a)\text{C}(\phi_{a1}) \\ \text{S}(\phi_a)\text{S}(\alpha_a) & \text{C}(\phi_a)\text{C}(\phi_{a1}) - \text{S}(\phi_a)\text{C}(\alpha_a)\text{S}(\phi_{a1}) & \text{C}(\phi_a)\text{S}(\phi_{a1}) - \text{S}(\phi_a)\text{C}(\alpha_a)\text{C}(\phi_{a1}) \\ \text{C}(\phi_a)\text{S}(\alpha_a) & -\text{S}(\phi_a)\text{C}(\phi_{a1}) - \text{C}(\phi_a)\text{C}(\alpha_a)\text{S}(\phi_{a1}) & -\text{S}(\phi_a)\text{S}(\phi_{a1}) + \text{C}(\phi_a)\text{C}(\alpha_a)\text{C}(\phi_{a1}) \end{bmatrix} \tag{3.22}$$

Where S( ) and C( ) represent the Sin( ) and Cos( ), respectively.

This matrix is the aeroballistic axis model attitude angle matrix. Setting the Velocity Vector Component matrix and the aeroballistic axis model attitude angle matrix equal results in the following equations:

$$\text{M11} = \left(\frac{u_{ts}}{U_{ts}}\right) = \text{Cos}(\alpha_a) \tag{3.23}$$

$$\text{M21} = \left(\frac{v_{ts}}{U_{ts}}\right) = \text{Sin}(\phi_a)\,\text{Sin}(\alpha_a) \tag{3.24}$$

$$\text{M31} = \left(\frac{w_{ts}}{U_{ts}}\right) = \text{Cos}(\phi_a)\,\text{Sin}(\alpha_a) \tag{3.25}$$

$$\text{M12} = \text{Sin}(\alpha_a)\,\text{Sin}(\phi_{a1}) \tag{3.26}$$

$$\text{M22} = \text{Cos}(\phi_a)\,\text{Cos}(\phi_{a1}) - \text{Sin}(\phi_a)\,\text{Cos}(\alpha_a)\,\text{Sin}(\phi_{a1}) \tag{3.27}$$

$$\text{M32} = -\,\text{Sin}(\phi_a)\text{Cos}(\phi_{a1}) - \text{Cos}(\phi_a)\,\text{Cos}(\alpha_a)\,\text{Sin}(\phi_{a1}) \tag{3.28}$$

$$\text{M13} = -\,\text{Sin}(\alpha_a)\,\text{Cos}(\phi_{a1}) \tag{3.29}$$

$$\text{M23} = \text{Cos}(\phi_a)\,\text{Sin}(\phi_{a1}) + \text{Sin}(\phi_a)\,\text{Cos}(\alpha_a)\,\text{Cos}(\phi_{a1}) \tag{3.30}$$

$$\text{M33} = -\,\text{Sin}(\phi_a)\text{Sin}(\phi_{a1}) + \text{Cos}(\phi_a)\,\text{Cos}(\alpha_a)\,\text{Cos}(\phi_{a1}) \tag{3.31}$$

The results of solving these equations for α_a, ϕ_a, and ϕ_{a1} are:

$$\phi_{a1} = \text{ATan2}\left(\frac{\text{M12}}{-\text{M13}}\right) \tag{3.32}$$

$$\alpha_a = \text{ACos}\left(\frac{u_{ts}}{U_{ts}}\right) \tag{3.33}$$

$$\phi_a = \text{ATan2}\left(\frac{v_{ts}}{w_{ts}}\right) \tag{3.34}$$

3.11 Missile Axis System Angles

The model is positioned in the missile axis system through a yaw, pitch, roll rotation sequence. These angles are defined to be $-\beta_p$, α_p, and ϕ_p, respectively. Unlike the body, stability, wind, and aeroballistic axis systems all three angles are necessary to define the model's aerodynamic attitude in the missile axis system. Also for the previously discussed axis systems any direction could be taken as a positive pitch direction because a roll rotation occurs prior to the pitch rotation. However, because the pitch rotation in the missile axis system occurs before the roll rotation, a positive rotation about the yawed (by $-\beta_p$) missile y-axis is the only positive pitch direction.

It should also be noted that for a two-degree-of-freedom support system, only two of the three angles may be controlled with the third being determined by the two controlled angles and the installation. The use of a pitch/roll system to position the model results in controlling the angles α_p and ϕ_p with β_p being determined by α_p, ϕ_p, and installation angles, deflections, and misalignments. In other words, specific values of α_p and ϕ_p can be set, but the value β_p could change with each new set of values input for the control angles. Similar limitations will apply to pitch/yaw and double roll/pitch system or for that matter any tunnel model attitude control system other than a yaw, pitch, roll system.

In matrix form the rotation sequence is:

$$\left[M_{\phi_p}\right] \qquad \left[M_{\alpha_p}\right] \qquad \left[M_{-\beta_p}\right]$$

Where:

$$\left[M_{\phi_p}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{Cos}(\phi_p) & \text{Sin}(\phi_p) \\ 0 & -\text{Sin}(\phi_p) & \text{Cos}(\phi_p) \end{bmatrix} \tag{3.35}$$

$$\left[M_{\alpha_p}\right] = \begin{bmatrix} \text{Cos}(\alpha_p) & 0 & -\text{Sin}(\alpha_p) \\ 0 & 1 & 0 \\ \text{Sin}(\alpha_p) & 0 & \text{Cos}(\alpha_p) \end{bmatrix} \tag{3.36}$$

$$\left[M_{-\beta_p}\right] = \begin{bmatrix} \text{Cos}(-\beta_p) & \text{Sin}(-\beta_p) & 0 \\ -\text{Sin}(-\beta_p) & \text{Cos}(-\beta_p) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.37}$$

Multiplying these matrices together in the proper order results in the following matrix:

$$\left[M_{\phi_p,\,\alpha_p,\,-\beta_p}\right] = \begin{bmatrix} \text{C}(\alpha_p)\text{C}(\beta_p) & -\text{C}(\alpha_p)\text{S}(\beta_p) & -\text{S}(\alpha_p) \\ \text{C}(\phi_p)\text{S}(\beta_p) + \text{S}(\phi_p)\text{S}(\alpha_p)\text{C}(\beta_p) & \text{C}(\phi_p)\text{C}(\beta_p) - \text{S}(\phi_p)\text{S}(\alpha_p)\text{S}(\beta_p) & \text{S}(\phi_p)\text{C}(\alpha_p) \\ \text{C}(\phi_p)\text{S}(\alpha_p)\text{C}(\beta_p) - \text{S}(\phi_p)\text{S}(\beta_p) & -\text{S}(\phi_p)\text{C}(\beta_p) - \text{C}(\phi_p)\text{S}(\alpha_p)\text{S}(\beta_p) & \text{C}(\phi_p)\text{C}(\alpha_p) \end{bmatrix} \tag{3.38}$$

Where S( ) and C( ) represent the Sin( ) and Cos( ), respectively.

This matrix is the missile axis model attitude angle matrix. Setting the Velocity Vector Component matrix and the missile axis model attitude angle matrix equal results in the following equations:

$$\text{M11} = \left(\frac{u_{ts}}{U_{ts}}\right) = \text{Cos}(\alpha_p)\text{Cos}(\beta_p) \tag{3.39}$$

$$\text{M21} = \left(\frac{v_{ts}}{U_{ts}}\right) = \text{Cos}(\phi_p)\text{Sin}(\beta_p) + \text{Sin}(\phi_p)\text{Sin}(\alpha_p)\text{Cos}(\beta_p) \tag{3.40}$$

$$M31 = \left(\frac{w_{ts}}{U_{ts}}\right) = \text{Cos}(\phi_p)\text{Sin}(\alpha_p)\text{Cos}(\beta_p) - \text{Sin}(\phi_p)\text{Sin}(\beta_p) \tag{3.41}$$

$$M12 = -\text{Cos}(\alpha_p)\text{Sin}(\beta_p) \tag{3.42}$$

$$M22 = \text{Cos}(\phi_p)\text{Cos}(\beta_p) - \text{Sin}(\phi_p)\text{Sin}(\alpha_p)\text{Sin}(\beta_p) \tag{3.43}$$

$$M32 = -\text{Sin}(\phi_p)\text{Cos}(\beta_p) - \text{Cos}(\phi_p)\text{Sin}(\alpha_p)\text{Sin}(\beta_p) \tag{3.44}$$

$$M13 = -\text{Sin}(\alpha_p) \tag{3.45}$$

$$M23 = \text{Sin}(\phi_p)\text{Cos}(\alpha_p) \tag{3.46}$$

$$M33 = \text{Cos}(\phi_p)\text{Cos}(\alpha_p) \tag{3.47}$$

The results of solving these equations for α_p, β_p, and ϕ_p are:

$$\phi_p = \text{ATan2}\left(\frac{M23}{M33}\right) \tag{3.48}$$

$$\alpha_p = \text{ASin}(-M13) \tag{3.49}$$

$$\text{IF}\left(\frac{u_{ts}}{U_{ts}}\right) \Big/ \text{Cos}(\beta_p) < 0 \; ; \; \alpha_p = -\text{ASin}(M13) - 180\left(\frac{M13}{|M13|}\right) \tag{3.50}$$

$$\beta_p = -\text{ATan2}\left(\frac{M12}{M11}\right) \tag{3.51}$$

Equation (3.50) is necessary because Eq. (3.49) can only determine angles between ±90 deg. Equation (3.50) will provide the correct value and sign when $|\alpha_p| > 90$ deg.

3.12 Balance Attitude

The attitude of any balance is required during the checkout phase of the installation and to account for the effects of the model/balance weight and cg. The balance attitude matrix for balance n is defined as

$$\begin{bmatrix} B11, B12, B13 \\ B21, B22, B23 \\ B31, B32, B33 \end{bmatrix} = \left[M_{\text{Facility defined angles comprising the balance attitude for balance n}} \right] \tag{3.52}$$

The balance attitude angles are defined as a yaw, pitch, roll sequence of rotations. In matrix form these rotations are

$$\left[B_{\phi_{bal}}\right] \qquad \left[B_{\theta_{bal}}\right] \qquad \left[B_{\psi_{bal}}\right]$$

Where:

$$\left[B_{\phi_{bal}}\right] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{Cos}(\phi_{bal}) & \text{Sin}(\phi_{bal}) \\ 0 & -\text{Sin}(\phi_{bal}) & \text{Cos}(\phi_{bal}) \end{bmatrix} \tag{3.53}$$

$$\left[B_{\theta_{bal}}\right] = \begin{bmatrix} \text{Cos}(\theta_{bal}) & 0 & -\text{Sin}(\theta_{bal}) \\ 0 & 1 & 0 \\ \text{Sin}(\theta_{bal}) & 0 & \text{Cos}(\theta_{bal}) \end{bmatrix} \tag{3.54}$$

$$\left[B_{\psi_{bal}}\right] = \begin{bmatrix} \text{Cos}(\psi_{bal}) & \text{Sin}(\psi_{bal}) & 0 \\ -\text{Sin}(\psi_{bal}) & \text{Cos}(\psi_{bal}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.55}$$

Multiplying these matrices together in the proper order results in the following matrix:

$$\left[B_{\phi_{bal},\,\theta_{bal},\,\psi_{bal}}\right] =$$

$$\begin{bmatrix} C(\theta_{bal})C(\psi_{bal}) & C(\theta_{bal})S(\psi_{bal}) & -S(\theta_{bal}) \\ S(\phi_{bal})S(\theta_{bal})C(\psi_{bal}) - C(\phi_{bal})S(\psi_{bal}) & C(\phi_{bal})C(\psi_{bal}) + S(\phi_{bal})S(\theta_{bal})S(\psi_{bal}) & S(\phi_{bal})C(\theta_{bal}) \\ S(\phi_{bal})S(\psi_{bal}) + C(\phi_{bal})S(\theta_{bal})C(\psi_{bal}) & C(\phi_{bal})S(\theta_{bal})S(\psi_{bal}) - S(\phi_{bal})C(\psi_{bal}) & C(\theta_{bal})C(\phi_{bal}) \end{bmatrix} \tag{3.56}$$

Where S( ) and C( ) represent the Sin( ) and Cos( ), respectively.

This matrix is the balance angle matrix. Setting the balance angle matrix and the balance attitude angle matrix equal results in the following equations:

$$B11 = \text{Cos}(\theta_{bal})\text{Cos}(\psi_{bal}) \tag{3.57}$$

$$B21 = \text{Sin}(\phi_{bal})\text{Sin}(\theta_{bal})\text{Cos}(\psi_{bal}) - \text{Cos}(\phi_{bal})\text{Sin}(\psi_{bal}) \tag{3.58}$$

$$B31 = \text{Sin}(\phi_{bal})\text{Sin}(\psi_{bal}) + \text{Cos}(\phi_{bal})\text{Sin}(\theta_{bal})\text{Cos}(\psi_{bal}) \tag{3.59}$$

$$B12 = \text{Cos}(\theta_{bal})\text{Sin}(\psi_{bal}) \tag{3.60}$$

$$B22 = \text{Cos}(\phi_{bal})\text{Cos}(\psi_{bal}) + \text{Sin}(\phi_{bal})\text{Sin}(\theta_{bal})\text{Sin}(\psi_{bal}) \tag{3.61}$$

$$B32 = \text{Cos}(\phi_{bal})\text{Sin}(\theta_{bal})\text{Sin}(\psi_{bal}) - \text{Sin}(\phi_{bal})\text{Cos}(\psi_{bal}) \tag{3.62}$$

$$B13 = -\text{Sin}(\theta_{bal}) \tag{3.63}$$

$$B23 = \text{Sin}(\phi_{bal})\text{Cos}(\theta_{bal}) \tag{3.64}$$

$$B33 = \text{Cos}(\theta_{bal})\text{Cos}(\phi_{bal}) \tag{3.65}$$

The results of solving these equations for ψ_{bal}, θ_{bal}, and θ_{bal} are:

$$\psi_{bal} = \text{ATan2}\left(\frac{B12}{B11}\right) \tag{3.66}$$

$$\theta_{bal} = \text{ASin}(-B13) \tag{3.67}$$

$$\phi_{bal} = \text{ATan2}\left(\frac{B23}{B33}\right) \tag{3.68}$$

Table 2 — Axis system and angles nomenclature

Axis Systems			
Computer Name	Description	Units	Publication Name
Balance Axis	Origin fixed at the Balance Moment (reference) Center, BMC		
XBAL_SCC	Collinear with the direction in which the axial-force and/or rolling-moment calibrations were determined, positive in the direction of negative axial-force and positive rolling-moment vectors		X_{bal}
YBAL_SCC	Collinear with the direction in which the side-force and/or pitching-moment calibrations were determined, positive in the direction of positive side-force and positive pitching-moment vectors		Y_{bal}
ZBAL_SCC	Collinear with the direction in which the normal-force and/or yawing-moment calibrations were determined, positive in the direction of negative normal-force and positive yawing-moment vectors		Z_{bal}
Gravity axis	Origin fixed at the model Moment Reference Center, MRC		
XG_SCC	Gravity longitudinal axis, perpendicular to the gravity vector and contained in a plane parallel to the primary support system pitch plane, positive upstream		X_g
YG_SCC	Gravity lateral axis, perpendicular to the gravity x-z plane, positive direction determined by the positive X_g and Z_g directions in conjunction with the right-hand rule		Y_g
ZG_SCC	Gravity vertical axis, collinear with the gravity vector, positive toward the tunnel floor		Z_g
Tunnel Flow Axis	Origin fixed at the tunnel pitch center		
XTF_SCC YTF_SCC ZTF_SCC	This axis system orientation is obtained by rotating the gravity axis system x-axis first through the angle, $-\theta_{FA,ts}$, and then through the angle, $-\psi_{FA,ts}$. This axis system then has its x-axis aligned with the velocity vector.		X_{tf} Y_{tf} Z_{tf}
Body axis	Origin fixed at the model MRC		
XB_SCC	Model longitudinal reference axis, positive out the nose of model		X_b
YB_SCC	Model lateral reference axis, perpendicular to the body x-z plane and positive as defined by a right-handed system		Y_b
ZB_SCC	Model vertical reference axis, parallel to and directed the same as the gravity z-axis with the model upright and level in pitch and roll		Z_b
Stability Axis	Origin fixed at the model MRC		
XS_SCC	Stability longitudinal axis, parallel to the projection of the total velocity vector in the body axis x-z plane, differs from the body x-axis by the angle α_s		X_s
YS_SCC	Stability lateral axis, coincident with and directed the same as the body y-axis		Y_s

ZS_SCC	Stability vertical axis, perpendicular to the stability x-y plane and contained in the body x-z plane, differs from the body z-axis by the angle α_s		Z_s
Wind Axis	Origin fixed at the model MRC		
XW_SCC	Wind longitudinal axis, parallel to the total velocity vector, differs from body x-axis by the angles α_s and β_s		X_w
YW_SCC	Wind lateral axis, perpendicular to the wind x-axis and contained in the stability axis x-y plane, differs from the stability axis system y-axis by the angle β_s		Y_w
ZW_SCC	Wind vertical axis, coincident with and directed the same as the stability z-axis		Z_w
Aeroballistic Axis	Origin fixed at the model MRC		
XA_SCC	Aeroballistic longitudinal axis, coincident with and directed the same as the body x-axis		X_a
YA_SCC	Aeroballistic lateral axis, perpendicular to the aeroballistic x-z plane and directed according to the right-hand rule		Y_a
ZA_SCC	Aeroballistic vertical axis, contained in the plane defined by the aeroballistic x-axis and the total velocity vector, positive is in the direction of the component of the velocity vector along the Z_a axis (an increasing α_a rotates the X_a axis toward the negative Z_a axis)		Z_a
Missile Axis	Origin fixed at the model MRC		
XP_SCC	Missile longitudinal axis, coincident with and directed the same as the body x-axis		X_p
YP_SCC	Missile lateral axis, perpendicular to the missile axis x-z plane and directed according to the right-hand rule		Y_p
ZP_SCC	Missile vertical axis, perpendicular to the body x-axis and contained in the (missile axis) pitch plane defined by the body x-axis and an intersecting gravity vector.		Z_p
Aerodynamic and Orientation Angles			
Computer Name	Description	Units	Publication Name
Body, Stability, and Wind Axes Angles			
ALPHAS_SAC	Stability axis aerodynamic angle of attack (also used in the body and wind axis systems); angle between the X_s axis and the X_b body axis	deg	α_s

BETAS_SAC	Stability axis aerodynamic sideslip angle (also used in the body and wind axis systems), angle between the X_s axis and the X_w axis; positive rotates the $+Y_b$ axis into the $+X_s$ axis (opposite the right-hand rule)	deg	β_s
PHIS_SAC	Stability axis yaw plane orientation roll angle; angle between the Y_{tf} axis and the Y_w axis	deg	ϕ_s
Aeroballistic Axis Angles			
ALPHAA_SAC	Aeroballistic axis (total) aerodynamic angle of attack; angle between the total velocity vector and the X_b axis, always positive	deg	α_a
PHIA_SAC	Aeroballistic axis roll angle; angle between the aeroballistic Y_a axis to the Y_b axis	deg	ϕ_a
PHIA1_SAC	Aeroballistic axis pitch plane orientation roll angle; angle between the Y_{tf} axis and the Y_a axis	deg	ϕ_{a1}
Missile Axis Angles			
ALPHAP_SAC	Missile axis aerodynamic angle of attack; angle between the projection of the X_b axis in the tunnel flow x-y plane to the X_b axis	deg	α_p
PHIP_SAC	Missile axis aerodynamic roll angle, angle between the Y_p axis and the Y_b axis	deg	ϕ_p
BETAP_SAC	Missile axis aerodynamic sideslip angle; angle between the projection of the X_b axis in the tunnel flow x-y plane to the X_{tf} axis	deg	β_p
Balance Axis Angles			
n - Indicates the parameter is associated with balance number, 1 to 99			
THETABALn_SAC	Balance pitch angle; angle from the gravity x-y plane to the balance x-axis	deg	$\theta_{bal,n}$
PSIBALn_SAC	Balance yaw angle, angle from the tunnel gravity x-axis to the projection of the body x-axis in the tunnel gravity x-y plane	deg	$\psi_{bal,n}$
PHIBALn_SAC	Balance roll angle; angle measured from the positive balance angle of attack ($\theta_{bal,n}$) direction to the balance negative z axis	deg	$\phi_{bal,n}$
Balance to Model Angles			
n - Indicates the parameter is associated with balance number, 1 to 99			
PHIBMn_SGC	Balance to model roll angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\phi_{bal\text{-}m,n}$
THETABMn_SGC	Balance to model pitch angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\theta_{bal\text{-}m,n}$
PSIBMn_SGC	Balance to model yaw angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\psi_{bal\text{-}m,n}$

4 Dimensional References

The dimensional references are comprised of the model and tunnel reference lengths, areas, distances, and weight. The reference areas and lengths used to convert force, moment, and pressure measurements into coefficient data are presented in this section. In addition, coordinates within, and transfer distances between, the Balance and Body Axis Systems are defined.

4.1 Reference Areas and Lengths

In practice, model reference area, $S_{w,n}$, is typically derived from a missile cross section or airplane wing plan form area, while reference lengths, L_R, L_Y, and L_P, are based upon missile diameter or wing mean aerodynamic chord and span dimensions. Alternate area and length references may be used based upon customer preference. In all circumstances, reference areas and lengths are user defined in accordance with Table 3.

4.2 Balance Reference Center

Measurements of the aerodynamic and gravitational loads acting on the test article are made using an internal strain-gage balance and initially referenced to an orthogonal axis system defined as the Balance Axis. In accordance with Reference 4, the origin of the Balance Axis System, the Balance Moment (reference) Center, BMC, is recommended to be placed at the physical center of the balance for Moment and Force balance types and at the point about which both the pitching and yawing moments are resolved for a Direct-Read balance. The balance axis system and forces and moments are directed as shown in Figure 7. The positive directions for the axes, forces, and moments are shown in Figure 7. Note that the sign convention for the normal and axial forces do not conform to the balance axis system. As stated in Reference 4, this was done to conform with the common practice used in conducting wind tunnel tests in North America in which the normal force is positive upward and axial force is positive downstream. This results in the axial and normal forces having positive senses that are opposite to the positive directions of the respective balance X and Z axes.

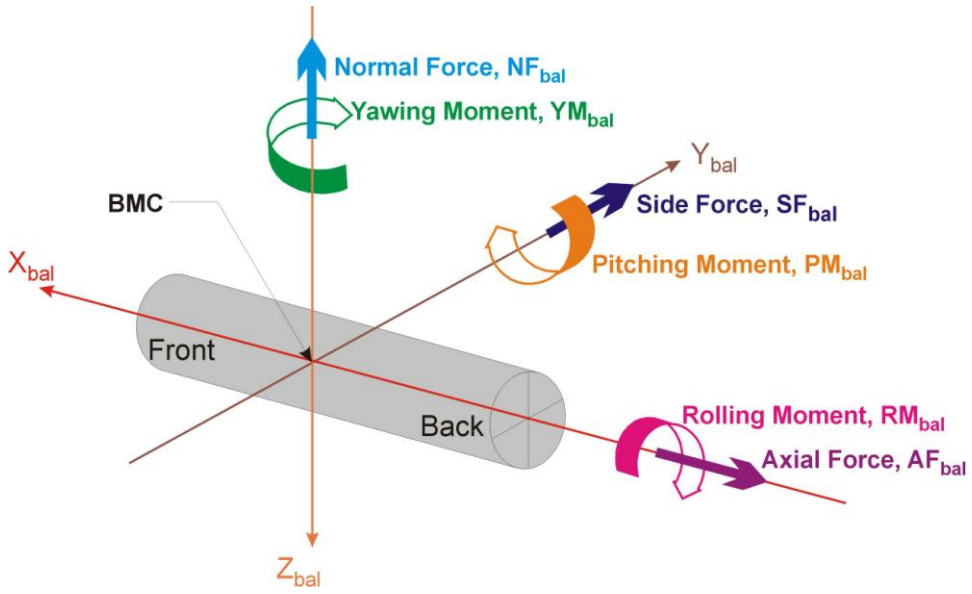
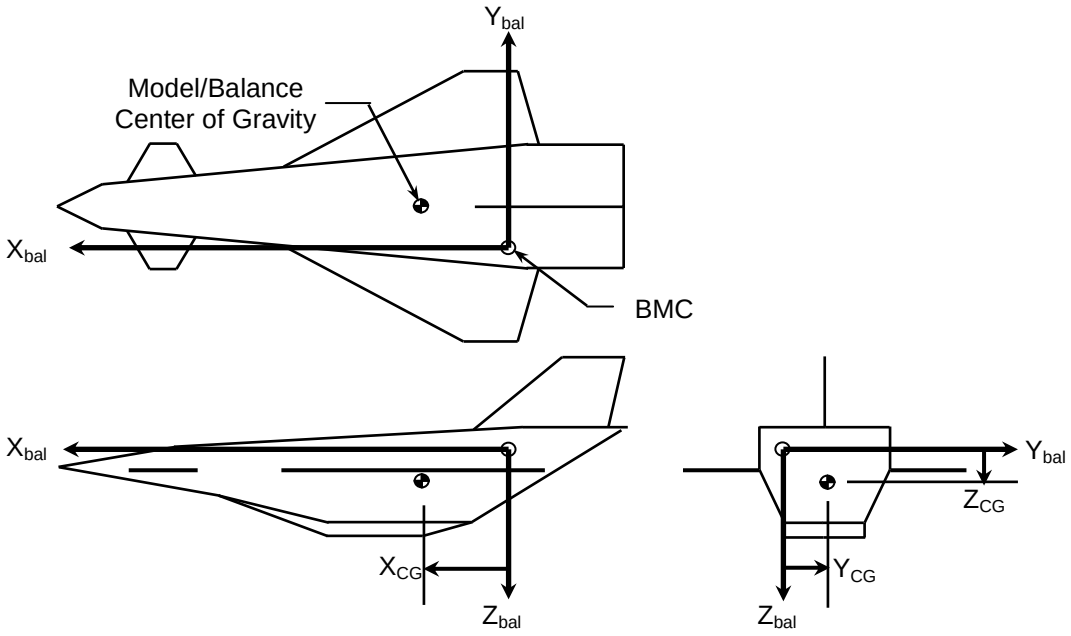


Figure 7 — Balance axis system and forces and moments

4.3 Model/Balance Center of Gravity

The balance measures a combination of the aerodynamic loads, model weight, and a portion of the weight of the balance itself. The latter two contributors are grouped to form $W_{model,n}$, as defined in Table 3. The X, Y, and Z coordinates of the center of gravity of the model and metric portion of the balance, $X_{CG,n}$, $Y_{CG,n}$, and $Z_{CG,n}$, respectively, are defined in Table 3 and depicted in Figure 8.

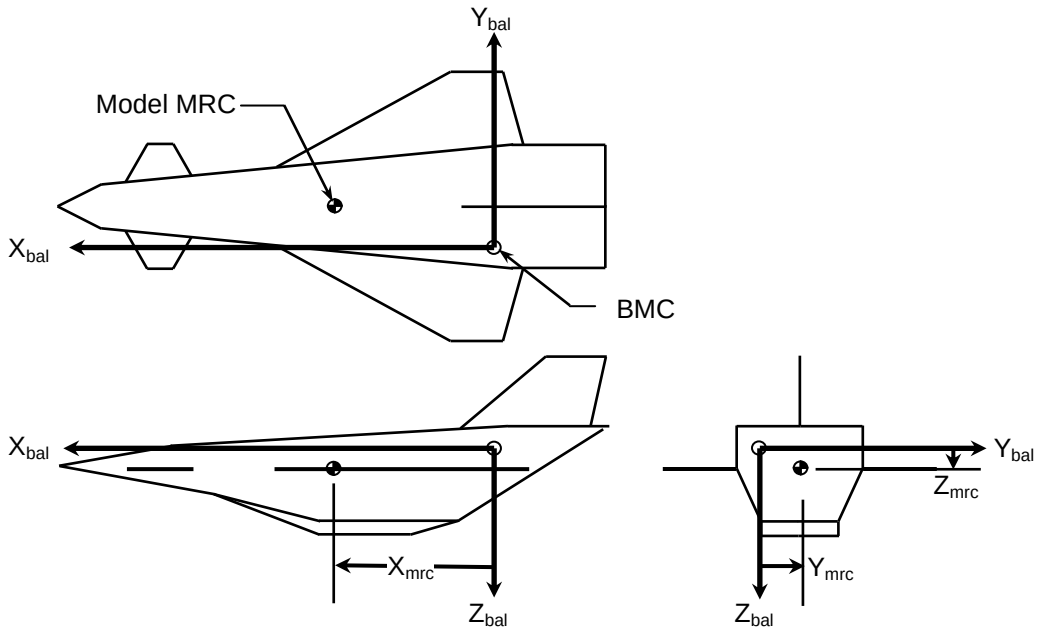


NOTE All of the parameters are depicted in a positive orientation.

Figure 8 — Model/balance center of gravity location

4.4 Moment Reference Center

The aerodynamic forces and moments are resolved about a point called the Moment Reference Center, MRC, which defines the origin of the orthogonal Body Axis System. The MRC is identified by coordinates in the Balance Axis system, X_{mrc}, Y_{mrc}, and Z_{mrc}, respectively, as defined in Table 3 and depicted in Figure 9. The cavity and base pressure area centroid coordinates that will be introduced in Section 4.5, and height relative to the ground plane, H_{mrc}, are defined relative to the Body Axis System in Table 3.



NOTE All of the parameters are depicted in a positive orientation.

Figure 9 — Model reference center location

4.5 Cavity and Base Pressure Areas and Lengths

The aft body on many test articles is truncated to allow for sting mounting. The resulting cross section of the model's aft end is typically divided into cavity and base areas, $A_{cav,n}$ and $A_{base,n}$, respectively, with the open area defining the cavity and the wall of the model representing the base, refer to Figure 10. Note that the balance cross-sectional area is included in the cavity area measurement, and in many circumstances, the base area is considered to be insignificant and defined equal to zero.

Cavity and base pressure area centroid coordinates, $X_{cav,n}$, $Y_{cav,n}$, $Z_{cav,n}$, and $X_{base,n}$, $Y_{base,n}$, and $Z_{base,n}$, respectively, are defined in Table 3 and depicted in Figure 11. A correction to the aerodynamic axial force is calculated and applied for the effects of the base and cavity pressures. Note that an inclined base such as shown in Figure 11 will result in a pitching moment and normal force produced by the base and cavity pressures. In this situation, corresponding corrections to pitching moment and normal force would need to be calculated and applied in addition to the axial force correction.

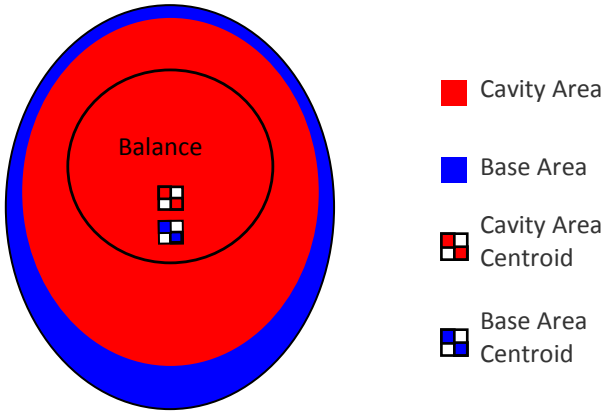
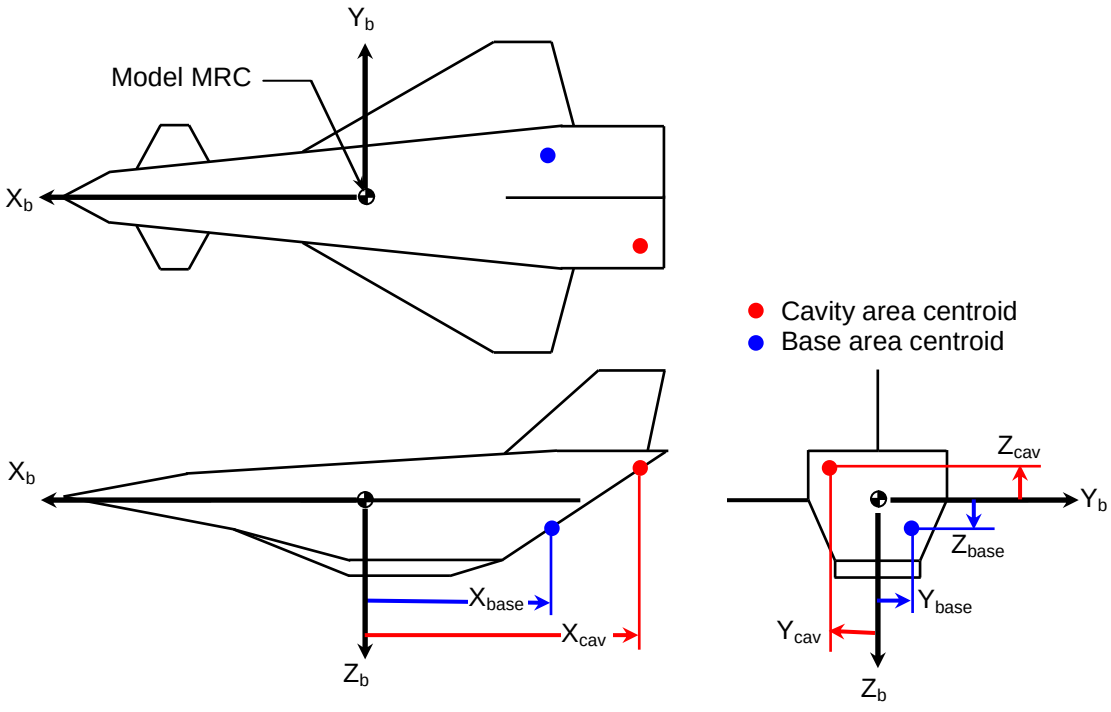


Figure 10 — Model aft body cross-section—cavity and base area



NOTE Cavity and base centroid locations are exaggerated for illustrative purposes. All of the cavity and base parameters are depicted in a negative orientation except for Y_{base} and Z_{base}.

Figure 11 — Cavity and base pressure area centroid coordinates

Table 3 — Dimensional references nomenclature

Computer Name	Description	Units	Publication Name
n - Indicates the parameter is associated with balance number, 1 to 99			
SWn_SGE, I	Model reference area used to reduce the forces and moments to coefficients	in^2, m^2	$S_{w,n}$
LREFRn_SGE, I	Model lateral reference length used to reduce the rolling moment to coefficient form	in, m	L_R
LREFYn_SGE, I	Model lateral reference length used to reduce the yawing moment to coefficient form	in, m	L_Y
LREFPn_SGE, I	Model longitudinal reference length used to reduce the pitching moment to coefficient form	in, m	L_P
ACAVn_SGE, I	Area used in cavity-pressure corrections for balance n	in^2, m^2	$A_{cav,n}$
XCAVn_SGE, I YCAVn_SGE, I ZCAVn_SGE, I	X-, Y-, and Z-coordinates of the centroid of balance n cavity area, used in cavity-pressure corrections, body axis system	in, m	$X_{cav,n}$ $Y_{cav,n}$ $Z_{cav,n}$
ABASEn_SGE, I	Area used in base-pressure corrections for balance n	in^2, m^2	$A_{base,n}$
XBASEn_SGE, I YBASEn_SGE, I ZBASEn_SGE, I	X-, Y-, and Z-coordinates of the centroid of the model base area, used in base-pressure corrections, body axis system	in, m	$X_{base,n}$ $Y_{base,n}$ $Z_{base,n}$
HMRCAGP_SGE, I	Height of MRC above ground plane	in, m	H_{mrc}
XTRANn_SGE, I YTRANn_SGE, I ZTRANn_SGE, I	X, Y, and Z-coordinates of the model MRC; balance axis system	in, m	$X_{mrc,n}$ $Y_{mrc,n}$ $Z_{mrc,n}$
WTMODELn_SGE, I	Weight of model and metric portion of balance	lb, N	$W_{model,n}$
XCGMODELn_SGE,I YCGMODELn_SGE,I ZCGMODELn_SGE,I	X-, Y-, and Z-coordinates of the model and metric portion of the balance center of gravity, balance axis system	in, m	$X_{CG,n}$ $Y_{CG,n}$ $Z_{CG,n}$

5 Pressures, Forces, Moments, and Coefficients

The recommended nomenclature for the pressures, forces, and moments, along with the associated normalized coefficients, that are acquired during typical wind tunnel tests are provided in Table 4. As discussed in Section 1, the list constitutes a top-level selection of general parameters. The force and moment naming conventions are provided for the axes systems defined in Section 3; these include the balance, body, stability, wind, aeroballistic, and missile axes.

The letter "n" at the end of a parameter name indicates that the parameter is associated with a particular balance number, between 1 and 99. The letter "x" at the end of a parameter name but before the suffix descriptor indicates the number of the parameter (i.e., P_{base1}, P_{base2}, etc). In addition, a pressure parameter with "()" in the name constitutes that it is an array.

5.1 Pressures and Associated Coefficients

The five basic types of pressures typically measured during wind tunnel tests are model surface pressures, base and cavity pressures, test section wall pressures, and off-body rake pressures. Conversion of some of these absolute pressures to coefficient form is accomplished by the following equations:

$$CP(i) = [P(i) - P_{S,ts}] / q_{ts} \tag{5.1}$$

$$CP_{base,x} = [P_{base,x} - P_{S,ts}] / q_{ts} \tag{5.2}$$

$$CP_{cav,x} = [P_{cav,x} - P_{S,ts}] / q_{ts} \tag{5.3}$$

Surface pressures. Due to the quantity of channels measured, surface pressures are typically defined as arrays, organized by location of the corresponding pressure orifice on the model or rake (e.g., wing span-wise row, fuselage model station).

Base and cavity pressures. Base and cavity pressures are measured and used to correct the body-axes forces and moments for changes to the internal or external model geometry that result from accommodation of a support system. The pressures are converted directly to pressure loads by subtracting the final corrected test section static pressure and multiplying by the appropriate reference areas defined in Section 4. The resultant pressure load is located at the centroid of that reference area and is resolved in both the body axis system of the auxiliary metric component to which it is acting and in the main model body axis system. Depending on the orientation of the base area (i.e., surface normal) and the location of the centroid relative to the MRC to which it is resolved, all six body-axis forces and moments could be affected. Some model-support configurations require the measurement of multiple cavity and/or base pressures, such as those utilizing an upswept aft sting.

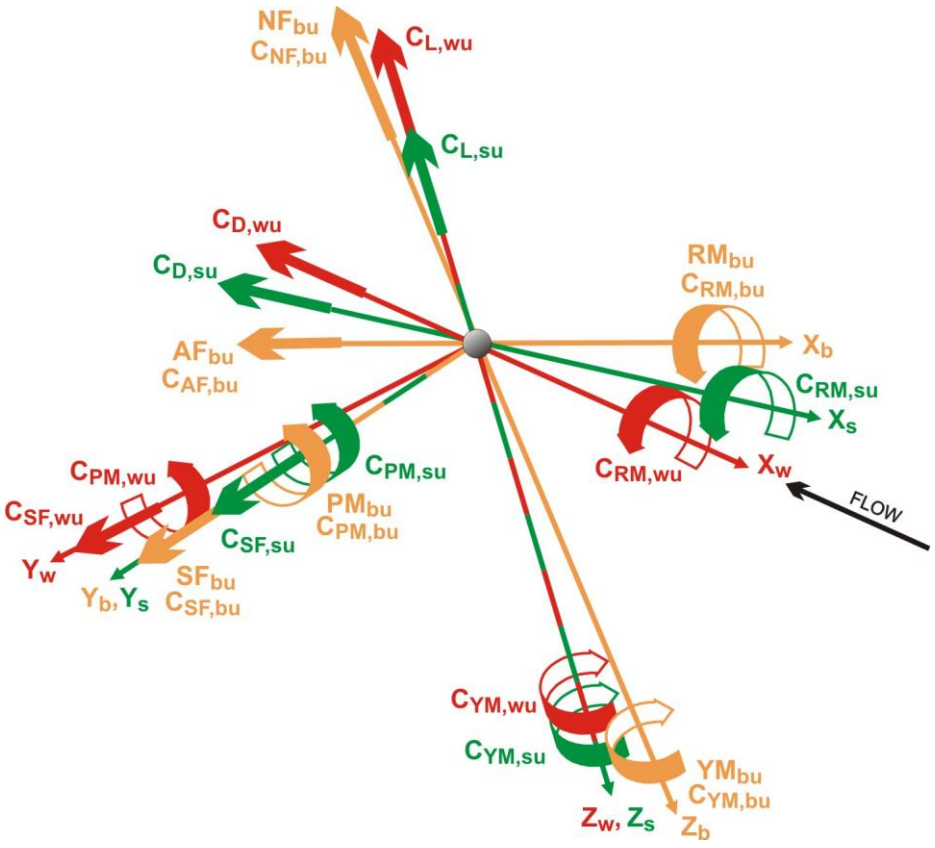
Test section wall and rake pressures. These pressures are acquired and typically used as input to a facility's wall correction scheme and/or for diagnostic purposes and are not typically reduced to coefficient form.

5.2 Forces, Moments, and Associated Coefficients

The external aerodynamic and gravitational forces and moments acting on the typical wind tunnel model are sensed by a strain-gage balance. These loads are resolved into the body axis system per the rotation and transfer methodology provided in Section 4. The positive conventions for the balance forces and moments are shown in Figure 7 and are consistent with the conventions defined in Reference 4. The positive conventions for the aerodynamic forces, moments, and coefficients are shown in Figures 12 and 13. Note that these figures are taken from those shown in Section 3.

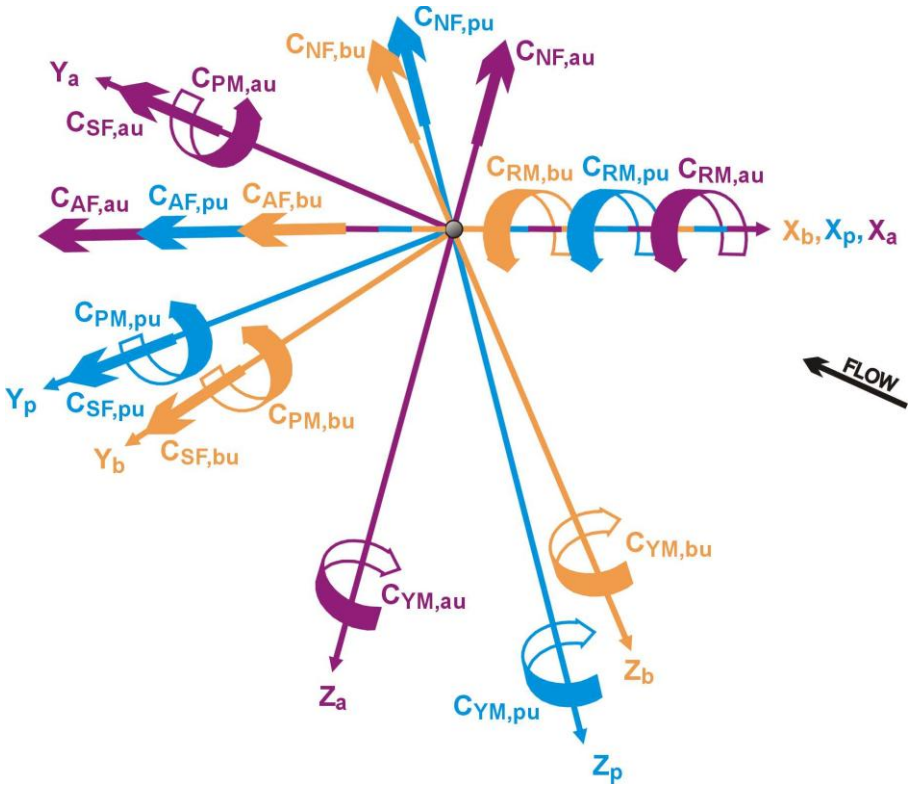
Balance Axis Loads — Naming conventions are defined for the aerodynamic forces and moments that are derived from the gross strain-gage-derived loads and corrected for model weight and center of gravity location (i.e., weight tares) using $W_{model,n}$, $X_{CG,n}$, $Y_{CG,n}$, and $Z_{CG,n}$.

Body Axis Loads — The corrected balance axis forces and moments above are first translated to the MRC using $X_{mrc,n}$, $Y_{mrc,n}$, and $Z_{mrc,n}$ and then rotated to the body-axis system using $\phi_{bal\text{-}m,n}$, $\theta_{bal\text{-}m,n}$, and $\psi_{bal\text{-}m,n}$,.



NOTE The size of the arrows does not indicate the relative magnitude of the forces, moments, or coefficients.

Figure 12— Depiction of the body axis forces and moments, and the body, stability, and wind axis coefficients



NOTE The size of the arrows does not indicate the relative magnitude of the coefficients.

Figure 13 — Depiction of the body, missile, and aeroballistic axis coefficients

Given the signs on NF_{bal} and AF_{bal}, are the opposite of Z_{bal} and X_{bal} respectively care must be taken when rotating the forces into the body axis. To be correct for all values of forces and rotations, the signs on NF_{bal} and AF_{bal} must be changed, then the forces rotated into the body axis system and the sign then changed again on NF_{bu} and AF_{bu}. Note that the same logic also applies when rotating force coefficients from the body axis system into other axis systems. Naming conventions are defined for the body axis forces and moments which are uncorrected and corrected for the application of the base and cavity pressure loads defined above.

The body axis forces and moments are generally normalized to coefficient form by the following equations:

$$C_{AF,bu,n} = AF_{bu,n} / [q_{ts} * S_{w,n}] \quad (5.4)$$

$$C_{SF,bu,n} = SF_{bu,n} / [q_{ts} * S_{w,n}] \quad (5.5)$$

$$C_{NF,bu,n} = NF_{bu,n} / [q_{ts} * S_{w,n}] \quad (5.6)$$

$$C_{RM,bu,n} = RM_{bu,n} / [q_{ts} * S_{w,n} * L_R] \quad (5.7)$$

$$C_{PM,bu,n} = PM_{bu,n} / [q_{ts} * S_{w,n} * L_P] \quad (5.8)$$

$$C_{YM,bu,n} = YM_{bu,n} / [q_{ts} * S_{w,n} * L_Y] \quad (5.9)$$

The body axis system coefficients are then rotated into the stability, wind, aeroballistic, and missile axis systems defined in Section 3. For each of these axis systems, coefficient sets are defined for the three levels of correction addressed in this Guide. The first set of parameter coefficients are uncorrected for everything except dynamic pressure (q_{ts}) and are denoted with a “U” at the end of the name. The second

set of coefficients is additionally corrected for base and cavity pressures and the corresponding names are each denoted with a “BC” at the end of the name. The third set of parameter coefficients are corrected for dynamic pressure, base and cavity pressures, duct flow, buoyancy, wall interference, and flow non-uniformity, and have no descriptor at the end of the names.

Table 4 — Pressures, forces, moments, and coefficients nomenclature

Computer Name	Description	Units	Publication Name
n - Indicates the parameter is associated with balance number, 1 to 99 x - Indicates the number of the parameter (i.e. PBASE1_SPE, PBASE 2_SPE, etc) () – Indicates an array			
P()_SPE, I	Model surface absolute pressure array	psia, kPa	P()
CP()_SPC	Model surface pressure coefficient array		CP()
PBASEx_SPE, I	Model base pressures	psia, kPa	$P_{base,x}$
PCAVx_SPE, I	Balance cavity pressures	psia, kPa	$P_{cav,x}$
CPBASEx_SPC	Model base pressure coefficients		$CP_{base,x}$
CPCAVx_SPC	Balance cavity pressure coefficients		$CP_{cav,x}$
PWALLx_SPE, I	Test section wall, ceiling, and floor pressures	psia, kPa	$P_{wall,x}$
PRAKEx_SPE, I	Off-body rake pressures.	psia, kPa	$P_{rake,x}$
Balance Axis			
AFBALn_SLE, I; SFBALn_SLE, I; NFBALn_SLE, I; RMBALn_SLE, I; PMBALn_SLE, I; YMBALn_SLE, I	Aerodynamic loads, balance axis (balance measured loads corrected for loads produced by W_{model}, X_{CG}, Y_{CG}, and Z_{CG})	lbs & in-lbs, N & Nm	$AF_{bal,n}$; $SF_{bal,n}$; $NF_{bal,n}$; $RM_{bal,n}$; $PM_{bal,n}$; $YM_{bal,n}$
Body Axis			
AFBASEn_SLE, I; SFBASEn_SLE, I; NFBASEn_SLE, I; RMBASEn_SLE, I; PMBASEn_SLE, I; YMBASEn_SLE, I	Forces and moments in the body axis produced by the model base pressure load	lbs & in-lbs, N & Nm	$AF_{base,n}$; $SF_{base,n}$; $NF_{base,n}$; $RM_{base,n}$; $PM_{base,n}$; $YM_{base,n}$
AFCAVn_SLE, I; SFCAVn_SLE, I; NFCAVn_SLE, I; RMCAVn_SLE, I; PMCAVn_SLE, I; YMCAVn_SLE, I	Forces and moments in the body axis produced by the balance cavity pressure load	lbs & in-lbs, N & Nm	$AF_{cav,n}$; $SF_{cav,n}$; $NF_{cav,n}$; $RM_{cav,n}$; $PM_{cav,n}$; $YM_{cav,n}$

AFBUn_SLE, I; SFBUn_SLE, I; NFBUn_SLE, I; RMBUn_SLE, I; PMBUn_SLE, I; YMBUn_SLE, I	Aerodynamic forces and moments, body axis, rotated from balance axis values above and transferred to the model MRC	lbs & in-lbs, N & Nm	$AF_{bu,n}$; $SF_{bu,n}$; $NF_{bu,n}$; $RM_{bu,n}$; $PM_{bu,n}$; $YM_{bu,n}$
AFBBCn_SLE, I; SFBBCn_SLE, I; NFBBCn_SLE, I; RMBBCn_SLE, I; PMBBCn_SLE, I; YMBBCn_SLE, I	Aerodynamic forces and moments, body axis, rotated from balance axis values above and transferred to the model MRC (corrected for base and cavity pressures)	lbs & in-lbs, N & Nm	$AF_{bbc,n}$; $SF_{bbc,n}$; $NF_{bbc,n}$; $RM_{bbc,n}$; $PM_{bbc,n}$; $YM_{bbc,n}$
CAFBUn_SLC, CSFBUn_SLC CNFBUn_SLC, CRMBUn_SLC CPMBUn_SLC, CYMBUn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts})		$C_{AF,bu,n}$; $C_{SF,bu,n}$; $C_{NF,bu,n}$; $C_{RM,bu,n}$; $C_{PM,bu,n}$; $C_{YM,bu,n}$
CAFBBCn_SLC, CSFBBCn_SLC CNFBBCn_SLC, CRMBBCn_SLC CPMBBCn_SLC, CYMBBCn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,bbc,n}$; $C_{SF,bbc,n}$; $C_{NF,bbc,n}$; $C_{RM,bbc,n}$; $C_{PM,bbc,n}$; $C_{YM,bbc,n}$
CAFBn_SLC, CSFBn_SLC CNFBn_SLC, CRMBn_SLC CPMBn_SLC, CYMBn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{A,b,n}$; $C_{S,b,n}$; $C_{N,b,n}$; $C_{RM,b,n}$; $C_{PM,b,n}$; $C_{YM,b,n}$
Stability Axis			
CDSUn_SLC, CSFSUn_SLC CLSUn_SLC, CRMSUn_SLC CPMSUn_SLC, CYMSUn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts})		$C_{D,su,n}$; $C_{SF,su,n}$; $C_{L,su,n}$; $C_{RM,su,n}$; $C_{PM,su,n}$; $C_{YM,su,n}$
CDSBCn_SLC, CSFSBCn_SLC CLSBCn_SLC, CRMSBCn_SLC CPMSBCn_SLC, CYMSBCn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts}, and corrected for base and cavity pressures)		$C_{D,sbc,n}$; $C_{SF,sbc,n}$; $C_{L,sbc,n}$; $C_{RM,sbc,n}$; $C_{PM,sbc,n}$; $C_{YM,sbc,n}$

CDSn_SLC, CSFSn_SLC CLSn_SLC, CRMSn_SLC CPMSn_SLC, CYMSn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{D,s,n}$; $C_{SF,s,n}$; $C_{L,s,n}$; $C_{RM,s,n}$; $C_{PM,s,n}$; $C_{YM,s,n}$
Wind Axis			
CDWUn_SLC, CCWUn_SLC CLWUn_SLC, CRMWUn_SLC CPMWUn_SLC, CYMWUn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts})		$C_{D,wu,n}$; $C_{SF,wu,n}$; $C_{L,su,n}$; $C_{RM,wu,n}$; $C_{PM,wu,n}$; $C_{YM,wu,n}$
CDWBCn_SLC, CCWBCn_SLC CLWBCn_SLC, CRMWBCn_SLC CPMWBCn_SLC, CYMWBCn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts}, and corrected for base and cavity pressures)		$C_{D,wbc,n}$; $C_{SF,wbc,n}$; $C_{L,wbc,n}$; $C_{RM,wbc,n}$; $C_{PM,wbc,n}$; $C_{YM,wbc,n}$
CDWn_SLC, CCWn_SLC CLWBn_SLC, CRMWn_SLC CPMWn_SLC, CYMWn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{D,w,n}$; $C_{SF,w,n}$; $C_{L,w,n}$; $C_{RM,w,n}$; $C_{PM,w,n}$; $C_{YM,w,n}$
Aeroballistic Axis			
CAFAUn_SLC, CSFAUn_SLC CNFAUn_SLC, CRMAUn_SLC CPMAUn_SLC, CYMAUn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic axis roll angle (uses q_{ts})		$C_{AF,au,n}$; $C_{SF,au,n}$; $C_{NF,au,n}$; $C_{RM,au,n}$; $C_{PM,au,n}$; $C_{YM,au,n}$
CAFABCn_SLC, CSFABCn_SLC CNFABCn_SLC, CRMABCn_SLC CPMABCn_SLC, CYMABCn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic axis roll angle (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,abc,n}$; $C_{SF,abc,n}$; $C_{NF,abc,n}$; $C_{RM,abc,n}$; $C_{PM,abc,n}$; $C_{YM,abc,n}$
CAFAn_SLC, CSFAn_SLC CNFAn_SLC, CRMAn_SLC CPMAn_SLC, CYMAn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic roll angle (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{AF,a,n}$; $C_{SF,a,n}$; $C_{NF,a,n}$; $C_{RM,a,n}$; $C_{PM,a,n}$; $C_{YM,a,n}$

Missile Axis			
CAFPUn_SLC, CSFPUn_SLC CNFPUn_SLC, CRMPUn_SLC CPMPUn_SLC, CYMPUn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile axis roll angle (uses q_{ts})		$C_{AF,pu,n}$; $C_{SF,pu,n}$; $C_{NF,pu,n}$; $C_{RM,pu,n}$; $C_{PM,pu,n}$; $C_{YM,pu,n}$
CAFPBCn_SLC, CSFPBCn_SLC CNFPBCn_SLC, CRMPBCn_SLC CPMPBCn_SLC, CYMPBCn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile axis roll angle (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,pbc,n}$; $C_{SF,pbc,n}$; $C_{NF,pbc,n}$; $C_{RM,pbc,n}$; $C_{PM,pbc,n}$; $C_{YM,pbc,n}$
CAFPn_SLC, CSFPn_SLC CNFPn_SLC, CRMPn_SLC CPMPn_SLC, CYMPn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile roll angle (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{AF,p,n}$; $C_{SF,p,n}$; $C_{NF,p,n}$; $C_{RM,p,n}$; $C_{PM,p,n}$; $C_{YM,p,n}$

6 Publications Names

The final column in the nomenclature tables lists the publication name (symbol, nomenclature) for each parameter. The publication name is simply the name or symbol use to describe a parameter in a written document, such as technical paper, or in a presentation. The publication names are generally based on both the computer code name and on typical usage in technical literature. For example, the tunnel conditions parameters code and publication names were developed based on review of terminology used by several wind tunnel organizations and from the nomenclature used in the AIAA standards documents previously developed by the Ground Testing Technical Committee. In fact, the nomenclature used in Reference 1 was based on an early draft of this document in order to develop consistency between these recommended practice documents.

The publication names do not include the computer code name suffixes that define each term as a standard, the group, or units (i.e., _SFE for standard name, facility group, and English units). In most cases, the publication name and the computer code name can be easily related. For example, the test section total pressure, which is part of the tunnel conditions facility group, is defined as PT_SFE for code usage and $P_{T,ts}$ for the publication name. In the publication name, the first letter, "P" indicates a pressure term, the capital "T" in the subscript indicates that this is a total (versus static) condition, and the lower case "ts" in the subscript means test section (same definitions used in Reference 1).

Some of the computer code names are complex and lengthy, although every effort has been made to keep the computer code names as short as possible yet still remain unambiguous. Similar effort was put into the development of the publication names. The idea was to create a name that ties to its definition so that the reader does not have to repeatedly refer to the symbols list, but is also of reasonable length to make it easy to use in text and equations. The longest term names are those for forces, moments, and related coefficients. As an example, consider the axial force measurement from the primary balance in a test setup (n=1). The axial force in the balance axis is listed as $AF_{bal,1}$ (code: 1AFBAL_SLE, assuming English units). Transferring to the body axis, without correcting for base of cavity pressure, the axial force is $AF_{bu,1}$ (code: 1AFBU_SLE), where the subscript "bu" refers to the body axis ("b") and that the force is uncorrected ("u"), just like in the code name for this term. If the axial force in the body axis is now corrected for base and cavity pressures, the term is defined as $AF_{bbc,1}$ (code: 1AFBBC_SLE), where the subscript "bbc" refers to the body axis ("b") and the base and cavity corrections ("bc"). The other force, moment, and coefficient terms follow the same construction rules.

7 References

1. AIAA Recommended Practice, "Calibration of Subsonic and Transonic Wind Tunnels," AIAA R-093-2003.
2. NACA Report 1135 – Equations, Tables, and Charts for Compressible Flow.
3. Naval Ordinance Laboratory Report (NOLR) 1241, "Compilation of Aerodynamic Nomenclature and Axes Systems."
4. AIAA Recommended Practice, "Calibration and Use of Internal Strain-Gage Balances With Application to Wind Tunnel Testing," R-091-2003.

Annex A Wind Tunnel Nomenclature (Informative)

Table A.1 — Compilation of wind tunnel nomenclature

Tunnel Conditions			
Computer Name	Description	Units	Publication Name
PS_SFE, I	Test section Static pressure. Facility final corrected value	Psia, kPa	$P_{S,ts}$
PT_SFE, I	Total pressure	Psia, kPa	$P_{T,ts}$
Q_SFE, I	Dynamic Pressure. Facility final corrected value	Psia, kPa	q_{ts}
TT_SFE, I	Total temperature	R, K	$T_{T,ts}$
RE_SFE, I	Reynolds Number /length x E-06	Millions ft^{-1} Millions m^{-1}	Re_{ts}
RHO_SFE, I	Density	slugs ft^{-3} kg m^{-3}	ρ_{ts}
M_SFC	Mach number, facility final corrected value		M_{ts}
TDP_SFE, I	Dew point temperature	R, K	$T_{DP,ts}$
MU_SFE, I	Viscosity	slugs ft^{-1} sec^{-1} kg m^{-1} sec^{-1}	μ_{ts}
U_SFE, I	Velocity, facility final corrected value	ft sec^{-1} m sec^{-1}	U_{ts}
UX_SFE, I UY_SFE, I UZ_SFE, I	Rectangular components of the tunnel flow velocity vector (U_SFE,I) in the body axis system x-, y-, and z-directions, respectively	ft sec^{-1} m sec^{-1}	u_{ts},v_{ts},w_{ts}
THETAFA_SFC	Model integrated up flow angle, angle from the projection of the relative wind vector in the gravity axis x-z plane to the gravity x-axis	deg	$\theta_{FA,ts}$
PSIFA_SFC	Model integrated side flow angle, angle from the projection of the relative wind vector in the gravity axis x-y plane to the gravity x-axis	deg	$\psi_{FA,ts}$
TS_SFE, I	Static temperature	R, K	$T_{S,ts}$
SH_SFC	Specific humidity. Ratio of the mass of water in the air to the total mass of the air.		SH_{ts}
GAMMA_SFC	Specific heat ratio		γ_{ts}

R_SFE, I	Gas constant	$ft^2\ sec^{-2}\ R^{-1}$, $m^2\ sec^{-2}\ K^{-1}$	R
A_SFE, I	Speed of sound	ft sec^{-1} m sec^{-1}	a_{ts}
Axis Systems			
Balance Axis	Origin fixed at the balance moment (reference) center, BMC		
XBAL_SCC	Collinear with the direction in which the axial-force and/or rolling-moment calibrations were determined, positive in the direction of negative axial-force and positive rolling-moment vectors		X_{bal}
YBAL_SCC	Collinear with the direction in which the side-force and/or pitching-moment calibrations were determined, positive in the direction of positive side-force and positive pitching-moment vectors		Y_{bal}
ZBAL_SCC	Collinear with the direction in which the normal-force and/or yawing-moment calibrations were determined, positive in the direction of negative normal-force and positive yawing-moment vectors		Z_{bal}
Gravity axis	Origin fixed at the model moment reference center, MRC		
XG_SCC	Gravity longitudinal axis, perpendicular to the gravity vector and contained in a plane parallel to the primary support system pitch plane, positive upstream		X_g
YG_SCC	Gravity lateral axis, perpendicular to the gravity x-z plane, positive direction determined by the positive XG and ZG directions in conjunction with the right-hand rule		Y_g
ZG_SCC	Gravity vertical axis, collinear with the gravity vector, positive toward the tunnel floor		Z_g
Tunnel Flow Axis	Origin fixed at the tunnel pitch center		
XTF_SCC YTF_SCC ZTF_SCC	This axis system orientation is obtained by rotating the gravity axis system x-axis first through the angle, $-\theta_{FA,ts}$, and then through the angle, $-\psi_{FA,ts}$. This axis system then has its x-axis aligned with the velocity vector.		X_{tf} Y_{tf} Z_{tf}

Body axis	Origin fixed at the model MRC		
XB_SCC	Model longitudinal reference axis, positive out the nose of model		X_b
YB_SCC	Model lateral reference axis, perpendicular to the body x-z plane and positive as defined by a right-handed system		Y_b
ZB_SCC	Model vertical reference axis, parallel to and directed the same as the gravity z-axis with the model upright and level in pitch and roll		Z_b
Stability Axis	Origin fixed at the model MRC		
XS_SCC	Stability longitudinal axis, parallel to the projection of the total velocity vector in the body axis x-z plane, differs from the body x-axis by the angle α_s		X_s
YS_SCC	Stability lateral axis, coincident with and directed the same as the body y-axis		Y_s
ZS_SCC	Stability vertical axis, perpendicular to the stability x-y plane and contained in the body x-z plane, differs from the body z-axis by the angle α_s		Z_s
Wind Axis	Origin fixed at the model MRC		
XW_SCC	Wind longitudinal axis, parallel to the total velocity vector, differs from body x-axis by the angles α_s and β_s		X_w
YW_SCC	Wind lateral axis, perpendicular to the wind x-axis and contained in the stability axis x-y plane, differs from the stability axis system y-axis by the angle β_s		Y_w
ZW_SCC	Wind vertical axis, coincident with and directed the same as the stability z-axis		Z_w
Aeroballistic Axis	Origin fixed at the model MRC		
XA_SCC	Aeroballistic longitudinal axis, coincident with and directed the same as the body x-axis		X_a
YA_SCC	Aeroballistic lateral axis, perpendicular to the Aeroballistic x-z plane and directed according to the right-hand rule		Y_a

ZA_SCC	Aeroballistic vertical axis, contained in the plane defined by the Aeroballistic x-axis and the total velocity vector, positive is in the direction of the component of the velocity vector along the Z_a axis (an increasing α_a rotates the X_a axis toward the negative Z_a axis)		Z_a
Missile Axis	Origin fixed at the model MRC		
XP_SCC	Missile longitudinal axis, coincident with and directed the same as the body x-axis		X_p
YP_SCC	Missile lateral axis, perpendicular to the missile axis x-z plane and directed according to the right-hand rule		Y_p
ZP_SCC	Missile vertical axis, perpendicular to the body x-axis and contained in the (missile axis) pitch plane defined by the body x-axis and an intersecting gravity vector.		Z_p
Aerodynamic and orientation angles			
n - Indicates the parameter is associated with balance number, 1 to 99			
Body, Stability and Wind Axis Angles			
ALPHAS_SAC	Stability axis aerodynamic angle of attack (also used in the body and wind axis systems); angle from the projection of the total velocity vector in the body axis x-z plane (i.e., stability x-axis) to the body x-axis; positive rotates the $+Z_b$ axis into the $+X_b$ axis	deg	α_s
BETAS_SAC	Stability axis aerodynamic sideslip angle (also used in the body and wind axis systems), angle from the projection of the body x-axis in the wind axis x-y plane (i.e., the stability x-axis) to the wind x-axis; positive rotates the $+Y_b$ axis into the $+X_b$ axis	deg	β_s
PHIS_SAC	Stability axis yaw plane orientation roll angle; angle from the tunnel flow y-axis to the wind y-axis	deg	ϕ_s
Aeroballistic Axis Angles			
ALPHAA_SAC	Aeroballistic axis (total) aerodynamic angle of attack; angle from the total velocity vector to the body x-axis, always positive	deg	α_a

PHIA_SAC	Aeroballistic axis roll angle; angle from the aeroballistic y axis to the body y-axis	deg	ϕ_a
PHIA1_SAC	Aeroballistic axis pitch plane orientation roll angle; angle from the tunnel flow y-axis to the aeroballistic y-axis	deg	ϕ_{a1}
Missile Axis Angles			
ALPHAP_SAC	Missile axis aerodynamic angle of attack; angle from the projection of the body x-axis in the tunnel flow x-y plane to the body x-axis, deg	deg	α_p
PHIP_SAC	Missile axis aerodynamic roll angle, angle from the missile y-axis to the body y-axis	deg	ϕ_p
BETAP_SAC	Missile axis aerodynamic sideslip angle; angle from the projection of the body x-axis in the tunnel flow x-y plane to the tunnel flow x-axis, deg	deg	β_p
Balance Axis Angles			
THETABALn_SAC	Balance pitch angle; angle from the gravity x-y plane to the balance x-axis	deg	$\theta_{bal,n}$
PSIBALn_SAC	Balance yaw angle, angle from the tunnel gravity x-axis to the projection of the body x-axis in the tunnel gravity x-y plane	deg	$\psi_{bal,n}$
PHIBALn_SAC	Balance roll angle; angle measured from the positive balance angle of attack (θ_{bal}) direction to the balance negative z axis	deg	$\phi_{bal,n}$
Balance to Model Angles			
PHIBMn_SGC	Balance to model roll angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\phi_{bal\text{-}m,n}$
THETABMn_SGC	Balance to model pitch angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\theta_{bal\text{-}m,n}$
PSIBMn_SGC	Balance to model yaw angle, measured from the balance axis to the model axis, consistent with the order of rotation used	deg	$\psi_{bal\text{-}m,n}$
Dimensional References			
n - Indicates the parameter is associated with balance number, 1 to 99			
SWn_SGE, I	Model reference area used to reduce the forces and moments to coefficients	in^2, m^2	$S_{w,n}$

LREFRn_SGE, I	Model lateral reference length used to reduce the rolling moment to coefficient form	in, m	L_R
LREFYn_SGE, I	Model lateral reference length used to reduce the yawing moment to coefficient form	in, m	L_Y
LREFPn_SGE, I	Model longitudinal reference length used to reduce the pitching moment to coefficient form	in, m	L_P
ACAVn_SGE, I	Area used in cavity-pressure corrections for balance n	in^2, m^2	$A_{cav,n}$
XCAVn_SGE, I YCAVn_SGE, I ZCAVn_SGE, I	X-, Y-, and Z-coordinates of the centroid of the balance (n) cavity area, used in cavity-pressure corrections, body axis system	in, m	$X_{cav,n}$ $Y_{cav,n}$ $Z_{cav,n}$
ABASEn_SGE, I	Area used in base-pressure corrections for balance n	in^2, m^2	$A_{base,n}$
XBASEn_SGE, I YBASEn_SGE, I ZBASEn_SGE, I	X-, Y-, and Z-coordinates of the centroid of the model base area, used in base-pressure corrections, body axis system	in, m	$X_{base,n}$ $Y_{base,n}$ $Z_{base,n}$
HMRCAGP_SGE, I	Height of MRC above ground plane	in, m	H_{mrc}
XTRANn_SGE, I YTRANn_SGE, I ZTRANn_SGE, I	X, Y, and Z-coordinates of the model MRC; balance axis system	in, m	$X_{mrc,n}$ $Y_{mrc,n}$ $Z_{mrc,n}$
WTMODELn_SGE, I	Weight of model and metric portion of balance	lb, N	$W_{model,n}$
XCGMODELn_SGE,I YCGMODELn_SGE,I ZCGMODELn_SGE,I	X-, Y-, and Z-coordinates of the model and metric portion of the balance center of gravity, balance axis system	in, m	$X_{CG,n}$ $Y_{CG,n}$ $Z_{CG,n}$
Pressures, Forces and Moments, and Coefficients			
n - Indicates the parameter is associated with balance number, 1 to 99 x - Indicates the number of the parameter (i.e. PBASE1_SPE, PBASE 2_SPE, etc.) () – Indicates an array			
P()_SPE, I	Model surface absolute pressure array.	psia, kPa	P(i)
CP()_SPC	Model surface pressure coefficient array (subtract static tunnel pressure and normalize by final dynamic pressure).		CP(i)
PBASEx_SPE, I	Model base pressures	psia, kPa	$P_{base,x}$
PCAVx_SPE, I	Balance cavity pressures	psia, kPa	$P_{cav,x}$
CPBASEx_SPE, I	Model base pressure coefficients		$CP_{base,x}$
CPCAVx_SPE, I	Balance cavity pressure coefficients		$CP_{cav,x}$

PWALLx_SPE, I	Test section wall, ceiling, and floor pressure.	psia, kPa	$P_{wall,x}$
PRAKEx_SPE, I	Off-body rake pressure array.	psia, kPa	$P_{rake,x}$
Balance Axis			
AFBALn_SLE, I; SFBALn_SLE, I; NFBALn_SLE, I; RMBALn_SLE, I; PMBALn_SLE, I; YMBALn_SLE, I	Aerodynamic loads, balance axis (balance measured loads corrected for loads produced by W_{model}, X_{CG}, Y_{CG}, and Z_{CG})	lbs & in-lbs, N & Nm	$AF_{bal,n}$; $SF_{bal,n}$; $NF_{bal,n}$; $RM_{bal,n}$; $PM_{bal,n}$; $YM_{bal,n}$
Body Axis			
AFBASEn_SLE, I; SFBASEn_SLE, I; NFBASEn_SLE, I; RMBASEn_SLE, I; PMBASEn_SLE, I; YMBASEn_SLE, I	Forces and moments in the body axis produced by the model base pressure load	lbs & in-lbs, N & Nm	$AF_{base,n}$; $SF_{base,n}$; $NF_{base,n}$; $RM_{base,n}$; $PM_{base,n}$; $YM_{base,n}$
AFCAVn_SLE, I; SFCAVn_SLE, I; NFCAVn_SLE, I; RMCAVn_SLE, I; PMCAVn_SLE, I; YMCAVn_SLE, I	Forces and moments in the body axis produced by the balance cavity pressure load	lbs & in-lbs, N & Nm	$AF_{cav,n}$; $SF_{cav,n}$; $NF_{cav,n}$; $RM_{cav,n}$; $PM_{cav,n}$; $YM_{cav,n}$
AFBUn_SLE, I; SFBUn_SLE, I; NFBUn_SLE, I; RMBUn_SLE, I; PMBUn_SLE, I; YMBUn_SLE, I	Aerodynamic forces and moments, body axis, rotated from balance axis values above and transferred to the model MRC	lbs & in-lbs, N & Nm	$AF_{bu,n}$; $SF_{bu,n}$; $NF_{bu,n}$; $RM_{bu,n}$; $PM_{bu,n}$; $YM_{bu,n}$
AFBBCn_SLE, I; SFBBCn_SLE, I; NFBBCn_SLE, I; RMBBCn_SLE, I; PMBBCn_SLE, I; YMBBCn_SLE, I	Aerodynamic forces and moments, body axis, rotated from balance axis values above and transferred to the model MRC (corrected for base and cavity pressures)	lbs & in-lbs, N & Nm	$AF_{bbc,n}$; $SF_{bbc,n}$; $NF_{bbc,n}$; $RM_{bbc,n}$; $PM_{bbc,n}$; $YM_{bbc,n}$
CAFBUn_SLC, CSFBUn_SLC CNFBUn_SLC, CRMBUn_SLC CPMBUn_SLC, CYMBUn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts})		$C_{AF,bu,n}$; $C_{SF,bu,n}$; $C_{NF,bu,n}$; $C_{RM,bu,n}$; $C_{PM,bu,n}$; $C_{YM,bu,n}$

CAFBBCn_SLC, CSFBBCn_SLC CNFBBCn_SLC, CRMBBCn_SLC CPMBBCn_SLC, CYMBBCn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,bbc,n}$; $C_{SF,bbc,n}$; $C_{NF,bbc,n}$; $C_{RM,bbc,n}$; $C_{PM,bbc,n}$; $C_{YM,bbc,n}$
CAFBn_SLC, CSFBn_SLC CNFBn_SLC, CRMBn_SLC CPMBn_SLC, CYMBn_SLC	Body Axis aerodynamic force and moment coefficients (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{AF,b,n}$; $C_{SF,b,n}$; $C_{NF,b,n}$; $C_{RM,b,n}$; $C_{PM,b,n}$; $C_{YM,b,n}$
Stability Axis			
CDSUn_SLC, CSFSUn_SLC CLSUn_SLC, CRMSUn_SLC CPMSUn_SLC, CYMSUn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts})		$C_{D,su,n}$; $C_{SF,su,n}$; $C_{L,su,n}$; $C_{RM,su,n}$; $C_{PM,su,n}$; $C_{YM,su,n}$
CDSBCn_SLC, CSFSBCn_SLC CLSBCn_SLC, CRMSBCn_SLC CPMSBCn_SLC, CYMSBCn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts}, and corrected for base and cavity pressures)		$C_{D,sbc,n}$; $C_{SF,sbc,n}$; $C_{L,sbc,n}$; $C_{RM,sbc,n}$; $C_{PM,sbc,n}$; $C_{YM,sbc,n}$
CDSn_SLC, CSFSn_SLC CLSn_SLC, CRMSn_SLC CPMSn_SLC, CYMSn_SLC	Stability axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{D,s,n}$; $C_{SF,s,n}$; $C_{L,s,n}$; $C_{RM,s,n}$; $C_{PM,s,n}$; $C_{YM,s,n}$
Wind Axis			
CDWUn_SLC, CCWUn_SLC CLWUn_SLC, CRMWUn_SLC CPMWUn_SLC, CYMWUn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts})		$C_{D,wu,n}$; $C_{SF,wu,n}$; $C_{L,su,n}$; $C_{RM,wu,n}$; $C_{PM,wu,n}$; $C_{YM,wu,n}$
CDWBCn_SLC, CCWBCn_SLC CLWBCn_SLC, CRMWBCn_SLC CPMWBCn_SLC, CYMWBCn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts}, and corrected for base and cavity pressures)		$C_{D,wbc,n}$; $C_{SF,wbc,n}$; $C_{L,wbc,n}$; $C_{RM,wbc,n}$; $C_{PM,wbc,n}$; $C_{YM,wbc,n}$

CDWn_SLC, CCWn_SLC CLWBn_SLC, CRMWn_SLC CPMWn_SLC, CYMWn_SLC	Wind axis aerodynamic force and moment coefficients, transformed from body axis values using stability axis angle of attack and sideslip (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{D,w,n}$; $C_{SF,w,n}$; $C_{L,w,n}$; $C_{RM,w,n}$; $C_{PM,w,n}$; $C_{YM,w,n}$
Aeroballistic Axis			
CAFAUn_SLC, CSFAUn_SLC CNFAUn_SLC, CRMAUn_SLC CPMAUn_SLC, CYMAUn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic axis roll angle (uses q_{ts})		$C_{AF,au,n}$; $C_{SF,au,n}$; $C_{NF,au,n}$; $C_{RM,au,n}$; $C_{PM,au,n}$; $C_{YM,au,n}$
CAFABCn_SLC, CSFABCn_SLC CNFABCn_SLC, CRMABCn_SLC CPMABCn_SLC, CYMABCn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic axis roll angle (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,abc,n}$; $C_{SF,abc,n}$; $C_{NF,abc,n}$; $C_{RM,abc,n}$; $C_{PM,abc,n}$; $C_{YM,abc,n}$
CAFAn_SLC, CSFAn_SLC CNFAn_SLC, CRMAn_SLC CPMAn_SLC, CYMAn_SLC	Aeroballistic axis aerodynamic force and moment coefficients, transformed from body axis values using aeroballistic roll angle (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{AF,a,n}$; $C_{SF,a,n}$; $C_{NF,a,n}$; $C_{RM,a,n}$; $C_{PM,a,n}$; $C_{YM,a,n}$
Missile Axis			
CAFPUn_SLC, CSFPUn_SLC CNFPUn_SLC, CRMPUn_SLC CPMPUn_SLC, CYMPUn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile axis roll angle (uses q_{ts})		$C_{AF,pu,n}$; $C_{SF,pu,n}$; $C_{NF,pu,n}$; $C_{RM,pu,n}$; $C_{PM,pu,n}$; $C_{YM,pu,n}$
CAFPBCn_SLC, CSFPBCn_SLC CNFPBCn_SLC, CRMPBCn_SLC CPMPBCn_SLC, CYMPBCn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile axis roll angle (uses q_{ts}, and corrected for base and cavity pressures)		$C_{AF,pbc,n}$; $C_{SF,pbc,n}$; $C_{NF,pbc,n}$; $C_{RM,pbc,n}$; $C_{PM,pbc,n}$; $C_{YM,pbc,n}$
CAFPn_SLC, CSFPn_SLC CNFPn_SLC, CRMPn_SLC CPMPn_SLC, CYMPn_SLC	Missile axis aerodynamic force and moment coefficients, transformed from body axis values using missile roll angle (uses q_{ts}, and corrected for base and cavity pressures, duct flow, buoyancy, wall interference, and flow nonuniformity)		$C_{AF,p,n}$; $C_{SF,p,n}$; $C_{NF,p,n}$; $C_{RM,p,n}$; $C_{PM,p,n}$; $C_{YM,p,n}$

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