AIAA G-129-2012(2017)

Guide

Nomenclature and Axis Systems for Aerodynamic Wind Tunnel Testing

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Guide

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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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Published by
American Institute of Aeronautics and Astronautics
1801 Alexander Bell Drive, Reston, VA 20191

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Printed in the United States of America

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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

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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.

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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.

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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.

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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.”

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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).

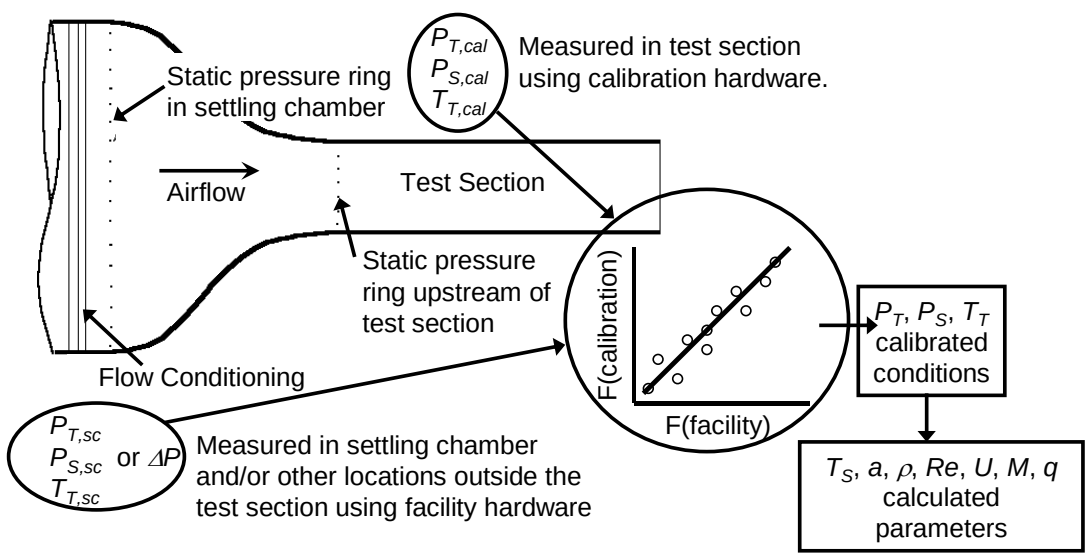

Figure 1 — Arrangement of measurements for monitoring operating conditions in a subsonic wind tunnel using a pair of static pressure rings

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

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(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.

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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}

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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.

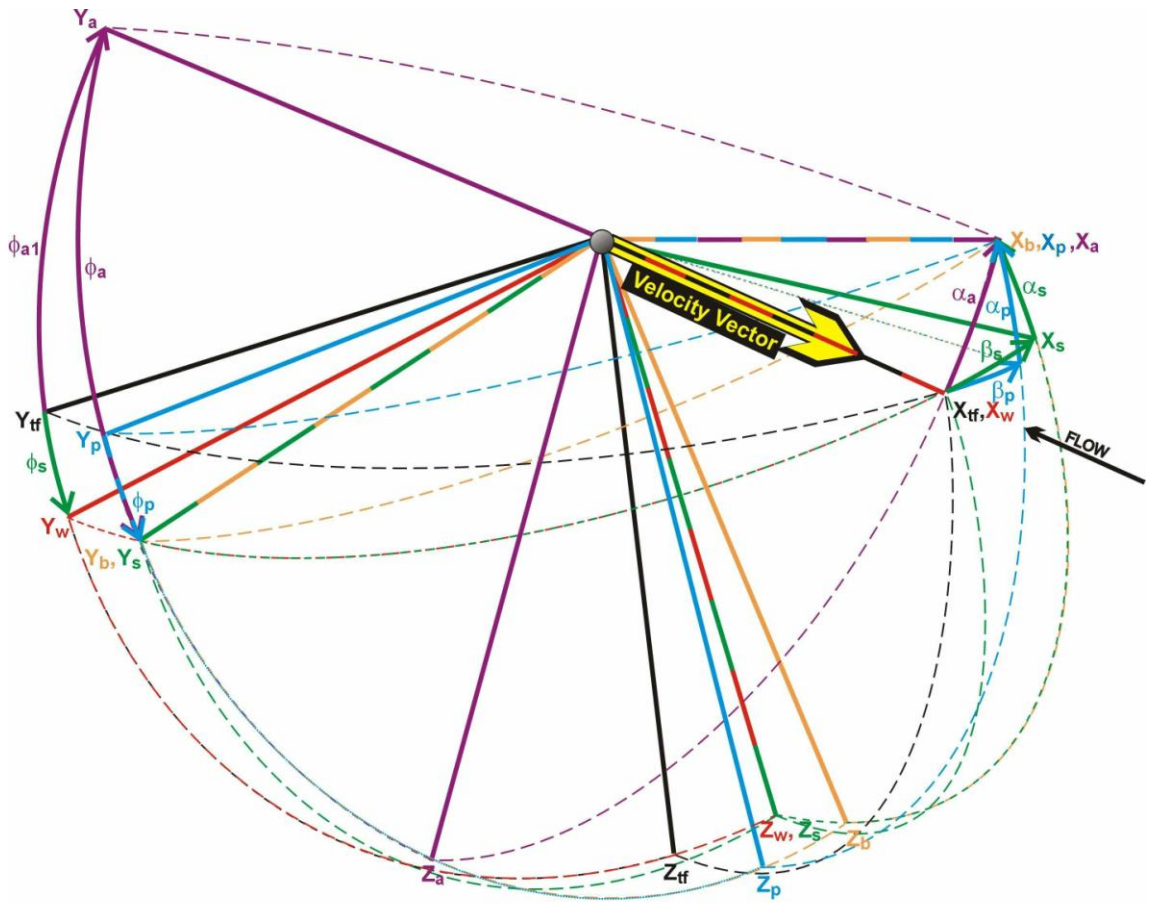

Figure 2 — All axis systems

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.

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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.”

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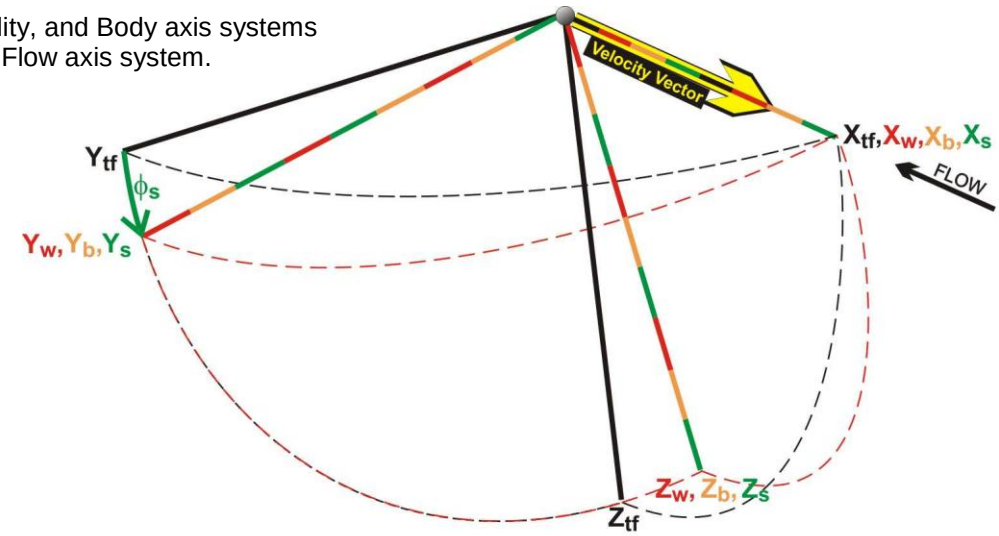
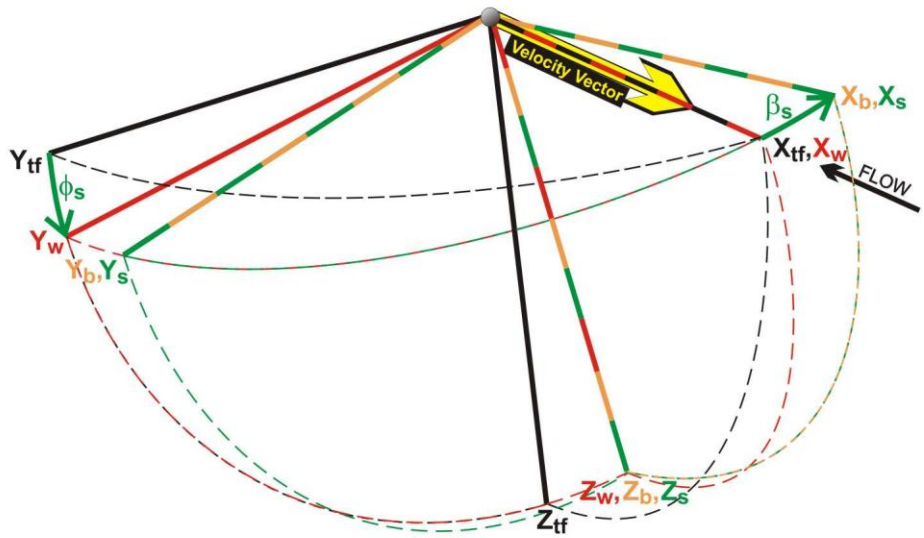
Begin with the Wind, Stability, and Body axis systems coincident with the Tunnel Flow axis system.

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.

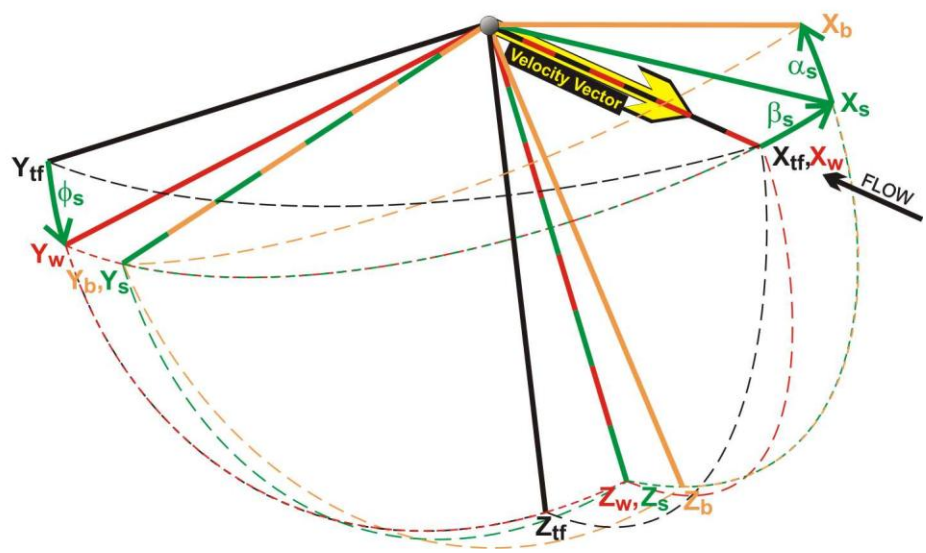


Figure 3 — Tunnel flow, body, stability, and wind axis systems

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