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Standard

Flight Dynamics Model Exchange Standard

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American National Standard

Flight Dynamics Model Exchange Standard

Sponsored by

American Institute of Aeronautics and Astronautics

Approved 25 March 2011

American National Standards Institute

Abstract

This is a standard for the interchange of simulation modeling data between facilities. The initial objective is to allow easy, straightforward exchanges of simulation model information and data between facilities. The standard applies to virtually any vehicle model (ground, air, or space), but most directly applies to aircraft and missiles.

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Foreword

This standard was sponsored and developed by the AIAA Modeling and Simulation Committee on Standards. Mr. Bruce Jackson of NASA Langley conceived Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML). DAVE-ML is the embodiment of the standard in XML. The DAVE-ML reference document, including examples of its use, and the document type definition for the XML implementation are included in this standard (Annex B).

This implementation was then tested by trial exchange of simulation models between NASA Langley Research Center (Mr. Bruce Jackson), NASA Ames Research Center (Mr. Thomas Alderete and Mr. Bill Cleveland), and the Naval Air Systems Command (Mr. William McNamara and Mr. Brent York). Numerous improvements to the standard resulted from this testing.

At the time of approval, the members of the AIAA Modeling and Simulation CoS were:

Bruce Hildreth, Chair	J. F. Taylor, Inc.
Bruce Jackson, DAVE-ML Chair	NASA Langley Research Center
Bimal Aponso	NASA Ames Research Center
Jon Berndt	Jacobs
William Bezdek	Boeing Phantom Works
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Peter Grant	University of Toronto
Michael Madden	NASA Langley Research Center
Michael Silvestro	Charles Stark Draper Laboratory, Inc.
Jean Slane	Engineering Systems Inc.
Brent York	Indra Systems, Inc.

The above consensus body approved this document in December 2011.

The AIAA Standards Executive Council (VP-Standards Wilson Felder, Chairman) accepted the document for publication in February 2011.

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Introduction

The purpose of this standard is to clearly define the information and format required to exchange air vehicle simulation models between simulation facilities (see Figure 1). This standard simulation interchange format is implemented in XML and is described fully in Annex B of this document.

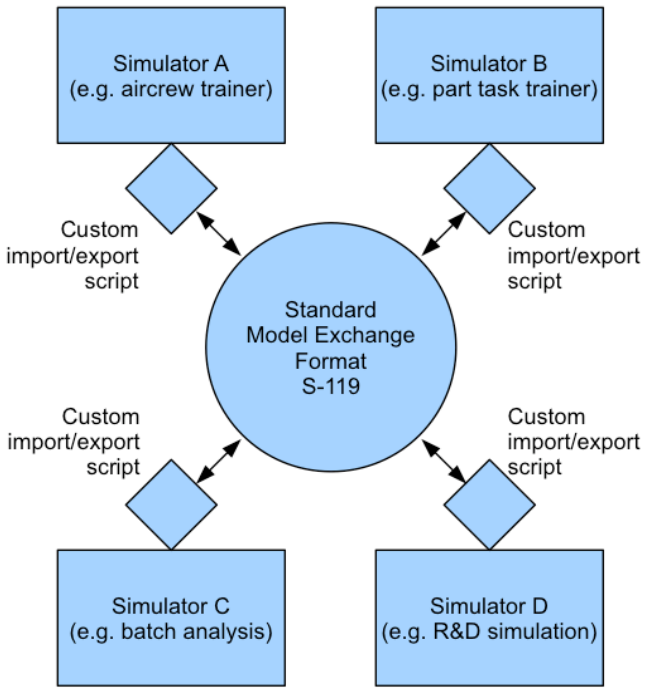

Figure 1 — Model exchange via a standardized format

The standard interchange format includes:

a) Standard variable name definitions — to facilitate the transfer of information by using these standard variables as a “common language.” The interchange format can be used without using standard variable names. However, it will be more difficult because the exported model will have to include explicit definitions of all variables instead of just a subset unique to the particular model.

b) Standard function table definition — to allow easy transfer of nonlinear function tables of arbitrary dimension.

c) Standard coordinate system and reference frame definitions — used by the variable names and function tables to clearly define the information being exchanged.

d) Standard static math equation representation — for definition of static equations forming part of aerodynamic, propulsive, or other models.

A specialized grammar of XML provides a format for the exchange of this information, therefore each organization is required to design import/export tools that comply with the standard one time only.

Use of this standard will result in substantially reduced cost and time necessary to exchange aerospace simulations and model information. Test cases have indicated an order of magnitude reduction in an effort to exchange simple models when utilizing this standard. Even greater benefits could be attained for large or complicated models.

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1 Scope

This standard establishes definitions of the information and format used to exchange air vehicle simulations and validation data between disparate simulation facilities. This standard is not meant to require facilities to change their internal formats or standards. With the concept of an exchange standard, facilities are free to retain their well-known and trusted simulation hardware and software infrastructures. The model is exchanged through the standard, so each facility only needs to create import/export tools to the standard once. These tools can then be used to exchange models with any facility at minimal effort, rather than creating unique import/export tools for every exchange.

The standard includes a detailed convention for representing simulation variables. The purpose of this is to unambiguously describe all variables within the model when it is exchanged between two simulation customers or facilities. The variable representation includes explicit specification of all coordinate systems, units, and sign conventions used. XML is used as the mechanism to facilitate automation of the exchange of the information. Based on the definitions in the standard, a list of recommended but nonobligatory simulation variable names is included in Annex A. This list of standard variable names should further simplify the exchange of information, but is not required for use of the standard.

The standard includes capabilities for a model to be self-validating and self-documenting, with the provenance of a model's components included within the model and transferred with it. Statistical descriptions of the quality of a model may also be included.

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2 Tailoring

The requirements defined in this standard may be tailored to match the actual requirements of any particular program or project. Tailoring of requirements should be undertaken in consultation with the procuring authority where applicable.

NOTE Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

The following sections provide further guidance on specific tailoring situations.

2.1 Partial Use of the Standard

2.1.1 General

Not all aspects of this standard may be applicable to all models or simulation applications. The following guidelines are provided to encourage appropriate use of the standard in a number of example situations.

2.1.2 Creating a New Simulation Environment

This situation calls for use of the complete standard. It is hoped that the team developing the new simulation environment would, if necessary, add to the list of standard variables and coordinate systems.

2.1.3 Creating a New Simulation Model in an Existing Simulation Environment

This situation is defined as creating a new system model (aircraft dynamic model for example) that will run in an existing simulation environment. It is expected that this is the most commonly performed work that will see benefit by application of this standard.

In this case the following tailoring guidelines are applicable.

a) Apply the standard to the new development aspects of the project and all the function tables.

b) Assuming that most or all of the standard variable names and coordinate systems are applicable to the simulation, use them for the new code developed for the simulation.

c) In the existing simulation environment that is being reused, for example the equations of motion, there is no need to rewrite the code to use the standard variable names or coordinate systems. However, in most cases the coordinate systems used in existing simulation environments will be covered in the standard coordinate system definitions herein (Section 5). Therefore the standard coordinate systems can easily be referenced when documenting the simulation and interfaces between the new simulation components and those reused.

2.1.4 Creating or Updating a Simulation with a Long Life Expectancy

A pilot training simulator is an excellent example of this type of simulation. This simulation may only be updated every 3—10 years, so at first glance the standard may seem to be less applicable.

In fact the opposite is true. It is because of the infrequent maintenance that application of the standard is critical. In this case, in each new software update, the original developers (or previous updaters) are probably no longer available, and the update is being performed by different personnel. Software developed using the standard should be easier for the new software team to understand. They are working with clear variable definitions with which they are familiar. The function table format is understood and the functions themselves are better documented. The coordinate system definitions are clear. Changes are recorded for the benefit of any future software update.

In simulations with a long expected life, use of the state, state derivative control, and output conventions as part of the variable naming convention becomes critical as these variables form the core of the model

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and the significant inputs. It is important that the personnel modifying the simulation are able to easily identify the states, state derivatives, and controls.

2.2 Implementing the Standard in a Nonflat or Nonscalar Namespace

The variable naming convention defined within the standard makes no assumption as to the hierarchy of data components, such as object-oriented model implementation or multidimensional storage of matrices and vectors. The standard can accommodate these implementations through the use of a period (.) inserted before the optional domain name (e.g., `aero.bodyForceCoefficient_X`) or through the use of an appropriate indexing mechanism for the chosen implementation language [e.g., `aerobodyForceCoefficient[0]` or `aerobodyForceCoefficient(1)`]. However, it should not be expected that other members of the simulation community maintain implementation-specific conventions. Therefore, on export these variable constructs, should be converted to the flat, scalar namespace defined herein.

2.3 New and Reused Software Tailoring Guidance

The longer the expected life of the simulation, the more helpful the application of the standard becomes. The above tailoring guidelines may be categorized into two common situations: new and reused code.

New simulation code should

a) use coordinate system definitions (Section 5) that coincide with the definitions in the standard;

b) use standard variable names (Section 6) to facilitate consistency and simplify documentation requirements;

c) apply the convention for states, state derivatives, and controls wherever possible; and

d) use standard function tables (Section 7) for all function tables.

NOTE This facilitates consistency in the data, the documentation of the data, and collaboration with other organizations to improve or debug the data.

Reused simulation code should reference the standard only when convenient to document interfaces with new code.

2.4 Creating New Variable Names and Coordinate Systems

The standard variable names and coordinate system definitions are included in the standard to facilitate communication. They provide a “common language” for the exchange. For example, it is not enough to exchange the values of the lift coefficient function. As a minimum, the independent variables used to define the function and their units, sign convention, and reference coordinate system must be defined. This need to precisely define variables is facilitated by having standard variable names and coordinate systems. Of course, new variable names, definitions, and other convenient coordinate systems may be used to exchange models between simulation facilities. However, in such cases, the exporters and importers must carefully define these variables and coordinate systems, or the exchanged model may not produce the desired results. Use of standard variable names and coordinate systems facilitates the exchange.

This standard includes a methodology for creating new standard variables. Its use is encouraged. Annex B provides the URL for submitting additional standard variable names and coordinate systems or comments on existing standard variable names and coordinate systems.

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3 Applicable Documents

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

AIAA R-004-1992	Atmospheric and Space Flight Vehicle Coordinate Systems
ISO 1151-1:1988	Flight dynamics – Concepts, quantities, and symbols – Part 1: Aircraft motion relative to the air
ISO 1151-2:1985	Flight dynamics – Concepts, quantities, and symbols – Part 2: Motions of the aircraft and the atmosphere relative to the Earth
ISO 1151-3:1989	Flight dynamics – Concepts, quantities, and symbols – Part 3: Derivatives of forces, moments and their coefficients
ISO 1151-4:1994	Flight dynamics – Concepts, quantities, and symbols – Part 4: Concepts, quantities and symbols used in the study of aircraft stability and control
ISO 1151-5:1987	Flight dynamics – Concepts, quantities, and symbols – Part 5: Quantities used in measurements
ISO 1151-6:1982	Terms and symbols for flight dynamics – Part 6: Aircraft geometry
ISO 19111:2007	Geographic information – Spatial referencing by coordinates
ISO 80000-1:2009	Quantities and Units – General
IST-CR-90-50	Distributed Interactive Simulation (DIS Application Protocols, Version 2, March 1994)
www.w3.org/XML	Extensible Markup Language (XML) 1.0 (Fifth Edition), 2008-11-26
www.w3.org/Math	Mathematical Markup Language (MathML) Version 2.0 (Second Edition), 2003-10-21

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4 Vocabulary

4.1 Acronyms and Abbreviated Terms

AIAA	American Institute of Aeronautics and Astronautics
AND	aircraft nose down
ANR	aircraft nose right
ANSI	American National Standards Institute
CM	center of mass
DAVE-ML	Dynamic Aerospace Vehicle Exchange Markup Language
DIS	Distributed Interactive Simulation
DTD	Document Type Definition
FE	Flat Earth coordinate system
GE	Geocentric Earth fixed coordinate system
HLA	High Level Architecture
IC	initial condition
ISO	International Organization for Standardization
ISQ	International System of Quantities
MathML	Mathematical Markup Language
MRC	moment reference center
MSL	Mean sea level
RWD	right wing down
SI	Système Internationale d'Unites
URL	Uniform Resource Locator
WGS	World geodetic system
XML	eXtensible Markup Language

4.2 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

Breakpoint
A value of an independent variable at which the value of its dependent variable is specified, or the x coordinate (or abscissa) of a one dimensional table

Center of mass
This standard uses center of mass (CM) as the default location for several coordinate systems. The long-

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standing aeronautical tradition is to refer to this location as the center of gravity (CG). Center of gravity and center of mass are interchangeable for vehicle modeling on or above a large gravitational body in hydrostatic equilibrium like the Earth. However, the difference between CM and CG can become significant when a vehicle maneuvers near small, irregularly shaped gravitational bodies (e.g., asteroids). Thus, center of mass is the more correct term for this important aerodynamic and kinematic reference point.

Confidence interval
An estimate of the computed or perceived accuracy of the data

Coordinate system
A measurement system for locating points in space and attached to a reference frame (Stevens and Lewis, 2003). In this standard they will be orthogonal right-handed triads unless specifically noted.

Dependent variable
An output that is obtained by evaluation of a tabulated function or a MathML expression

EXAMPLE For $C_L(\alpha,\beta)$, C_L is the dependent variable, also called the output.

Function Table
The numeral set of data points used to represent the value of an independent variable as a function of the value(s) of one or more independent variables

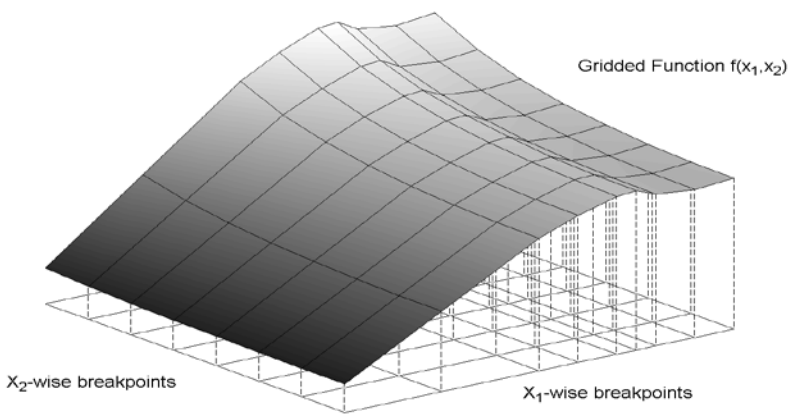
EXAMPLE $C_L(\alpha,\beta)$ may be represented by a function table.

Gridded Table
A multidimensional function table in which all independent variable breakpoints are constant across the function range, but not necessarily evenly spaced

NOTE 1 This is sometimes called an orthogonal table.

NOTE 2 All one-dimensional tables are gridded tables.

EXAMPLE A gridded two-dimensional function



Ground
Smooth surface of the earth at the nadir, not necessarily MSL.

Independent variable
The input(s) to a function table or a MathML expression

EXAMPLE For $C_L(\alpha,\beta)$, α and β are independent variables.

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Inertial velocity
The special case of a velocity for which the relative reference and observer coordinate systems are an inertial frame.

Mean Sea Level
The zero elevation reference in the simulation, normally the geoid. Although many simulations treat MSL and the smooth surface of the Earth as equivalent this is not always true. For example, the WGS84 model equates MSL with the geoid, not the smooth surface.

Observer coordinate system
A coordinate system from which motion of a point (a velocity, acceleration, or higher derivative) is observed (or measured). In many cases this coordinate system is in the same reference frame as the relative coordinate system, however in the most general case, may exist in a different frame. The magnitude and direction of velocity (and higher derivatives) differ depending on the observer coordinate system due to the fact that the relative coordinate system may be in motion relative to the observer. Identified in variable names by the "`ObsFr`" component. If not specified, the observer coordinate system defaults to the same coordinate system as the relative coordinate system.

One-dimensional table
A table whose values are based upon only one independent variable

EXAMPLE $C_L(\alpha)$ may be represented by a one-dimensional table.

Presentation coordinate system
The specific coordinate system in which a variable or vector is presented (or expressed). For example, a specific vector may be presented (expressed) in the body axis coordinate system, the geocentric Earth (ge) coordinate system, or one of the alternatives presented in Section 5. The value of the vector's components (e.g., X, Y, and Z) differs depending on the presentation coordinate system. The presentation frame only determines how the vector is expressed as X, Y, and Z components, as the specific vector of an object is invariant with respect to any arbitrary coordinate frame (i.e., they are contravariant rank one tensors). In other words, the specific vector in two presentation frames differs only by a linear transformation (i.e., a rotation matrix). When one "presents" or "expresses" the vector in a presentation coordinate system, that presentation coordinate system is treated as if it is instantaneously fixed relative to the observer for the given time t (even if the presentation coordinate system is translating and rotating relative to the observer).

The presentation coordinate system is identified in variable names by the initial coordinate system prefix.

Reference coordinate system
The coordinate system that defines the frame of interest of a rotational measurement such as attitude, angular rate, or angular acceleration. Identified in variable names by the "`Of`" component. If not present, the default reference coordinate system is the body coordinate system.

Reference frame
Frames for short. A general definition for a reference frame is: three or more noncolinear points on a rigid body define a reference frame (Stevens and Lewis, 2003). Unlike a coordinate system, a reference frame has no fixed origin, it is in essence a rigid body wherein all points are fixed in position relative to each other. The location of a point or vector in a frame is expressed using a specified coordinate system. Any number of points or vectors may be expressed with any number of coordinate systems (with no relative motion) in the same frame. For example, the Earth is often a reference frame and may have the geocentric Earth (ge) coordinate system attached to the center, and any number of user defined topodetic coordinate systems (such as runways or launch sites) used to locate and orient fixed objects on the Earth. Note however an object moving on or above the surface of the Earth would be in a different reference frame.

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Reference point
The point of interest of a translational measurement such as position, velocity, or acceleration. Identified in variable names by an "`Of`" component. If not specified, the default reference point is the ownship's center of mass.

Relative coordinate system
A coordinate system that defines the origin of a measurement such as position, velocity, or acceleration (translational or rotational). Identified in variable names by the "`Wrt`" component. If not specified, the default relative coordinate system is the same as the presentation coordinate system for translation and the locally-level coordinate system for rotations.

Simulation states (and state derivatives)
In the formulation of a nonlinear simulation model shown as

$$\dot{x} = f_1\{x(t), u(t), w(t)\}$$
$$y = f_2\{x(t), u(t)\}$$

where

$\dot{x}$ represents a vector of the simulation state derivatives

x represents a vector of the simulation states

u represents a vector of the simulation controls

w represents a vector of disturbances

y represents a vector of the simulation outputs.

Static equation
A mathematical statement where the output (left-hand side) does not have direct dependence (right-hand side) on a simulation state

Two-dimensional table
A table whose values are based upon two independent variables

EXAMPLE $C_L(\alpha,\beta)$ may be represented by a two-dimensional table.

Ungridded Table
A multidimensional function table in which the independent variable breakpoints need not be constant across the function range

NOTE This is sometimes called a nonorthogonal table.

EXAMPLE An ungridded two-dimensional function

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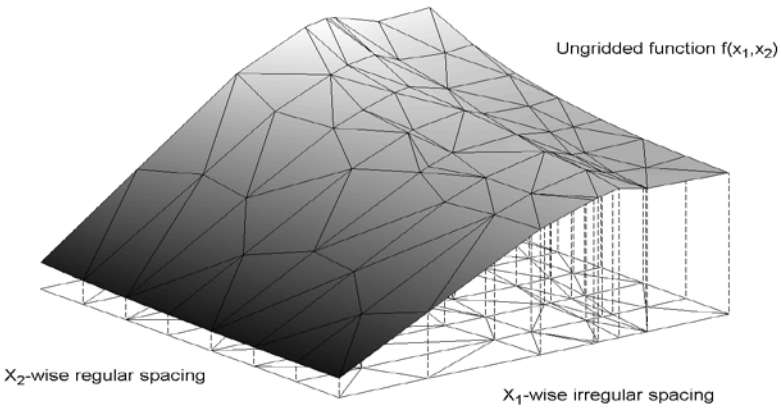

Velocity

The first derivative of position; in the general case, can be applied to either translational or rotational rate-of-change of position. This term normally applies to translational motion; the rotational equivalent is normally called “angular rate.”

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5 Standard Simulation Coordinate Systems

5.1 Background / Philosophy

Most of the coordinate system definitions discussed herein were taken from existing standards, the *ANSI/AIAA Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems* (ANSI/AIAA R-004-1992) and the *Distributed Interactive Simulation* (DIS Application Protocols, Version 2, IST-CR-90-50, March 1994). AIAA R-004-1992 is based on ISO 1151-1:1988 and ISO 1151-3:1972.

Coordinate system standards are also reflected in the variable naming convention. When applicable, the coordinate system is included in the variable name (see Section 6).

5.1.1 Coordinate System Conventions

In general, ANSI/AIAA R-004-1992 is the normative reference for coordinate system definitions. These coordinate systems are discussed in Table 1. However, it is important to emphasize the correlation of the AIAA document and the *Distributed Interactive Simulation* (DIS) coordinate systems. The geocentric Earth fixed coordinate system and body coordinate system are both used in DIS and High Level Architecture (HLA) simulations.

5.1.1.1 Geocentric Earth-Fixed Coordinate System

The Geocentric Earth-Fixed Coordinate System (coordinate system 1.1.3 of Table 1) is identical to the DIS "Geocentric Cartesian Coordinate System" (also referred to as "World Coordinate System" in the DIS).

All variables referenced to this coordinate system use "`ge`" as part of their name for the Geocentric Earth-Fixed Coordinate System. This coordinate system is also frequently called "Earth-centered, Earth-fixed."

5.1.1.2 Body Coordinate System

Another standard coordinate system is the Body Coordinate System (coordinate system number 1.1.7 in ANSI/AIAA R-004-1992). This is identical to the DIS "Entity Coordinates System." The body coordinate system is identified in the variable names by "`body.`"

5.1.1.3 Additional Coordinate Systems

In addition to the coordinate systems defined in ANSI/AIAA R-004-1992, this standard has added the Moment Reference Center, Flat Earth, Locally Level, and Vehicle Reference (or Structural) coordinate systems. The Moment Reference Center coordinate system is a special case body coordinate system (number 1.1.7 in ANSI/AIAA R-004-1992, number 1.1.5 in ISO 1151-1:1998). The Flat Earth and Locally Level coordinate systems are respectively variants of the Normal Earth-fixed coordinate system (number 1.1.4 in ANSI/AIAA R-004-1992, number 1.1.2 in ISO 1151-1:1998) and the Vehicle-carried normal Earth coordinate system (number 1.1.6 in ANSI/AIAA R-004-1992, number 1.1.4 in ISO 1151-1:1998). Both these coordinate systems are normally used in conjunction with an assumption that the Earth forms an inertial reference frame. They are useful for simple simulations, and for creating vehicle model validation data. The Vehicle Reference coordinate system is a body coordinate system that may be used to locate vehicle components within the structure of the vehicle.

The moment reference center coordinate (MRC) system may be used to locate objects in the vehicle. Its axes are aligned with the body coordinate system, however, its origin is fixed at the moment reference center of the vehicle while the body coordinate system origin is at the center of mass (CM) and moves as the center of mass (CM) moves.

The moment reference center coordinate system is identified in the variable names by "`mrc.`"

The flat Earth coordinate system is based on a fixed, nonrotating, flat Earth with no mapping to a round Earth coordinate system, and therefore, latitude and longitude are inappropriate (but can be scaled for

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small maps). The purpose of this coordinate system is to allow, if desired, vehicle checkout simulation to be performed in this coordinate system. This simplifies the use of this standard by simulation facilities that do not normally use a round or oblate spheroidal, rotating Earth model.

The flat Earth coordinate system is identified in the variable names by "`fe.`"

The locally level coordinate system is the reference coordinate system for angles and angular motion. Its origin is fixed at the vehicle center of mass.

The locally level coordinate system is identified in variable names by "`ll.`"

The vehicle reference coordinate system is used to locate vehicle components. It is fixed to the vehicle structure and does not move. The specific definition differs for each vehicle. Sometimes the vehicle system may be the weight and balance reference system for the vehicle. The X origin is often in front of the vehicle, the Y origin in the centerline of the vehicle and the Z origin below the vehicle. The X-axis is often called the fuselage station and is often positive aft, the Y-axis is called the butt line and is often positive to right, and the Z-axis is the waterline and is often positive up. However, these definitions may change with the vehicle and a manufacturing reference system may instead be used.

The vehicle reference system is identified in variable names by "`vrs.`"

5.2 Complete List of Coordinate Systems

The coordinate systems that are referenced are taken largely from paragraph 1.1 of ANSI/AIAA R-004-1992. The moment reference center, flat Earth and locally level coordinate systems for atmospheric flight simulation approximation are additional to that reference. A vehicle reference coordinate system is added for the purpose of locating systems and subsystems in the vehicle. Table 1 is the comprehensive list of coordinate systems that may be used under this standard.

The first column in Table 1 provides the abbreviation recommended for each coordinate system. The coordinate system may be referenced in a variable name by use of its abbreviation. See Section 6 on the variable naming convention.

Table 1 — Standard coordinate systems

Reference Abbreviation	R-004-1992 Paragraph Number	Term	Definition	Symbol
`ei` (for Earth-centered inertial)	1.1.1	Geocentric inertial coordinate system (See Appendix D.2 of R-004 for a modification of this system used for launch vehicles.)	An inertial reference system of the FK5 mean equator and equinox of J2000.0 has the origin at the center of the Earth, the X_I-axis being the continuation of the line from the center of the Earth through the center of the Sun toward the vernal equinox, the Z_I-axis pointing in the direction of the mean equatorial plane's north pole, and the Y_I-axis completing the right-hand system. (See Figure 1A in R-004)	$X_I Y_I Z_I$
Not used, this forms a basis for other definitions	1.1.2	Earth-fixed coordinate system	A right-hand coordinate system, fixed relative to and rotating with the Earth, with the origin and axes directions chosen as appropriate.	$x_O y_O z_O$
`ge` (also called Earth-centered,	1.1.3	Geocentric Earth-fixed coordinate system	A system with both the origin and axes fixed relative to and rotating with the Earth (1.1.2). The origin is at the center of the Earth, the x_G-axis being the continuation of the line	$x_G y_G z_G$

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Reference Abbreviation	R-004-1992 Paragraph Number	Term	Definition	Symbol
Earth-fixed)			from the center of the Earth through the intersection of the Greenwich meridian and the equator, the z_G-axis being the mean spin axis of the Earth, positive to the north, and the y_G-axis completing the right-hand system. (See Appendix D.3 in R-004-1992)	
	1.1.4	Normal Earth-fixed coordinate system	An Earth-fixed coordinate system (1.1.2) in which the z_o-axis is oriented according to the downward vertical passing through the origin (from the origin to the nadir). (See Figure 1C in R-004-1992)	$x_O y_O z_O$
vo	1.1.5	Vehicle-carried orbit-defined coordinate system[a]	A system with the origin fixed in the vehicle, *(the default being the center of mass),* in which the z_o-axis is directed from the spacecraft toward the nadir, the y_o-axis is normal to the orbit plane (positive to the right when looking in the direction of the spacecraft velocity), and the x_o-axis completes the right-hand system. (See Figure 1A in R-004-1992)	$x_O y_O z_O$
ve	1.1.6	Vehicle-carried normal Earth coordinate system[a]	A system in which each axis has the same direction as the corresponding normal Earth-fixed axis, with the origin fixed in the vehicle, *the default being* the center of mass.	$x_O y_O z_O$
body	1.1.7	Body coordinate system[a]	A system fixed in the vehicle, *with the default origin being the center of mass,* consisting of the following axes:	$x\ y\ z$
		Longitudinal axis	An axis in the reference plane or, if the origin is outside that plane, in the plane through the origin parallel to the reference plane, and positive forward.[b] In aircraft or missiles, this is normally from the CM forward towards the nose in the vertical plane of symmetry. It is also normally parallel to the waterline of the vehicle.	x
		Lateral axis	An axis normal to the reference plane and positive to the right of the x-axis (henceforth, positive to the right).	y
		Normal axis	An axis that lies in or parallel to the reference plane, whose positive direction is chosen to complete the orthogonal, right-hand system xyz.	z
mrc	none	A body coordinate	This is a body coordinate system. The default origin is not fixed at the center of	$x_M y_M z_M$

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Reference Abbreviation	R-004-1992 Paragraph Number	Term	Definition	Symbol
(for moment reference center)		system (not in R-004) Longitudinal axis Lateral axis Normal axis	mass, but at the moment reference center (mrc) and therefore does not move. It consists of the following axes: An axis in the reference plane or, if the origin is outside that plane, in the plane through the origin parallel to the reference plane, and positive forward.[b] In aircraft or missiles, this is normally from the MRC forward towards the nose in the vertical plane of symmetry. It is also normally parallel to the waterline of the vehicle. An axis normal to the reference plane and positive to the right. An axis that lies in or parallel to the reference plane, whose positive direction is chosen to complete the orthogonal, right-hand system xyz.	
`wind` (for wind coordinate system)	1.1.8	Air-path system[a] x_a-axis; air-path axis y_a-axis; lateral air-path axis; cross-stream axis z_a-axis; normal air-path axis	A vehicle carried system with the origin fixed in the vehicle, *located at* the center of mass, consisting of the following axes: An axis in the direction of the vehicle velocity relative to the air An axis normal to the air-path axis and positive to the right of the plane formed by the x_a and z_a axes. An axis ▪ in the reference plane or, if the origin is outside that plane, parallel to the reference plane, and ▪ normal to the air-path axis. The positive direction of the z_a-axis is chosen so as to complete the orthogonal, right-hand system $x_a y_a z_a$.	$x_a y_a z_a$ x_a y_a z_a
`sa` (for stability axis system)	1.1.9	Intermediate coordinate system[a] x_s-axis	A system with the origin fixed in the vehicle, *located at* the center of mass, consisting of the following axes. The projection of the air-path x axis on the	$x_s y_s z_s$ x_s

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Reference Abbreviation	R-004-1992 Paragraph Number	Term	Definition	Symbol
		y_s-axis z_s-axis	reference plane, or, if the origin is outside that plane, on the plane through the origin, parallel to the reference plane. An axis normal to the reference plane and positive to the right, coinciding with or parallel to the lateral axis (1.1.7). An axis that coincides with or is parallel to the normal air-path axis so as to complete the orthogonal right-hand system.	y_s z_s
fp	1.1.10	Flight-path coordinate system[a]	A system with the origin fixed in the vehicle (*at* the center of mass) and in which the x_k-axis is in the direction of the flight-path velocity relative to the Earth. The y_k axis is normal to the plane of symmetry and positive to the right. The z_k axis completes the orthogonal right-hand system	$x_k y_k z_k$
aa	1.1.11	Total-angle-of-attack coordinate system[a] (USA practice: aeroballistic coordinate system.)	A system with the origin fixed in the vehicle, *at* the center of mass, in which the x_t-axis is coincident with the x-axis in the body coordinate system (1.1.7). The y_t-axis is perpendicular to the plane formed by the x_t-axis and the velocity vector, positive to the right. The z_t-axis is formed to complete the orthogonal, right-hand system.	$x_t y_t z_t$
fe	None	Flat Earth system (not in R-004)	The Flat Earth coordinate system origin is situated on the Earth's surface directly under the center of mass of the vehicle at the initialization of the simulation. The X_{FE}-axis points northwards and the Y_{FE}-axis points eastward, with the Z_{FE}-axis down. The X_{FE} and Y_{FE} axes are parallel to the plane of the flat Earth.	$X_{FE} Y_{FE} Z_{FE}$
ll	None	Locally Level coordinate system (not in R-004)	A vehicle related coordinate system (1.1.6) with the origin instantaneously at the ownship center of mass. The Z_{LL}-axis passes through the vehicle center of mass and points towards the nadir. The X_{LL}-axis is parallel to the smooth surface of the Earth and oriented toward true north in the geometric Earth model. The Y_{LL}-axis is parallel to the smooth surface of the Earth completing the right-hand triad (East). The locally level coordinate system is valid for	$X_{LL} Y_{LL} Z_{LL}$

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Reference Abbreviation	R-004-1992 Paragraph Number	Term	Definition	Symbol
			geometric or flat Earth models.	
vrs	None	Vehicle Reference system (not in R-004)	A vehicle fixed coordinate system used to locate items in the vehicle. It is often the weight and balance coordinate reference system for the vehicle, or the manufacturing coordinate reference system. The VRS may not be a right-handed coordinate system. X-axis is the longitudinal reference. It may be the Fuselage Station line, normally 0 being in front of the vehicle with the coordinate increasing aft. Y-axis is the lateral reference. It may be the Butt line perpendicular to the vertical symmetric plane of the vehicle and in the geometric center of the vehicle. Positive to the right facing forward (Starboard) Z-axis is the vertical reference. It may be the Waterline and its origin is normally under the vehicle, positive up.	

[a]*By default*, the origins of the coordinate systems selected from ANSI/AIAA-R-004-1992 1.1.5 through 1.1.11 coincide *and are at the center of mass*. If that is not the case, it is necessary to distinguish the different origins by appropriate suffixes and additional coordinate system references.

[b]The reference plane should be a plane of symmetry, or a clearly specified alternative. *This may be specified by the vehicle reference system (vrs).*

[c]Italics indicate clarifications to ANSI/AIAA-R-004-1992.

5.3 Summary

This coordinate system standard should be followed for all future equations of motion. It is necessary for unambiguous reference to coordinate systems in simulation variable names.

5.4 References

ANSI/AIAA Recommended Practice R-004-1992, *Atmospheric and Space Flight Vehicle Coordinate Systems*, 28 February 1992.

Distributed Interactive Simulation (DIS Application Protocols, Version 2, IST-CR-90-50, March 1994)

ISO 1151-1:1988, *Flight Dynamics – Concepts, quantities and symbols – Part 1: Aircraft motion relative to the air,* 15 April 1988.

ISO 1151-3:1989, *Flight dynamics – Concepts, quantities, and symbols – Part 3: Derivatives of forces, moments and their coefficients,* 1 April 1989.

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6 Standard Simulation Variables

6.1 Background / Philosophy

6.1.1 Rationale for Having Standard Variable Name and Naming Conventions

The standard variable names and coordinate system definitions are part of this standard to facilitate communication. They provide a “common language” for information exchange. For example, to unambiguously exchange a function representing a lift coefficient, the minimum information required to be transmitted includes the independent variables used to define the function (such as angle-of-attack, angle-of-sideslip, Mach number, Reynolds number, and aircraft configuration), their units, their sign conventions, and their reference coordinate systems. Such an exchange will be facilitated by using standard variable names and coordinate systems.

If a model uses standard variable nomenclature the information defining the model data may be exchanged entirely by reference to this standard. Additionally, adherence to the variable naming convention included herein will allow the list of standard variables to grow as needed by the user community. Use of the convention to maintain consistent variable names will ease user workload and maximize the benefits to be obtained from this standard.

Positions, angles, velocities, and angular velocities referred to in this standard are defined in accordance with ANSI/AIAA R-004-1992.

6.2 Variable Naming Convention

The purpose of the naming convention is to provide guidance for the creation of variable names consistent with the standard variable names (Annex A). This will allow expansion of Annex A over time, further expanding the set of names available to facilitate model exchanges.

Variable names are constructed from components that jointly serve to fully define the variable in its particular application. A combined mixed case and underscore variable name convention is used. In variable name components that consist of multiple words, the first letter of each word is capitalized (medial capitals). Where the simulation language in use allows it, and where the logic of the simulation requires it, an underscore may be replaced by a period (.) to indicate an object member, or by parentheses or brackets to indicate an array member.

The following general rules for naming all variables shall be followed.

a) Variables shall have meaningful names.

b) Variable names shall not exceed 63 characters in length. Brief, but complete, names are most effective.

c) Names shall be constructed using US-ASCII 7-bit character encodings.

6.3 Variable Name Methodologies

There are three methods specified for defining variables consistent with this standard. Different methods are described for

a) Position variables (linear or angular), arrays or structures;

b) Motion variables (velocities, accelerations, or higher derivatives, both linear and angular), arrays or structures; and

c) All other variable names.

The naming convention for position variables and for variables describing motion are different than other types of variables because of the general requirements to specify coordinate systems that uniquely define

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position and velocity. In addition, the following guidelines for capitalization when creating variable names are provided:

d) The first letter in the variable name is lower case. Similarly, the first letter in the prefix and the first component following the prefix are lower case.

e) The first letters in acronyms and abbreviations are capitalized.

f) Distinct components in variable names, after the first component, shall begin with a capital letter.

g) Units are not capitalized unless the unit abbreviation itself is.

6.3.1 The Physical Basis for the Position, Velocity, Acceleration (and Derivatives thereof) Naming Convention

To ground the discussion of variable names it is useful to refer to a standard dynamics text and to review the equation of Coriolis. Figure 2 below shows the derivation of the three-dimensional linear velocity of point p with respect to coordinate system **M** as observed from coordinate system **O**. Coordinate system **M** has translational and rotation motion relative to **O**; in the figure, ω depicts the angular rate of **M** with respect to **O**.

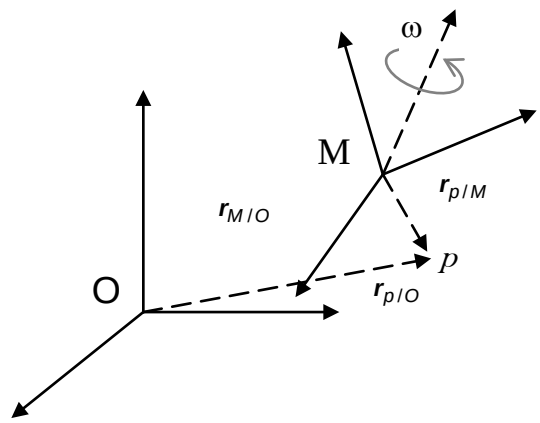

Figure 2 — Rotating reference frames and relative geometry

The velocity of p with respect to **M** as observed from **O** is the vector difference of the velocity of p with respect to **O** and the velocity of **M** with respect to **O** (both of which are observed from **O**):

$$^{O}\dot{r}_{p/M} = {}^{O}\dot{r}_{p/O} - {}^{O}\dot{r}_{M/O} \tag{1}$$

For this discussion, the vector notation used by Stevens and Lewis is used (see Figure 3 below) but other notations are equally valid. Using the equation of Coriolis (Stevens and Lewis equation 1.2-10), the velocity of p with respect to **O** observed from **O** is given by:

$$^{O}\dot{r}_{p/O} = {}^{O}\dot{r}_{M/O} + {}^{M}\dot{r}_{p/M} + \omega_{M/O} \times r_{p/M} \tag{2}$$

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The left-hand side term and the first right hand side term in equation (2) are the velocity terms in the right-hand side of equation (1). Combining the two equations produces the following relationship:

$$ {}^{O}\dot{r}_{p/M} = {}^{M}\dot{r}_{p/M} + \omega_{M/O} \times r_{p/M} \tag{3} $$

Equation (3) shows that the velocity of p with respect to **M** as observed from **O** does not equal the velocity of p with respect to **M** as observed from **M** in the general case. This illustrates the need to clearly specify, for derivatives of a linear position vector, the coordinate systems that define the point (this standard designates the point on the vehicle by "Of"), the origin from which the position is measured (this standard designates this by "Wrt"), and the frame in which the observation is made ("ObsFr"). An additional challenge is to achieve this specification using just the ASCII set of characters that are used to compose variable names.

Figure 3 shows how the notation used by Stevens and Lewis are mapped into the coordinate system components of the variable name schema. Within this standard, point p will be illustrative of the Of variable name component, coordinate system **M** will be illustrative of the Wrt variable name component and coordinate system **O** will be illustrative of the ObsFr variable name component.

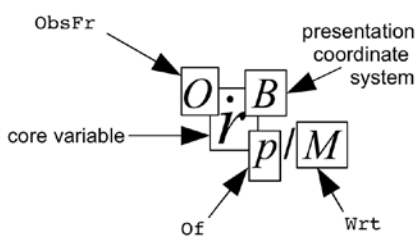

Figure 3 — Mapping Stevens and Lewis notation into variable name components

Another coordinate system that must be specified is that into which the three vector components are resolved in (this standard uses the term 'presentation coordinate system'). This is indicated in Figure 3 as the right superscript B, which would indicate which coordinate system is used to resolve the vector into three scalar components.

In order to define position, velocity, acceleration, or higher derivative variables (both translational and rotational), it is often necessary to specify each of these various coordinate systems. The kinematic requirements to clearly define these variables are presented below.

Positions: For positions (including rotational attitudes), the variable name must specify the origin from which the position is being measured. The name also must specify the coordinate system in which the vector is being resolved.

Take, for example, the core variable name

```
position
```

This name alone is meaningless. Therefore, it is necessary to describe what the position is representing:

```
positionOfPilotEye
```

This is still ambiguous as it is necessary to specify both the point from which the pilot's eyepoint is being measured and into which coordinate system the position vector is being resolved.

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`positionOfPilotEyeWrtCm`

This indicates what point is being located relative to what reference point, and therefore a relative position vector may be defined in 3-space. However, without knowing in which coordinate system the vector is being resolved, any number of coordinate systems could be used. Thus

`bodyPositionOfPilotEyeWrtCm`

This is a complete and unambiguous variable name representing a three-dimensional position. To define the name of any of the three body coordinate system axes, we need to append the name of the appropriate axis and units of measurement:

`bodyPositionOfPilotEyeWrtCm_ft_X`
This defines a scalar variable representing the X-body axis offset of the eyepoint from the center of mass, measured in feet.

Attitudes: Attitude (rotational position) is the orientation of one coordinate system relative to another; therefore, two coordinate systems are required (either explicit or implied) in the variable name to define an attitude. These axis systems are specified using the '`Of`' and '`Wrt`' components. The presentation coordinate system is not used because attitude (either as a quaternion, Euler angles, or rotation cosine matrix) is not a vector quantity resolved into X, Y, and Z components.

If the attitude is expressed as a set of Euler angles, the aeronautical convention of yaw-pitch-roll (3-2-1) rotation sequence is the default. To specify a different rotation sequence, the sequence should be appended to the Euler angle core name, e.g., eulerAngle313 for 3-1-3 rotations. To avoid confusion, for any rotation sequence other than 3-2-1, `_First`, `_Second`, `_Third` should be used for angle selectors in lieu of `_Roll`, `_Pitch`, `_Yaw`.

For example:

`eulerAngleOfIssWrtEi_rad_Pitch`
This variable represents the pitch attitude (rotation about the Y axis) of the user-defined International Space Station (`Iss`) coordinate system relative to the Earth-centered inertial (`ei`) coordinate system, measured in radians. This rotation uses the default yaw-pitch-roll (3-2-1) rotation convention.

`eulerAngle313OfIssWrtOrion_rad_Second`
This variable represents the second rotation angle of the International Space Station (`Iss`) coordinate system relative to another user-defined (`Orion`) spacecraft coordinate system measured in radians. This variable uses yaw-roll-yaw (3-1-3) rotation convention.

`eulerAngleOfImuWrtBody_rad[_Roll|_Pitch|_Yaw]`
This variable represents the three Euler angles of a user-defined inertial measurement unit (`Imu`) coordinate system relative to the body coordinate system.

`eulerAngleOfImu1WrtImu2_rad[_Roll|_Pitch|_Yaw]`
This variable represents the three Euler angles of a user-defined inertial measurement unit (`Imu1`) coordinate system relative to an `Imu2` coordinate system, using the default yaw, pitch, roll

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(3-2-1) rotation convention.

Derivatives of position (translational or rotational): For variables representing derivatives of *translational* positions (velocities, accelerations and higher derivatives thereof) the observer coordinate system must be specified by the naming methodology. The observer coordinate system exists in the reference frame from which the movement (a velocity, acceleration or higher derivative) is observed (or measured). In many cases this is the same reference frame as the relative coordinate system (defined by the `Wrt` component) used to specify the position of the object being observed, but in the most general case may be a different frame. The magnitude and direction of velocity (and higher derivatives) varies with selection of the observer's coordinate system since the relative coordinate system may be moving relative to the observer's coordinate system.

For *rotational* derivatives, it is unnecessary to specify an observer's coordinate system, but both coordinate frames that describe the rotational derivatives are necessary (both `Of` and `Wrt` components).

For example:

`eiAngularRateOfIssWrtOrion_rad_s_Y`
This variable represents the angular rate of the ISS coordinate system relative to the `Orion` spacecraft coordinate system. This is the angular velocity vector is resolved to the Earth-centered inertial (`ei`) coordinate system to measure the Y component in that system.

6.3.2 New Position Variables Naming Convention

The methodology for creating and defining a position variable (linear or angular) that is consistent with the requirements of this standard are as follows.

a) Each variable name may have up to nine components.

b) With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is nondimensional and then the _nd units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

1. <*variable domain*>
2. _<*dynamic equation formulation prefix*>_
3. <*presentation coordinate system*>
4. <*core name*> — the only required component
5. `Of`<*a point for positions or coordinate system for angles, normally on the vehicle*>

   If omitted in the variable name, `Of` defaults to the Cm for translational position and the body coordinate system for rotational position.

6. `Wrt`<"With respect to" *a point or coordinate system*>

   If omitted in the variable name, `Wrt` defaults to the presentation coordinate system for linear positions and to the locally level coordinate system (`ll`) for angular position.

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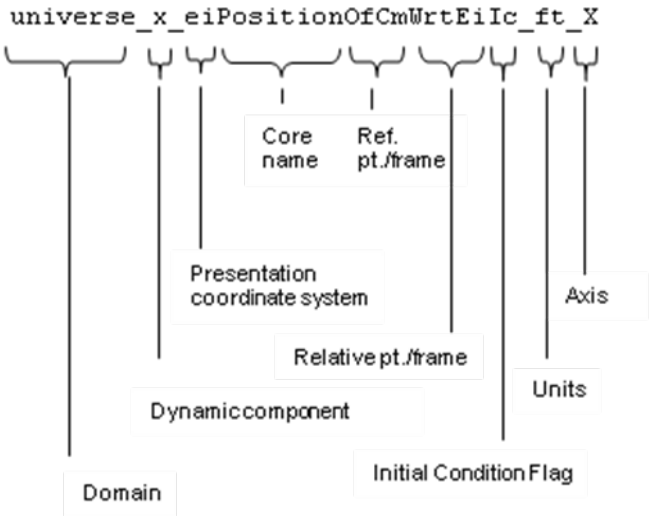
7. `Ic` — initial condition designation
8. _<*units*>
9. _<*specific axis of the presentation coordinate system*>

Rarely are all 9 components of a name used.

For example:



6.3.3 New Velocity, Acceleration, or Higher Derivative Motion Variables Naming Convention

The methodology for creating and defining velocity and acceleration variables (or higher derivatives) consistent with the requirements of this standard are as follows:

a) Each variable name may have up to ten components.

b) With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is nondimensional and then the _nd units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

1. <*variable domain*>
2. _<*dynamic equation formulation prefix*>_
3. <*presentation coordinate system*>
4. <*core name*> — the only required component
5. `Of`<*a point for translation or coordinate system for rotation, normally on the vehicle*>

   If omitted, `Of` defaults to the Cm for translation derivatives and the body coordinate system (`body`) for rotational derivatives.

6. `Wrt`<"With respect to" *a point, frame or coordinate system*>

   The `Wrt` component (relative coordinate system) may be omitted; if so, the relative coordinate system defaults to the presentation coordinate system for translational variables and the locally-

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level coordinate (`ll`) system for rotational variables.

7. `ObsFr`<*"Observed From" coordinate system, only used for translational motion*>

   If "ObsFr" is not specified, it defaults to the same coordinate system specified by the relative coordinate system (the `Wrt` component). If the relative coordinate system is not present, `ObsFr` defaults to the presentation coordinate system.

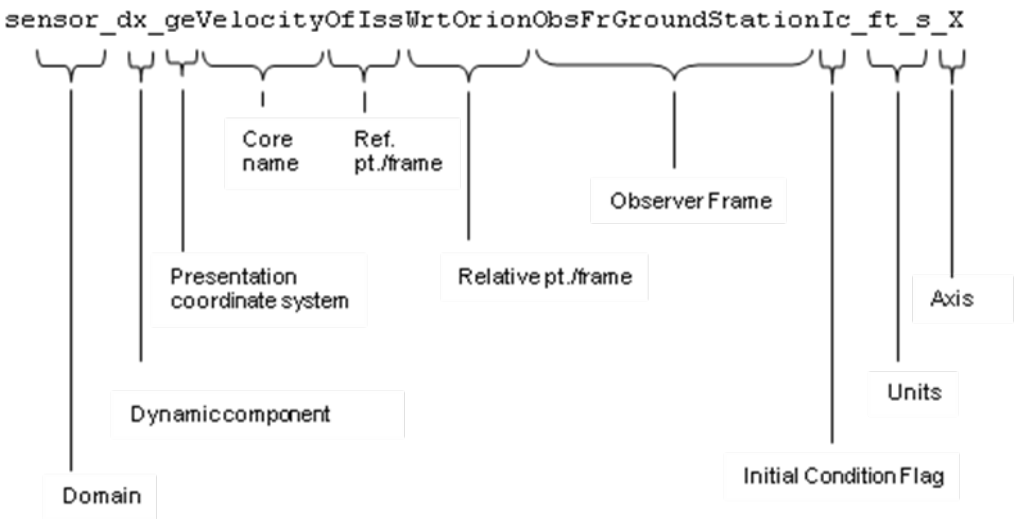
8. `Ic` — initial condition designation

9. _<*units*>

10. _<*specific axis of the presentation coordinate system*>

Rarely are all 10 components of a name used.

For example:



6.3.4 New General Variables Naming Convention

The methodology for defining variables other than positions and derivatives thereof that is consistent with the requirements of this standard are as follows.

a) Each variable name may have up to seven components.

b) With the exception of the core name, all components are optional and should only be used if required by the application. Units must be specified unless the variable is nondimensional and then the _nd units specification is encouraged.

The variable name components are listed immediately below. Descriptions of all the components follow in this section.

1. <*variable domain*>

2. _<*dynamic equation formulation prefix*>_

3. <*presentation coordinate system*>

4. <*core name*> — the only required component

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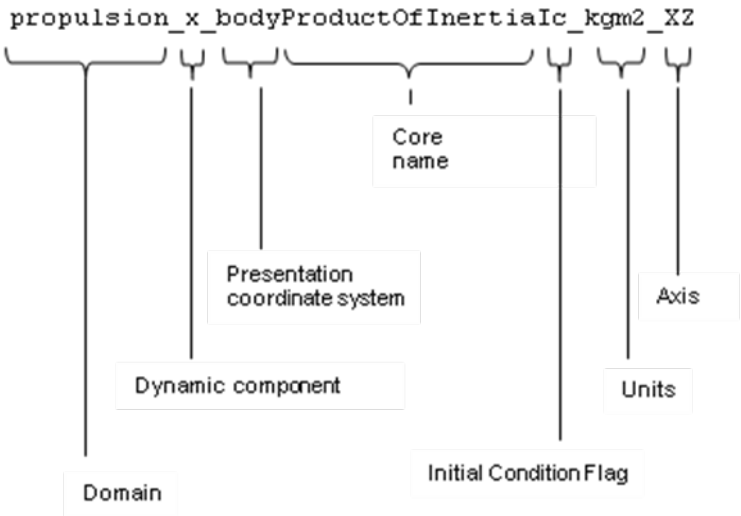
5. `Ic` — initial condition designation
6. _<*units*>
7. _<*specific axis of the presentation coordinate system*>

For example:



6.3.5 Adapting the Naming Convention to Hierarchical and Nested Data Representations

The naming methodology provides all the essential information about a variable in its name. This convention is concise for flat data representations (e.g., single-datum variables, arrays, common blocks). However, the convention can lead to repetition of information if applied to the members of hierarchical and nested data structures (e.g., classes, structures, records) since structure organization might parallel one or more of the variable name components. For example, a developer could create a structure to hold all of the variables in an aerodynamics model. The developer could then declare an instance of the structure with the name “aero;” the structure name would repeat information in the variable source domain component of its member variables.

An example of a “flat” variable name is:

`aero_bodyForceCoefficient_X` where “aero” is the variable domain

Prepending the name of the structure to the standard variable name could result in an expression like the one below:

`aero.aero_bodyForceCoefficient_X`

Such repetition can lead to unnecessarily long expressions. To avoid such repetition, developers may use the following guidelines to adapt the naming convention to hierarchical and nested data structures. First, when a level of a structure represents an organization of data that is equivalent to a variable name component, the developer should use the naming rules for that component to name instances of that structure level. Second, if a component of the variable name appears at a higher level or lower level, the developer should not include that component in the variable names at the current level. Using these guidelines, the example above can be changed to:

`aero.bodyForceCoefficient_X`

If the developer made a further change to represent a vector as a structure and replaced the X, Y, and Z variables for the body force coefficient with that structure, the above expression would change to:

`aero.bodyForceCoefficient.X`

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To meet the intent of the guidelines, it is not necessary that the structure levels address the variable name components in the same order that the convention specifies for variable names. The intent of the naming convention is to unambiguously identify the information represented by a variable; it is not intended to shape data design. Thus, the name components can appear in a different order for a hierarchical or nested data expression. For example:

`bodyForce_lbf.aero.X`

In this example, the data design is such that all the external forces on a vehicle (expressed in body coordinates and in units of pound-force) are collected in a structure whose instance is named "bodyForce" and whose members represent each generator of force as an instance of a structure representing a vector. The variable source domain appears after the core name and units due to the chosen data design. Even so, this data expression unambiguously identifies the variable as effectively as the equivalent scalar variable name, `aero_bodyForce_lbf_X`.

6.4 Components Used to Create Variable Names

6.4.1 Variable Domain Component

This represents the domain in which the variable is calculated. In object-oriented design, it could logically be the object. The domain is normally not included if it (or the object) is the vehicle or aircraft being simulated, for example, airspeed.

In some cases the domain name component only provides background information when exchanging models. For example, in one simulation architecture the domain for `ambientPressure_N_m2` might be "`environment`" and in another architecture the domain might be "`atmosphere.`" The core component of the name is the key. For example:

> `environment_ambientPressure_N_m2` in one simulation architecture is identical to
> `atmosphere_ambientPressure_N_m2` in an another simulation architecture

However in some cases the domain component is critical. For example:

> `aero_bodyForce_lbf_X` and `thrust_bodyForce_lbf_X` are two different variables, both are body axis forces but one comes from the propulsion system model and one from the aerodynamic model. It is this type of variable where domain must be included.

Some domain examples are presented in Table 2. The domain names presented here are not part of any standard; instead they are presented here as examples.

Table 2 — Examples of domain names

`aero`	aerodynamic models
`airLaunchedWeapon`	modeling of munitions launched into the air that have their own dynamics; includes Missile as a sub-domain
`cautionAndWarning`	caution and warning simulation
`cockpit`	input/output from/to cockpit instruments and controls
`controlLaw`	simulation of a control algorithm
`controlLoading`	models of the control system feel
`controlSurface`	simulation of an aerodynamic control effector
`controlSystem`	collective model of control laws and control effectors on a vehicle

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`electrical`	models of the electrical system
`engine` (or `thrust` or `propulsion`)	thrust generation models
`environment`	atmospheric models (ambient properties, wind, clouds, etc.)
`failureSystem`	failure modeling and fault injection
`fltDirect`	flight director models
`fuelSystem`	fuel system models
`gun`	model of vehicle mounted guns
`hydraulics`	hydraulic system models
`landingGear`	landing gear models
`massProperties`	tree-based modeling of vehicle mass and moments of inertia
`missile`	missile models. Domain could be more specific, for example `missileAim9x`.
`motion`	motion system models and algorithms
`navigationDatabase`	mapping of waypoints, airports, runways, legs, procedures, and navigation transmitters (all of which are subdomains)
`navigationReceiver`	modeling of signal-based navigation sensors
`navigationTransmitter`	modeling of navigation signal generators (e.g., radios, GPS)
`parachute`	parachute models
`propulsion`	models the collection of thrust generators (engines) on a vehicle
`radar`	models the radar system. Domain could be more specific, for example `radarApg79`)
`relGeom`	relative state (position, velocity, and acceleration) of each vehicle to each other vehicle
`sensor`	models of sensors
`sensorSystem`	modeling the collection of sensors on a vehicle
`sim`	Domain encompassing control of the simulation, configuration of a simulation run, control of mathematical techniques such as integration type, etc.
`vehicle`	modeling of the vehicle as a cooperating system of other domain models
`weaponSystem`	collective model of guns and air-launched weapons on a vehicle
`wheel`	landing gear wheel models

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`world`	world model [shape, dynamics, and reference time(s) plus navigation database and environment domains]
`universe`	domain encompassing world, vehicle, and relative geometry domains

NOTE Users may add as many domains as needed to clearly identify the variable.

Variable name examples using “aero” and “thrust” include:

a) `aero_bodyForce_lbf_X`

b) `thrust_bodyForce_lbf_X`

c) `aero_bodyForceCoefficient_X`

d) `thrust.bodyForceCoefficient_X` — this is an example of `thrust` as a structure.

e) `thrust.bodyForceCoefficient(X)`

6.4.2 Dynamic Equation Formulation Prefix Component

The dynamic equation formulation prefix is used to identify the most important dynamic variables in the simulation, the states (x) and their derivatives ($\dot{x}$), inputs (u), outputs (y), and disturbances (w) as presented in the equation below. These variables characterize the resultant dynamic response of a vehicle as shown in the equations below. In addition to these variables, the standard allows the prefix to separately designate simulation control variables (c). Simulation control variables are used to modify the behavior of the model during simulation and are not part of the vehicle model, while inputs (u) are variables that represent the inputs to the vehicle model which may include pilot control positions. Finally, in simulation or analysis where noise and environmental disturbances are modeled, the disturbances (w) are the final component in the simulation of the total system dynamics.

$$\dot{x} = f_1\{x(t), u(t), w(t)\}$$
$$y = f_2\{x(t), u(t)\}$$

The prefix shall be separated from the body of the variable by an underscore (_) and from the domain name by an underscore (or a period if preceded by a member of a structure or class). The leading underscore is not permitted if a domain name is not present.

6.4.2.1 Identification of Simulation Model States and State Derivatives

The states (x) and state derivatives (dx) are those variables that make the simulation dynamic and are the key variables in a flight simulation model. Basically, any variable that is mathematically integrated is a state derivative. The result of integration of a state derivative over a period of time is a change in the value of the corresponding state over that time. This is true for any integration in a simulation. If the user controls the changes in all the states, they control the trajectory of the simulated model. The time histories of the states and inputs are the key variables required for validation. All outputs are computed directly or indirectly from states and inputs.

The formulation of the equations of motion and the model itself determines what variables are states. This naming convention is not meant to standardize on any variable as a state, but allows the simulation engineer to explicitly identify states in the model implementation, making it easier to document and exchange the models.

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Examples:

`x_bodyVelocityWrtEi_ft_s_X`	`x_` prefix indicates that this variable is a state
`dx_bodyAccelerationWrtEi_ft_s2_X`	`dx_` prefix indicates that this variable is a state derivative

6.4.2.2 Identification of Simulation Model Inputs

The simulation model inputs (u) are those variables that provide the pilot or autopilot inputs to the vehicle model. These are also called controls in many references. As with the states and state derivatives, the model inputs are key variables for validation. All model outputs are computed directly or indirectly from model states and inputs.

The formulation of the model itself determines which variables are inputs. This naming convention is not meant to standardize on any variable as an input, but allows the simulation engineer to explicitly identify them, making it easier to document models, exchange them, and verify them.

Examples:

`u_controlSurfacePos_deg_avgAileron`	`u_` prefix indicates that this is a model input
`controlLaw_u_controlSurfacePos_deg_avgAileron`	same variable name with domain prefix
`controlLaw.u_controlSurfacePos_deg_avgAileron`	same variable name in a hierarchical architecture
`u_pilotControlPos_rad_long`	Another example of the longitudinal pilot input

6.4.2.3 Identification of Simulation Model Disturbances

The disturbances (w) are those variables that provide environmental disturbances or system noise to the simulation models.

Disturbances may be inserted into the vehicle model, environment, or equations of motion, depending upon implementation schemes. This naming convention is not meant to standardize on any variable as a disturbance, but allows the simulation engineer to explicitly identify disturbances, making it easier to document models, exchange them, and verify them.

Examples:

`w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw`	`w_` prefix indicates that this variable is a disturbance
`environment_w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw`	same variable name with domain (environment) added
`environment.w_bodyAngularRateTurbulenceWrtGe_deg_s_Yaw`	same variable name in a hierarchal architecture

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6.4.2.4 Identification of Simulation Model Outputs

The simulation model outputs (y) are those variables that are the outputs of the physics of the simulation models as formulated by the state equations. This is meant to assist in the specification of the state equations, mainly to help simplify model exchanges between simulations used for analysis and those used for real-time man-in-the-loop or hardware-in-the-loop simulations.

Example:

`y_leftHorizonalActuatorRamPosition_deg`	y_ prefix indicates that this variable is a model output.

6.4.2.5 Identification of Simulation Controls

The simulation controls (c) are those variables that provide the simulation operator control of the simulation [not to be confused with simulation model inputs (u)]. The simulation controls should not affect any vehicle states, state derivatives, or outputs.

The software and hardware architecture of the simulation determines what variables are simulation controls. This naming convention is not meant to standardize on any variable as a control, but allows the simulation engineer to explicitly identify simulation controls. Clear definition of simulation controls makes validation of a simulation much easier after a model is exchanged.

Examples:

`c_simDuration_s`	c_ prefix indicates that this variable is a simulation control
`c_deltaTime_s`	another example
`sim_c_deltaTime_s`	same variable name with domain added
`sim.c_deltaTime_s`	same variable name in a hierarchal architecture

6.4.3 Presentation Coordinate System Component

This is the coordinate or reference system to which the variable is referenced or in which it is measured (it is indicated by the “B” in Figure 3). Table 1 specifies the standard coordinate system abbreviations that should be used. If no coordinate system pertains to the variable or the core variable name needs no reference system to be unambiguous (e.g., Airspeed), this part of the variable name may be omitted.

6.4.3.1 Conventions Used

Earth fixed and local coordinate systems by convention use X, Y, Z, for both translation and (X, Y, Z), (Pitch, Roll, and Yaw), or (First, Second, Third) for rotation axis indices. The origin and attitude of local coordinate systems (flat Earth for example) may be user defined (such as N, E, D). Local coordinate systems are meant for runway, test range, target reference, navigational aids, etc.

6.4.3.2 Variable Name Examples

The following variable names are provided as examples.

`x_bodyAngularRate_rad_s_Roll`	These are all equivalent variable names where `body` is the coordinate system and `roll` is the

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`x_bodyAngularRate_rad_s.Roll` `x_bodyAngularRate_rad_s_X`	specific axis in the body axis system, roll indicating angular motion about the longitudinal axis relative to the locally-level frame (`Wrt` defaults to locally-level for rotational variables). NOTE In this example the variable is designated as a state.
`x_bodyVelocityWrtEi_m_s_X` `x_bodyVelocityWrtEi_m_s.X`	These represent translational inertial velocity in the body coordinate system along the longitudinal axis (the translational variable analogous to the rotational variable above). These are all equivalent variable names.
`geVelocity_m_s_Y`	This represents a translational velocity with `ge` specified as the coordinate system and `Y` as the specific axis. This noninertial velocity of the CM is relative to and measured in the geocentric Earth-fixed (ge) coordinate system.

`bodyTurbulenceVelocityWrtGe_ft_s_Z`
`bodyTurbulenceVelocityWrtGe_ft_s [3]`
`bodyTurbulenceVelocityWrtGe_ft_s.Z`
	These are all equivalent variable names where `body` is the coordinate system and `Z` is the specific axis in the body coordinate system, `Z` indicating vertical translational motion. Also illustrated as a vector and structure.

`runway22VelocityOfLeftWheelWrtTd_ft_s_Z`	Here `runway22` is the coordinate system (user defined) and `Z` is the specific axis, also indicating translational motion. `LeftWheel` is the point on the vehicle and `Td` (touchdown point) is the reference point.
`bodyAccelOfPilotEyeWrtEi_m_s2_Y`	Here `body` is the coordinate system and `Y` is the specific axis, also indicating translational motion. Design pilot eyepoint is the point on the vehicle.
`x_eiVelocity_ft_s_X`	This is a case where the equations of motion are formulated such that the variable is a state, resolved in the Earth centered inertial (ei) coordinate system
`eiVelocity_ft_s_X`	This is a case where the equations of motion are formulated such that the variable is not a state
`x_llVelocity_ft_s_X`	Locally Level coordinate system
`x_feVelocity_ft_s_X`	Flat Earth coordinate system
`bodyAngularRate_rad_s_Pitch`	
`bodyAngularRate_rad_s_Roll`	
`bodyAngularAccel_rad_s2_Yaw`	

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