NASA/TM-2009-215701

Mars Aerial Regional-Scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations

Christopher A. Kuhl
Langley Research Center, Hampton, Virginia

March 2009

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at 443-757-5803

- Phone the NASA STI Help Desk at 443-757-5802

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2009-215701

Mars Aerial Regional-Scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations

Christopher A. Kuhl
Langley Research Center, Hampton, Virginia

March 2009

TABLE OF CONTENTS

TABLE OF FIGURES

1.0 INTRODUCTION

This document defines the formal coordinate systems for the Aerial Regional-scale Environmental Survey (ARES) flight systems, subsystems, and assemblies. The purpose of a formal coordinate systems document is to ensure the reliability and compatibility of the various ARES flight systems design and analyses activities. The systems specified herein apply to the ARES Flight Spacecraft, including the Cruise Stage, the Entry, Descent, & Landing (EDL) system, the Atmospheric Flight System (AFS).

The coordinate systems are direct (right-handed) orthogonal axis system. All references to aircraft and spacecraft coordinates are made using millimeters, with indication of dimensions in inches in brackets [].

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

1

2.0   ARES PRIMARY COORDINATE SYSTEMS

ARES has multiple coordinate systems in use for design and analysis purposes. Several of these coordinate systems are interdependent as shown in Fig X.   The primary coordinate system for interdisciplinary communication is through the Airplane Design Axis System, which is ultimately transposed to the Aeroshell then the Launch Vehicle coordinates for reference.
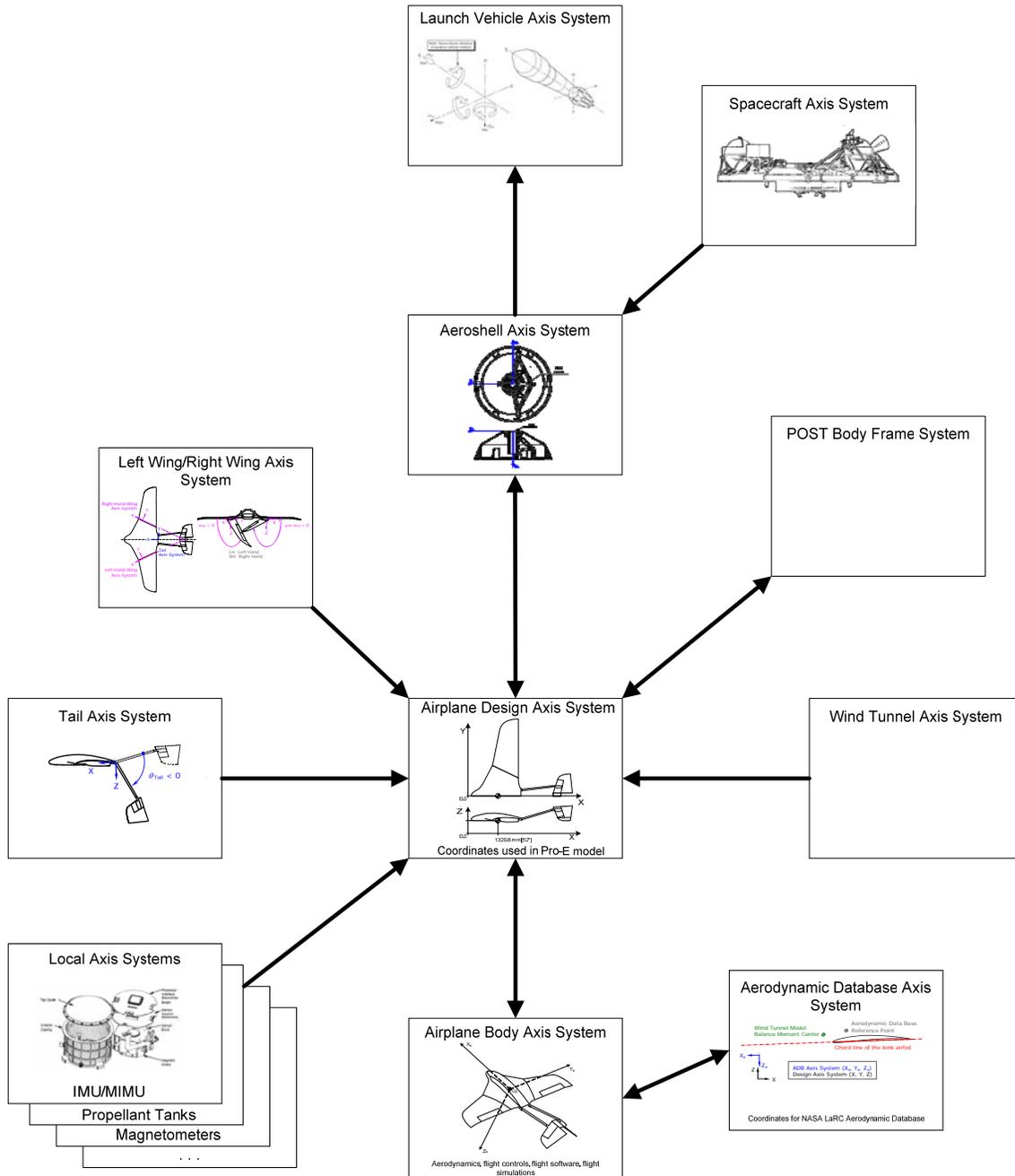
Figure 1. ARES Coordinate Systems and Interdependency

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

2

2.1 AIRPLANE DESIGN AXIS SYSTEM

The ARES Airplane Design Axis System is used for all engineering drawings, CAD models, mechanical and thermal analysis results, tracking mass properties, in the manufacturing of aircraft structure, mechanical systems. It is common practice to name the X, Y and Z axis respectively Fuselage Station (FS), Butt Line (BL) and Water Line (WL). For reference, the Airplane nose is located at FS(x) = 143.334 mm and WL(z) = 194.505 mm. The Airplane Design Axis is defined by:

X-axis: orthogonal to the main spar forward face, positive towards the aft
Y-axis: orthogonal to the Airplane symmetry plane, positive towards the right wing
Z-axis: completes a right hand system (positive out the top of the airplane)

Figure 2 shows the axis origin located at:

X_0: 1311.4 mm in front of the Main Spar tooling face
Y_0: on the Airplane symmetry plane
Z_0: 116.662 mm below the intersection of the main spar forward face and OML at Y_0
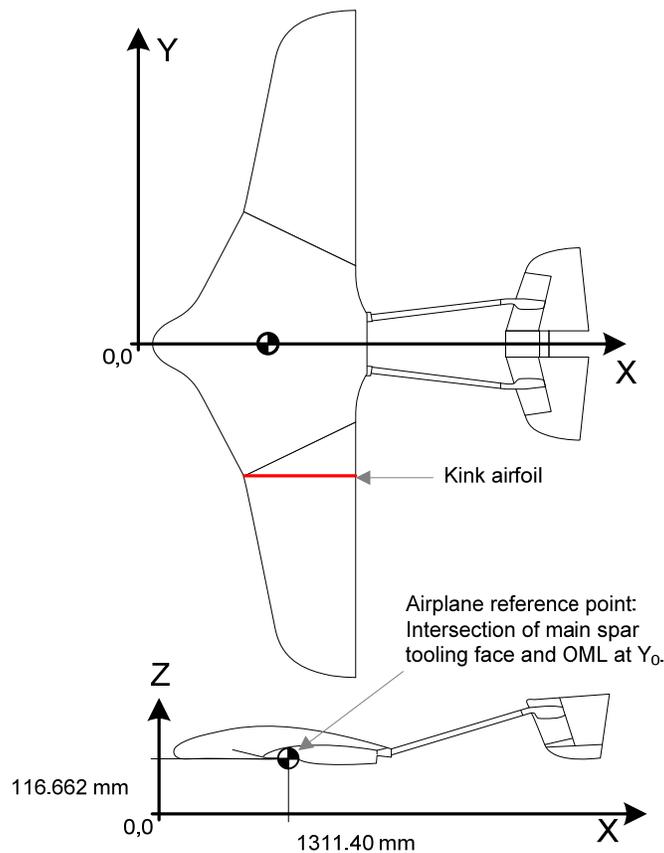
Figure 2. Airplane Design Axis System

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

3

2.2   AERODYNAMIC DATABASE (ADB) AXIS SYSTEM

The Airplane's aerodynamic data sets are contained in the Aerodynamic Data Base (ADB) established by NASA LaRC. The Axis System used in the Aerodynamic Data Base, subscript a, is defined by:

X_a-axis: aligned with the chord line of the kink airfoil, positive forward
Y_a-axis: orthogonal to the Airplane symmetry plane, positive out the right wing
Z_a-axis: completes a right hand system, positive down

Figure 3 shows the ADB Origin is located along with Design Axis BL, -41.6 mm below the Design Axis Origin WL, and +10.4457 mm ahead of the Design Axis Origin FS pitched 177.925°. The ADB Axis Origin relative to the Airplane Design Axis Origin is given by:

Translation:
Fuselage Station (x) = 10.4457 mm
Butt Line (y) = 0 mm
Water Line (z) = -41.6 mm

Rotation:
Yaw (ψ) = 0°
Pitch (θ) = 177.925°
Roll (φ) = 0°

For reference, the Airplane nose is located at X_a = -141.35 mm, y_a = 0 mm, z_a = -231.1386 mm. The coordinates of Aerodynamic Data Base Reference Point in the ADB Axis System are: X_a = -1266.9 mm, y_a = 0.0 and z_a = -313.1 mm.
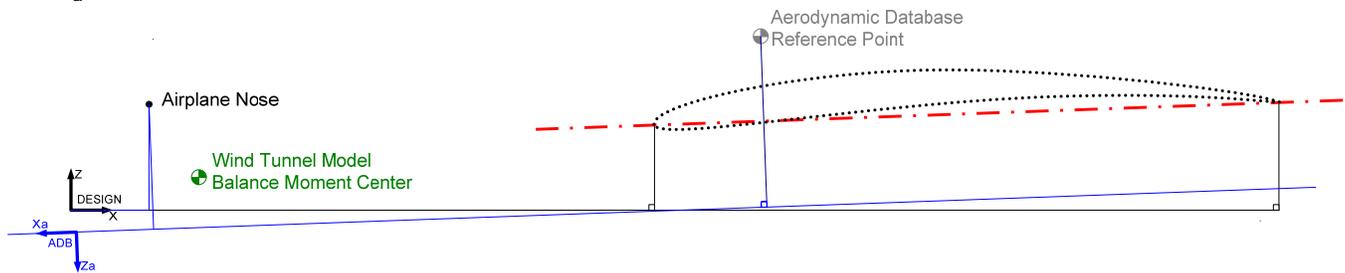
Figure 3. Aerodynamic Data Base Axis System
(ABD Axis Origin shown in blue)

2.3   QUARTER SCALE WIND TUNNEL MODEL AXIS SYSTEM

The Wind Tunnel Model is a quarter scale (1/4) model of the ARES Airplane used for wind tunnel testing. The aerodynamic forces and moments are measured at the Balance Moment Center (Figure 3). The coordinates of the Balance Moment Center in the Wind Tunnel Model Axis System are:
x = 234.315 mm, y = 0.0 mm, z = 65.8876 mm

The Wind Tunnel Model Axis Origin Relative to Airplane Design Axis Origin is given by:

Translation:
Fuselage Station (x) = 0.28857 mm
Butt Line (y) = 0 mm
Water Line (z) = -6.452435 mm

Rotation:
Yaw (ψ) = 0°
Pitch (θ) = 0 °
Roll (φ) = 0°

2.4   AIRPLANE BODY AXIS SYSTEM

The Body Axis System convention is used for aircraft-related technical communications regarding Aerodynamics, Flight Controls, Dynamics, Flight Software, and Modeling discussions.

The Body Axis System, subscript b, is the Aerodynamic Data Base (ADB) Axis System translated to the Airplane Center of Gravity. The Center of Gravity is chosen at the state where the airplane has a full propellant load with the Mass Spectrometer inlet cover in place (the Mass Spectrometer cover is ejected after extraction and prior to flight).
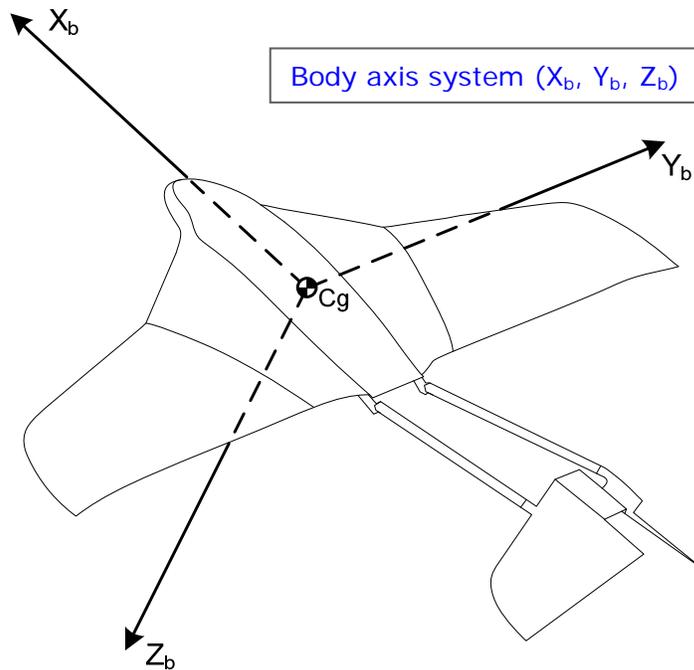
Figure 4. Body Axis System convention

The Airplane Body Axis System, shown in **Error! Reference source not found.**, is defined by:
 X_b-axis: aligned with the chord line of the kink airfoil, positive forward
  Y_b-axis: orthogonal to the Airplane symmetry plane, positive out the right wing
  Z_b-axis: completes a right hand system, positive down

The axis Origin, located at the airplane center of gravity, is:
Airplane Center of Gravity: To Be Chosen during Phase A Study.

For purposes of analyses, The Airplane velocity components with respect to the Body Axis System shall follow the following convention:
  U   velocity along the axis X_b
  V   velocity along the axis Y_b
  W   velocity along the axis Z_b
  p   roll rate along the axis X_b (positive to the right)
  q   pitch rate along the axis Y_b (positive nose upward)
  r   yaw rate along the axis Z_b (positive nose right)

2.5 COORDINATES FOR MOVEABLE SURFACES

The master geometry CAD model is used for definition of the movable control surfaces Axis Systems. The Flight Control Unit specification [TBD] shall be used for convention of the movable control surfaces deflections.

2.5.1 Left Wing / Right Wing Axis Systems

Aeroshell packaging requires the wings and the tail of the Airplane to be folded to accommodate the space allocated to the Airplane. An Axis System is defined for each folding section: Left Wing, Right Wing and Tail. The Right Wing is defined by the wing located on the positive Y-Axis of the Airplane Design Axis System (see Section 1.1).
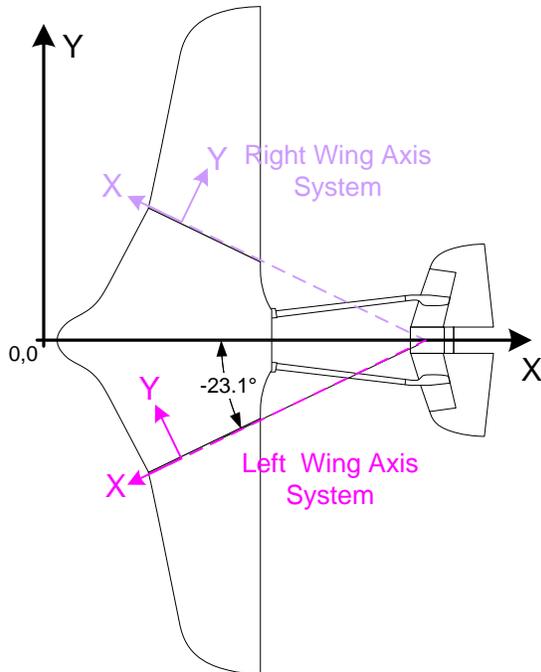

Figure 5. Airplane folding sections Axis Systems
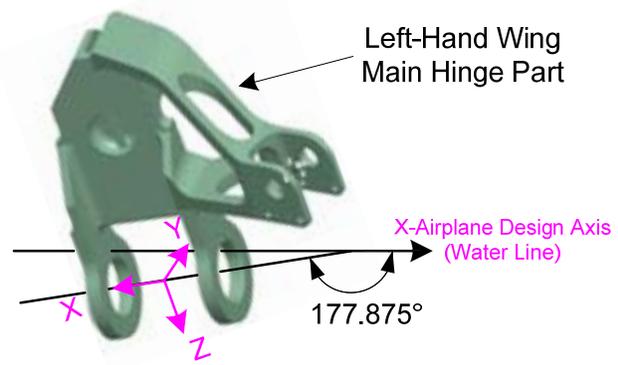
Figure 6. Left Hand Wing Hinge Axis System

The Left Wing/Right Wing Axis System, shown in Figure 5, is defined by:

X-axis: along the wings hinge axis, positive forward
Wing Y- and Z-axes define planes that intersect the Airplane symmetry plane through a common line.
Z-axis: positive down

The direction of the X-axis is chosen to ease transformation to the ARES Airplane Body Axis System. The axis origin, X_0, is located at the Main Hinge center (See).

The Left Wing Axis Origin Location Relative to Airplane Design Axis origin is given by:

Translation:	**Rotation**:
Fuselage Station (x) = 1328.84 mm	Yaw (ψ) = 23.1°
Butt Line (y) = -1119.02 mm	Pitch (θ) = 177.875°
Water Line (z) = 131.104 mm	Roll (φ) = 0°

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

6

The Right Wing Axis Origin Location Relative to Airplane Design Axis origin is given by:

Translation:	Rotation:
Fuselage Station (x) = 1328.84 mm	Yaw (ψ) = -23.1°
Butt Line (y) = 1119.02 mm	Pitch (θ) = 177.875°
Water Line (z) = 131.104 mm	Roll (φ) = 0°

2.5.2 Tail Axis System

The Tail Axis System, shown in Figure 7, is defined by:
- X-axis: aligned with the ABD Axis System longitudinal axis.
- Y-axis: along the tail hinge axis, also orthogonal to the Airplane symmetry plane
- Z-axis: completes a right hand system, positive down

With the Origin located at:
- Y_0: on the Airplane symmetry plane
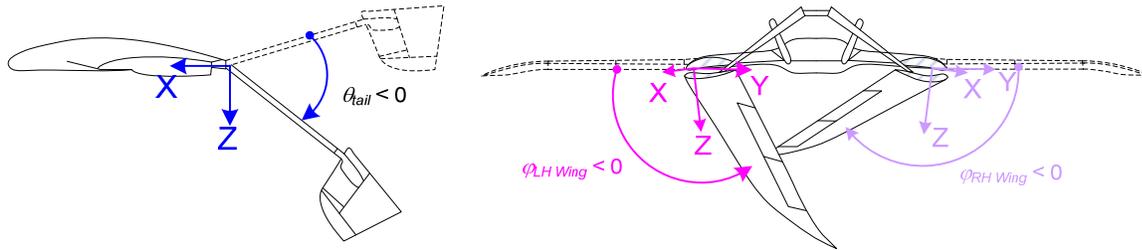
Figure 7. Folding sections angles sign convention

The Tail Axis Origin Location Relative to Airplane Design Axis origin is given by:

Translation:	Rotation:
Fuselage Station (x) = 2383.97 mm	Yaw (ψ) = 0°
Butt Line (y) = 0 mm	Pitch (θ) = 177.925°
Water Line (z) = 167.478 mm	Roll (φ) = 0°

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

7

2.5.3 Angles sign convention

The following sign convention is used for the folding sections:
-      Deployed angles = 0º
-      Stowed angles < 0º, measured from the deployed configuration

The Wings stowed configuration is composed of two rotations; the first one around the Main Hinge axis and the second one around the lower rocket pin axis (See Figure 8).
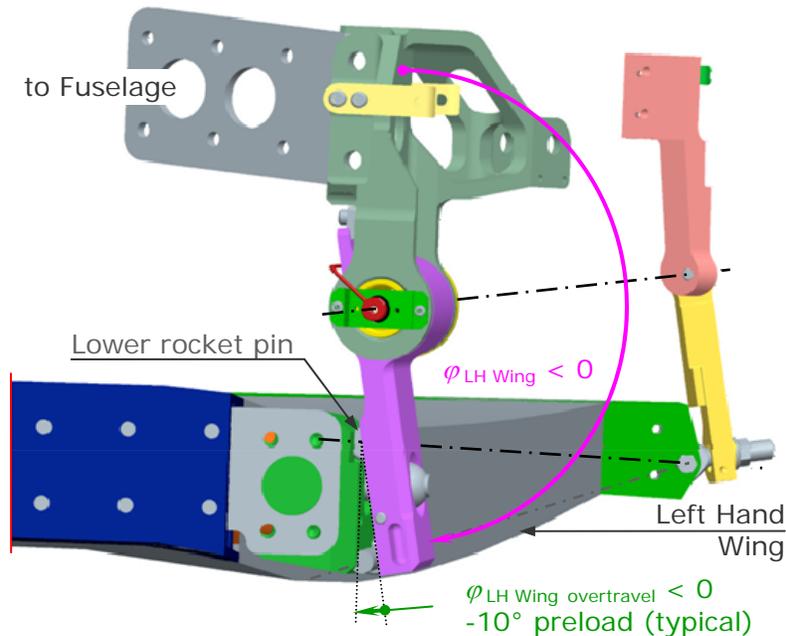
Figure 8. Left Hand Wing Stowed configuration angles

2.6   LOCAL AXIS SYSTEMS

Local Axis Systems may be defined for each specific Airplane sections (i.e. Wings, Tail, etc.) and movable control surfaces. Preferably, the Local Axis Systems should be extracted from the master geometry CAD model. A local coordinate system for hardware and components that are position sensitive or where position must be tracked (i.e. science instruments, cameras, etc) will be recorded in this document. Components that will contain local axis systems include: Airplane Thrusters, IMU-MIMU, Radar Altimeter, Radar Altimeter Antenna, Radar Altimeter Absorber, Air Data System Probes, CAS Actuators and Resolvers, CAS Position Transducers, Fuel Load, Oxidizer Load, Helium Load, Magnetometers, Context Camera, Video Camera, Mass Spectrometer, Neutron Spectrometer, Entry Data System.

2.7   AEROSHELL AXIS SYSTEM

The Aeroshell Axis System, shown in Figure 9, is defined by:

X_A-axis: orthogonal to the Aeroshell centerline, in the plane of the AES aft leg, positive towards the Airplane nose

Y_A-axis: completes a right hand system

Z_A-axis: on the Aeroshell centerline, positive towards heat shield tip

The axis Origin is located at:

X_{AO} is on the Aeroshell centerline

Y_{AO} is on the Aeroshell centerline

Z_{AO} is on the top surface of the Backshell Interface Plate (BIP)
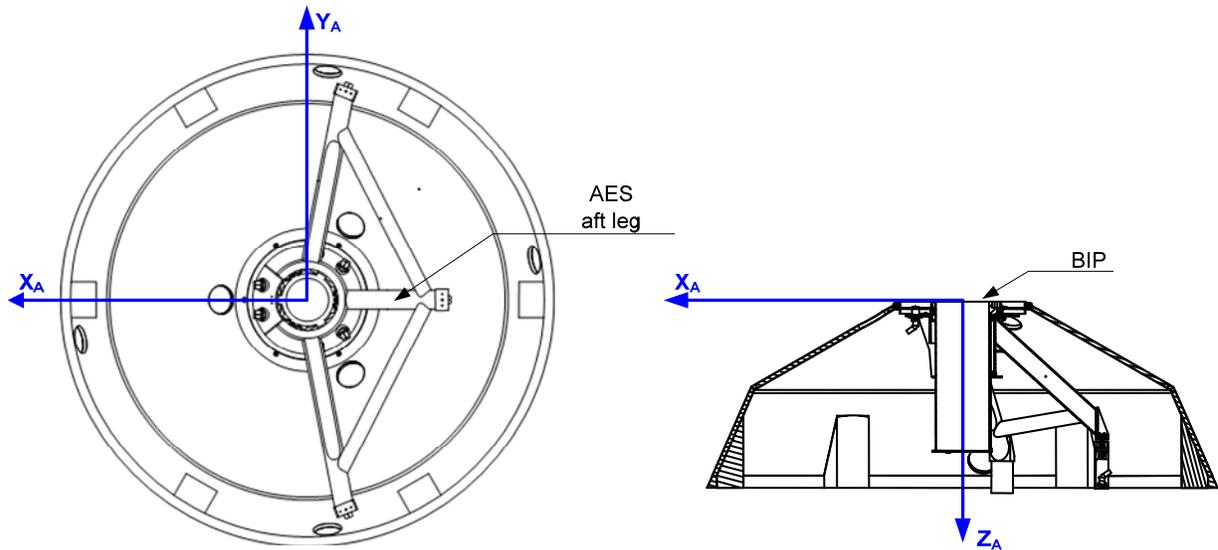
Figure 9. Aeroshell Axis System
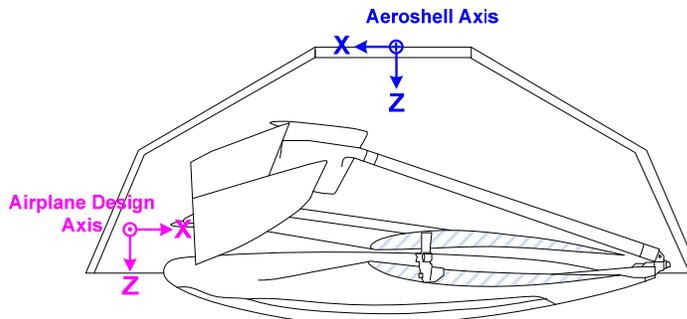
Figure 10. Aeroshell Axis Relative to Airplane Design Axis

The Aeroshell Axis Origin Location Relative to Airplane Design Axis origin (Figure 10) is given by:

Translation:	**Rotation**:
Fuselage Station (x) =1219.20 mm	Yaw (ψ) =180°
Butt Line (y) = 0 mm	Pitch (θ) = 0°
Water Line (z) = 816.9046 mm	Roll (φ) = 0°

3.0 SPACECRAFT (CRUISE STAGE) AXIS SYSTEM

The Spacecraft Axis System is nominally identical to the Aeroshell Axis System with the origin and positive direction of each axis identical (Figure 11).

The Spacecraft Axis System is defined by:

X_A-axis: origin location and positive direction identical to Aeroshell Axis System, Section 1.1.

Y_A-axis: completes a right hand system

Z_A-axis: identical to Aeroshell Axis System, Section 1.1.

The Axis Origin is located at:

X_{AO} is on the Aeroshell centerline

Y_{AO} is on the Aeroshell centerline

Z_{AO} is on the top surface of the Backshell Interface Plate (BIP)
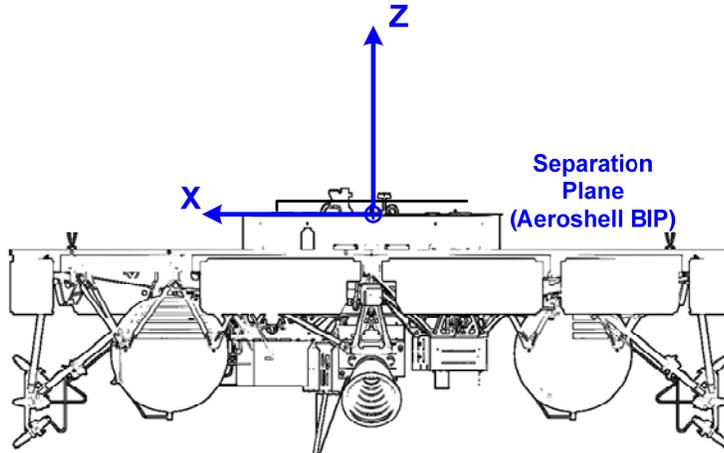
Figure 11. Spacecraft Axis System

The Spacecraft Axis Origin Location Relative to Airplane Design Axis origin is given by:

Translation:	Rotation:
Fuselage Station (x) =1219.20 mm	Yaw (ψ) =180°
Butt Line (y) = 0 mm	Pitch (θ) = 0°
Water Line (z) = 816.9046 mm	Roll (φ) = 0°

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

10

4.0   LAUNCH VEHICLE (DELTA 2925) AXIS SYSTEM

4.1   LAUNCH VEHICLE AXIS SYSTEM

The Delta II 2925 vehicle axes are shown in Figure 12. The vehicle longitudinal axis is inline with the vehicle centerline. Axis II is on the downrange side and axis IV is on the up-range side of the vehicle. The vehicle pitches about the I and III axes. Positive pitch is defined by the rotation of the nose of the vehicle upward, toward axis IV. The vehicle yaws about axes II/IV. Positive yaw rotates the nose to the right, towards the I axis. The vehicle rolls about the centerline. Positive roll is clockwise rotation, looking forward (from axis I towards axis II). The third-stage spin table also spins in the same direction as the positive roll direction.
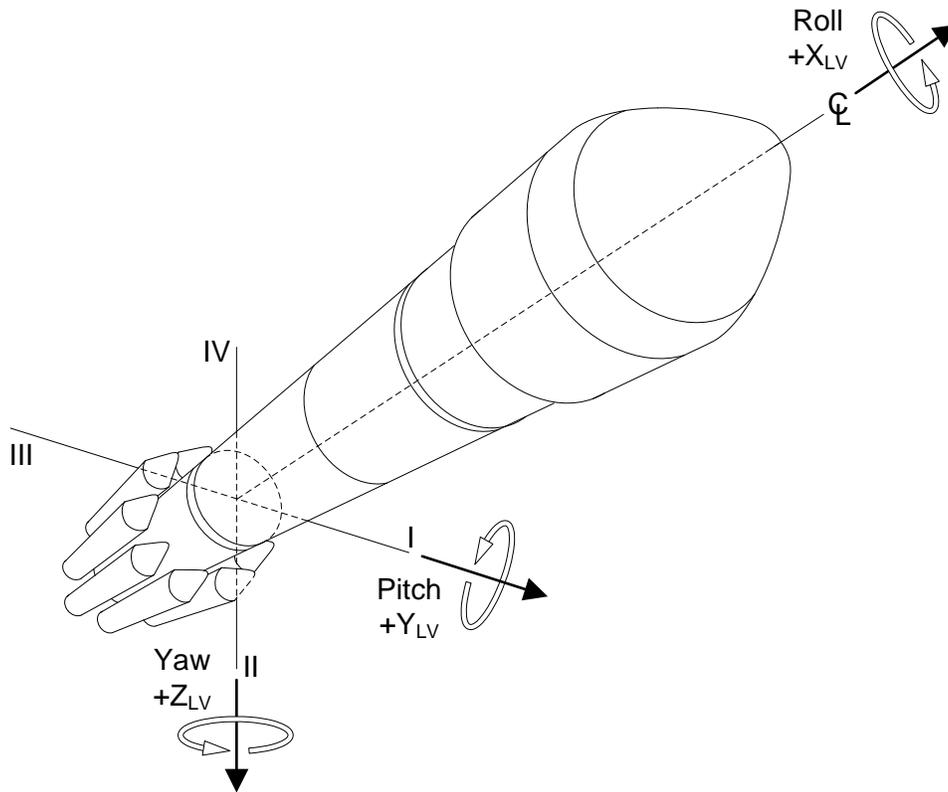

Figure 12. Delta 2925 Vehicle Axes
[Delta II Payload Planner's Guide – July 2006, The Boeing Corporation]

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

11

4.2 PAYLOAD STATIC ENVELOPE REFERENCE

Location of the payload is referenced to Delta II 2925 Station Number notation is shown in Figure 13. Station number units are in inches and measured along the X-axis of the launch vehicle coordinate system (station number is positive in the $-X_{LV}$ direction, see Figure 12). The origin of the launch vehicle station number notation is near the top of the mobile service tower.
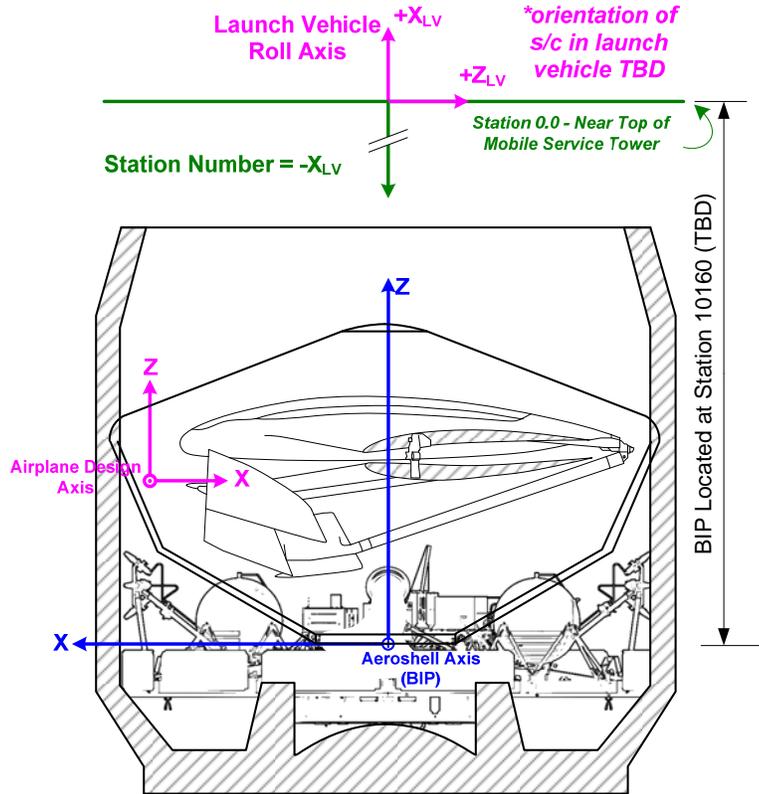
Figure 13. Payload Static Envelope 2.9-m Fairing, Three-Stage Configuration

The Launch Vehicle Axis Origin Location Relative to Aeroshell Axis origin is given by:

Translation:	**Rotation**:
Station 0 ($-X_{Lv}=0$) =4000 mm	Yaw (ψ) =0°
$Y_{LV} = 0$ mm	Pitch (θ) = -90°
$Z_{LV} = 0$ mm	Roll (φ) = 0°

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

12

5.0   ARES TRANSPARENT COORDINATE SYSTEMS

ARES design and analysis tools as well as testing facilities utilize internal coordinate systems to develop design and/or testing data. These coordinate systems are used only by the software or test facility and transparent to the rest of the ARES design activities. All results from these sources shall be transformed back into the ARES Design Axis System. Transparent coordinate systems within various analyses tools include; Post Body Frame Coordinate System, Pro-Engineer Reference Frame, and NASTRAN Reference Frame.

6.0 PRIMARY COORDINATE SYSTEMS COMPARISONS

$X_{S/C}$

X_{AS}

AES aft leg

Z_A

X_{AFS}

$Z_{S/c},\ Z_{AS},\ Z_{AFS}$
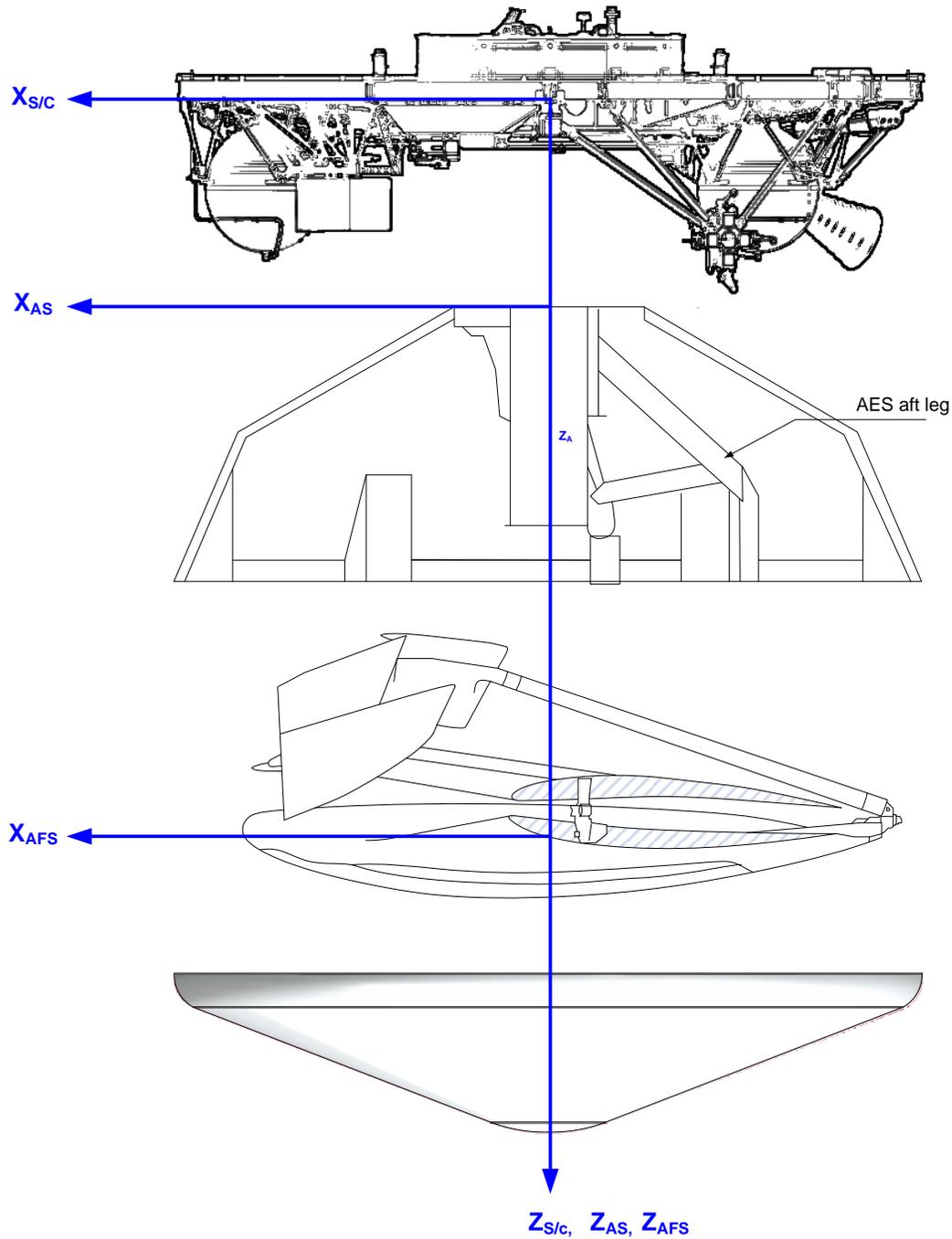
Figure 14. Primary Coordinate Systems Comparison

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

14

7.0   TRANSFORMATION MATRICES

7.1   DEFINITION: LOCAL TO GLOBAL AXIS SYSTEM

According to Euler's rotation theorem, any rotation may be described using three angles. The convention used here is the yaw-pitch-roll convention, where the first rotation is by an angle ψ about the Z-axis (yaw), the second is by an angle θ about the new Y-axis (pitch), and the third is by an angle φ about the new X-axis (roll).

Any rotation can be given as a composition of rotations about three axes:

- a rotation around Z $\quad R_Z = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$

- a rotation around Y $\quad R_Y = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$

- a rotation around X $\quad R_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{bmatrix}$

and thus can be represented by a 3 x 3 matrix:

$$R = \begin{bmatrix} \cos\psi\cdot\cos\theta & -\sin\psi\cdot\cos\varphi+\cos\psi\cdot\sin\theta\cdot\sin\varphi & \sin\psi\cdot\sin\varphi+\cos\psi\cdot\sin\theta\cdot\cos\varphi \\ \sin\psi\cdot\cos\theta & \cos\psi\cdot\cos\varphi+\sin\psi\cdot\sin\theta\cdot\sin\varphi & -\cos\psi\cdot\sin\varphi+\sin\psi\cdot\sin\theta\cdot\cos\varphi \\ -\sin\theta & \cos\theta\cdot\sin\varphi & \cos\theta\cdot\cos\varphi \end{bmatrix}$$

Then the total transformation can be given as a composition of a rotation and a translation:

$$M = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \text{ with } T = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} \text{ a translation in the three directions, X, Y and Z}$$

To be consistent, the coordinates of a point **A** are altered according to: $A = \begin{bmatrix} A_x \\ A_y \\ A_z \\ 1 \end{bmatrix}$

The *Local Axis* is the coordinate system on which the original data points exist and the *Global Axis* is the coordinate system to which those points will be transformed. Angles and Translations are referenced to the *Global Axis* system.   The transformation given below transforms Local points to Global points by first rotating then translating the Global Axis to the Local Axis.

$A_{global\_referenced} = (\vec{R}\cdot\vec{T})\cdot A_{local\_referenced}$

To transform from Local to Global, the transformation becomes:

$A_{local\_referenced} = (\vec{R}\cdot\vec{T})^{-1}\cdot A_{global\_referenced}$

7.2   AERODYNAMIC DATABASE AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

Note: Transformation matrix returns results relative to the Global Axis System:
    Local = "Aerodynamic Database Axis System"
    Global = "Airplane Design Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 10.1117 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & -40.2156 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{in millimeters}$$

with $\theta = 177.925°$

7.3   LEFT WING AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

Note: Transformation matrix returns results relative to the Global Axis System:
    Local = "Left Wing Axis System"
    Global = "Airplane Design Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} \cos\psi \cdot \cos\theta & -\sin\psi & \cos\psi \cdot \sin\theta & 1328.84 \\ \sin\psi \cdot \cos\theta & \cos\psi & \sin\psi \cdot \sin\theta & -1119.02 \\ -\sin\theta & 0 & \cos\theta & 131.104 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\psi = 23.1°$ *and* $\theta = 177.875°$

7.4   RIGHT WING AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

Note: Transformation matrix returns results relative to the Global Axis System:
    Local = "Right Wing Axis System"
    Global = "Airplane Design Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} \cos\psi \cdot \cos\theta & -\sin\psi & \cos\psi \cdot \sin\theta & 1328.84 \\ \sin\psi \cdot \cos\theta & \cos\psi & \sin\psi \cdot \sin\theta & -1119.02 \\ -\sin\theta & 0 & \cos\theta & 131.104 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\psi = -23.1°$ *and* $\theta = 177.875°$

7.5   TAIL AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

<u>Note</u>: Transformation matrix returns results relative to the Global Axis System:
     <u>Local</u> = "Tail Axis System"
     <u>Global</u> = "Design Axis System"

$$\vec{R}\cdot\vec{T} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 2383.97 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 167.478 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\theta = 177.925°$

7.6   WIND TUNNEL MODEL AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

<u>Note</u>: Transformation matrix returns results relative to the Global Axis System:
     <u>Local</u> = "Wind Tunnel Model Axis System"
     <u>Global</u> = "Design Axis System"

$$\vec{R}\cdot\vec{T} = \begin{bmatrix} 1 & 0 & 0 & -0.045434 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -6.452435 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

7.7   AEROSHELL AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

<u>Note</u>: Transformation matrix returns results relative to the Global Axis System:
     <u>Local</u> = "Aeroshell Axis System"
     <u>Global</u> = "Airplane Design Axis System"

$$\vec{R}\cdot\vec{T} = \begin{bmatrix} -1 & 0 & 0 & 1328.84 \\ 0 & -1 & 0 & -1119.02 \\ 0 & 0 & 1 & 131.104 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\psi = 180°$

7.8 SPACECRAFT AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

<u>Note</u>: Transformation matrix returns results relative to the Global Axis System:
    <u>Local </u>= "Spacecraft Axis System"
    <u>Global</u> = "Airplane Design Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} -1 & 0 & 0 & 1328.84 \\ 0 & -1 & 0 & -1119.02 \\ 0 & 0 & 1 & 131.104 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\psi = 180°$

7.9 SPACECRAFT AXIS SYSTEM TO AEROSHELL AXIS SYSTEM

<u>Note</u>: Spacecraft Axis System and Aeroshell Axis System are ***identical***.
    Transformation matrix returns results relative to the Global Axis System:
    <u>Local </u>= "Spacecraft Axis System"
    <u>Global</u> = "Aeroshell Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

7.10 LAUNCH VEHICLE AXIS SYSTEM TO AEROSHELL AXIS SYSTEM

<u>Note</u>: Transformation matrix returns results relative to the Global Axis System:
    <u>Local </u>= "Launch Vehicle Axis System"
    <u>Global</u> = "Aeroshell Axis System"

$$\vec{R} \cdot \vec{T} = \begin{bmatrix} 0 & 0 & -1 & 4000 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{millimeters}$$

with $\theta = -90°$

7.11 AIRPLANE BODY AXIS SYSTEM TO AIRPLANE DESIGN AXIS SYSTEM

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

18

8.0   APPENDIX A: AIRPLANE NOSE LOCATION

The airplane nose is located at the following positions on various coordinate systems:

Airplane Design Axis System
      x = 143.334 mm
      y = 0 mm
      z = 194.505 mm

Aerodynamic Database (ADB) Axis System
      x = -141.35 mm
      y = 0 mm
      z = -231.1386 mm

Body Axis System
      x = 0 mm
      y = 0 mm
      z = 0 mm

Left Wing Axis System
      x = 1526.10 mm
      y = 564.19 mm   (Right Wing y = -564.19 mm)
      z = -120.07 mm

Tail Axis System
      x = 2238.19 mm
      y = 0 mm
      z = -108.14 mm

Aeroshell Axis System
      x = 1075.866 mm
      y = 0 mm
      z = 1011.410 mm

Launch Vehicle Axis System
      x = -2988.590 mm (Station 2988.590)
      y = 0 mm
      z = -1075.866 mm

Spacecraft Axis System
      x = 0 mm
      y = 0 mm
      z = 0 mm

9.0   APPENDIX B: EXCEL TOOL FOR COORDINATE SYSTEM TRANSFORMATIONS.

A Microsoft® Excel 2003 tool was created to assist in coordinate system transformations. The transformation matrices listed in this document are implemented into this tool.   Figure 15 shows the main worksheet of the excel tool. The original points are entered as x, y, z coordinates and the original and subsequent transformation coordinates are selected from the columns above the points.

Not every coordinate system combinations have direct transformations. Consequently almost all transformations most pass through either the Airplane Design Axis or the Aeroshell Axis.   If a particular transformation does not exist, the spreadsheet will display an error.
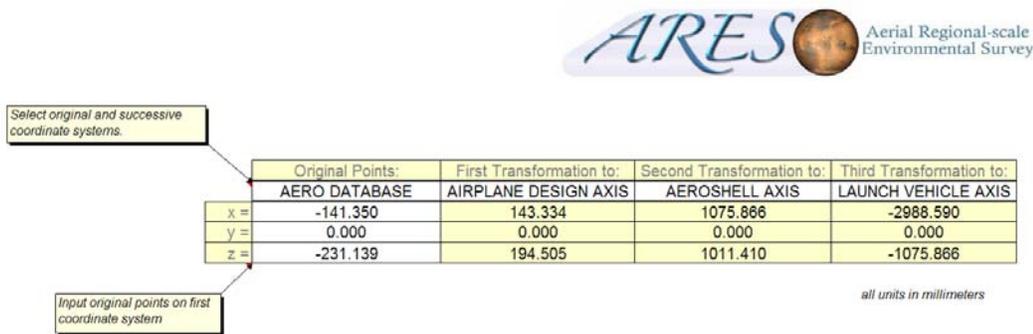
Figure 15. EXCEL Tool for Coordinate Transformation

The second worksheet in the excel tool comprises the majority of the transformation calculations. This sheet acts as a database of the transformation coefficients between two coordinate systems, which are rotations of yaw, pitch, and roll listed in degrees, and translations Tx, Ty, Tz listed in millimeters. The program determines if the transformation is "forward" or "reverse" based on the axis chosen on the main page.

Mars Aerial Regional-scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations
NASA/TM-2009-215701

20

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-03-2009	Technical Memorandum	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Mars Aerial Regional-Scale Environmental Survey (ARES) Coordinate Systems Definitions and Transformations	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Kuhl, Christopher A.	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
	698671.02.07.02.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
NASA Langley Research Center Hampton, VA 23681-2199	L-19409

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
National Aeronautics and Space Administration Washington, DC 20546-0001	NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
	NASA/TM-2009-215701

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 20
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This document defines the formal coordinate systems for the Aerial Regional-scale Environmental Survey (ARES) flight systems, subsystems, and assemblies. The purpose of a formal coordinate systems document is to ensure the reliability and compatibility of the various ARES flight systems design and analyses activities. The systems specified herein apply to the ARES Flight Spacecraft, including the Cruise Stage, the Entry, Descent, and Landing (EDL) system, the Atmospheric Flight System (AFS).

15. SUBJECT TERMS
ARES; Airplane; Coordinate; Mars; Transformation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	27	(443) 757-5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18