

AMS Orientation in LVLH System

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ABSTRACT

The AMS reference system is fixed with respect to the shuttle or the ISS. This paper gives the transformations from this reference to the Local Vertical/Local Horizontal (LVLH) system.

Subject headings: AMS, shuttle and LVLH reference systems

1. Introduction

In the EVENTH block of the standard AMS ntuple, we can find the shuttle (or ISS) ephemerides: altitude (RadS, cm) in the Aries Mean-of-2000 inertial reference frame [1] (I2000), latitude (ThetaS, rad) in the Greenwich True-of-Date reference [1] (GTOD), longitude (PhiS, rad) in GTOD, attitude (YawS, PitchS, RollS angles, rad) in LVLH, and velocity (angular velocity VelocityS, rad/s, speed vector latitude VelTheta and longitude VelPhi in rad).

We are mainly interested in the particle arrival direction, both in the AMS (local) and in the LVLH reference systems.

2. Definition of used reference systems

Figure 1 shows the orientation of the AMS reference system (in red) and of the shuttle one: their axes are parallel, but AMS adopts the opposite directions for the X and Z axes.

Let's define the shuttle axes directions using the unit vectors $\{\hat{e}_1, \hat{e}_2, \hat{e}_3\}$ (X_S, Y_S, Z_S axis respectively).

The *roll* angle is defined about the shuttle X_S axis (positive when \hat{e}_2 goes toward \hat{e}_3); the *pitch* angle is about the Y_S axis (positive when \hat{e}_3 goes toward \hat{e}_1); the *yaw* angle is about the Z_S axis (positive when \hat{e}_1 goes toward \hat{e}_2).

Figure 2 shows the Local Orbital, or Local Vertical/Local Horizontal reference frame.

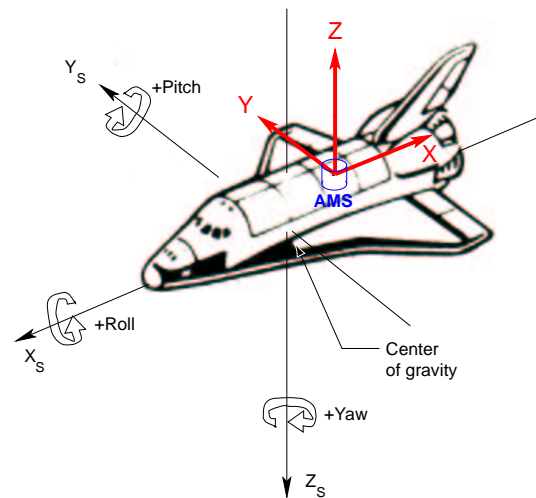


Figure 1. Shuttle and AMS reference systems. Yaw, pitch, roll definitions.

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In LVLH, the Z_{LO} axis is directed toward the Earth center, the X_{LO} axis is along the orbital velocity and the Y_{LO} axis completes the right handed triplet.

3. Transformations

The shuttle *attitude* (i.e. the orientation of its reference system with respect to another “privileged” system) is expressed giving the Roll, Pitch and Yaw angles of rotation around the X_S , Y_S and Z_S axis respectively. These are the rotations the pilot has to do in order to align the shuttle system with the privileged one. The rotations should be done in the following order: pitch–yaw–roll (i.e. around Y_S , Z_S and X_S axis)².

There exists one ntuple (in the /afs/cern.ch/exp/ams/Offline/ntuples/cas directory) containing all the CAS data for the STS-91 mission, starting from the shuttle on the launch ramp. The first entry of this ntuple, that should refer to the shuttle in vertical position, gives: $y = 1.5714 \approx \pi/2$, $p = -1.3787 \approx -\pi/2$, $r = -0.1934 \approx 0$ (yaw, pitch, roll values).

Let’s see how the pitch-yaw-roll sequence works with these values. After the pitch-yaw-roll alignment, the shuttle axes are shown in the upper left panel of figure 3. We get the shuttle position starting from this final position and applying the inverse transformation to the Shuttle reference system, that is we apply: $T^{-1}(r, p, y) = [R_1(r)R_3(y)R_2(p)]^{-1} = R_2(-p)R_3(-y)R_1(-r)$.

Thus, we have to apply first a rotation of 0 (i.e. nothing) around the shuttle X_S axis, then a rotation of $-\pi/2$ around the shuttle Z_S axis (lower left panel of figure 3), and finally a rotation of $\pi/2$ around the shuttle Y_S axis (lower right panel). The last panel of figure 3 shows the shuttle in vertical position, as it should be.

We have seen that the transformation that goes from the shuttle reference frame to the LVLH system is:

$$\hat{\mathbf{E}}_j = (\mathbf{T}^{-1})_{jk} \hat{\mathbf{e}}_k = \mathbf{T}_{kj} \hat{\mathbf{e}}_k, \quad (1)$$

(\mathbf{T} is orthogonal and the sum over the repeated indices is understood) while the inverse is

$$\hat{\mathbf{e}}_i = \mathbf{T}_{ij} \hat{\mathbf{E}}_j, \quad (2)$$

where

$$[\mathbf{T}(r, p, y)]_{ij} = \hat{\mathbf{E}}_i \cdot \hat{\mathbf{e}}_j = [R_1(r)R_3(y)R_2(p)]_{ij}. \quad (3)$$

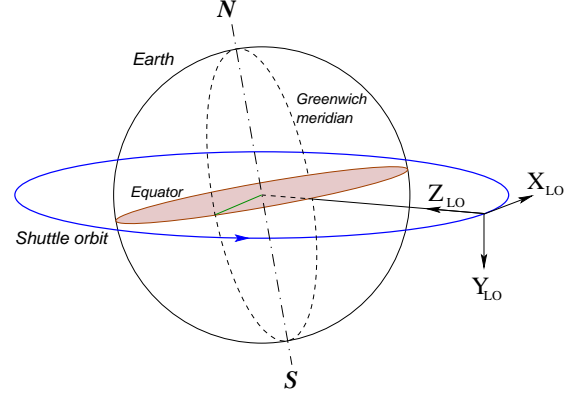


Figure 2. Local Vertical/Local Horizontal reference system.

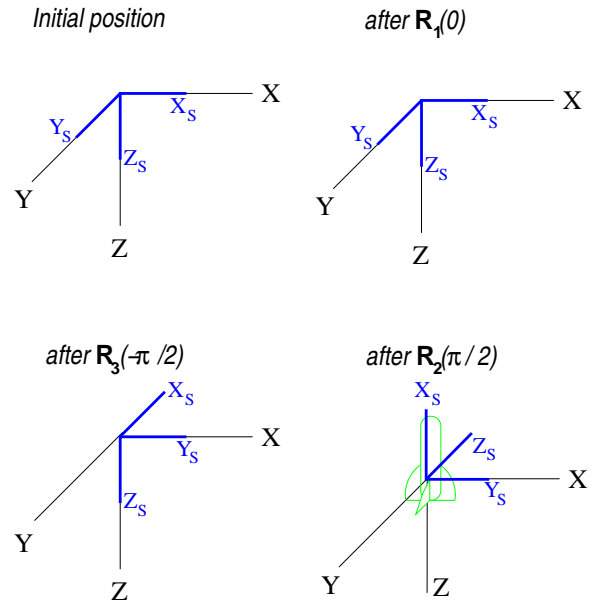


Figure 3. Transformation from LVLH to shuttle reference system.

²See http://liftoff.msfc.nasa.gov/academy/rocket_sci/shuttle/attitude/pyr.html.

If x_i are the components in the AMS frame, ξ_i are the components in the shuttle frame and X_i refer to LVLH, we have: $X_i = T_{ij}\xi_j = T_{ij}A_{jk}x_k = M_{ik}x_k$, where

$$A = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad (4)$$

is the transformation matrix from the AMS reference frame to the shuttle one: $\xi_i = A_{ij}x_j$.

Hence:

$$X_j = M_{ji}x_i. \quad (5)$$

Finally, we write down the expression for the matrix T , starting from its components:

$$R_1(r) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos r & \sin r \\ 0 & -\sin r & \cos r \end{pmatrix}, \quad (6)$$

$$R_2(p) = \begin{pmatrix} \cos p & 0 & -\sin p \\ 0 & 1 & 0 \\ \sin p & 0 & \cos p \end{pmatrix}, \quad (7)$$

$$R_3(y) = \begin{pmatrix} \cos y & \sin y & 0 \\ -\sin y & \cos y & 0 \\ 0 & 0 & 1 \end{pmatrix}. \quad (8)$$

Hence,

$$T(r, p, y) = \begin{pmatrix} \cos y \cos p & \sin y & -\cos y \sin p \\ -\cos r \sin y \cos p + \sin r \sin p & \cos y \cos r & \cos r \sin y \sin p + \sin r \cos p \\ \sin r \sin y \cos p + \cos r \sin p & -\sin r \cos y & -\sin r \sin y \sin p + \cos r \cos p \end{pmatrix}. \quad (9)$$

To go from the AMS basis to LVLH we use the matrix $M = T \cdot A$:

$$M(r, p, y) = \begin{pmatrix} -\cos y \cos p & \sin y & \cos y \sin p \\ \cos r \sin y \cos p - \sin r \sin p & \cos r \cos y & -\cos r \sin y \sin p - \sin r \cos p \\ -\sin r \sin y \cos p - \cos r \sin p & -\sin r \cos y & \sin r \sin y \sin p - \cos r \cos p \end{pmatrix}. \quad (10)$$

REFERENCES

- [1]H. Suter, "Space Shuttle Flight Parameters for Mission STS-91", AMS Internal Note 98_29, October 20, 1998.