Data Processing for 3D LAMS

Al Cooper

RAF Instrumentation Meeting 16 Sept 2013

Outline

NORMAL WIND PROCESSING

Component Measurements

Relative Wind: air motion relative to the aircraft

Ground Velocity: motion of the aircraft relative to the ground

Sum: motion of air relative to the ground = wind

LAMS provides an alternate measurement of relative wind

NORMAL WIND PROCESSING

Component Measurements

Relative Wind: air motion relative to the aircraft

Ground Velocity: motion of the aircraft relative to the ground

Sum: motion of air relative to the ground = wind

LAMS provides an alternate measurement of relative wind

Radome gust system:

Pitot tubes for true airspeed;
Radome for flow angles;
Combine to get relative wind

NORMAL WIND PROCESSING

Component Measurements

Relative Wind: air motion relative to the aircraft

Ground Velocity: motion of the aircraft relative to the ground

Sum: motion of air relative to the ground = wind

LAMS provides an alternate measurement of relative wind

Radome gust system:

Pitot tubes for true airspeed;
Radome for flow angles;
Combine to get relative wind

LAMS:

Measurements in 3 beams;
Not orthogonal system;
Need usual 3-component wind

STEPS REQUIRED TO USE LAMS FOR WIND

1. Determine the geometry with precision:
    (a) Pointing angles
    (b) Relative location, LAMS vs IRS

STEPS REQUIRED TO USE LAMS FOR WIND

1. Determine the geometry with precision:
   (a) Pointing angles
   (b) Relative location, LAMS vs IRS
2. From the three available measurements, find the rectilinear wind components (u,v,w}.

STEPS REQUIRED TO USE LAMS FOR WIND

1. Determine the geometry with precision:
   (a) Pointing angles
   (b) Relative location, LAMS vs IRS
2. From the three available measurements, find the rectilinear wind components (u,v,w}.
3. Correct for false wind introduced by angular motion of the aircraft.

STEPS REQUIRED TO USE LAMS FOR WIND

1. Determine the geometry with precision:
   (a) Pointing angles
   (b) Relative location, LAMS vs IRS
2. From the three available measurements, find the rectilinear wind components (u,v,w}.
3. Correct for false wind introduced by angular motion of the aircraft.
4. Correct for changes in orientation, LAMS vs IRS.

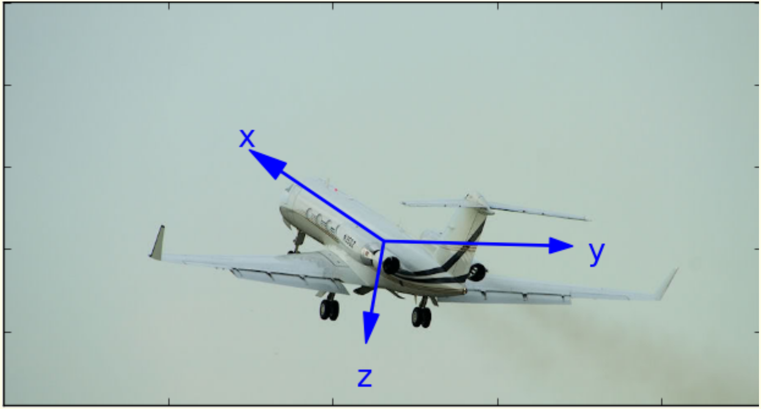
STEPS REQUIRED TO USE LAMS FOR WIND

1. Determine the geometry with precision:
   (a) Pointing angles
   (b) Relative location, LAMS vs IRS
2. From the three available measurements, find the rectilinear wind components (u,v,w}.
3. Correct for false wind introduced by angular motion of the aircraft.
4. Correct for changes in orientation, LAMS vs IRS.

At this point:

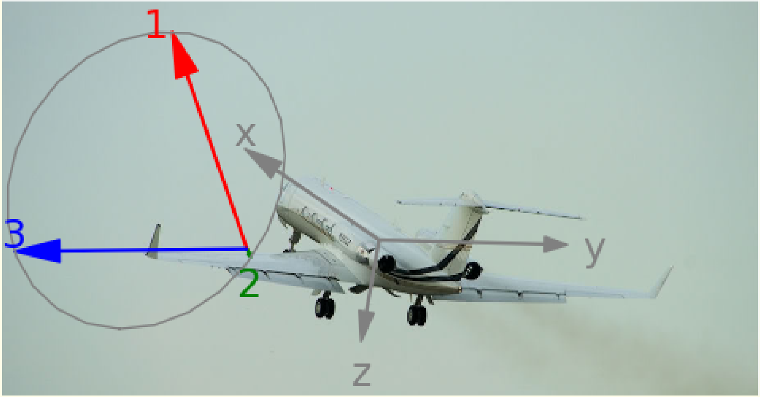
- have the usual relative-wind components
- existing processing will give wind

THE COORDINATE SYSTEM



x is forward along the longitudinal axis of the aircraft;
y is to starboard;
z is downward (to provide a right-handed cooredinate system).
u, v, w have positive sign if *inward* along the respective axes.

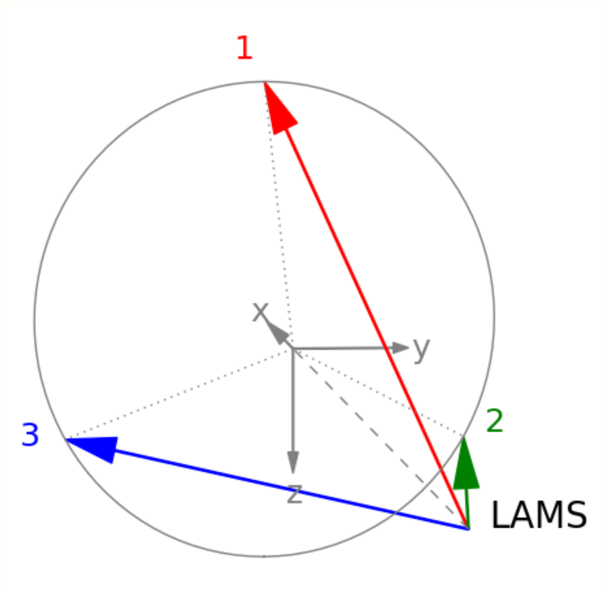
THE THREE BEAMS



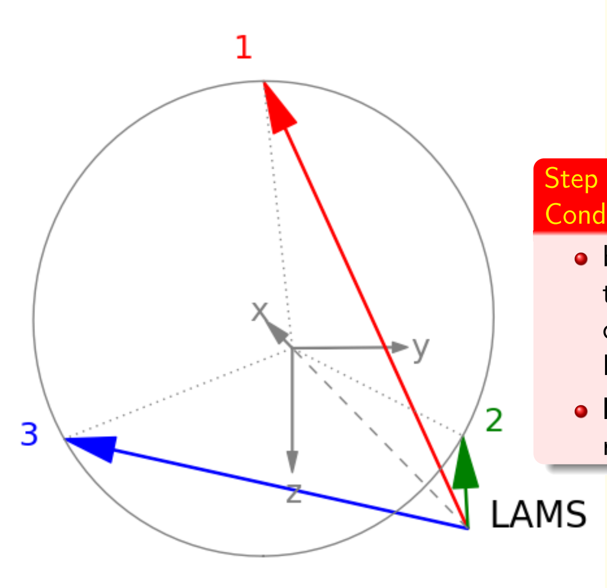
Orientation of the Three Beams:

1. Upward: 35° from the x axis and 120° from the z axis
2. Downward right: 35° from the x axis and $-60°$ from the z axis
3. Downward left: 35° from the x axis and $+60°$ from the z axis

ANOTHER VIEW



ANOTHER VIEW



Step 1: Careful Survey Conducted:

- beam angles relative to housing (which contains a CMIGIT IRS)
- location of housing relative to IRS

TRANSFORM FROM {u, v, w} TO BEAMS

Direction Cosines

Definition: cosine of angle between two unit vectors

Each beam: contributions from {u,v,w}

Write as matrix: 3x3

TRANSFORM FROM {u, v, w} TO BEAMS

Direction Cosines

Definition: cosine of angle between two unit vectors

Each beam: contributions from {u,v,w}

Write as matrix: 3x3

The Direction Cosine Matrix, **S**

$$\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \mathbf{S} \begin{pmatrix} u \\ v \\ w \end{pmatrix} \tag{1}$$

$$\mathbf{S} = \begin{pmatrix} \cos\Theta & 0 & -\sin\Theta \\ \cos\Theta & \sin\Theta\sin\Phi & -\sin\Theta\cos\Phi \\ \cos\Theta & -\sin\Theta\sin\Phi & -\sin\Theta\cos\Phi \end{pmatrix} \tag{2}$$

SOLVING FOR {u, v, w}

Invert the matrix:

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \mathbf{S}^{-1} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \tag{3}$$

where

$$\mathbf{S}^{-1} = \begin{pmatrix} 0.4069249 & 0.40692490 & 0.4069249 \\ 0 & 1.0065795 & -1.0065795 \\ -1.1622979 & 0.5811489 & 0.5811489 \end{pmatrix} \tag{4}$$

SOLVING FOR {u, v, w}

Invert the matrix:

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \mathbf{S}^{-1} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \tag{3}$$

where

$$\mathbf{S}^{-1} = \begin{pmatrix} 0.4069249 & 0.40692490 & 0.4069249 \\ 0 & 1.0065795 & -1.0065795 \\ -1.1622979 & 0.5811489 & 0.5811489 \end{pmatrix} \tag{4}$$

Step-2 Result:

Relative wind components in a rectilinear coordinate system relative to the LAMS housing.

STEP 3: WHY ANGULAR MOTION MATTERS

Effect of heading change in still air:

The rotation will cause a false indication of wind toward LAMS.

STEP 3: WHY ANGULAR MOTION MATTERS

Effect of heading change in still air:

The rotation will cause a false indication of wind toward LAMS.

Correction provided by Bulletin 23

$$\vec{\Omega}_p \times \vec{R}$$

(False contribution to be *subtracted* from measured wind)

> $\vec{\Omega}_p$ *has three components corresponding to change in roll, pitch, and heading, all such that a positive change gives a positive component in* $\vec{\Omega}_p$.

STEP 3: WHY ANGULAR MOTION MATTERS

Effect of heading change in still air:

The rotation will cause a false indication of wind toward LAMS.

Correction provided by Bulletin 23

$$\vec{\Omega}_p \times \vec{R}$$

(False contribution to be *subtracted* from measured wind)

$\vec{\Omega}_p$ has three components corresponding to change in roll, pitch, and heading, all such that a positive change gives a positive component in $\vec{\Omega}_p$.

Result through step 3:

$$\mathbf{v} = \mathbf{S}^{-1}\mathbf{a} - \vec{\Omega} \times \vec{R} \ . \tag{5}$$

FINAL TRANSFORMATION TO IRS COORDINATES

The orientation of the LAMS is measured and so can be compared to that of the aircraft reference frame. The three-component correction needed is given by this product of rotation matrices from Bulletin 23:

$$\begin{pmatrix} \cos\delta\psi & -\sin\delta\psi & 0 \\ \sin\delta\psi & \cos\delta\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\delta\theta & 0 & \sin\delta\theta \\ 0 & 1 & 0 \\ -\sin\delta\theta & 0 & \cos\delta\theta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\delta\phi & -\sin\delta\phi \\ 0 & \sin\delta\phi & \cos\delta\phi \end{pmatrix}$$

where $\{\delta\phi, \delta\theta, \delta\psi\}$ are the respective differences in roll, pitch, and heading. Angle differences of 1° can changed v and w by 1.5 m/s, so are significant.

FINAL TRANSFORMATION TO IRS COORDINATES

The orientation of the LAMS is measured and so can be compared to that of the aircraft reference frame. The three-component correction needed is given by this product of rotation matrices from Bulletin 23:

$$\begin{pmatrix} \cos\delta\psi & -\sin\delta\psi & 0 \\ \sin\delta\psi & \cos\delta\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\delta\theta & 0 & \sin\delta\theta \\ 0 & 1 & 0 \\ -\sin\delta\theta & 0 & \cos\delta\theta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\delta\phi & -\sin\delta\phi \\ 0 & \sin\delta\phi & \cos\delta\phi \end{pmatrix}$$

where $\{\delta\phi, \delta\theta, \delta\psi\}$ are the respective differences in roll, pitch, and heading. Angle differences of 1° can changed v and w by 1.5 m/s, so are significant.

Final result: If the above matrix is $\mathbf{T}$:

$$\mathbf{v} = \mathbf{T}\,(\mathbf{S}^{-1}\mathbf{a} - \vec{\Omega} \times \vec{R})\ . \tag{6}$$

FURTHER DOCUMENTATION

RAF Science Wiki:

- This presentation
- A memo with more details
- A python routine used to test these matrix transformations