NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Aviation Engineering Division
Washington, DC 20594

February 27, 2004

ADDENDUM NUMBER 1C TO THE STRUCTURES GROUP CHAIRMAN'S FACTUAL REPORT

DCA02MA001

A. ACCIDENT

Location:	Belle Harbor, NY
Date:	November 12, 2001
Time:	09:16:14 EST
Aircraft:	American Airlines Flight 587, Airbus Model A300-605R, N14053 Manufactures Serial Number (MSN) 420

B. STRUCTURES GROUP

Chairman: Brian K Murphy
National Transportation Safety Board
Washington, DC

C. AIRBUS REPORT

1. "AAL587 Investigation, side-slip computation with integration method"

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PROGRAM : Wide Body	O.F. : 51239.107
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TITLE : AAL 587 Accident investigation: side-slip computation with integration method

AUTHOR : -------- ------------------ -------[redacted]

SUMMARY: [redacted]

This note explains the method used to reconstitute the side-slip from the FDR parameters in the American Airline Flight 587 accident. This method relies on the integration of the three flight mechanic equations.

The first part focuses on the method principles and validation. The second part explains the re-synchronization of the parameters which is performed prior to the use of the method; compensating for filtered parameters, transport delays, as well as correction for center of gravity/sensor location is also described.
Eventually the application to the accident case is done and compared with our aircraft movement simulation tool result.
It is to be emphasized that the presented method does not need any aircraft related data like aerodynamic model, weight/inertia and so on.

Edition 2: Introduction of the new wind calculation to compute the aerodynamic side-slip.

KEY WORDS : wide body, accident, Ny integration

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AIRBUS

1 - Ny integration

This method is used to derive the aircraft side-slip from FDR parameters. Actually this method based on inertial data gives us aircraft ground side-slip. We don't have access to the aircraft aerodynamic side-slip, which is equal to the ground side-slip plus the wind side-slip, in calm air these two values are equal. This method relies on the integration of the three flight mechanic equations; it is the same but generalized approach when compared to the one used by the loads community (which uses only one equation)

1.1 - Principles

The presented side-slip computation method relies on Flight mechanics equation integration and kinetic relations between Euler's angle derivatives and angular velocities. The inputs we need for side-slip computation are: Pitch angle (θ), Bank angle (Φ), Heading angle (Ψ) and accelerations (Nx, Ny, Nz) coming from the FDR. In order to initiate the computation we also need an initial ground speed, ground side-slip and ground angle of attack.

First of all it is important to have a clear view of all the different axes:

- **Earth axes GX0, Y0, Z0**
  - G Center of gravity
  - GX0 Horizontal and positive northward
  - GY0 Horizontal and positive eastward
  - GZ0 Orthogonal to GX0, GY0 and positive downward

- **Aircraft axes GX1, Y1, Z1**
  - GX1 is parallel to the body horizontal reference and positively oriented from tail to nose.
  - GY1 is perpendicular to the aircraft symmetry plane and positively oriented on the right side.
  - GZ1 complete these axis.

The Pitch angle (θ), Bank angle (φ), heading angle (Ψ) determine the aircraft axes compared to the earth axes.

Aircraft absolute rotation (in aircraft axes): $\left(\vec{\Omega}_{1/0}\right)_1 = \begin{pmatrix} p1 \\ q1 \\ r1 \end{pmatrix}$

- **Ground speed axes GX gr, Y gr, Z gr**
  - GX gr is equivalent to the ground speed vector (aircraft speed with regard to earth)
  - GZ gr is perpendicular to GX gr and located in the symmetry plane
  - GY gr completes those axes

The ground angle of attack (α_{gr}) and the ground side-slip (β_{gr}) determine the ground speed axes compared to the aircraft axes.

Let's have a look at the formulas used in the algorithm. We first have to calculate the Euler's angles derivatives from the three angles we know, this gives us: $\overset{\circ}{\theta}$, $\overset{\circ}{\phi}$ and $\overset{\circ}{\psi}$. Euler's angle derivatives can be deduced from the angular velocities by the following relations:

$$\overset{\circ}{\theta} = q1 \cdot \cos\phi - r1 \cdot \sin\phi$$

$$\overset{\circ}{\phi} = p1 + tg\theta \cdot \left(q1 \cdot \sin\phi + r1 \cdot \cos\phi\right)$$

$$\overset{\circ}{\psi} = \frac{q1 \cdot \sin\phi + r1 \cdot \cos\phi}{\cos\theta}$$

So if we invert these relations the angular velocities can be calculated from $\overset{\circ}{\theta}$, $\overset{\circ}{\phi}$ and $\overset{\circ}{\psi}$:

$$\boxed{\begin{aligned} p1 &= \overset{\circ}{\varphi} - \sin\theta \cdot \overset{\circ}{\psi} \\ q1 &= \cos\phi \cdot \overset{\circ}{\theta} + \sin\phi \cdot \cos\theta \cdot \overset{\circ}{\psi} \\ r1 &= -\sin\phi \cdot \overset{\circ}{\theta} + \cos\phi \cdot \cos\theta \cdot \overset{\circ}{\psi} \end{aligned}} \qquad \text{E1}$$

Accelerations differential equations

$$\sum \vec{f} = m\,\vec{\Gamma} \qquad \text{where : } \vec{\Gamma} = \frac{d\vec{V}_{gr}}{dt}$$

projected in ground speed axes : $\left(\vec{\Gamma}\right)_{gr} = \left(\dfrac{d\vec{V}_{gr}}{dt}\right)_{gr}$

using partial derivation : $\left(\vec{\Gamma}\right)_{gr} = \left(\dfrac{\partial\vec{V}_{gr}}{\partial t}\right)_{gr} + \left(\vec{\Omega}_{gr/0}\right)_{gr} \wedge \left(\vec{V}_{gr}\right)_{gr}$

with : $\vec{\Omega}_{gr/0} = \vec{\Omega}_{gr/1} + \vec{\Omega}_{1/0}$, so :

$$\left(\frac{\partial\vec{V}_{gr}}{\partial t}\right)_{gr} + \left(\vec{\Omega}_{gr/1}\right)_{gr} \wedge \left(\vec{V}_{gr}\right)_{gr} = \left(\vec{\Gamma}\right)_{gr} - \left(\vec{\Omega}_{1/0}\right)_{gr} \wedge \left(\vec{V}_{gr}\right)_{gr}$$

Finally, we obtain the expression:

$$\begin{pmatrix} \overset{\circ}{V}gr \\ Vgr\,\overset{\circ}{\beta}gr \\ Vgr.\cos\beta gr.\overset{\circ}{\alpha}gr \end{pmatrix} = M(\beta gr, \alpha gr)\ \left\{\left(\vec{\Gamma}\right)_1 - \left(\vec{\Omega}_{1/0}\right)_1 \wedge M^T(\beta gr, \alpha gr)\left(\vec{V}gr\right)_{gr}\right\}$$

With M equal to the Matrix of axis change from Aircraft axes to ground speed axes :

$$\left(\vec{U}\right)_{gr} = M(\beta gr, \alpha gr)\left(\vec{U}\right)_1$$

$$M(\beta gr, \alpha gr) = \begin{pmatrix} \cos\alpha gr \cdot \cos\beta gr & \sin\beta gr & \sin\alpha gr \cdot \cos\beta gr \\ -\cos\alpha gr \cdot \sin\beta gr & \cos\beta gr & -\sin\alpha gr \cdot \sin\beta gr \\ -\sin\alpha gr & 0 & \cos\alpha gr \end{pmatrix}$$

Eventually we have:

$$\begin{pmatrix} \overset{\circ}{Vgr} \\ \overset{\circ}{\beta}\, gr \\ \overset{\circ}{\alpha}\, gr \end{pmatrix} = \begin{pmatrix} \dfrac{\cos\alpha gr\cdot\cos\beta gr}{\dfrac{-\cos\alpha gr\cdot\sin\beta gr}{Vgr}} & \dfrac{\sin\beta gr}{\dfrac{\cos\beta gr}{Vgr}} & \dfrac{\sin\alpha gr\cdot\cos\beta gr}{\dfrac{-\sin\alpha gr\cdot\sin\beta gr}{Vgr}} \\ \dfrac{-\sin\alpha gr}{Vgr\cdot\cos\beta gr} & 0 & \dfrac{\cos\alpha gr}{Vgr\cdot\cos\beta gr} \end{pmatrix} \cdot \begin{pmatrix} \dfrac{\sum fx1}{m} - Vgr(q1\cdot\sin\alpha gr\cdot\cos\beta gr - r1\cdot\sin\beta gr) \\ \dfrac{\sum fy1}{m} - Vgr(r1\cdot\cos\alpha gr\cdot\cos\beta gr - p1\cdot\sin\alpha gr\cdot\cos\beta gr) \\ \dfrac{\sum fz1}{m} - Vgr(p1\cdot\sin\beta gr - q1\cdot\cos\alpha gr\cdot\cos\beta gr) \end{pmatrix}$$

So if we develop this matrices product, we have the formulas used in the algorithm:

$$\boxed{\begin{aligned} \overset{\circ}{V}_{gr} &= \cos\alpha_{gr}\cdot\cos\beta_{gr}\cdot\left(\frac{\sum fx1}{m} - V_{gr}\left(q1\cdot\sin\alpha_{gr}\cdot\cos\beta_{gr} - r1\cdot\sin\beta_{gr}\right)\right) \\ &+\sin\beta_{gr}\cdot\left(\frac{\sum fy1}{m} - V_{gr}\left(r1\cdot\cos\alpha_{gr}\cdot\cos\beta_{gr} - p1\cdot\sin\alpha_{gr}\cdot\cos\beta_{gr}\right)\right) \\ &+\sin\alpha_{gr}\cdot\cos\beta_{gr}\cdot\left(\frac{\sum fz1}{m} - V_{gr}\left(p1\cdot\sin\beta_{gr} - q1\cdot\cos\alpha_{gr}\cdot\cos\beta_{gr}\right)\right) \end{aligned}}$$

$$\boxed{\begin{aligned} \overset{\circ}{\beta}_{gr} &= -\frac{\cos\alpha_{gr}\cdot\sin\beta_{gr}}{V_{gr}}\cdot\left(\frac{\sum fx1}{m} - V_{gr}\left(q1\cdot\sin\alpha_{gr}\cdot\cos\beta_{gr} - r1\cdot\sin\beta_{gr}\right)\right) \\ &+\frac{\cos\beta_{gr}}{V_{gr}}\cdot\left(\frac{\sum fy1}{m} - V_{gr}\left(r1\cdot\cos\alpha_{gr}\cdot\cos\beta_{gr} - p1\cdot\sin\alpha_{gr}\cdot\cos\beta_{gr}\right)\right) \\ &-\frac{\sin\alpha_{gr}\cdot\sin\beta_{gr}}{V_{gr}}\cdot\left(\frac{\sum fz1}{m} - V_{gr}\left(p1\cdot\sin\beta_{gr} - q1\cdot\cos\alpha_{gr}\cdot\cos\beta_{gr}\right)\right) \end{aligned}} \qquad \text{E2}$$

$$\boxed{\begin{aligned} \overset{\circ}{\alpha}_{gr} &= -\frac{\sin\alpha_{gr}}{V_{gr}\cdot\cos\beta_{gr}}\cdot\left(\frac{\sum fx1}{m} - V_{gr}\left(q1\cdot\sin\alpha_{gr}\cdot\cos\beta_{gr} - r1\cdot\sin\beta_{gr}\right)\right) \\ &+\frac{\cos\alpha_{gr}}{V_{gr}\cdot\cos\beta_{gr}}\cdot\left(\frac{\sum fz1}{m} - V_{gr}\left(p1\cdot\sin\beta_{gr} - q1\cdot\cos\alpha_{gr}\cdot\cos\beta_{gr}\right)\right) \end{aligned}}$$

The last unknown parameters in these expressions are $\sum fx1$, $\sum fy1, \sum fz1$ which are calculated through these equations:

$$nx = -\frac{\sum fx1 - \overrightarrow{Weight} \cdot \vec{x}}{mg} = -\frac{\sum fx1 + mg \cdot \sin\theta}{mg}$$ which gives us :

$$\boxed{\sum fx1 = mg \cdot (-nx - \sin\theta)}$$

$$ny = -\frac{\sum fy1 - \overrightarrow{Weight} \cdot \vec{y}}{mg} = -\frac{\sum fy1 - mg \cdot \sin\phi \cdot \cos\theta}{mg}$$ which gives us :

$$\boxed{\sum fy1 = mg \cdot (-ny + \cos\theta \cdot \sin\phi)}$$

$$nz = -\frac{\sum fz1 - \overrightarrow{Weight} \cdot \vec{z}}{mg} = -\frac{\sum fz1 - mg \cdot \cos\phi \cdot \cos\theta}{mg}$$ which gives us :

$$\boxed{\sum fz1 = mg \cdot (-nz + \cos\theta \cdot \cos\phi)}$$

So by integrating these expressions, an estimation of the ground speed, the ground side-slip and ground angle of attack can be calculated. Since there are 3 integrations to initiate, we need a calm period where it is easy to evaluate the initial side-slip by a static calculation. The initial ground speed and ground angle of attack are evaluated from the recorded ground speed, and aerodynamic angle of attack measured by the probe.

1.2 - Implementation and validation of the algorithm

The algorithm has been implemented in an Excel Worksheet. In order to validate the method, a first computation has been made by replacing FDR parameters by those resulting from a complete aircraft simulation (OSMA simulation and model); this simulation has been run without wind.

The first computation done by the process is the angular speed computation: $\left(\vec{\Omega}_{1/0}\right)_1 = \begin{pmatrix} p1 \\ q1 \\ r1 \end{pmatrix}$. They have a key role in the method, so their calculation has to be validated first. To do so, we took OSMA Pitch angle (θ), Bank angle (Φ) and Heading angle (Ψ) outputs, then we computed their derivatives and eventually the angular speed with the equations E1. This result was compared with the angular speed calculated in OSMA.

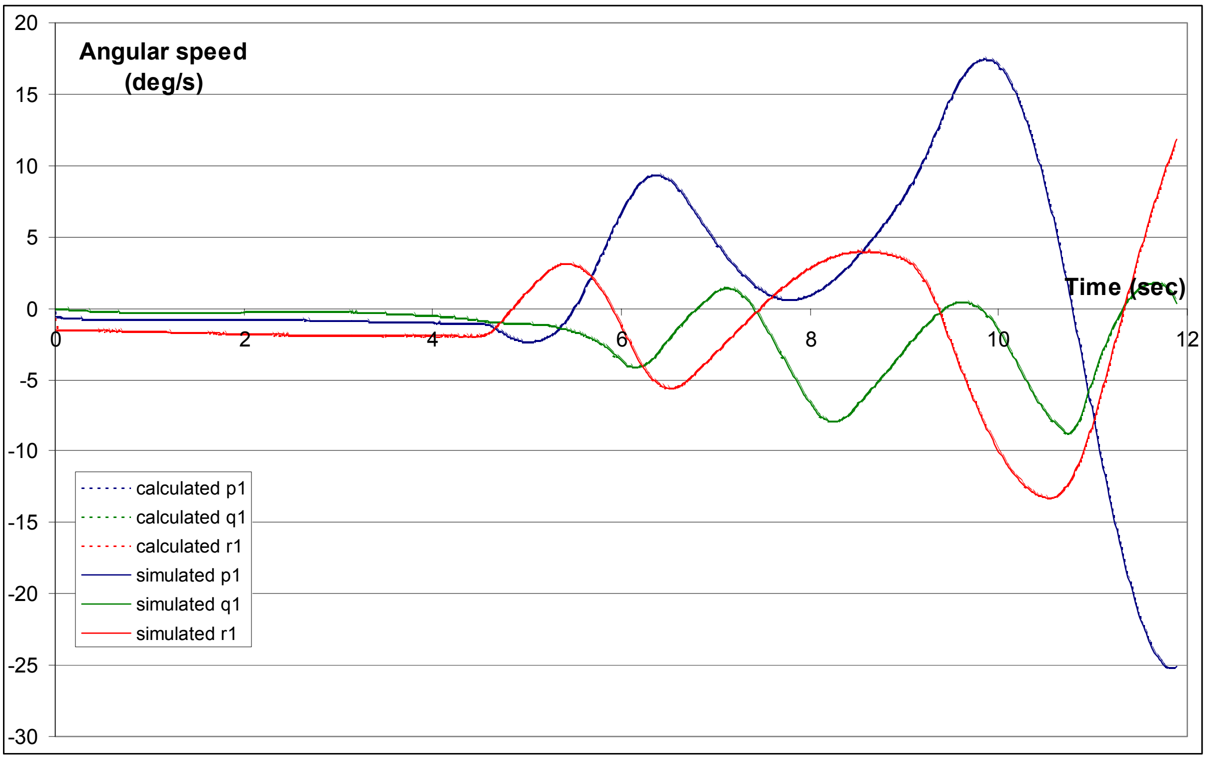


Figure 1- angular speed computation validation

As you can see in the preceding graph, the angular speeds computed according to the process are essentially identical to the OSMA angular speed, this computation does not introduce biases or latency.

Once this first step of the method is validated, we can integrate the side-slip equation E2. We calculate the side-slip derivative 64 times per seconds to have better accuracy. Then to integrate this parameter, the trapezoid integration method described bellow was used :

$$\Delta\beta_n = \frac{\dot{\beta}_{n-1} + 2\cdot\dot{\beta}_n + \dot{\beta}_{n+1}}{4}\cdot\Delta T$$

A first validation was performed without wind (to eliminate this source of error), the discrepancy highlights the difference introduce by the method as the ground angle of attack, the ground side-slip and Ground speed are equal to their air correspondent.
We ran an OSMA simulation without wind, this gave us all the aircraft parameters, we took the parameters we need (θ, Φ, Ψ, Nx, Ny, Nz) for the Ny integration methods and gave them to the program, eventually we compare the side-slip calculated in the OSMA simulation with the estimated side-slip from the Ny integration:

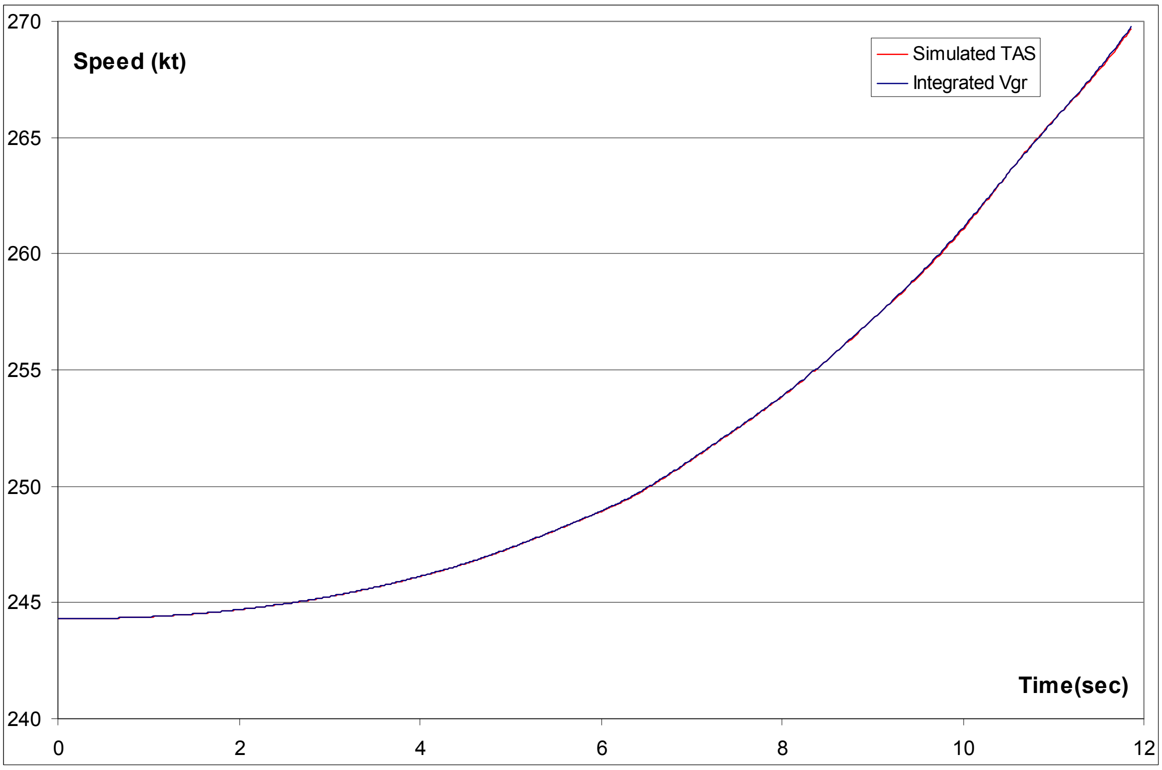


Figure 2- Ground speed comparison between Ny integration and simulation in calm air

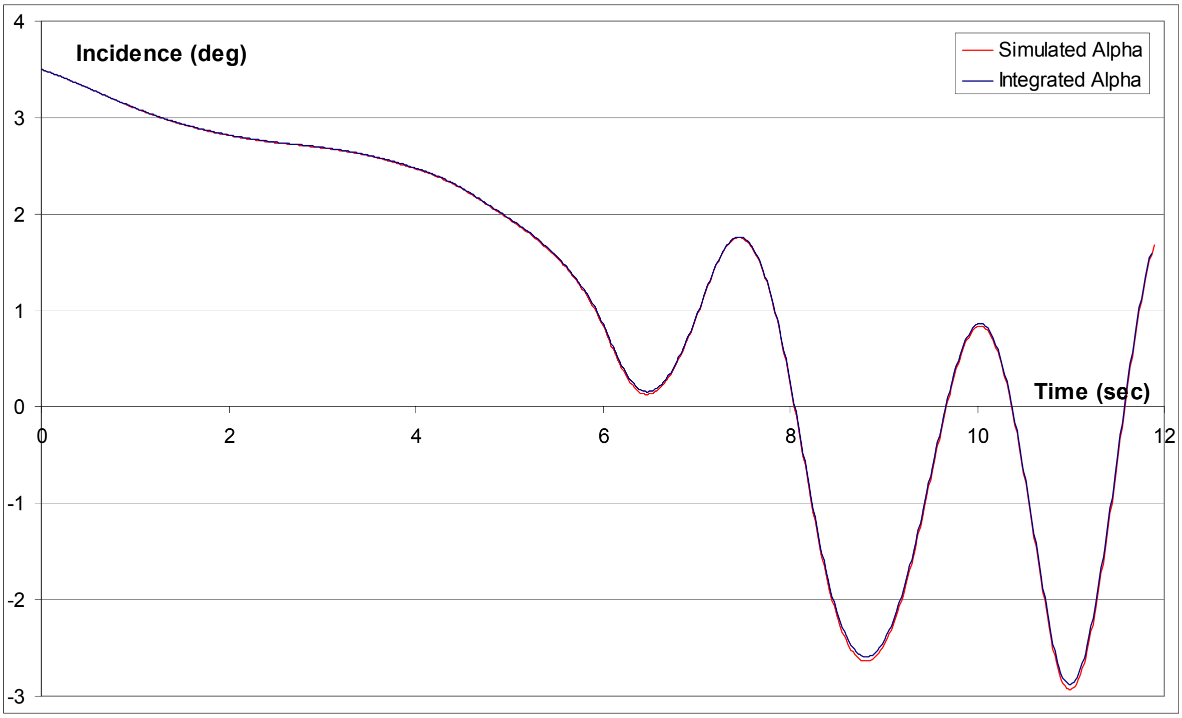


Figure 3 - Incidence comparison between Ny integration and simulation in calm air

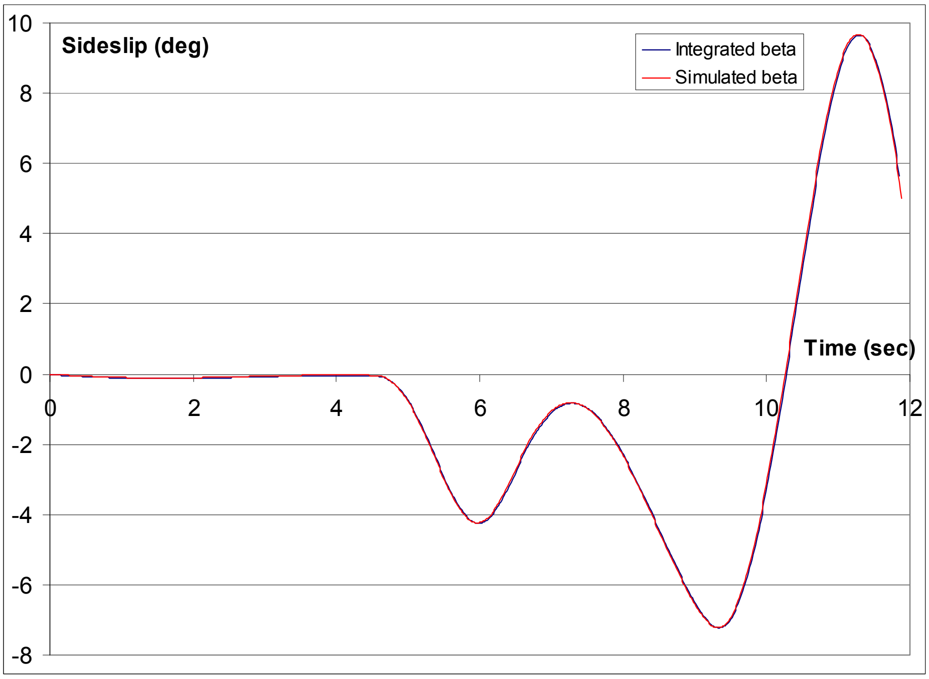


Figure 4 - Angle of attack comparison between Ny integration and simulation in calm air

We used this case to validate the Ny integration method since we find the same result as OSMA with the inputs coming from OSMA treated by the Ny integration.

The same simulation was used to perform an estimation of the lateral wind influence. Actually, this parameter has a direct influence on the aircraft side-slip through this approximated formula:

$$aircraft \cdot sideslip \approx ground \cdot sideslip + \arctan\left(\frac{lateral \cdot wind}{aircraft \cdot velocity}\right) \qquad \text{E3}$$

In order to evaluate this influence, we took the simulation in calm air to which a lateral gust was added. The results are presented in the following graphs:

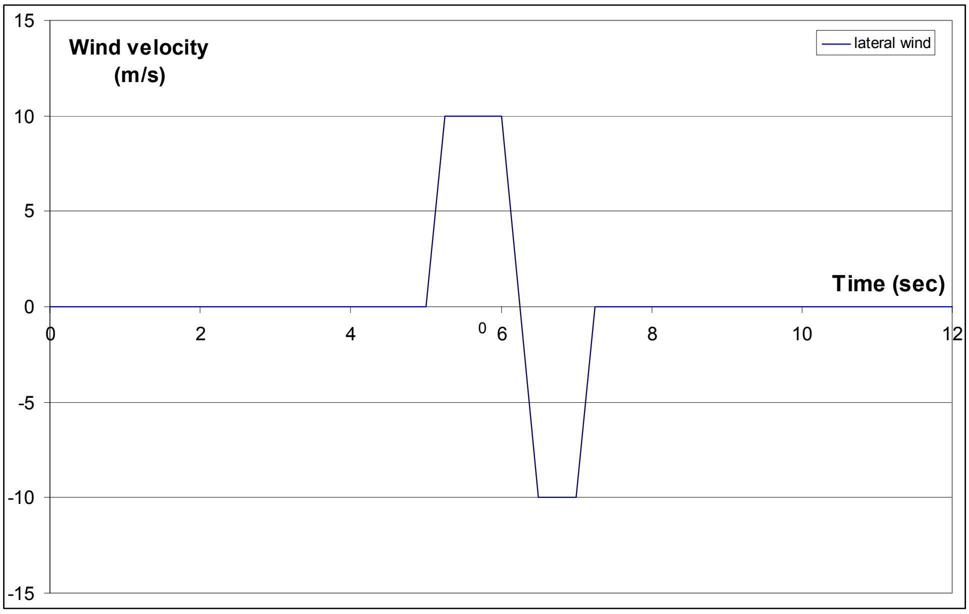


Figure 5 - wind velocities used in OSMA simulation

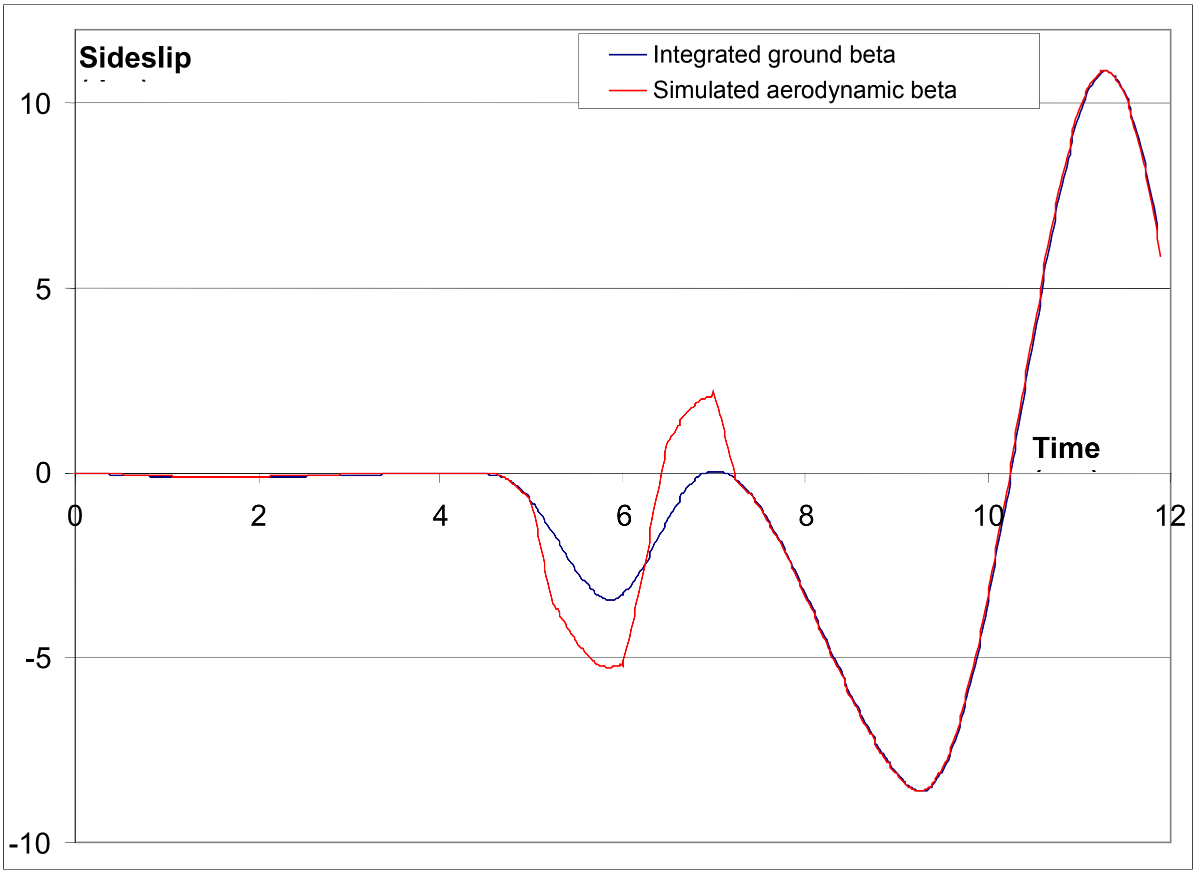


Figure 6 - Comparison between integrated and simulated Side-slip with a lateral wind

We can clearly see the influence of the gust on the aerodynamic side-slip. During this significant gust reaching 10m/s, the integration method gives a result, which presents a 4 degrees error. This error represents the value of the second term of E3 $\left(\arctan\left(\frac{lateral \cdot wind}{aircraft \cdot velocity}\right)\right)$. This is a **major source of difference** between the Ny integration method and the OSMA simulation, **in case of lateral gust**, where the results provided by the method are **not valid without correction**.

On the other hand, a constant wind won't have any influence. Actually, in this case the second term of E3 is constant and can be added to the ground side-slip at the initialization of the process.

We also wanted to have an idea of the error in presence of **vertical and longitudinal wind**, the same OSMA simulation in calm air was used with addition of vertical and longitudinal wind. As before, we took from this last simulation the parameters used by the Ny integration, with this values we computed a side-slip estimation with the Ny integration method which was compared with the OSMA side-slip. The error highlighted in this process also comes from the second term of E3 $\left(\arctan\left(\frac{lateral \cdot wind}{aircraft \cdot velocity}\right)\right)$, but indirectly in the aircraft velocity term. You can see the wind which is introduced in the OSMA simulation, lateral gust is frozen to 0 :

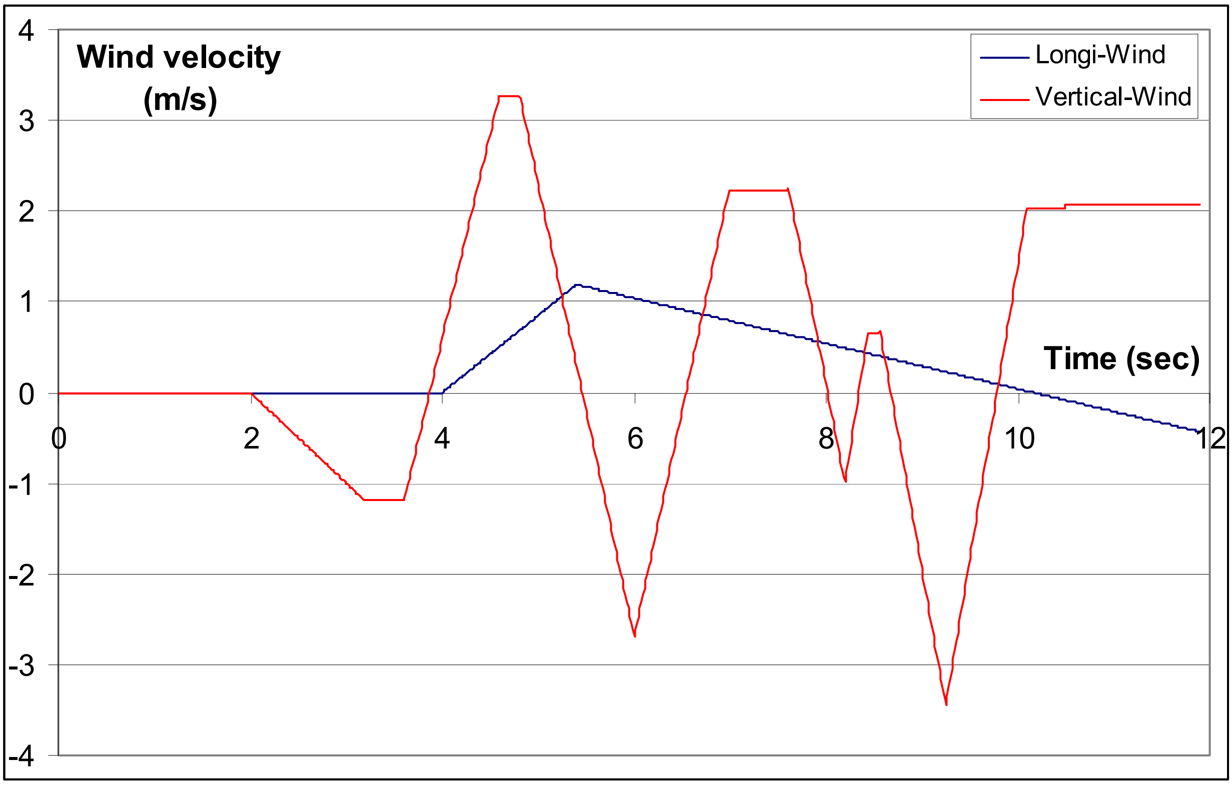


Figure 7- wind velocities used in OSMA simulation

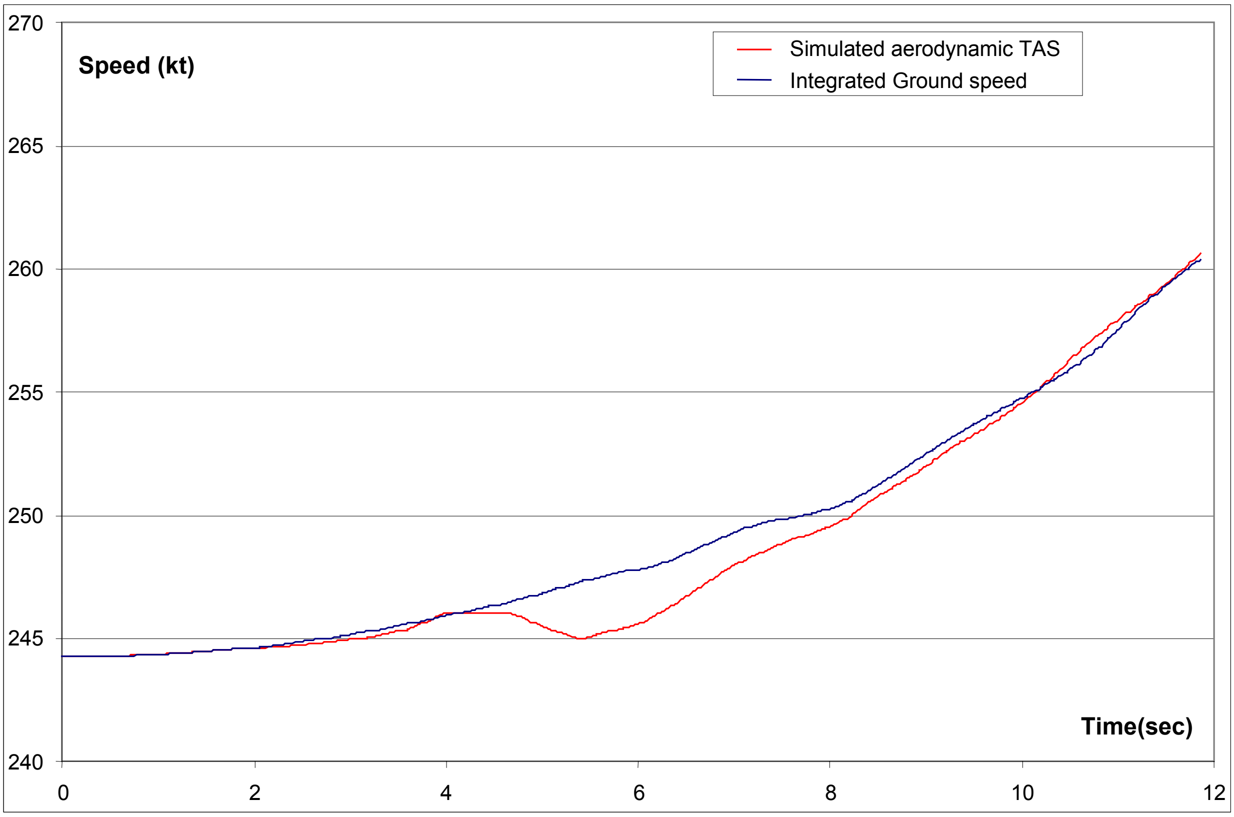


Figure 8- Comparison between integrated ground speed and simulated TAS with wind (Vertical + Longitudinal)

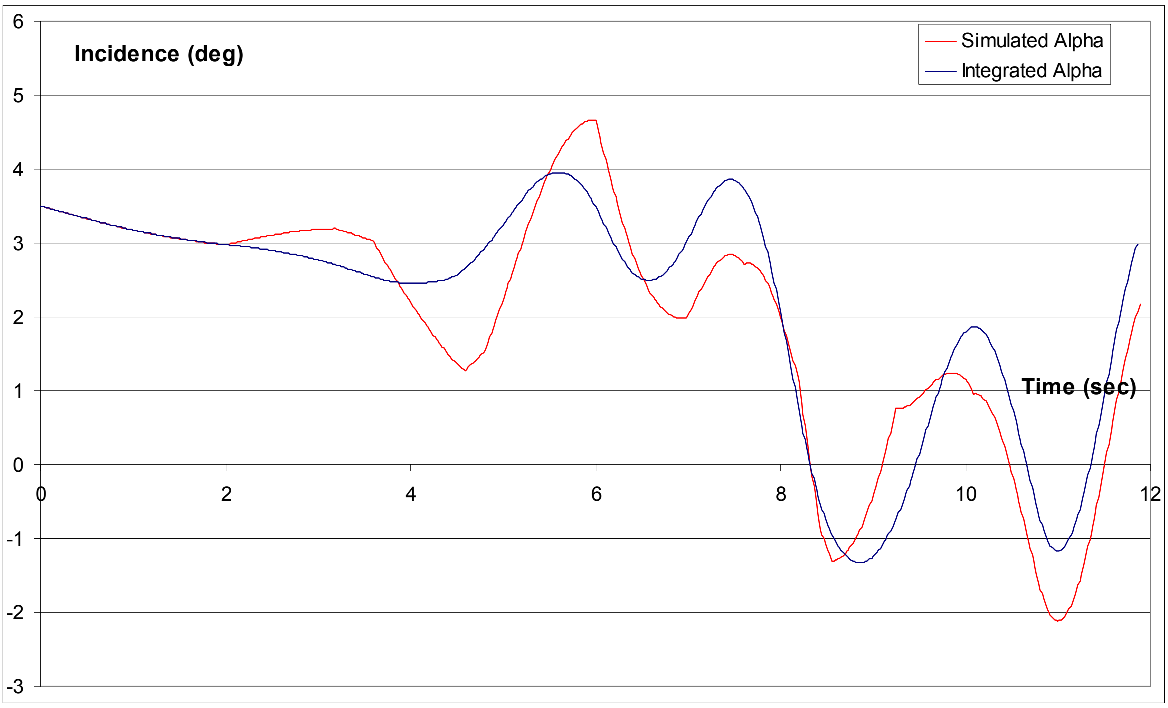


Figure 9 - Comparison between integrated ground angle of attack and simulated aerodynamic angle of attack in presence of wind (Vertical + Longitudinal)

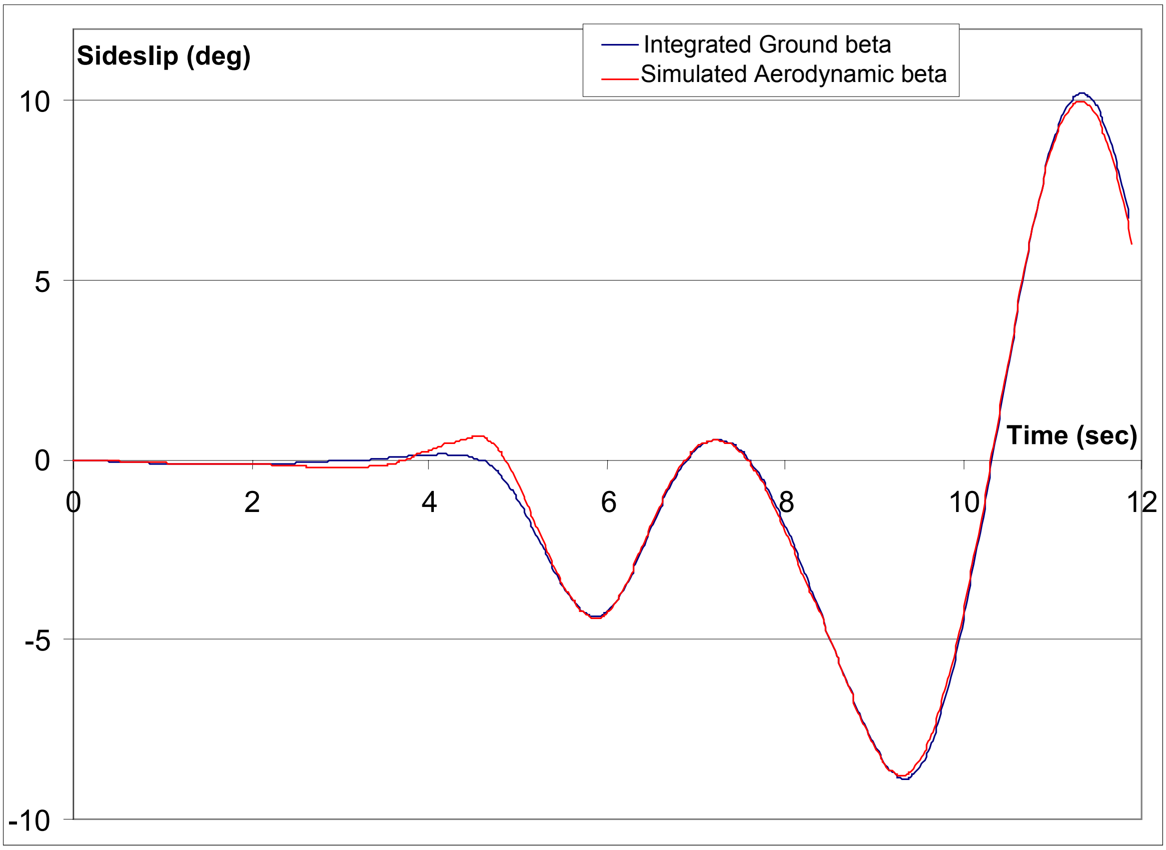


Figure 10 - Comparison between integrated and simulated Side-slip with wind (Vertical + Longitudinal)

In this case the discrepancy introduced by the longitudinal wind reaches 0.6° of side-slip at max., this is a **minor** identified **source of difference** between Ny integration method and an OSMA simulation. The difference is more important when the difference between the aerodynamic speed and the integrated ground speed is higher.

2 - Use of FDR data

2.1 - Interpolation

After the initial FDR treatment made by EYT done, we receive a file sampled at 64pps with the data coming from the FDR. Basically, for each parameter, the value is refreshed at the recorded value at the recorded time and then hold till the next value record. So depending on the signal, we have some true points and a lot of "frozen" one. For instance let's consider the magnetic heading, this value is recorded once per second, therefore on the 64 pps file we have only 1 true point per seconds and 63 "frozen" points.
Before using this file, we first have to remove all the "false" points and reconstruct an information in order to have a continuous signal with a continuous derivative. Cubic and spline interpolation algorithms have been tested with MATLAB, an evaluation of the differences has been made. The results were very similar and the spline interpolation was chosen to build a 64 pps information. The NTSB uses a spline interpolation also combined with a cubic and Akima interpolation to highlight the small differences between results.
After this process we have a 64 pps file containing the true points plus interpolated points between the true points.

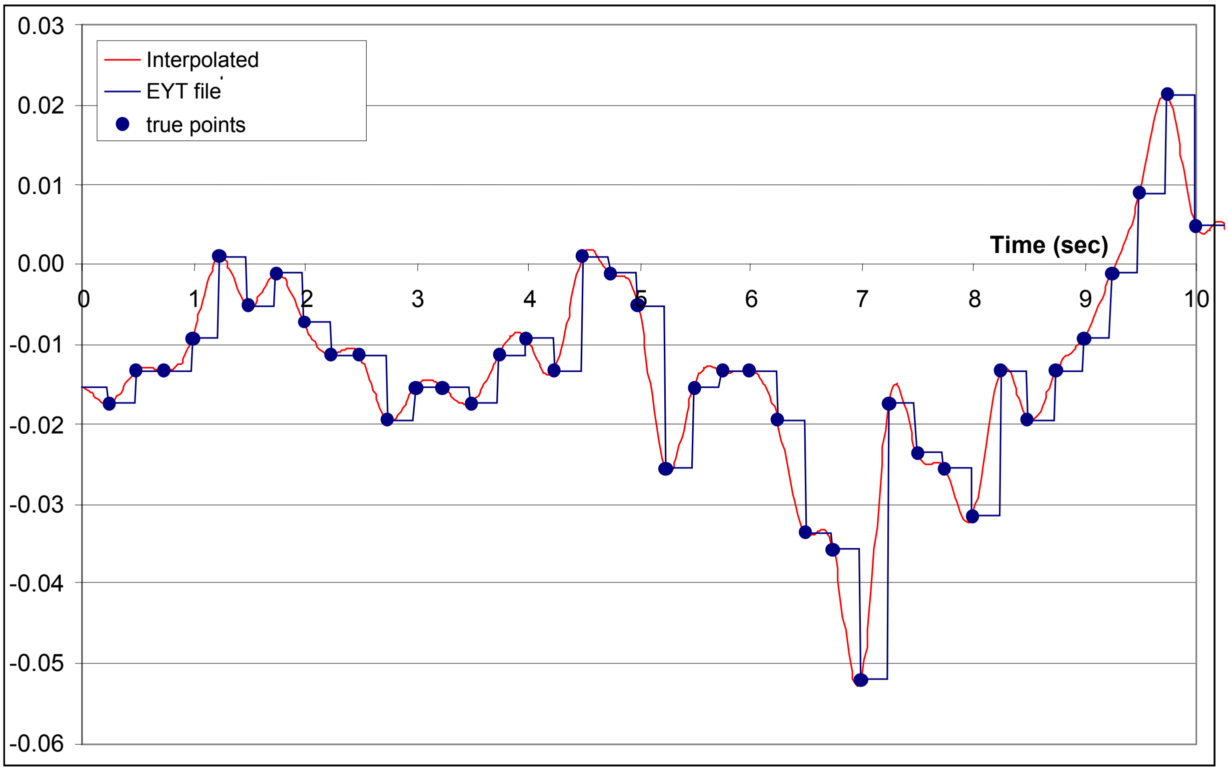


Figure 11-Effect of Matlab treatment on Bank angle

2.2 - Time offset/re-synchronization

Every recorded parameter does not follow the same path between the measurement and the recording on the FDR. For example the acceleration are measured on specific accelerometers then directly sent to the DFDAU/FDR unit whereas other information like the attitude information is generated by the IRU, then go through the SGU EFIS before being sent to the DFDAU/FDR. This difference of path introduces different latencies between recorded signal, which are accounted for by appropriate time offsets applied to the FDR file.

Time offsets for pitch angle, bank angle and magnetic angle are respectively 125ms, 125ms and 250ms. They come from the note ref. 506.0009/2001"AAL A300-600 MSN420 Accident at New York, 12 Nov. 2001, Flight 587 – Time delays for recorded parameters" written by A. Maumus. They take into account both delays and filtering characteristics.
Similarly, the incidence information has been processed. We have applied a 250ms offset (ref 506.009/2001 for 125 ms in the DADC and SGU, remaining 125 ms for the probe) complemented by an inverse filtering of 400ms(probe characteristics, checking of this value still on going). Note that the incidence information is only used for the initialization and for comparison with the angle of attack deduced by the method.

2.3 - Biases

An accelerometer is naturally subject to a bias. This bias depend on the history of the accelerometer and has been assumed constant over a period of time around 1 minute. The accelerations are a direct input of the integration method and influence a lot the result, so it is important to take into account this bias in order to integrate the actual acceleration encountered by the aircraft.

To estimate the nz bias, a delta in "accelerometric" altitude is computed by integration of the vertical acceleration (mainly nz but also nx and ny depending on the aircraft attitude). Then we compare this delta in "accelerometric" altitude with the delta in pressure altitude recorded on the FDR, the difference between these two delta of altitude comes from the bias on the nz. We assumed that contribution of bias on nx and ny are negligible in the difference as their influence are small.

The nx bias is estimated through a comparison between the ground speed (from the integration of the Flight mechanic equations) and the TAS (directly recorded on the FDR or reconstituted from Vc and altitude assuming a standard atmosphere). The difference between this two is due to the wind and mainly nx bias (although ny and nz are required to compute Vground, their influence are small). The bias introduces an error, which is in the form of Δ=ΔNx*Time, therefore it can be tracked by plotting the difference. The long-term and deviating error comes from the bias and the short-term error is the wind. Roughly, it is supposed that the estimated bias will be the one minimizing the vertical wind.

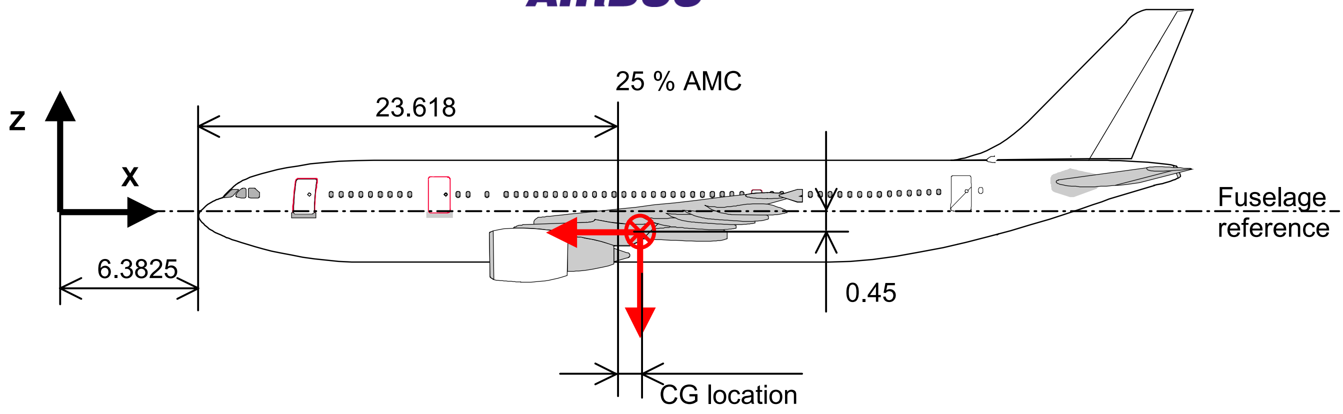
Concerning the ny bias, we don't have a direct point of comparison. To have the best bias estimate, we are running the integration a few seconds before the interesting time period and we assume that during this quiet period, the aerodynamic side-slip is equal to zero. We adjust the bias to keep the integrated ground side-slip around zero if there is no gust and around another value if the presence of wind is highlighted (βsol = βair + Wy/Vtas = Wy/Vtas).

2.4 - Acceleration transport

The inputs required for the Ny integration method **have to be expressed at the CG location**. The recorded G-loads are measured at a different location by specific accelerometers located under the floor 61.68 cm forward of the 25% AMC location, so we have to correct this location in order to have the accelerations at the CG:

$$g * nx_{CG} = g * nx_{FDR} + \dot{q} * Z_M - \dot{r} * Y_M + p * (q * Y_M + r * Z_M) - X_M * (q^2 + r^2)$$
$$g * ny_{CG} = g * ny_{FDR} + \dot{r} * X_M - \dot{p} * Z_M + q * (p * X_M + r * Z_M) - Y_M * (p^2 + r^2)$$
$$g * nz_{CG} = g * nz_{FDR} + \dot{p} * Y_M - \dot{q} * X_M + r * (p * X_M + q * Y_M) - Z_M * (q^2 + p^2)$$

We have to compute the X_M, Y_M, Z_M which are the coordinates of the accelerometers in the aircraft axes. Let's introduce axes used to define the position of one element in the aircraft (the Data Basis for Design axes in black) and the aircraft axes (referenced to the CG in red) used by the method, they are presented in a side view, Y axes complete the two others:



In the DBD axis we have concerning the accelerometers positioning:

X= 29.3835
Y= -0.07
Z= -0.47

So expressed in the aircraft axes we have:

X_M=23.6183+6.3825+CG location -29.3835= $0.6173+\frac{CG-25}{100}*6.60806$ with CG in % Mean Aerodynamic Chord

Y_M=-0.07
Z_M=-0.45-(-0.47)= 0.02 (the CG is located 0.45m below the x axis from DBD in this particular case)

2.5 - Incidence treatment

In order to initialize the computation, the incidence at the CG location is required. However the probe measure the incidence at a more forward location to minimize the wing effect. This probe measurement is then recorded on the FDR, therefore, in order to have the incidence at the CG location, we have to correct the recorded incidence by the aircraft movement. To do so we are using this formula:

$$\alpha_{CG} = \alpha_{PROBE} + \frac{\arctan(q \cdot \left(L1 + \frac{CG-25}{100} \cdot AMC\right) + p \times L2)}{V_{TAS}} - J \times \left[\beta + \arctan\left(\frac{r \cdot \left(L1 + \frac{CG-25}{100} \cdot AMC\right)}{V_{TAS}}\right)\right]$$

Where:

- L1=distance from the captain probe (No. 1) to 25% of wing AMC
- CG= CG location in AMC reference
- AMC= Aerodynamic Mean Chord
- L2=distance from the captain probe to the aircraft plane of symmetry
- J = 0.178 is the effect of side-slip (for the captain probe, in the clean conf)
- Beta = side-slip at the probe (side-slip at CG plus yaw rate effect)

With on a A300-600:

- L1 = 16.301 m (vane in front CG)
- AMC=6.608 m
- L2 = 2.613 m (vane is on the LH side of the plane of symmetry)

3 - A300-600 MSN420, Flight AA 587

3.1 - Side-slip computation

The process described below has been applied to the FDR data furnished by EYT. The corrections applied to the accelerations reflecting the biases are:

Longitudinal load factor bias (ΔNx)= -0.002, Nx = recorded Nx-0.002
Lateral load factor bias (ΔNy)= -0.004, Ny = recorded Ny-0.004
Vertical load factor bias (ΔNz)= 0.016, Nz = recorded Nz+0.016

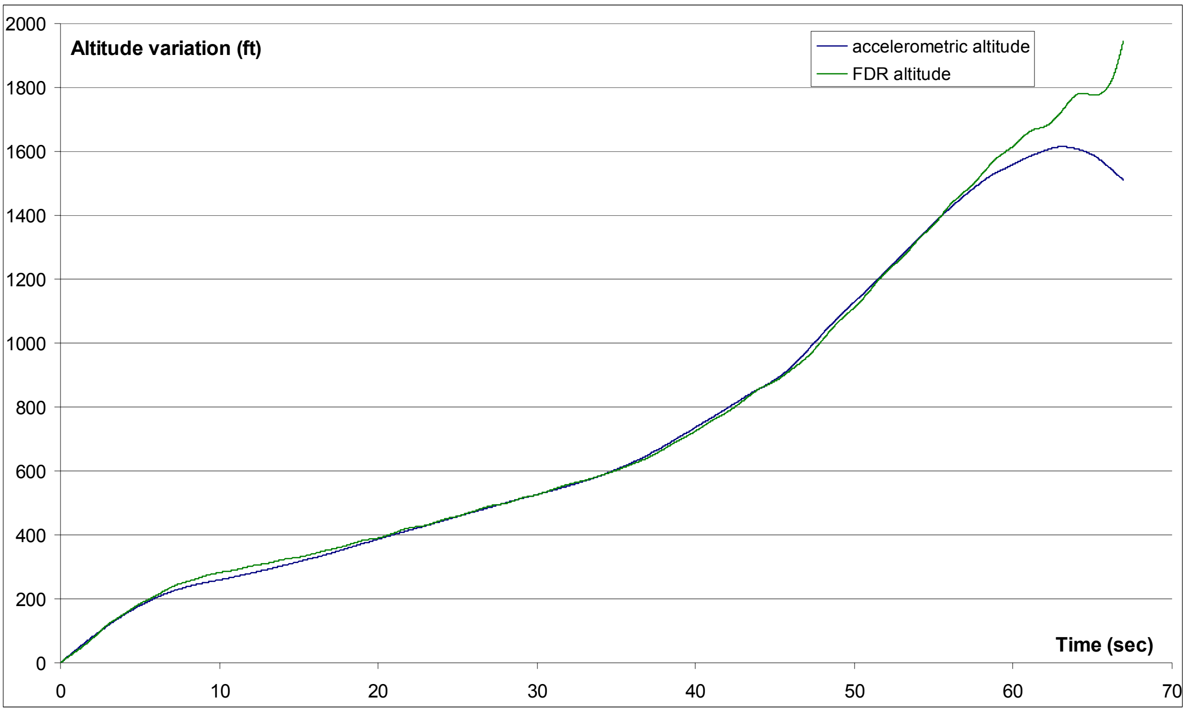


Figure 12- altitude variations used to check nz bias

We can see that we have a good matching of the altitude variations till T=56sec where the aircraft begins to experience high sideslip angle and angular speeds affecting the static pressure measurement and consequently the recorded pressure altitude.

The integration has been initialized at time GMT 14:14:54 FDR time. This time corresponds to the passage at 500 ft on the FDR, 54 seconds ahead of the OSMA simulation. The initialization took into account the Headwind recorded on the FDR (Ground Speed=159 kt and VTAS=180 kt gives Wind=21kt). The ground speed is initialized at the value recorded of the FDR, the ground sideslip is assumed equal to zero (wind in the aircraft plane of symmetry and aerodynamic sideslip equal to zero) and the ground incidence takes into account the headwind (αground = αaero * VTAS/Ground speed).

The result concerning the sideslip is presented in the following chart:

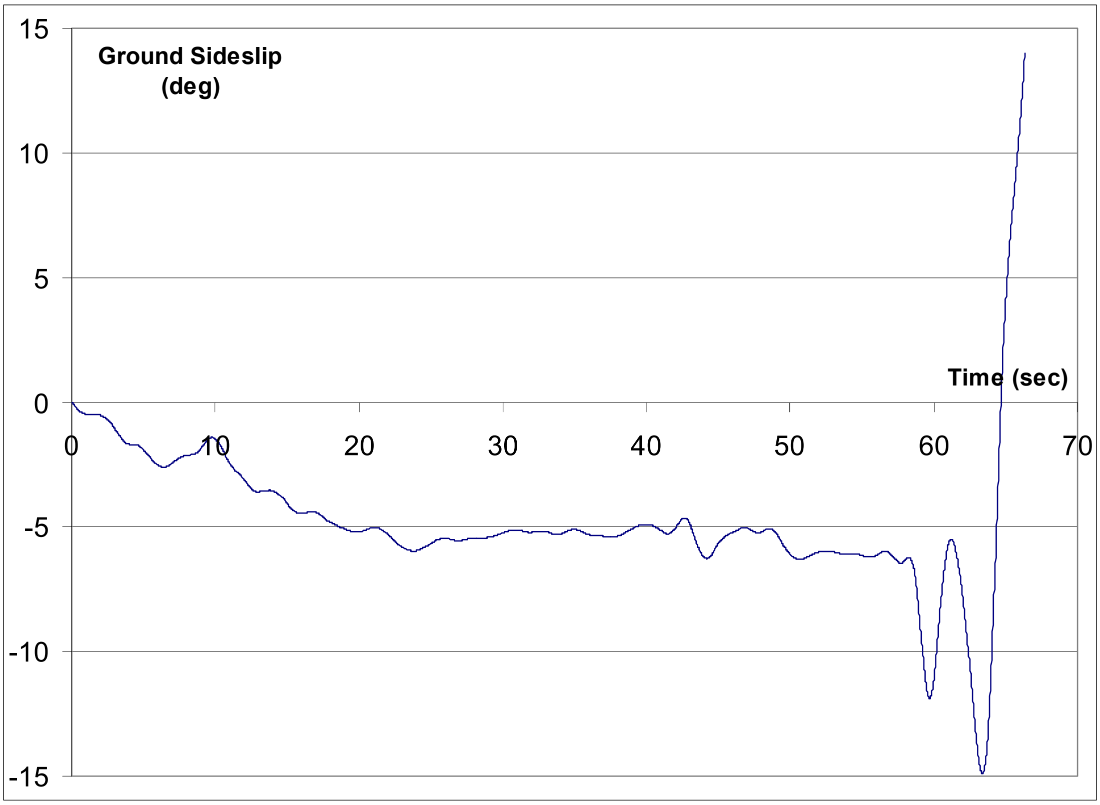


Figure 13 - Computed Ground sideslip

We can see that the ground sideslip decreases till T=20s then remains around –5 degree till T=50s, then reaches another value (-6.1°) till T=56s. This evolution has to be compared with the magnetic heading:

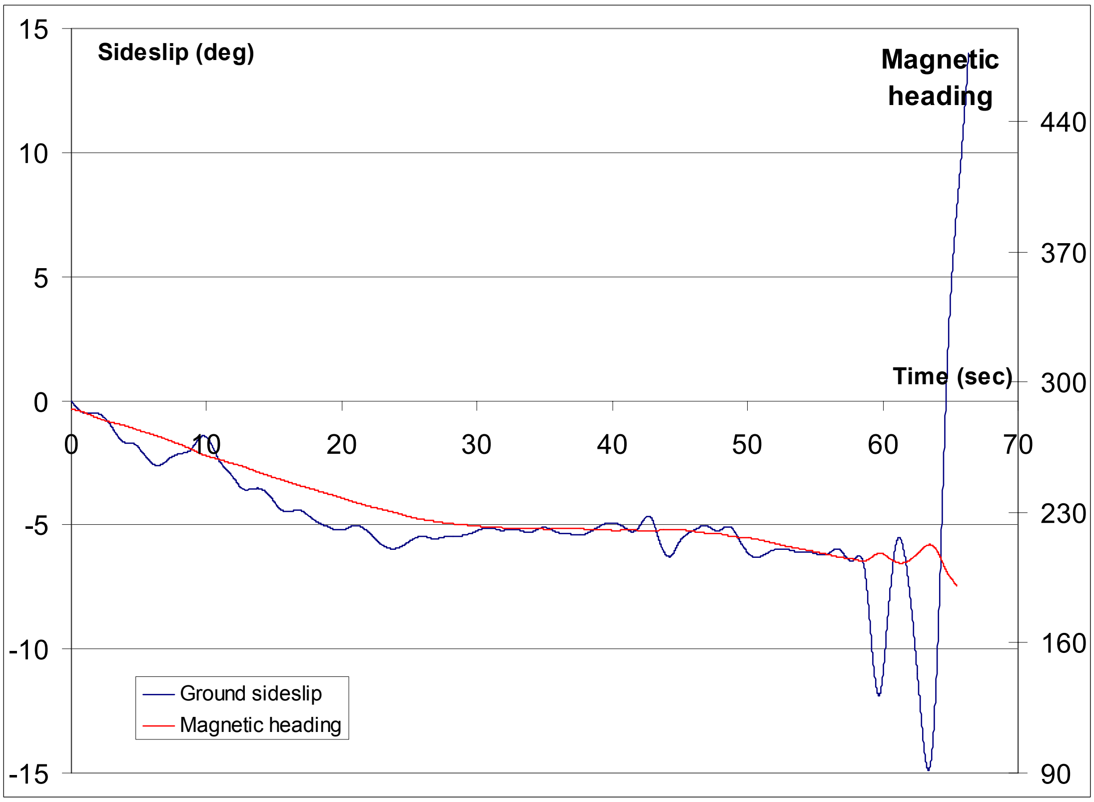


Figure 14 - Magnetic heading- ground sideslip comparison

We can see in this chart that: as the aircraft is turning the headwind changes to crosswind (around 80-degree turn) and therefore generates a ground sideslip. The aircraft is flying with a drift angle building up as the aircraft turns.

3.2 - Aerodynamic side-slip computation

The final purpose of this integration is to generate an aerodynamic side-slip, which is the relevant parameter for load computation. Actually the Aerodynamic side-slip is equal to the ground side-slip plus the wind side-slip. **As a result we have to make an assumption concerning the wind.**

Ed2

3.2.1 - Constant wind hypothesis

On a first step, the wind has been considered constant during the last moment before the accident (T=54s to T=66s). The wind estimation has been done to have an aerodynamic side-slip equal to zero at T=54s, this aerodynamic sideslip has been confirmed by the OSMA simulation (Aircraft movement simulation tool). This induced a wind side-slip of –6.1° corresponding to a constant wind of 25.5 kt blowing from 282° heading (same direction as the wind introduced at T=0 but 4.5kt stronger, which is reasonable at the ground effect reduces with the altitude).

Our aerodynamic sideslip resulting for the integration method then corrected by the value of the wind side-slip is presented in the following chart:

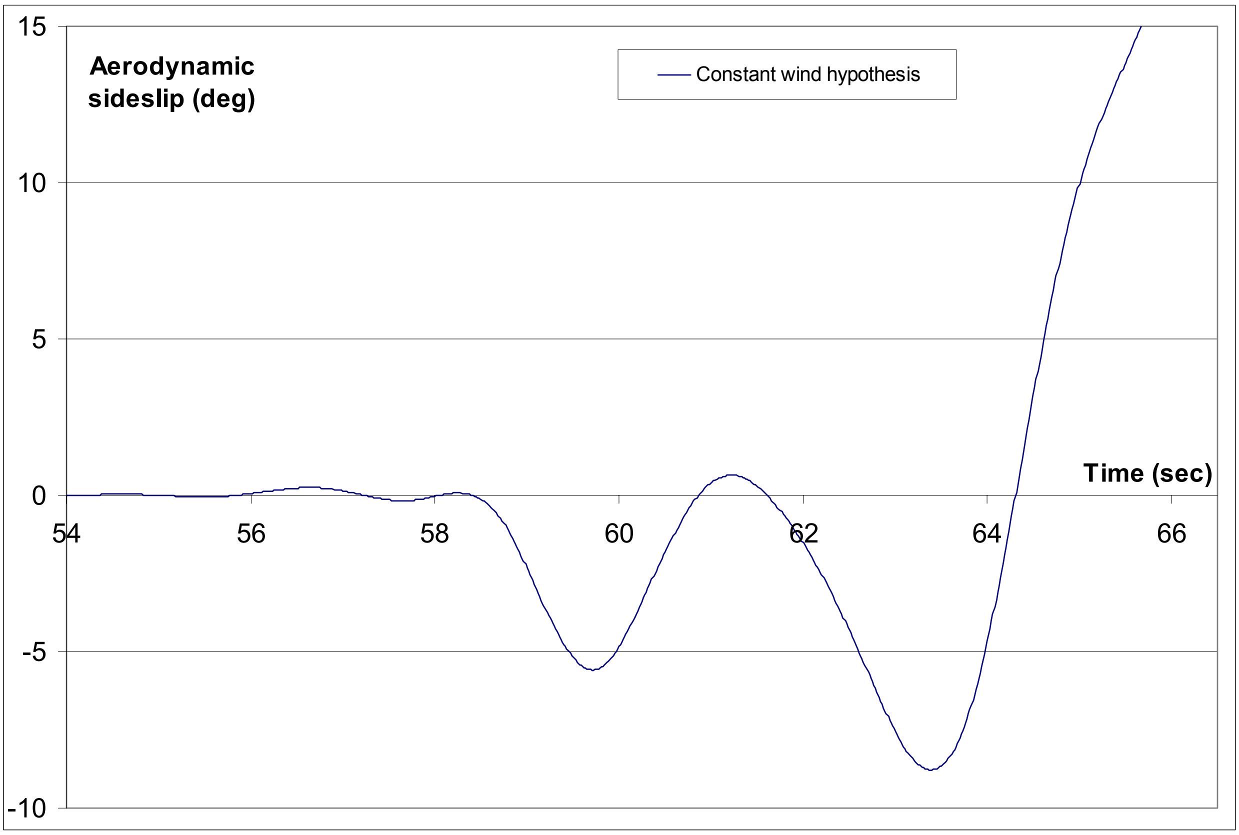


Figure 15 - Integration method side-slip

3.2.2 - Extrapolated wind hypothesis

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On a second step, the wind estimation from T=54s has been done taking into account the wind history before this time reference. The wind history velocity has been computed from the difference between aerodynamic speed (function of VTAS, α and sideslip) and ground speed (coming from the integration). As side-slip is not measured on the A/C, we assumed it equal to zero in all the computation (this hypothesis is valid because the A/C did not experienced large side-slips before the pilot pedals inputs).

This calculation gives us instant wind velocity and direction versus altitude:

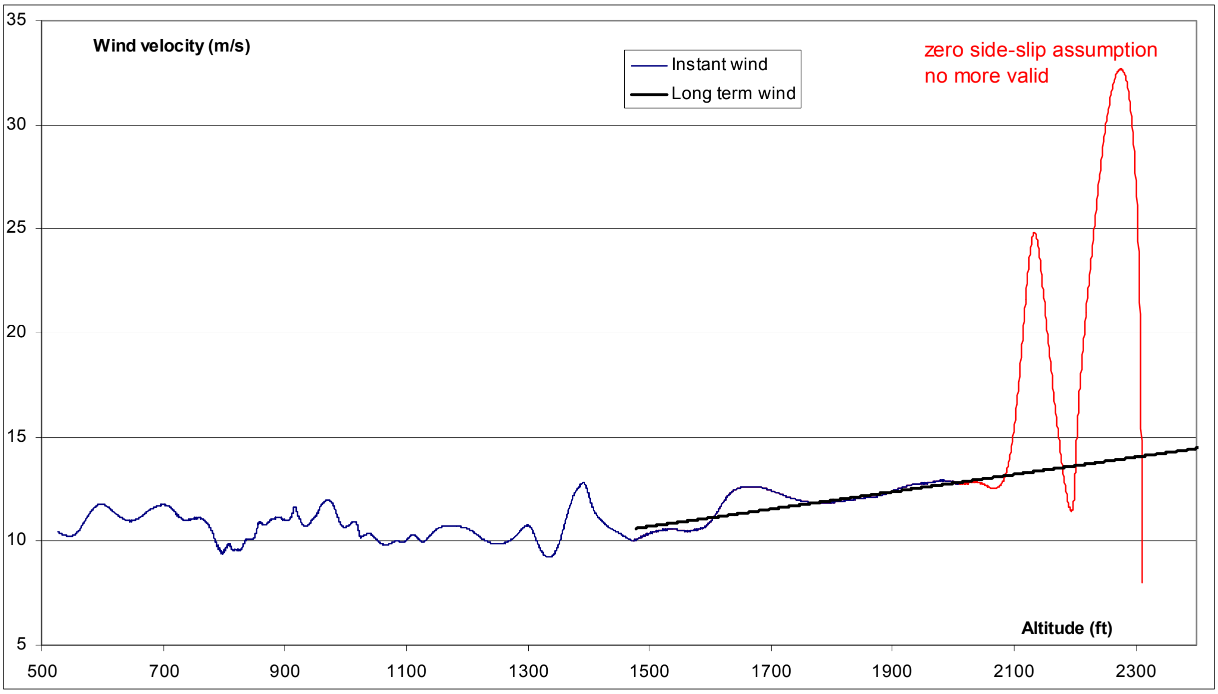

Figure 16 - Instant wind velocity and wind extrapolation versus altitude

A first phase shows moderate wind variation around a constant value of 11m/s.

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A second phase shows a velocity ramp up proportional to altitude increase followed by a third phase where wind velocity is strongly affected by aerodynamic side-slip variations. This computation is no more valid in this range of altitude; to cope with this phenomenon we extrapolated the wind velocity history of the second phase in order to have a realistic value of the wind in this third phase.

The same process is applied to the wind direction:

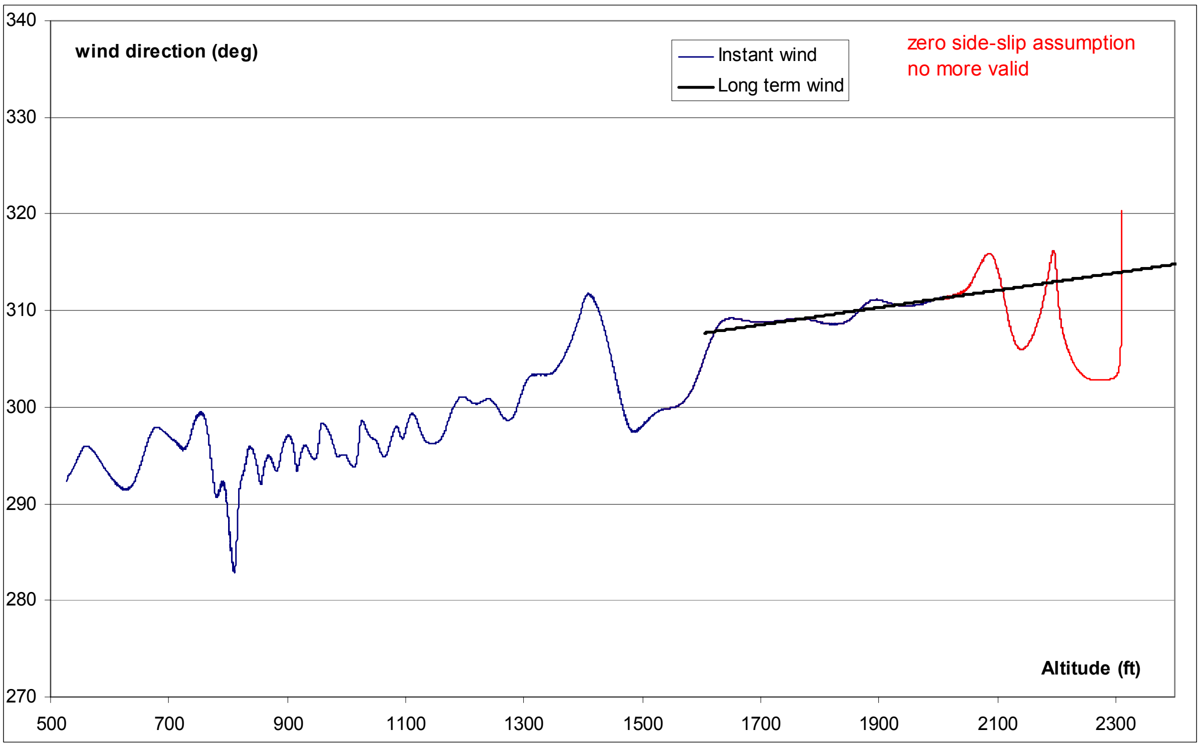

Figure 17 - Instant wind direction and wind extrapolation versus altitude

The wind velocity and direction extrapolation is used to compute the aerodynamic sideslip of the A/C in the last seconds of the accident. We can see in the following chart the impact of this wind estimation on the aerodynamic side-slip:

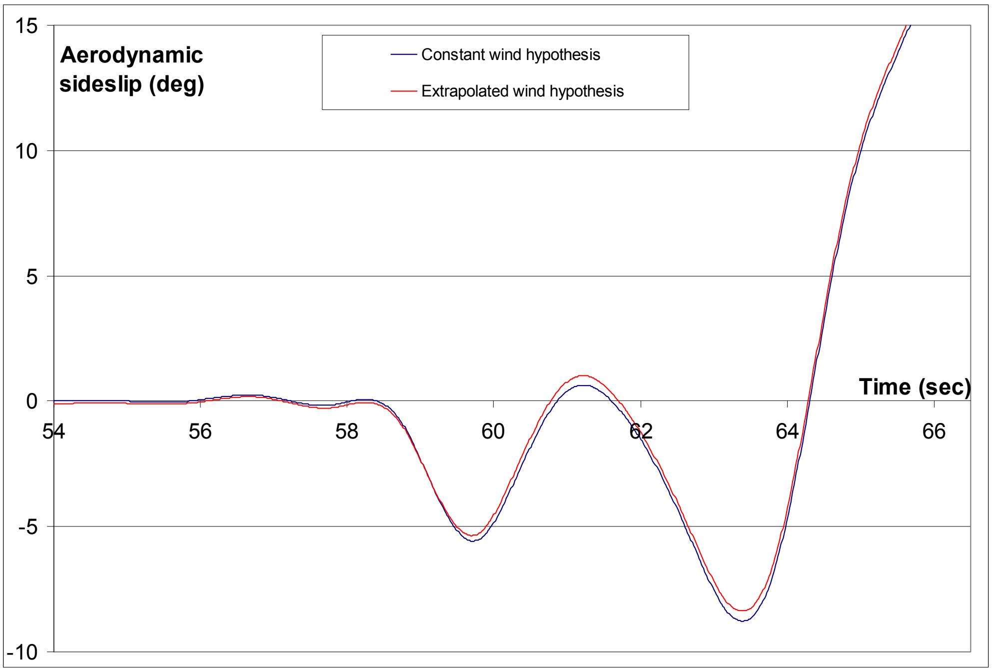

Figure 18 - wind hypothesis comparison

3.3 - Side-slip comparison

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It is possible to compute the aerodynamic side-slip with our aircraft movement simulation tool (OSMA). This tool relies on an aircraft aerodynamic model, so it is interesting to compare the two results given by these two different tools.
The computed aerodynamic side-slip relying on integration method is presented in the following chart and compared with the OSMA simulation from note 517.0082/2002 issue3:

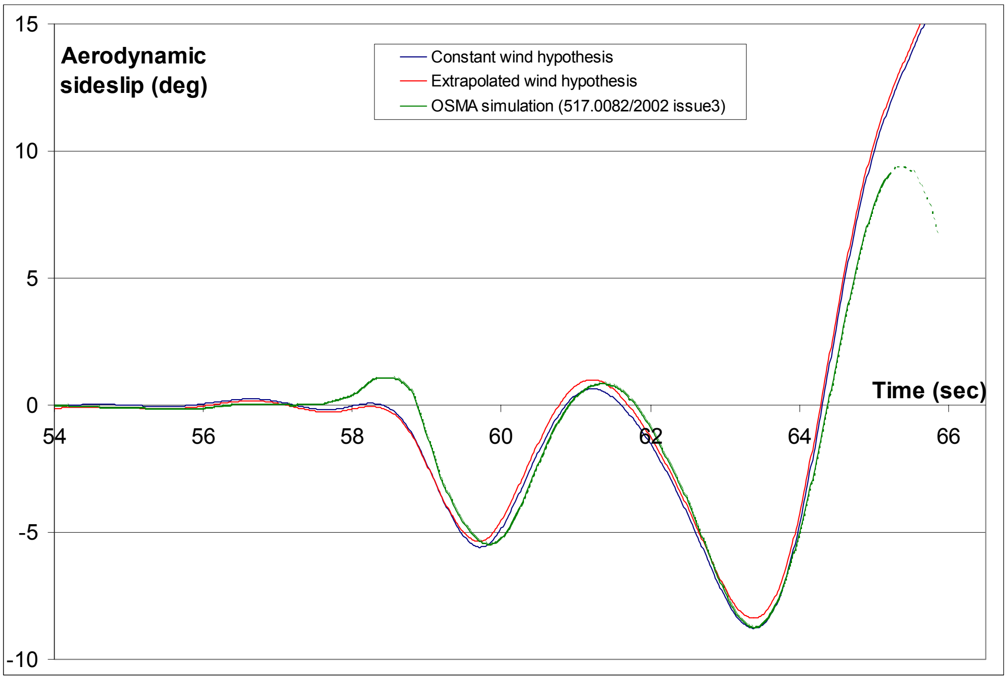

Figure 19-OSMA simulation versus FDR Ny integration

The results are pretty close especially in the last moment of the simulation before the two curves diverge. The major differences appear in the time period 57s-60s where lateral gust has been introduced in the OSMA simulation. This is an encouraging statement since these two methods are completely different: With OSMA the complete aircraft movement is simulated by entering the control surface position to an aircraft model and simulator whereas the integration method only relies on the kinematics equations fed by FDR data. It must be noted that after the estimated time of fin separation, the model and simulation derived side-slip cannot faithfully reproduce the actual motion of flight 587 (doted line).