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

February 27, 2004

ADDENDUM NUMBER 1D 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, HANDLING QUALITIES INVESTIGATIONS"***

DEPARTEMENT : EYCD SECTION : 517 GO : PROGRAMME :A300-600 : DATE :01/10/2003	REFERENCE : 517.0082/2002 TOME : EDITION : 03 PROJET : REF PROJET : REV : O.F. : ATA : 27 - CLIENT :

TITRE : AAL 587 – HANDLING QUALITIES INVESTIGATIONS

AUTEURS ---------------------

RESUME :

The purpose of this note is to summarize the work done up to october 2003 by EYCDA in the frame of AAL 587 investigations.

This note provides:

1) The way the primitive rudder position deflection has been reconstitued with OSMA tool and the check that has been done using the rudder pedal inputs.
Ed 3 2) The best simulation of the event performed with the basic A300-600 aerodynamic model and its matching with the recorded parameters (simulation referenced 16.7).
3) An additive simulation with simulated loss of A/C components (fin & rudder)(Ed 2)
Ed 3 4) An illustration of the event in a rudder deflection vs sideslip diagram.
5) The corresponding hinge moment on the rudder during the event and a complementary analysis of the effect of the aerodynamic load compared to the rudder actuators forces.
6) The estimated spoiler surfaces history and their coherences with the corresponding FDR booleans.

Main results are:

- a good continuous rudder deflection time history is established.
- the result of the simulation is very close to recorded parameters from FDR
- hinge moment analysis excludes back driving.
- spoiler activity shows three hydraulics circuit activity throughout the sequence.
- rudder deflection time history is consistent with nominally working TLU.
- rudder deflection and rudder pedal deflection indicate nominal function of yaw damper and cable stretching.

MOTS CLES : ACCIDENT

LIENS : 517.0013/2002 – 506.0008/2002 ed2 – EYCAA_C27D03017000_v01

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1) Introduction:

The purpose of this note is to summarize the work done up to October 2003 by EYCDA in the frame of AAL 587 investigations.

This note provides :

1) The way the primitive rudder position deflection has been reconstitued with OSMA tool (Outil de Simulation des Mouvements Avion) (basically a six degrees of freedom program) and the check which has been done using the rudder pedal inputs.

2) The best simulation of the event performed with the basic A300-600 aerodynamic model and its matching with the recorded parameters. And ,as a complement ,a simulation introducing a fin / rudder modified efficiency associated to a complete loss of this part from the A/C and giving a better matching is also provided.

3) An illustration of the event in a rudder deflection versus sideslip diagram.

4) The corresponding hinge moment on the rudder during the event and a complementary analysis of the effect of the aerodynamic load compared to the rudder actuators forces.

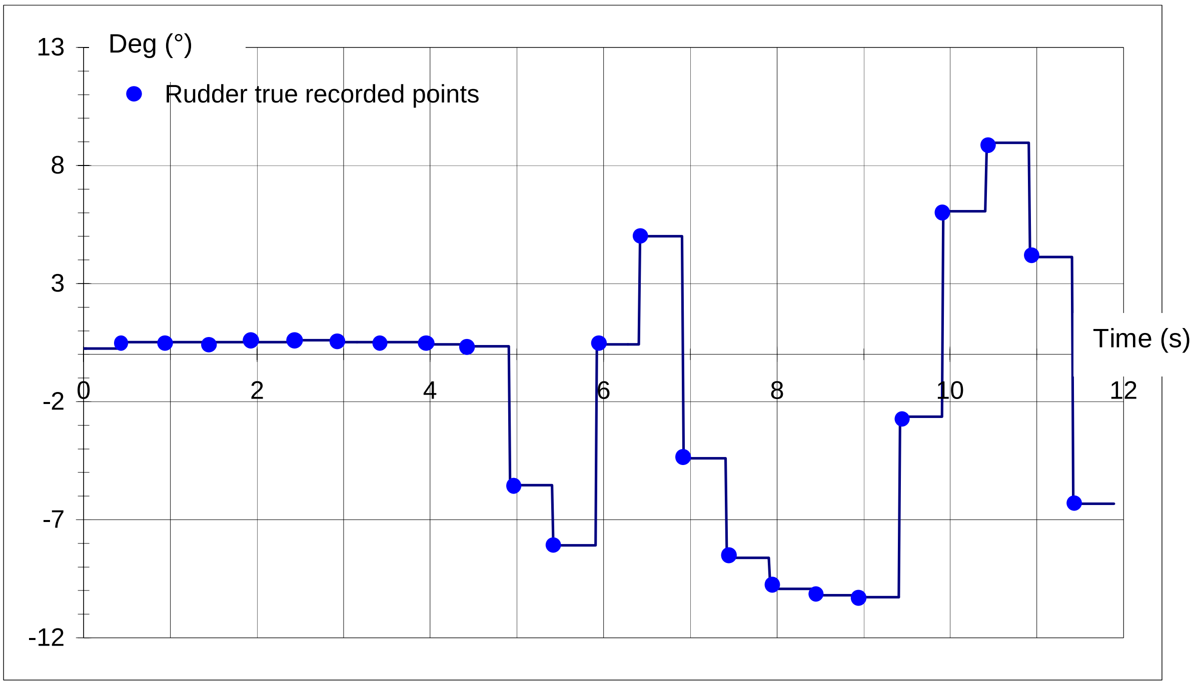
5) The estimated spoiler surfaces history and their coherences with the corresponding FDR booleans.

2) Rudder surface position history - reconstitution with OSMA:

The data which are available for this process are the FDR surface position recordings.These recorded data are coming from SDAC (System Data Acquisition Concentrator) and are sampled by the DFDAU (Digital Flight Data Acquisition Unit) with a time stamp information. It has been assumed that the DFDAU does not introduce any signal distortion.

The SDAC collects the primary flight control surfaces information with a built in signal processing which has been assimilated to a digital first order filter with a time constant which has been estimated close to 434 ms. Technical note ref 506.0008/2002 defines the correct time constant of the filter.

The 2 points per second FDR recorded rudder surface position filtered by the SDAC is the following:
(The time scale in all the following simulation and charts are such that t=0 corresponds to GMT=14.15.48 and FDR elapsed time 838.985)

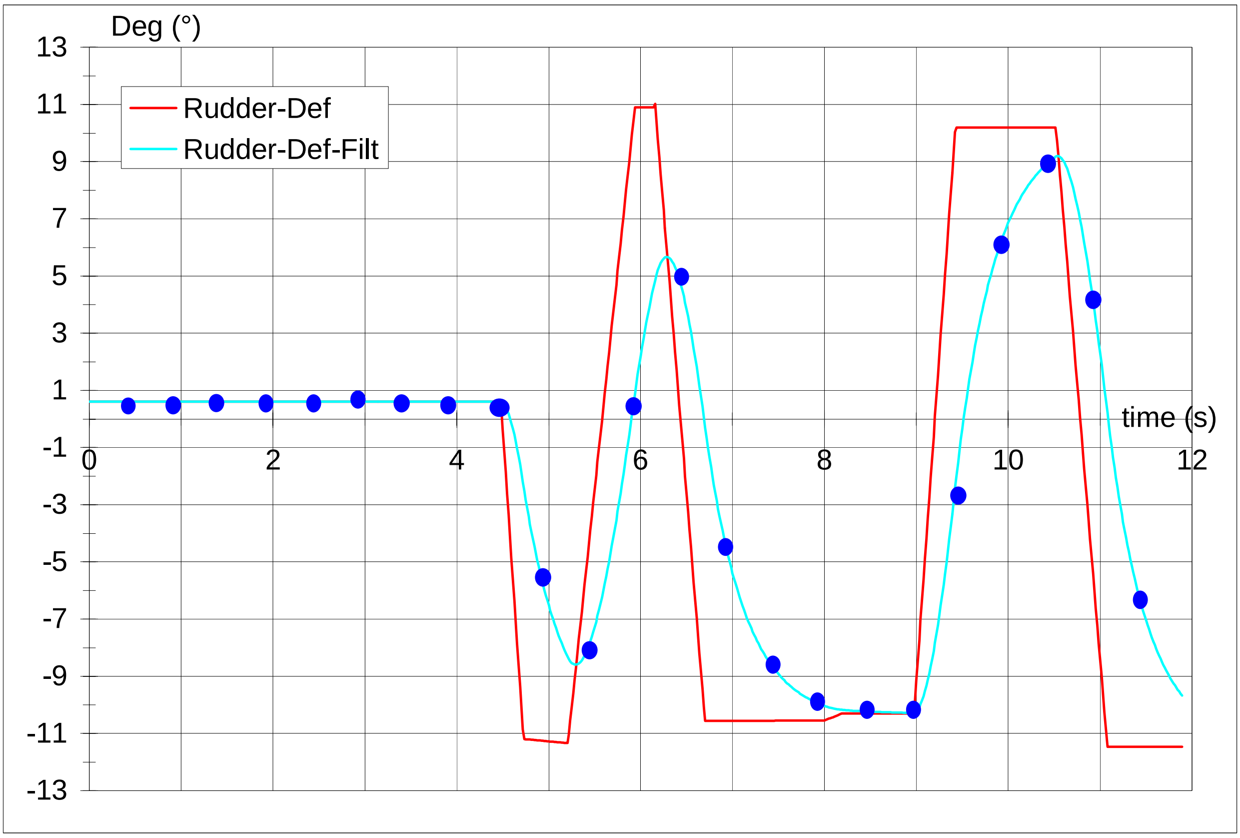


To reconstitute the primitive rudder position which gives the same filtered output and which gives the best matching in term of A/C lateral recorded parameters (lateral load factor,heading and roll angle) we have introduced the SDAC filter modelization in the six degrees of freedom OSMA tool.

<u>The question is</u>: what are the inputs of the simulation which give the same filtered outputs than the recorded ones and giving the same A/C behavior?

The primitive rudder position is determined using an iterative process where each iteration is a dynamic simulation. Each output of the simulation is compared to the corresponding FDR recorded para Time (s) primitive rudder position is then adjusted and the process applied again until the matching with recorded parameters is satisfactory.

The rudder input which has been estimated using this process is the following. This primitive input (in continue red) gives the same filtered output than the FDR recorded one when filtered with the digital first order filter defined in the beginning of 2) (SDAC effect).



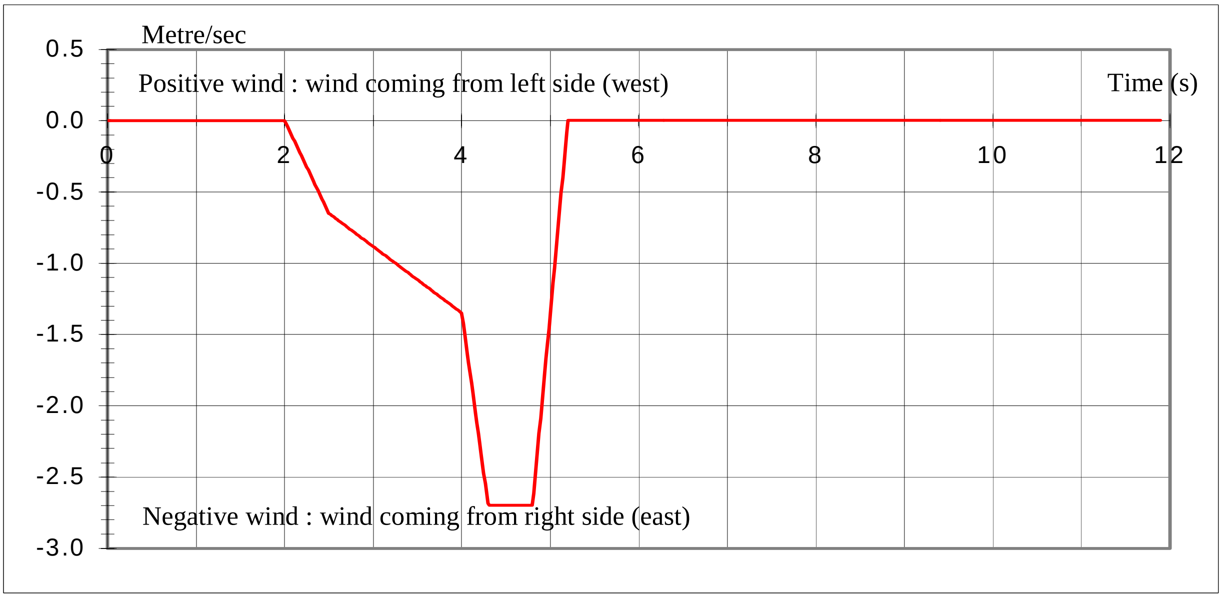
3) Simulation of the event and matching with FDR parameters :

The basic identification of the event has been made with OSMA tool using the A300-600 aerodynamic model adjusted from flight tests.
The simulation leading to the best matching with FDR parameters is the following:
(FDR parameters in blue with indicated recorded true points – Results of the simulation in red)

NOTE:Consistency between rudder and rudder pedals is analysed at §9.

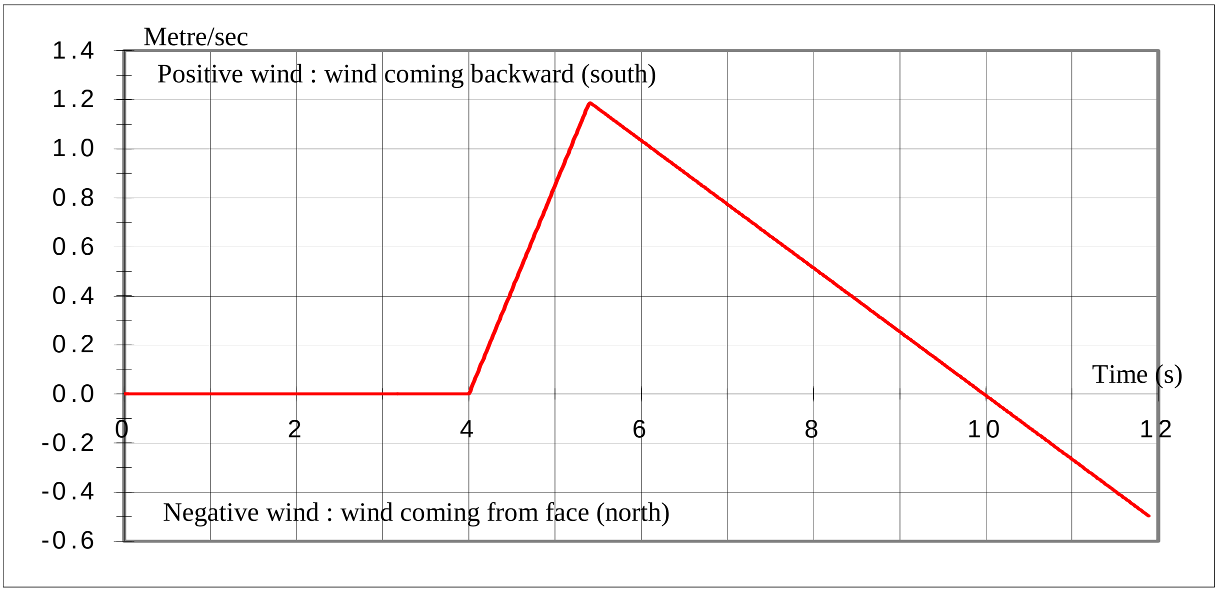
WIND COMPONENTS:
(NOTA:Wind velocities are given in ground axis)

- Lateral wind component = f(time)

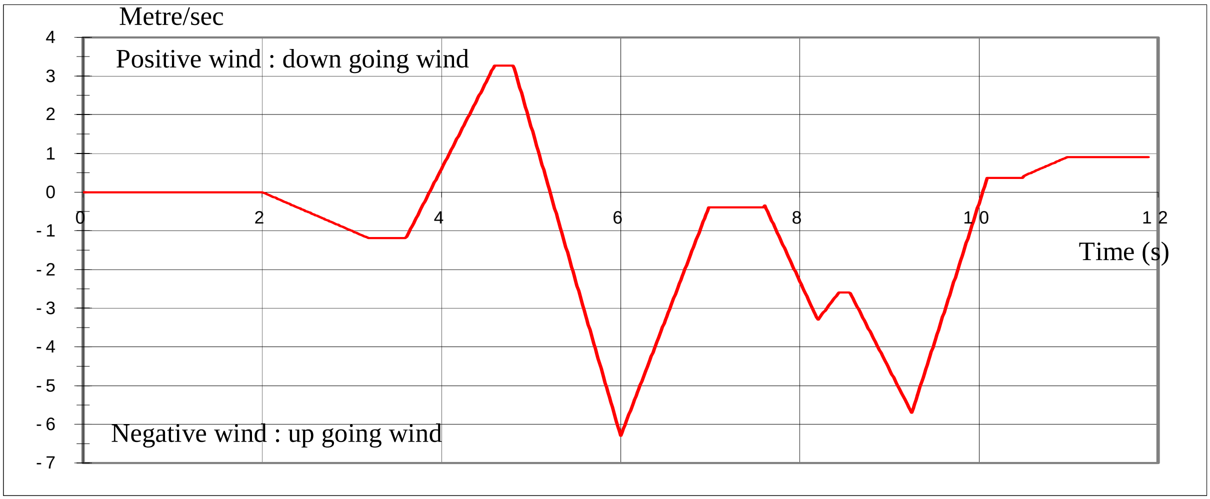


Ed 3

- Longitudinal wind component = f(time)

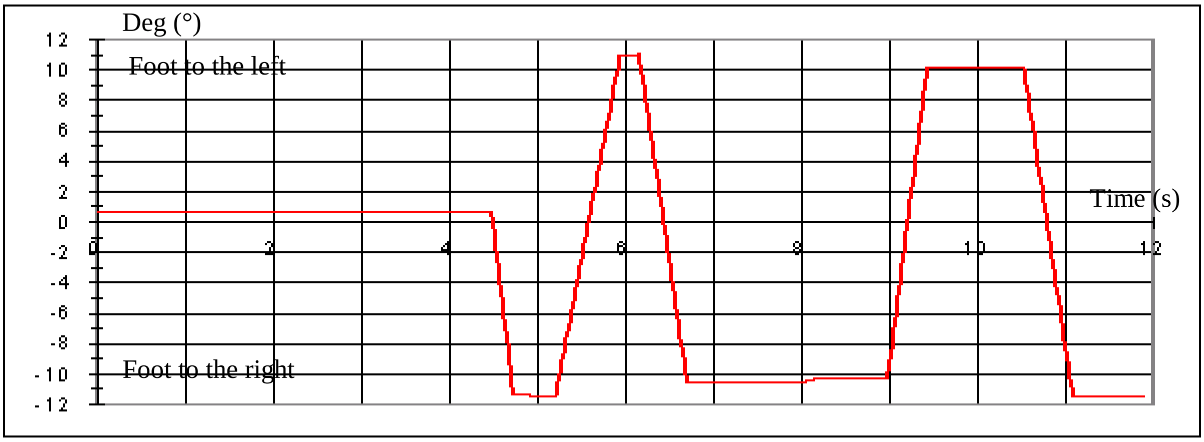


• Vertical wind component = f(time)



YAW AXIS:

• Rudder deflection = f(time)



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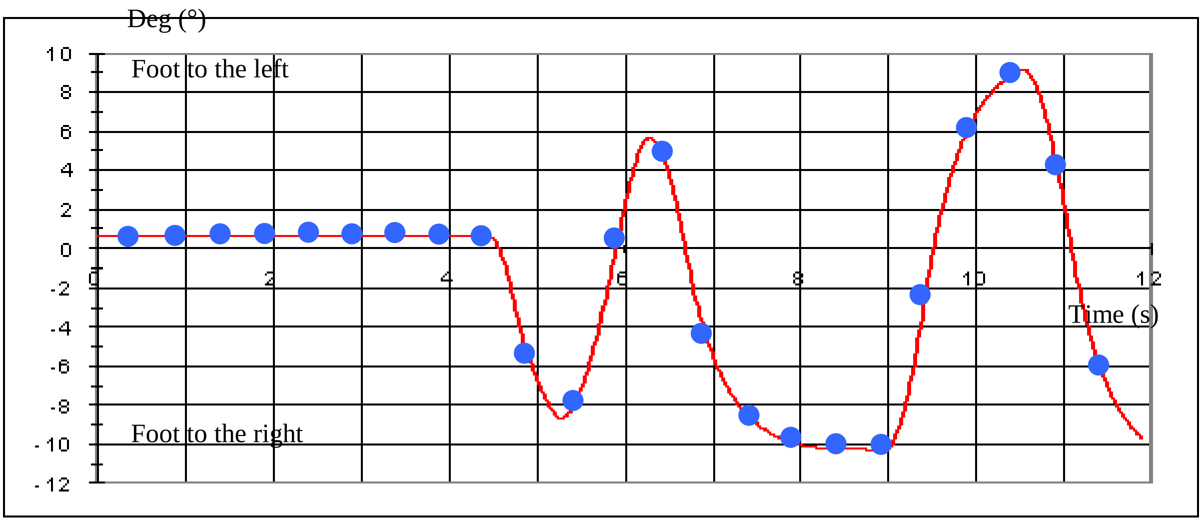
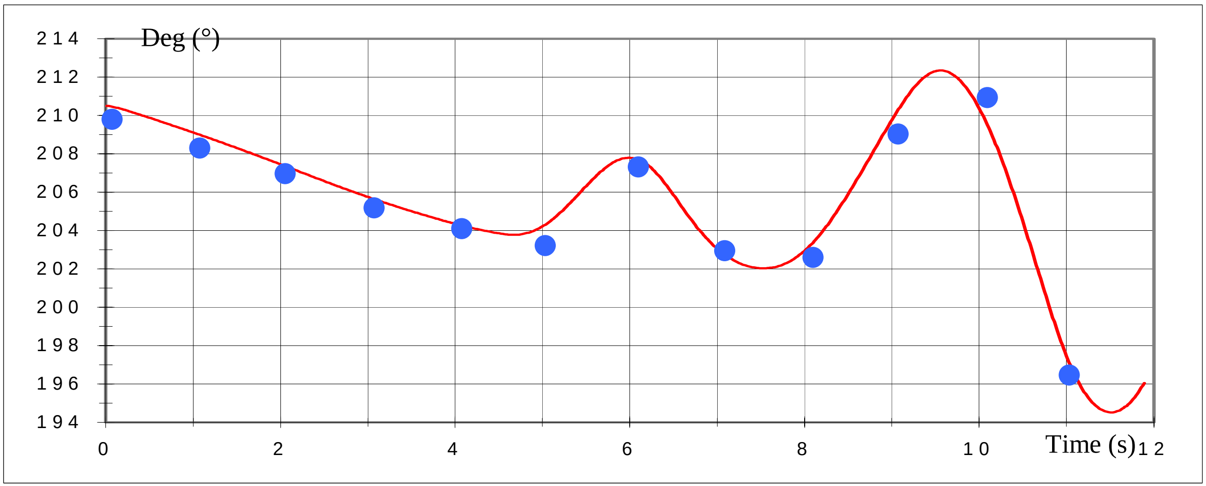
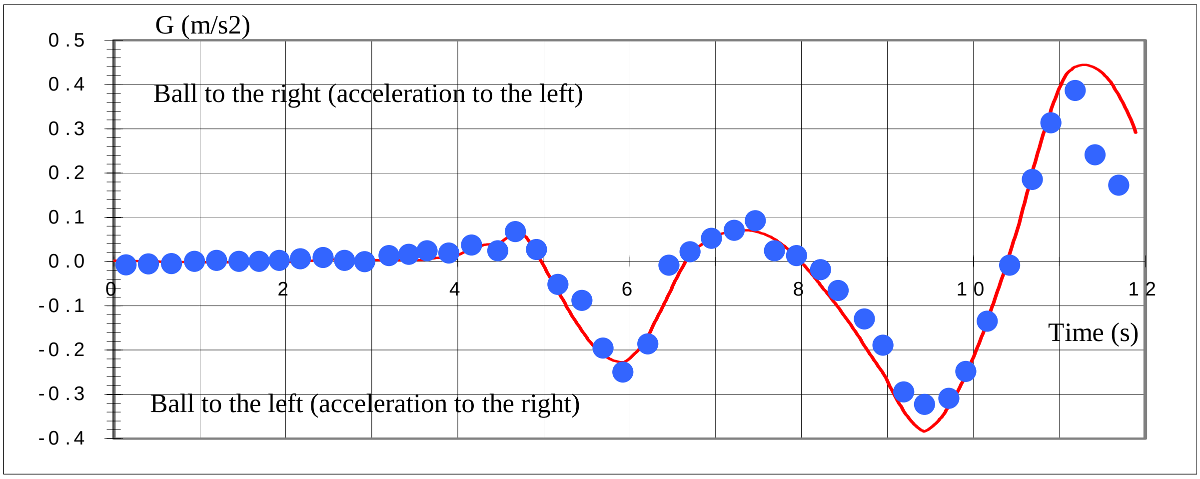
• Rudder deflection filtered = f(time)



• Heading angle = f(time)



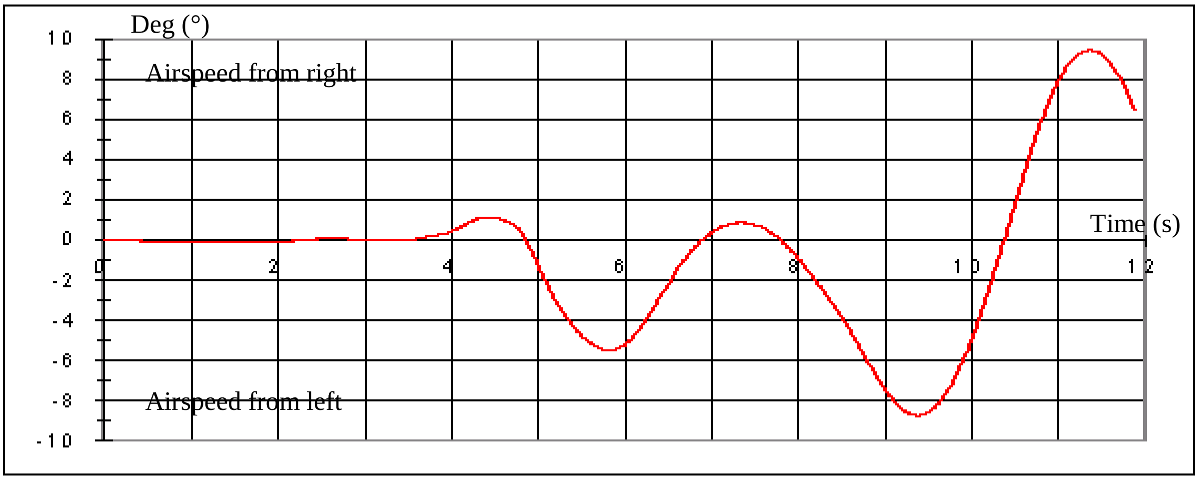
• Lateral load factor = f(time)



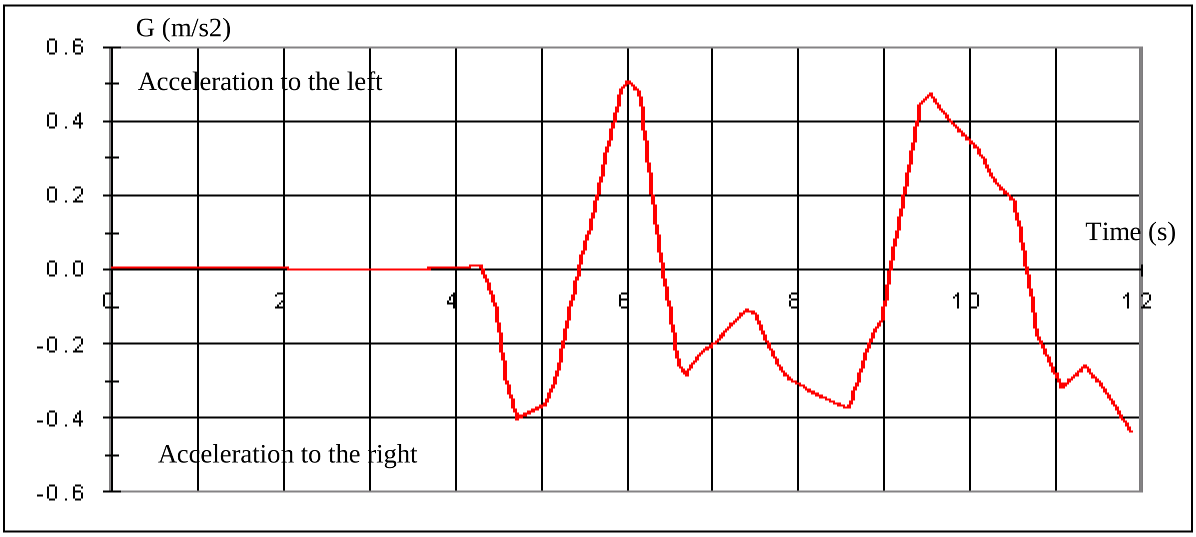
Ed 3

NOTA: This lateral load factor has been computed at the exact location of FDR accelerometer (which is different from center of gravity location)

• Sideslip angle = f(time)

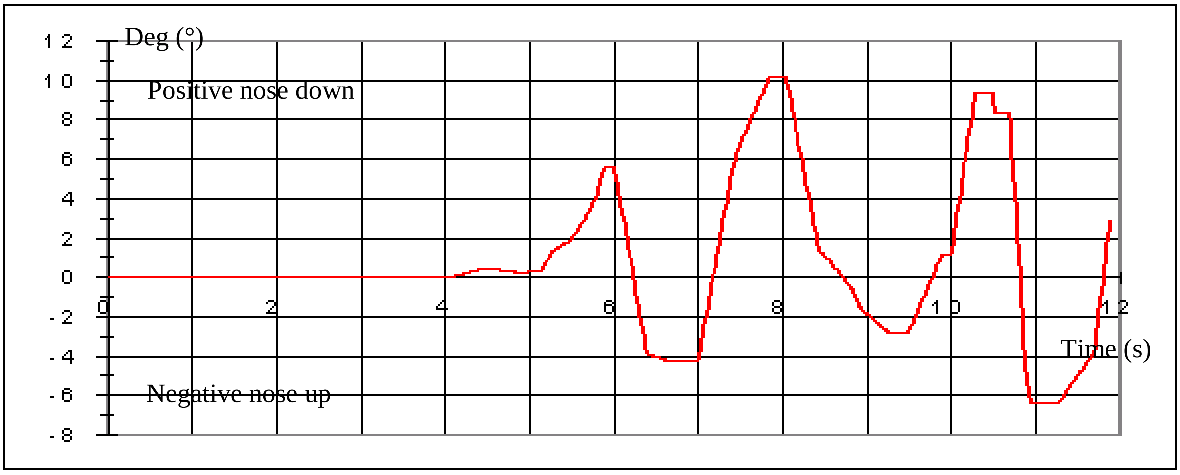


• Cockpit lateral load factor = f(time)

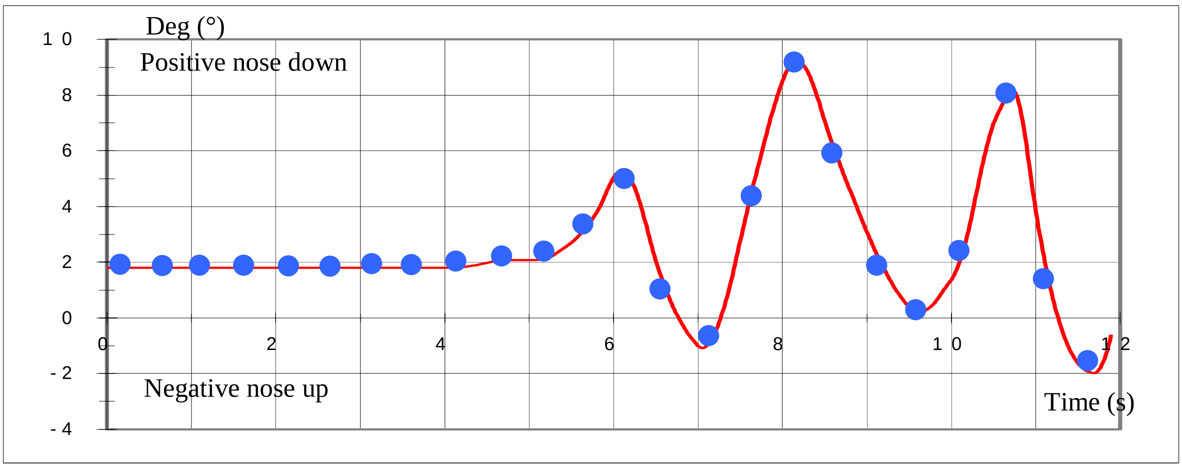


LONGITUDINAL AXIS:

• Elevator deflection = f(time)

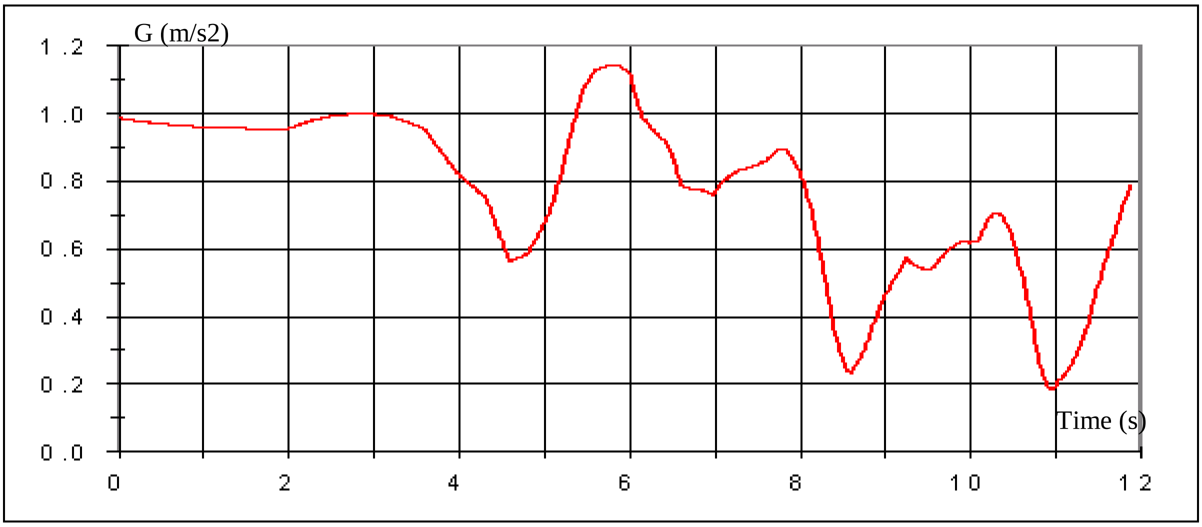


• Elevator deflection filtered = f(time)

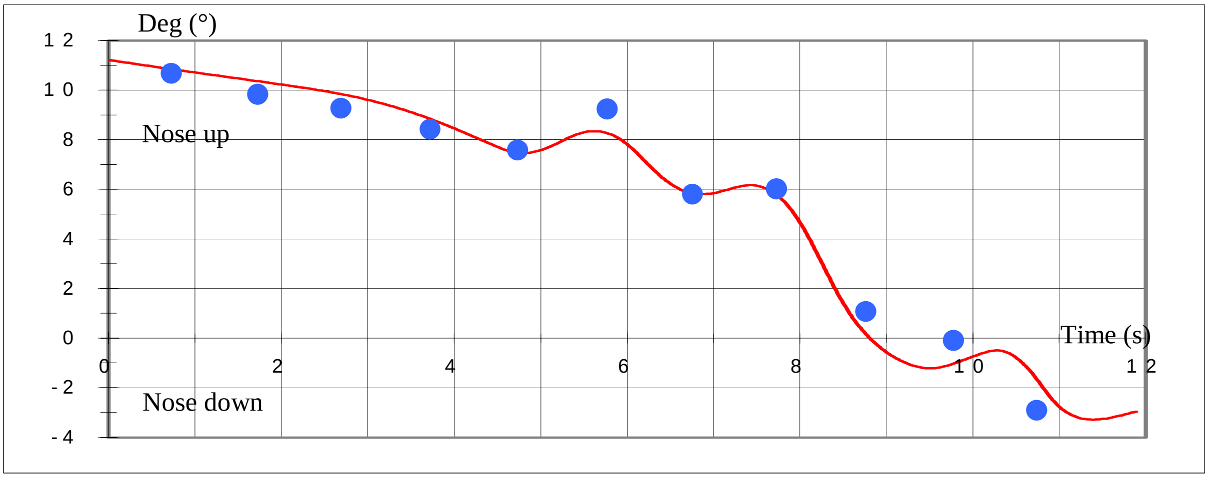


Ed 3

• Vertical load factor = f(time)



• Pitch attitude = f(time)



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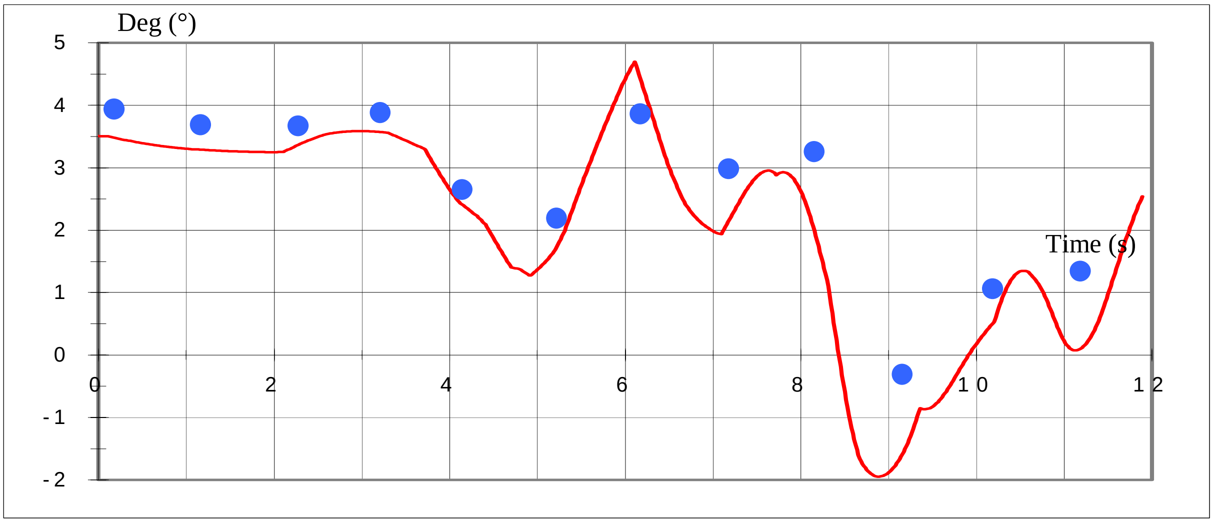
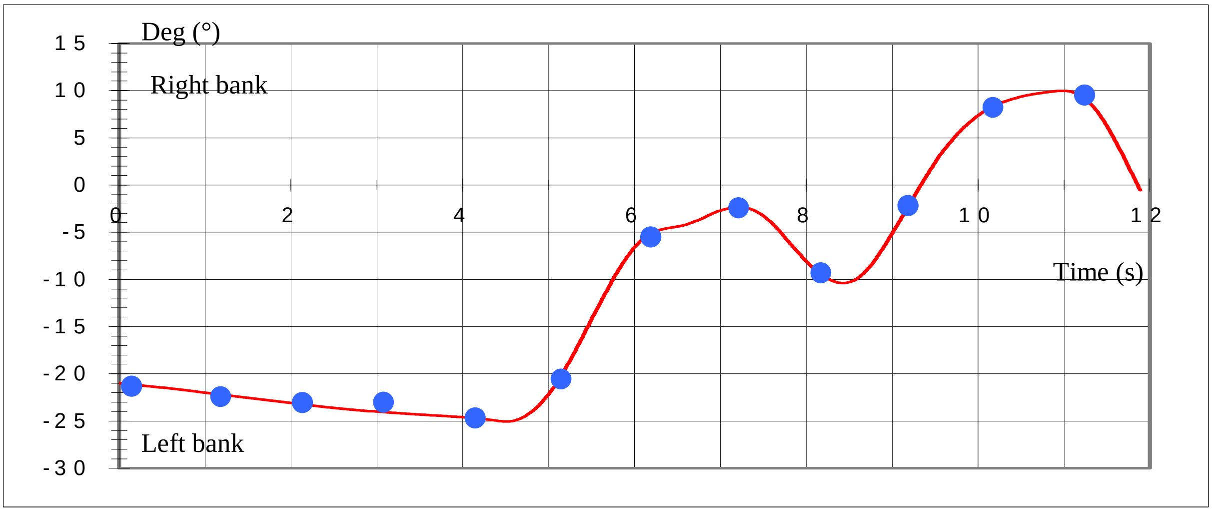
• Angle of attack (probe 1) = f(time)

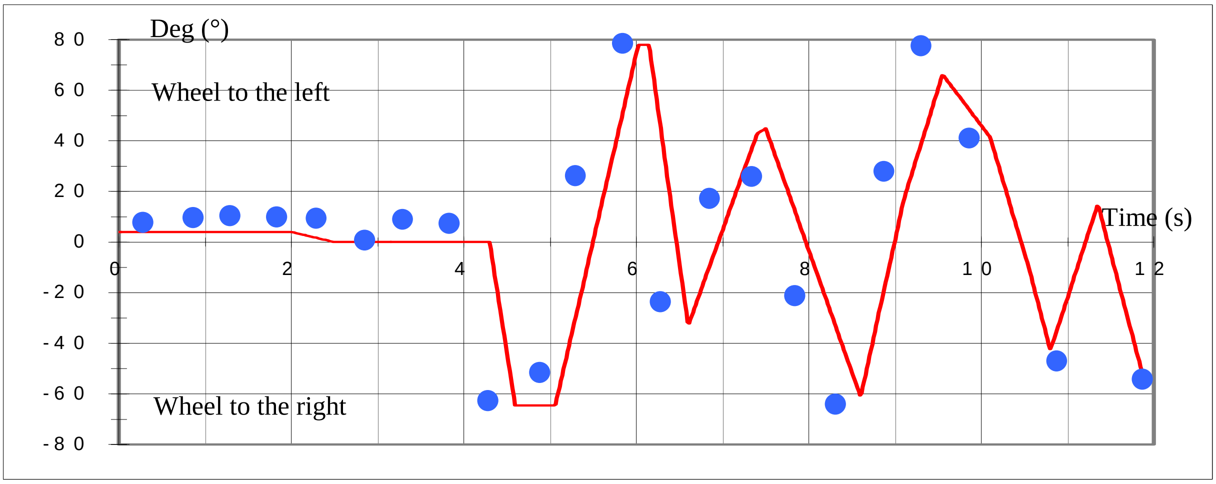


ROLL AXIS:

• Roll angle = f(time)

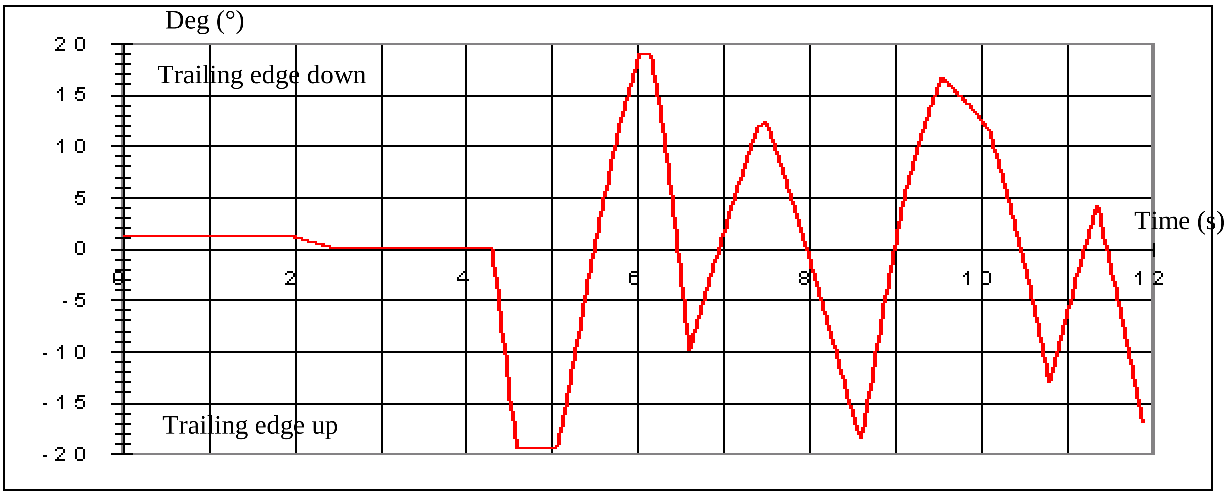


• Roll control wheel = f(time)

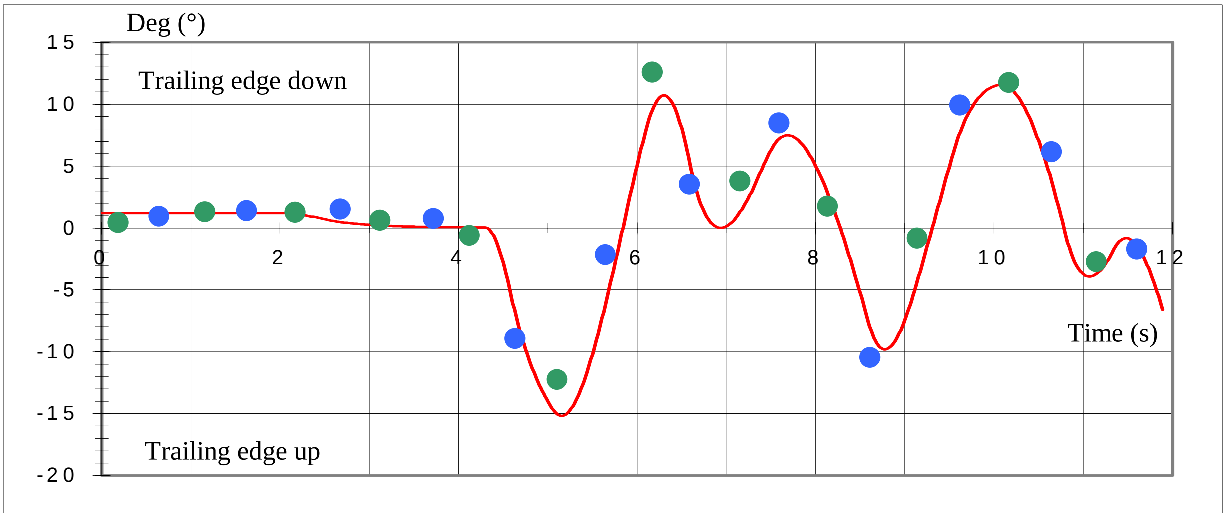


Ed 3

• Right aileron deflection = f(time)

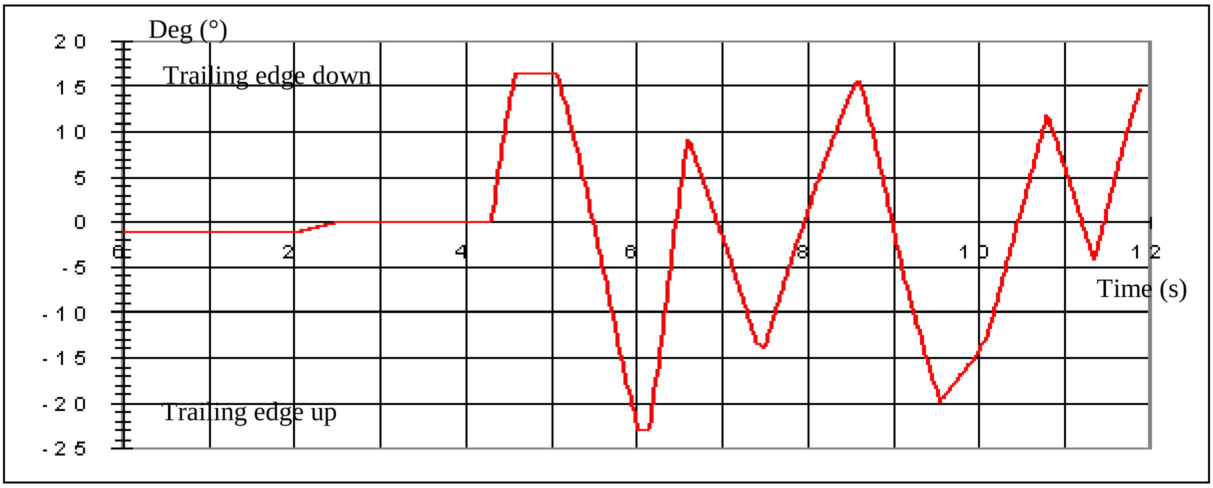


• Right aileron deflection filtered = f(time)

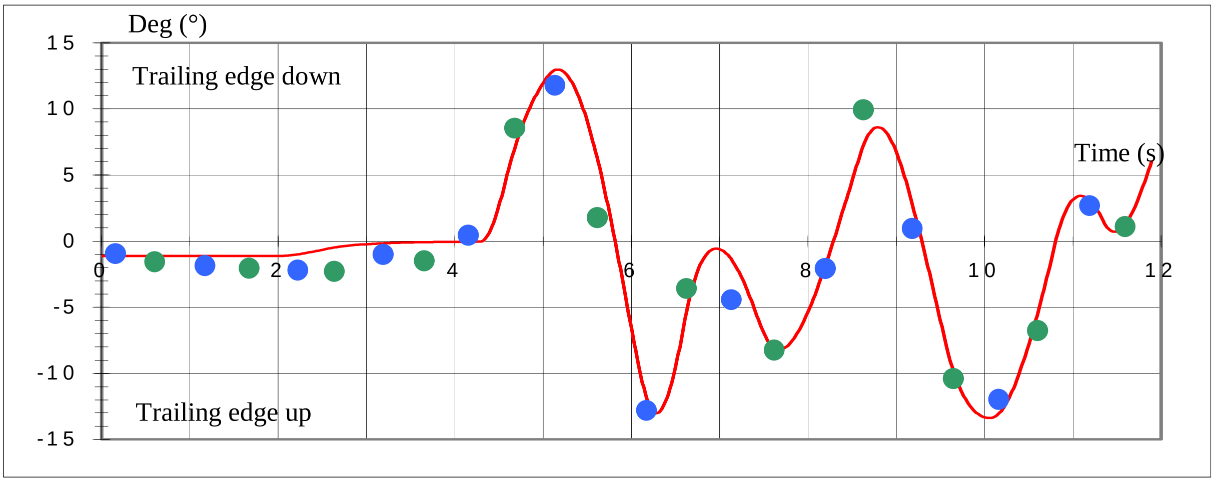


NOTA:In green is indicated the opposite of FDR left aileron parametre.

• Left aileron deflection = f(time)



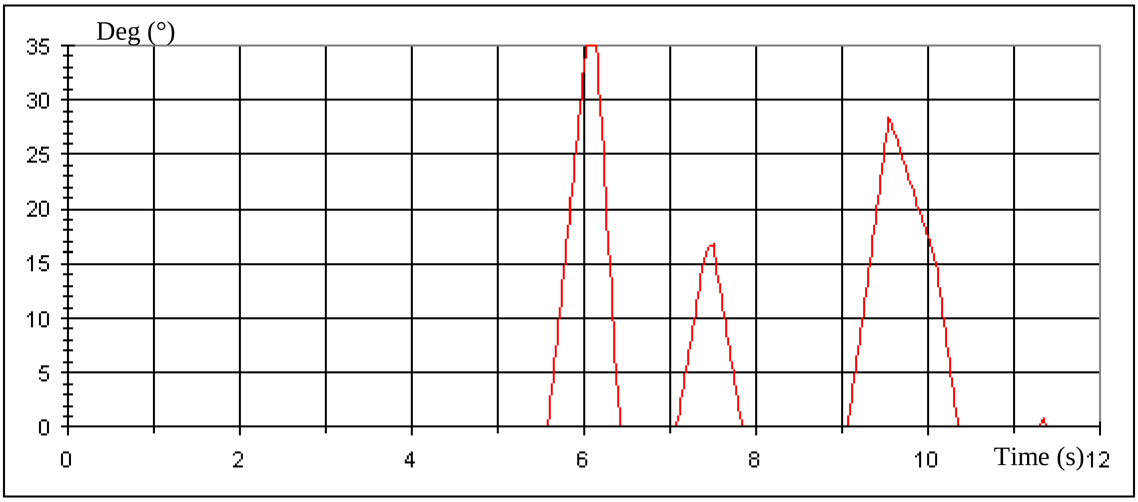
• Left aileron deflection filtered = f(time)



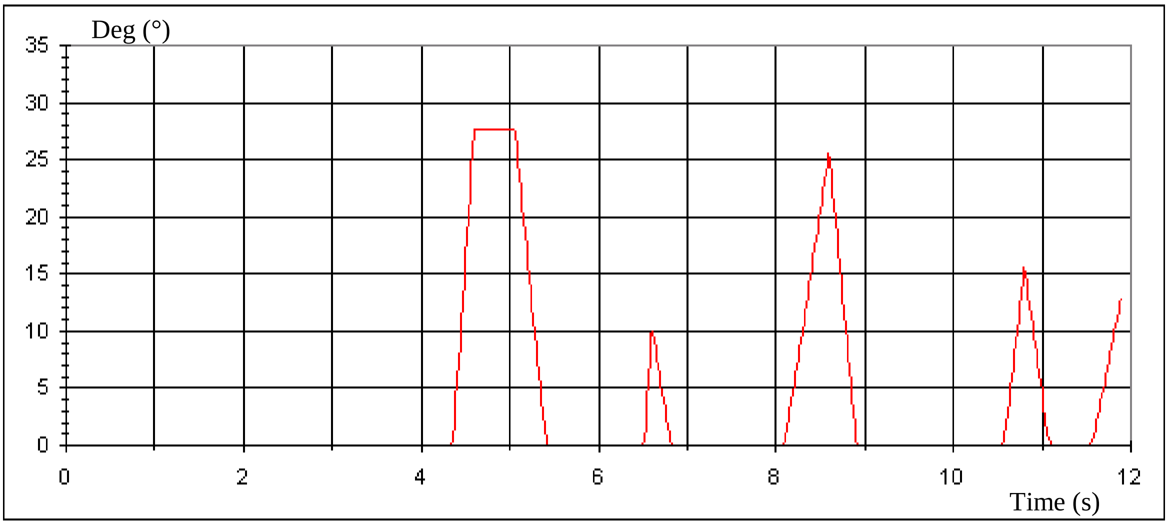
NOTA:In green is indicated the opposite of FDR right aileron parametre.

Ed 3

• Spoilers 3,4,5 left deflection = f(time)

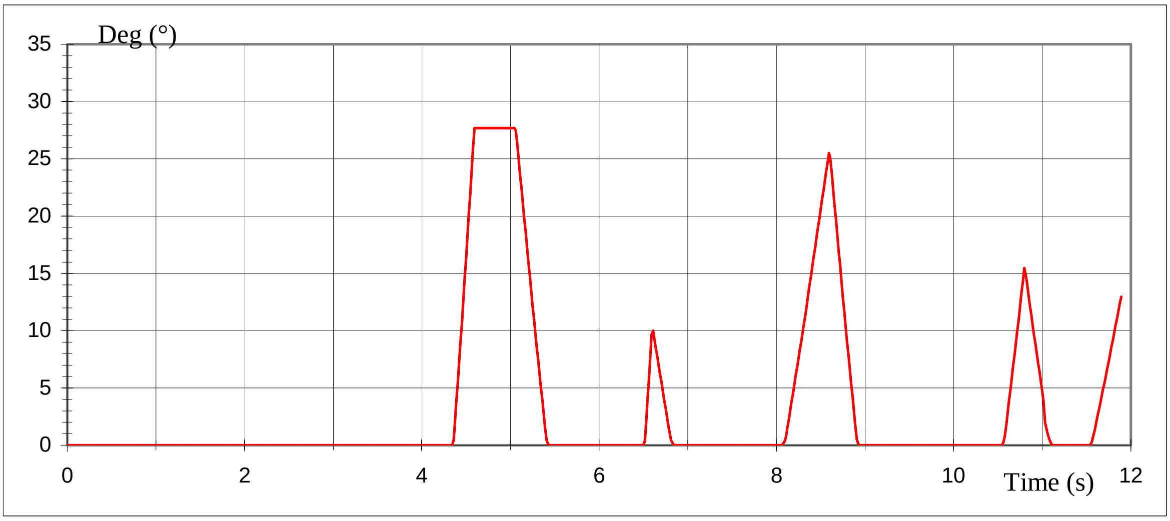


• Spoilers 3,4,5 right deflection = f(time)



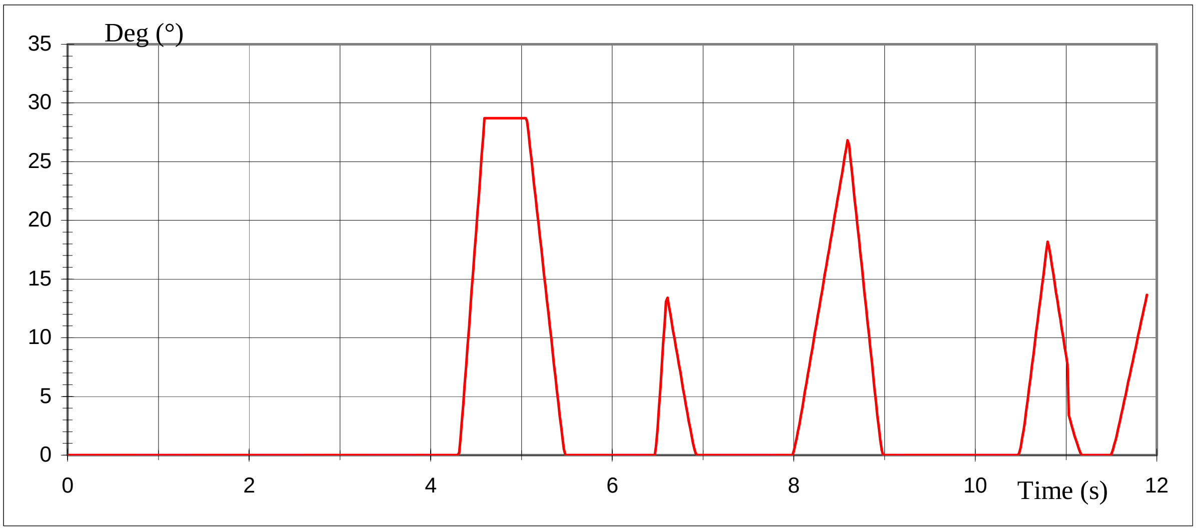
Ed 3

• Spoilers 6,7 left deflection = f(time)



Ed 3

• Spoilers 6,7 right deflection = f(time)



The processing which is applied here consists in a close reproduction of A/C roll behaviour.
Ailerons and spoilers deflections which have been used are coherent with the theoretical kinematic in roll (left aileron deflection is the opposite of the right one ,spoilers deflection is a function of ailerons deflection).

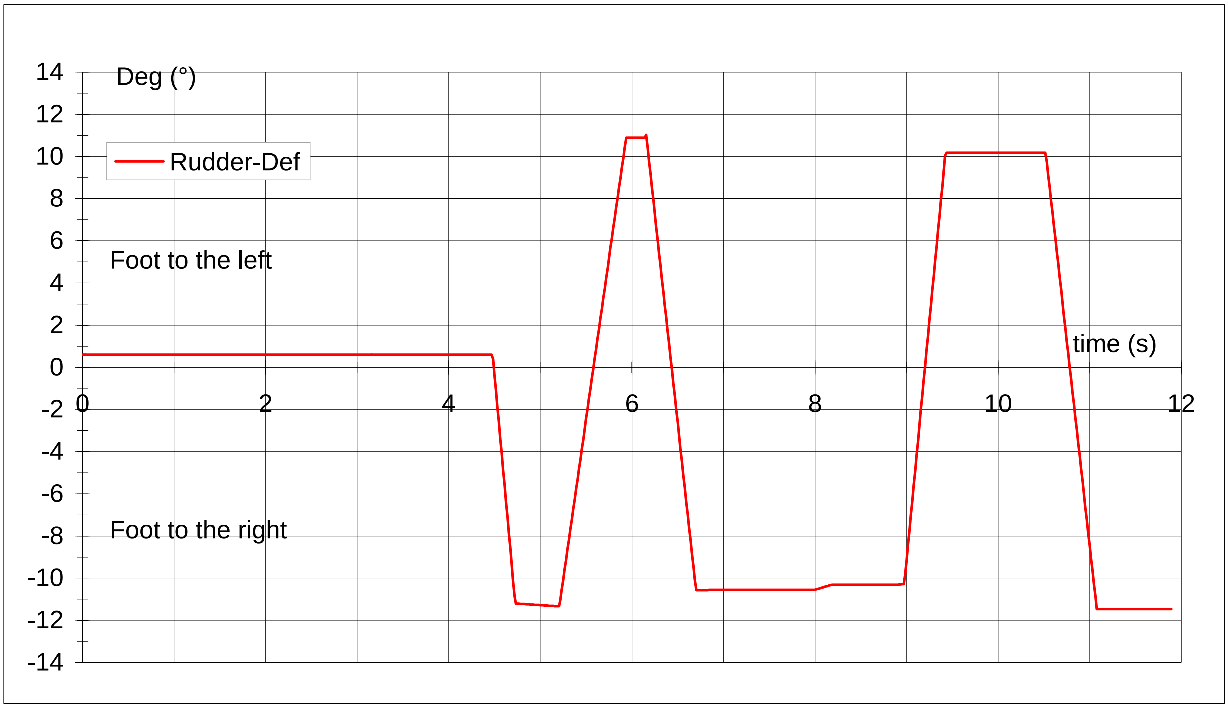
We are looking for a comparison between a set of continuous ,coherent and theoretical data (in term of ailerons and spoilers deflection) which are matching as close as possible with FDR parameters which are recorded with a loose sampling.

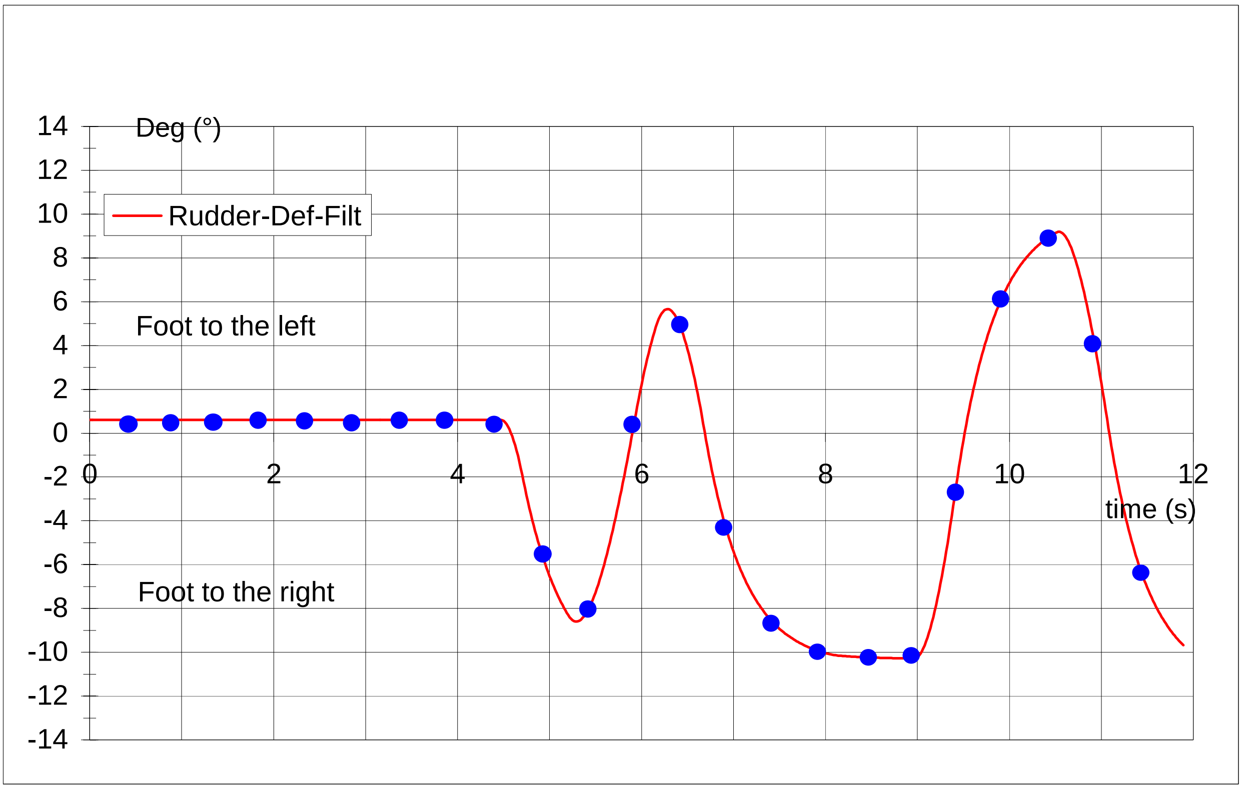
For instance ,when comparing filtered computed aileron position with FDR recorded aileron position ,we have complemented the available 1 pps points for a given aileron by the opposite points of the other ailerons ,also sampled at 1 pps but at a time frame different by 0.5 second.

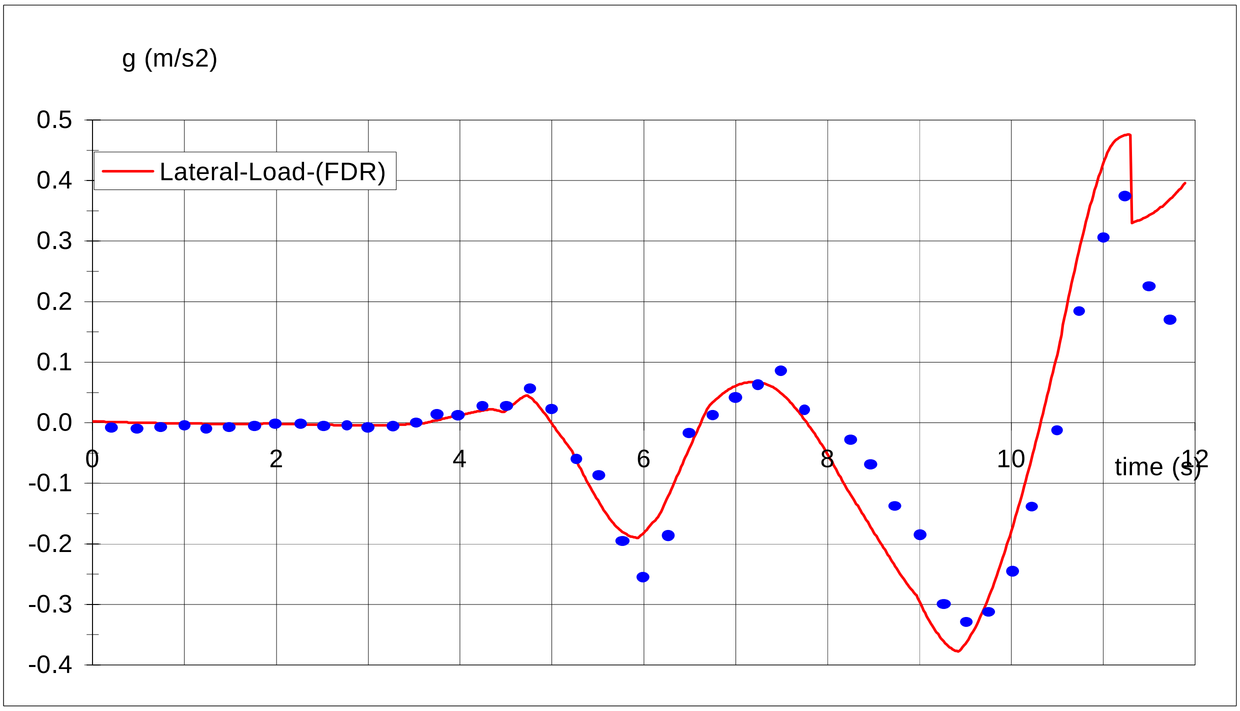
4) Further simulation with simulated loss of A/C components :

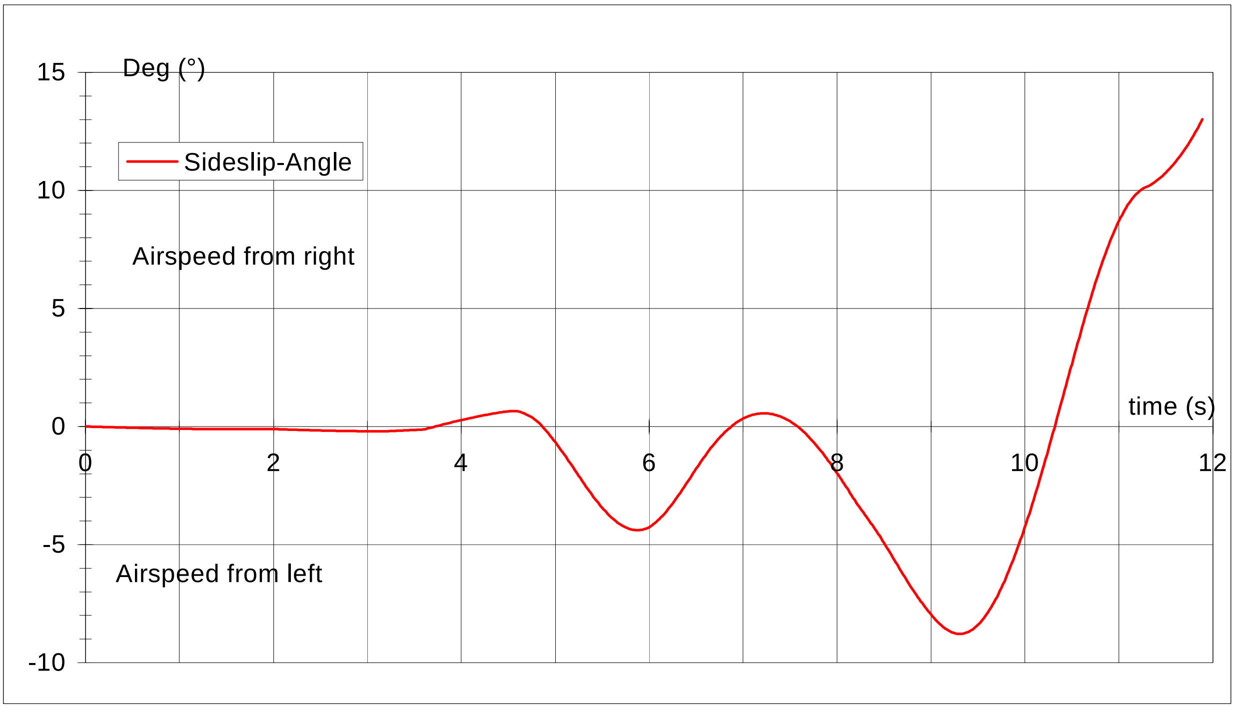
Looking at these results (particularly A/C matching with lateral load factor and heading angle) ,we have decided to modify A/C lateral efficiency to modelize the total loss of the fin at 11.2 sec of the simulation (cancellation of all fin efficiency at this time) to improve this matching.

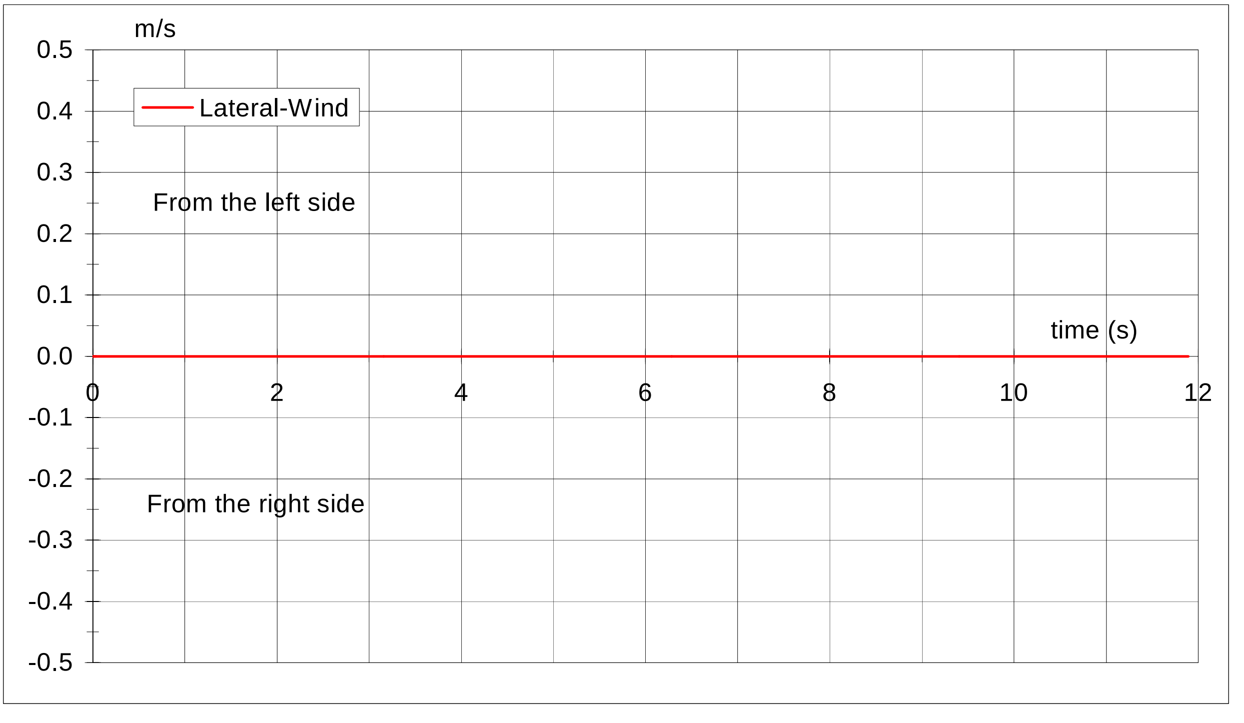
The results of this simulation is presented hereafter (A/C behavior on longitudinal and roll axis being the same than previously ,only the traces relative to the yaw axis are presented):

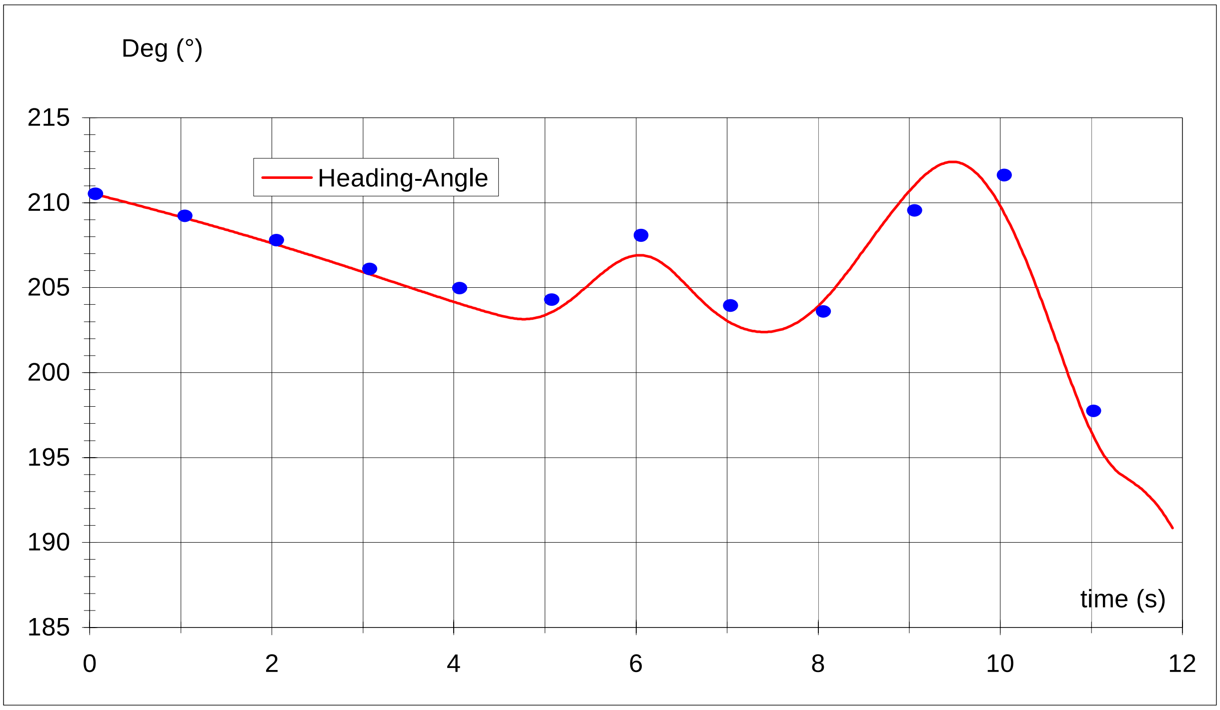


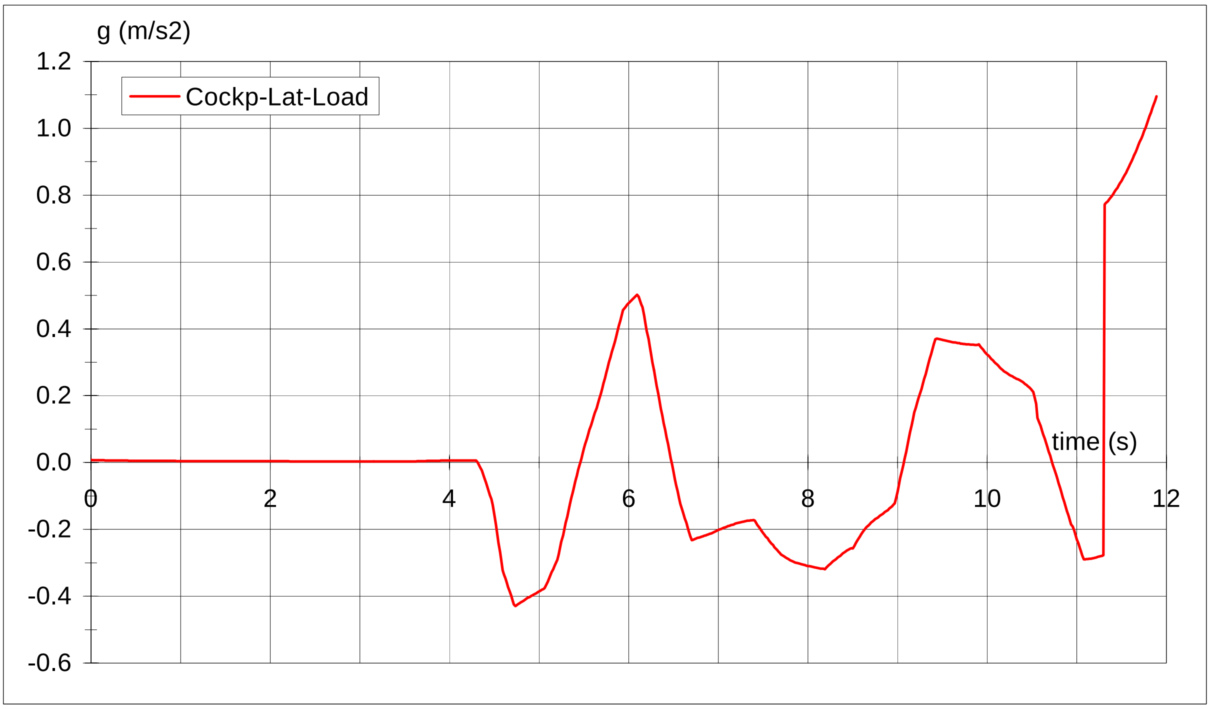

Deg (°)
Rudder-Def-Filt
Foot to the left
Foot to the right
time (s)
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
2
4
6
8
10
12

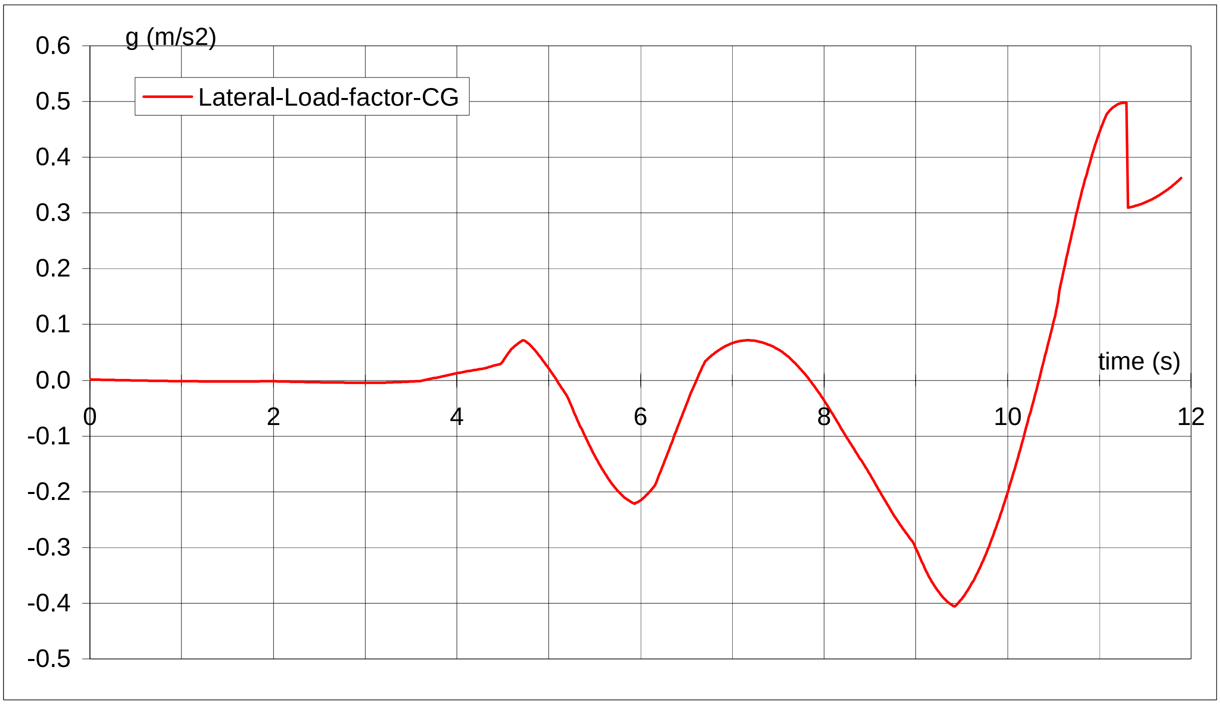

g (m/s2)
Lateral-Load-(FDR)
time (s)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
2
4
6
8
10
12


Deg (°)
Sideslip-Angle
Airspeed from right
Airspeed from left
time (s)
15
10
5
0
-5
-10
0
2
4
6
8
10
12


m/s
Lateral-Wind
From the left side
From the right side
time (s)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
12


Deg (°)
215
210
205
200
195
190
185
Heading-Angle
time (s)
0
2
4
6
8
10
12

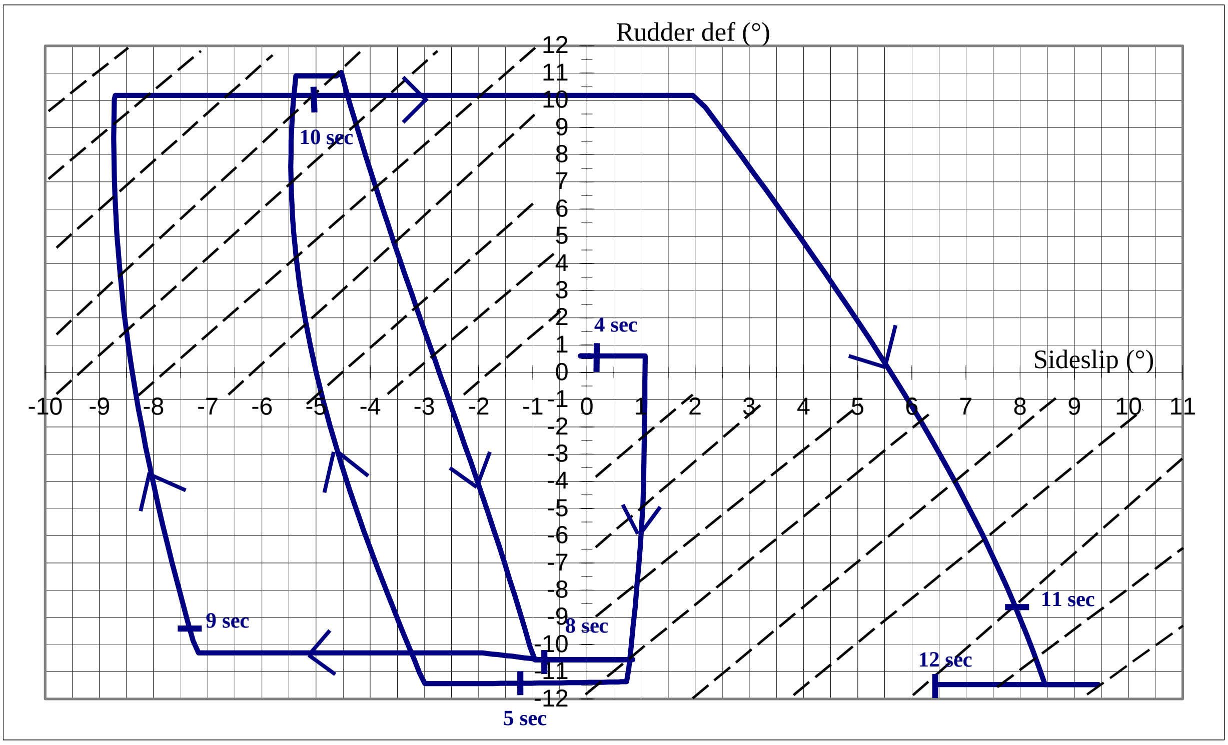

g (m/s2)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
Cockp-Lat-Load
time (s)
0
2
4
6
8
10
12



The introduction of the total loss of the fin allows us to reproduce as well as possible the sudden sharp Ny decrease at 11.2 sec of the simulation.

5) Illustration of the event in a Rudder (OSMA) = f (Sideslip (OSMA)):

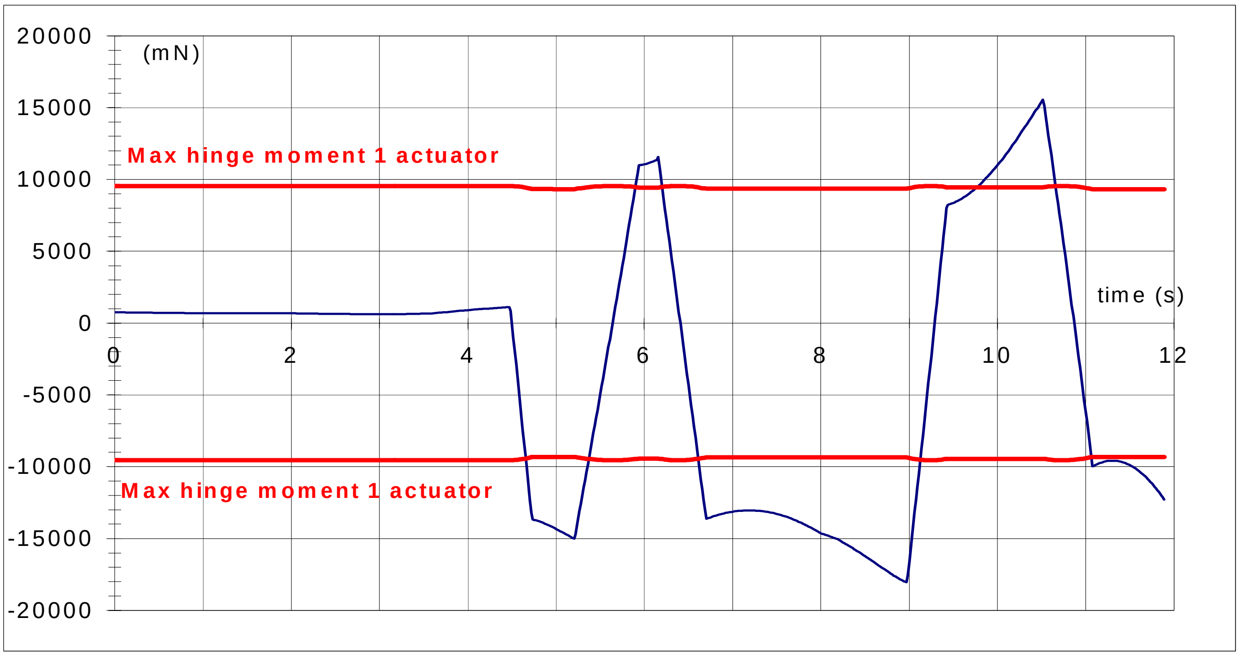
Ed3



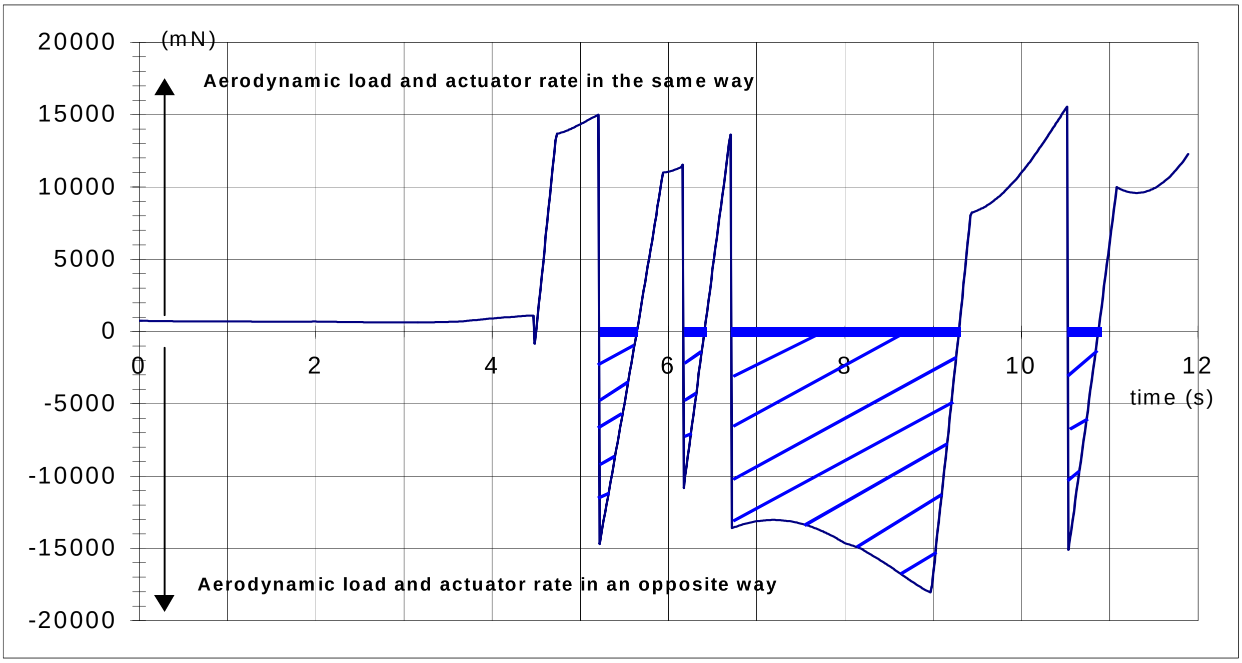
The two hatched areas of this diagram (rudder deflection and sideslip) indicate the combination of sideslip and rudder deflection which increases the loads on the fin/rudder part of the A/C.

6) Rudder hinge moment analysis:

The trace hereafter gives the evolution of the aerodynamic hinge moment (theoretical computation) of the rudder surface during the event.
The red bold traces give the maximum hinge moment provided by an actuator alone.



In addition to the previous trace ,it appeared interesting to show out when ,during the event ,the aerodynamic load and the rudder surface are pulling in the same direction or in an opposite way.
A way to point out this phenomenom is to trace the product $(Rudder\ Hinge\ Mt) \times sign(\dot{\delta r})$

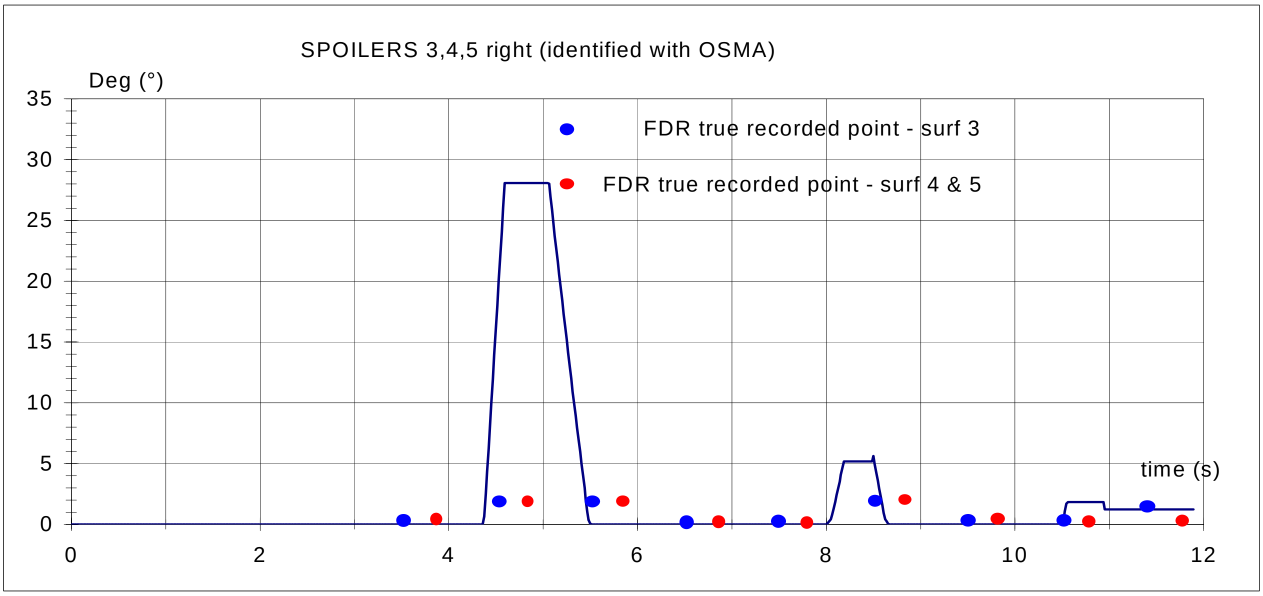


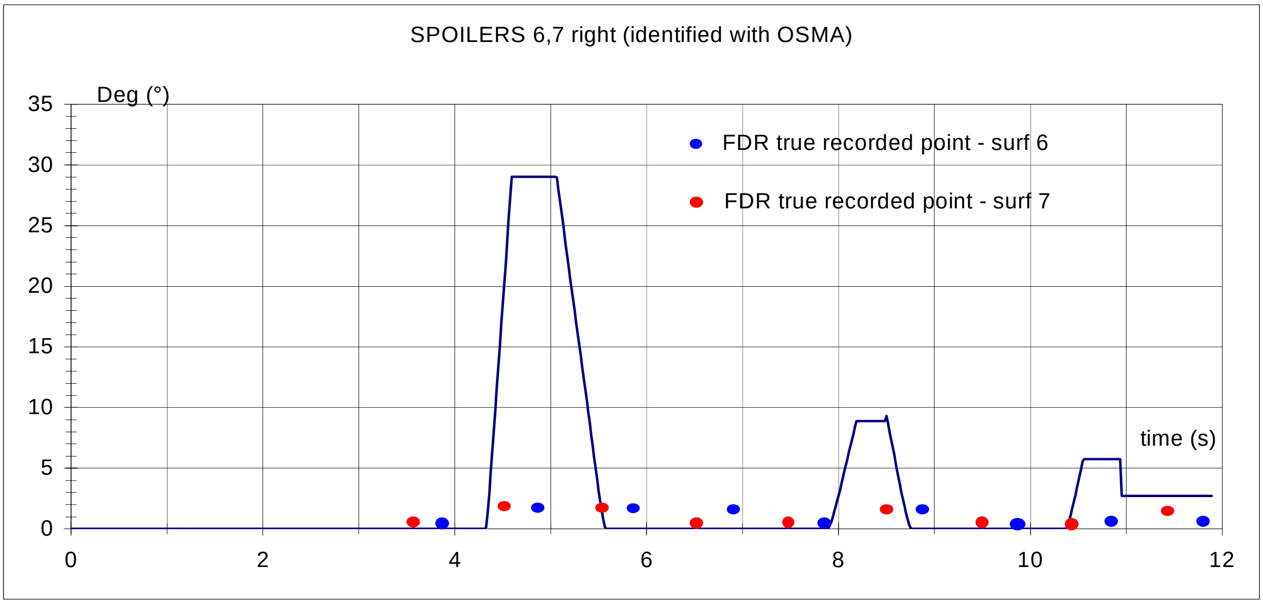
Conclusion: in all the blue hatched areas ,the rudder deflection cannot be explained by any backdrive assumptions.

7) Hydraulics availability – coherence with the FDR booleans:

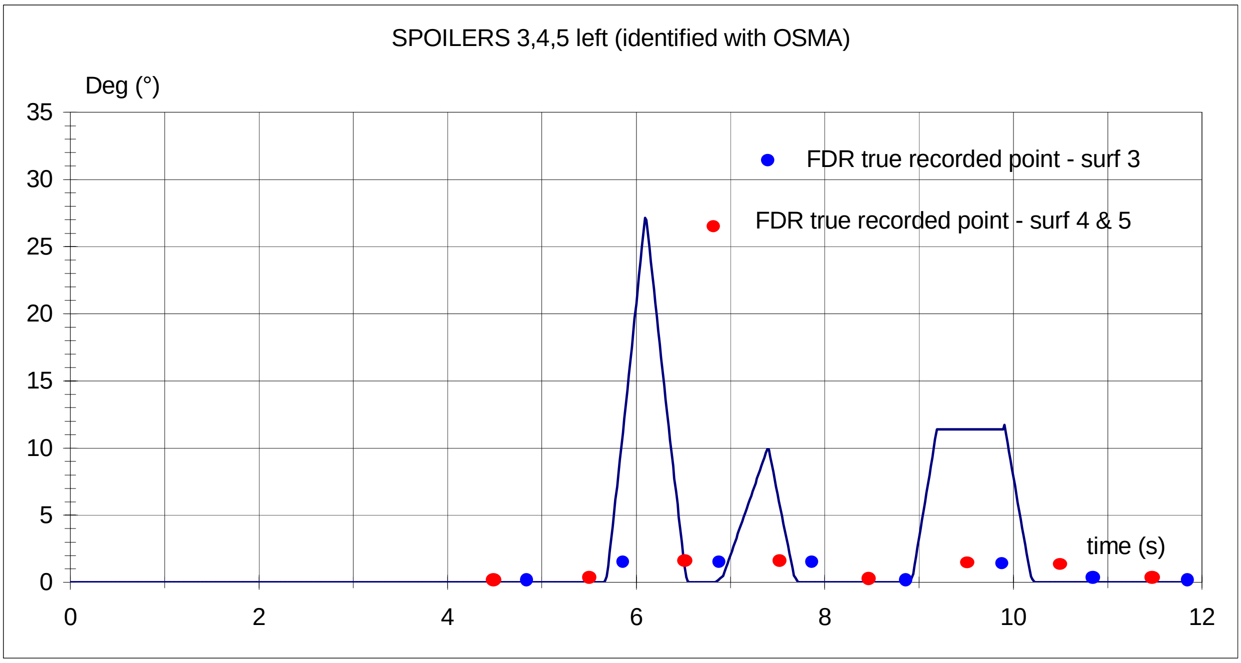
The purpose of this traces is to check the coherence existing between the spoilers deflection estimated with the OSMA simulation and the spoilers FDR booleans (sampling 1 PPS ,based on deflection greater than 2 deg):

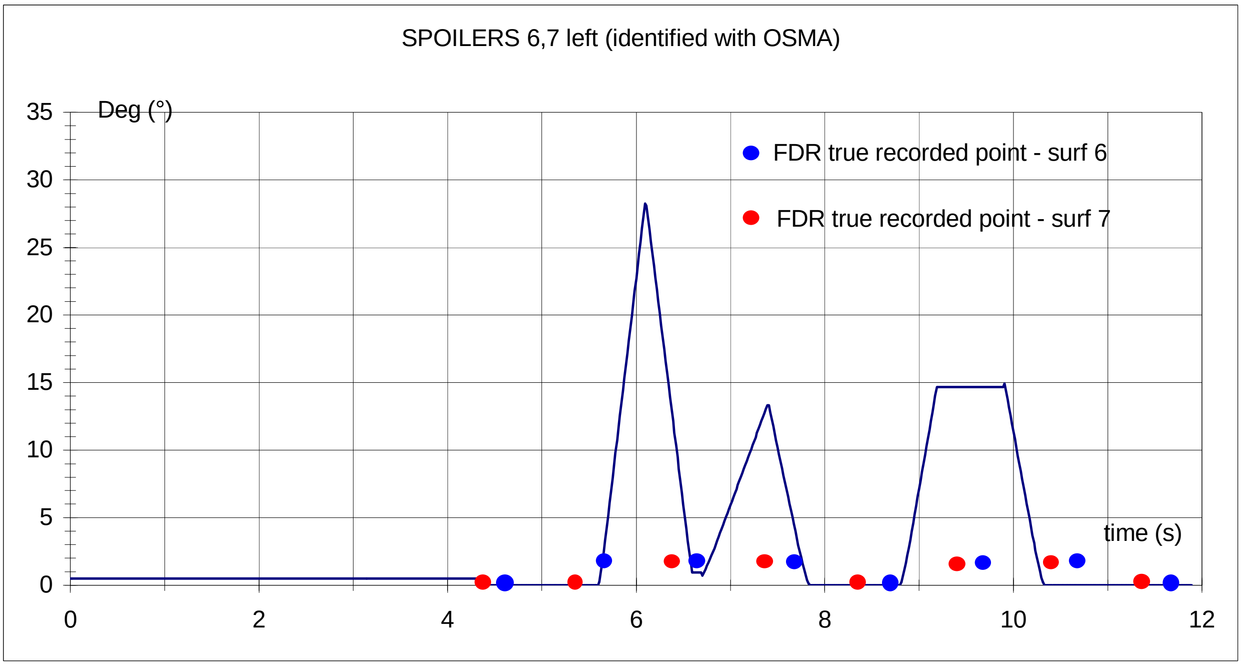
RIGHT WING





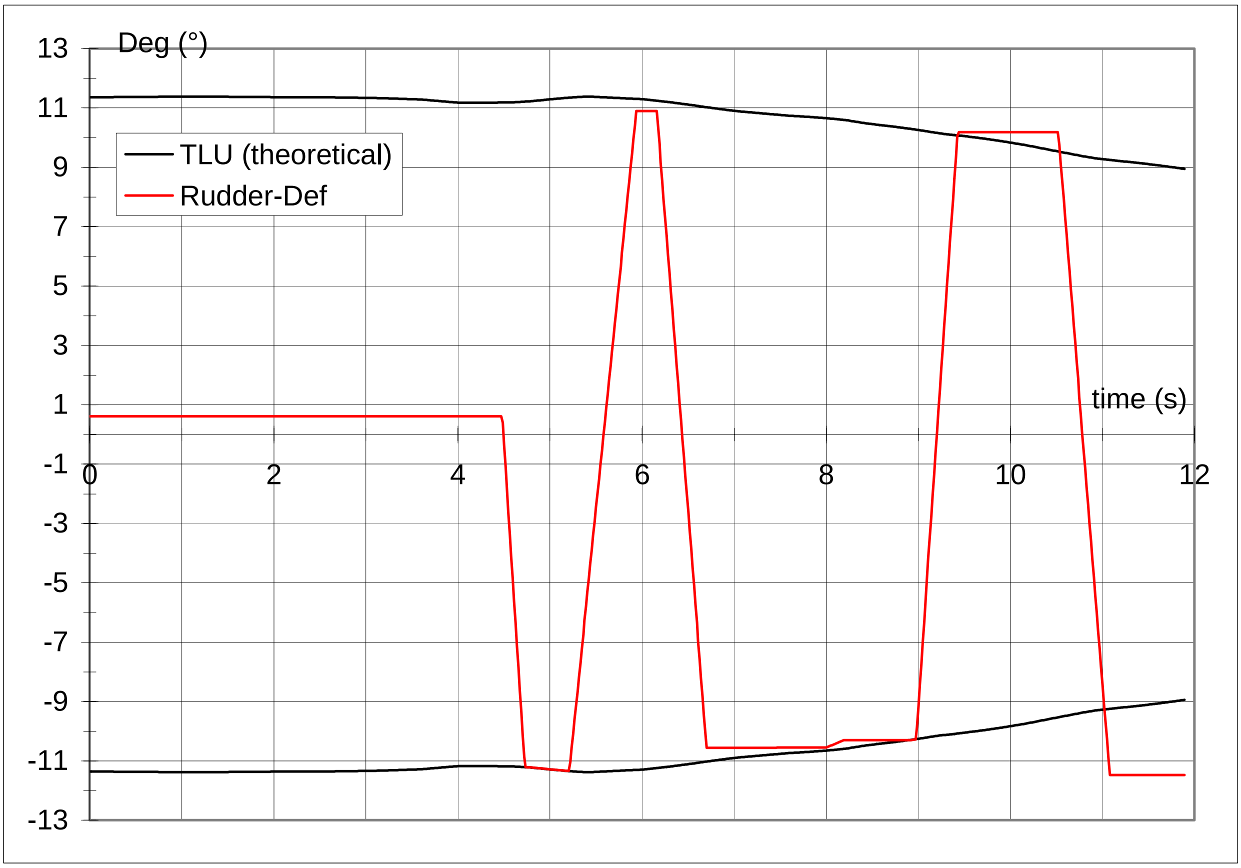
LEFT WING





Conclusion: spoilers deflection ,despite a loose sampling on DFDR ,is pretty consistent with our simulation.
We can also see that ,on right wing ,and between t=10.6 sec and t=11.6 sec ,all spoilers are deflected according to the overall roll order ,whereas on left wing ,the same conclusion applies between t=9 sec and t=10.6 sec.
This is a good indication that all three hydraulics circuits were operative during this period of time at least.

8) Consistency between rudder deflection and TLU:



When comparing rudder deflection obtained from § 2 and 3 with the theoretical TLU limitation as a function of speed ,we see that rudder stays globally contained within TLU limits and also that rudder is actually applied against TLU during 4 time periods.

After t=11.2 sec ,rudder is no longer compatible with theoretical TLU ;this is at the time ,or close to the time of estimated fin separation and the sign of TLU apparent exceedence is consistent with traction of the rudder actuator input rods.

9) Consistency between rudder deflection and rudder pedals deflection:

In the previous § of this note we have shown a pretty consistent behaviour between rudder deflection and recorded A/C parameters.The objective now is to show similar cocnsistency between rudder and rudder pedals.

The rudder deflection order is the sum of rudder pedal order and yaw damper order.
This sum is limited by TLU and the rudder actuator dynamics might be assimilated to a first order filter.

The rudder pedal order must be converted by the kinematic ratio hereafter before being summed up with yaw damper (origin : ground test on A300-600 MSN 701).

Pedal (°)	-21	-20	-15	-10	-5	-2	-0.5	0	0.5	2	5	10	15	20	21
Rudder (°)	-30	-29.8	-21.8	-14.2	-7	-2.2	0	0	0	2.2	7	14.2	21.8	29.8	30

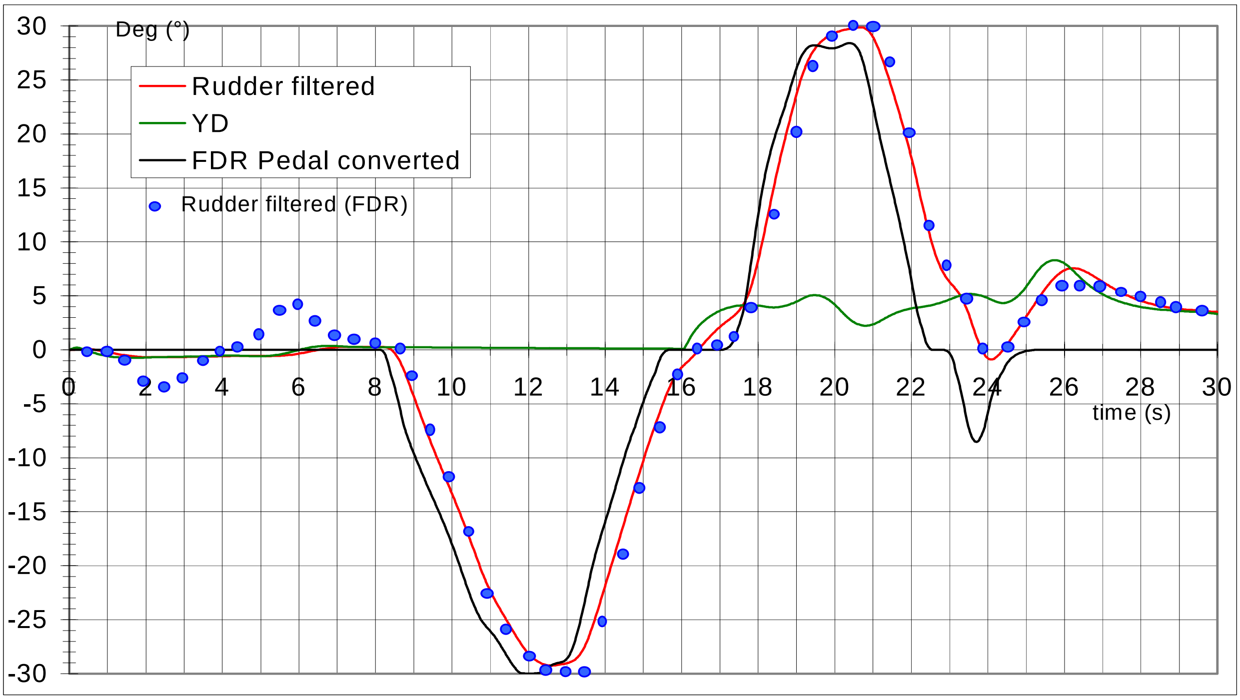
We use first the flight control checks recorded on FDR between GMT time 14.02.00 and 14.02.32.

The FDR recorded pedal input (corrected at t=0 of the 0.27° recorded offset) has been converted to equivalent rudder deflection (see above table) and introduced into a MATLAB modelization of FAC computer able to determine the corresponding rudder deflection taking into account the computed Yaw Damper order.

The resulting rudder deflection has been filtered at 434 ms (SDAC filtering).
There is a pretty good coherence between this information (red curve) and rudder true points recorded on the FDR (blue points).

The converted rudder pedals input during the flight control check and the computed Yaw Damper order used within this computation are presented respectively in black and in green.

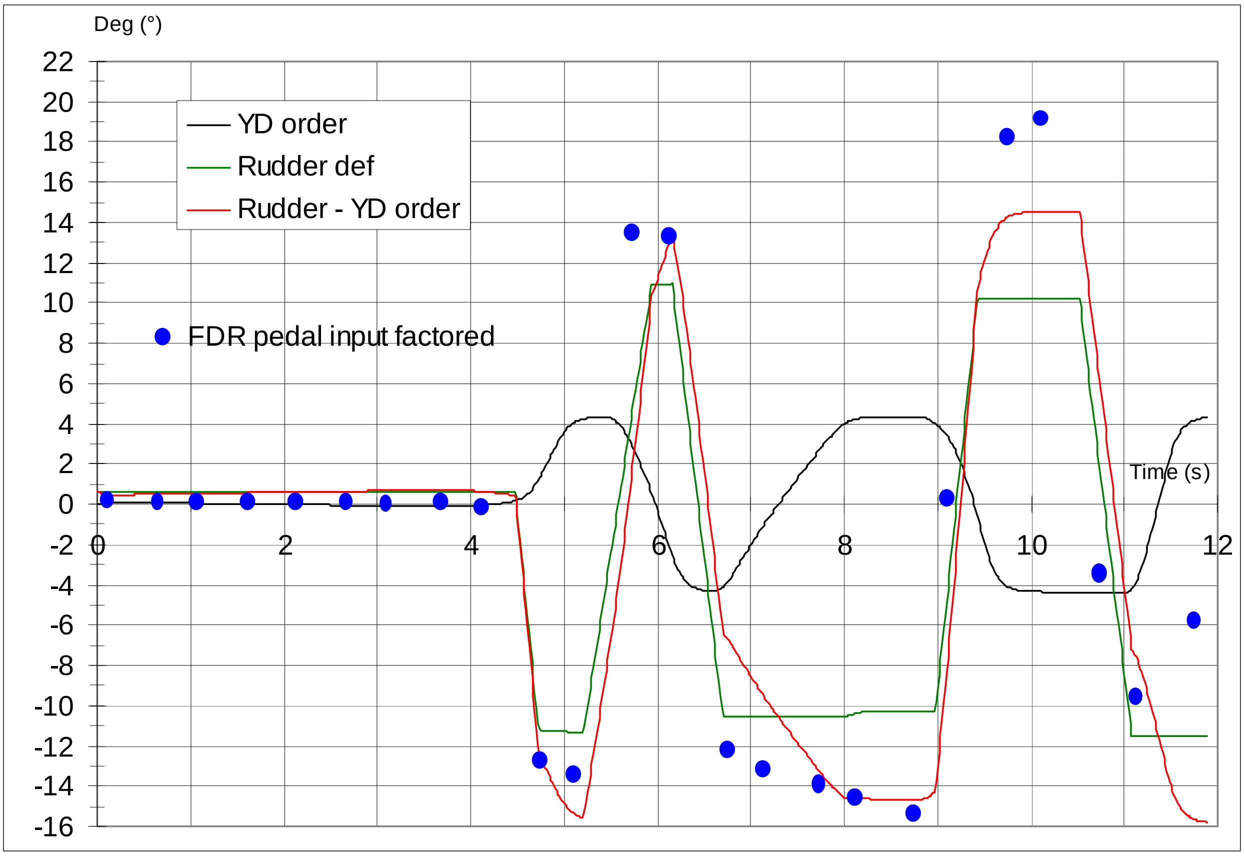
Note that turn coordination has not been modelised ,which explains the difference until t=8 sec.



The yaw damper hydraulic actuator force capability is greater than the pilot capability. Therefore ,whenever the sum of rudder pedal order + yaw damper order becomes greater than the TLU value ,the limitation actually applies to the rudder pedal order.

In other words ,the net TLU effect is to limit the available rudder pedal travel to a value equal to (TLU-yaw damper order).But in fact ,in this condition (rudder deflection order on the TLU stop) ,if the pilot applies a still larger effort on the pedals ,these will move farther than this "limitation" imposed by the TLU ,and the rudder control cables will stretch.

We have computed the theoretical yaw damper order and subtracted from rudder deflection used throughout this study.
We have compared the result with the rudder pedal deflection from FDR ,converted by the kinematic ratio which have shown very good correlation during the flight control checks.



The curves show that the two parameters (rudder – yaw damper order) and converted rudder pedal input ,are in good agreement ,naturally out of the time slots when the rudder deflection order is on the TLU stop.
➔ the yaw damper behaved as per design.

If the rudder deflection order is on the TLU stop ,and the converted rudder pedal input exceeds the (rudder – yaw damper order) parameter ,this implies that the pilot stretches the cables.

This occurs mainly during the following time slots:
➔ 6.5 sec to 7.8 sec on the right side
➔ 8.7 sec to 10.2 sec on the left side

(refer to technical note ref EYCAA_C27D03017000_v01 “AAL 587 Pedal force analysis”).