European Union Aviation Safety Agency

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ENHANCED FAULT DETECTION AND DIAGNOSIS SOLUTIONS FOR AIR DATA SYSTEMS - [EASA.2022.C15]

[NADIR - D-2.2 - V5]

Robustness Cases

An Agency of the European Union

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SUMMARY

Problem area

Looking back at aviation history, multiple factors such as e.g. improved training or Safety Management System implementation have brought continuous significant safety improvements. Innovative and advanced control also played a major role in enhancing the safety, especially thanks to technology like the digital Fly-By-Wire (FBW) systems first introduced in 1988 with the Airbus A320 Program. FBW technology provides more sophisticated control of the aircraft and flight envelope protection functions. However, some systems failures may lead i.a. to unexpected behavior of these useful features which could lead, under some extremely unlikely combination of factors and / or circumstances, to more complex situations to manage from the control point of view. A particular failure class of interest is related to aircraft sensors prone to harsh environmental (e.g. probe contamination), operating (e.g. severe fuselage damage) or damage conditions (e.g. during maintenance) which could lead to simultaneous and potentially consistent multiple erroneous measurements. The current certified system monitoring state of practice is mainly based on consistency tests, cross checks, or built-in-test of various sophistication, and inspection.

In this R&T project, the introduction of additional safety nets that are meant to catch complex failures upon occurrence is expected to enable the next step in aviation safety.

In summary, this project aims at developing new solutions to tackle the detection and isolation of multiple, simultaneous and consistent air data probe failures while relying on the understanding of the underlying failure modes and associated mechanisms.

Description of work

As part of Task 2, the objective of Task 2.2 is to identify representative fault-free scenarios for the assessment of the monitors' robustness. This document describes the tests that must be conducted to evaluate the robustness of the designs proposed by the academic partners in the Task 3.5 - Selection of the monitors to be considered in the further tasks (and summarised in D-3.1: Identification of possible solutions). This document is the Deliverable 2.2 as part of the Task 2.2 - Identification of robustness cases & associated scenarios.

Results and Application

4 complementary steps are proposed: (i) Robustness to representative flight conditions; (ii) Robustness to representative manoeuvres; (iii) Robustness to strong wind conditions; (iv) Robustness during steady flights.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
A/C	Aircraft
AoA	Angle of Attack
CAS	Calibrated Airspeed
CG	Center of Gravity
FL	Flight Level
ISA	International Standard Atmosphere
M	Mach number
TAS	True Air Speed

1. Scope of the document

This document describes the tests that must be conducted to evaluate the robustness of the designs proposed by the academic partners in the Task 3.5 - Selection of the monitors to be considered in the further tasks (and summarised in D-3.1: Identification of possible solutions). This document is the Deliverable 2.2 as part of the Task 2.2 - Identification of robustness cases & associated scenarios.

Robustness means that any proposed designs, intended to detect simultaneous faults at the Angle of Attack (AoA), total pressure (Pitot tube), static pressure (Ps) and altitude sensor level, must not trigger a fault detection in the absence of fault (no False Alarm).

It is proposed to evaluate the robustness in 4 complementary steps:

- Section II: Robustness to representative flight conditions. This means the assessment of the design robustness on real flight data sets, in an open loop scheme (i.e. not on the provided high-fidelity simulator).
- Section III: Robustness to representative manoeuvres. This corresponds to the assessment on the provided simulator by playing typical manoeuvres, including dynamic manoeuvres.
- Section IV: Robustness to strong wind conditions. This section is devoted to the assessment on the provided simulator by running strong wind conditions, e.g. reconstructed from real event data.
- Section V: Robustness during steady flights. These simple tests are dedicated to check the steady behaviour of the proposed designs.

Note: the validation framework depends a lot on the kind of techniques which are proposed (e.g. based on flight mechanics equations, data driven techniques, etc…). The validation framework could evolve depending on the solutions proposed.

Note: due to the huge combination of all possible parameters (aircraft configuration, flight conditions, manoeuvres, etc…), and due to the limited duration of the project, it is impossible to be exhaustive in the set of scenarios to be considered for robustness analysis.

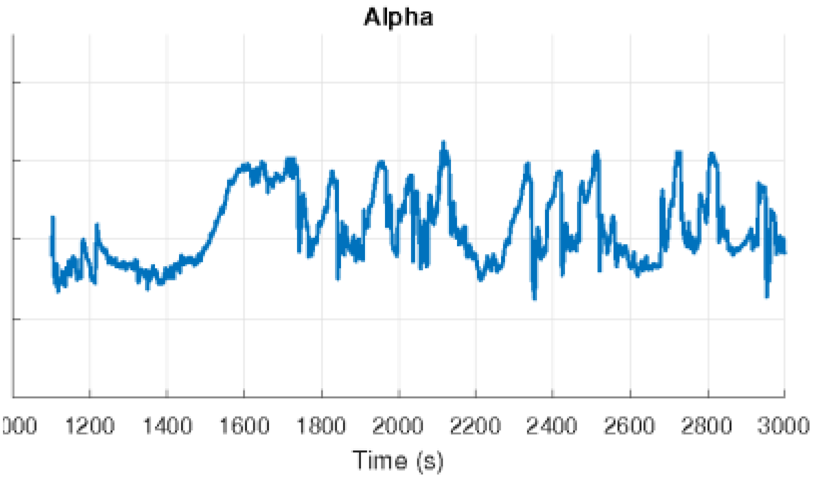
2. Robustness to representative flight conditions

Several flight test data sets have been selected for their representativeness in specific flight conditions for which a perfect robustness of the designs is expected. This forms a general basis for the robustness assessment but depending on the nature of the proposed designs, additional flight cases could be added.

2.1 High Angle of Attack (AoA)

High Angle of Attack (AoA), close to stall or in stall condition. Stall is the sudden reduction in the lift coefficient at high AoA. Since AoA could be one of the selected design inputs, it could have significant influence in the robustness when the values are high as in the stall case. One or several flight test data sets will be provided. An example is provided below.

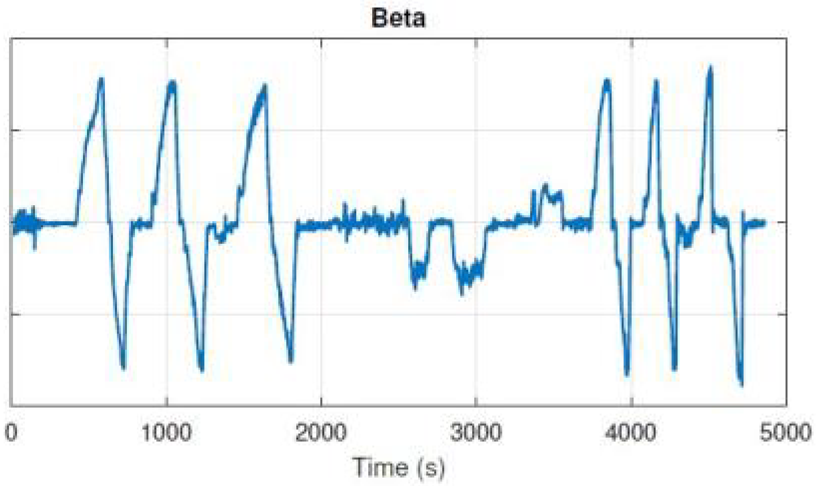
Figure 2-1 overview of AoA variations during flight test.



2.2 High sideslip

Flights with notable variations in the sideslip will be selected, during cruise conditions. Flights with stabilised sideslip will be chosen. An example is provided below.

Figure 2-2 overview of sideslip variations during flight test.



2.3 Erroneous spoiler deflection

Spoiler is deflected erroneously to observe the effect it will have on the proposed designs. The spoiler deflections tested here are not real deflections and are introduced off-line in the spoiler position data (open loop). Two erroneous deflection situations are considered: (i) only one spoiler (location: next to fuselage) is deflected to its maximum capacity; (ii) a hydraulic failure where the spoiler is connected. Since the deflections are induced during simulation, only few flights with least possible change in altitude, roll, pitch, yaw, etc... for long duration are considered to be able to study the exact influence of the erroneous spoiler deflection on the design robustness.

2.4 High Delta_ISA conditions

ISA stands for International Standard Atmosphere. It is a static atmospheric model describing how the air pressure, temperature, density, and viscosity change over a wide range of altitudes or elevations.

It could be relevant to evaluate the air data monitoring robustness when there is a significant difference between the ISA model and the real atmospheric conditions. The consequence may be a significant difference between the geometric (GPS/GPIRS measurement) and barometric (Static pressure measurement) aircraft altitudes as the barometric correction and Delta ISA are related.

At least one flight test file presenting a significant difference between the ISA model and the ground truth will be provided.

3. Robustness to representative manoeuvres

A series of typical manoeuvers is proposed to evaluate the robustness of the proposed designs. They are inspired by specific manoeuvres used to evaluate the performance of the Flight Control Laws and their associated protections.

Full Back Stick

For different combinations of aircraft weight, CG, Slat and Flap configurations, altitude and speed:

- The aircraft is initialised in straight flight at constant altitude and speed
- At t=10s, perform a full back stick input during 10s
- At t=20s, release the stick

Full Forward Stick

For different combinations of aircraft weight, CG, Slat and Flap configurations, altitude and speed:

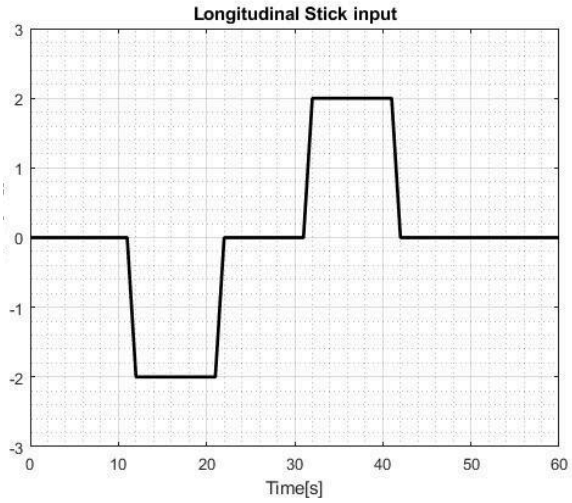
- The aircraft is initialised in straight flight at constant altitude and speed
- At t=10s, perform a full forward stick input during 10s
- At t=20s, release the stick

Small Double Steps

For different combinations of aircraft weight, CG, Slat and Flap configurations, altitude and speed:

- Simulate the following longitudinal stick input:

Figure 3-1 double step input (in DEG)



Acceleration / Deceleration

For different combinations of aircraft weight, CG, Slat and Flap configurations and altitude :

- The aircraft is initialised in straight flight at constant altitude and 1.3*VS1G
- At t=10s, move progressively throttle forward, to obtain an acceleration of around 1 kt/second
- Reach VMAX, then, move throttle back to obtain a deceleration of 1 kts/second

4. Robustness to strong wind conditions

As explained in the introduction, the scenarios proposed below are not exhaustive but we consider that it should provide a first qualitative feedback. Wind profiles reconstructed from real in-service events proposed in Section 4.3 ensure a complementary representativeness compared to the more (and limited) theoretical scenarios proposed in Section 4.1 and 4.2.

It is proposed to split these robustness tests into three categories:

- Windshear profiles used for certification process
- Gust sollicitations
- Wind profiles reconstructed from real in-service events

The wind profiles are defined by using the following convention:

- Wx: headwind component, along the x axis (oriented forward).
- -Wx: rear wind component
- Wy: lateral wind component, along the y axis
- Wz: vertical wind component, along the z axis

The gust profiles are defined by using the following convention:

- Wgx: longitudinal headwind gust, along the x axis (oriented forward)
- -Wgx: longitudinal rear wind gust.
- Wgy: lateral gust, along the y axis
- Wgz: vertical gust, along the z axis (z axis is oriented upward)

4.1 Windshear profiles used for certification process

Horizontal Windshear:

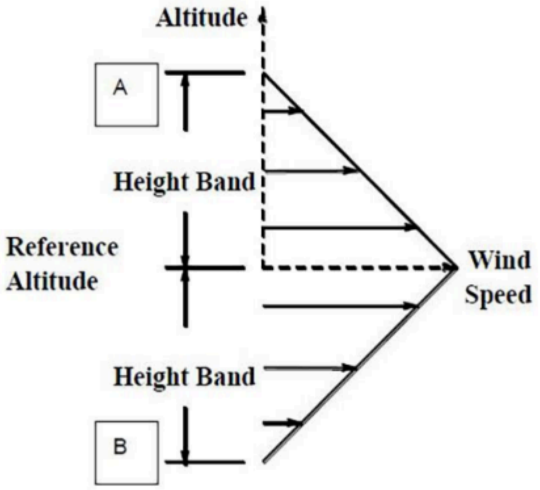
Inspired by the AMC 25.335(b)(2) “Design Dive Speed” (CS-25. Amendment 27), considering the atmospheric variations and according to available meteorological data, which are based on world-wide extreme values, the following wind gradients must be tested systematically along the x axis (head and rear wind, Wx and –Wx) and along the y axis (Wy) (The horizontal windshear region is assumed to have no significant vertical gradient of wind speed):

- Windshear #1: wind reaching 90 kts in 190 sec.
- Windshear #2: wind reaching 125 kts in 380 sec.
- Windshear #3: wind reaching 180 kts in 760 sec.

Vertical Windshear:

According to the AMC 25.335(b)(2) “Design Dive Speed” (CS-25. Amendment 27), “the windshear region is assumed to have the most severe of the following characteristics and design values for windshear intensity and height band. As shown in Figure 4.1 [below], the total vertical thickness of the windshear region is twice the height band so that the windshear intensity specified in the [Vertical Windshear Intensity Characteristics Table] applies to a vertical distance equal to the height band above and below the reference altitude. The variation of horizontal wind speed with altitude in the windshear region is linear through the height band from zero at the edge of the region to a strength at the reference altitude determined by the windshear intensity multiplied by the height band.”

Figure 4-1 Windshear Region (from AMC 25.335(b)(2))



Note: The analysis should be conducted by separately descending from point "A" and climbing from point "B" into initially increasing headwind.

In a first test phase, it is proposed to restrict the Vertical Windshear Intensity Characteristics to the following cases:

1- First case

Height Band = 3000ft

Reference Altitude = 40000 ft

Vertical Windshear Units: ft./sec. per foot of height (KTAS per 1000 feet of height): 0.075 (44.4)

2- Second case

Height Band = 5000ft

Reference Altitude = 45000 ft

Vertical Windshear Units: ft./sec. per foot of height (KTAS per 1000 feet of height): 0.10 (59.2)

4.2 Gust sollicitations

All manoeuvers below must be simulated during the cruise phase.

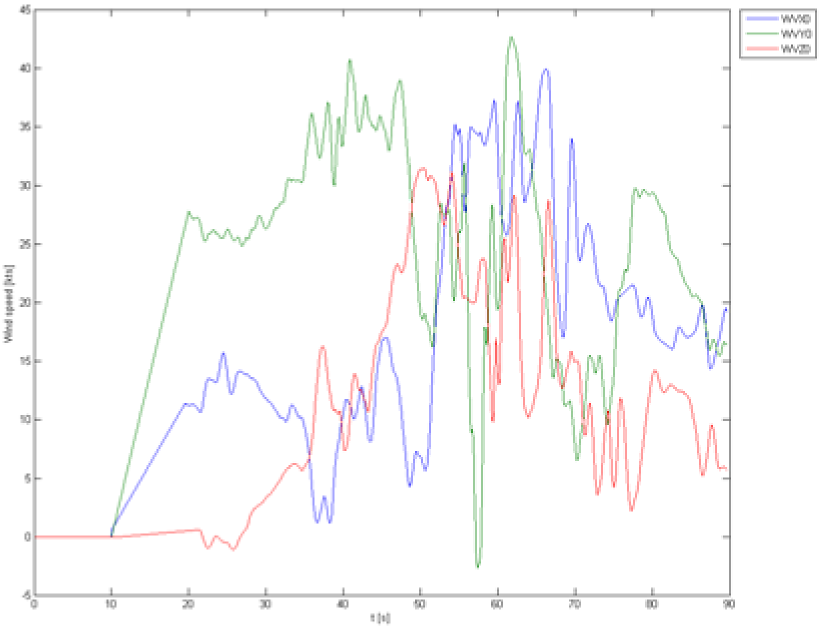
- Response to vertical gust:
  - At t=10s apply Wz=10kts (2 seconds ramp) during 10 seconds
  - AutoThrust is engaged
- Response to longitudinal headwind gust (speed variations):
  - At t=10s apply Wx=30kts (2 seconds ramp) during 5 seconds
- Response to longitudinal tailwind gust (speed variations):
  - At t=10s apply –Wx=30kts (2 seconds ramp) during 5 seconds

4.3 Wind profiles reconstructed from real in-service events

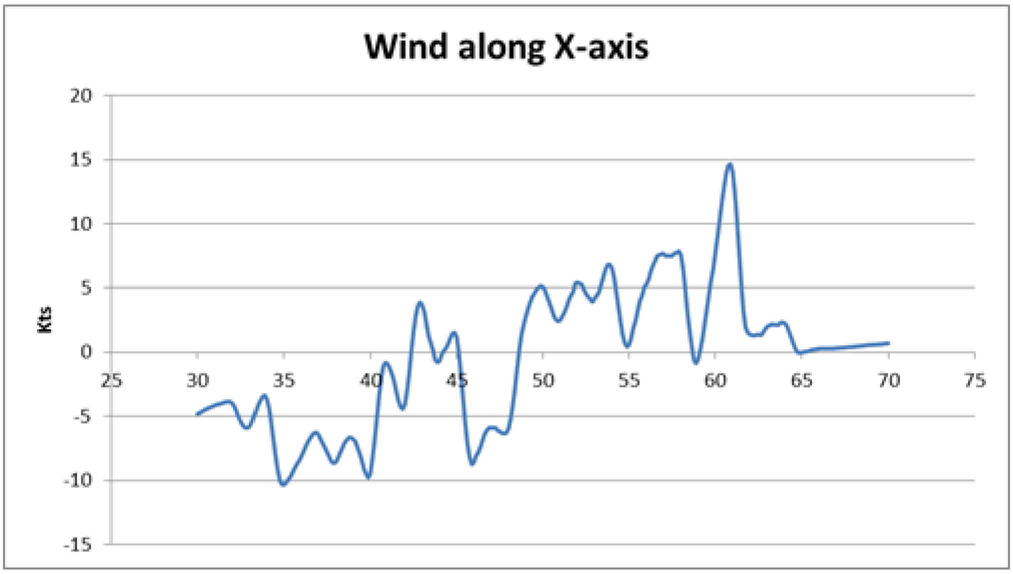
A series of 4 wind profiles (termed WScx for Wind Scenario #x) has been reconstructed from real in-service events. The corresponding 3 axis wind profiles will be provided as input files directly usable in the Airbus simulator.

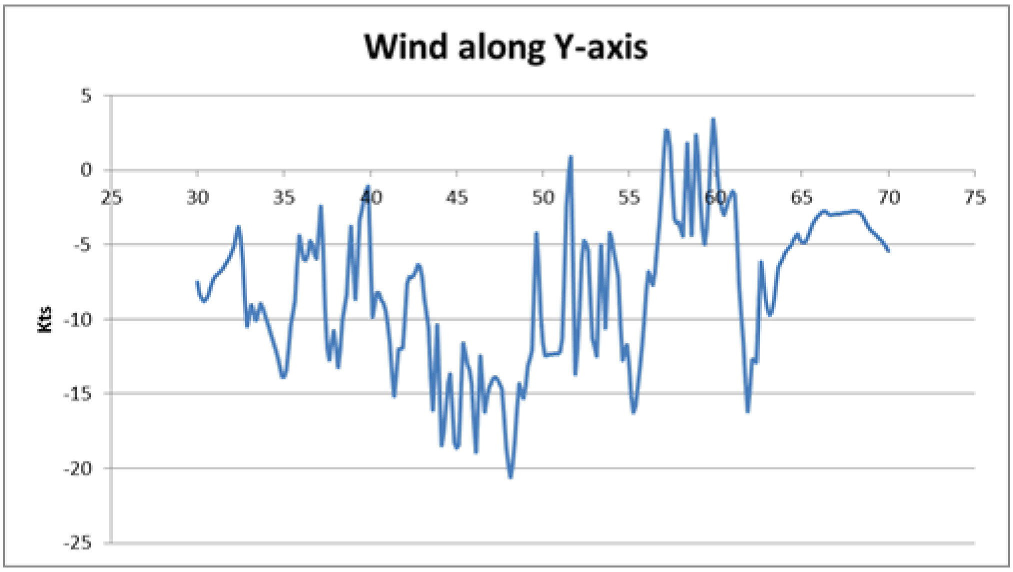
- WSc1: during the descent phase, the aircraft encountered very difficult weather conditions (strong rear wind and downward air stream) leading to increased angle of attack constantly and AoA protection function activation. In the figure below, the winds are given in the aircraft reference:

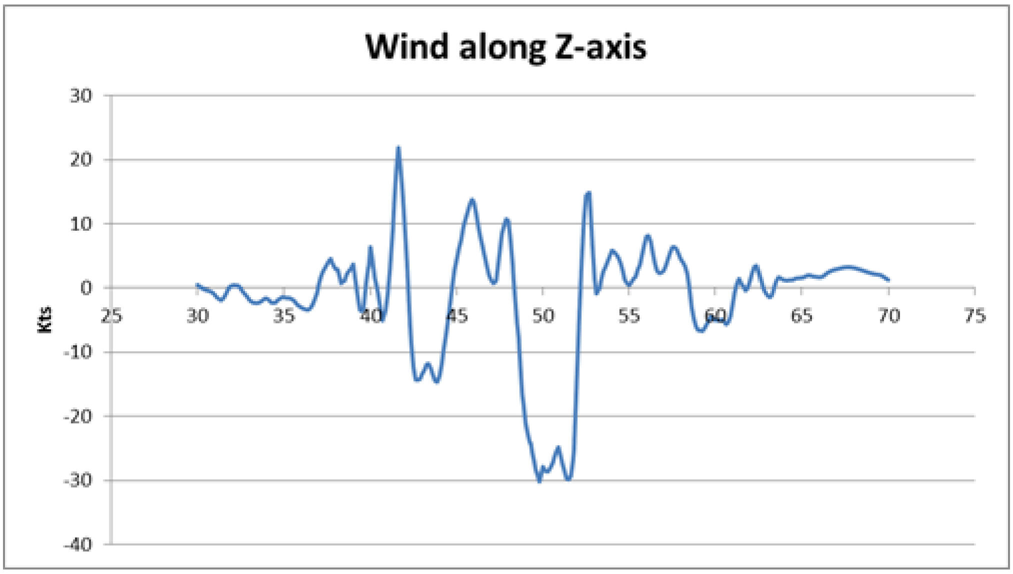
Figure 4-2 the 3 wind components for scenario W1



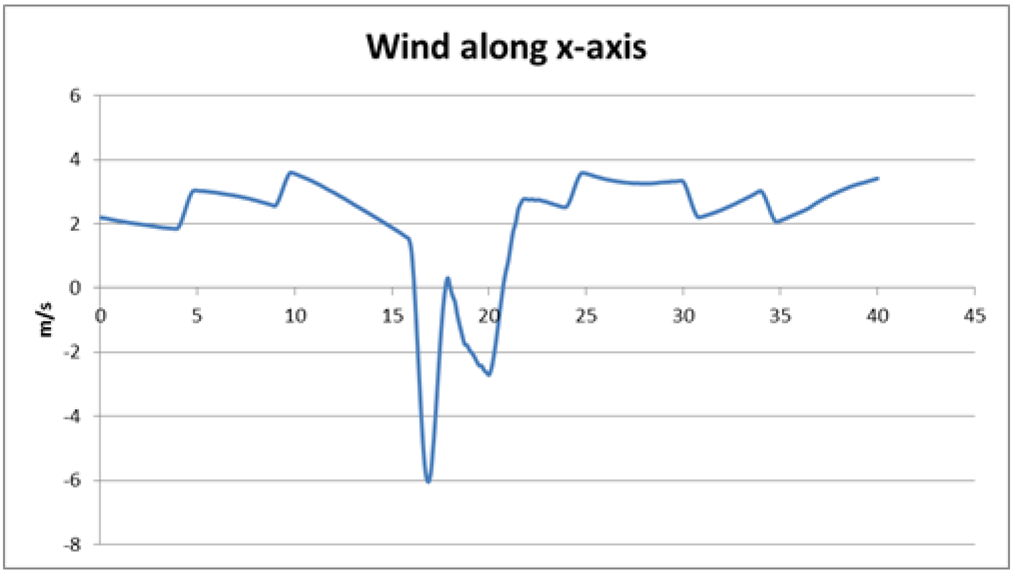
- WSc2: aircraft descending towards Flight Level 15000ft (FL150). Aircraft suffered severe turbulence during 1min 30sec. The wind components have been reconstructed in the aircraft reference system (same convention for next wind profiles in this document):

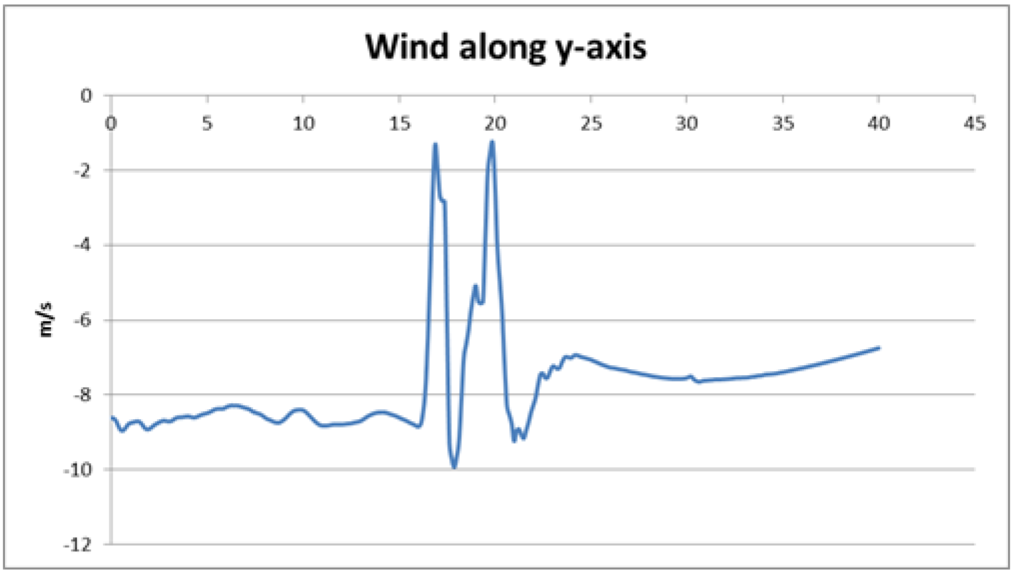


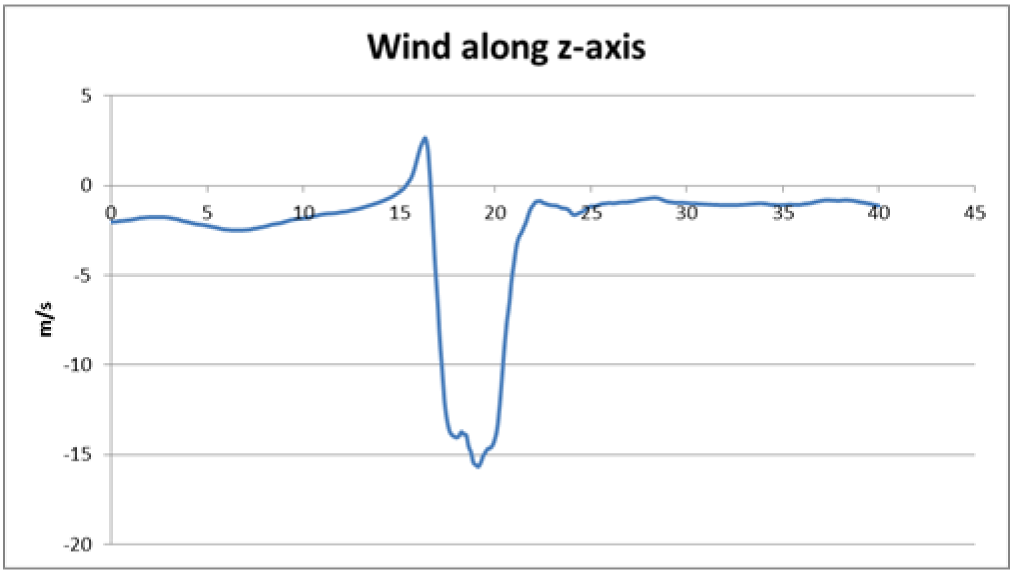




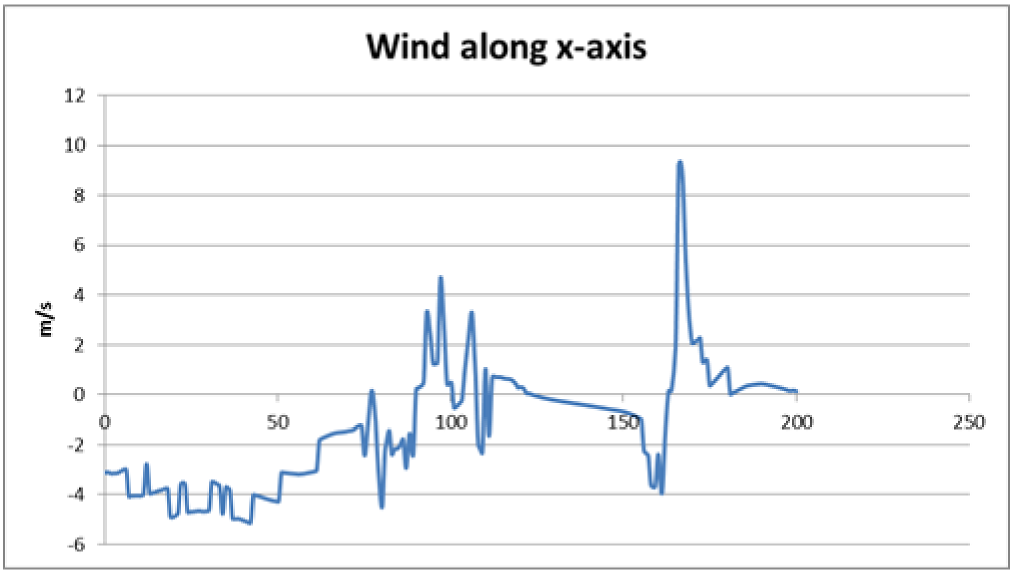
- WSc3: aircraft was in descent crossing FL150 (CG = 33.5%. Slat and Flap clean configuration, landing gears up). The Auto-Pilot was engaged. Auto-Thrust was engaged in speed mode, speed was selected at 310kt then 300kt. Between 3 and 4 seconds of cloud passage created up and down draft effects which caused some cabin crew injuries:

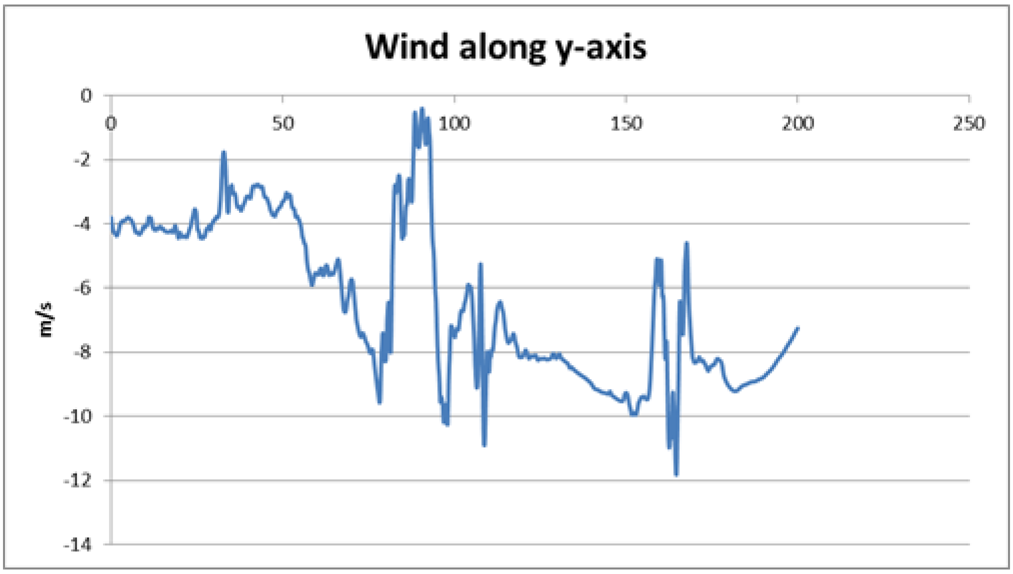


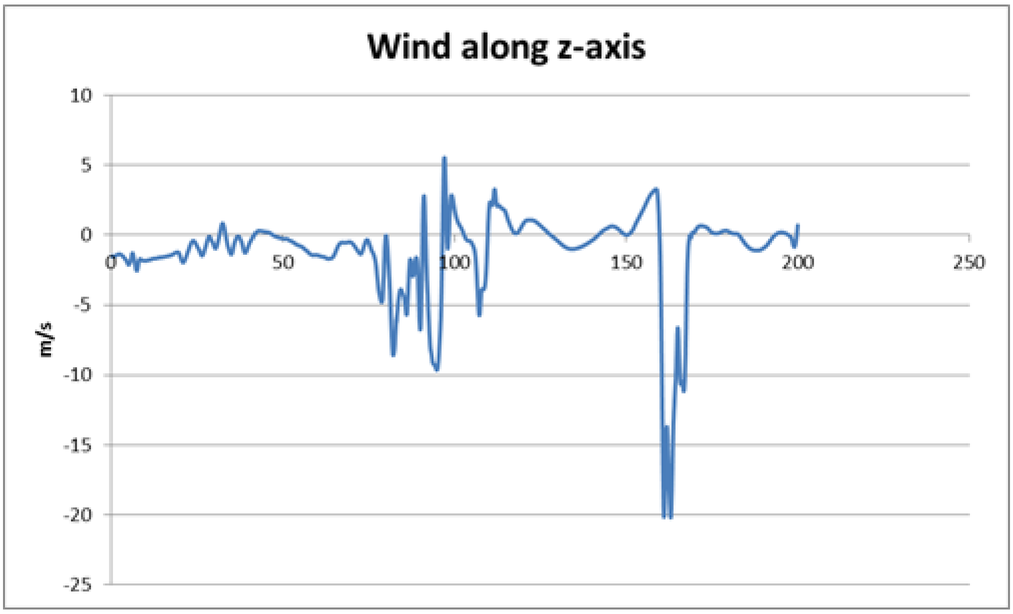

Wind along y-axis
0
-2
-4
-6
-8
-10
-12
m/s
0
5
10
15
20
25
30
35
40
45


Wind along z-axis
5
0
-5
-10
-15
-20
m/s
0
5
10
15
20
25
30
35
40
45

- WSc4: turbulence in cruise phase (FL300, M=0.77, CG = 38.1%).






Wind along z-axis
m/s
10
5
0
-5
-10
-15
-20
-25
0
50
100
150
200
250

5. Robustness during steady flights

During a normal flight, operated by any airline, most of the time is spent in the cruise phase, especially on the long routes. It is then of primary interest to check that any Fault Detection algorithm design does not enter in a diverging behaviour or in any saturated state.

Verification Objective: to test the robustness of the submitted designs during a very long and steady cruise flight, in a fault-free situation. This manoeuvre is independent of any flight scenarios and must be played only one time per design.

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