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TITRE

HELICOPTER FAILURES CORRECTION TIMES PHASE 2

SUMMARY DOCUMENT

DIFFUSION (SIGLES)

INTERNE DIRECTION EMETTRICE		EXTERNE DIRECTION EMETTRICE	
DOCUMENT COMPLET	RESUME (Page 1 à)	DOCUMENT COMPLET	RESUME (Page 1 à)
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SUMMARY

This document is the summary report of project “Helicopter Failures Correction Times” phase 2, as defined in DGAC contract 99 50 075

It contains:

- a reminder of the first phase results;
- a presentation of second phase simulation results;
- a discussion about these simulation results.

This document is the translation of document TNX 000 AR 420 F03 “Temps de Reprise en main des Pannes Hélicoptère Phase 2 – Document de synthèse” which is the reference version should a discrepancy appear.

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LIST OF ACRONYMS

AC	Advisory Circular
ACJ	Advisory Circular, Joint
ADI	Attitude Indicator
AFCS	Automatic Flight Control System
ALT	Altitude
APU	Auxiliary Power Unit
BAT	Battery
CAT	Catastrophic
CDS	Control Display System
CDP	Critical Decision Point
CWP	Central Warning Panel
EC	EuroCopter
ECS	Electrical Control System
EGS	Electrical Generation System
EMS	Emergency Medical Service
ENG	Engine
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulations
FCS	Flight Control System
FHA	Functional Hazard Assessment
FLI	First Limitation Instrument
FLIR	Forward Looking Infra-Red
FND	Flight & Navigation Display
HAZ	Hazardous
HMI	Human Machine Interface
H/C	Helicopter
IEBD	Integrated Engine Backup Display
IHM	Interface Humain Machine
IMC	Instrument Meteorological Condition
IPS	Ice Protection System
IRS	Inertial Reference System
JAR	Joint Aviation Requirements
LDP	Landing Decision Point
L/G	Landing Gear
LS	Landing System
MAJ	Major
MIN	Minor
MGB	Main Gear Box
MFD	Multi Function Display
NA	Not Applicable
NAV	NAVigation system
NR	Nombre de tours du Rotor principal
NVG	Night Vision Goggle
OEI	One Engine Inoperative
OHCP	OverHead Control Panel
PA	Pilote Automatique
PHL	Preliminary Hazard List
PMS	Plant Management System
PT	ProtoType
RA	Radio Altimeter
RAGB	Remote Access Gear Box

SAR	Search And Rescue
SAS	Stabilization Augmentation System
SHA	System Hazard Analysis
SOV	Shut Off Valve
TCAS	Traffic Collision Avoidance System
TGB	Tail Gear Box
T^2CAS	Terrain and Traffic Collision Avoidance System
VMC	Vision Meteorological Condition
VMD	Vehicle Management Display
V_{NE}	Velocity Not to Exceed
WAT	Weight, Altitude, Temperature
WWWS	Windshield Washer Wiper

1 Introduction

The increasing automation of systems and the evolution of the technologies applied to helicopters have modified crew workloads. The pilot is now both a supervisor and decision maker, and leaves the basic tasks to systems.

New interfacing capabilities have made it possible to redesign the human machine interfaces for best synthesis of the helicopter's condition, thus enabling the pilot to ensure this new role of supervisor and decision maker.

However, with system automation, the pilot is no longer in direct contact with basic helicopter data. It is therefore necessary to insure that none of the pilot's mental representations of the helicopter are false, and that the time required to analyse and rectify a given degraded situation is appropriate.

The current regulations specify the applicable detection and recovery time requirements in the event of a degraded situation. These regulations need to be amended to take the new pilot's role into account.

The purpose of this study is to define the technical basis necessary to amend the regulations with respect to correction times for (major or hazardous) failures that would have catastrophic effects if the pilot fails to react quickly.

During phase 1 of this study, the following steps were performed to establish a basic reference:

- 1: Analysis of FAR/JAR 29 regulations.
- 2: Definition of failures that need to be studied.
- 3: Scope of failures to be selected.
- 4: Experiments with a reference pilot.

This document covers the second phase of the study, during which tests were conducted with a panel of 7 pilots.

2 Reference Documents

The reference regulatory documents are:

- JAR 29 (05/11/1993)
- FAR Part 29 (15/08/1985)
- AC29-2C (30/09/1999)
- AC29-2A (16/09/1987)
- ACJ29 - subpart of JAR 29 (05/11/1993)

The internal reference documents related to the study and used as intermediate reports, are:

- "Phase 2, 1st Quarter" progress report – 16/07/2002 – Ref. OTSM/1074/2002 (SH)
- "Phase 2, 2nd Quarter" progress report -29/10/2002 – Ref. OTSM/1097/2002 (PB)
- "Phase 2, 3rd Quarter" progress report -20/01/2003 – Ref. OTSM/1010/2003 (BDR)
- Minutes of the meeting held on 03/12/2002 – Ref. OTSM/1011/2003 (BDR).

The summary documents of study Phase 1 are:

- “Helicopter Failure Correction Times – Summary Document” – Ref. TN X 000 AR 431 E01 issue A
- “Analysing of Helicopter Failure Correction Times – Analysis Document” – Ref. TN X 000 AR 414 E01 issue B

3 Scope of the Survey

3.1 Approach

Phase 2 of the TRPH survey basically consisted of experimentation. It included the following steps:

- Selecting a panel of pilots.
- Training the pilots of the panel.
- Simulating the failure scenarios defined on phase 1.
- Analysing and summarising the collected data in accordance with the methods selected on phase 1.

This description does not necessarily follows a time sequence as certain pilots were trained immediately before simulation.

These tasks were performed by specialists in human factors and simulation, with the assistance of specialists in helicopter systems and flight tests. Safety specialists participated in the analysis of the collected data.

3.2 Definition of the Times Related to Failure Resolution

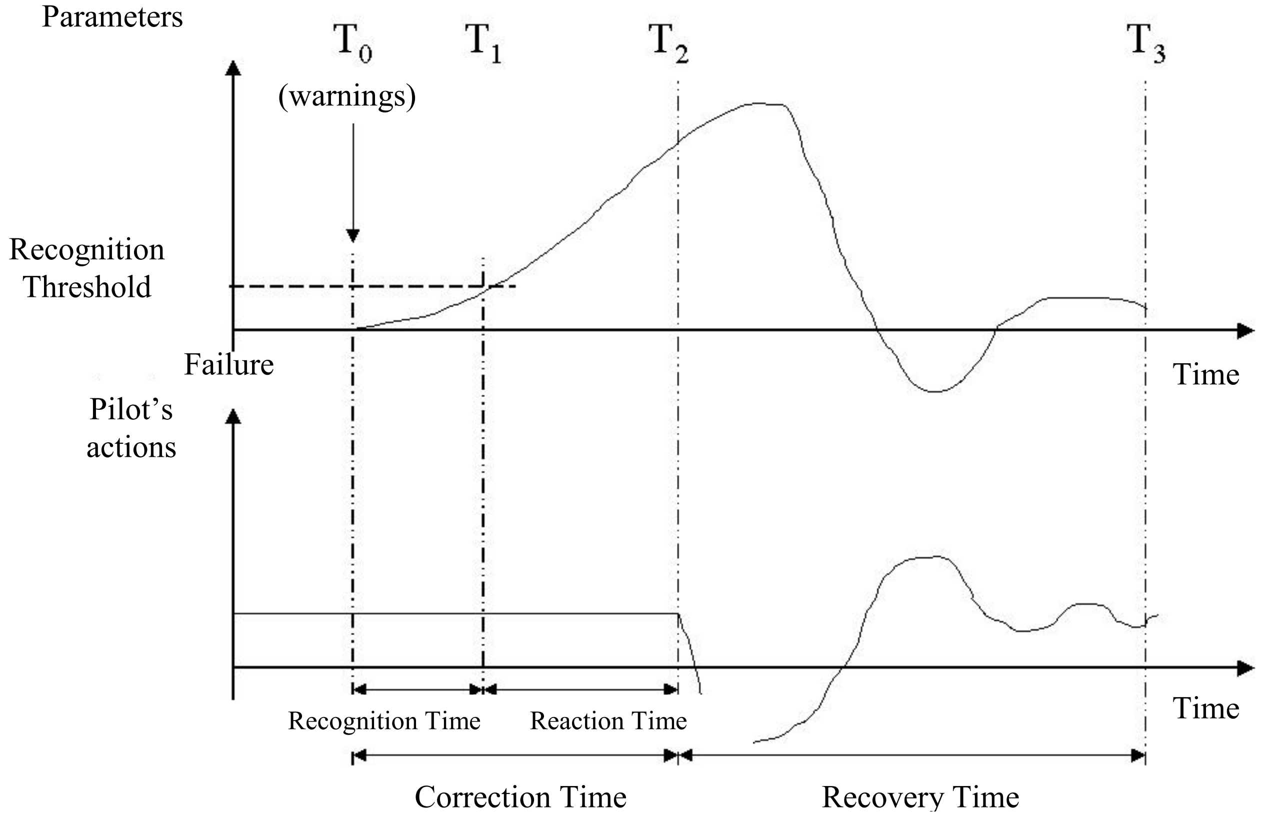
The terms used for time parameters differ between the SHA and HMI fields. To provide a precise understanding of the terms used, the following definitions have been applied throughout the study (SHA terminology):

<u>Recognition Time</u>: Time elapsed between failure occurrence (T0) and initial pilot's reaction (T1), i.e. the time needed by the pilot to understand that a failure has occurred.

<u>Reaction Time</u>: Time elapsed between the moment the pilot realizes that a failure has occurred (T1) and the initial, appropriate corrective action (T2), i.e. the time needed by the pilot to initiate a corrective action after he has realized that a failure has occurred.

<u>Recovery Time</u>: Time elapsed between the initial corrective action (T2) and the moment the system's nominal operation is restored (T3), i.e. the time needed for the corrective action.

In our study, the times of interest are the pilot's recognition and reaction times (T0 to T2).



Correction Time = Recognition Time + Reaction Time

Figure 1 : Definition of the Studied Times

3.3 Typical Configuration of a New-Generation Helicopter

This study considers only one generic aircraft, which is representative of new-generation helicopters of the medium/heavy twin-engine type – i.e. within the 6 to 10 metric tons range and compliant with JAR and FAR 29 regulations. This generic aircraft is equipped with a "full glass" cockpit including a basic helicopter management system.

The study covers single- and two-pilot operation of civil helicopters. The tests were performed in single-pilot configuration to obtain more relevant results.

3.4 Extent of the Study

3.4.1 Failures

The experimental phase of this study is limited to a selection of 5 failures, occurring in the most relevant conditions, i.e. in the single-pilot configuration.

3.4.2 Simulator

Experimentation is carried out on the EUROCOPTER development simulator called SPHERE (cf. Appendix 1), with the external environment image being projected over a fixed, non-vibrating field of 180° x 80° horizontally and vertically, respectively.

The simulator cabin used for this study is a cockpit of a new-generation twin-engine helicopter of the 8 - 10 metric tons range.

The simulation restrictions have been taken into account when selecting the failures and their occurrence.

Due to simulation constraints, SPHERE does not allow simulation of failures detectable by crewmembers' proprioceptors (vibrations, accelerations, oscillations, etc.) or by some exteroceptors such as those involved in the sense of smell. Hearing is limited to conversations with the control room (notably to reproduce the exchange of information with the air traffic control) and to the sounds planned in the simulation: warnings, voice alarms, engine noise; main rotor noise, and a few environmental noises (rain). The failures selected in Phase 1 can therefore be detected by sight and/or touch (e.g. flight control jerks) and by audio warnings.

Note that a high increase in the load factor can still be detected due to its effect on the main rotor sound.

3.4.3 Time

The tests shall be performed on a generic helicopter representative of the new generation ones.

Yet recovery times are helicopter specific and therefore shall not be taken into account.

4 Overview of Regulations

4.1 Reference Regulatory Documents

The following reference regulatory documents were studied in Phase 1, and analysed according to the medium/heavy helicopter range under study:

- JAR 29 (05/11/1993)
- FAR Part 29 (15/08/1985)
- AC29-2C (30/09/1999)
- AC29-2A (16/09/1987)
- ACJ29 - subpart of JAR 29 (05/11/1993)

Their requirements were analysed in Phase 1 of the study and are summarised below.

4.2 Summary of Regulatory Requirements

JAR and FAR 29 regulations mainly provide qualitative safety objectives to be applied whenever a pilot action is required. The only exception is engine failures for which quantified correction times are provided according to flight phases.

The Advisory Circulars (AC) are more specific and recommend maximum correction times according to the occurrence of one or more SAS failures. These maximum times depend on the different flight phases and conditions (IMC, VMC, etc.). The safety objectives shall be demonstrated in IMC. The maximum correction times also apply to hardovers.

This data (mainly drawn from AC29-2A) is summarised in the table below (See Figure 2), but does not apply the flight control systems.

As regards those failures detected by the helicopter and reported with a visual (red) or audio warning, the maximum time for the pilot to recognise a failure is usually 0.5 sec.

On the other hand, for those failures not detected by the helicopter, the maximum time for the pilot to recognise a failure includes his/her failure detection time.

The applicable correction times further to failures that do not affect engines or flight control systems have not yet been defined. The times defined for SAS or engine failures can therefore be applied but are not covered in JAR/FAR regulations or ACs.

	IFR CERTIFICATION			VFR CERTIFICATION	
	General (Single-Pilot)	*Two Pilots WITH Upper Mode(s)*	**Two Pilots WITHOUT Upper Mode(s)**		
Pilot's Degree of Attention					
Hover	**Rec. T + 0 sec (Reaction time)**	*Rec. T + 1 sec (Reaction time) Auto hover mode*	**Rec. T + 0 sec (Reaction time)**	*Rec. T + 1 sec (Reaction time) Auto hover mode*	**Rec. T + 0 sec (Reaction time)**
Takeoff Landing	**Rec. T + 0 sec (Reaction time)**		**Rec. T + 0 sec (Reaction time)**	**Rec. T + 0 sec (Reaction time)**	
Maneuvers Approach	**Rec. T + 1 sec (Reaction time)**		**Rec. T + 1 sec (Reaction time)**	**Rec. T + 0 sec (Reaction time)**	
Descent Climb	**Rec. T + 3 sec (Reaction time)**		**Rec. T + 1 sec (Reaction time)**	**Rec. T + 1 sec (Reaction time)**	
Cruise	**Rec. T + 3 sec (Reaction time)**		**Rec. T + 1 sec (Reaction time)**	**Rec. T +3 sec* (Reaction time)**	**Rec. T +1 sec* (Reaction time)**

IMC demonstration required

⇨ **The failure recognition time (Rec. T) is normally considered to be 0.5 sec for those failures reported with warnings**

⇨ **The data in italics are not defined in AC29-2A but suggested by the French authorities for the certification of automatic hover modes (Night SAR mode).**

* **The reaction times of the pilot(s) in cruise as well as for VFR certification are dependent on helicopter speed. If the speed is between V_H and V_{NE}, a 1 sec reaction time is appropriate but is the speed is less than or equal to V_H the normal reaction time is 3 sec (See AC29-2B, Chapter 3, §775 b(6)(iii)(A), page 13).**

Figure 2 : Theoretical Failure Recognition Times Taken From AC 29 – 2A

It stems from the above table that the pilots failure recognition times depend on speed V_H, in cruise phase and VMC conditions.

- V_H is the maximum speed the helicopter can reach at a given altitude and maximum power.

Figure 3 below defines V_H with respect to the various specific speeds of the helicopter and as a function of power, at constant altitude.

Two additional speeds are also defined at constant altitude:

- Max. long-range cruise speed at which the helicopter covers the longest leg.
- Speed V_Y at which the helicopter flies the longest time (maximum endurance). It is also the speed at which power is minimum in level flight and the helicopter thus has a large power reserve to climb.

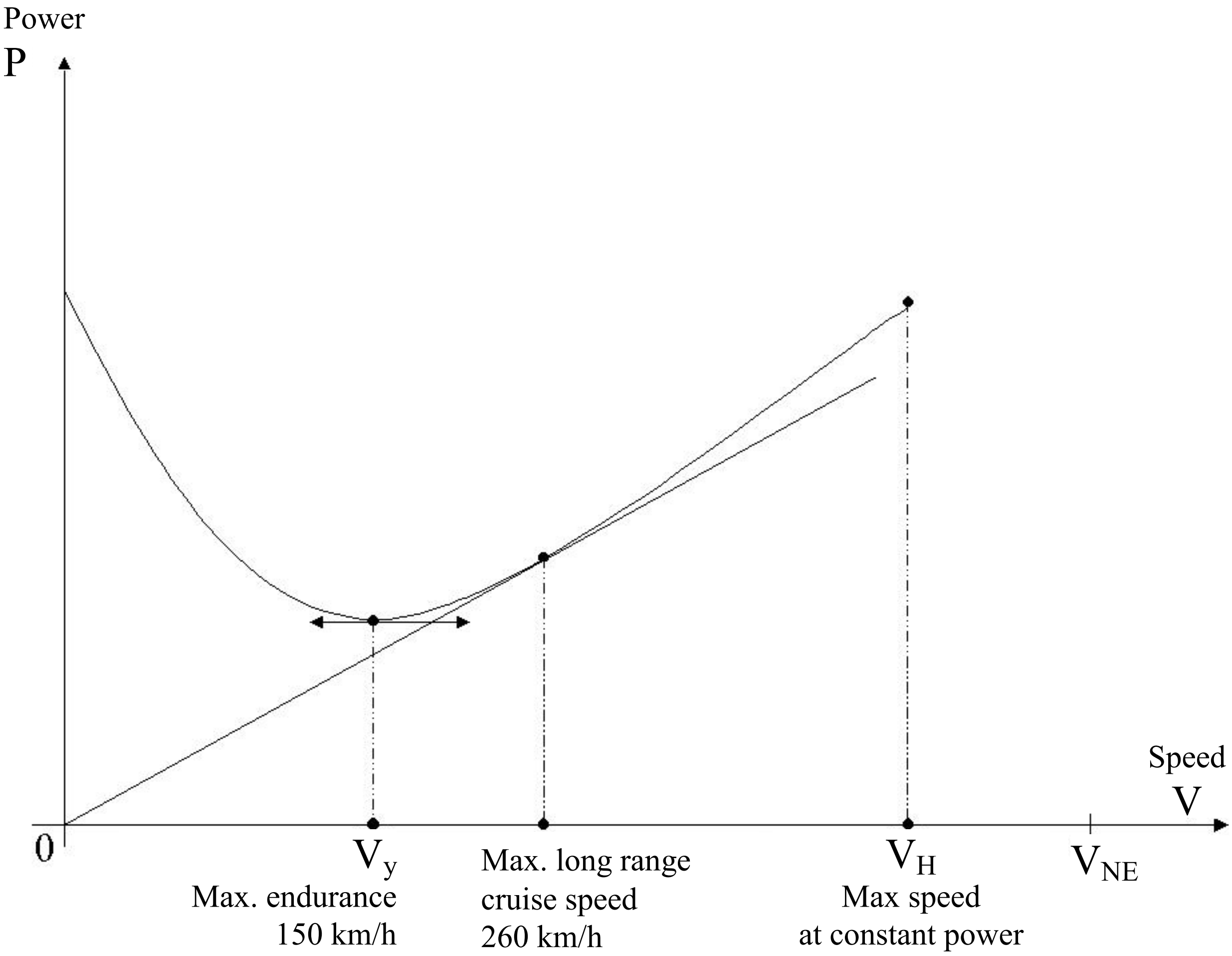


Figure 3 : Definition of Maximum Speed VH at a Given Altitude

5 Summary of Simulations To Be Performed

5.1 Selected Failures

The 5 failures selected during phase 1 and their associated occurrence are as follows:

Failure		Occurrence
1	Slow IRS2 drift at 2.4°/s	Cruise in IMC conditions
2	Loss of one engine detected by FADEC	HOVER while sling loading operation is in progress
3	Partial loss of engine power	VMC approach during night landing
4	Slow drift of the AFCS altitude hold upon a barometric altimeter failure	Cruise in IMC conditions
5	Hardover on AFCS roll axis	Cruise in VMC conditions at low altitude

The 3-D failure characteristics show the space covered by the 5 selected failures, in the following combinations:

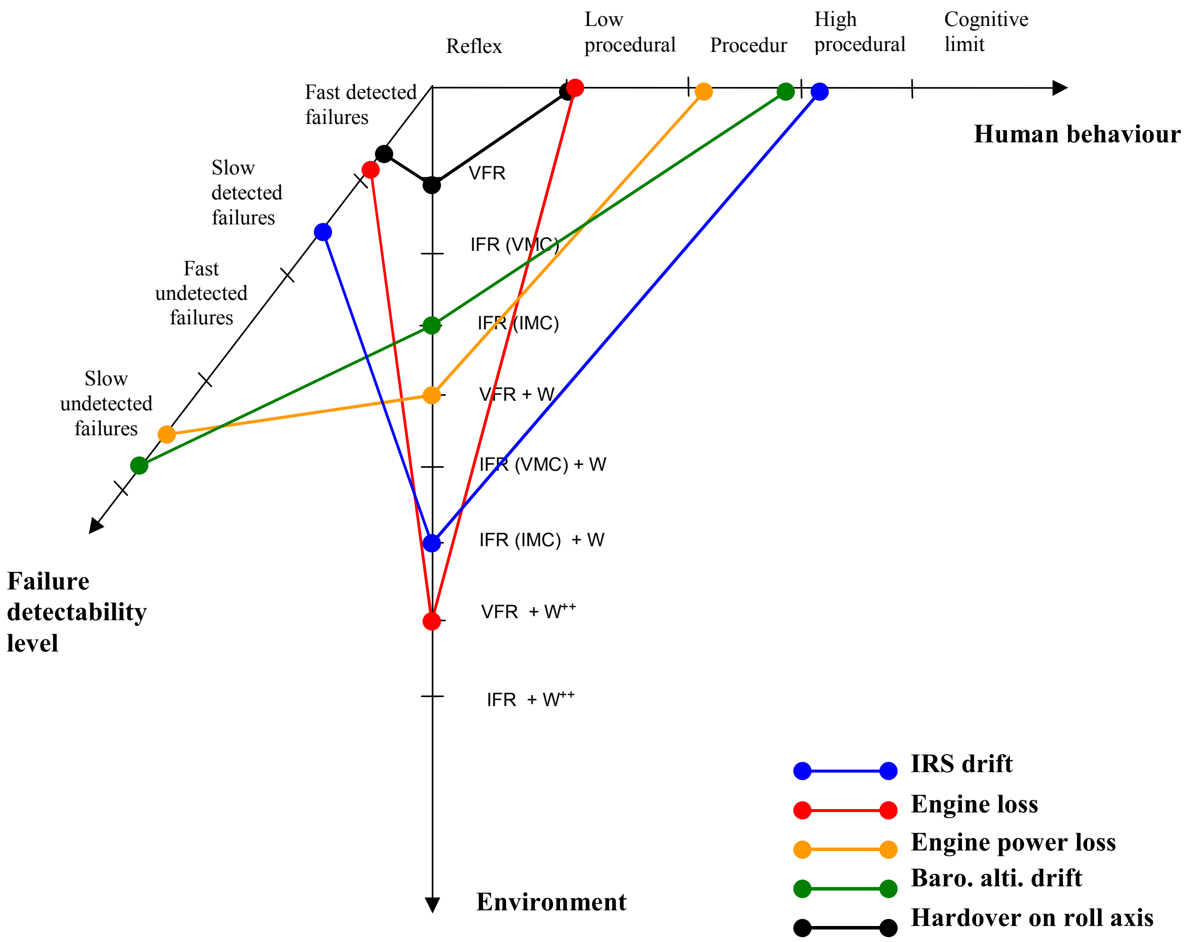


Figure 4 : 3-D characteristics of failures – Human behaviour

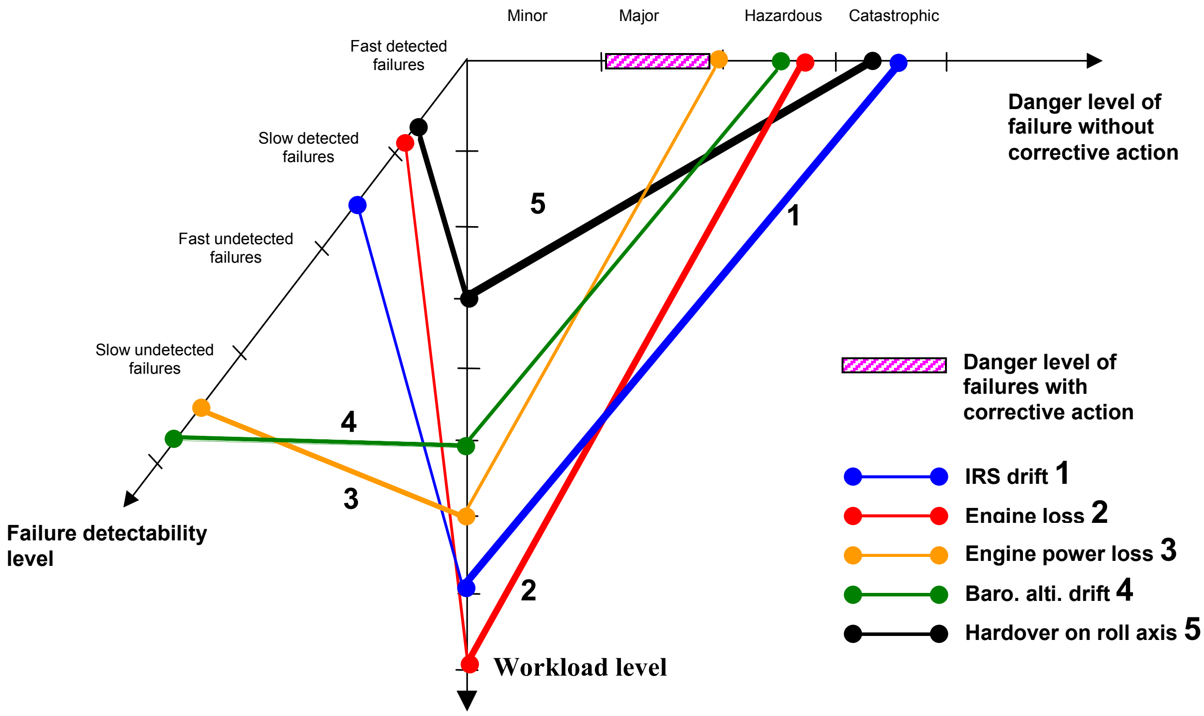


Figure 5 : 3-D characteristics of failures – Danger level of the failure

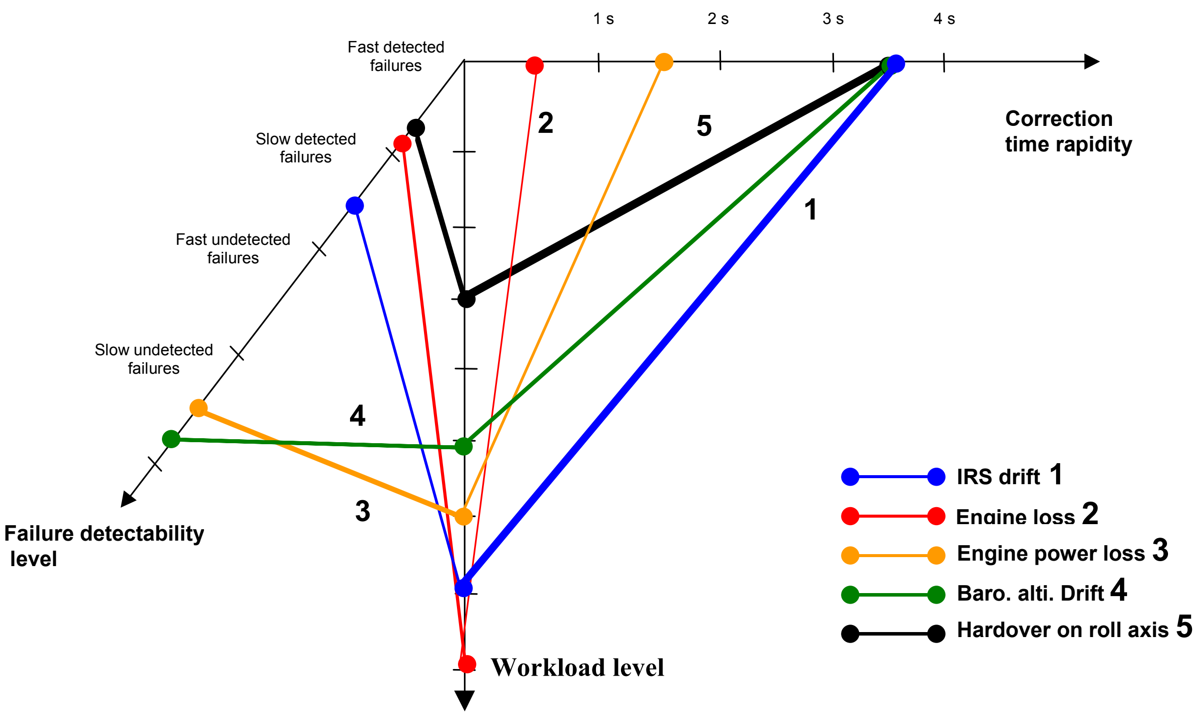


Figure 6 : 3-D characteristics of failures – Correction time rapidity

5.2 Description of Scenario Patterns

5.2.1 Failure No 1: Slow IRS 2 drift

The slow IRS2 drift failure was selected for its « slowover » aspect detectable by the pilot. It is an illustration of the potential temporal drift of a failure, after detection of a deviation between the 2 IRS's, if the pilot does not execute positive cross-checks of the data from the various equipment.

5.2.1.1 Systems involved in the failure

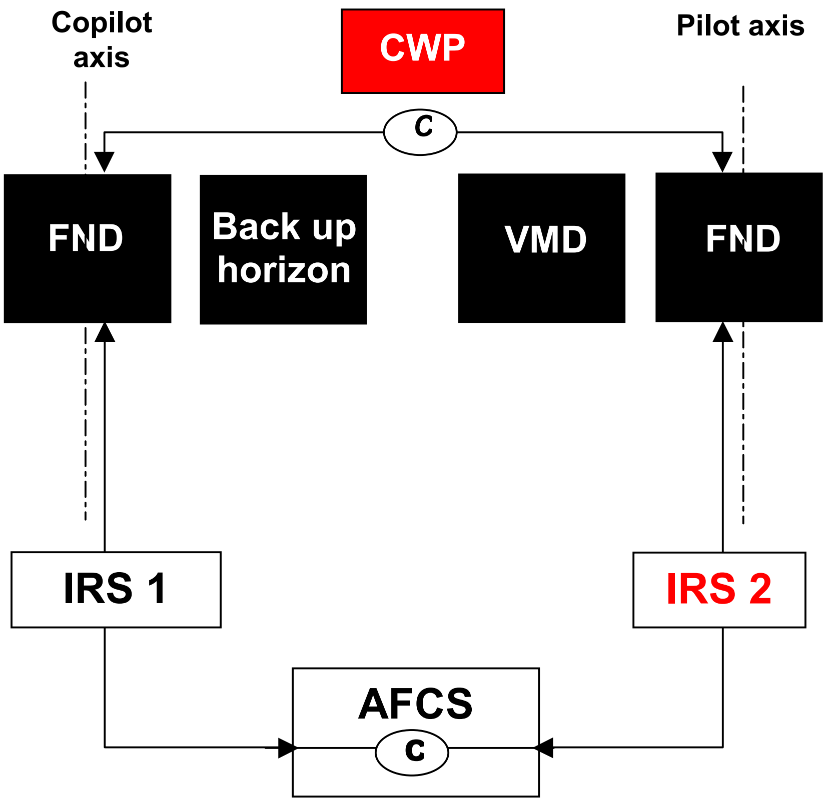


Figure 7 : Description of failure 1 constituent elements

The failure is detected by the system:

- in case of an attitude deviation between the 2 IRS's exceeding 3°
- in case of an angular speed deviation exceeding 2.5°/s

In this case, since the drift is 2.4°/s, the failure is detected by the system after 1.25 s.

5.2.1.2 Detection Means and Expected Correction

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Nose-down movement and RH roll attitude displayed on pilot FND - Loss of upper modes (ALT, speed, attitude hold) - Deviation between FND symbologies - “HANDS ON” audio warning - Temporary illumination of “FCS” warning light (red) (meaning « hands on ») + “FCS” and “AVICS” (amber) on CWP	- Correction - Crosscheck between both displays/ stand-by instrument - Warning acknowledgement - Identification of display providing false information - MFD2 reconfiguration on IRS1 ** Automatic AFCS switch off*

5.2.1.3 Effects Induced

EFFECTS INDUCED	
NO CORRECTIVE ACTIONS: CATASTROPHIC (in IMC conditions)	PROPER CORRECTIVE ACTIONS MAJOR EFFECTS
- Spatial disorientation *In case of a manual correction attempt from information from failed IRS:* - Roll to the left - Pitch nose-up attitude - All leading to loss of helicopter control	- Identification of display providing false information - Helicopter stabilisation

5.2.1.4 Recognition And Reaction Times Expected From the Pilot

The failure will occur in « IMC cruise » phase to provide no external information to help the pilot rectify the failure.

EXPECTED PILOT REACTION
- Recognition time: 0.5 s
- Reaction time: 3 s
- Recovery time: NA

5.2.1.5 Scenario Pattern

The scenario presented in the briefing phase is as follows:

- Take-off from the off-shore station
- Oversea flight under the cloud cover south of Marseille-Provence

• Transition to IFR (communication with ATC Marseille-Provence) and climb to cruise altitude, direct flight to Eyguières

• Landing at Eyguières in VMC conditions (if out of the bad weather zone) or break-through at Salon de Provence

• Embarking of passengers

• Return flight to the off-shore station in IFR conditions via Istres (break-through over the sea zone controlled by Marseille-Provence)

The failure will occur on the outbound leg, when flying over Etang de Berre and crossing the TMA (terminal area), with the aircraft stabilised in IMC cruise mode with the AFCS upper modes engaged.

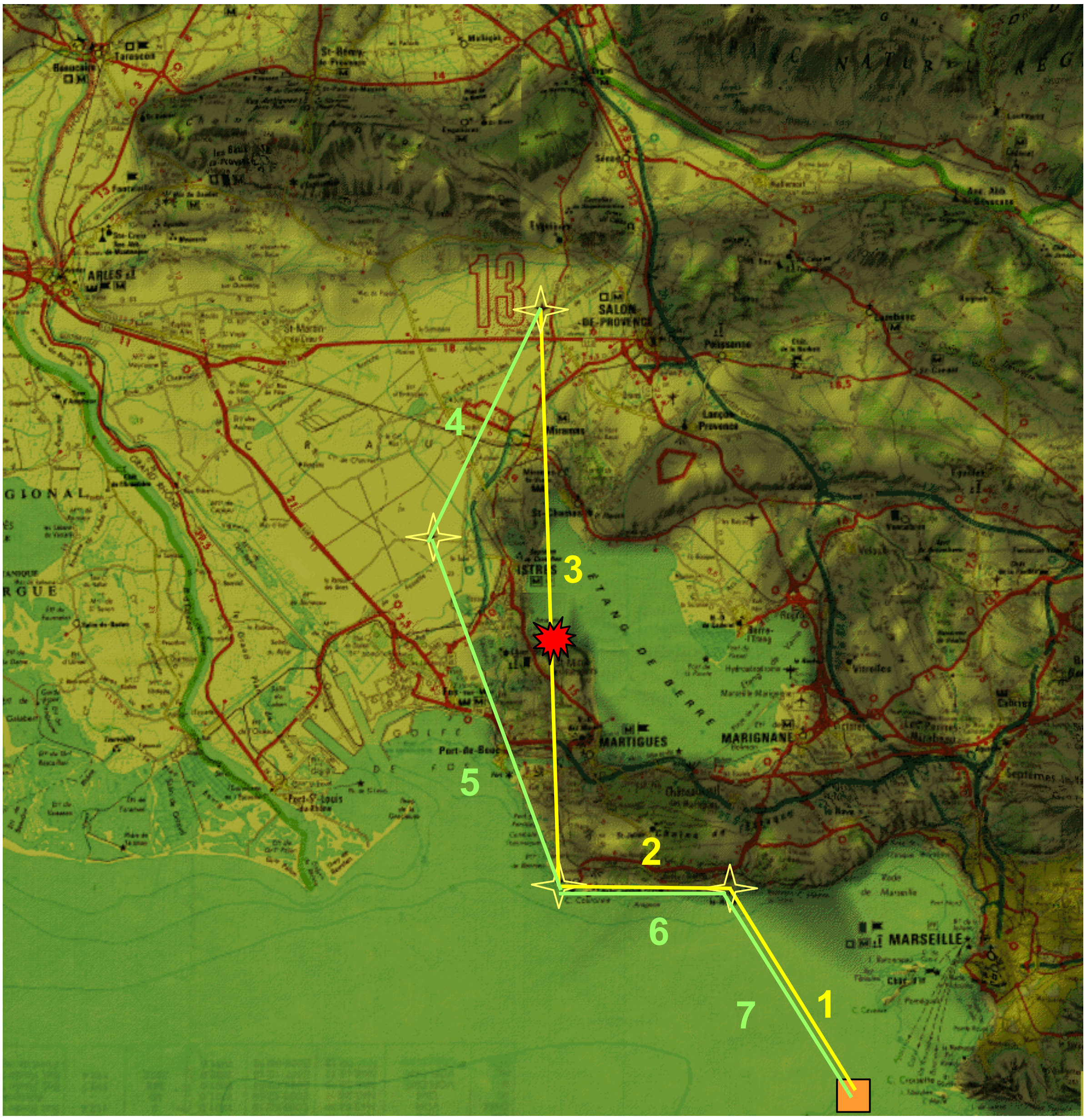


Figure 8 : Scenario No 1 pattern on map

5.2.2 Failure No 2: Loss of Engine 1 Detected By The FADEC

The engine 1 loss failure was selected as an obvious failure detectable by the system. This illustrates a failure degrading helicopter controllability (loss of power margin) and occurring simultaneously in a flight phase requiring high piloting skill.

5.2.2.1 Systems Involved In The Failure

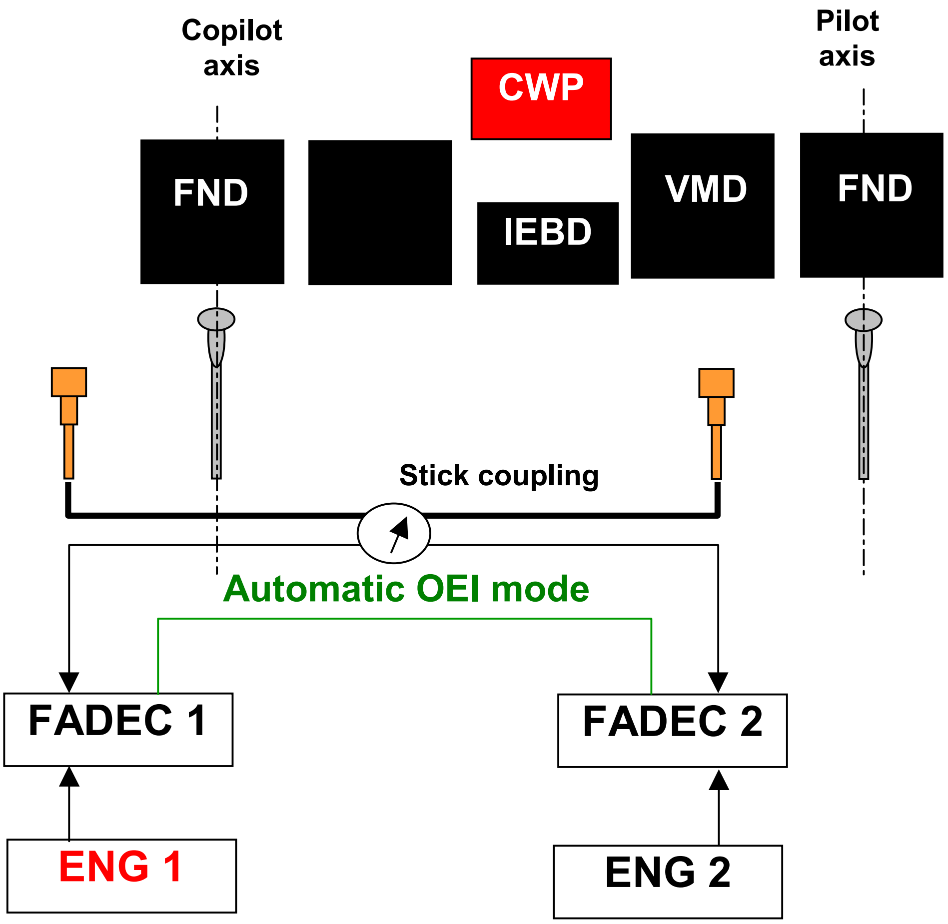


Figure 9 : Description of failure 2 constituent elements

The failure is detected by the system as soon as the torque deviation exceeds 30 % for 0.5 s. The warning indication is therefore initiated by the system 0.5 s after failure injection.

5.2.2.2 Detection Means and Expected Correction

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Engine No 2 switched to OEI mode - Engine parameters modification displayed with red warnings on IEBD - OEI mode reported on the FND's - "ENG DF" red warnings on CWP and audio warning	- Release of the sling load - Lower collective pitch to retain rotor NR - Accelerate (push cyclic stick forward) and control path (obstacle avoidance) - Warning acknowledgement - Switch engine No 1 off to prevent fuel supply

5.2.2.3 Effects Induced

EFFECTS INDUCED	
NO CORRECTIVE ACTIONS: HAZARDOUS	PROPER CORRECTIVE ACTIONS: MAJOR
- Altitude loss with risk of crash on the ground *(hard landing to crash)*	- Stabilise the helicopter: - Shut down the faulty engine

5.2.2.4 Recognition And Reaction Times Expected From The Pilot

The failure occurs with the aircraft virtually in hover, at the very end of the laying phase of an external load (weight close to the maximum weight) on the off-shore platform (limited touchdown area, obstacles by cranes and structure of the platform).

EXPECTED PILOT REACTION
- Recognition time: 0.5 s
- Reaction time: 0 s
- Recovery time: NA

5.2.2.5 Scenario Pattern

The scenario presented in the briefing is as follows:

- Take-off from Istres at the maximum weight
- VFR flight with sling load, up to the off-shore station
- Laying of the sling load on the off-shore station helipad.
- VFR return empty and landing at Istres

The failure will occur at the very final approach phase on the off-shore platform (aircraft almost in hover above the platform, manual piloting).

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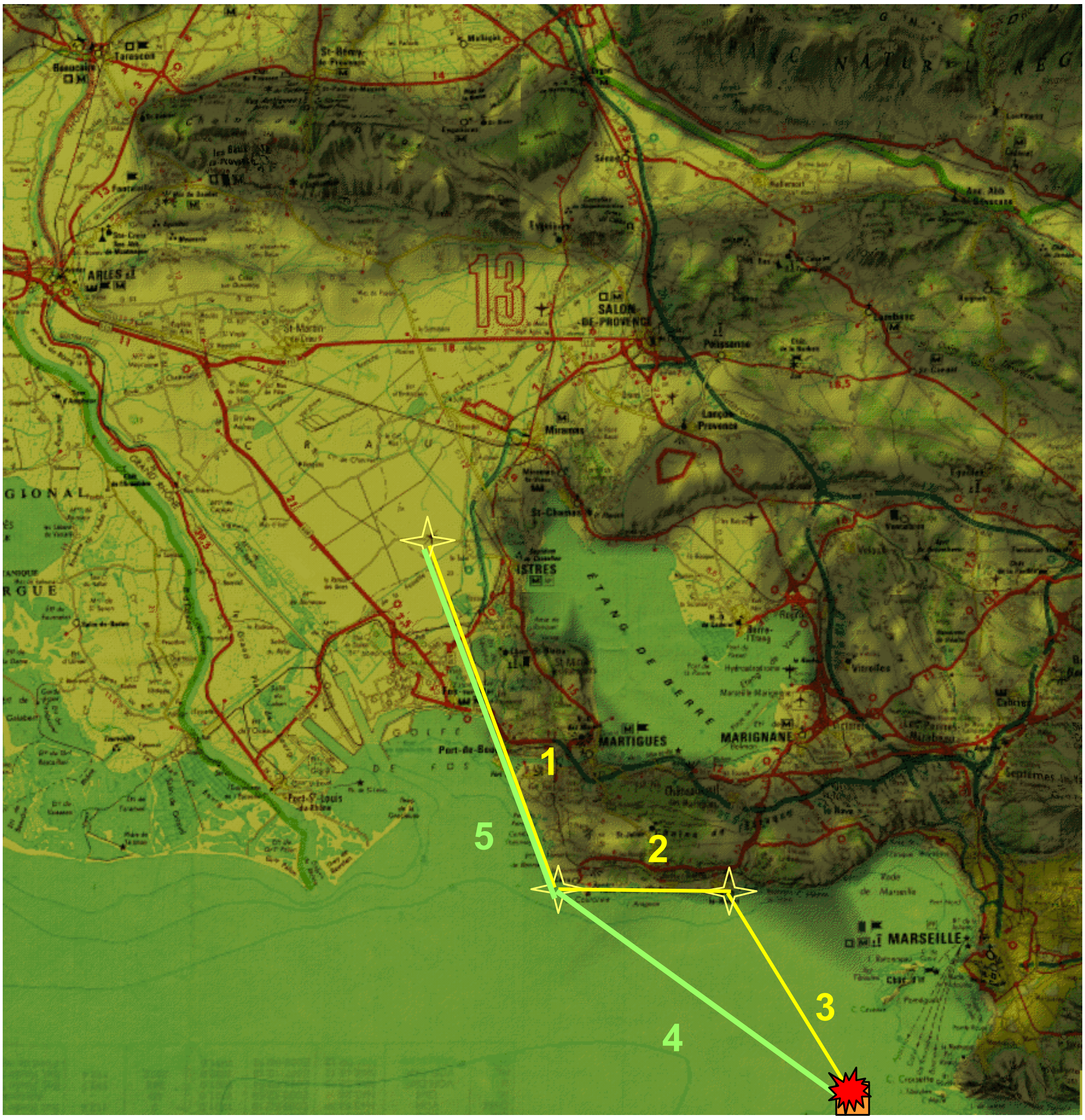


Figure 10 : Scenario No 2 pattern on map

5.2.3 Failure No 3: Reduction of Engine 1 Power

The partial reduction of engine No 1 power has been selected for its «slowover» that is not quickly detectable by the pilot. This illustrates the potential temporal drift of a failure and the pilotability degradation it induces.

This failure also illustrates a loss of helicopter performance in a high workload phase, requiring the pilot to make a priority selection.

5.2.3.1 Systems Involved in the failure

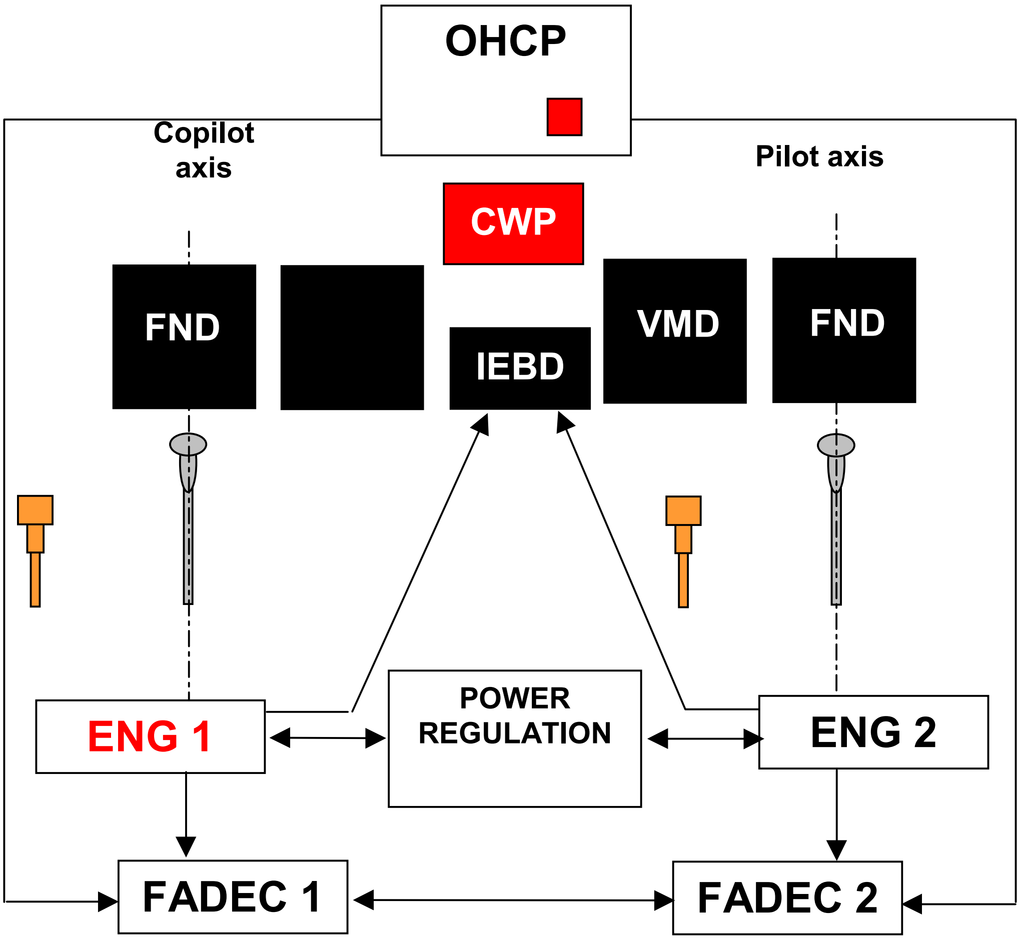


Figure 11 : Description of failure 3 constituent elements

The failure is detected by the system as soon as the torque deviation exceeds 30 % for 0.5 s.

Engine 1 slowly degrades, losing 1 % torque per second (taken up by engine 2, hence a difference of 2 %/s). The warning indication is therefore initiated by the system 15.5 s after injection of the failure.

5.2.3.2 Detection Means and Expected Correction

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Power indication for both engines on IEBD and crosscheck with the associated VMD page *If not initially detected:* - Switch to OEI mode reported on the FND's - Lighting of "ENG DF" warning lights on CWP and audio warning	- Stop failed engine 1 and switch to controlled OEI mode *if not initially detected:* - Reduce collective pitch to retain rotor NR - Land with reduced power or increase speed (pilot's decision) - Acknowledge warning - Stop engine 1

5.2.3.3 Effects Induced

EFFECTS INDUCED	
NO CORRECTIVE ACTIONS: MAJOR TO HAZARDOUS	PROPER CORRECTIVE ACTIONS: MAJOR
- No max; power available to "break" the speed during landing phase - Automatic switching to OEI mode during landing phase	- Helicopter regulation – Faulty engine stop - Go around and possible diversion

5.2.3.4 Recognition And Reaction Times Expected from the Pilot

The failure will occur during the final phase of landing « in a clearing » so that the pilot detecting the failure before the system has to correct it immediately, and so that the pilot only informed of it by the system has to immediately decide whether to proceed with landing without power margin or change his route.

EXPECTED PILOT REACTION
- Recognition time: up to 15.5s
- Reaction time: 1s
- Recovery time: NA

5.2.3.5 Scenario Pattern

The scenario presented in the briefing is as follows:

- Take off from Marseille-Provence airport with 18 passengers (almost at all-up weight)
- Night flight in VMC to Les Baux-de-Provence
- Landing on Les Baux landing area and disembarking of passengers
- Leaving (empty) for Marseille-Provence airport (still VMC night flight)

The failure will occur in the final approach to Les Baux de Provence, so that, if the pilot does not detect the failure by reading the engine parameters, the warning is initiated at the decision point, thus requiring the pilot to immediately decide whether to proceed with landing (difficult without power margin) to an unprepared area (no possible running landing) or to execute a go-around which is critical when approaching the OEI performance range limits.

Figure 12 : Scenario No 3 pattern on map

5.2.4 Failure No 4: Slow drift of Barometric Altimeter No 2

The slow drift of AFCS altitude hold as a result of barometric altimeter failure was selected for its very slow drift « slowover » aspect that is not rapidly detectable by the pilot.

This illustrates the potential temporal drift of a very slow failure when the external events combined with the flight phase (Radio height in this specific case) and the workload prevent the pilot from fully monitoring flight parameters and also from cross-checking data between the various equipment.

5.2.4.1 Systems Involved In The Failure

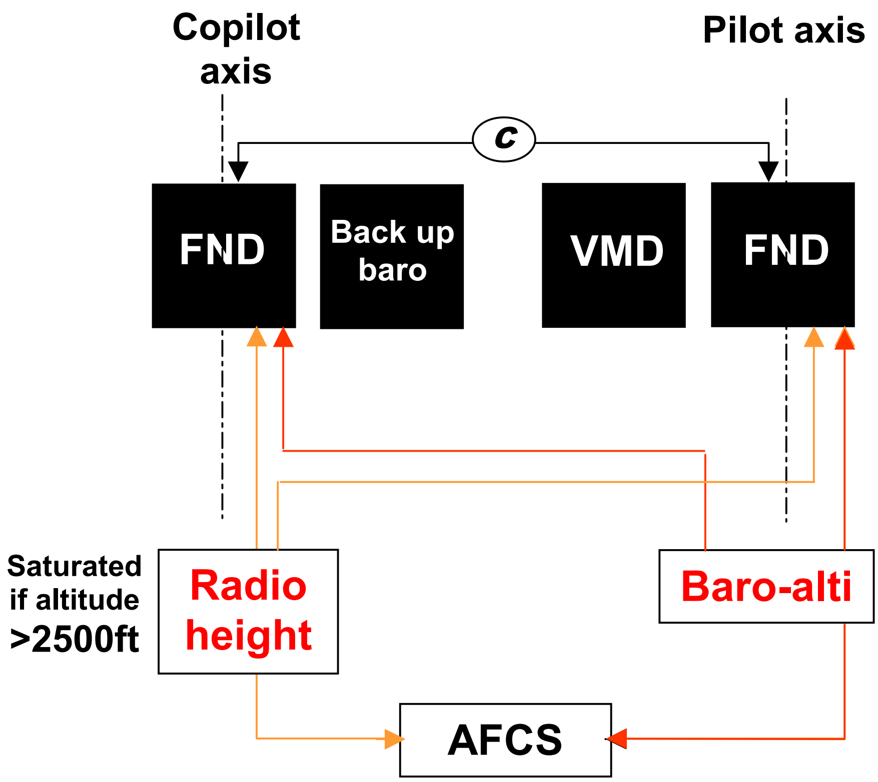


Figure 13 : Description of failure No 4 constituent elements

The simulated detection threshold of the system corresponds to an altitude hold deviation higher than 300 ft/min. Since the failure corresponds to a slow drift of 100 ft/min, it is not detected by the system.

5.2.4.2 Detection Means and Expected Correction

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Vertical climb indicator reporting a 100ft/min drift - Discrepancy between pilot and standby altimeters	- Correction - ALT mode disengagement

5.2.4.3 Effects Induced

EFFECTS INDUCED	
NO CORRECTIVE ACTIONS: HAZARDOUS	PROPER CORRECTIVE ACTIONS: MAJOR
- Helicopter altitude increase - Risk of collision with other aircraft	- Proper altitude hold with Hands On - Disengagement of altitude hold upper mode - Higher air traffic workload

5.2.4.4 Recognition and Reaction Times Expected From the Pilot

The failure will occur in «IMC cruise » phase to provide no external information for the failure resolution.

EXPECTED PILOT REACTION
- Recognition time: NA
- Reaction time: 3s
- Recovery time: NA

5.2.4.5 Scenario Pattern

The scenario presented in the briefing is as follows:

- VFR take-off from the "Moulin de Daudet"
- Transition to IFR mode (communication with Istres et Marseille-Provence ATC) and climb to cruise altitude, heading to MTG
- IFR break-through and landing at Marseille-Provence airport
- Embarking passengers
- IFR departure from Marseille-Provence airport, outbound leg through sea lane
- Direct IMC cruise flight to Le moulin de Daudet
- Break out from bad weather zone, or diversion above Saint-Martin-de-Crau and break-through at Istres
- VFR approach and landing at Le moulin de Daudet

The failure occurs in direct IMC stabilised flight, on return from mission, without any tell-tale signs that might alert the pilot, on a fairly long leg.

Figure 14 : Scenario No 4 pattern on map

5.2.5 Failure No 5: Hardover on AFCS Roll Axis

The hardover on AFCS roll axis failure, in VMC conditions, was selected for its sudden occurrence very quickly detectable by the pilot. This illustrates a failure that occurs suddenly and is immediately detected.

5.2.5.1 Systems involved in the failure

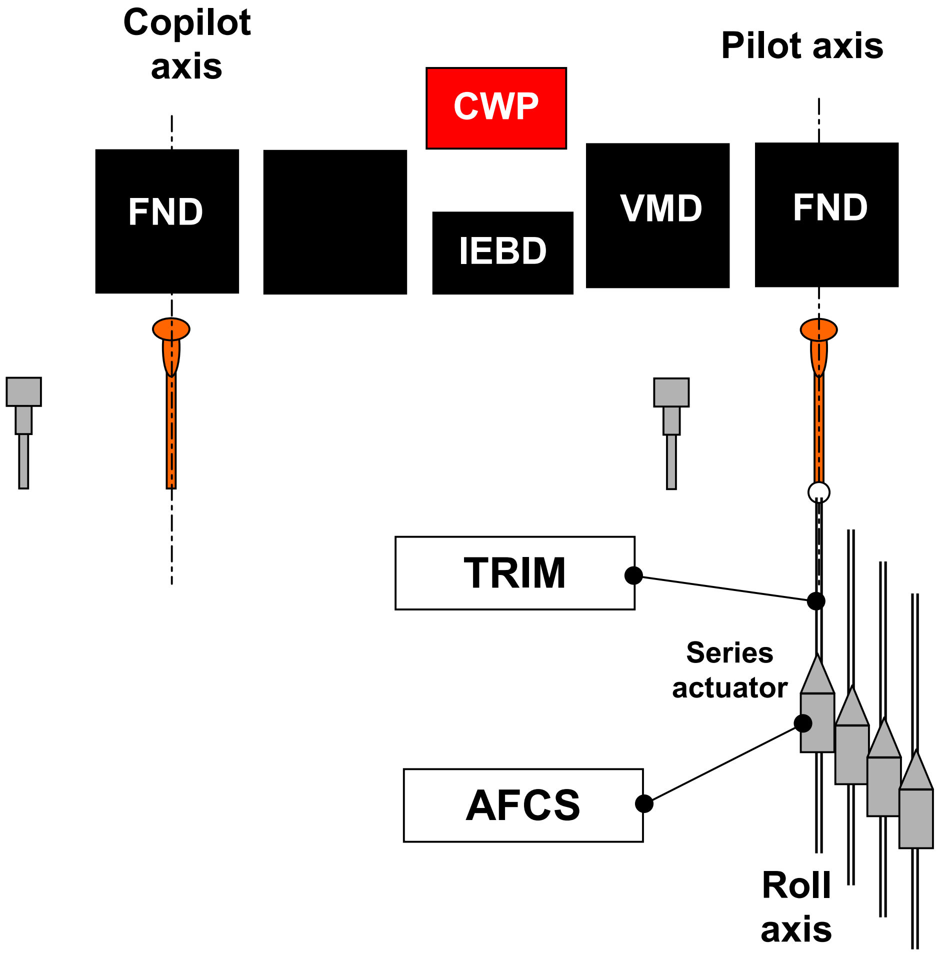


Figure 15 : Description of failure No 5 constituent elements

This failure immediately initiates a RH roll movement, perceptible on the attitude indicators and also by observation of the external environment and is immediately indicated by a system warning.

5.2.5.2 Detection Means and Expected Correction

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Audio warning “HANDS ON” - On CWP, illumination of “FCS” red warning light (temporarily lit – meaning « hands on »)+ “FCS” amber - Warning on FND – AFCS disengagement - FND’s reporting a roll movement to the right - Movement of external landscape	- Correction - Correction with cyclic stick

5.2.5.3 Effects Induced

EFFECTS INDUCED	
NO CORRECTIVE ACTIONS: CATASTROPHIC	PROPER CORRECTIVE ACTIONS: MAJOR
- Loss of stability on roll axis - Exponential lateral drift which may result in the loss of helicopter control	- Trajectory hold - Loss of automatic roll stabilization with an increased workload

5.2.5.4 Recognition and Reaction Times expected from the Pilot

The failure will occur in low altitude VMC cruise flight to increase the stress of the pilot who will have to react more rapidly than when flying at high altitude.

PILOT REACTION EXPECTED
- Recognition time: 0.5s
- Reaction time: 3s
- Recovery time: NA

5.2.5.5 Scenario Pattern

The scenario presented in the briefing is as follows:

- Take-off from Le Mazet with passengers on board
- Direct VFR cruise to Carro
- Descent and landing on off-shore station
- Take-off (empty) and oversea flight at low altitude south of Marseille-Provence airport
- Direct VFR cruise flight to Le Mazet, at the appropriate altitude for flying over Les Alpilles
- Landing at Le Mazet

The failure will occur on return from mission, in cruise flight when closing in to Les Alpilles. This failure will illustrate both the end of a fairly long leg of flight without any problem encountered and the end of a stabilised phase without any tell-tale signs that might alert the pilot and the nearing of the terrain.

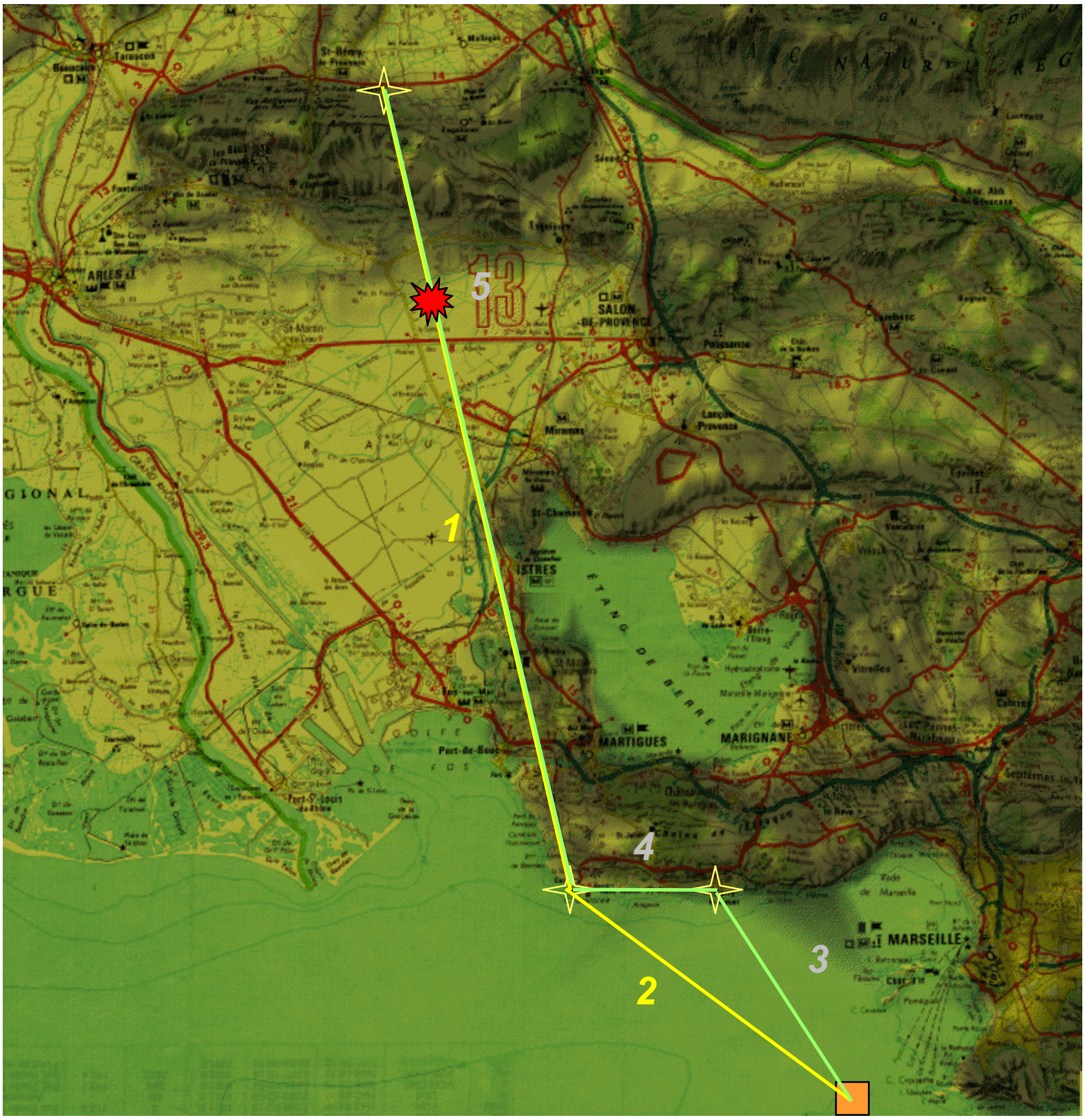


Figure 16 : Scenario No 5 pattern on map

5.3 Panel of Pilots

The experimentation was conducted by a panel of pilots from different environments. These pilots were supposed to be familiar with the latest generation cockpits, to have a cognitive flexibility for taking best advantage of the training sessions, and to have experience in simulation procedures in order to limit the secondary effects resulting from the differences between the simulation environment and the actual flying conditions.

This panel included 7 pilots:

- 3 Government test pilots
- 2 test pilots from the Industry

- 2 instructor pilots

The list of the pilots is summarised in the table below:

Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Current position	Industry test pilot	Instructor	Industry test pilot	Govern. test pilot	Instructor	Govern. test pilot	Govern. Test pilot
Experience	Navy	Army	Off-shore	Army	Navy	Army	Army

6 Overview of Methodology

6.1 Pilot Training and Familiarisation

Training sessions have been organised in order to:

- familiarise the pilots with flying in the SPHERE simulator;
- familiarise the pilots with the layout of the cockpit utilised;
- to train the pilots to fly the generic helicopter;
- to train the pilots in the operation of the generic helicopter systems;

Since the pilots from the panels are all experienced pilots, test pilots or flying instructors, a large part of the training is made up of self-training flight (though with advice from the instructor) so that each pilot can personalise the training to suit his particular experience.

This training is completed by initiating failures – other than those selected for the evaluation – so that the pilots can test and, if necessary, round off their know-how.

The experience with the first pilots has shown that pilots tend to overestimate the value of their training. Consequently, a more formal assessment has been added at the end of the training program. Three self-assessment scenarios are scheduled. The pilots only start the evaluations once these scenarios have been completed to their own satisfaction and that of the instructor. In the self-assessment scenarios, the following are performed:

- a failure-free arrival on an offshore platform at maximum weight with a sling load, aimed at assessing the ability to fly the generic helicopter;
- a second arrival on the platform, this time complicated by an engine fire in the short final approach phase;
- an IRS 2 failure during an IMC procedure to Marseille-Provence.

Whenever there is a gap of several weeks between the training session and the evaluation, a new familiarisation period (self-training flight and a few failures) is scheduled at the beginning of the evaluation session.

6.2 Briefings

During the evaluation sessions, the evaluating pilots are given an initial general briefing, which is followed by a specific briefing prior to each scenario.

The aim of the general briefing is to reiterate:

- the general rules for the simulation, i.e. the limits of the simulator, radio communications traffic, position of the standby instruments, etc.;
- the scope of the scenarios and applicable procedures (civil flights, single pilot, IFR procedure to Marseille-Provence, etc.);

- the differences between the generic helicopter and the specific helicopter whose cockpit the pilot uses, or between the generic helicopter and the helicopter in which he usually flies.

In the specific briefing before each scenario, both the mission to be flown and the forecast weather conditions are presented. The topics discussed in the general briefing can also be repeated (IFR procedure, safety rules applying to sling flight, etc.).

6.3 Simulating the Failure Scenarios

The simulation is then conducted with the pilot by himself in the cockpit. In the test monitoring room, the evaluator notes the pilot's reactions, intervenes on the audio system to simulate the air traffic control, and decides when to trigger the failures.

Both the flight parameters and the aircraft and cockpit status are recorded during the simulation so that the pilot's actions can subsequently be analysed in depth.

6.4 Debriefings

A debriefing is conducted immediately after each scenario so that the pilot has no time to "over-interpret" the facts, or to mix up two different scenarios. The introduction of this evaluation time period also helps preventing fatigue, thus avoiding "botched-up" scenarios, and answers "copied" from a workload evaluation questionnaire to the other.

6.4.1 Informal Debriefings

In the informal debriefing, the pilot can explain his actions, comment on the scenario, and indicate any interference from the simulation environment that could affect the success of the mission.

The notes taken in the debriefing are used to adjust the raw measurements of the reaction times, and the results from the subjective evaluation of the workload.

6.4.2 Subjective Evaluation of the Workload

The pilot then fills out a subjective evaluation questionnaire on the workload. Comments are often added to the informal debriefing notes when this questionnaire is being completed.

In this evaluation, the flight is broken down into 4 sub-segments:

1. Start of the scenario, with the helicopter systems in nominal state;
2. Occurrence of the failure;
3. Handling of the failure;
4. Continuation of the flight, with the helicopter systems in degraded state.

The questionnaire is used to assess a subjective workload with a score from 1 to 10 on the Cooper-Harper scale, making allowance for the uncertainties introduced in the simulation by means of a fuzzy logic system.

Refer to Appendix 3 for a questionnaire and the uncertainty recording formula.

All the results are shown in Appendix 4. The text of the document only presents the median values.

6.5 Measuring the Reaction Time

By matching up the recordings, the explanations given in the debriefings, and the notes taken during the simulation, the evaluator can analyse the flight parameter recordings.

The analysis is based on the plot that shows the sequencing of the failure and pilot's actions. In the next step, the unprocessed recording file gives the precise dates of the various events.

In study phase 1, "thermometers" were defined to clarify the pilot's tasks in the expected recovery process. By indicating the events associated with these tasks, the pilot's reaction time can be measured.

A typical plot with explanatory comments is shown overleaf to illustrate the method. Refer to Appendix 2 for the definition of the recorded parameters, and the plots.

TRPH Pilot 6 Failure 2

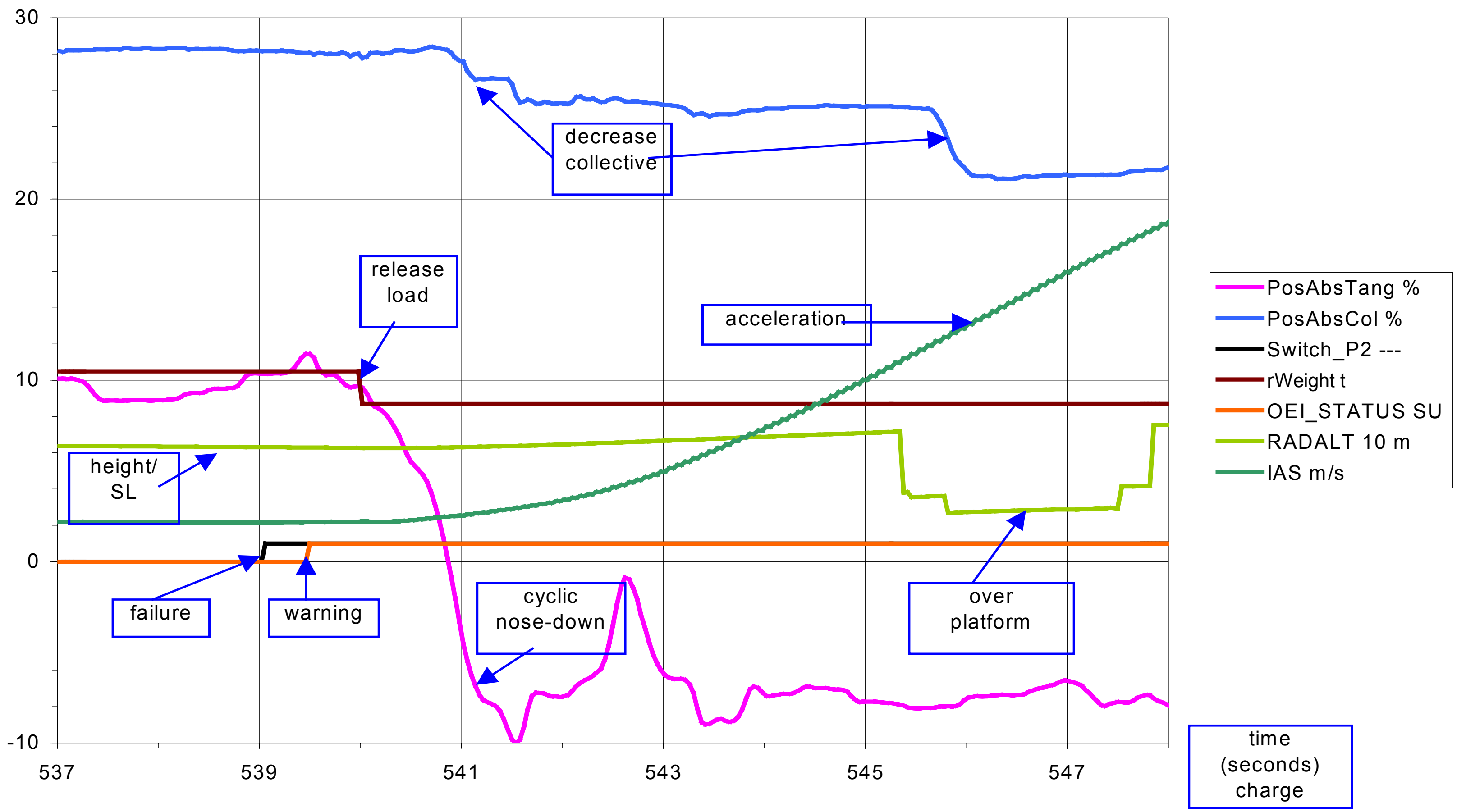


Figure 17 : Typical Recording of Simulation Parameters

7 Simulation Results

7.1 Failure 1: IRS 2 Drift

7.1.1 Scenario Sequence

The failure is initiated in a steady cruise flight in IMC conditions. The first sign of the failure, which was only detected by one pilot, is an attitude indicator that starts to deflect as if for the beginning of a turn.

When the attitude difference between the two IRS units reaches 3°, the system detects the anomaly after 1.25 s and initiates the following actions:

- hands-on warning including:
  - ➢ disconnection of the AFCS upper modes;
  - ➢ the AFCS zone indicators on the MFD flash red;
  - ➢ temporary red FCS on the CWP;
  - ➢ hands-on audio warning;
- warning indicating the avionics/AFCS problem (AFCS detects discrepancy) and including:
  - ➢ amber FCS on the CWP;
  - ➢ amber AVICS on the CWP;

The pilot can consult the FCS or avionics pages on the VMD and see that the IRS are indicated as being unreliable (amber) This check can only be made subsequently as the recovery action must be fast.

As the pilots have been told during training, when an AVICS failure is indicated, the attitude indicators and the standby indicator must be read before attempting to use the indicator in front of the pilot for flying. The failure may then be analysed in more detail via the VMD pages.

In the simulations, the pilots behaved as follows:

- Pilot 2 detected an abnormal deflection on the attitude indicator before the warning, which confirmed his analysis of a problem with this indicator
- Pilots 3, 6 and 7 carried out the check as soon as the warning occurred. Pilot 3 reconfigured before re-engaging the AFCS. Pilot 7 decided to fly using the standby indicators. Pilot 6 knew he was above the Etang de Berre and simply decreased the collective pitch to initiate a descent under the cloud layer to regain some visual cues.
- Pilots 1, 4 and 5 started to follow the failed IRS. Pilot 1 quickly analysed the problem by detecting the discrepancies between his apparent attitude and the heading variations. Pilot 4 and 5 took longer to complete this analysis and were alerted by the effect of the load factor (not detected directly on the simulator) on the main rotor noise or because they had descended below the cloud layer.

7.1.2 Reaction Time

HELICOPTER FAILURE CORRECTION TIMES – SCENARIO 1										
Significant Variables	N°	FAILURE RESOLUTION TASKS IRS2 SLOWOVER	TIME (seconds)							
			Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Theory
SWITCH 1	1	Occurrence of failure	T0	T0	T0	T0	T0	T0	T0	T0
	D	Detection by the system	T0 + 1.25	T0 + 1.25	T0 + 1.25	T0 + 1.25	T0 + 1.25	T0 + 1.25	T0 + 1.25	T0 + 1.25
	2	"Hands-on" audio warning On aural + Master visual	-	-	-	-	-	-	-	TD + 0,5
	3	CWP display: red FCS + amber FCS + amber AVICS								
POSABSROU + POSABSTANG + POSABSLAC + POSABSCOL	4	Recovering cyclic and collective controls	**T0 + 4.96**	T0 + 6.68	**T0 + 5.25**	**T0 + 4.8**	**T0 + 1.92**	**T0 + 4.0**	**T0 + 2.67**	T0 + 4.75 (TD + 3.5) (T2 + 3)
	5	Cross-check of MFDs 1 and 2	-	**< T0 + 1.25** (car < TD)	< T4	-	-	-	-	
	6	Cross-check with standby horizon to identify the screen providing the incorrect data	-	< T4	< T4	-	-	-	-	
RP+RQ+RR + PHI + THETA + PSI	7	Checking helicopter attitude	T0 + 23.06	T4	T4	T0 + 30.87	T0 + 33.91	T0 + 26.15	T4	-
ETAT RCP	8	Switching from MFD 2 to IRS 1 via the reconfiguration panel on console	T0 + 42.12	T0 + 2 min	T0 + 28.35	- (flying with standby)	T0 + 72.0	- (descent in VMC)	- (flying with standby)	-
-	9	Acknowledging the master				-		-	-	-

The "thermometer" defined in phase 1 corresponds to tasks 4-7.

The times recorded here yield a median reaction at **T0 + 4 s**, compared to a theoretical forecast at T0 + 4.75 s.

7.1.3 Informal Debriefings

The following remarks were made in the debriefings after the simulation sessions:

- Pilot 1 considered that failure detection would be even more obvious with proprioceptive sensations, unlike the other pilots who found them unreliable in IMC flight.
- Pilot 5 felt he had forgotten this third source was available because the standby instruments were shown on the same display as the others.
- Pilot 6 considered there was a temptation in the climb to cruise altitude to stay close to the terrain in order to fly in VMC conditions, as the ceiling seemed high enough.
- Pilot 7 felt that the drift was fast enough to sense that something unusual was happening with the attitude indicator.

7.1.4 Subjective Evaluations of the Workload

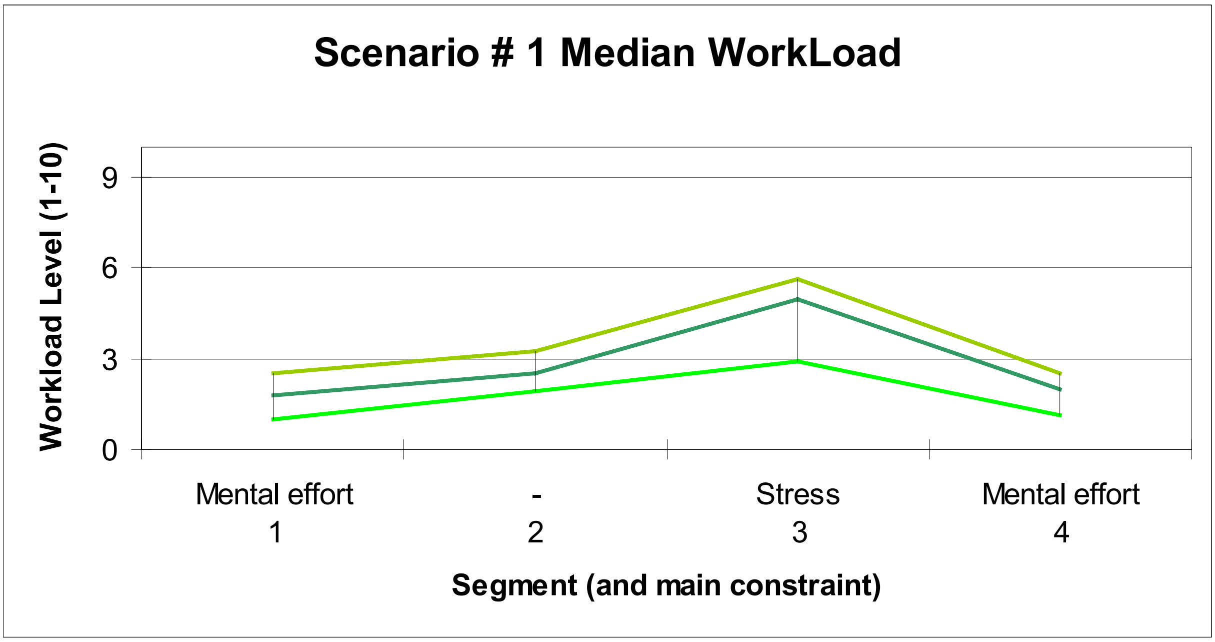


Figure 18 : Subjective Median Evaluation of the Workload for Scenario 1

The evaluation shows that the workload increased during the handling of the failure. This increase is mainly due to the stress induced by an untrustworthy attitude source in IMC flight. This is especially important for the pilots who did not analyse the failure immediately, as they found themselves in a potentially dangerous situation.

In the rest of the flight, the workload remained similar to that at the start of the flight. Some of the pilots, who feared a dual failure, claimed the workload was higher as they had to read the standby instruments more attentively. Other pilots, who had preferred to declare an emergency to obtain a descent to VMC from Marseille-Provence, have found the continuation of the flight in VFR conditions easier than the first part in an IFR environment.

7.1.5 Discussion

This kind of failure, which involves an incorrect value not reported to the crew, is of one of the failures of particular concern to pilots as it can have catastrophic consequences. The reaction of some pilots who had initiated a turn indicated that, even in this case when the discrepancy had been detected, it is vital to display the warning for the pilot.

This is why on its helicopters, Eurocopter now indicates any discrepancies between sources directly on the incriminated indicator. The pilot is thus instinctively aware he can no longer rely on the indicator without making a check. Furthermore, the new self-contained standby instruments have a digital output, whose value can be used directly by the systems to perform a poll and automatically tell the pilot which source agrees with the standby instrument[1].

As for the reaction time, the pilots were classified in two groups. One group - 2 flying instructors and 1 test pilot – took over the controls immediately in response to the hands-on warning, whereas the second group – 4 test pilots – took a few brief seconds to decide how to react. The correction times of the second group were from T0 + 4 s to T0 + 5 s, which agree with the theoretical times specified in phase 1. In contrast the first group took over the controls at about T0 + 2 s but this fast reaction had no negative effects on their failure analysis. The thought-processing time of the pilots in the second group can be interpreted as the custom of test pilots and their being less prone to stress.

To sum up, the reaction times recorded for this failure agree with the theory. However, what can be seen is the positive effect of the “hands-on” warning, combining the visual mode (temporary illumination of a red warning) and audio mode (“hands-on” voice) to indicate an urgent need for manual recovery. As of today, this observation cannot be used as an argument to relax the requirements on correction times, as different pilots perceive this urgency differently.

7.2 Failure 2: Loss of Engine 1

7.2.1 Scenario Sequence

The engine failure is initiated in the very short final approach to an offshore rig. The helicopter is virtually in hovering flight, almost over the platform, or even already over the platform for those pilots who opted for a very low approach speed.

The engine failure triggers a red ENG DF warning on the CWP, and displays the FLI scale on the FND in OEI mode.

Notwithstanding the reminder in the briefing of the necessity to immediately release the load in case of a problem, the first reaction of all the pilots was to control the helicopter. Whereas some pilots released the load in the ensuing seconds, others concentrated on managing the flight path and power, only performing release afterwards.

[1] Thus, on a new medium-heavy helicopter like EC 225/725 or NH 90, such a failure scenario would mean the flight departed with a failed IRS. Then, IRS 2 drift would not only trigger “avionics” and “hands-on” warnings, but would also display a discrepancy flag directly on the ADI. For instance, on the NH 90, the pilot would see a red “CHECK ATT” on a black background.

Only one pilot (pilot 1) decided to carry-on his landing. He nevertheless took the time to steady the helicopter in IGE hover in order to check over the radio whether the released load had caused excessive damage to the platform. All the other pilots elected to take advantage of the platform's height above the sea to pick up speed again.

7.2.2 Reaction Time

HELICOPTER FAILURE CORRECTION TIMES – SCENARIO 2										
Significant Variables	No.	FAILURE RESOLUTION TASKS, LOSS OF ENGINE 1	TIME (seconds)							
			Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Theory
SWITH 2	**1**	Occurrence of failure	T0	T0	T0	T0	T0	T0	T0	T0
OEI STATUS	**2**	Detection by the system: Audio warning + OEI FND display+ Master display	T0 + 0.5	T0 + 0.5	T0 + 0.5	T0 + 0.5	T0 + 0.5	T0 + 0.5	T0 + 0.5	T0 + 0.5
MASSE HELI	**3**	Sling load release	**T0 + 3.68**	T0 + 1.76	T0 + 2.8	**T0 + 3.5**	T0 + 15.21	**T0 + 0.96**	T0 + 16.8	T0 + 1 (T2 + 0.5)
	4	CWP display: ENG DF	-	-	-	-	-	-	-	-
POSABSROU + POSABSTANG + POSABSLAC + POSABSCOL + NR	**5**	Control of flight path/power + engine parameters display + NR monitoring	< T3	**T0 + 0.52**	**T0 + 0.64**	< T3	**< T0 + 5**	< T3	**T0 + 0.88**	-
SOV STATUS	**6**	Switching engine 1 fuel shutoff valve to OFF	left set to on	left set to on	left set to on	left set to on	left set to on	left set to on	left set to on	-
MOT STOP	**7**	Switching to engine 1 OFF	T0 + 56.13	not stopped	T0 + 34.35	T0 + 29.7	not stopped	T0 + 11.2	not stopped	-
	8	Acknowledging master	-	-	-	-	-	-	-	-

The "thermometer" defined in phase 1 corresponds to task 3. As the evaluating pilots focused on flight control to the detriment of strict compliance with the procedure, Eurocopter extended this "thermometer" to task 5.

The times recorded here yield a median reaction at **T0 +0.96 s**, compared to a theoretical forecast at T0 +1 s.

7.2.3 Informal Debriefings

In the briefings, the cruise speed was reduced by 100 kts, compared to the scenario defined in phase 1, to allow for the sling load.

According to the pilots, this failure is one of those that they most watch out for in this configuration (heavy, point landing) and it is therefore detected virtually immediately, as forecast by the regulations.

In contrast, the small decrease in NR attenuates the feeling of urgency, which explains the small number of "automatic" load releases. The generic helicopter has engines with a satisfactory power reserve above the maximum continuous level. It also has a FADEC that permits a very fast reaction by the remaining engine. Pilot 3 felt that this low release rate was in the end quite realistic, in that the average pilot would not want to endanger the lives of the ground personnel until absolutely unavoidable, despite what the procedure could call for.

7.2.4 Subjective Evaluations of the Workload

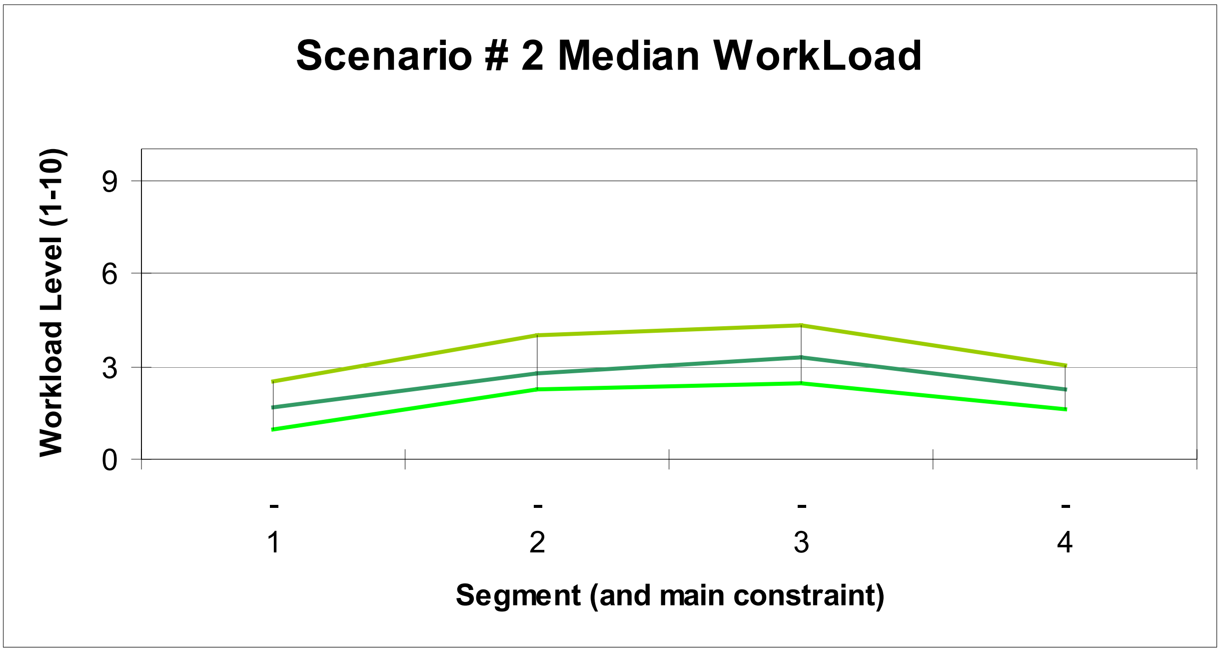


Figure 19 : Subjective Median Evaluation of the Workload for Scenario 2

The workload caused by the occurrence and handling of the failure is due both to the precise flight control required to avoid the obstacles (cranes, derricks) around the platform, and to the monitoring of the engine and rotor parameters.

The flight continues in conditions similar to those existing at the beginning, apart from helicopter monitoring, slightly amplified by the one-engine inoperative flight.

7.2.5 Discussion

The median reaction time agrees well with the theoretical forecasts when the failure is obvious and occurs in a phase of manual VMC flying.

Several of the measured times over the benchmark must be considered as upper bounds, selected because more reliable measurements were not available. When the failure occurs in a manual piloting phase, it may sometimes prove difficult to distinguish the normal control inputs from those caused by the detection of the failure.

The fact that pilots, not necessarily with recent practice of aerial work, did not immediately release the load does not seem to be a concern, insofar as this departure from the procedure did not place them in a dangerous situation. After the debriefings, it is estimated the releases would have been much quicker had there been less power available (for instance, a drop of NR). The pilot who validated the scenario in phase 1 of the study and who was better trained in the procedures for the generic helicopter, always released the load immediately despite his in-depth expertise of the generic machine and its reserve power.

Rather than being a source for concern, these deviations from the procedure - made by a pilot whose training for this type of mission may be relatively dated - highlight the safety margin added by a modern engine equipped with a FADEC system.

7.3 Failure 3: Progressive Reduction of Engine 1 Power

7.3.1 Scenario Sequence

When the failure is initiated, engine 1 slowly begins to develop less power than the power demand. This drop in power can be detected by the unbalanced engine parameters on the IEBD or, if the pilot is familiar with the helicopter, by a lower-than-usual power margin on the FLI.

If no action is taken, after 15 s the torque difference between the two engines reaches a threshold at which the FADEC units declare the failure of one the engines. Half a second later, the warning is given with the following consequences:

- an audio warning
- an ENG DF warning on the CWP;
- switchover of the FLIs to OEI mode on the FNDs.

The failure is initiated in a night VFR final approach to a landing pad. None of the pilots detected the problem before the warning was given, which occurred in the short final approach. The pilots elected to carry on – and even accelerate – the landing, apart from one pilot who opted for a go-around.

7.3.2 Reaction Time

HELICOPTER FAILURE CORRECTION TIMES – SCENARIO 3										
Significant Variables	No.	FAILURE RESOLUTION TASKS PARTIAL DROP OF ENGINE 2 POWER	TIME (seconds)							
			Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Theory
SWITCH 3	**1**	No report of failure	T0	T0	T0	T0	T0	T0	T0	T0
MOT 1 NV	**2**	FADEC threshold reached	T0 + 15	T0 + 15	T0 + 15	T0 + 15	T0 + 15	T0 + 15	T0 + 15	T0 + 15
OEI STATUS	**3**	Audio warning + FND display: OEI + Master display	T0 + 15.5	T0 + 15.5	T0 + 15.5	T0 + 15.5	T0 + 15.5	T0 + 15.5	T0 + 15.5	T0 + 15.5
	4	CWP display: ENG DF	-	-	-	-	-	-	-	T0 + 16 (T3 + 0.5)
	5	Display of engine parameters	-	-	-	-	-	-	-	
POSABSROU + POSABSTANG + POSABSLAC + POSABSCOL	**6**	Manual recovery	**T0 + 17.3**	**T0 + 17.78**	**T0 + 16.46**	**< T0 + 21.2**	**T0 + 16.22**	**T0 + 17.2**	**T0 + 16.74**	T0 + 17 (T5 + 1)
SOV STATUS	**7**	Switching engine 1 shutoff valve to OFF.	-	landing	landing	landing	landing	landing	landing	-
POSABSCOL	**8.1**	Release collective lever to shut down the engine.	-							-
MOT STOP	**8.2**	Switching engine 1 OFF.	T0 + 48.4							-
OEI HILO	**9**	Possible switching to OEI Low	T0 + 108.5							-
	10	Acknowledging the master	-							-

The "thermometer" defined in phase 1 corresponds to task 6.

The times recorded here yield a median reaction at **T0 +17.2 s**, compared to a theoretical forecast at T0 +17 s.

7.3.3 Informal Debriefings

In these debriefing sessions, most of the pilots said that, when they saw the ENG DF warning, they decided first to land, and then to analyse the failure. The warning had been given in the short final approach. All the pilots stated they did not perceive the failure until the warnings were shown because they were busy looking outside to identify the landing area – always tricky to pick out at night.

The only pilot (pilot 1) who decided to go around gave the following details of the procedure he followed:

- identification of the failure;
- acceleration;
- shutdown of the failed engine;
- moving out of the obstacles;
- switching to OEI low.

He added that, in comparison to an 'ordinary' pilot, his experience as a test pilot probably made him less susceptible to the stress involved in handling the failure.

Pilot 4 considered the scenario of "single-pilot transport of passengers at night" "rather nasty", and added that engine parameter monitoring during the approach was, as it happens, one of the tasks he would assign to the copilot.

Pilot 5 said he would have expected a copilot to focus on monitoring NR during failure management, but this had not caused him any distress because the low NR warning had not triggered.

7.3.4 Subjective Evaluations of the Workload

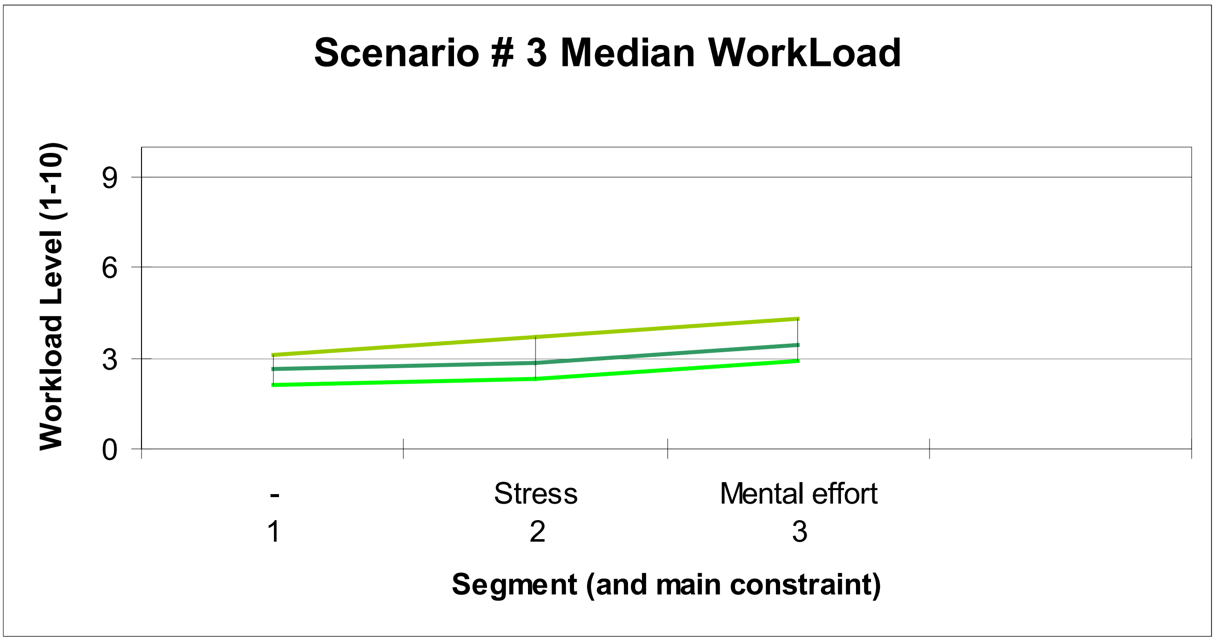


Figure 20 : Subjective Median Evaluation of the Workload for Scenario 3

Since most of the evaluating pilots (6 out of 7) had decided to deal with the failure by landing – and consequently had not performed segment 4 (continuing the flight) – the median workload was only computed over 3 segments.

The workload first increased due to the stress created by the red warning during a final approach at night, and then due to handling a heavy helicopter that no longer had any power margin available for landing in a clearing.

7.3.5 Discussion

Faced with this failure, the majority of pilots reacted as forecast by the theory, when the failure is not detected ahead of time.

When the scenario was being created, this lack of engine power in a short final approach had been considered to be potentially dangerous. Despite this, none of the pilots damaged the helicopter in their landings, although for VIP transport some of the touchdowns were rather "rough".

It can therefore be concluded that the system played its part by warning the pilot that one engine was degraded (once this seemed certain). A second conclusion is that the automatic switchover to OEI mode made it possible for the pilots, who reacted within the allotted times, to handle the situation. The only reaction time that was much longer than the theoretical forecast is an upper bound. It was used because, when the failure occurs during manual piloting, the normal control inputs could not be distinguished earlier from the inputs made in reaction to the failure. Naturally, this does not mean the pilot necessarily took all this time to react.

In the ideal situation, the FADEC would declare the failure of its engine sooner. But what can be done in a simulation environment would generate a risk of false warnings in real flight, and could therefore be more of a danger than a real help. The FADEC model used features the algorithms representative of an actual FADEC and is optimised to indicate the failure as early as possible without any risk of a false warning when one engine behaves slightly differently from the other.

7.4 Failure 4: Drift of AFCS-Held Altitude After Drift of Barometric Altimeter 2

7.4.1 Scenario Sequence

With the helicopter in steady IMC cruise flight, the altimeter that the AFCS is slaved to begins to drift, but the system does not detect the divergence from the second altimeter.

This produces a rate of climb of 100 ft/min whereas, for the crew, the altimeter indicates a constant altitude. The pilot is able to detect the failure by cross-checking on the standby altimeter, and a first indication can come from monitoring the vertical speed indicator.

The radio-altimeter is of no value in detecting the failure because it is initiated at an altitude when the radio-altimeter is already at its maximum.

Pilot 2 was the only one to detect the failure during the cruise flight; the others detected the failure in the descent to their destination

7.4.2 Reaction Time

HELICOPTER FAILURE CORRECTION TIMES – SCENARIO 4									
No.	FAILURE RESOLUTION TASKS SLOW DRIFT OF AFCS ALTITUDE AFTER DRIFT OF BAROMETRIC ALTIMETER	TIME							
		Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Theory
1	Start of drift	T0	T0	T0	T0	T0	T0	T0	T0
2	Identify the problem identified	**T0 + 6 min**	**T0 + 2 min 30 s**	**T0 + 14 min**	**T0 + 4 min 30 s**	**T0 + 6 min 30 s**	**T0 + 4 min 30 s**	**T0 + 5 min 40 s**	T2
3	Cross-check baro altimeter with standby alt. + display vertical speed indicator, if required.	-	T2	-	-	-	-	-	-
4	Switching to hands-on piloting.	already in descent	> T0 + 3 min 40 s	already in descent	already in descent	already in descent	already in descent	already in descent	T2 + 3 s
5	Recover the cyclic and collective flight controls								-
6	Disengage the ALT mode								-

The "thermometer" defined in phase 1 corresponds to task 4. In view of the time taken by the pilots to identify the failure, this "thermometer" was extended to task 2. Moreover, this point of time - easily identifiable in the control room – can clearly be measured on the simulation notes, whereas the need to limit the recording file to a manageable size prevents the pilot's control inputs from being accurately monitored.

The recorded times give a median reaction time at **T0 + 5 min 40 s**.

7.4.3 Informal Debriefings

Although the system description given during the training had emphasised the lack of a cross-checking system for the pitot-static sources on the generic helicopter, all the pilots admitted they had not attempted systematically to check their altimeter against the standby instruments. Pilot 2, who was the only one to have detected the failure before initiating his descent, had been alerted because the AFCS altitude bug on the copilot's FND was on its stop

One factor seems to have been the unusual location of the standby instruments, on the far left of the pilot.

When questioned about the vertical speed indicator, most of the pilots said they had noticed it but were not worried, thinking it was spurious interference from the AFCS. Some of the pilots indicated they would have probably found it more worrying had there been an indication of initiation of descent.

Pilot 3 considered that, being flying inside a TMA, ATC could have asked him to comply with his altitude clearance when his transponder was reporting the altitude drift.

Pilot 4 considered the lack of proprioceptive sensations had also been a factor in his case, since he considered he could detect the change in atmospheric pressure caused by rates of climb over 50 ft/min.

7.4.4 Subjective Evaluations of the Workload

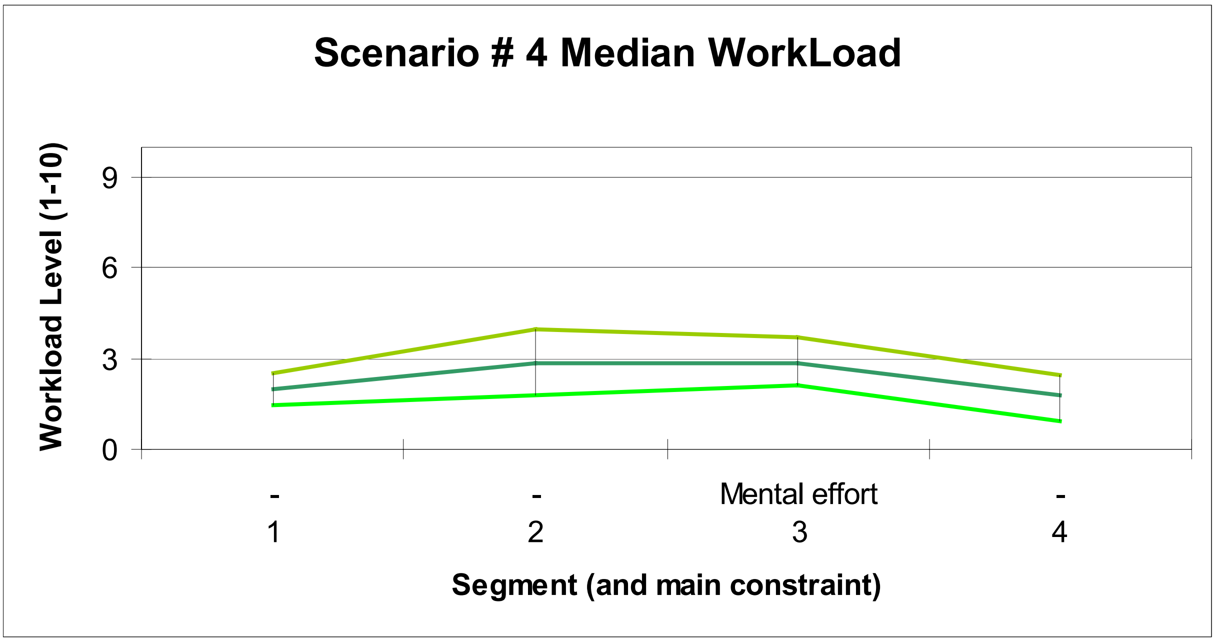


Figure 21 : Subjective Median Evaluation of the Workload for Scenario 4

In this case, the workload is chiefly the mental effort required to understand what is happening and why the descent is not occurring as planned (the ceiling seems lower than indicated in the weather forecast, discrepancy with the radio-altimeter reading). The uncertainty on altitude placing the aircraft higher above terrain than expected, the sense of urgency stayed very limited.

It was not possible to assess during the debriefing, if this limited danger feeling came from the controlled fly inside a TMA (altitude sent to ATC via transponder) or from a lack of realism of the radio loop (no party line could lead to the feeling of being the only aircraft flying in this area).

7.4.5 Discussion

In this scenario, it is difficult to draw any conclusions concerning the correction times for a slow undetected failure. As the pilots took a long time to detect the failure, most of them had already disconnected the AFCS altitude hold mode at the time of detection. Since the pilot who detected the failure in time was climbing and was not in a rush, he chose to notify the air traffic control and unhurriedly examine his systems before deciding on corrective action.

This failure highlights the risks of an incorrect signal that is not detected. This conclusion can nevertheless be attenuated because the standby instruments are usually within the pilot's field of view. In the debriefing sessions, several pilots declared they would have surely checked an instrument located in its usual place in front of them, and which they would therefore see instinctively. Moreover, the pilots seemed to feel being higher than expected was not so dangerous, their main concern being a terrain collision, which rise they would have been able to see through the radio-altimeter.

On new systems used in Eurocopter, the various sources are automatically cross-checked. Such a scenario could therefore only occur in the case of a dual failure, or a departure with a failed altimeter or a failed monitoring system[2]. One can assume that the persistence of the failure message would then entail a better pilot attention towards the stand-by altimeter[3]. Lastly, thanks to the encoding altimeter mounted on the transponder, the air traffic control – or even the TCAS of other traffic - can detect when the helicopter is not where it should be.

7.5 Failure 5: Hardover of Roll Trim Actuator

7.5.1 Scenario Sequence

The failure is triggered in VMC cruise flight at the ¾ point of a leg without any significant events. The AFCS upper modes are engaged, but the approach to Les Alpilles reduces the safe altitude margin.

When the failure is triggered, the following events occur immediately:

- the roll trim actuator goes hardover, causing roll to the right:
  - ➢ movement of the external environment;
  - ➢ the attitude indicators indicate rolling to the right;
- hands-on warning including:

[2] On future medium-heavy helicopters, like the NH 90, a failure of the monitoring system has a very low probability itself, due to several redundancies, and the auto-pilot itself checks the consistency of its different sources.

[3] Anyway, this pilot's monitoring is required by the degraded mode departure procedure. But, given the fact that the pilots were taught about the absence of pitot-static sources cross-checks during the training, then reminded during the familiarisation run on the morning of the evaluations when the training was old, it seems better that a failure reminder is kept.

  - disconnection of the AFCS upper modes;
  - the AFCS zone indicators on the MFD flash red;
  - temporary red FCS on the CWP;
  - hands-on audio warning;
- warning indicating the AFCS problem
  - amber FCS on the CWP.

By checking the FCS pages on the VMD, the pilot observes the failure declaration for the roll trim actuator (amber). However, this check can only be made subsequently as the recovery action must be fast.

All the pilots reacted by immediately implementing manual recovery and stabilising the helicopter. They then used the VMD to analyse the failure.

It is pointed out that pilot 6, who had maintained a cruise altitude of 1,200 ft, was in the process of switching to manual mode for climbing over Les Alpilles when the failure occurred

7.5.2 Reaction Time

HELICOPTER FAILURE CORRECTION TIMES – SCENARIO 5										
	No.	FAILURE RESOLUTION TASKS HARDOVER FAILURE ON AFCS ROLL AXIS	TIME (seconds)							
			Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot 7	Theory
SWITCH 5	**1**	Occurrence of failure	T0	T0	T0	T0	T0	T0	T0	T0
-	**2**	Hands-on audio warning + FND or external display + Master display	-	-	-	-	-	-	-	T0 + 0.5
POSABSROU	**3**	Switching to hands-on	**T0 + 0.72**	**T0 + 0.72**	**T0 + 0.88**	**T0 + 0.88**	**T0 + 0.72**	**T0 + 0.64**	**T0 + 0.8**	T0 + 3.5 (T2 + 3)
RP, PHI	**4**	Recovering the cyclic and collective controls and regulating the cyclic	T0 + 1.24	T0 + 1.24	T0 + 1.20	T0 + 1.04	T0 + 1.16	T0 + 1.20	T0 + 1.24	-
-	**5**	Acknowledging the master	-	-	-	-	-	-	-	-

The "thermometer" defined in phase 1 corresponds to task 3

The times recorded here yield a median reaction at **T0 +0.72 s**, compared to a theoretical forecast at T0 +3.5 s.

7.5.3 Informal Debriefings

As this failure was very obvious, the informal debriefing generated few comments.

Pilot 1 said the physiological constraint he reported in the subjective workload evaluation was compounded by the fatigue accumulated in the simulation sessions. Nevertheless in his opinion, this was realistic in terms of a pilot's working day.

Pilot 6 criticised the time that the event-free flight had lasted and said he would have preferred a more "active" scenario.

7.5.4 Subjective Evaluations of the Work Load

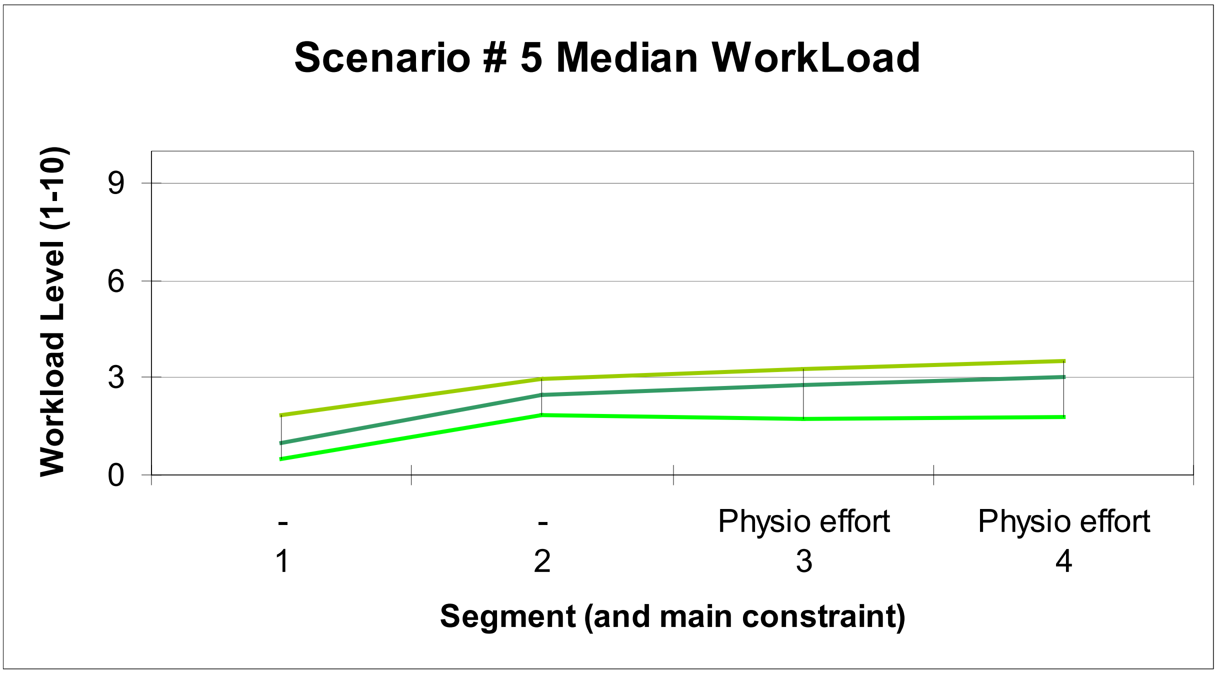


Figure 22 : Subjective Median Evaluation of the Work Load for Scenario 5

The workload increases after the occurrence of the failure, mainly because of the physiological effort involved in manually flying a helicopter that has lost its roll stability augmentation, and because of the additional difficulty of landing once the destination has been reached.

7.5.5 Discussion

This failure illustrates the instinctive reflex of the pilots when faced with an obvious failure impairing the helicopter stability in VMC flight. Although the simulator does not stimulate the proprioceptors, the sight of the moving external environment was enough to trigger a reflex of immediate manual recovery with all the pilots.

The time difference between pilot 6, who already had his hands on the controls, and the other pilots is very small. It can therefore be assumed that the correction time for this failure mainly consists of the failure recognition time, i.e. the time the pilot needs to register the appearance of the warnings, and the movement of the outside environment. It can also be inferred that the manual roll recovery is mainly based on reflex action.

The effect of being in cruise flight with the AFCS upper modes engaged does not seem to have increased the correction times as much as predicted by regulations.

8 Regulation Evolution Trends

8.1 Reported Failures

Given the results of this study, it seems that the reported failure correction time depends more on the difficulties in analysing the failure, on the failure display means available to the pilot, and on the resulting sense of urgency than on the flight phase itself.

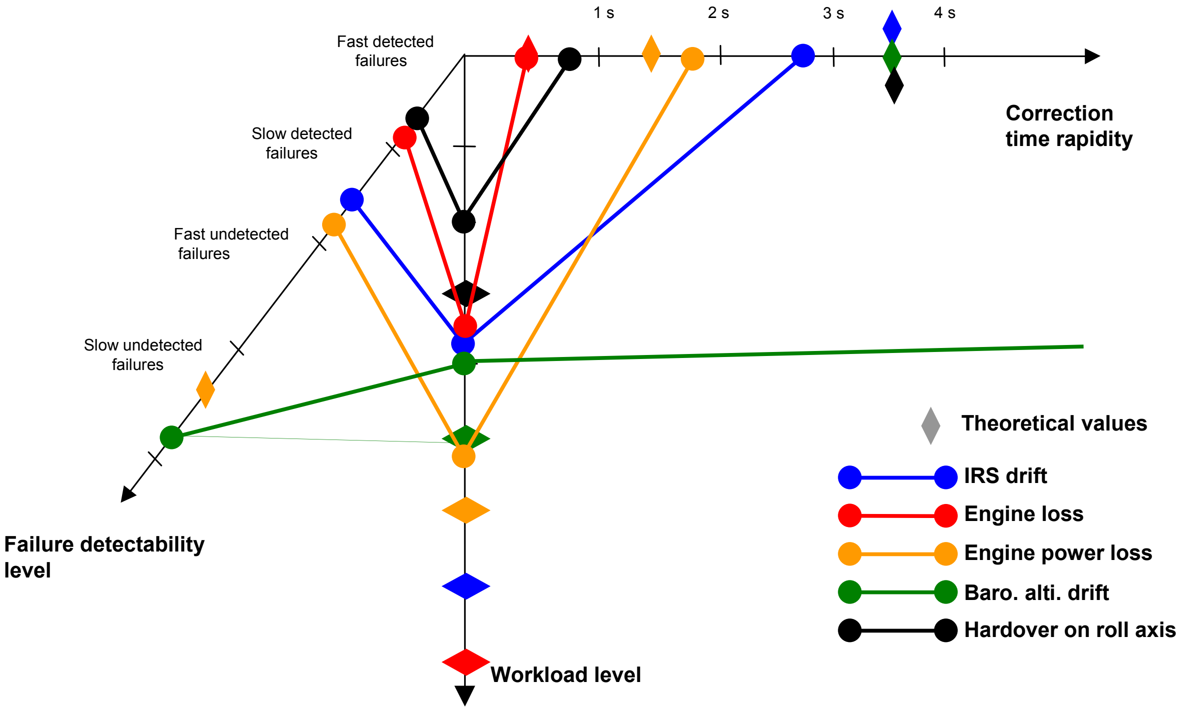


Figure 23 : 3-D median characteristics of failures – Measured correction time rapidity

Scenario	1 IRS Drift	2 Engine Loss	5 Roll Hardover
Weather conditions	IMC	VMC	VMC
Current Piloting Mode	AFCS, upper modes engaged	Manual piloting	AFCS, upper modes engaged
Main Failure detecting Means	Warnings + "hands-on" + deflection of ADI command bars	Warnings	Warnings + "hands-on" + moving external environment
Mean Reaction Time after Failure occurrence	2.75 sec	0.46 sec	0.72 sec

The above table shows that the reaction time for Failure No. 5 (roll hardover), which occurs in a flight phase where the pilot's degree of attention is expected to be minimum (stabilised cruise, upper modes engaged), is less than one second and mainly interpreted as recognition time. This failure causes the external environment to move, which is perceived by the pilot as an alert.

Only the scenario 2 (loss of one engine during landing), where the failure occurs in a manual piloting phase, induces faster reaction times.

However, as Failure No. 1 (IRS drift) occurred in IMC, even the pilots who relied on the failed IRS and therefore should have reacted as for Failure No. 5, had much slower reactions – as forecast by theory. These differences could be explained by the fact that the perception of an attitude indicator deflection is less intuitive, even for a trained pilot, than a movement of the external environment, which could even induce a reflex reaction.

In a future version of the regulations, the failure detecting means could therefore be used to help determine the reaction times expected from the pilot according to the type of failure and the conditions of its occurrence. In particular, it seems possible to relax the requirements concerning the obvious failures (red warnings or moving external environment) that occur in VMC.

As this study had a much wider scope, no final conclusions can be made about this matter. If this evolution trend is chosen, a more precise characterisation of the different failure detecting means and their effects on the pilot's reaction times under different workload levels will be required.

8.2 Non-Detected Drifts

As the regulations specify reaction times after failure recognition, the theoretical correction time for non-detected failures varies with the time taken by the pilot to detect the failure, and cannot therefore be specified.

As regards Failure No. 3 (degraded engine performance), the activation of warnings above a certain threshold enabled a time value to be determined but, under this condition, Failure No. 3 is to be considered as a reported failure. However, as regards Failure No. 4 (altitude drift not detected by the system), no theoretical time is available for comparison with the simulation results.

Above all, the simulations showed that, if no appropriate analysis means are available, the probability for the pilot to detect a simple drift is very low – but this matter falls outside the scope of the TRPH program. This is the reason why the systems on Eurocopter helicopters are now designed to detect and indicate any inconsistent parameter values to the pilots. This kind of drift then needs a dual failure or departure with a failed equipment. In the second possibility, the departure decision is taken by the pilot, who then has to abide by strict cross-check procedures on the failed parameter.

In this respect, the simulations therefore showed that modern cockpits, which assist the pilot in identifying failures, significantly enhance safety. Scenario No. 3 (degraded engine performance) provides a good example of a failure with hazardous consequences in its conditions of occurrence. This failure caused no harm to the pilots thanks to system warning and automatic activation of the OEI mode.

8.3 Assistance in Ambiguous Failure Analysis

In addition to the results on correction times, this study highlighted certain trends in pilot reaction to the simulated failures.

Most pilots tended to react improperly to Failure No. 1. Due to the simultaneous occurrence of the "hands-on" warning and an amber avionics warning, some pilots attempted to stabilise the aircraft in response to the indications displayed in front of them, hence the failed IRS, before analysing the failure.

This trend cannot be prevented by cancelling or changing the false indication since this is an ambiguous failure that the system is unable to identify. However, this confirms the need to warn the pilot of the poor reliability of the displayed indication in a direct and obvious manner. For this purpose, modern systems give unreliable values with an inconsistency marker directly superimposed on the unreliable information. Eurocopter is proposing to introduce more intuitiveness by replacing the inconsistency marker with an amber frame around the unreliable information on its new range of helicopters.

This study shows that advanced avionics systems must assist the pilot in analysing ambiguous failures. Due to system complexity, any "avionics" warning is no longer immediately meaningful to the pilot. However, the high level of integration that makes avionics systems complex also enables them to both indicate a failure and provide assistance to the pilot in resolving it.

9 Conclusions

This study showed that, overall, the measured reaction times are consistent with regulations except in two situations:

- An obvious failure inducing a sense of urgency or a reflex reaction, where the pilot react in less than one second even in stabilised cruise flight with the AFCS engaged.
- A non-reported drift, where conclusions can hardly be drawn in the absence of recognition time values.

As the scope of this study was wider, the factors giving rise to a sense of urgency or a reflex reaction could not be characterised with precision, except for the positive effect in scenario 5 in which the helicopter begins rolling in VMC conditions, and the non-conclusive effect in scenario 1, where the IRS drift could lead to a roll feeling but in IMC. It would also be necessary to test the permanence of these factors under different workload levels.

The study was conducted on a generic helicopter with simplified systems so that its conclusions can be easily generalised to all helicopters. Moreover, it showed the advantage of using cross-checks and failure indications integrated in the data display system of most modern avionics systems to prevent failure non-detection or misinterpretation.

APPENDIX 1 : SPHERE SIMULATOR

ROTORCRAFT SIMULATION: EUROCOPTER ENGINEERING SIMULATION CENTRE (SPHERE)

1 ROLE OF ENGINEERING SIMULATION

Initiated a decade ago for handling qualities and flight control laws research, and increasingly based on modern high level specification & software workshops, with extensive use of automated code generation, the real time piloted engineering simulation is playing a major role in Eurocopter new rotorcraft's development process. Its implication in the design and validation by flight test pilots starts upstream from early research and prototyping phases and continues downstream to full representation of a matured design for crew workload assessment.

Thanks to the progressive availability of generic and powerful computing resources, the real time piloted simulation has become the most appropriate answer to the need for a design evaluation tool assessing both flight controls & avionics systems and Human Machine Interface (HMI) aspects. The development of modern autopilots and Fly-By-Wire systems has imposed a very representative modelling of the helicopter flight mechanics, under the control of the design engineers who have the best knowledge of and direct access to the helicopter actual behaviour and data. In parallel, the use of computer aided workshops have contributed to the constitution and reuse of functions databases (HMI, FCS, architectures…) directly available for simulation with greater reactivity for minor/major evolutions or new programs. Common tools and procedures are thus used by the different engineering departments in the various engineering phases in order to ensure coherence of the whole development process. As a consequence, and as opposed to former development schemes, the use of the simulator for engineering purpose is no longer limited to major programs. It is now a standard approach for early research phases as well as new H/C functions developments.

The main topics currently covered in simulation are :

- Flight Loop and Handling Qualities,
- Human Machine Interface,
- Mission aids.

1.1 Flight Loop/Handling Qualities

The flight loop modelling is the basis of Handling Qualities oriented simulations. It covers the modelling of flight mechanics, control laws and engines. It was the initial motivation for implementing the engineering simulation centre, and a significant experience of these models has thus been acquired, from off-line isolated software development to real time implementation for pilot-in-the-loop assessments.

This flight loop modelling is based on a generic rotorcraft simulation model, the Helicopter Overall Simulation Tool (HOST), initiated by Eurocopter in the beginning of the nineties. German DLR and French ONERA were also invited to join the group of users and developers, and HOST is thus gathering the know-how of the industry and research centres Flight Mechanics Departments. The development specifications were carefully established to take into account the needs of the different users in the fields of research, rotorcraft design, real time simulation, and to guarantee strong capabilities of evolution.

The use of a single tool through all engineering steps of the helicopter development phase is an essential aspect ensuring the consistency of the handling qualities studies. The co-operation of industry and research centres to the HOST group is also a key point, as this approach leads to a modular and evolutionary software which benefits simultaneously from the last evolutions of flight mechanics modelling research and from immediate flight test validation under optimal conditions.

A specific real time application of the HOST model has been implemented by Eurocopter for the Sphere Pilot-in-the-loop simulations. This modelling is the basis of all research and development programs, which are now making intensive use of all the capabilities resulting from the coupling of these flight loop simulation with the environment simulation (evolutions of visual and meteorological conditions, degrades modes and failures, use of armaments…) and the analysis of corresponding consequences on flight mechanics. Thanks to its quality, this modelling is also currently extended to the training simulation framework : "level-D" pre-qualified complete flight loops software and their associated "proof of match" are to be delivered by Eurocopter for HELISIM® simulation centre and Franco-German TIGER training simulators

1.2 Human Machine Interface

This simulation activity covers the ergonomic aspects of the cockpit (general ergonomics & control panels definition), as well as the individual displays symbologies definition/specification and the overall consistency of the cockpit controls and modings. The simulation is used for dynamic pilot-in-the-loop testing and validation of the corresponding design as well as for early Customer evaluation.

1.3 Mission Aids

This simulation activity, principally involved in early phases, is mainly aimed at the identification of the mandatory characteristics and features of new generations of mission aids, from an H/C point of view (e.g. prospective simulations dealing with new or future sensors like Obstacle Warning Sensors or augmented vision generated from sensors fusion)

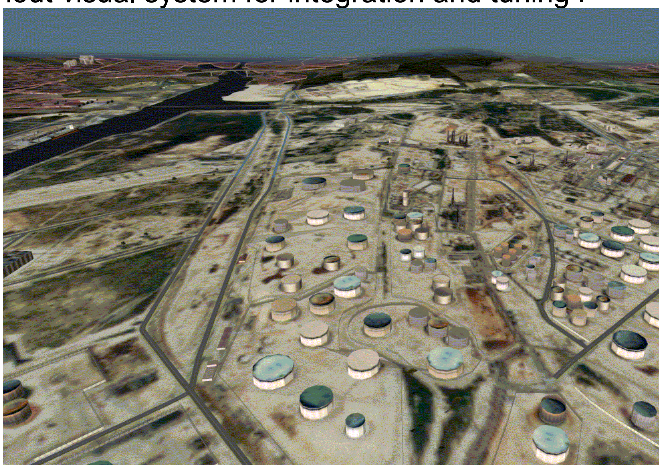
1.4 Global evaluations

Due to the high level of interactions between these different areas, the need for transversal validation taking into account the H/C and its mission as a whole appears rapidly. This is particularly true for new H/C under development. Full evaluation of the H/C is therefore performed, including systems failures and degraded modes simulations, under realistic mission conditions with representation of tactical situations and external threats. These evaluations can go up to Crew Workload Assessment through complete tactical missions.

2 MAIN CHARACTERISTICS OF THE SPHERE SIMULATION CENTER

The SPHERE simulation centre is primarily research & development oriented. As such, it provides a maximum hardware and software flexibility, and currently features the following capabilities :

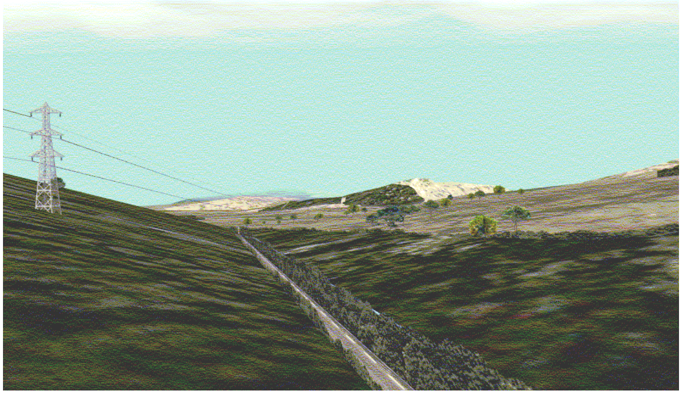
- Up to three different simulations sites, which can currently be run in parallel :
    a) A 8 meters diameter dome site with full cockpit immersion, fitted with a 6 channels projection system providing a 180° (horizontal) x 80° (vertical) field of view specifically adapted to the helicopter simulation needs (50° vertical downward visibility to take into account hovering, low speed flight close to obstacles and high slopes descents) for handling qualities ad HMI evaluations,
    b) A site with flat screen projection for integration and tuning, IFR and HMI evaluations,
    c) A site without visual system for integration and tuning .



- A state of the art image generation system :
    - Local terrain data base (60km x 80 km) developed for helicopter simulations (specific detailed zones),
    - Open software architecture (easy evolutions and adaptations of complements),

- Meteorological effects (day, night, NVG, FLIR, wind, rain, fog, adjustable light and distance of visibility,…) allowing simulation of the different types of degraded visual environment and their associated possible avionics aids.,
- Special effects (fires, smoke, armaments, …).

- Flexible real time digital computing architecture :
  - time delay <100ms,
  - use of high level formal specification languages,
  - possible import of different codes (FORTRAN, C, C++, ADA, …),
  - simulation of different I/O (ARINC 429, 1553 MIL BUS, …),
  - integration of real equipment (e.g. via CAN BUS connections),



- Flexible video architecture,
- NH90 fully representative (real equipment and panels) cockpit,

- Versatile and re-configurable research simulation cockpit,
  - New electric digital control loading system with adjustable stick efforts laws allowing to test new configurations or to simulate actual efforts laws of rotorcrafts. Control laws parameters and stick efforts can be modified in real time during pilot-in-the-loop simulations to support handling qualities research.
  - Conventional or mini sticks,
  - Virtual front panel allowing simulation of different HMI and symbologies,
  - Available simulation of different H/C behaviours (existing Eurocopter fleet, new fly-by-wire or modern autopilot research programs, tilt rotor, …).

APPENDIX 2 : SIMULATION PARAMETERS RECORDINGS

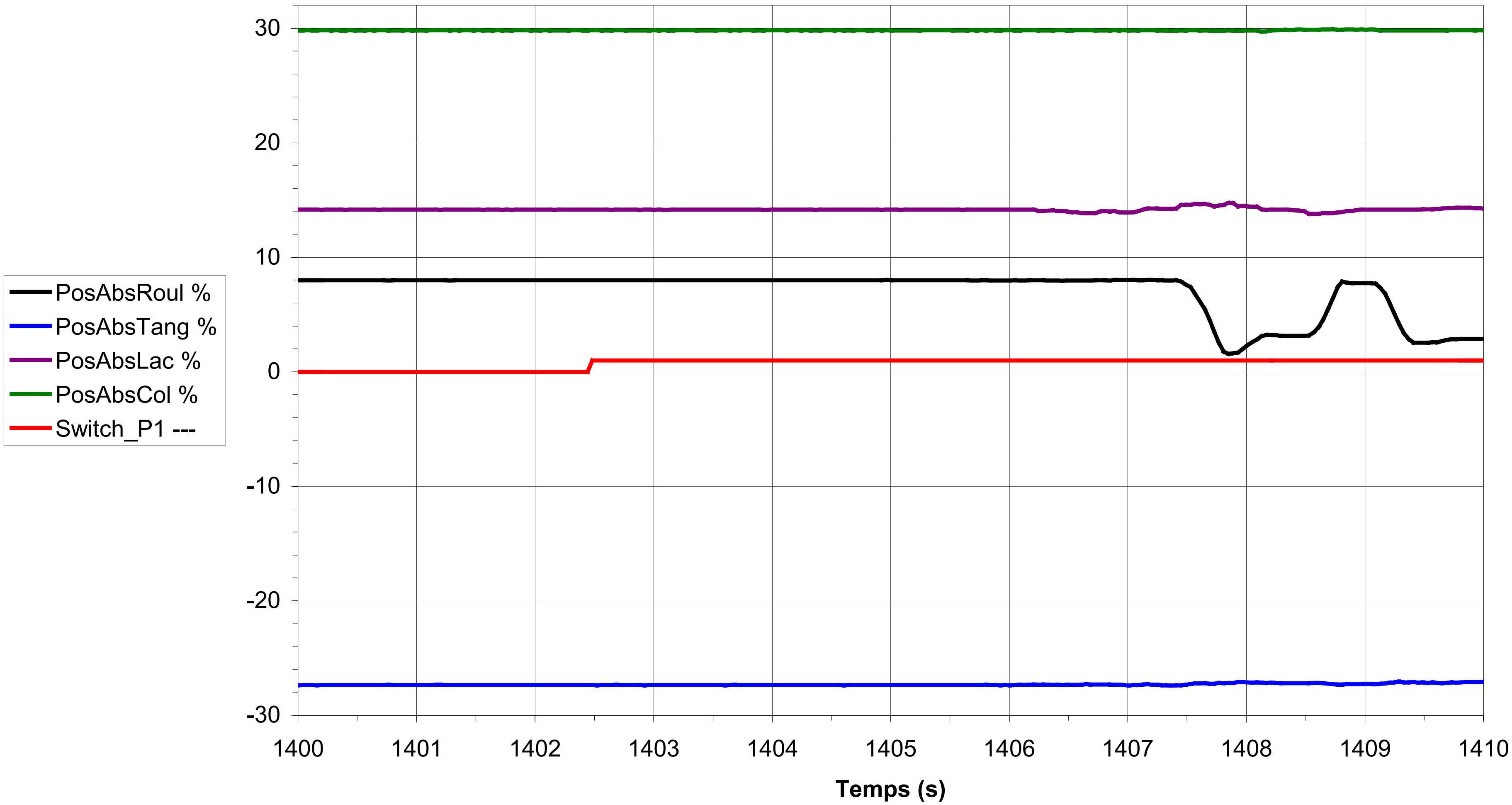
1 DISPLAYED PARAMETERS DEFINITION

Parameter name	Definition *(French language)*	Definition *(English language)*
Delta_TRQ %	Ecart de couple entre les moteurs en % du couple maximum continu	Difference between engines torque (% of maximum continuous torque)
hauteur dam	Hauteur au dessus du sol en décamètres	Height above ground (decametres)
hauteur m	Hauteur au dessus du sol en mètres	Height above ground (metres)
IAS m/s	Vitesse anémométrique en m/s	Indicated airspeed (m/s)
masse t	Masse totale hélicoptère en tonnes, charge à l'élingue incluse	Helicopter gross weight (metric tons), including sling load
NR %	Vitesse de rotation du rotor principal en % de la vitesse nominale	Main rotor speed (% of nominal speed)
OEI ---	Passage du FADEC en mode monomoteur (0 = non, 100 = oui)	FADEC on One Engine Inoperative mode (0 = no, 100 = triggered)
OEI_STATUS SU	Passage du FADEC en mode monomoteur (0 = non, 1 = oui)	FADEC on One Engine Inoperative mode (0 = no, 1 = triggered)
panne 1	Déclenchement panne 1 (0 = non, 100 = oui)	Failure 1 trigger (0 = no, 100 = triggered)
panne 2	Déclenchement panne 2 (0 = non, 100 = oui)	Failure 2 trigger (0 = no, 100 = triggered)
panne 3	Déclenchement panne 3 (0 = non, 100 = oui)	Failure 3 trigger (0 = no, 100 = triggered)
panne 4	Déclenchement panne 4 (0 = non, 100 = oui)	Failure 4 trigger (0 = no, 100 = triggered)
panne 5	Déclenchement panne 5 (0 = non, 100 = oui)	Failure 5 trigger (0 = no, 100 = triggered)
PHI deg	Inclinaison en degrés (+ = roulis à droite)	Roll angle (degrees) (+ = right roll)
PosAbsCol %	Position du manche collectif en % de course (100 % = tiré)	Collective stick position (100 % = max pull)
PosAbsLac %	Position du palonnier en % de course (+ = lacet à droite)	Rudder pedal position (+ = right yaw command)
PosAbsRoul %	Position latérale du manche cyclique en % de course (+ = à droite)	Lateral cyclic stick position (+ = right roll command)
PosAbsRang %	Position longitudinale du manche cyclique en % de course (+ = à cabrer)	Longitudinal cyclic stick position (+ = nose up command)
Switch_P1 ---	Déclenchement panne 1 (0 = non, 1 = oui)	Failure 1 trigger (0 = no, 1 = triggered)
Switch_P2 ---	Déclenchement panne 2 (0 = non, 1 = oui)	Failure 2 trigger (0 = no, 1 = triggered)

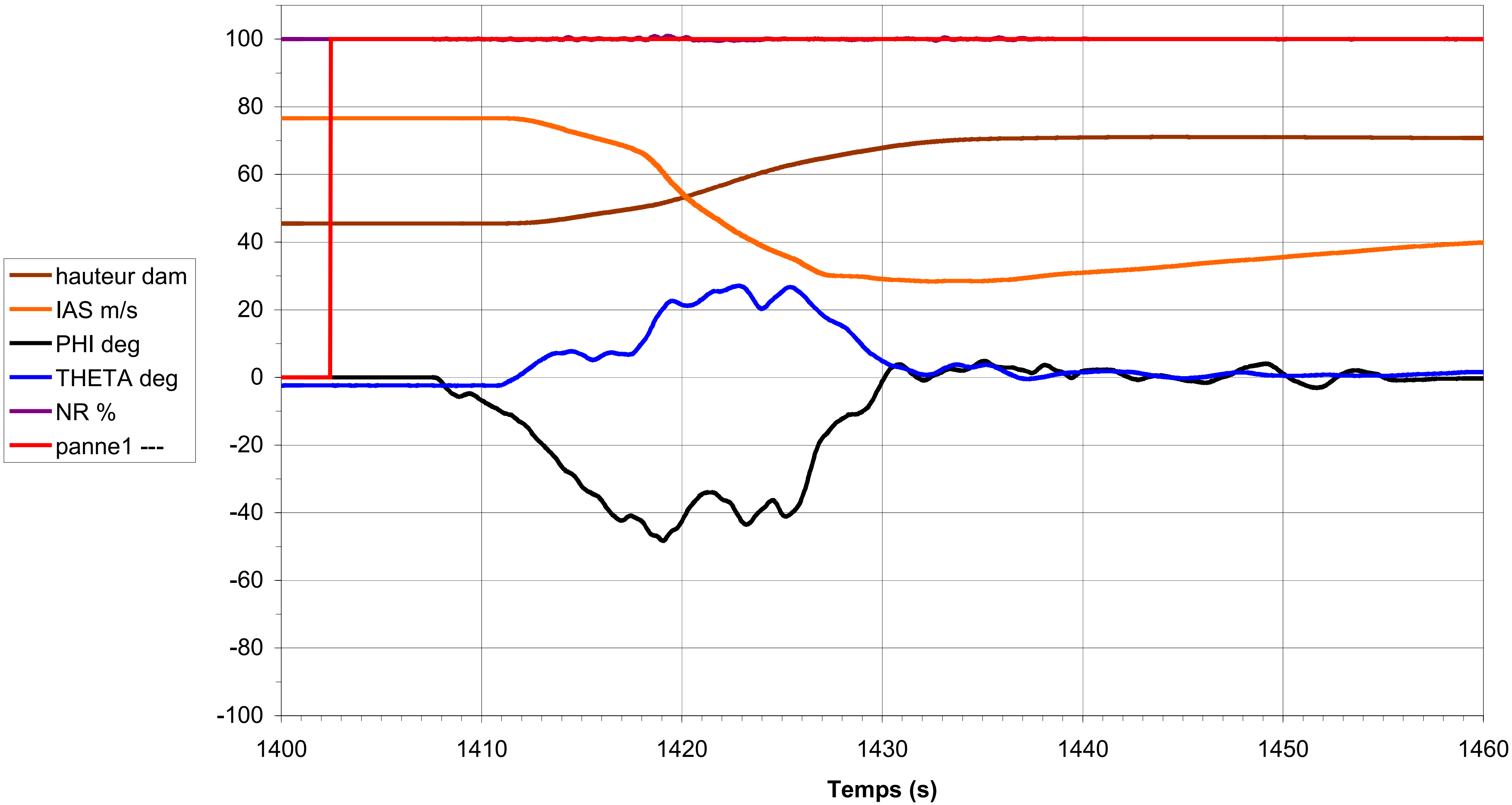
Parameter name	**Definition** *(French language)*	**Definition** *(English language)*
Switch_P3 ---	Déclenchement panne 3 (0 = non, 1 = oui)	Failure 3 trigger (0 = no, 1 = triggered)
Switch_P4 ---	Déclenchement panne 4 (0 = non, 1 = oui)	Failure 4 trigger (0 = no, 1 = triggered)
Switch_P5 ---	Déclenchement panne 5 (0 = non, 1 = oui)	Failure 5 trigger (0 = no, 1 = triggered)
Temps (s)	Date interne simulateur (en secondes)	Internal simulation date (seconds)
THETA deg	Tangage en degrés (+ = cabré)	Pitch angle (degrees) (+ = nose up)
Tq 1 %	Couple fourni par le moteur 1 en % du couple maximum continu	Engine 1 torque (% of maximum continuous torque)
Tq 2 %	Couple fourni par le moteur 2 en % du couple maximum continu	Engine 2 torque (% of maximum continuous torque)

2 RECORDINGS GRAPHS

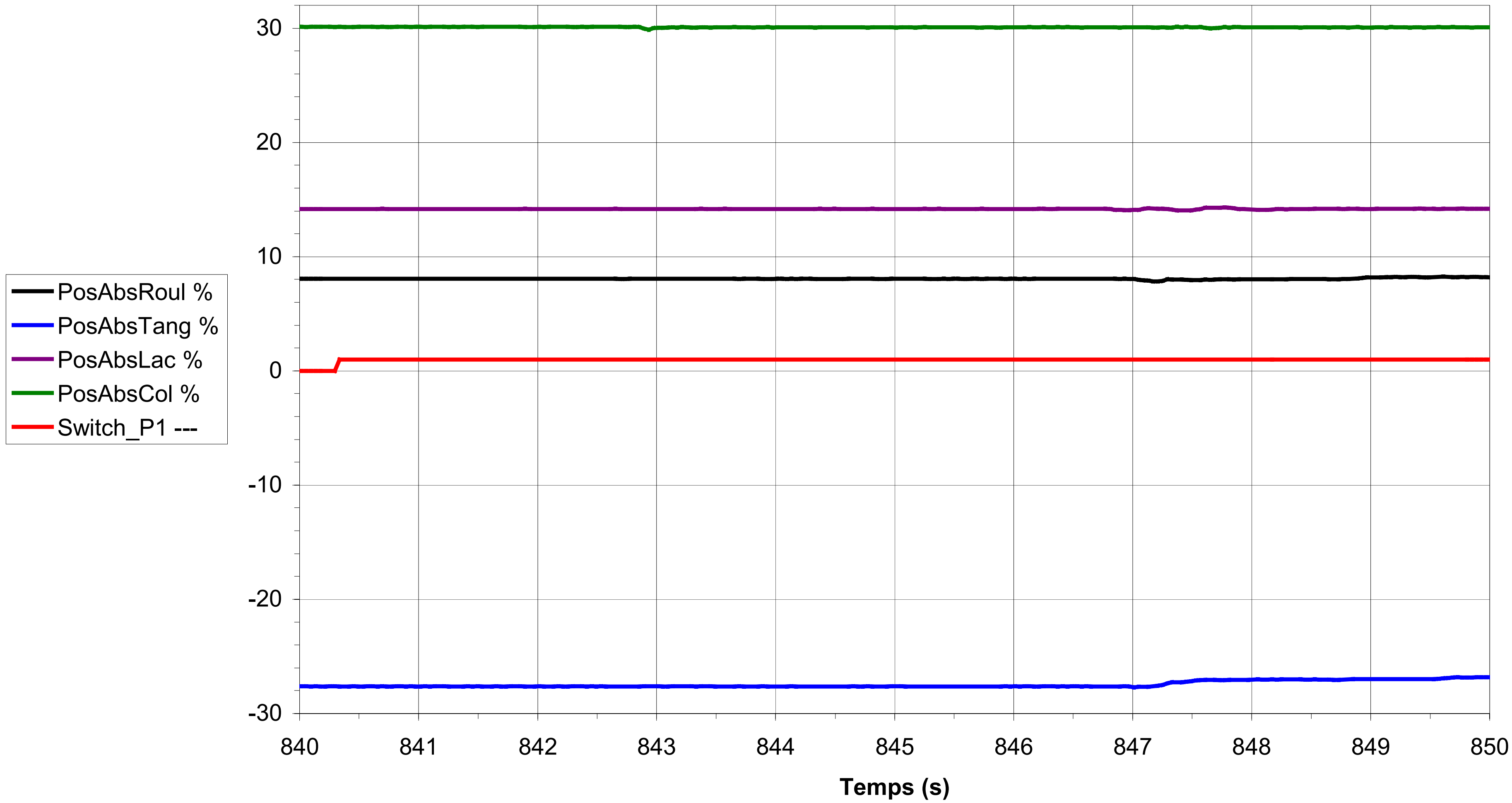
TRPH Pilote 1 Panne 1 - Positions Commandes



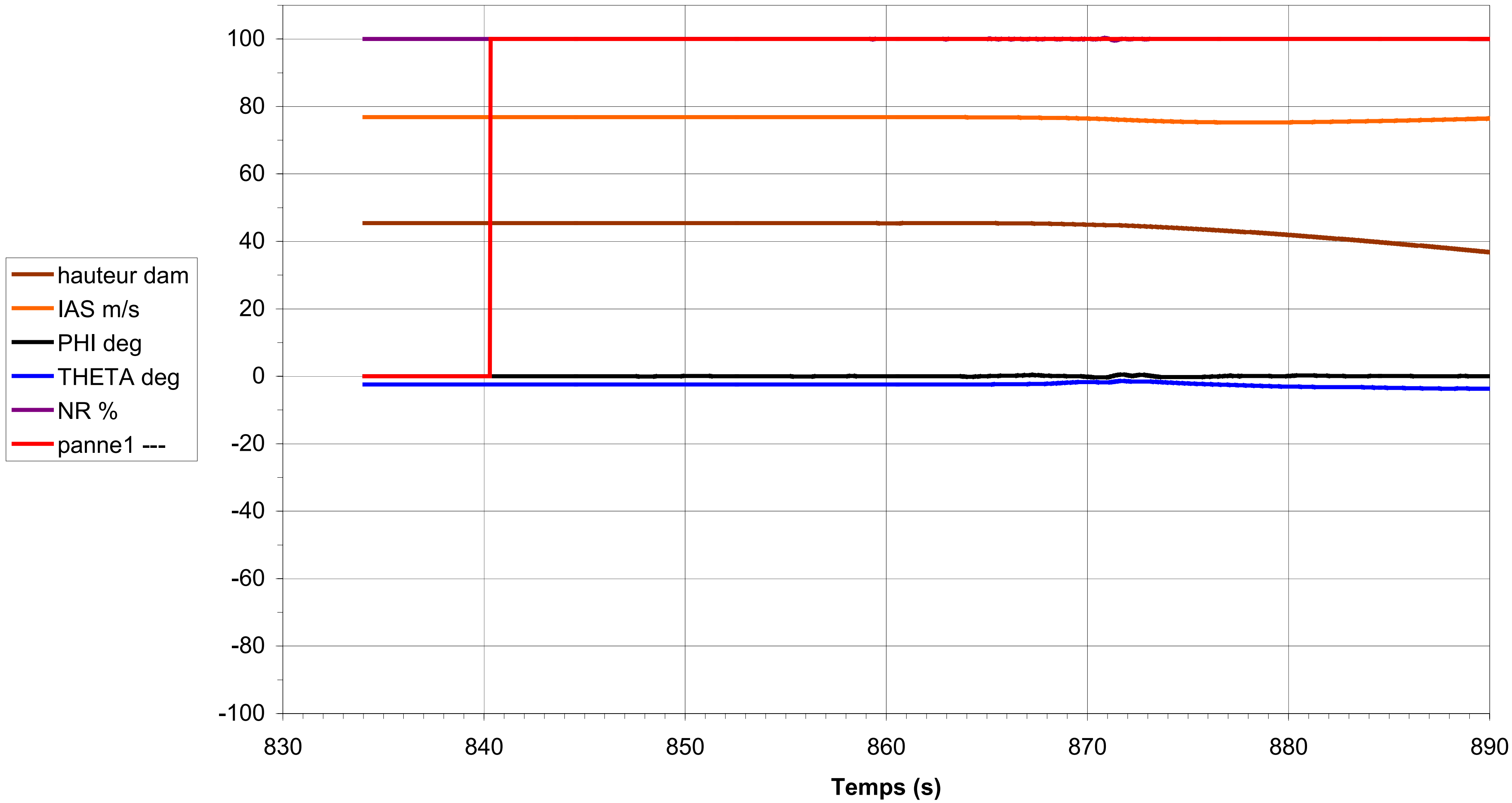
TRPH Pilote 1 Panne 1 - Paramètres de vol



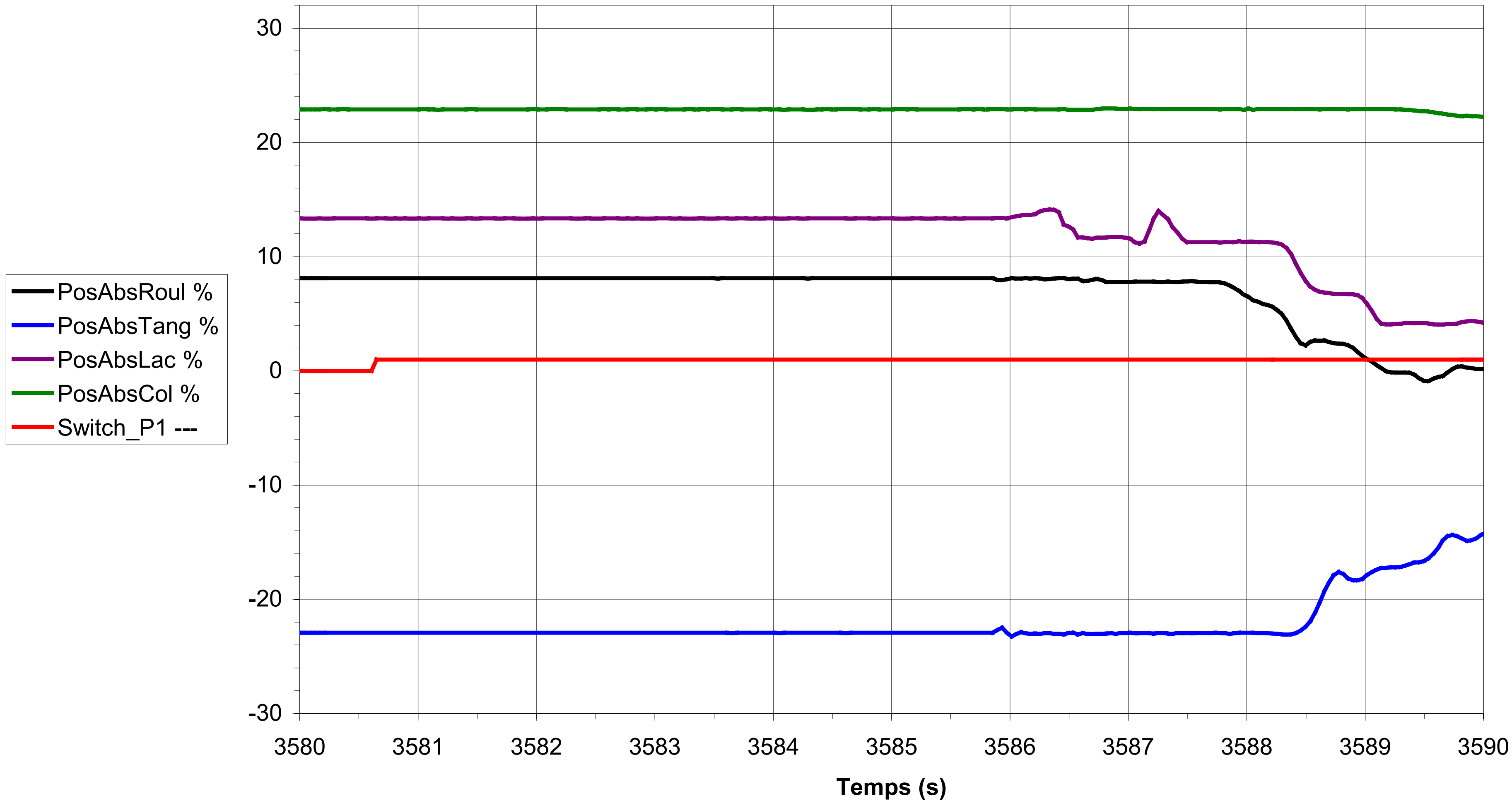
TRPH Pilote 2 Panne 1 - Positions Commandes



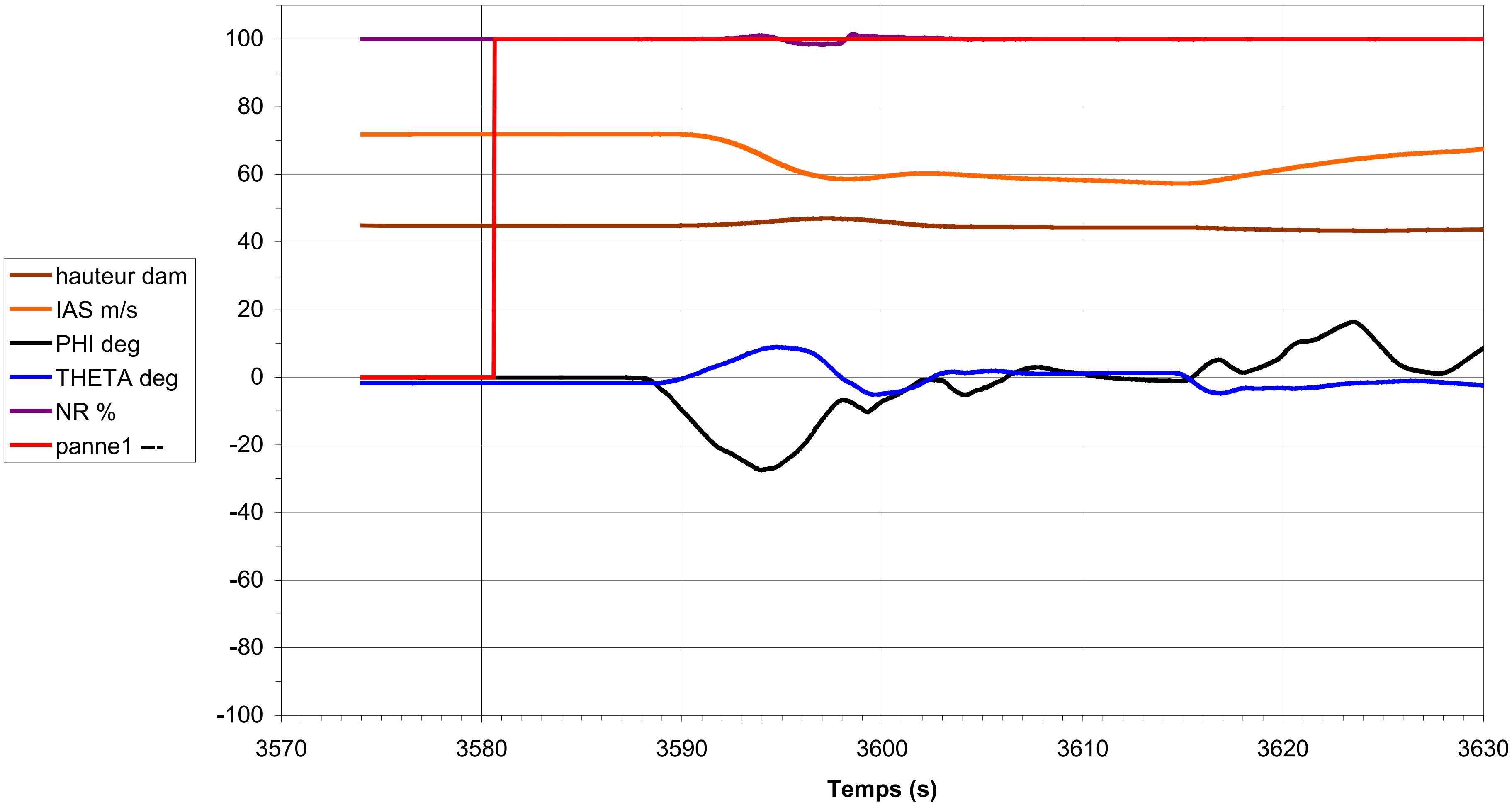
TRPH Pilote 2 Panne 1 - Paramètres de vol



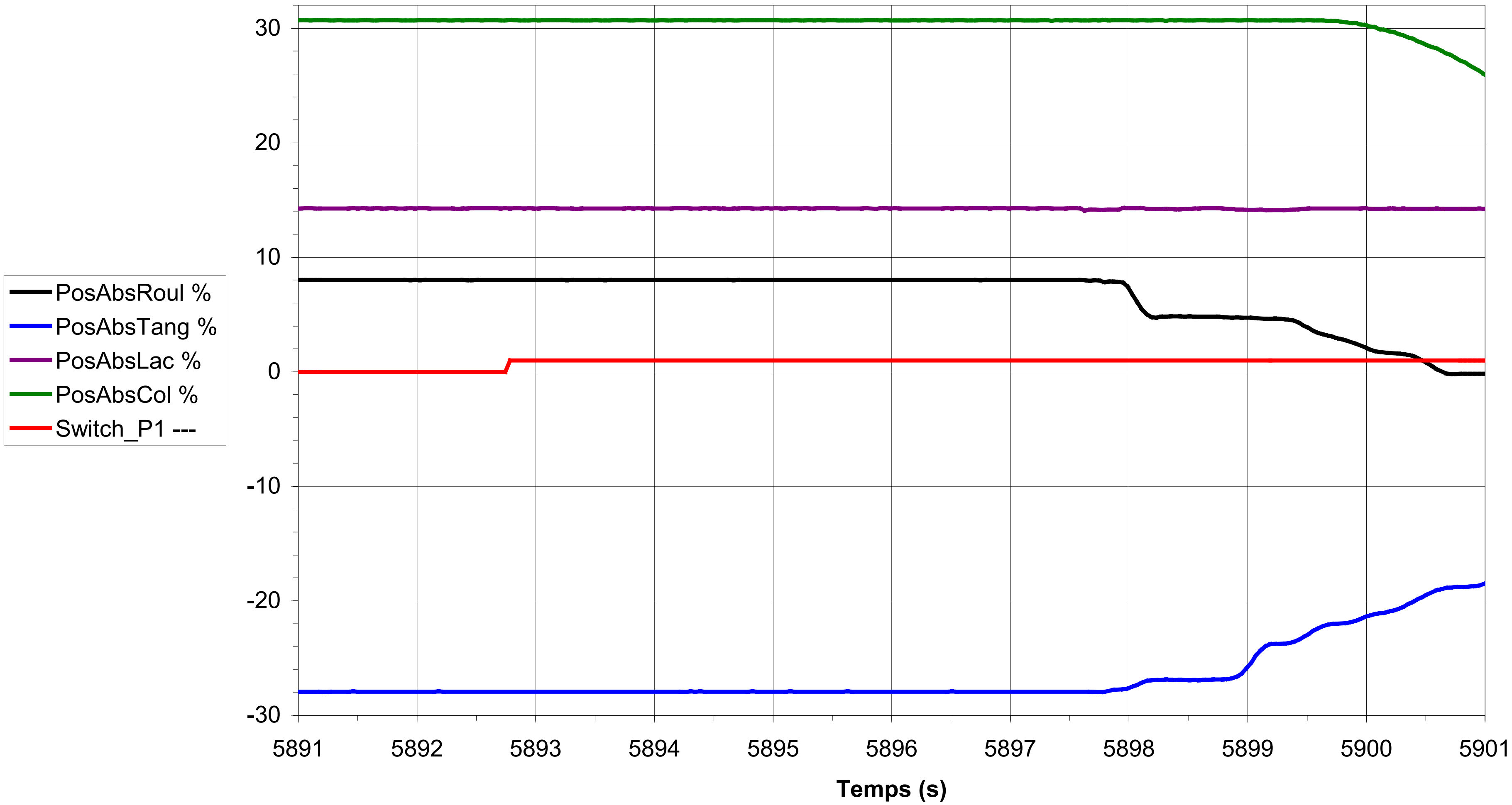
TRPH Pilote 3 Panne 1 - Positions Commandes

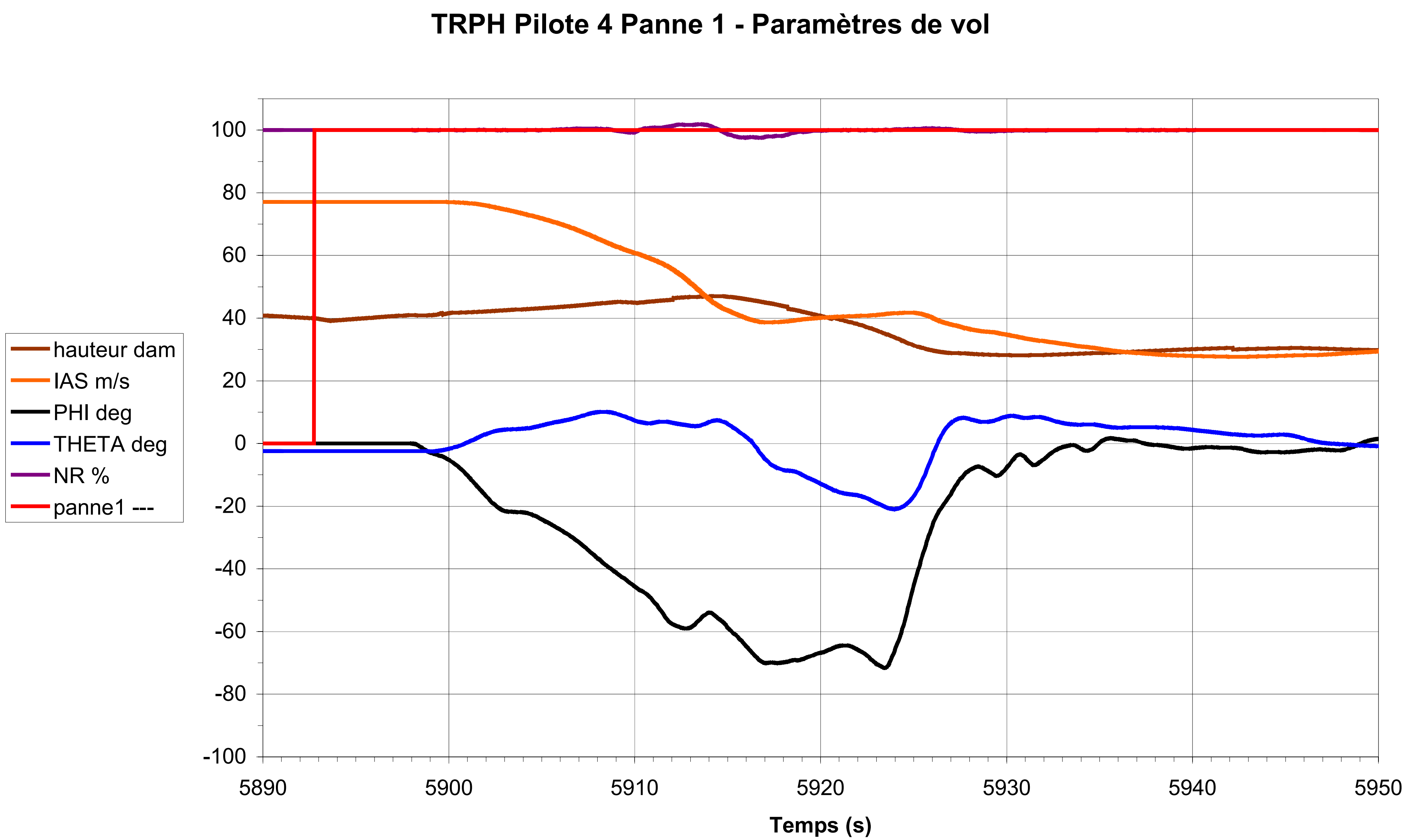


TRPH Pilote 3 Panne 1 - Paramètres de vol

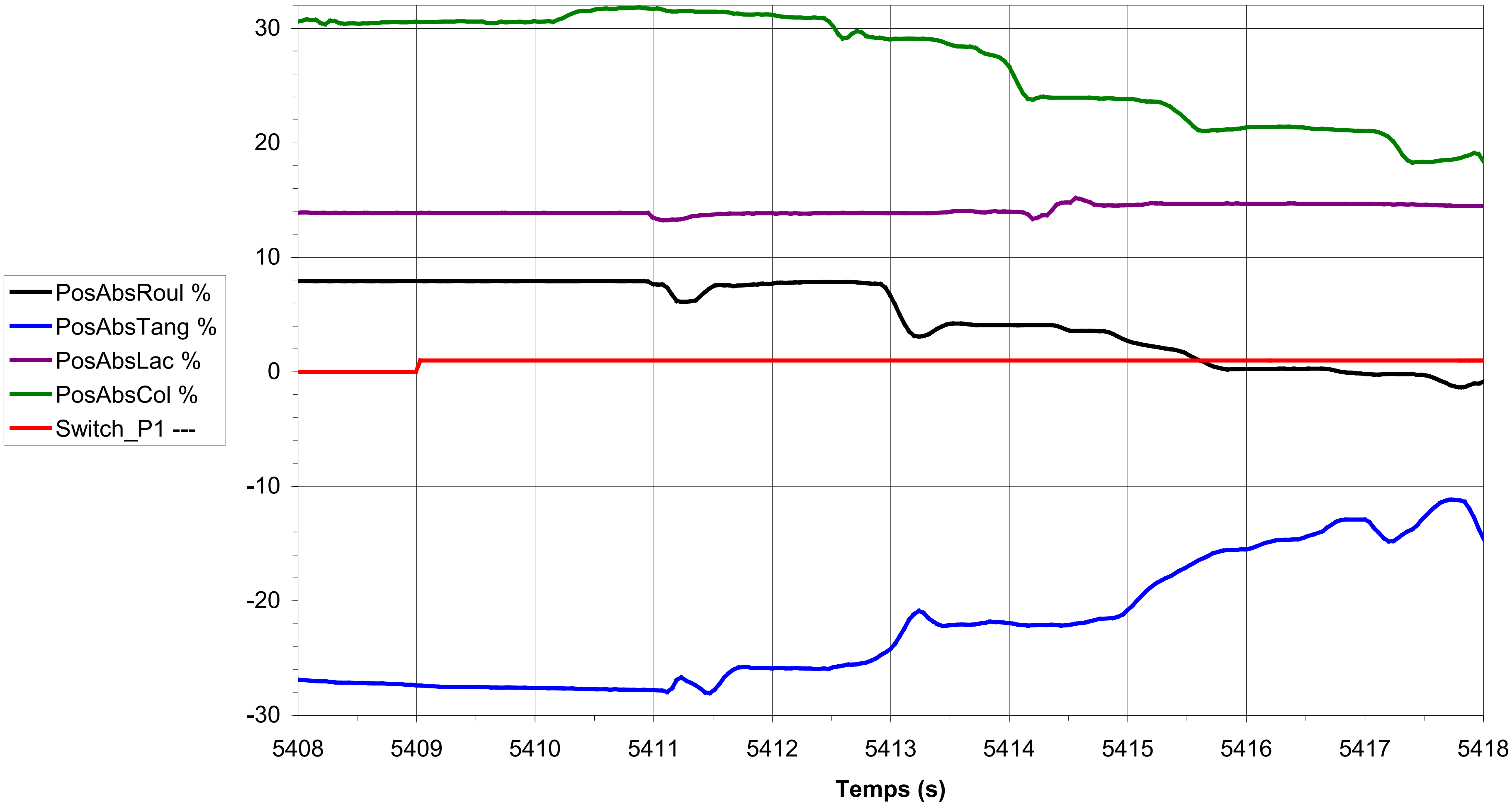


TRPH Pilote 4 Panne 1 - Positions Commandes

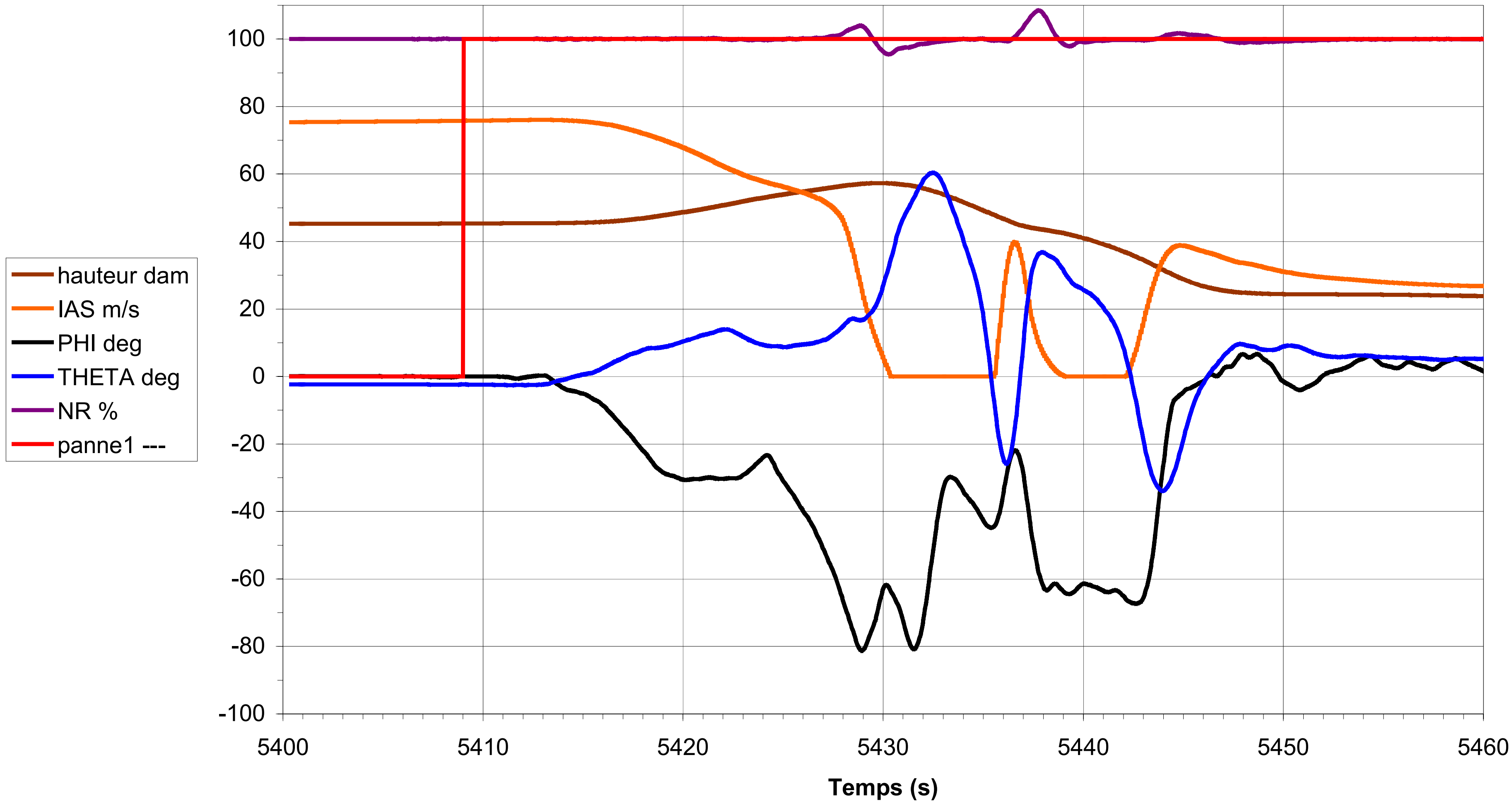



TRPH Pilote 4 Panne 1 - Paramètres de vol
hauteur dam
IAS m/s
PHI deg
THETA deg
NR %
panne1 ---
100
80
60
40
20
0
-20
-40
-60
-80
-100
5890
5900
5910
5920
5930
5940
5950
Temps (s)

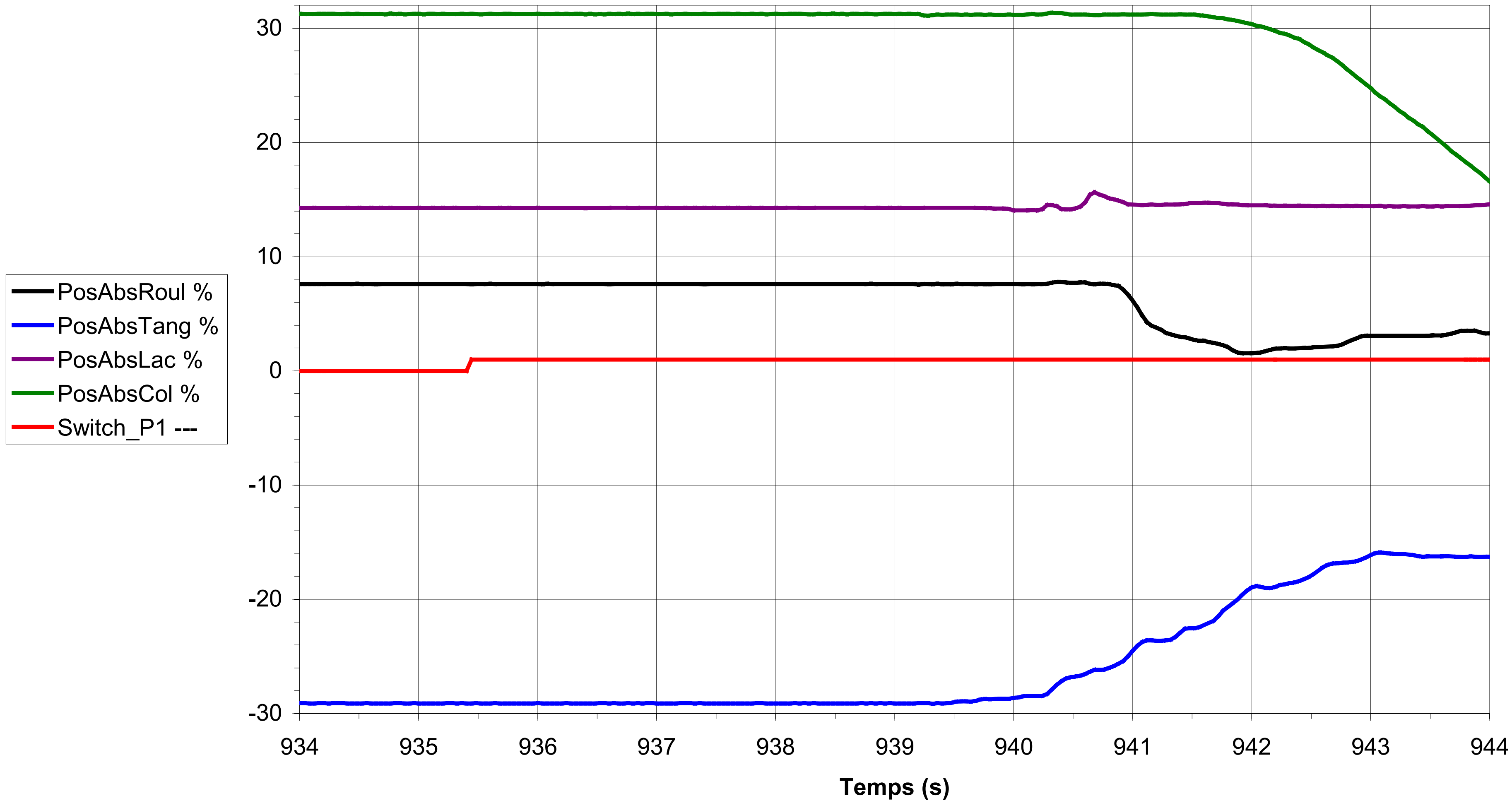
TRPH Pilote 5 Panne 1 - Positions Commandes



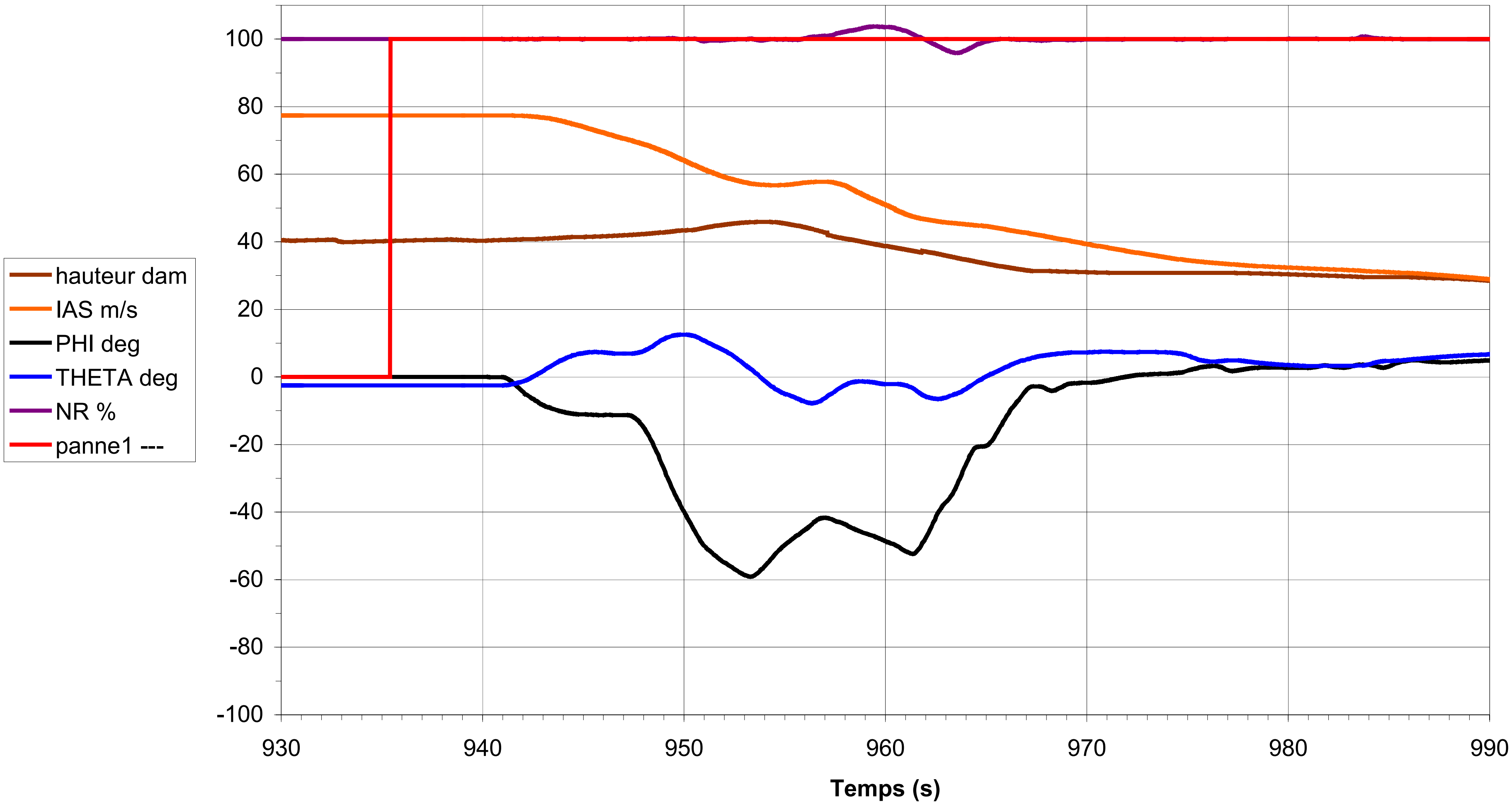
TRPH Pilote 5 Panne 1 - Paramètres de vol

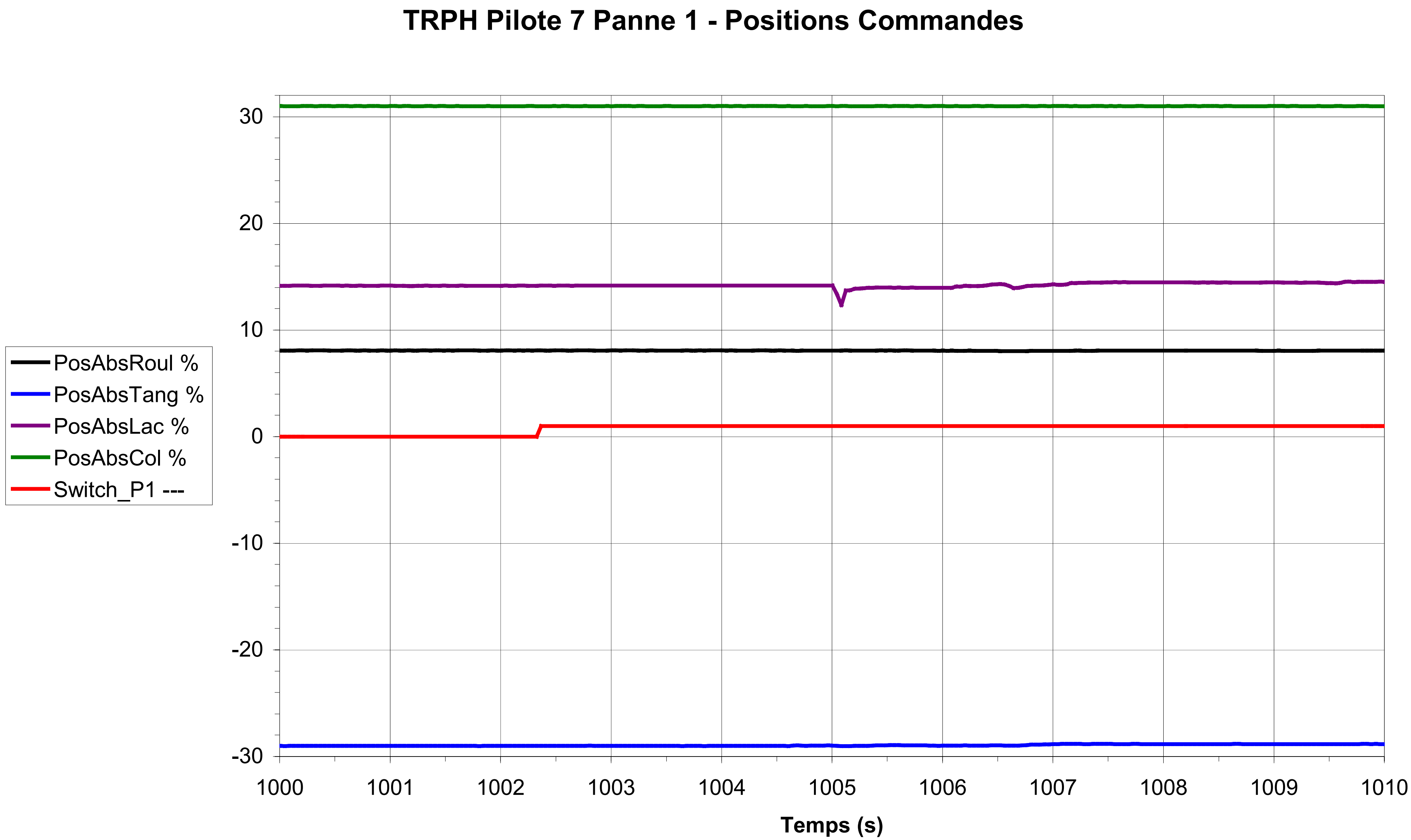


TRPH Pilote 6 Panne 1 - Positions Commandes

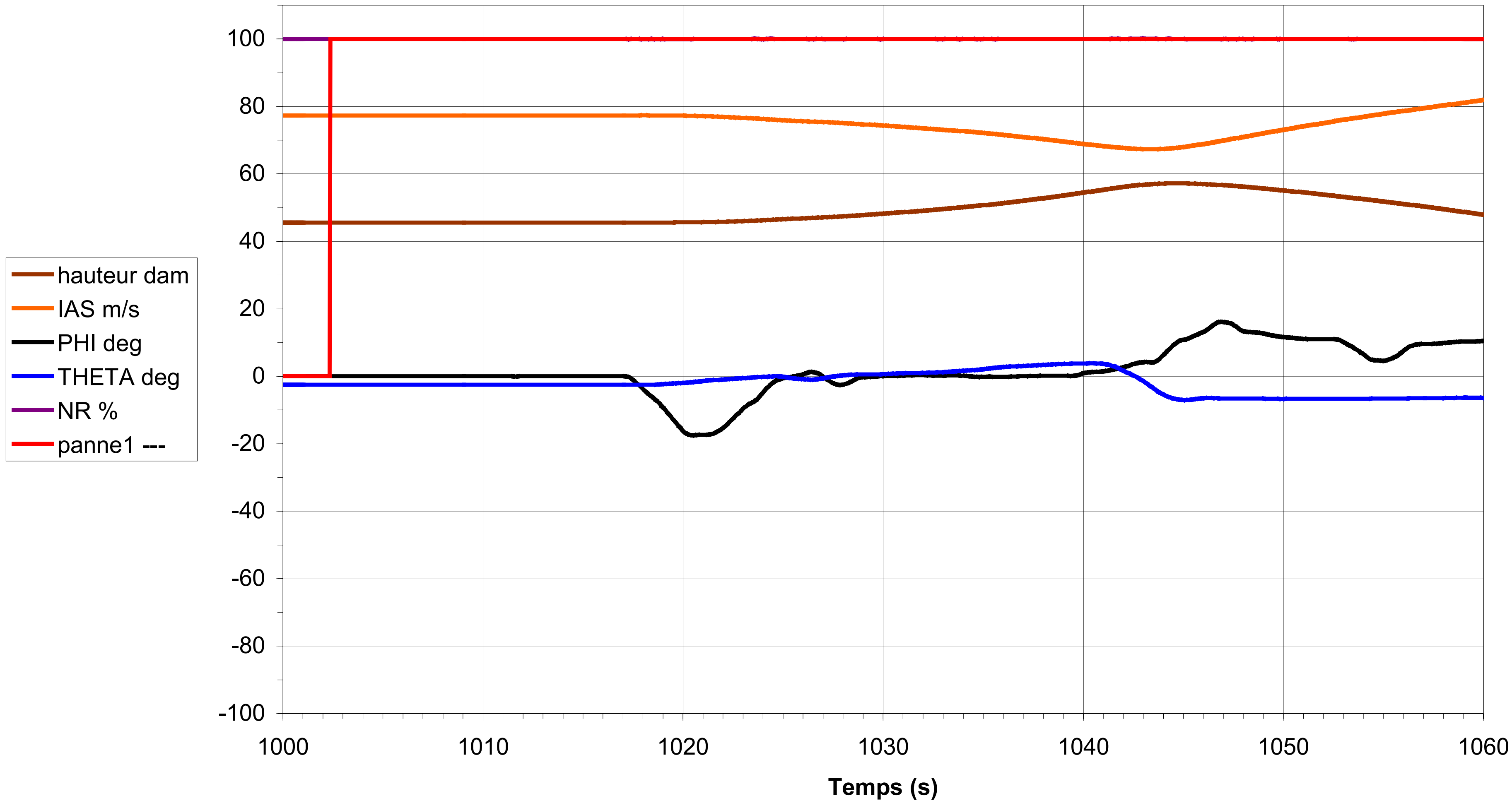


TRPH Pilote 6 Panne 1 - Paramètres de vol

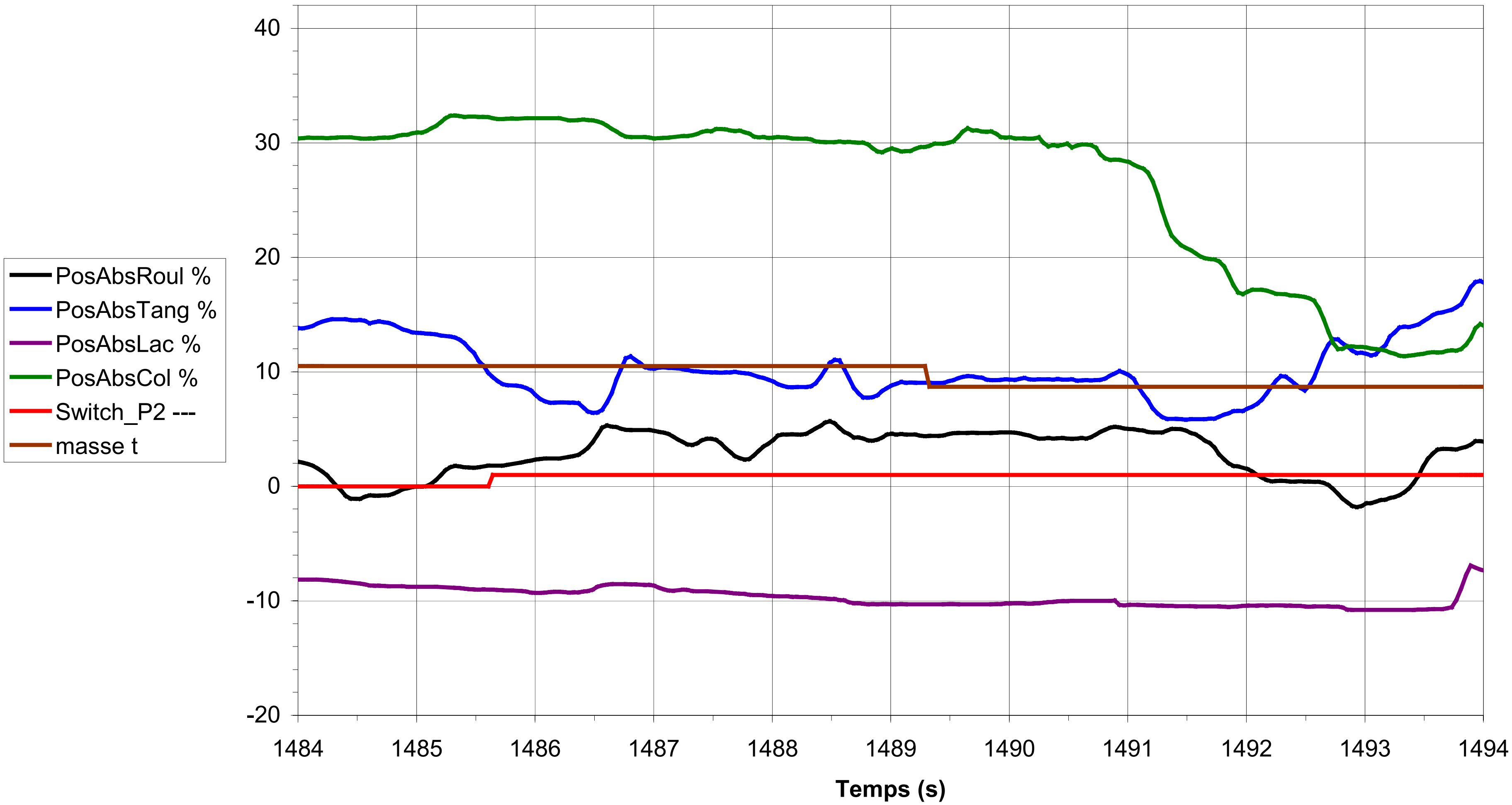


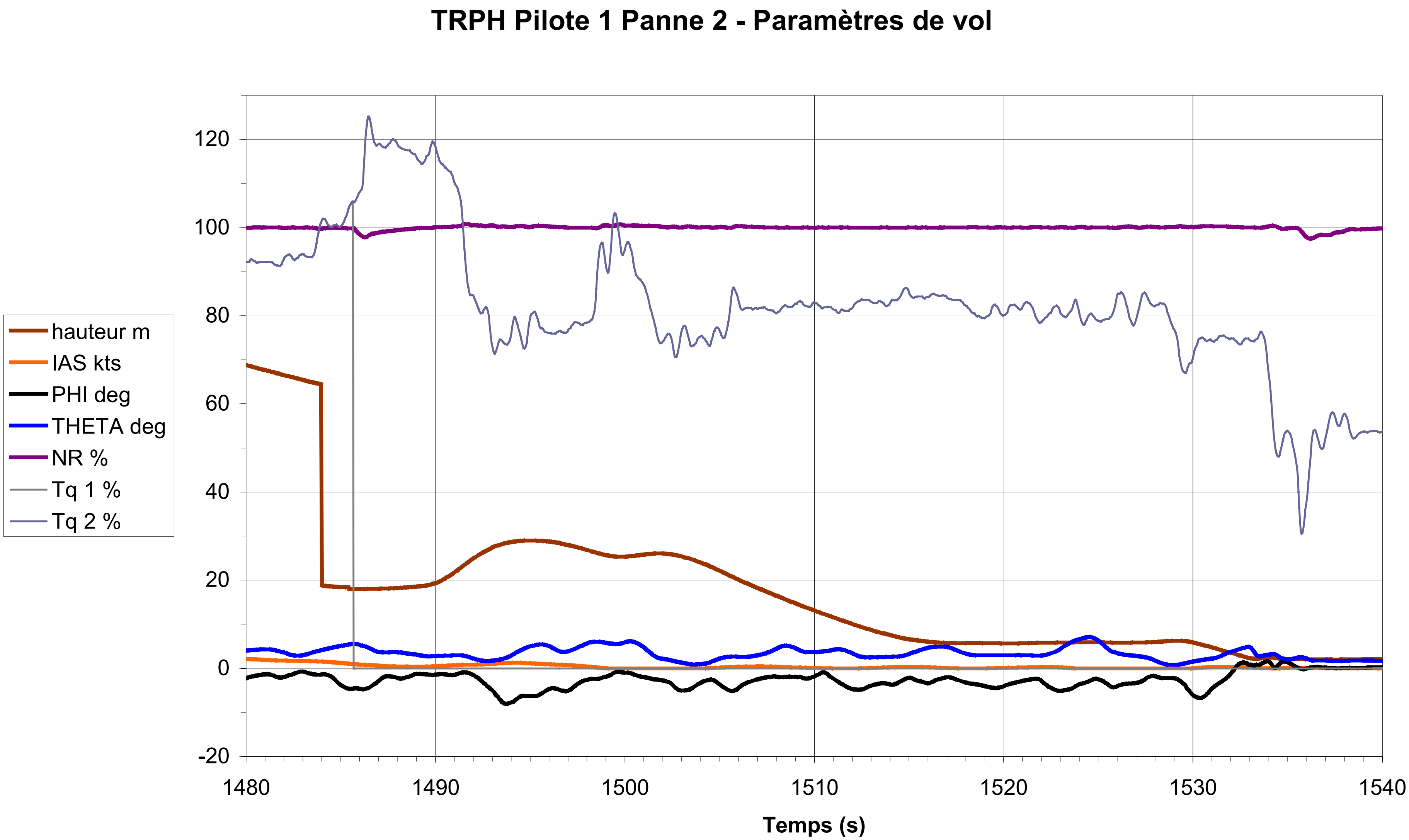

TRPH Pilote 7 Panne 1 - Positions Commandes
30
20
10
0
-10
-20
-30
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
Temps (s)
PosAbsRoul %
PosAbsTang %
PosAbsLac %
PosAbsCol %
Switch_P1 ---

TRPH Pilote 7 Panne 1 - Paramètres de vol

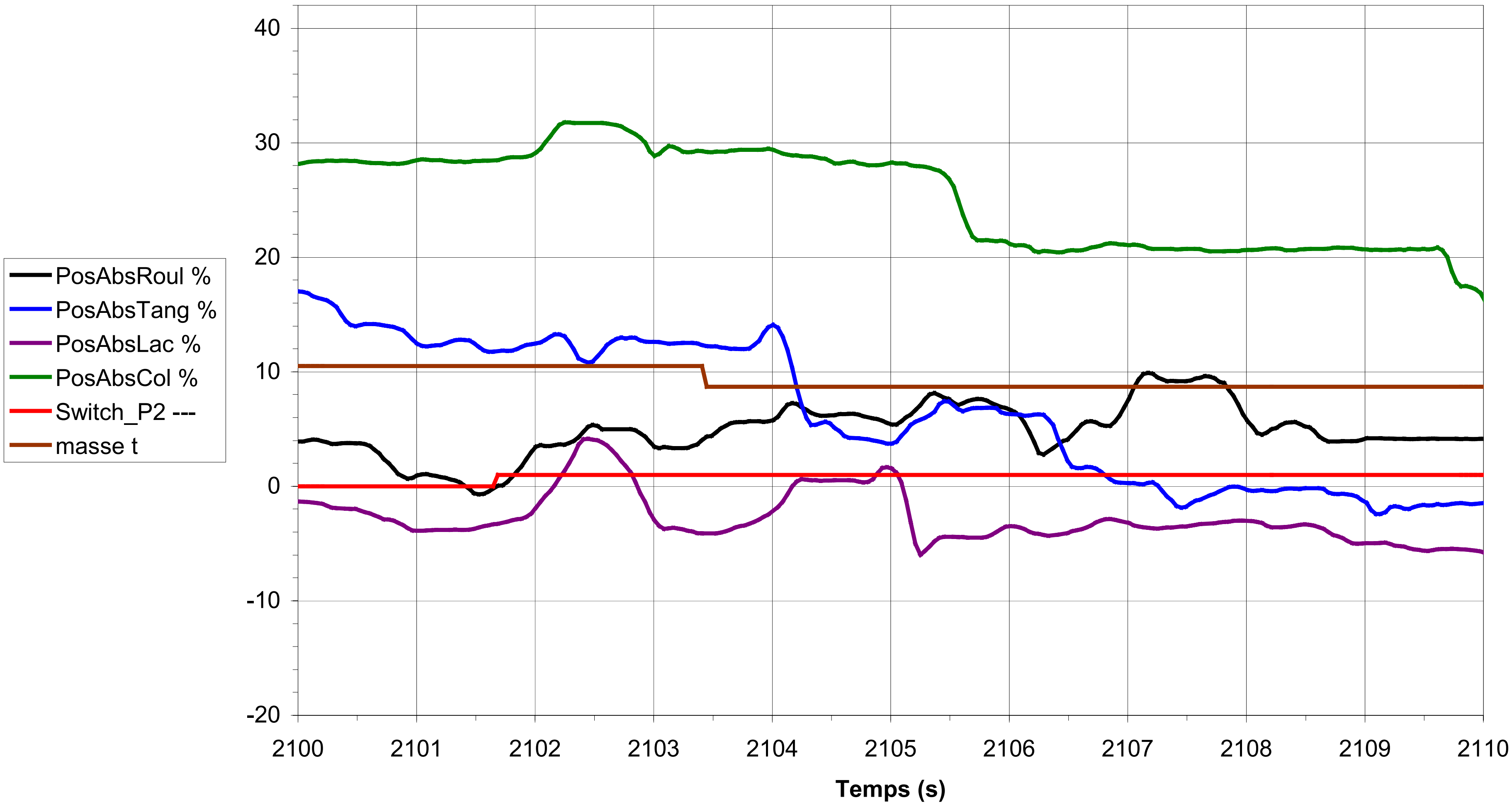


TRPH Pilote 1 Panne 2 - Positions Commandes

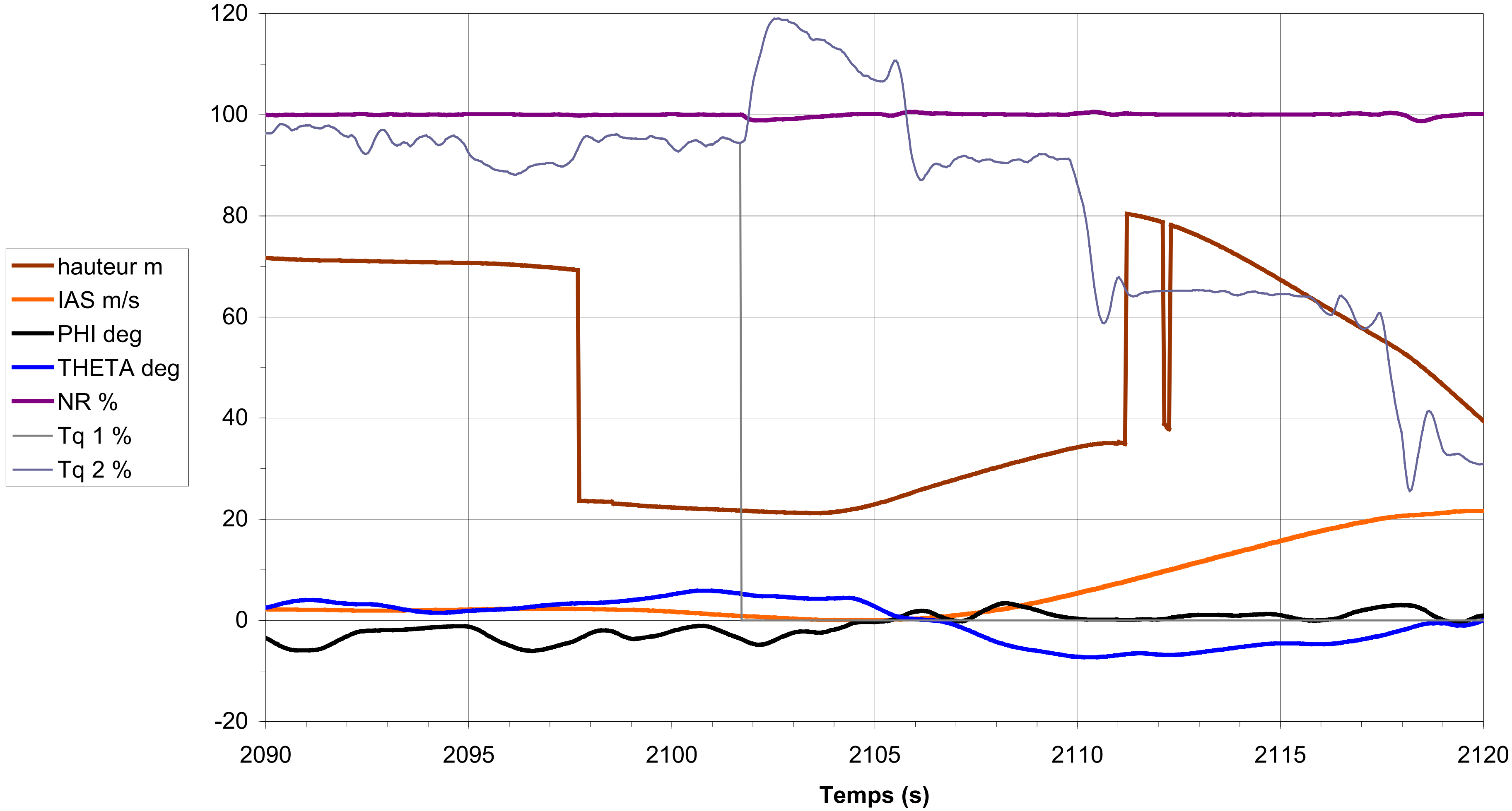



TRPH Pilote 1 Panne 2 - Paramètres de vol
hauteur m
IAS kts
PHI deg
THETA deg
NR %
Tq 1 %
Tq 2 %
120
100
80
60
40
20
0
-20
1480
1490
1500
1510
1520
1530
1540
Temps (s)

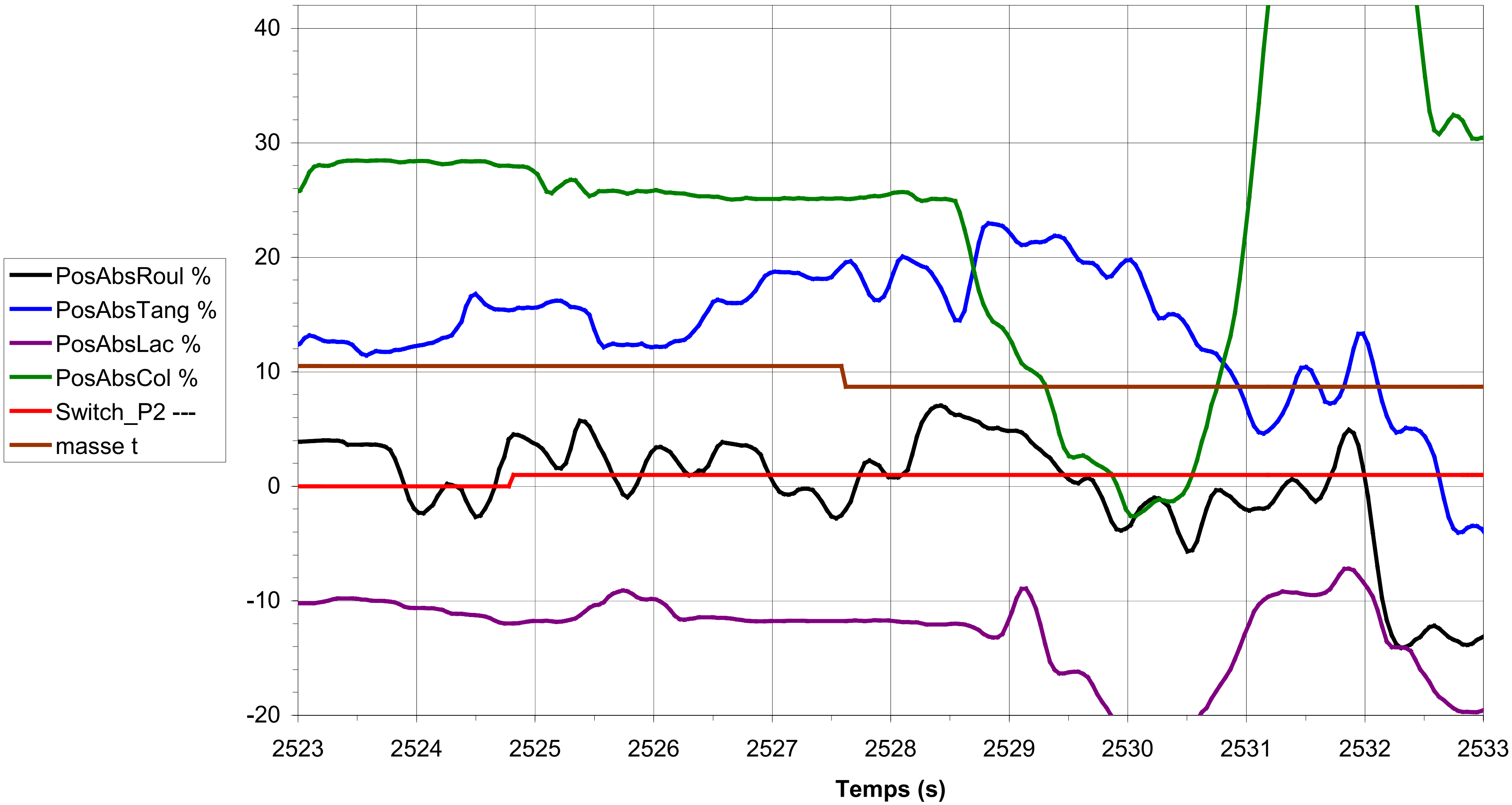
TRPH Pilote 2 Panne 2 - Positions Commandes



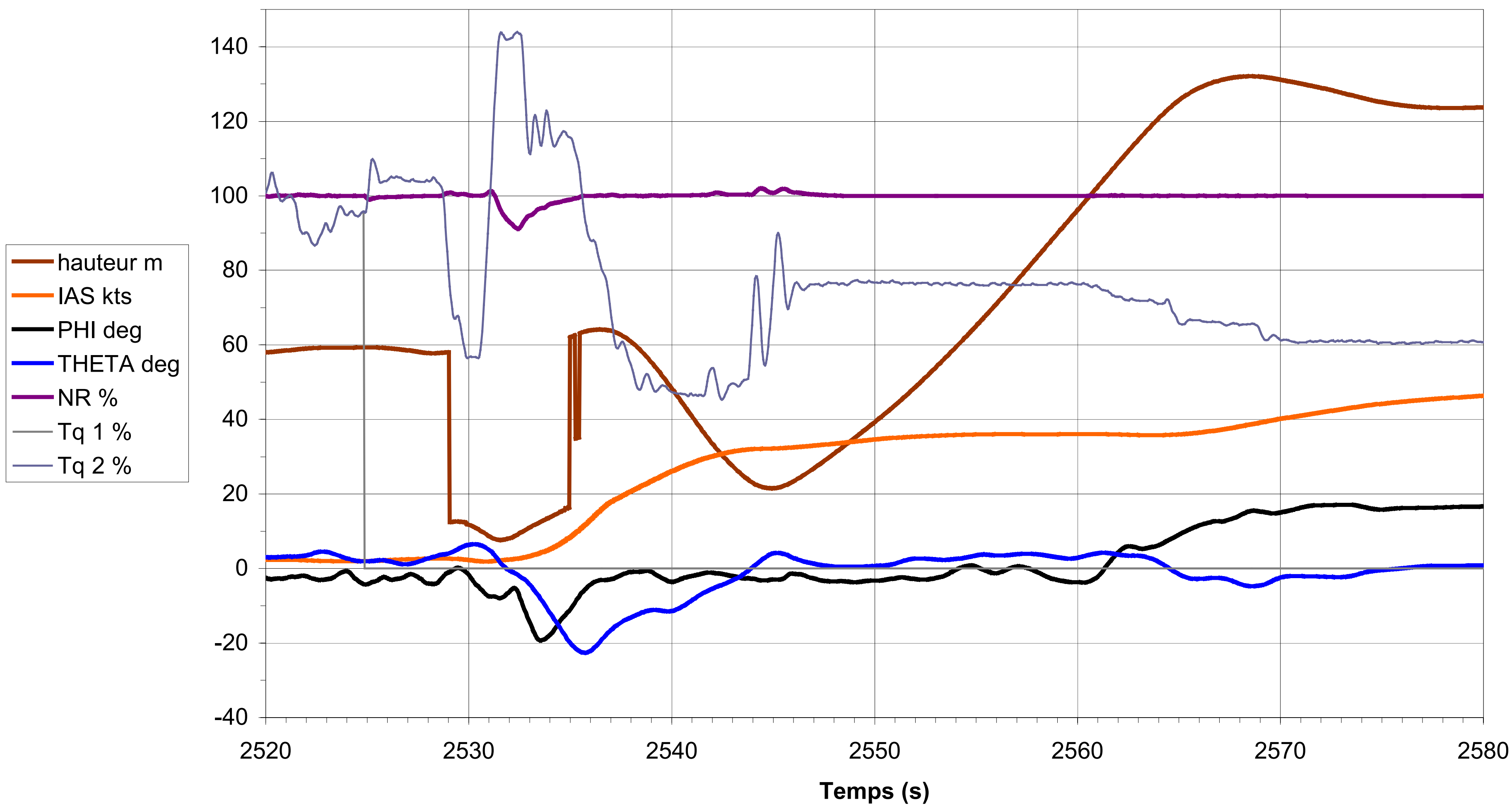
TRPH Pilote 2 Panne 2 - Paramètres de vol



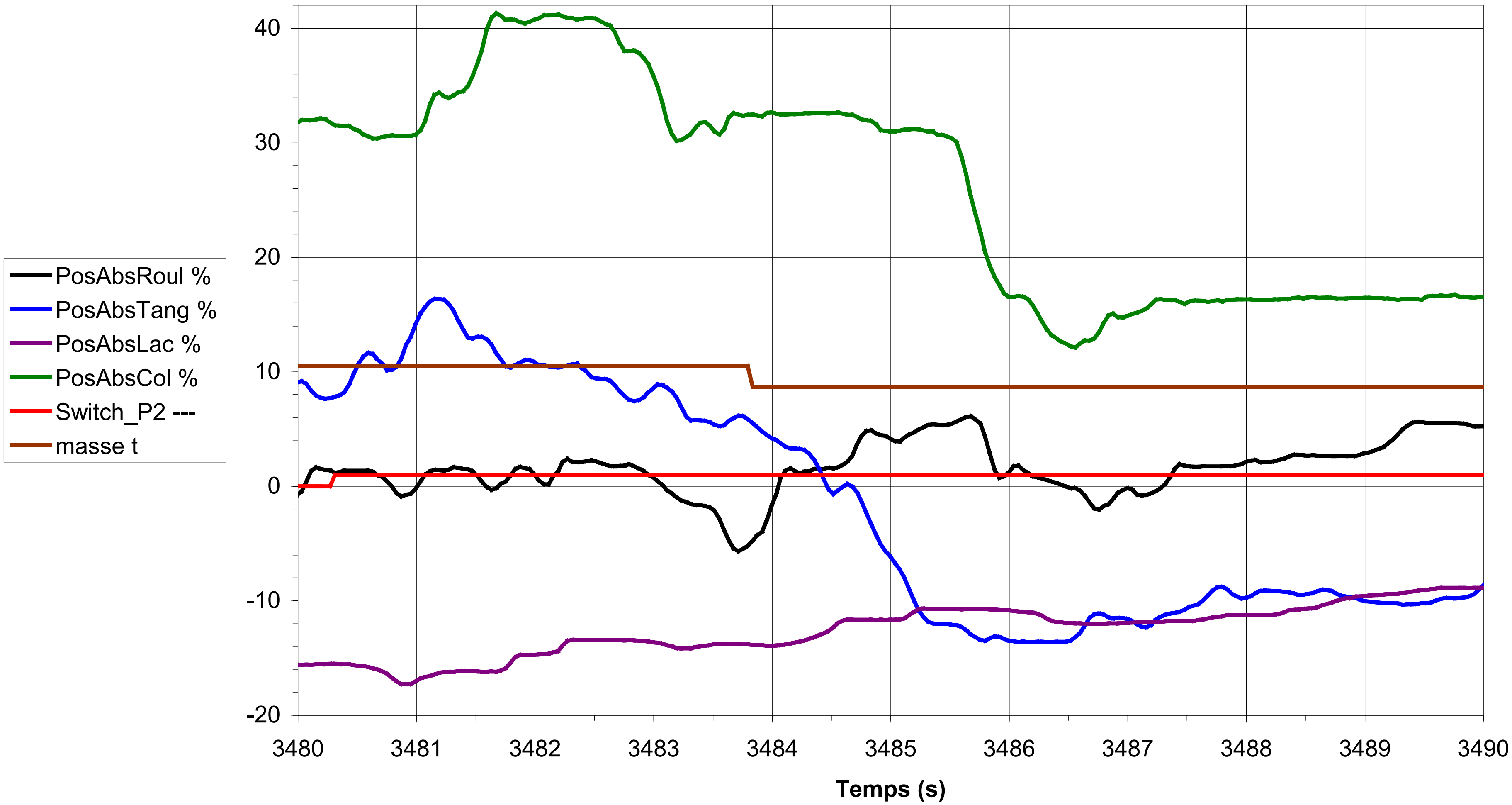
TRPH Pilote 3 Panne 2 - Positions Commandes



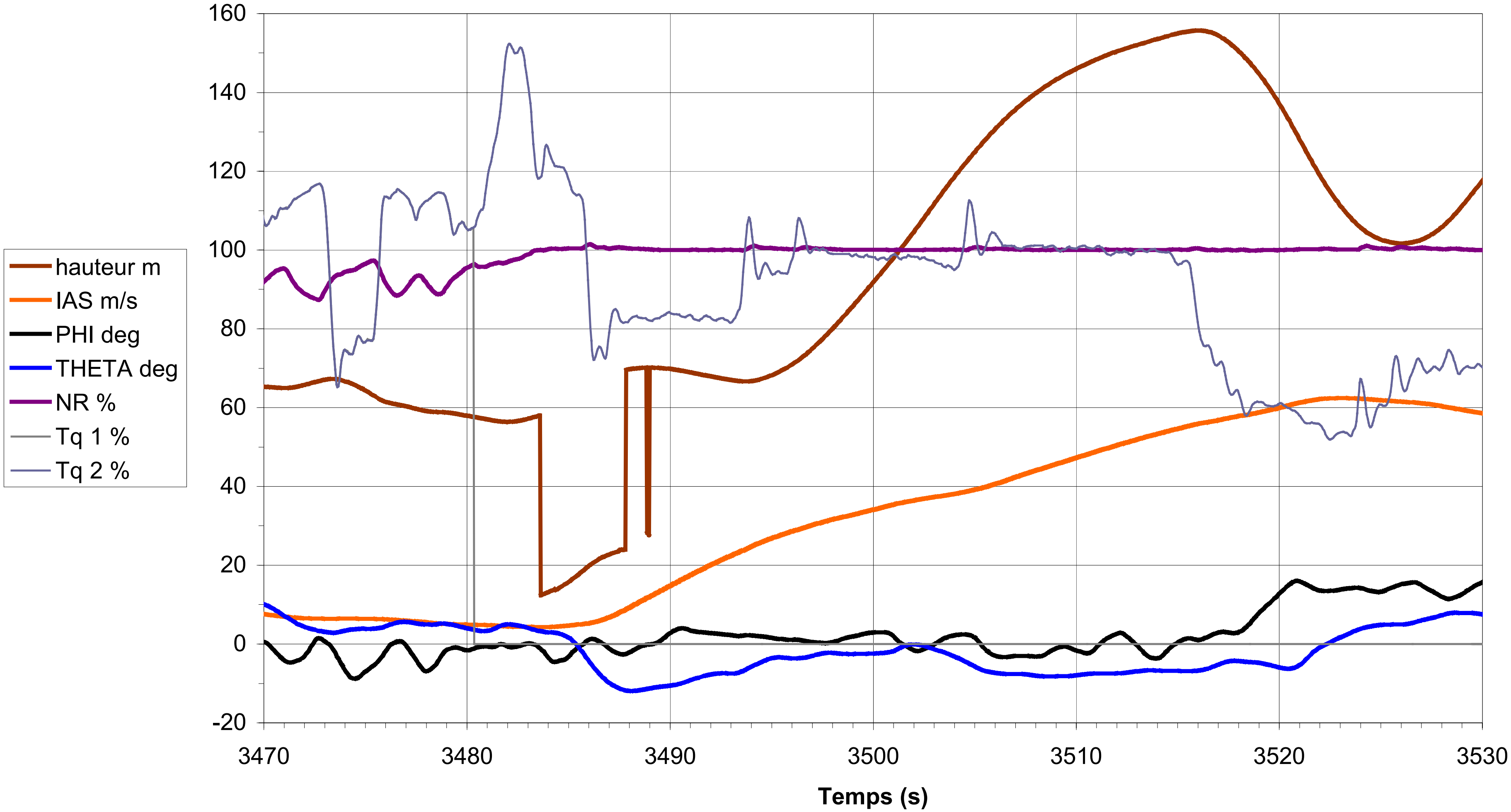
TRPH Pilote 3 Panne 2 - Paramètres de vol

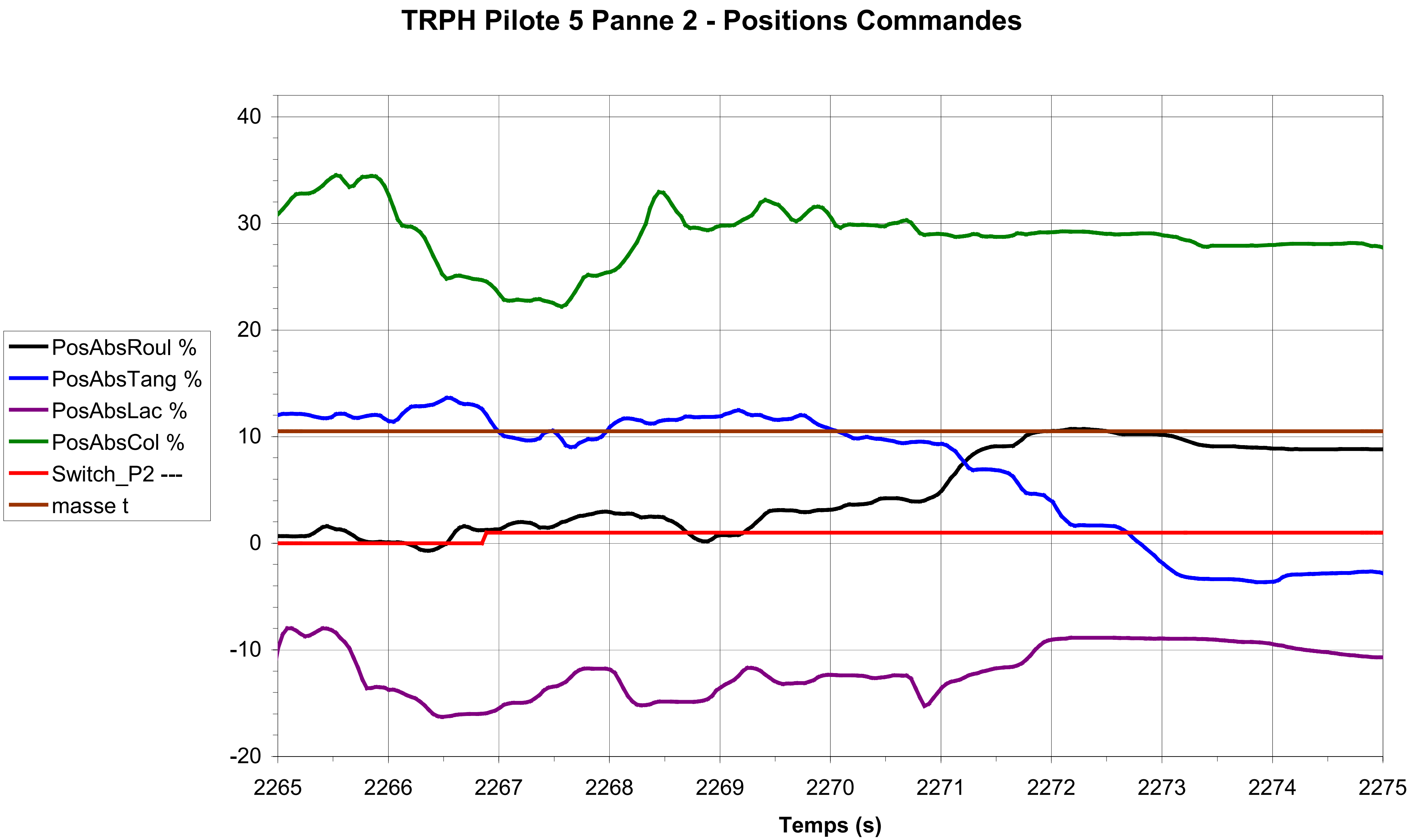


TRPH Pilote 4 Panne 2 - Positions Commandes

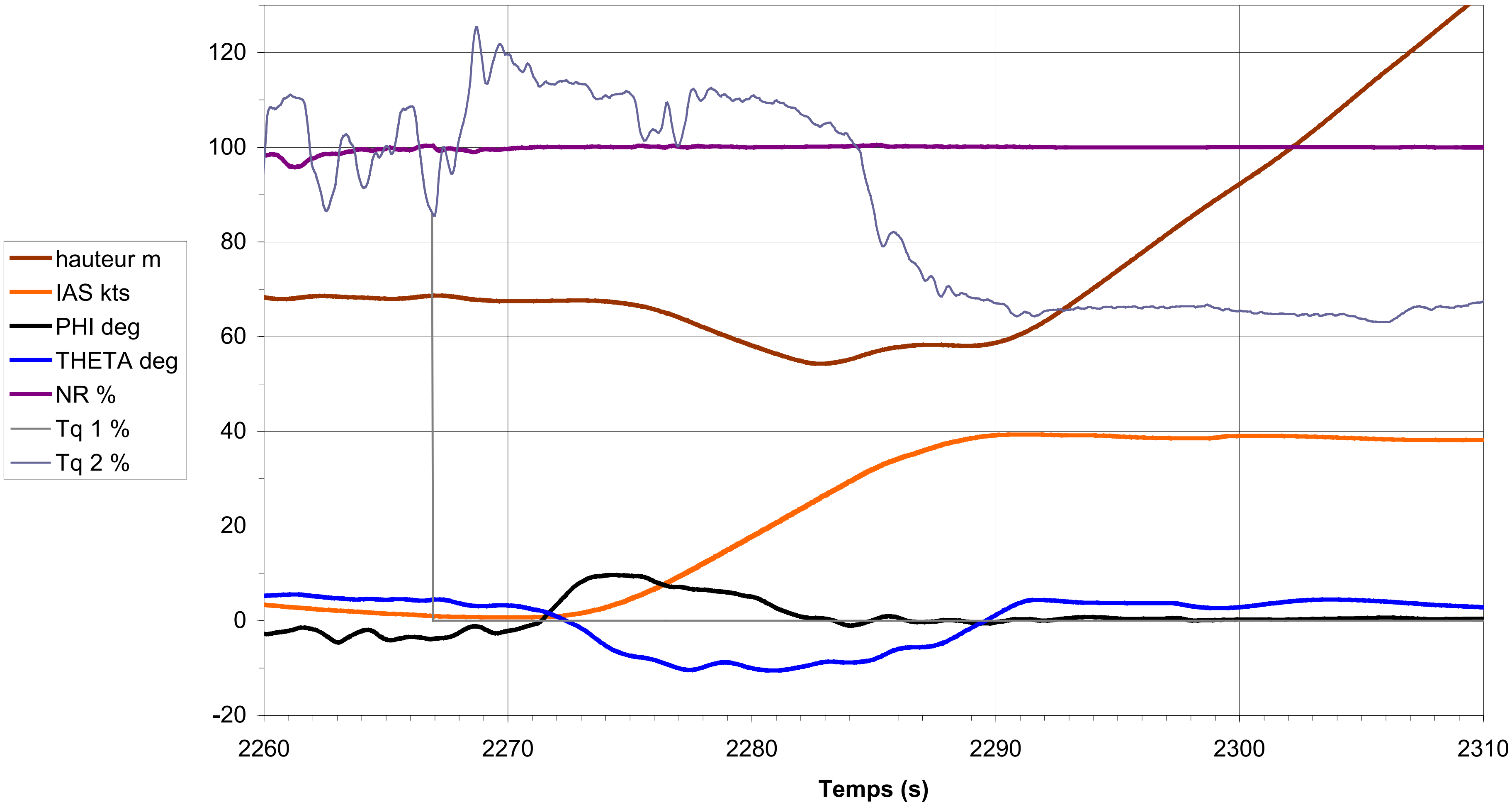


TRPH Pilote 4 Panne 2 - Paramètres de vol

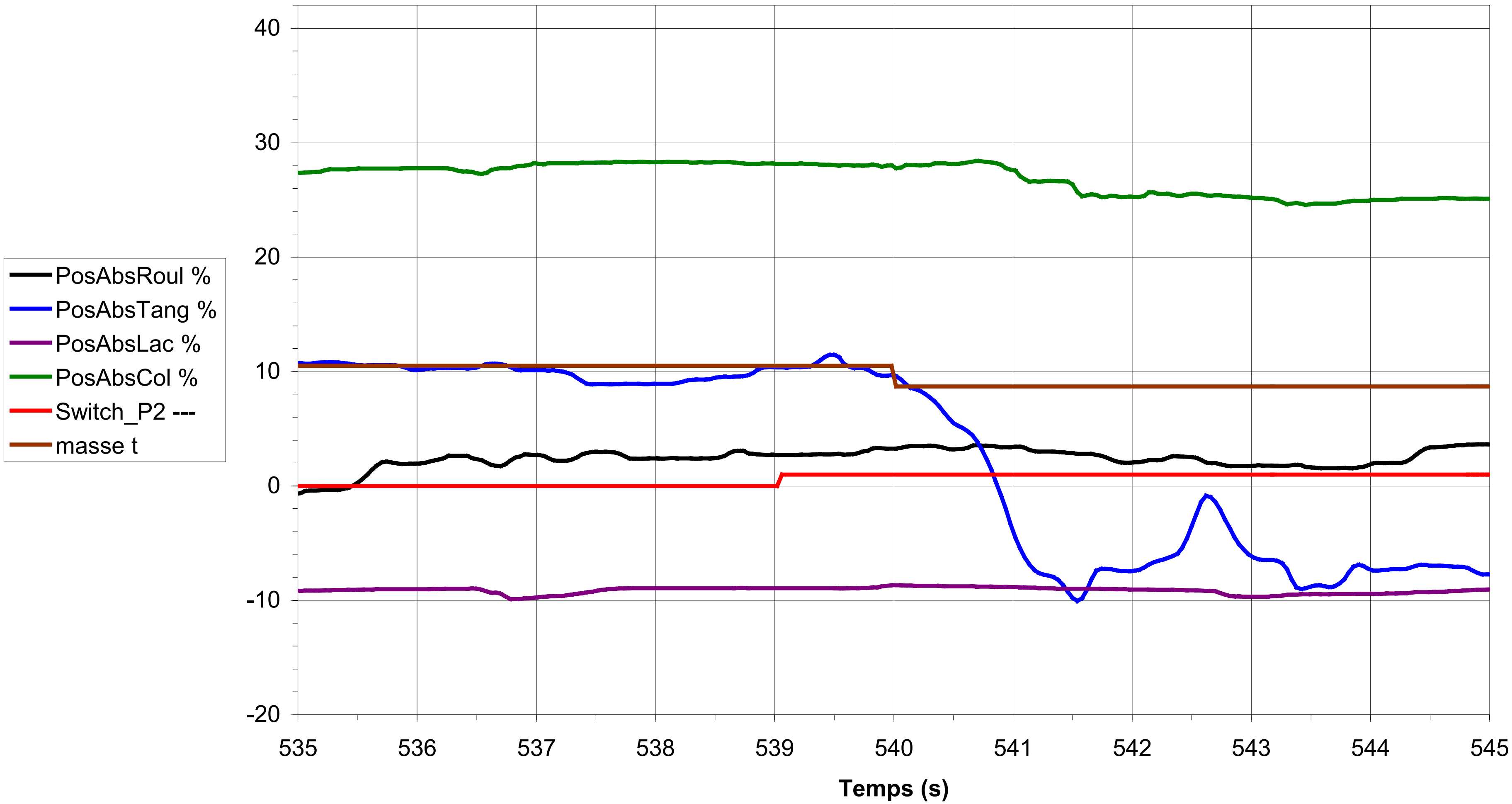



TRPH Pilote 5 Panne 2 - Positions Commandes
40
30
20
10
0
-10
-20
PosAbsRoul %
PosAbsTang %
PosAbsLac %
PosAbsCol %
Switch_P2 ---
masse t
2265
2266
2267
2268
2269
2270
2271
2272
2273
2274
2275
Temps (s)

TRPH Pilote 5 Panne 2 - Paramètres de vol



TRPH Pilote 6 Panne 2 - Positions Commandes



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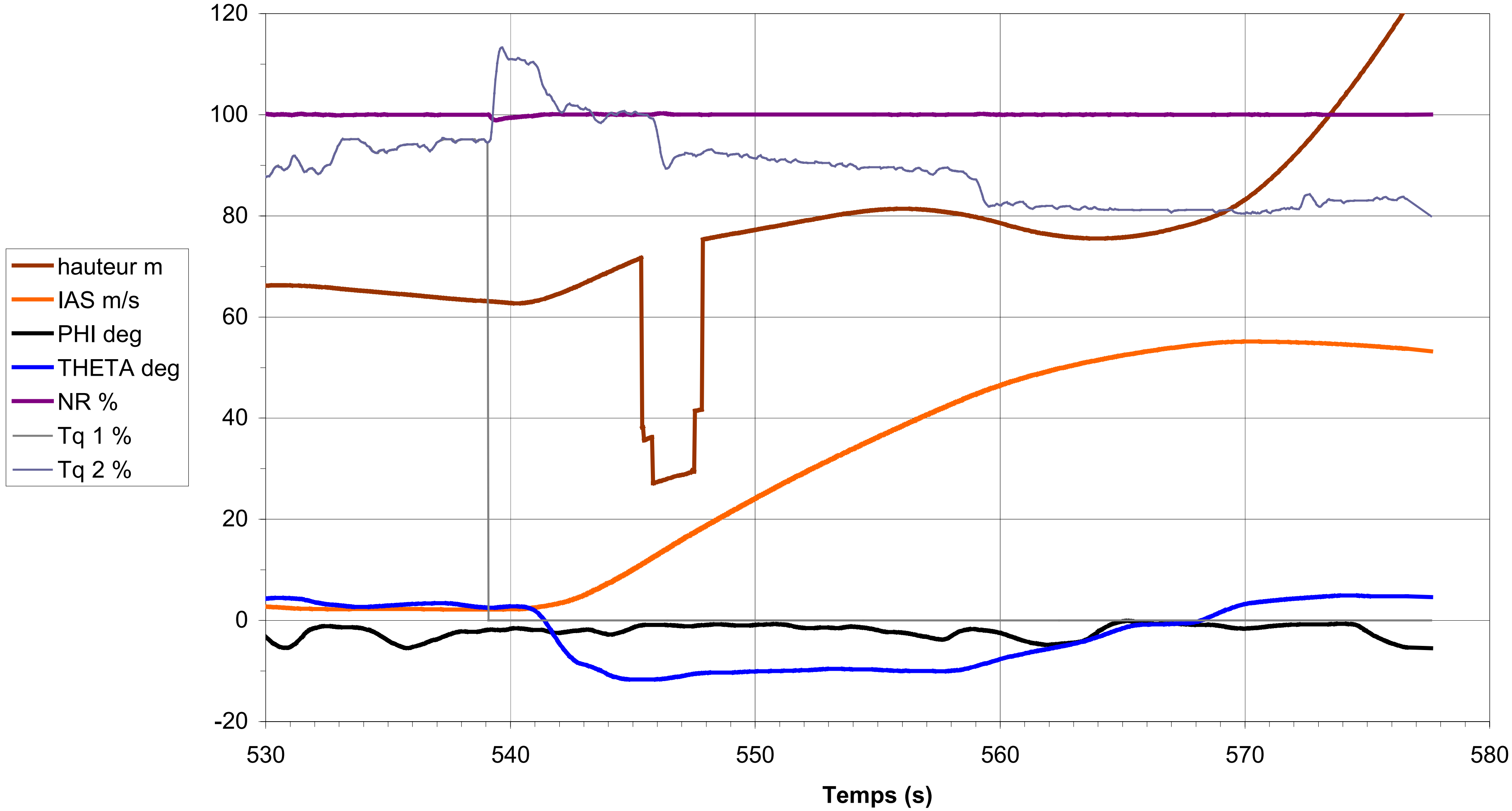
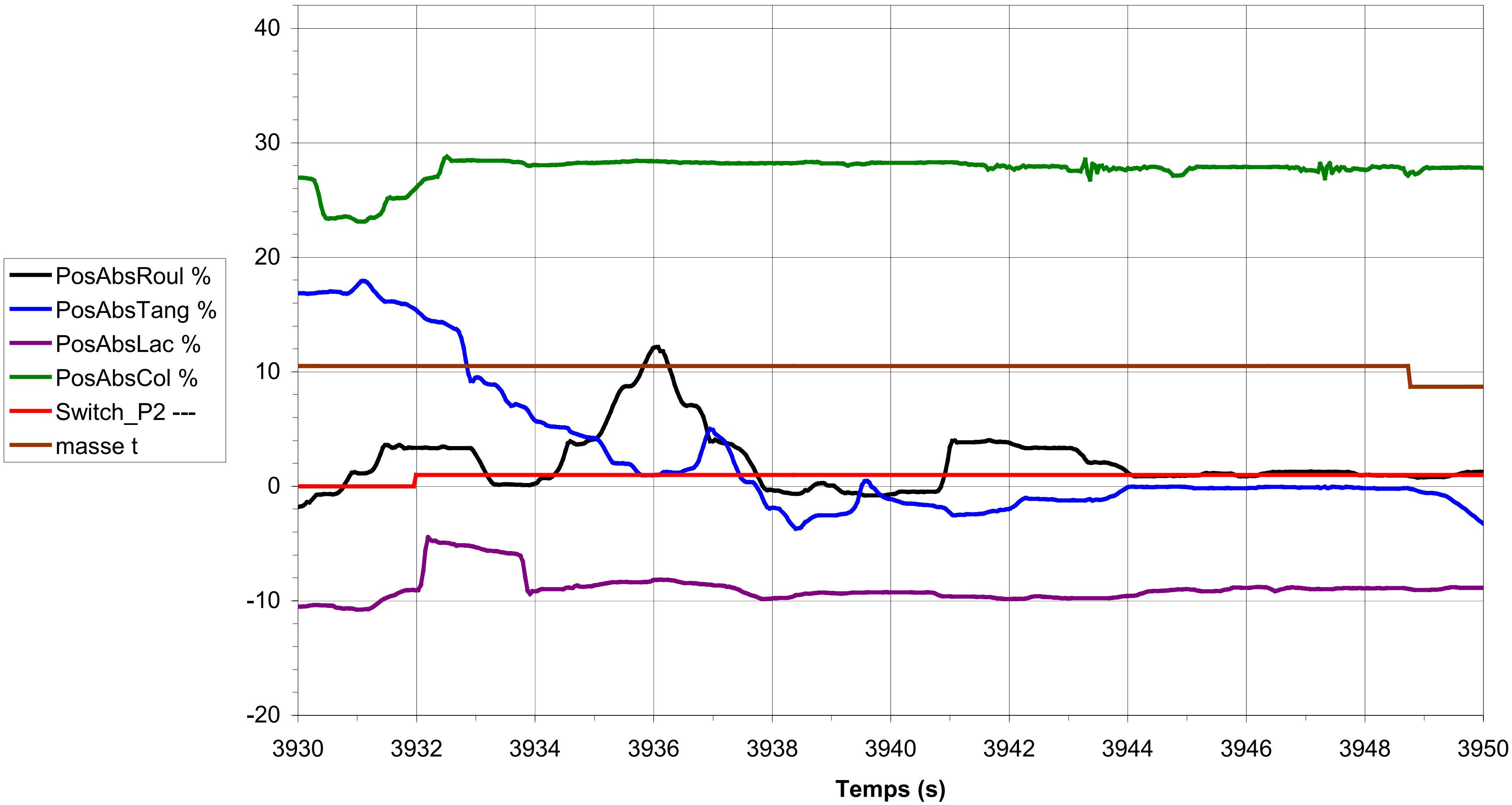
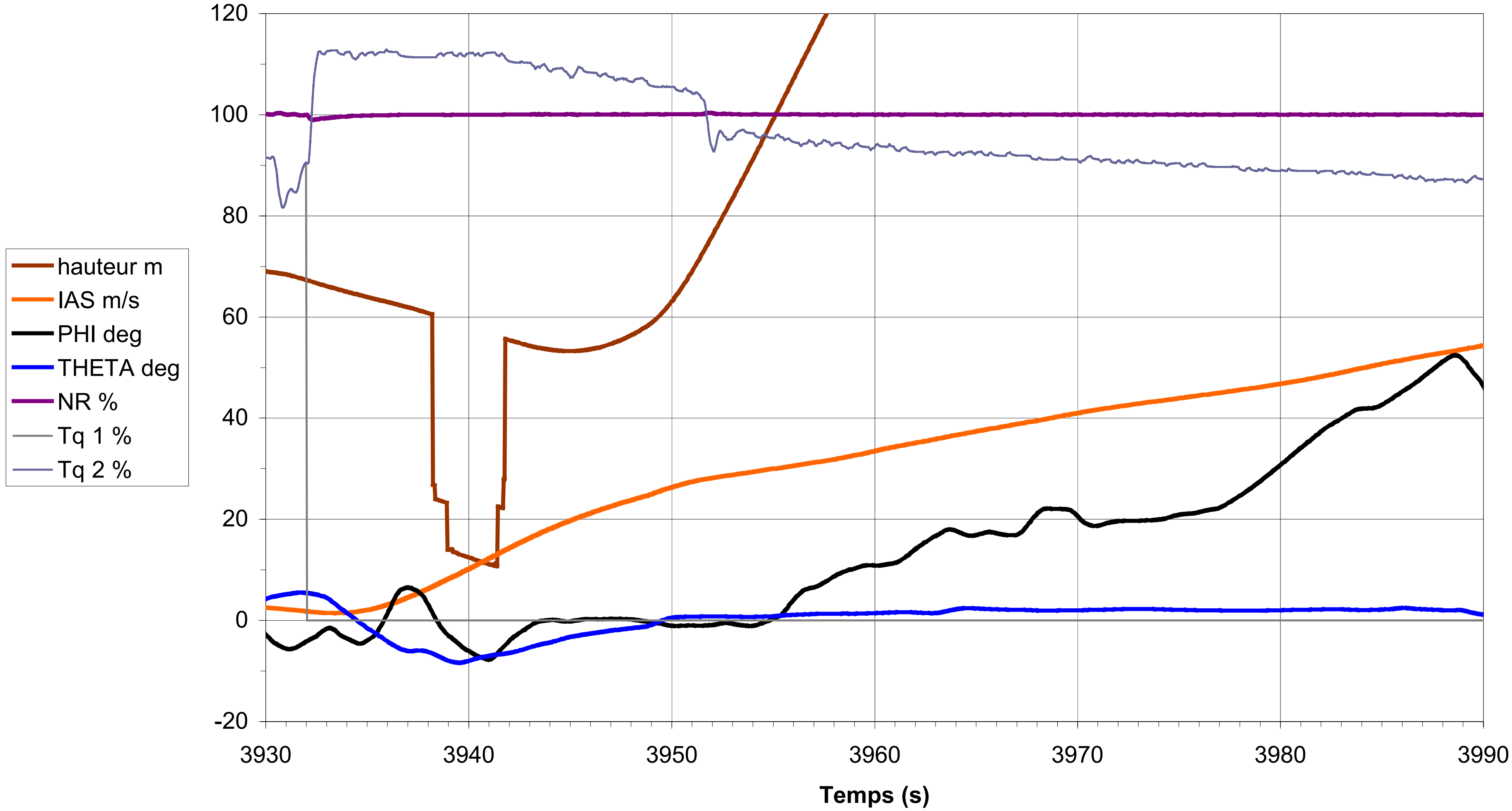
TRPH Pilote 6 Panne 2 - Paramètres de vol



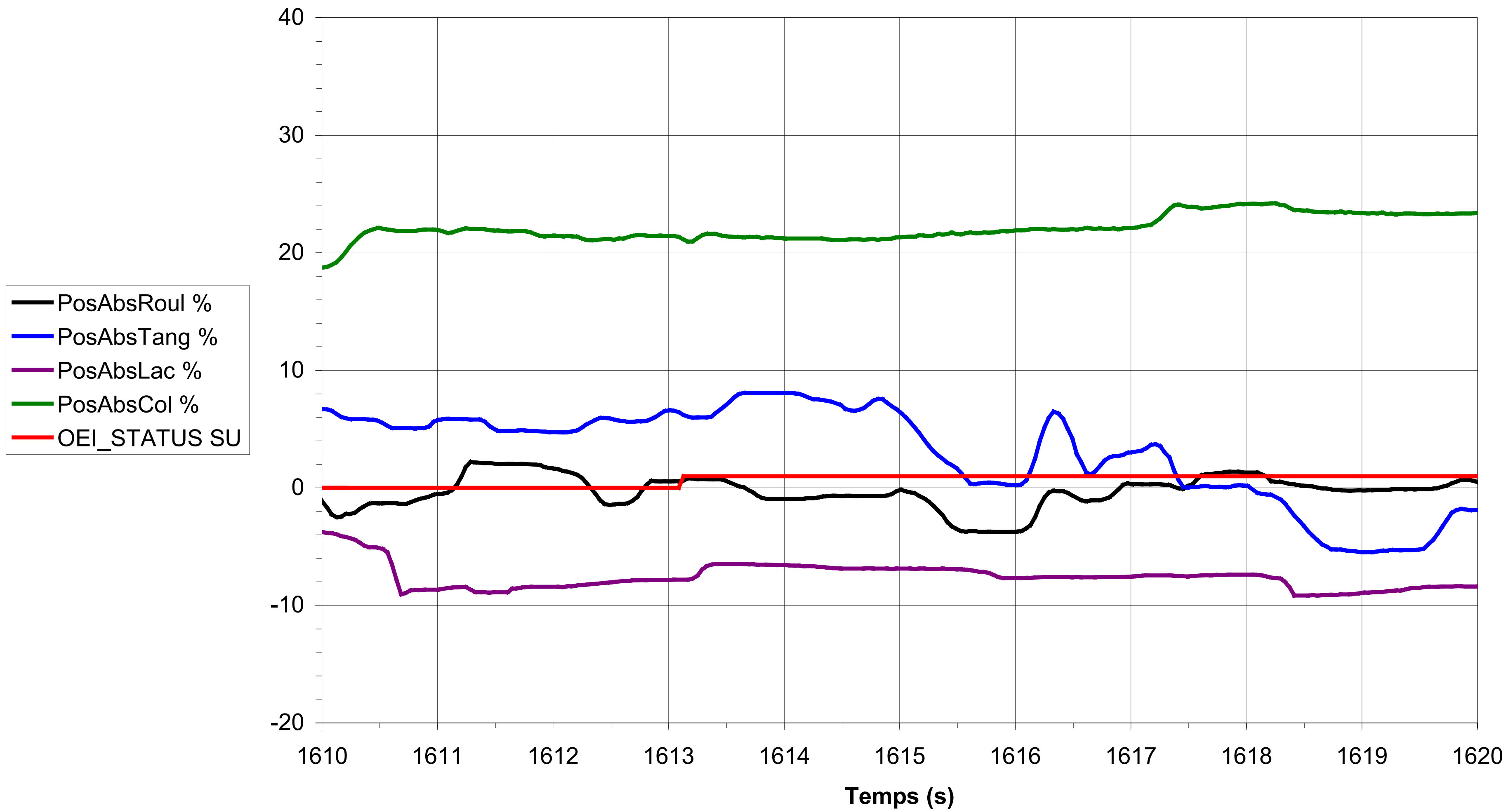
TRPH Pilote 7 Panne 2 - Positions Commandes



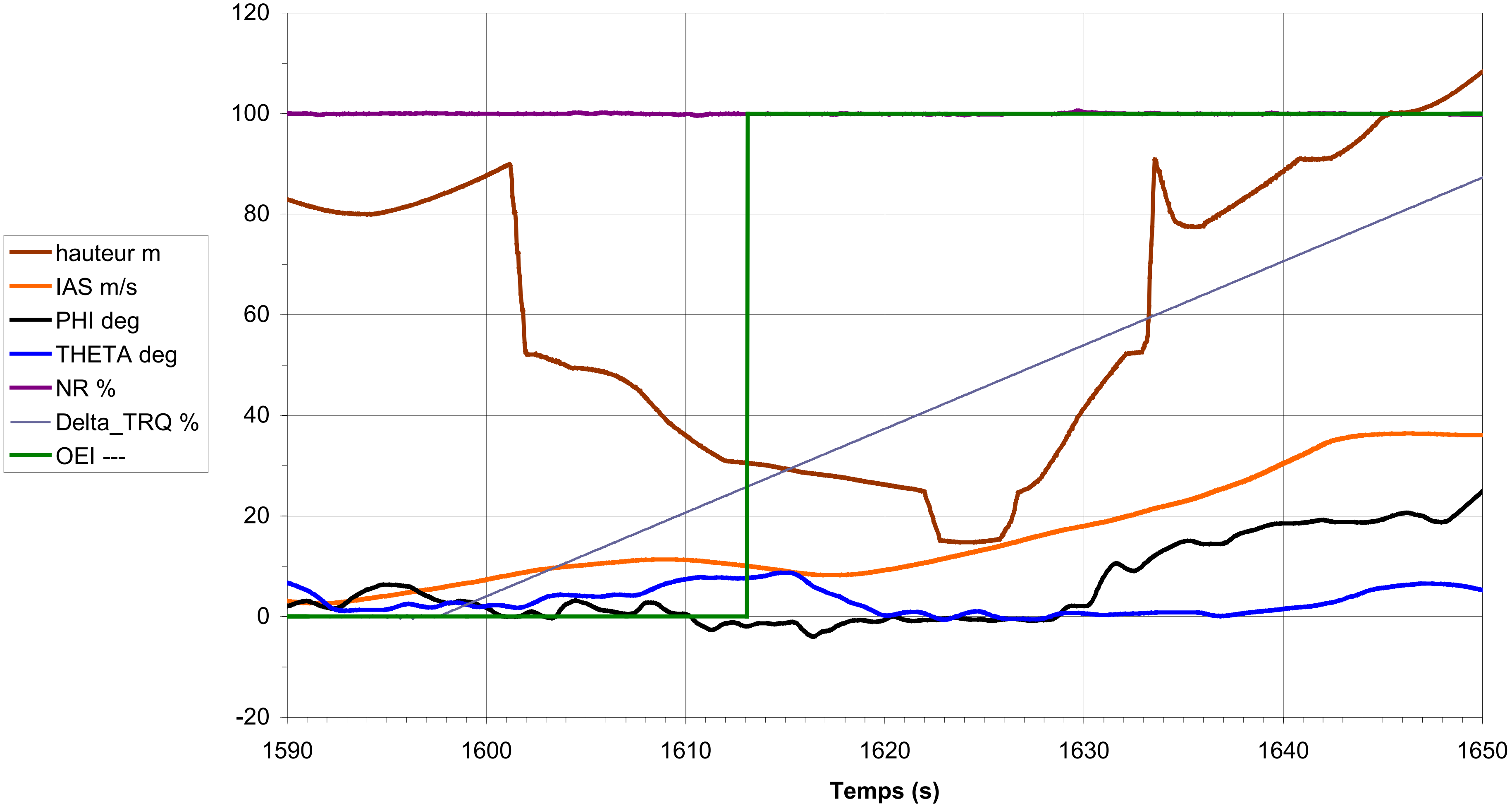
TRPH Pilote 7 Panne 2 - Paramètres de vol



TRPH Pilote 1 Panne 3 - Positions Commandes



TRPH Pilote 1 Panne 3 - Paramètres de vol



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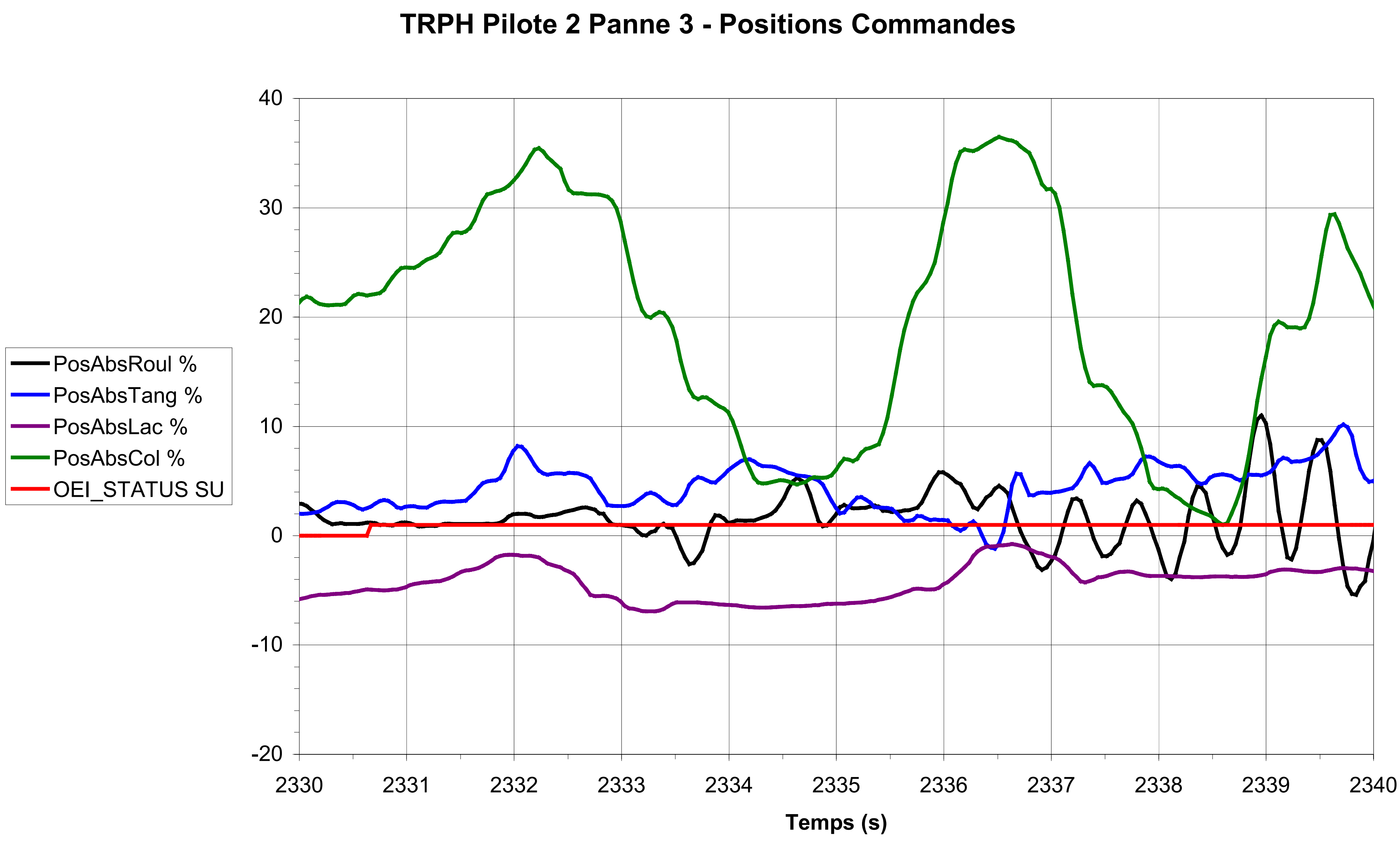

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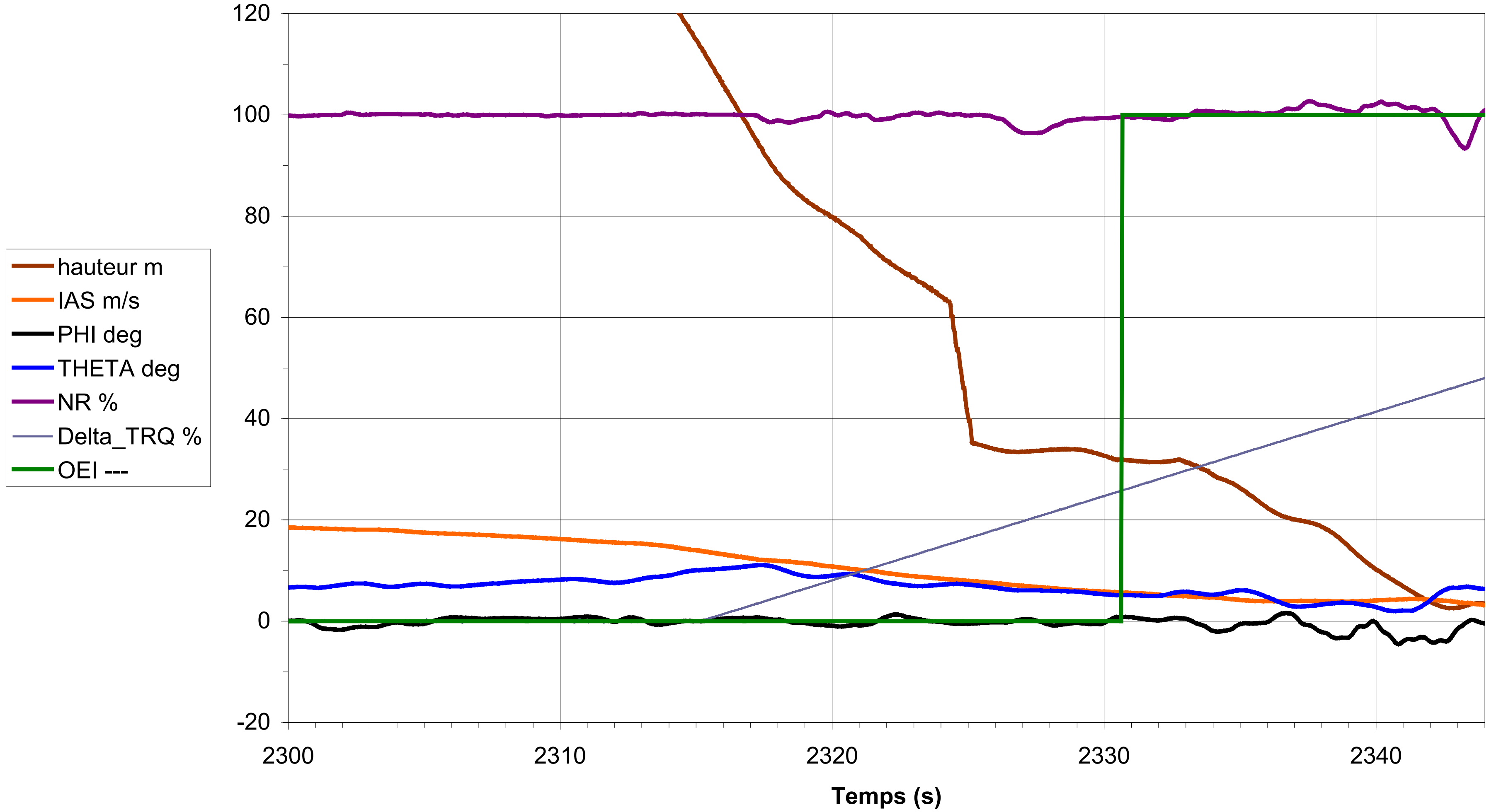
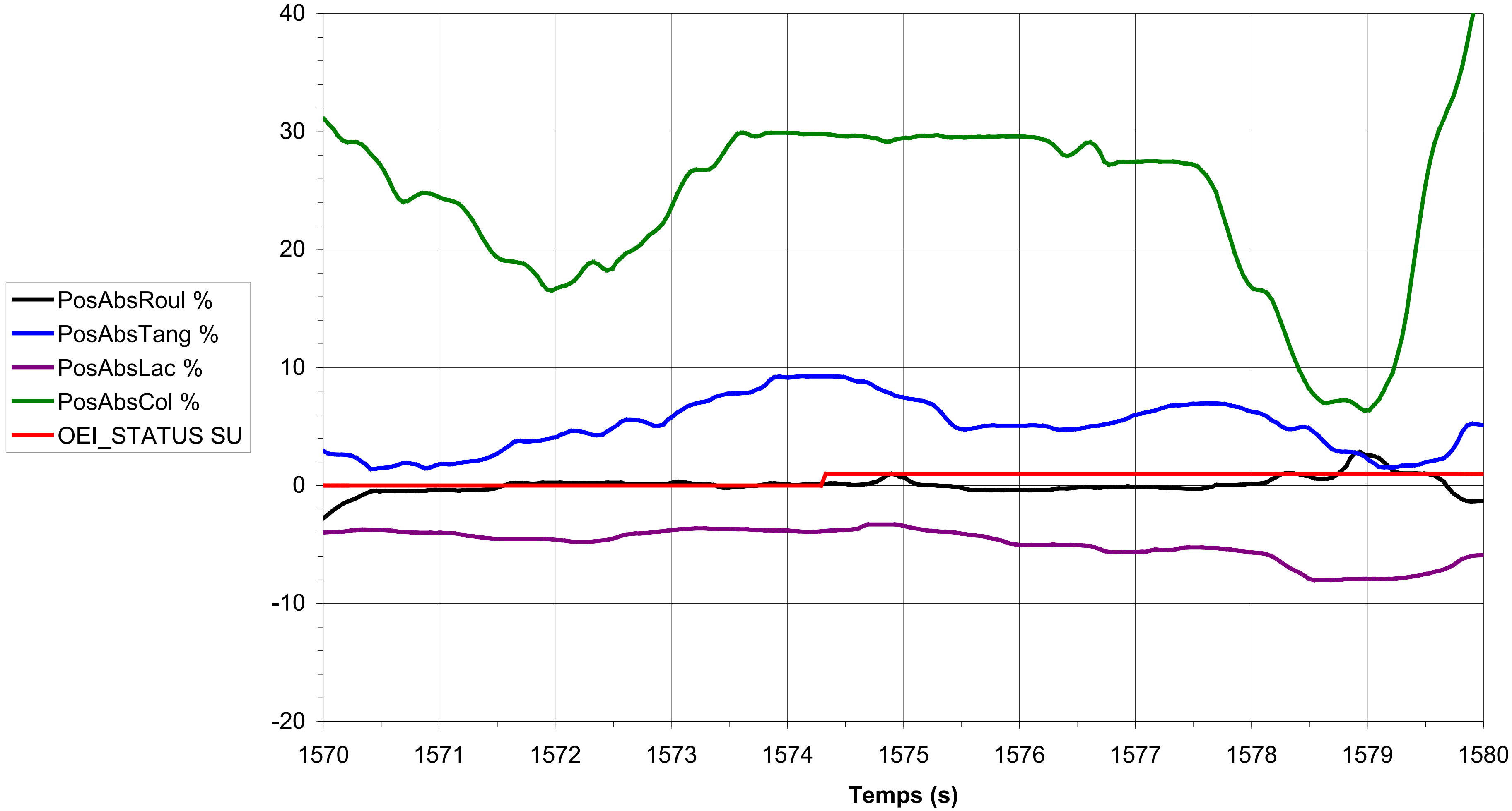
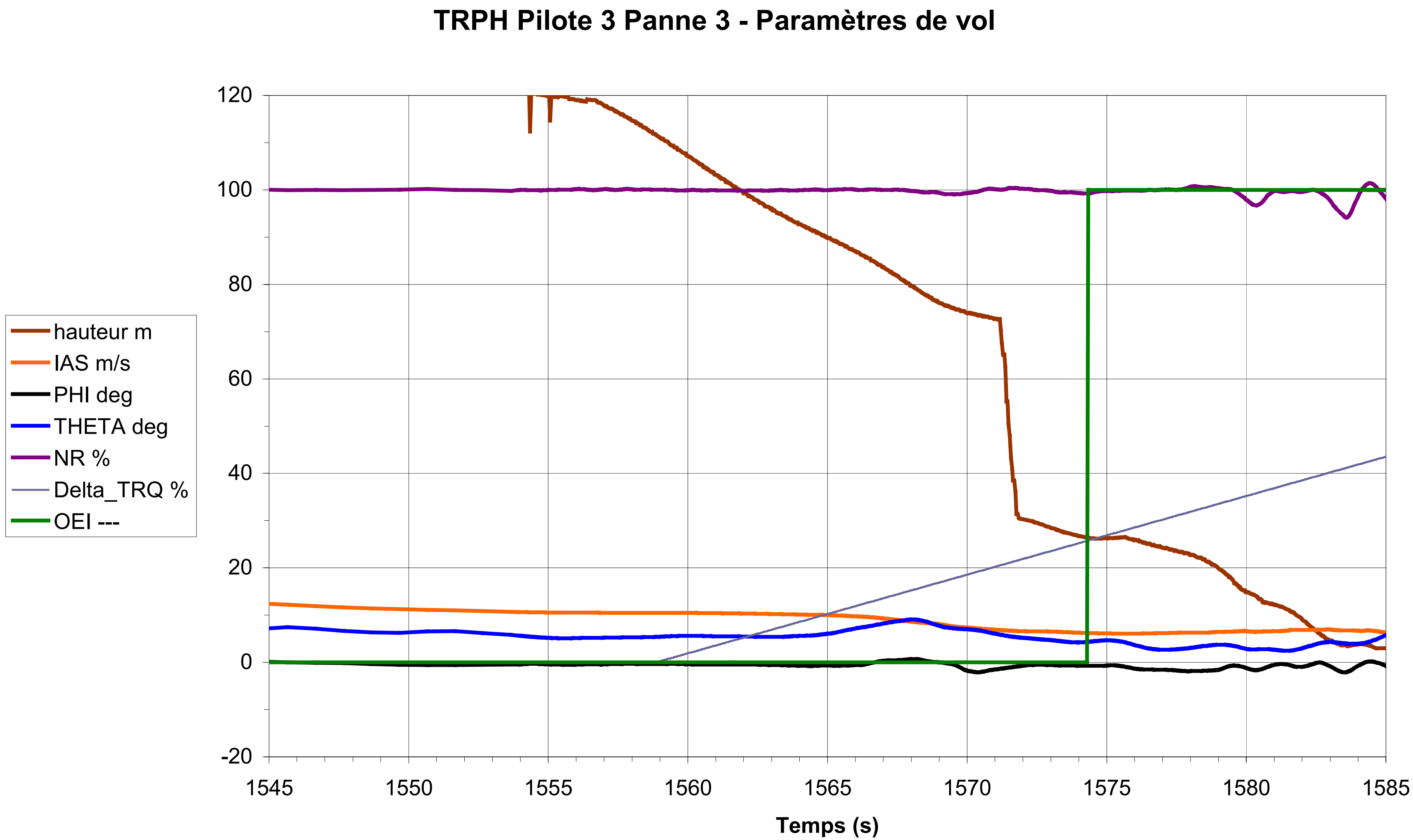
TRPH Pilote 2 Panne 3 - Paramètres de vol

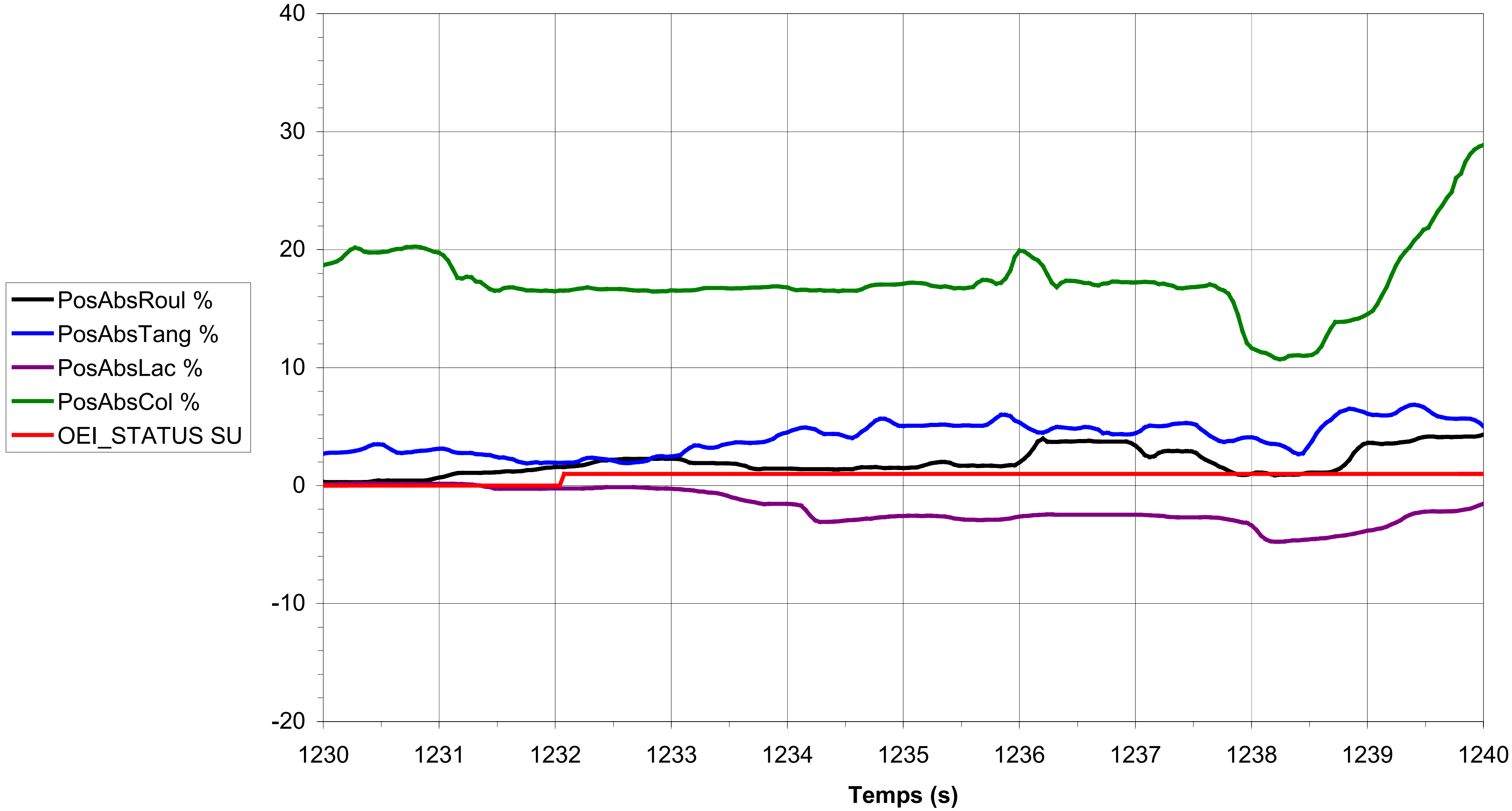


TRPH Pilote 3 Panne 3 - Positions Commandes

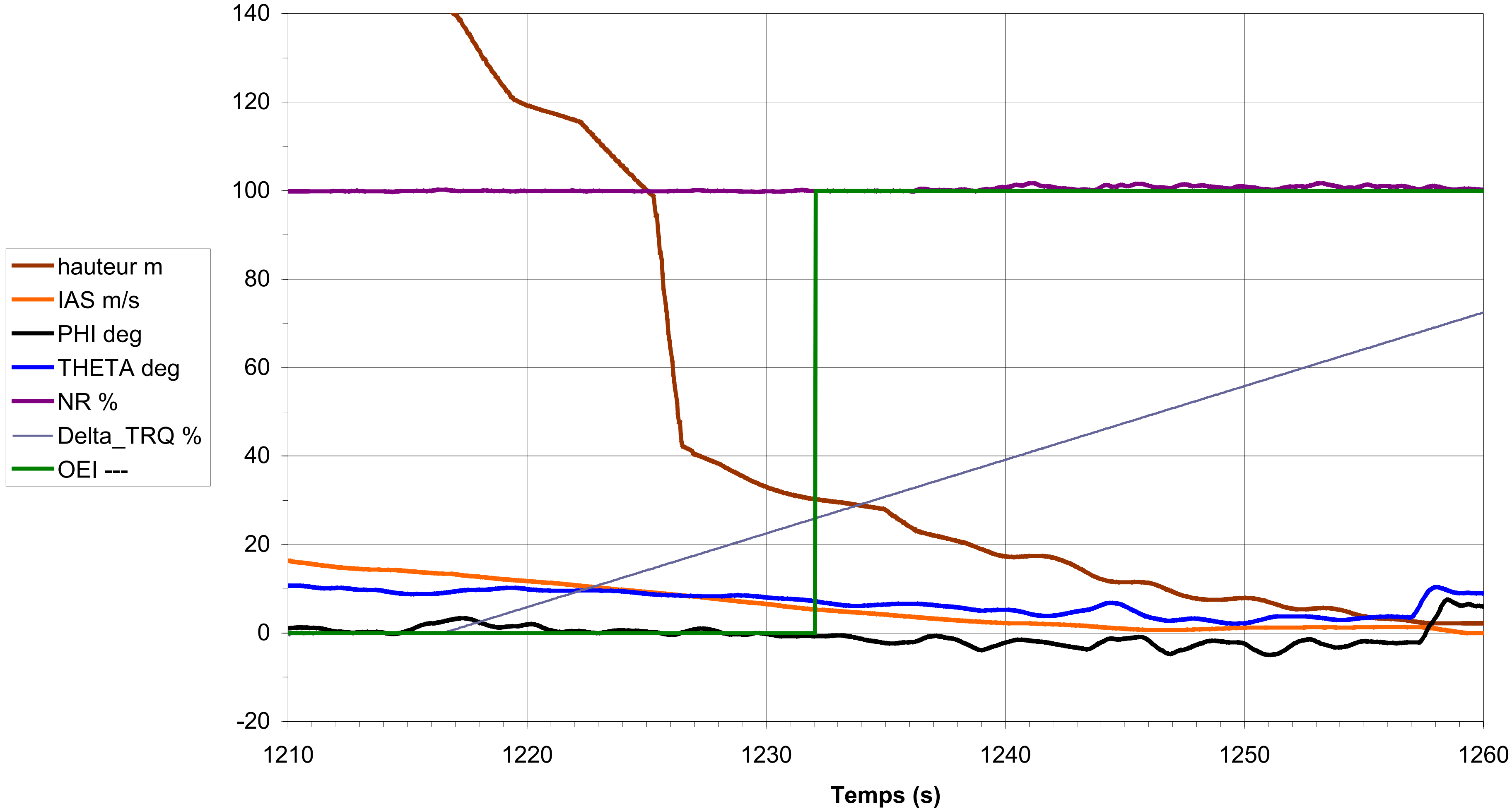



TRPH Pilote 3 Panne 3 - Paramètres de vol
hauteur m
IAS m/s
PHI deg
THETA deg
NR %
Delta_TRQ %
OEI ---
120
100
80
60
40
20
0
-20
1545
1550
1555
1560
1565
1570
1575
1580
1585
Temps (s)

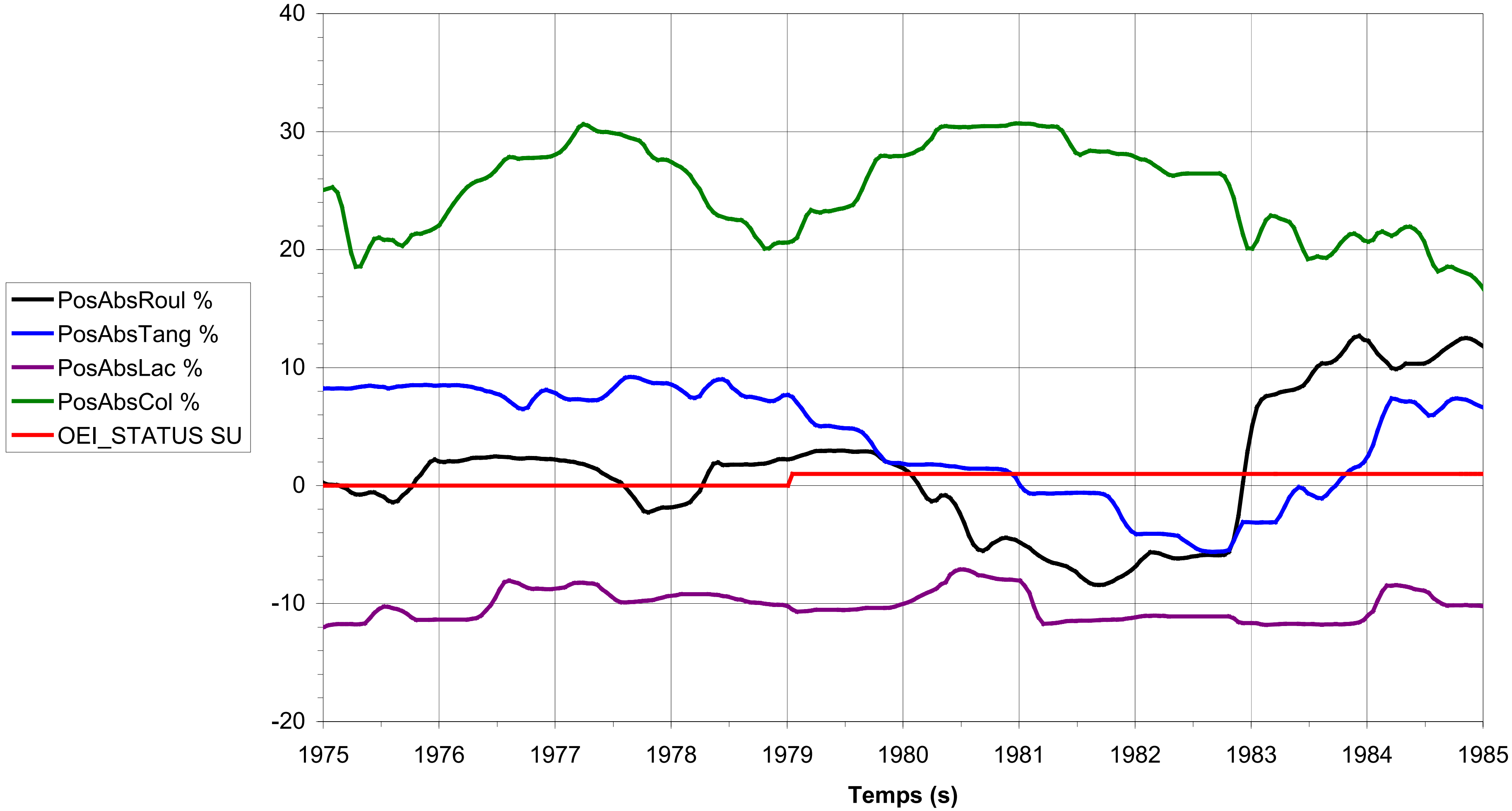
TRPH Pilote 4 Panne 3 - Positions Commandes



TRPH Pilote 4 Panne 3 - Paramètres de vol



TRPH Pilote 5 Panne 3 - Positions Commandes



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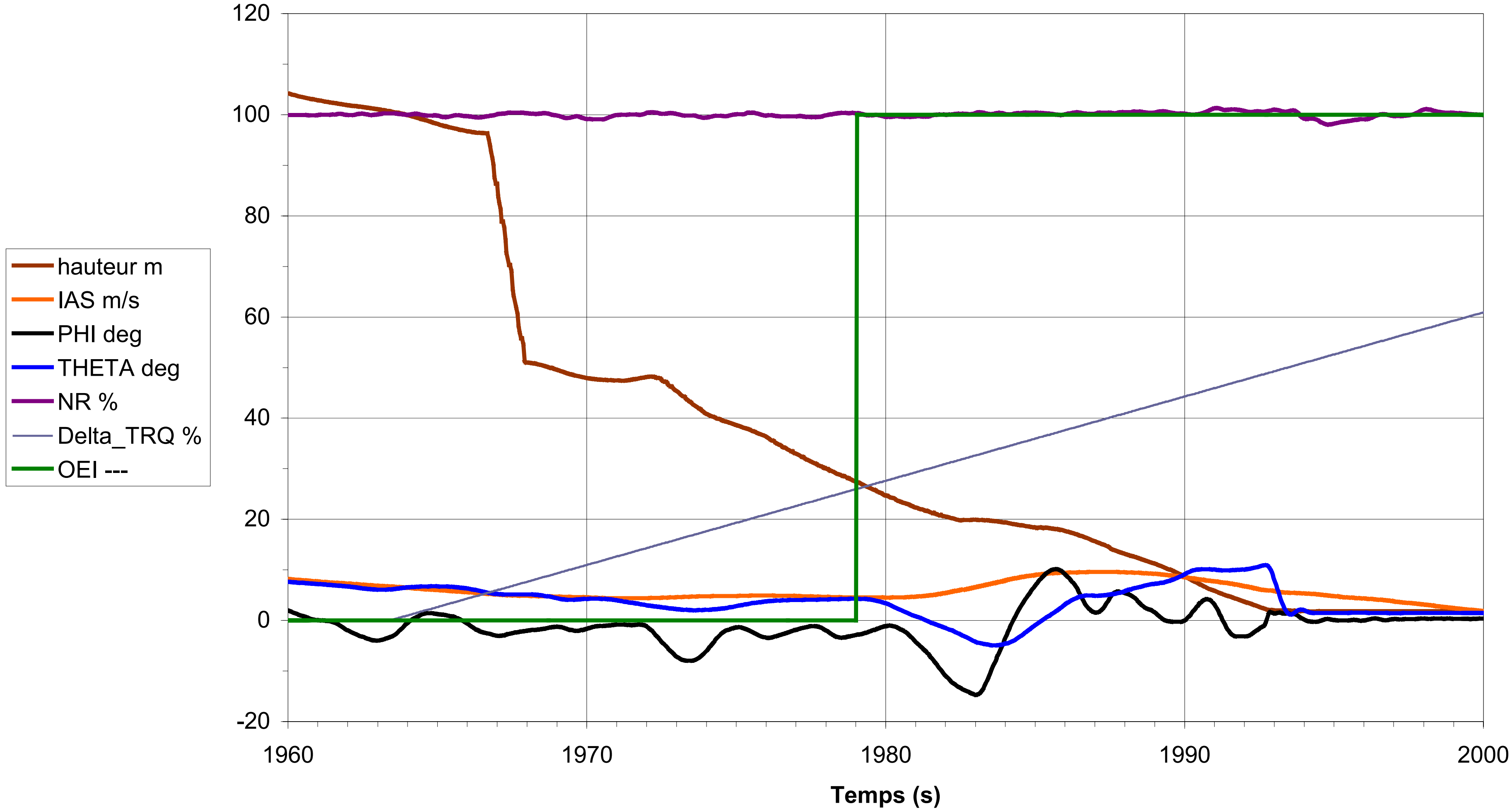
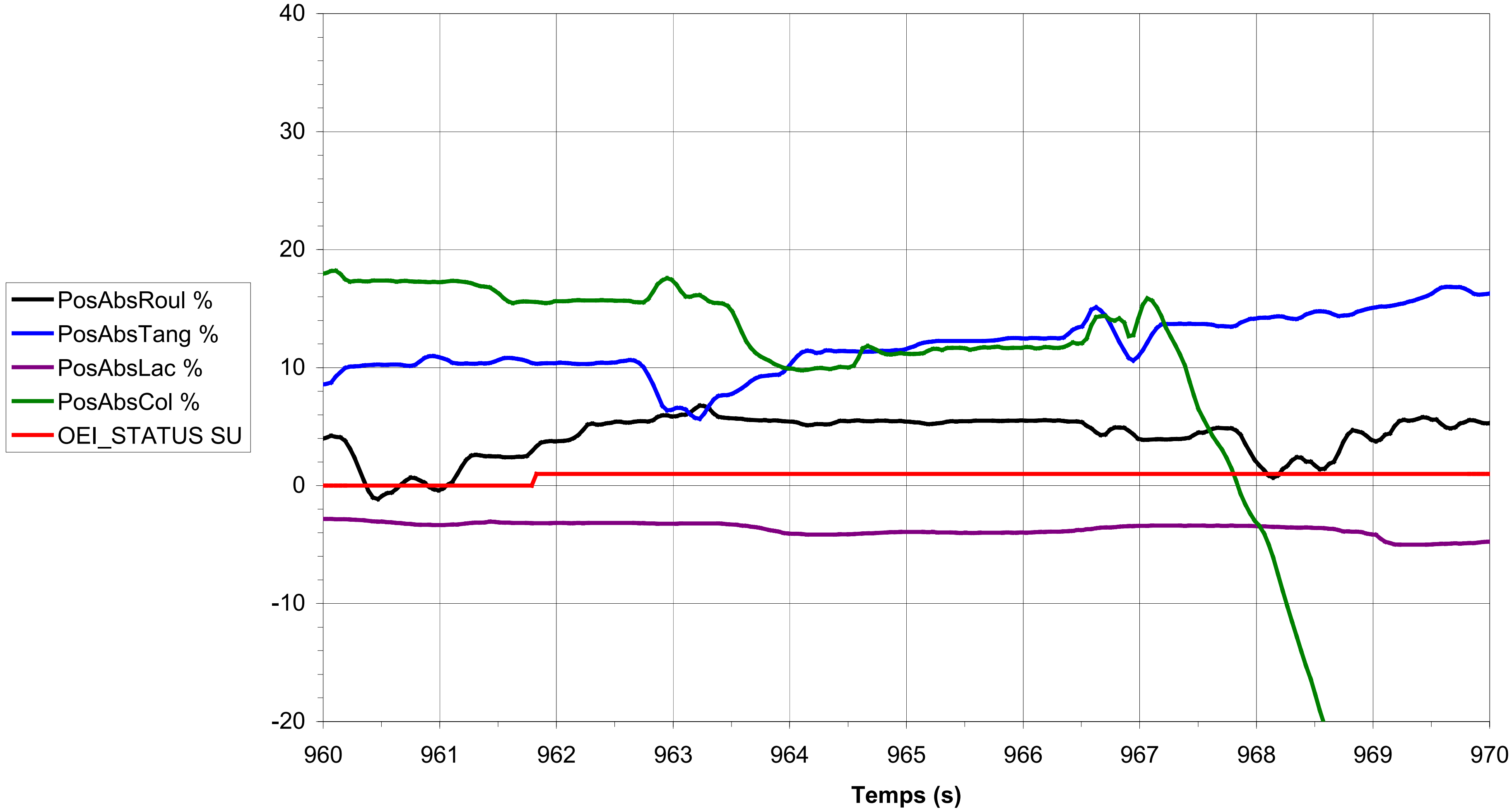
TRPH Pilote 5 Panne 3 - Paramètres de vol



TRPH Pilote 6 Panne 3 - Positions Commandes



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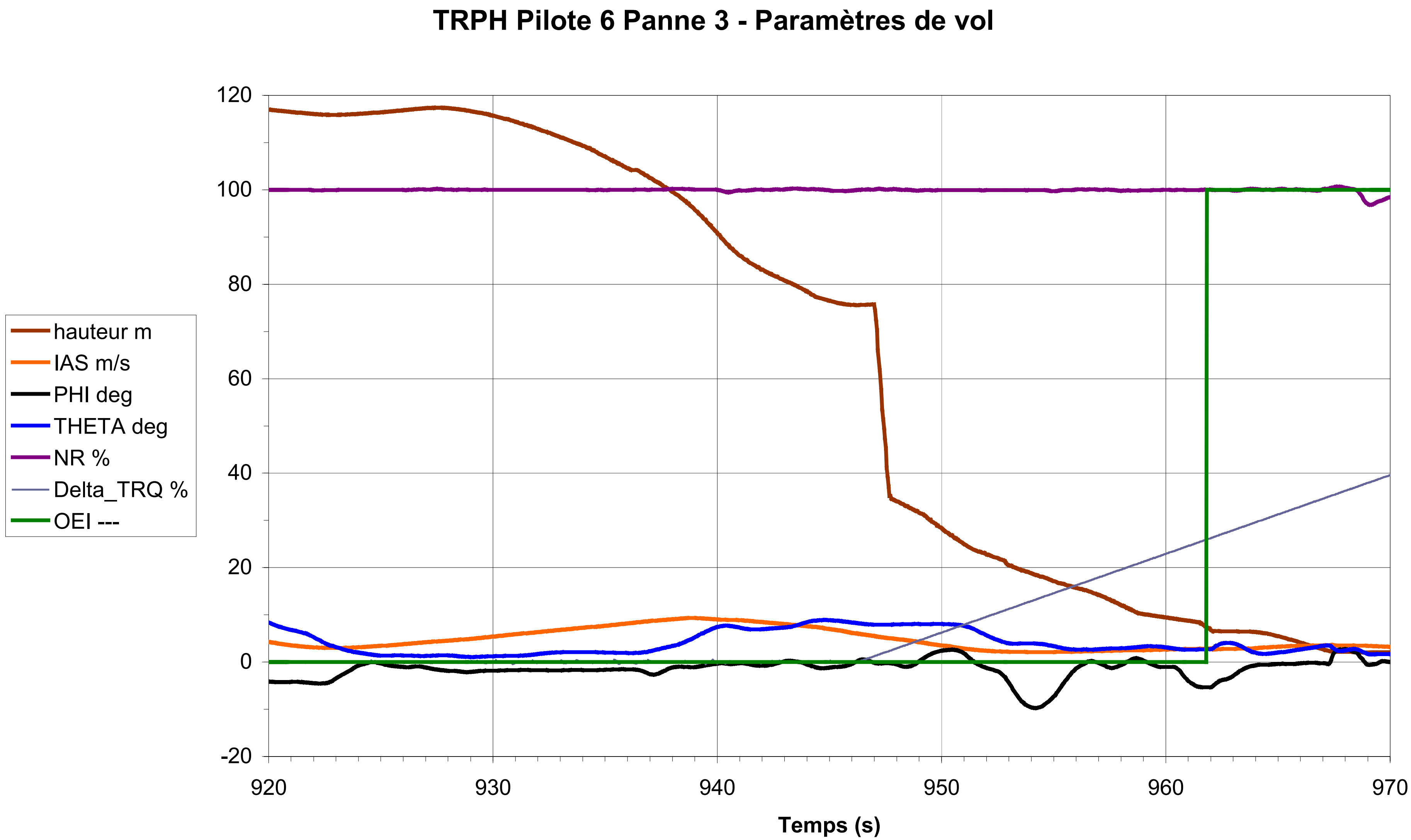
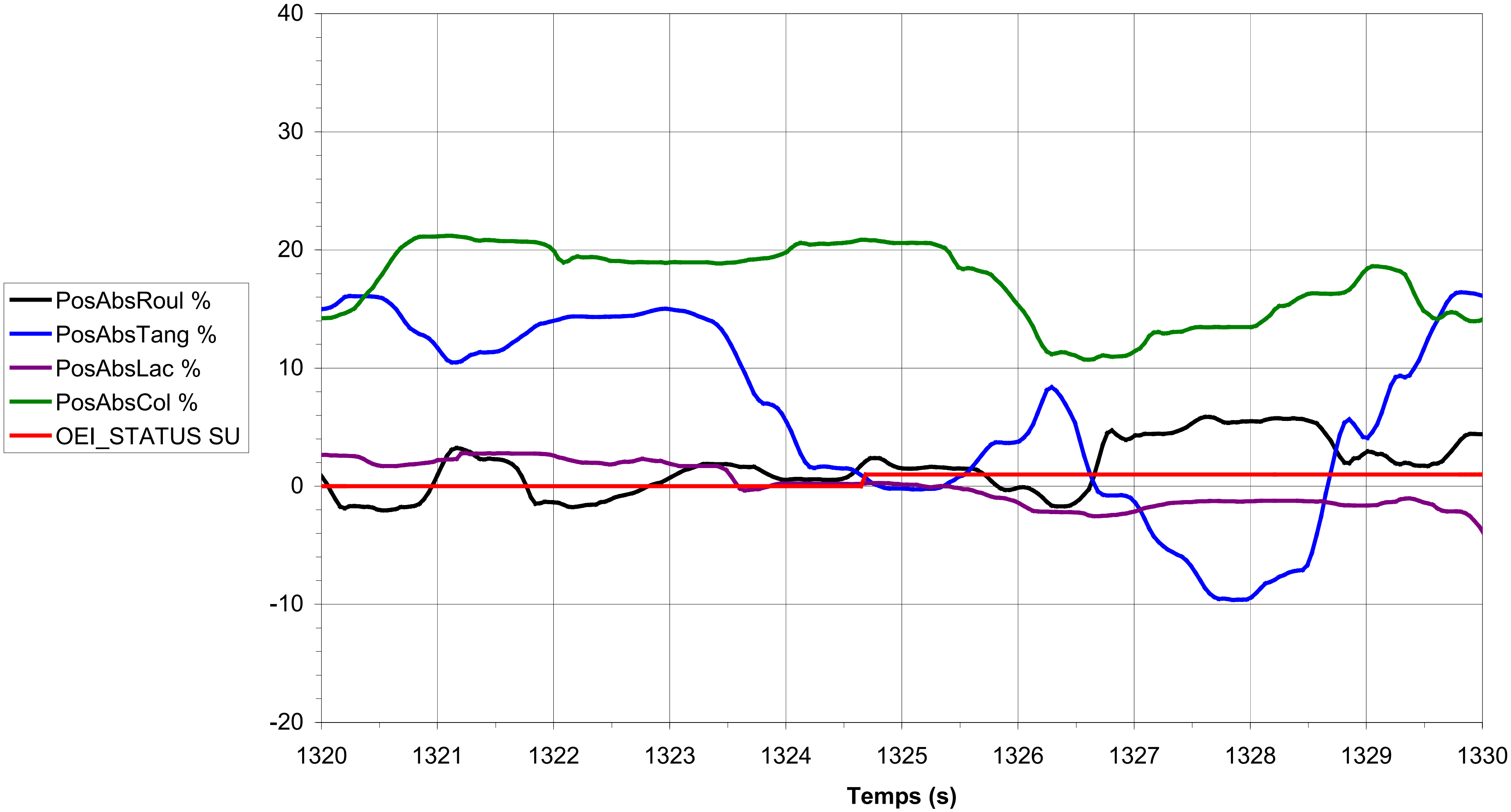
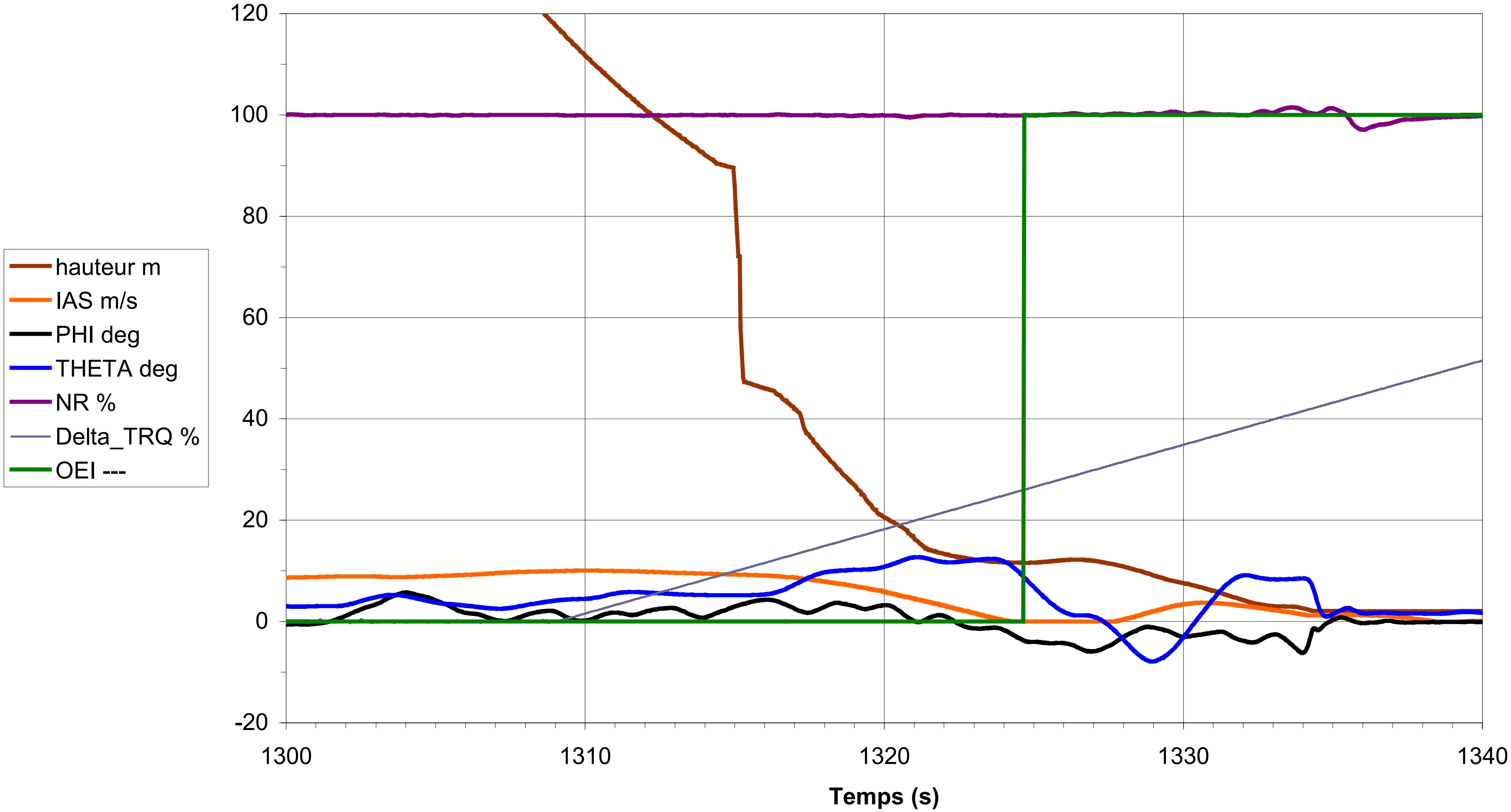
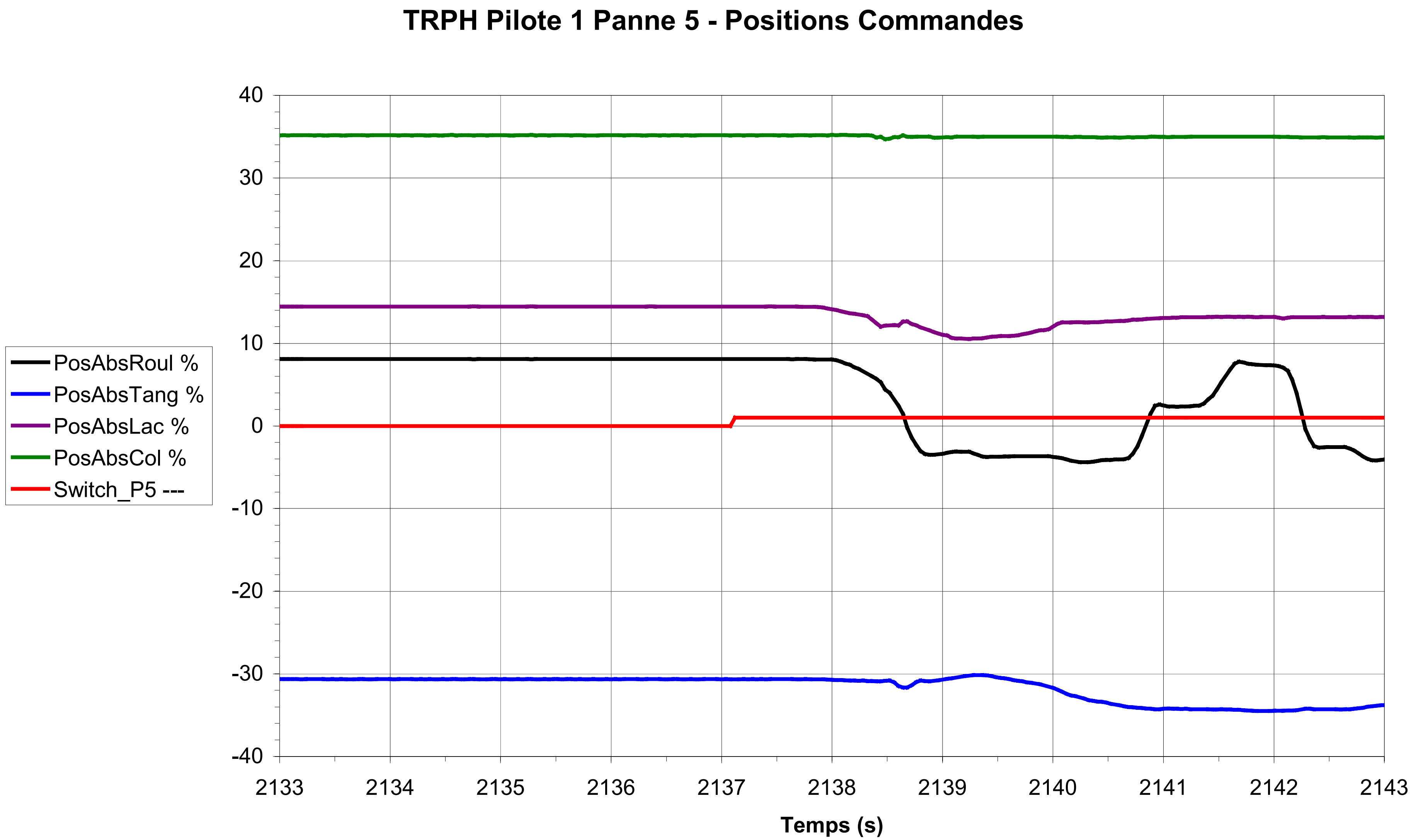


TRPH Pilote 7 Panne 3 - Positions Commandes



TRPH Pilote 7 Panne 3 - Paramètres de vol




TRPH Pilote 1 Panne 5 - Positions Commandes
40
30
20
10
0
-10
-20
-30
-40
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
Temps (s)
PosAbsRoul %
PosAbsTang %
PosAbsLac %
PosAbsCol %
Switch_P5 ---

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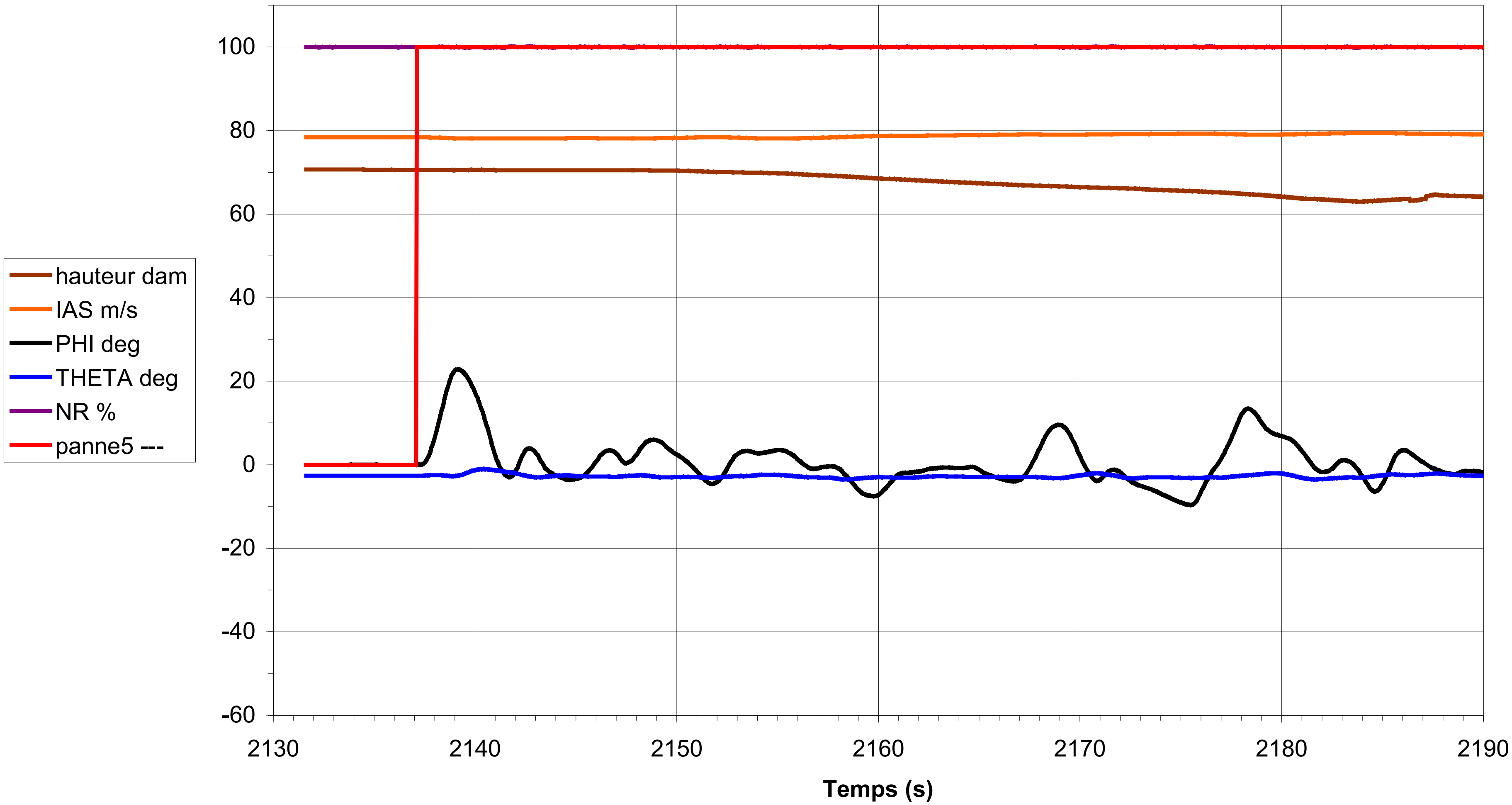
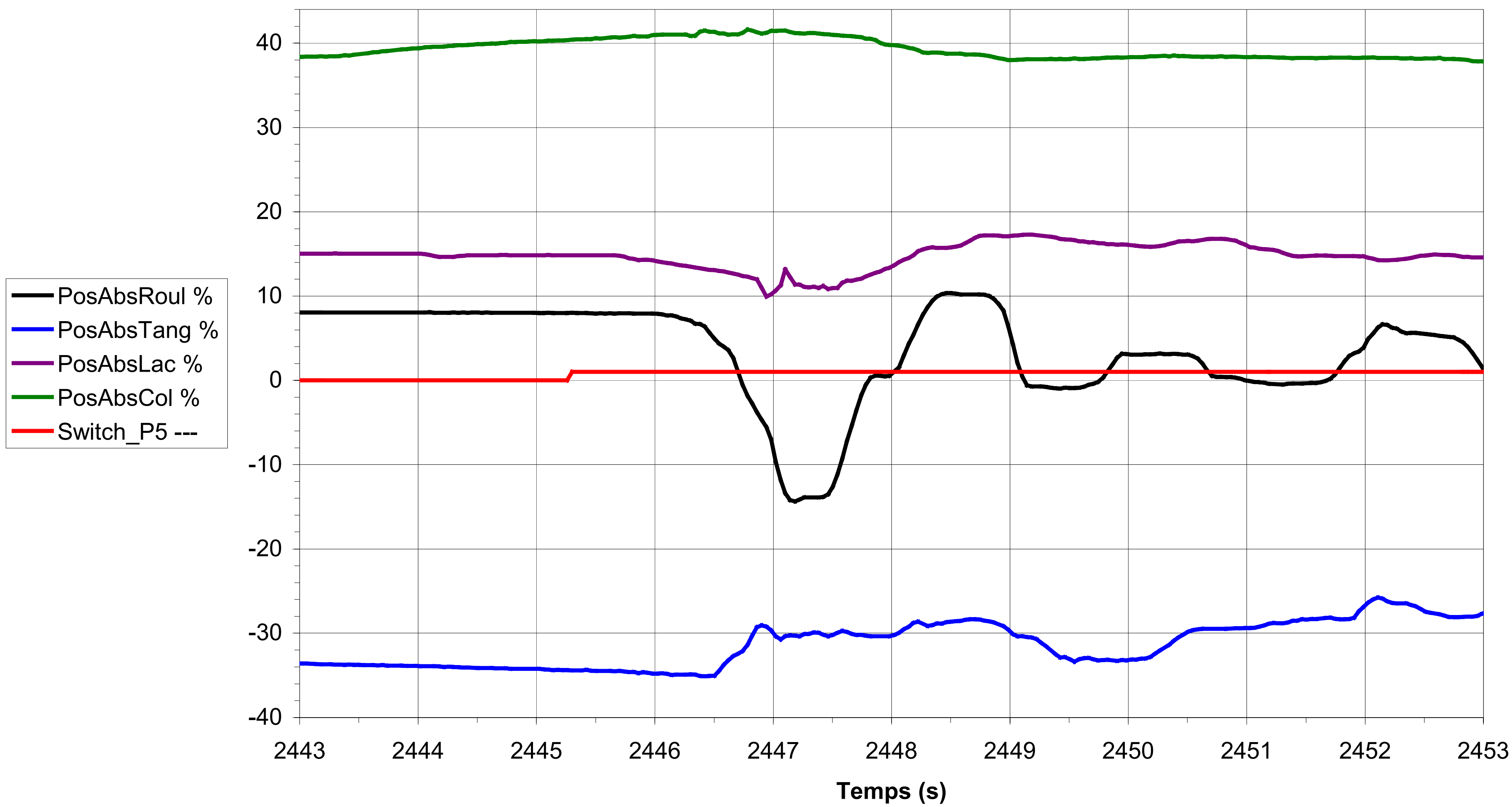
TRPH Pilote 1 Panne 5 - Paramètres de vol



TRPH Pilote 2 Panne 5 - Positions Commandes



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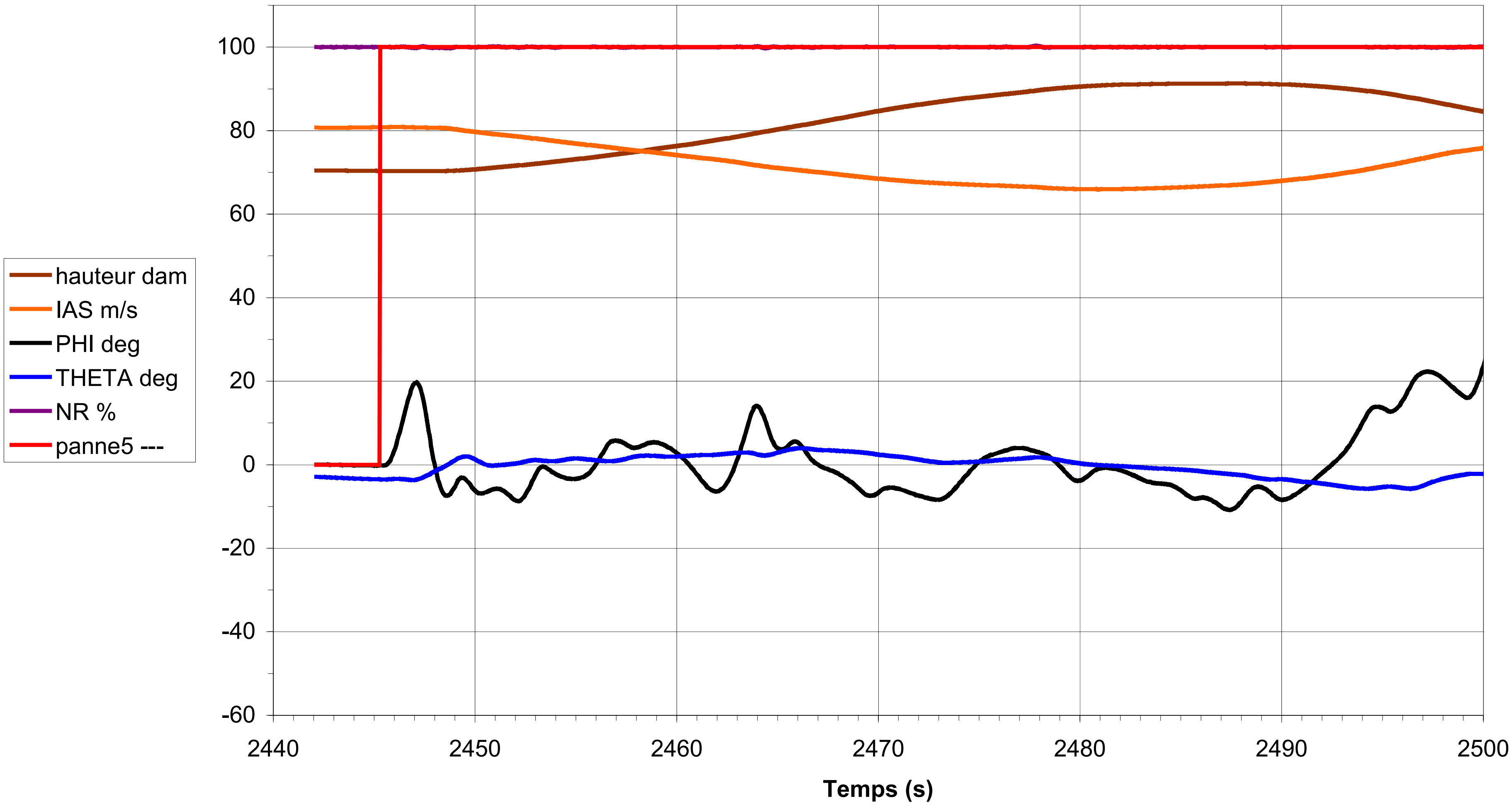
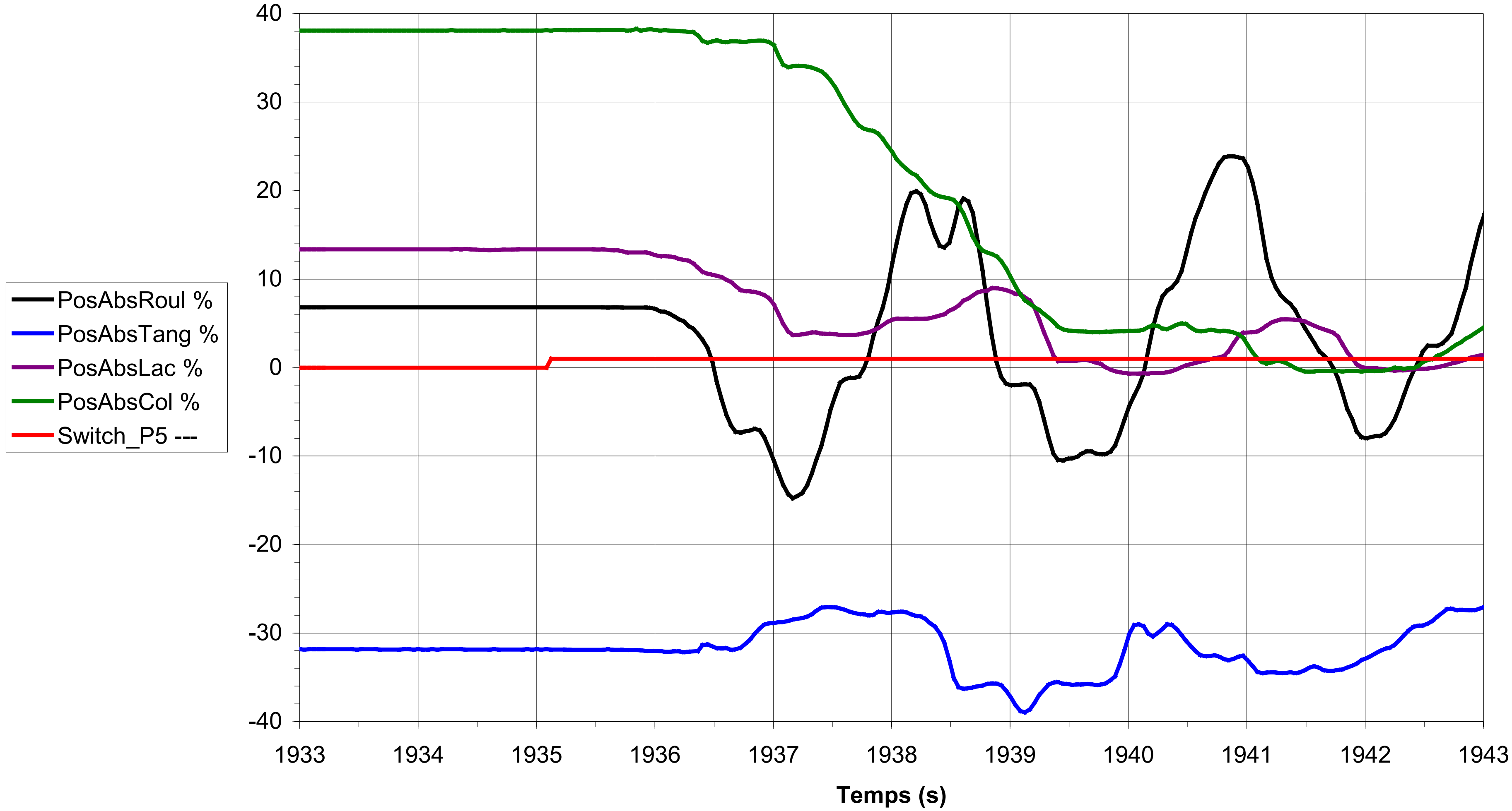
an EADS Company

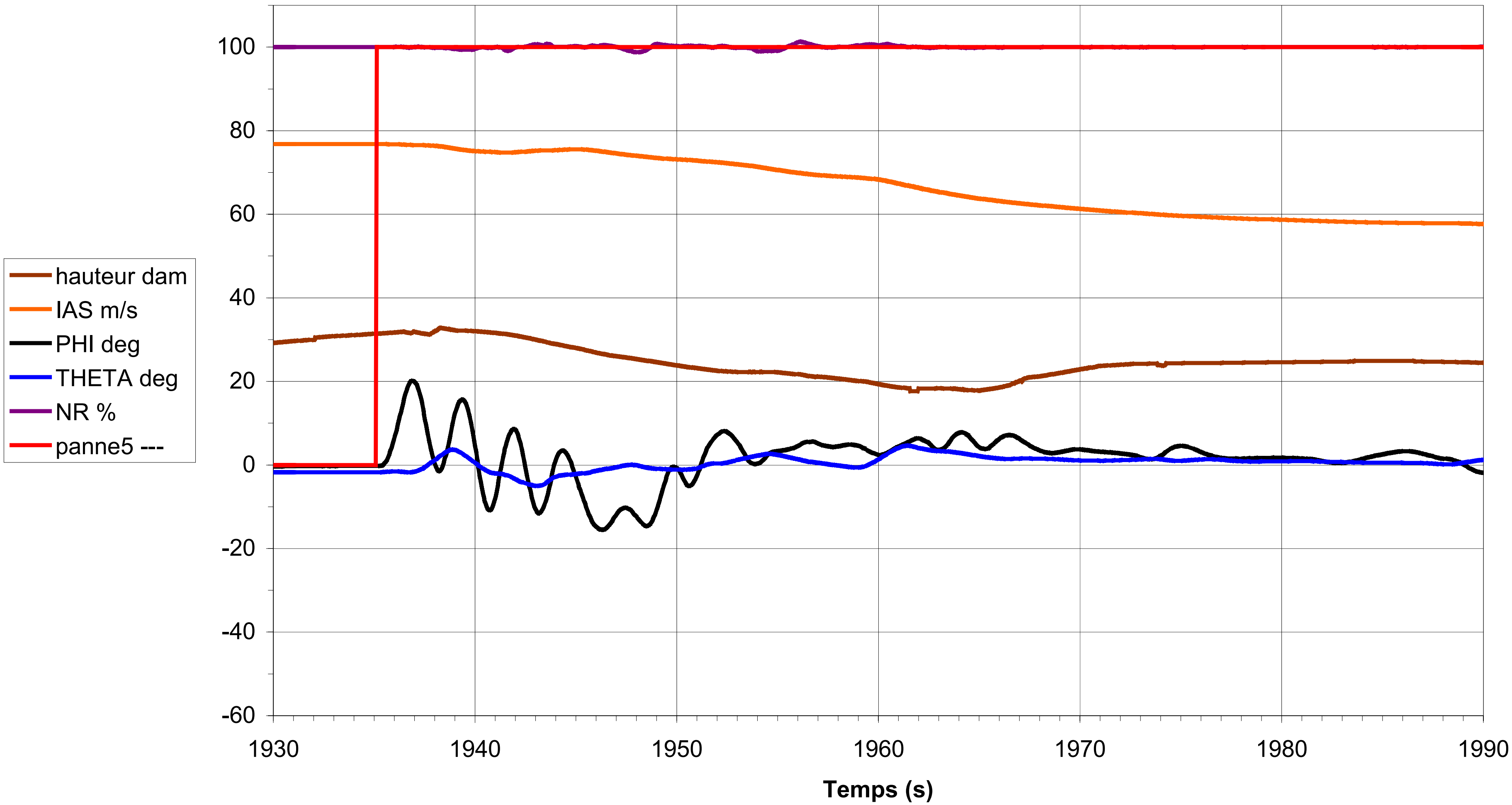
TRPH Pilote 2 Panne 5 - Paramètres de vol

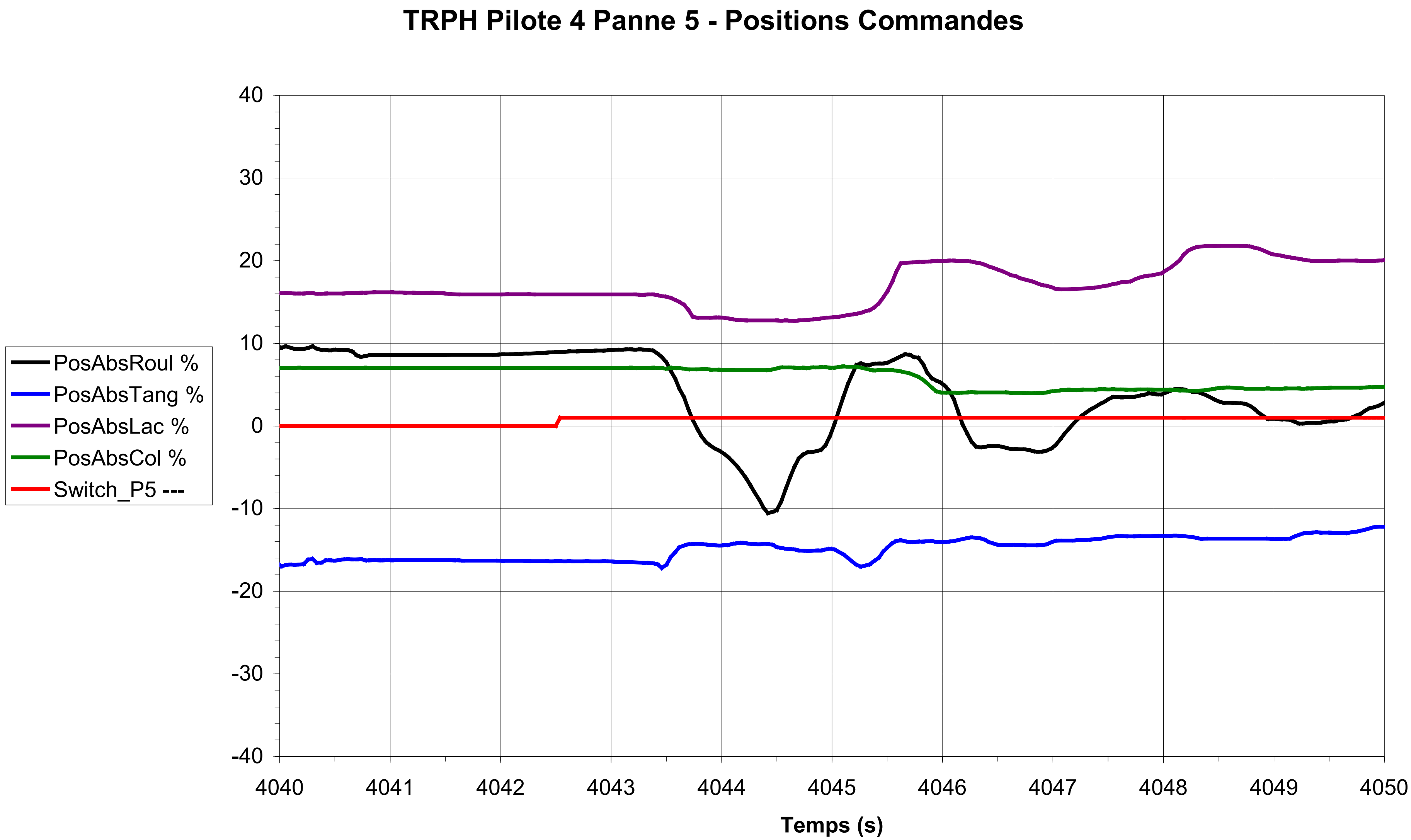


TRPH Pilote 3 Panne 5 - Positions Commandes

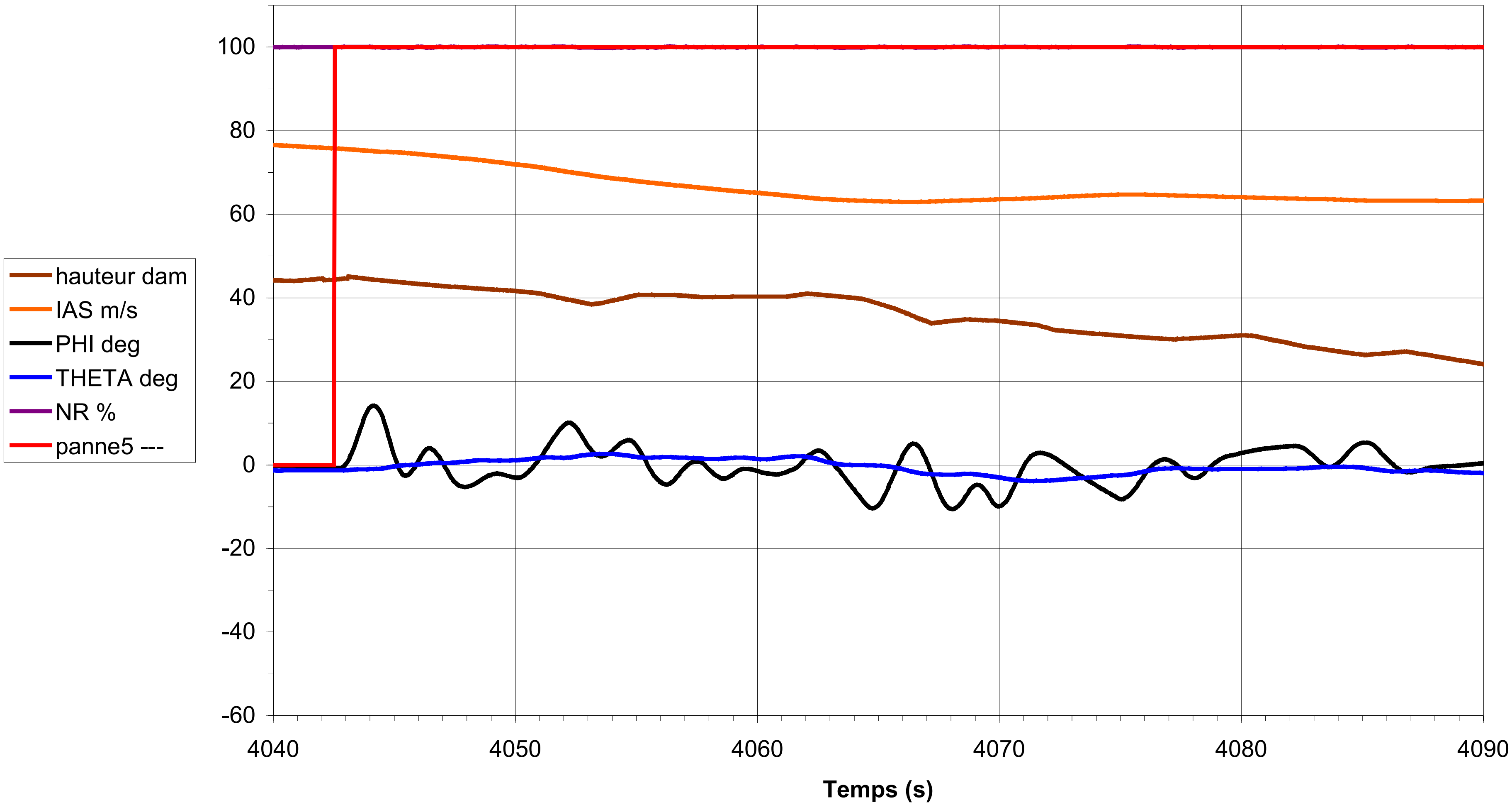


TRPH Pilote 3 Panne 5 - Paramètres de vol

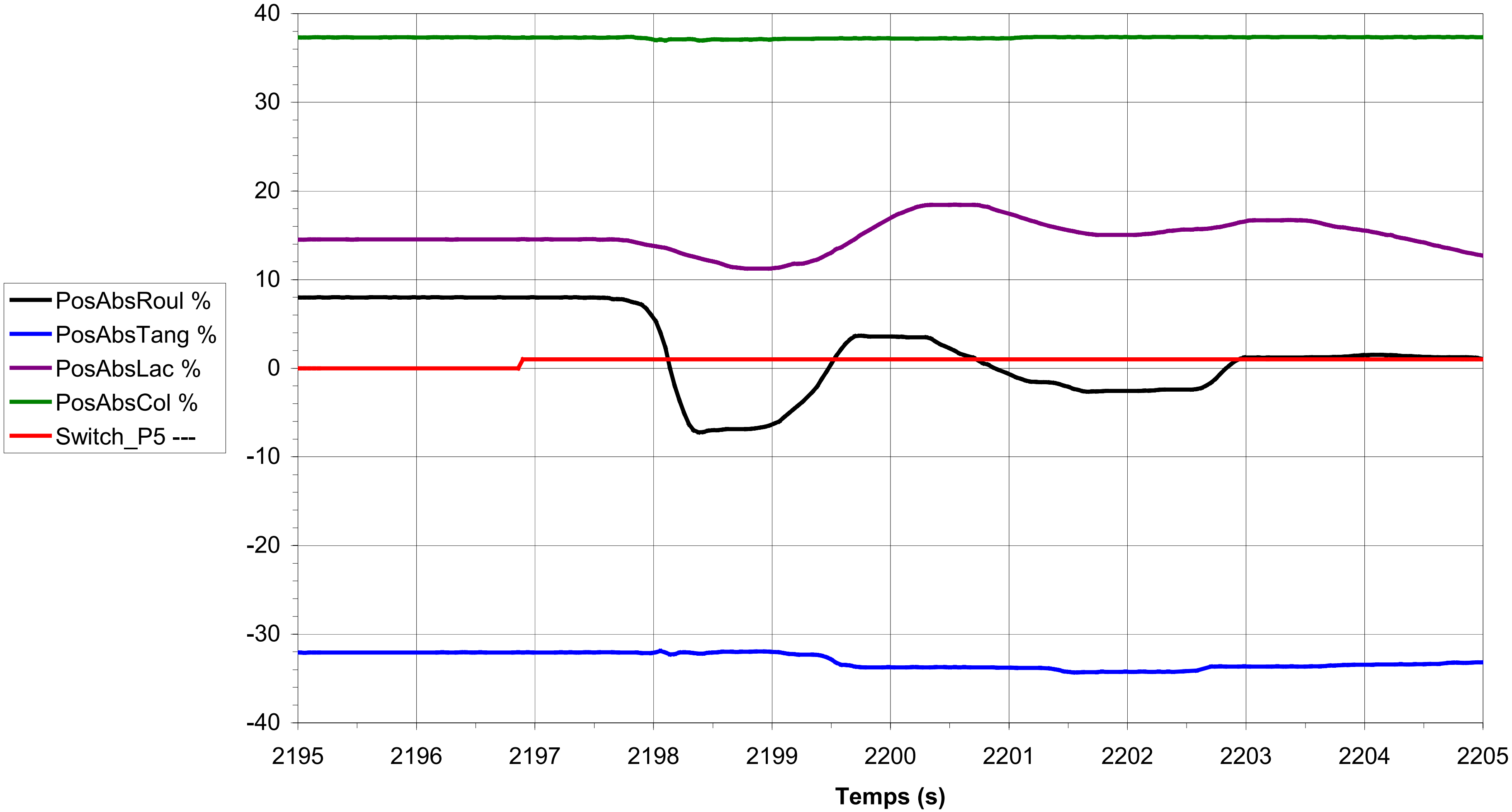



TRPH Pilote 4 Panne 5 - Positions Commandes
40
30
20
10
0
-10
-20
-30
-40
4040
4041
4042
4043
4044
4045
4046
4047
4048
4049
4050
Temps (s)
PosAbsRoul %
PosAbsTang %
PosAbsLac %
PosAbsCol %
Switch_P5 ---

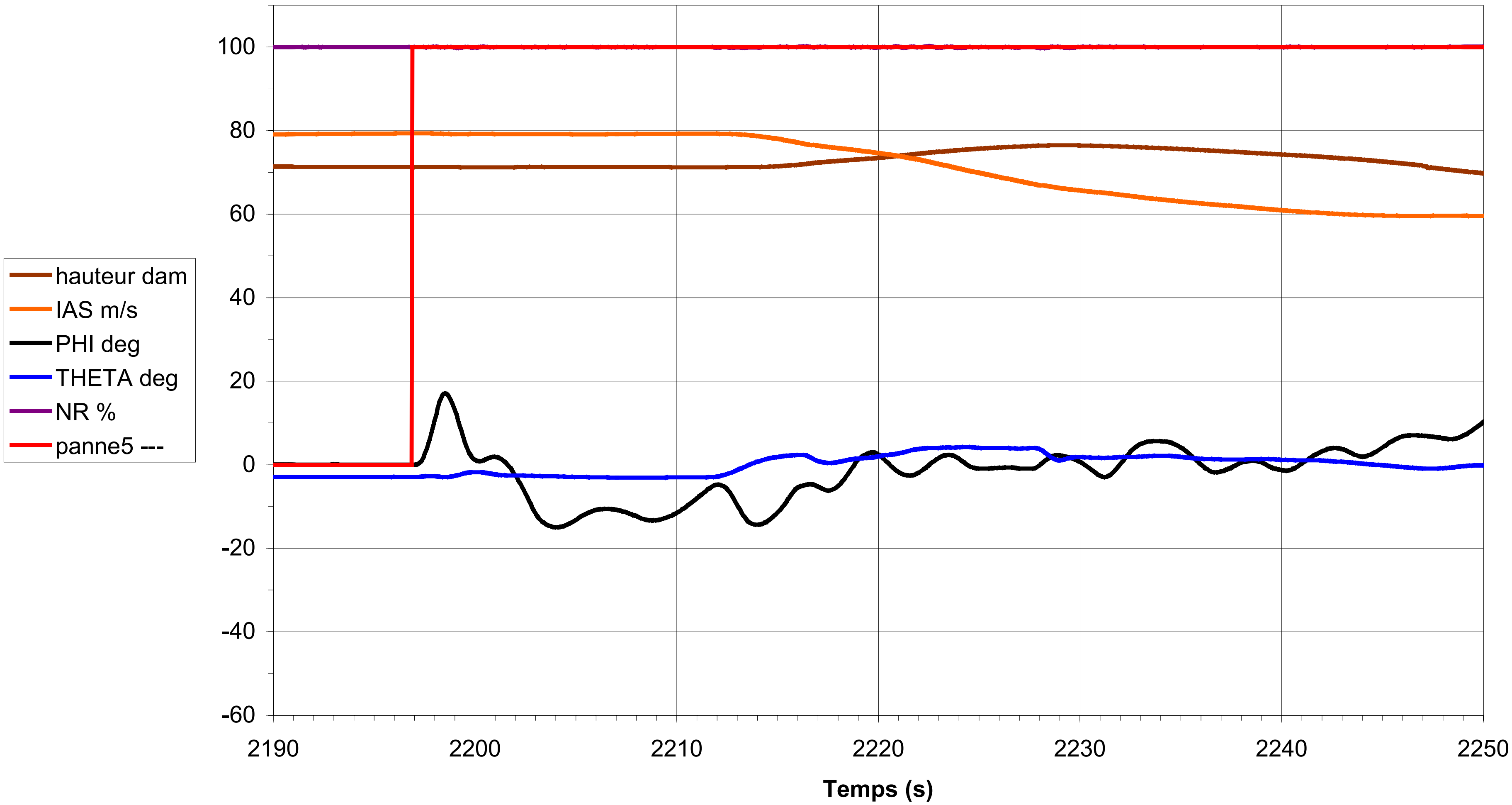
TRPH Pilote 4 Panne 5 - Paramètres de vol



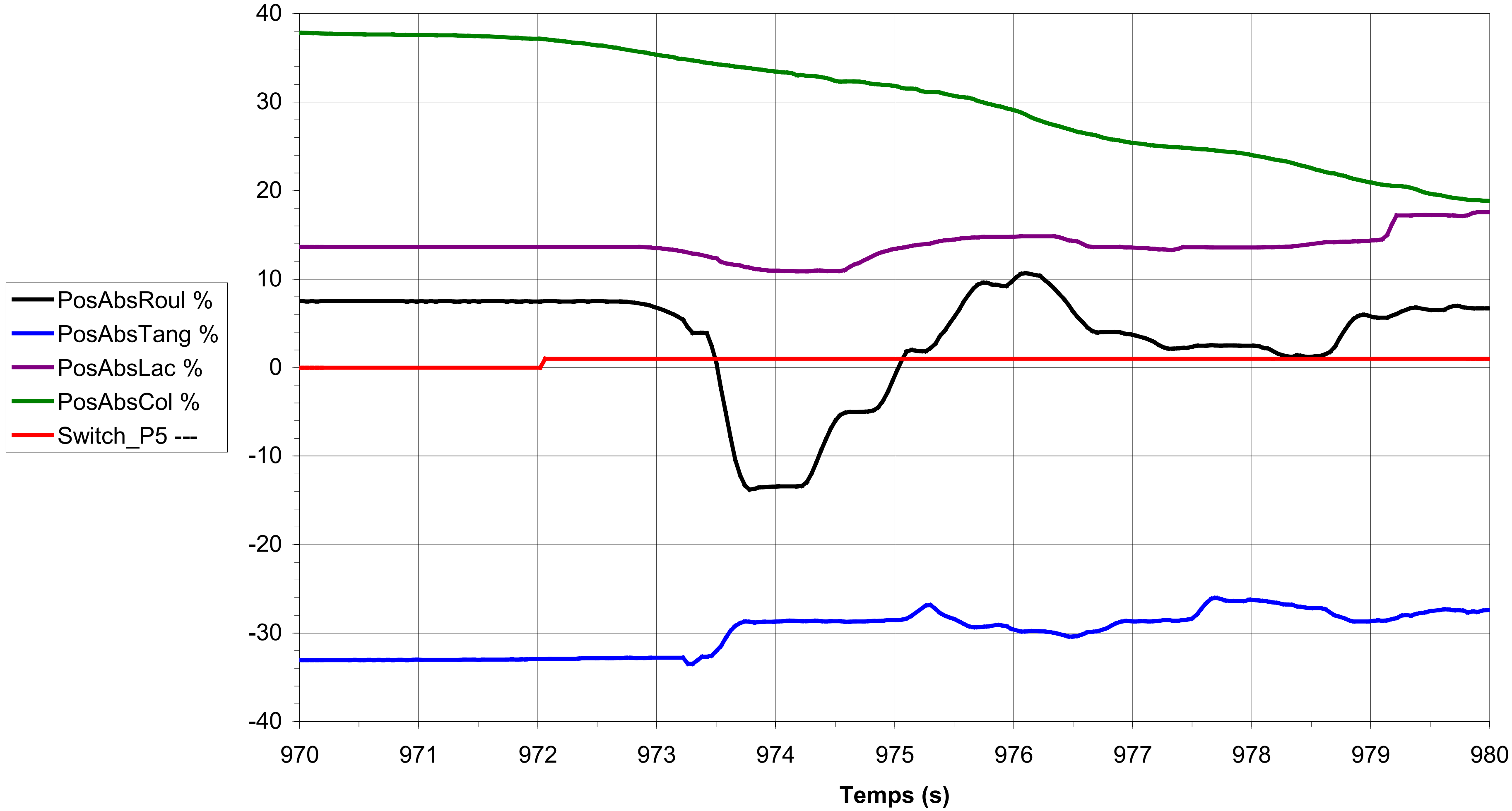
TRPH Pilote 5 Panne 5 - Positions Commandes



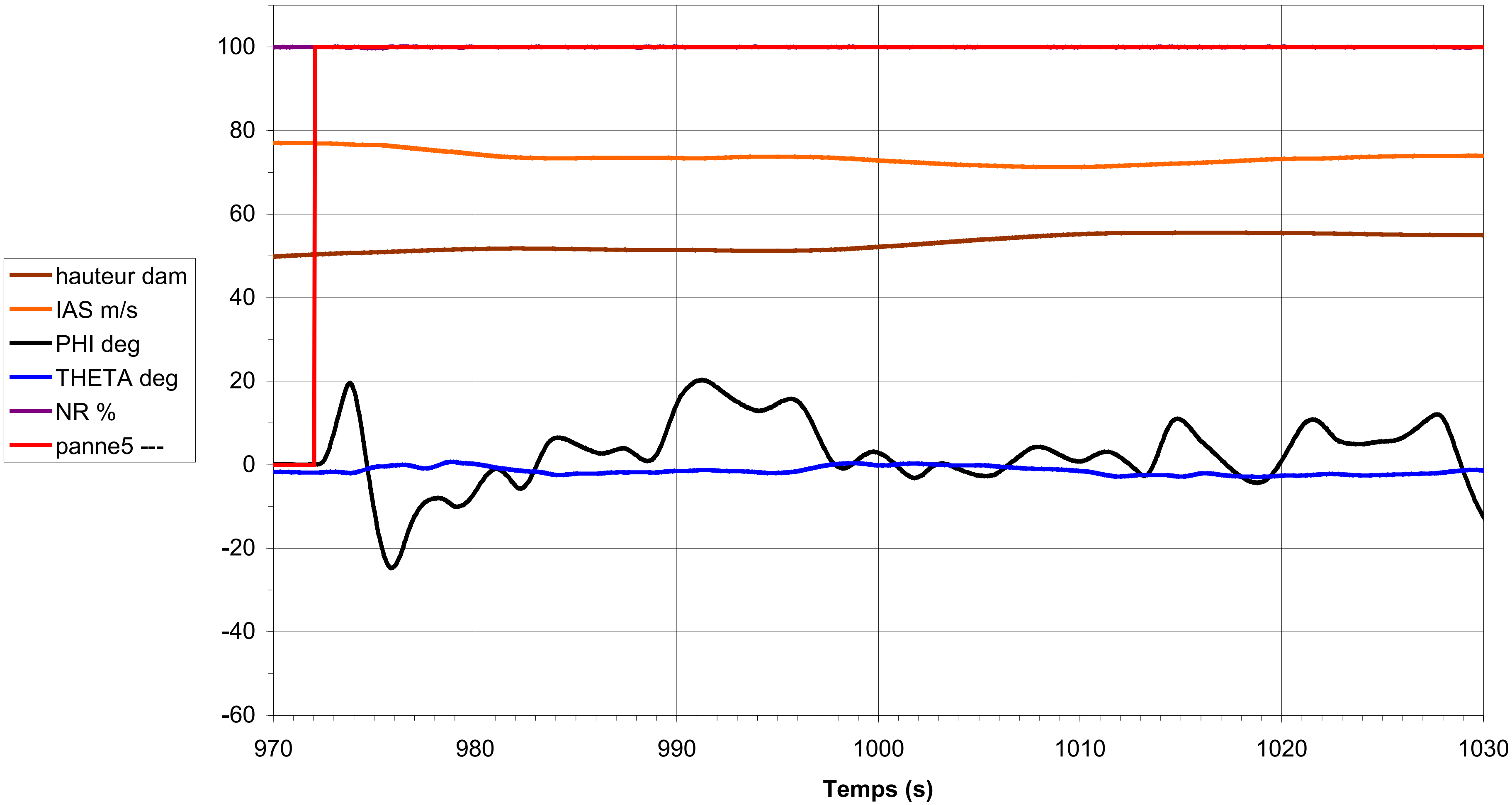
TRPH Pilote 5 Panne 5 - Paramètres de vol

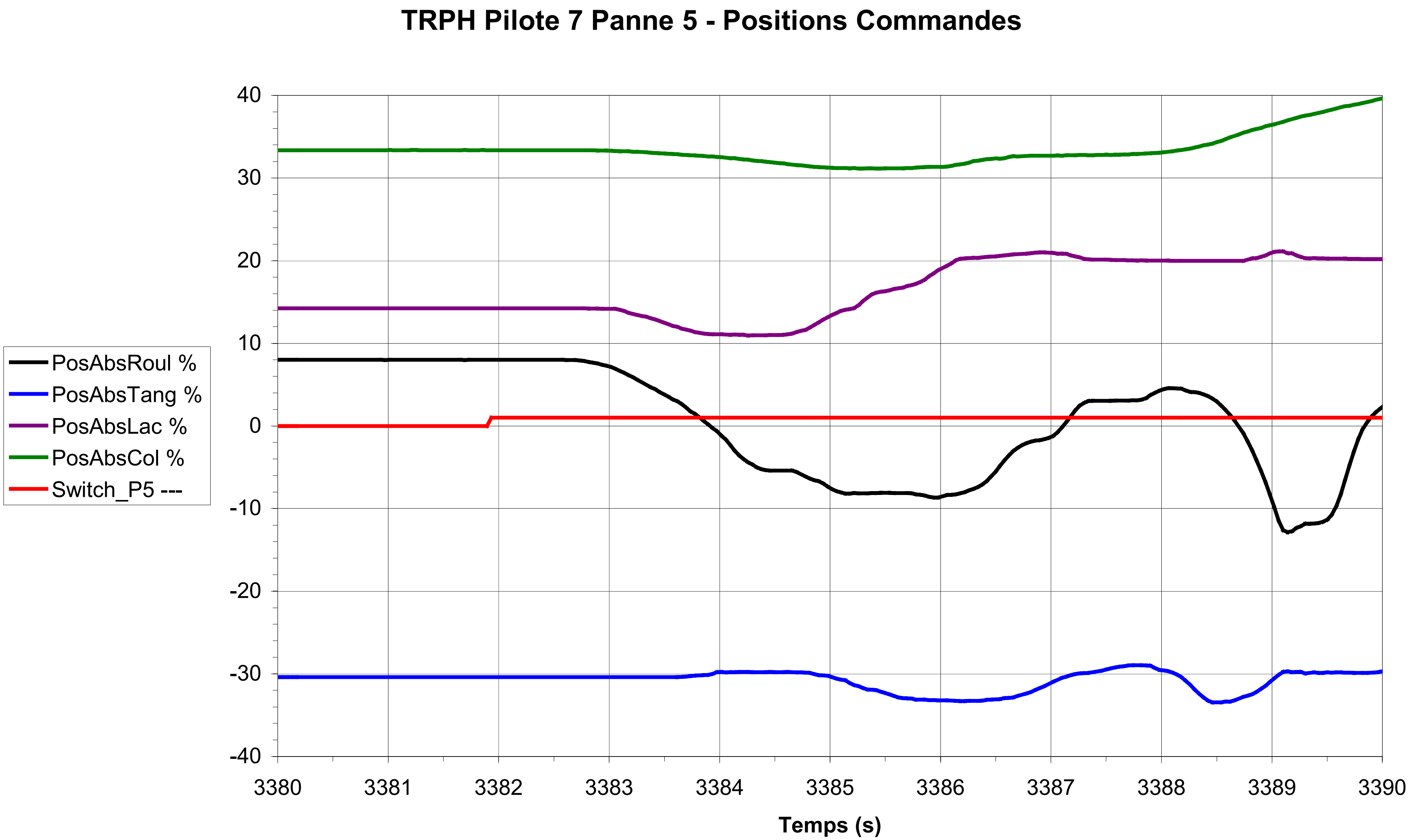


TRPH Pilote 6 Panne 5 - Positions Commandes

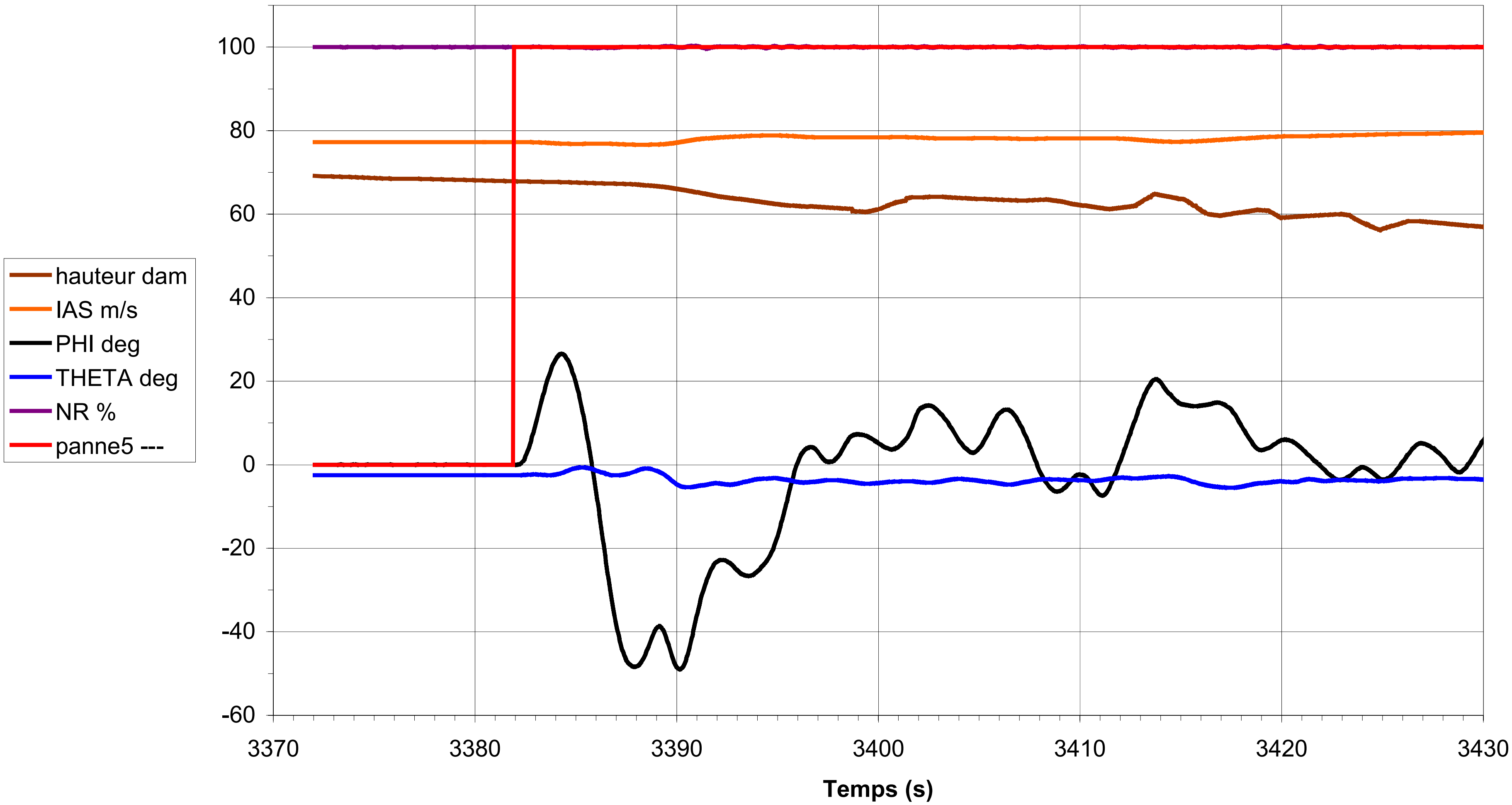


TRPH Pilote 6 Panne 5 - Paramètres de vol




TRPH Pilote 7 Panne 5 - Positions Commandes
PosAbsRoul %
PosAbsTang %
PosAbsLac %
PosAbsCol %
Switch_P5 ---
40
30
20
10
0
-10
-20
-30
-40
3380
3381
3382
3383
3384
3385
3386
3387
3388
3389
3390
Temps (s)

TRPH Pilote 7 Panne 5 - Paramètres de vol



APPENDIX 3 : WORKLOAD EVALUATION QUESTIONNAIRES

TRPH

EVALUATION DE LA CHARGE DE TRAVAIL PILOTE

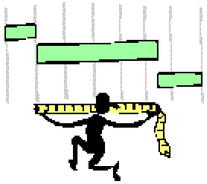
- DEBRIEFING -

1- CREWMEMBER SPECIFICITIES

FOR PILOT AND COPILOT

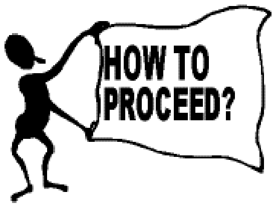
NAME:			BIRTH DATE:	
ORGANIZATION	PRESENT:		PREVIOUS:	
HELICO FLIGHT HOURS *TOTAL AMOUNT:*	LIGHT H/C:	4/6 T:	8/10 T:	> 10 T:
OPERATIONAL EXPERIENCE (FLIGHT HOURS)	NOE:	CONTOUR FLIGHT:	SHIP LANDING:	
	DAY:	NIGHT: NVG:	IMC: IFR:	FLIR:
SIMULATOR HABIT (FLIGHT HOURS)	MOVING BASE:		FIXED BASE:	
	WITH VISUAL: LIGHT H/C: 4/6 T: 8/10 T: > 10 T:	WITHOUT VISUAL: LIGHT H/C: 4/6 T: 8/10 T: > 10 T:	WITH VISUAL: LIGHT H/C: 4/6 T: 8/10 T: > 10 T:	WITHOUT VISUAL: LIGHT H/C: 4/6 T: 8/10 T: > 10 T

Breakdown of scenario into human behavior evolution subsegments:



SUB-SEGMENT	DESCRIPTION OF THE SUBSEGMENT	ALLOCATED TIME	PERFORMED TIME
1			
2			
3			
4			
5			
6			
7			
8			

3- WORKLOAD ASSESSMENT QUESTIONNAIRES (WLAQ)

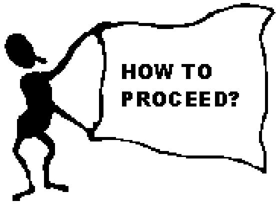


The workload assessment questionnaires are shared in 4 parts which express the main workload components involved in a helicopter crewmember workload. These 4 workload components are:

- ***mental effort,***
- ***time constraint,***
- ***stress,***
- ***physio effort.***

Two kinds of questionnaires have to be filled per components (with an additive one for the mental workload, explained in detail inside). These two kinds of questionnaires are the following:

3- WORKLOAD ASSESSMENT QUESTIONNAIRES (WLAQ)



THE WORKLOAD ASSESSMENT QUESTIONNAIRES ARE SHARED IN 4 PARTS WHICH EXPRESS THE MAIN WORKLOAD COMPONENTS INVOLVED IN A HELICOPTER CREWMEMBER WORKLOAD. THESE 4 WORKLOAD COMPONENTS ARE:

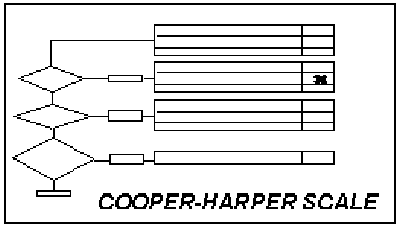
- ***MENTAL EFFORT,***
- ***TIME CONSTRAINT,***
- ***STRESS,***
- ***PHYSIO EFFORT.***

TWO KINDS OF QUESTIONNAIRES HAVE TO BE FILLED PER COMPONENTS (WITH AN ADDITIVE ONE FOR THE MENTAL WORKLOAD, EXPLAINED IN DETAIL INSIDE). THESE TWO KINDS OF QUESTIONNAIRES ARE THE FOLLOWING:

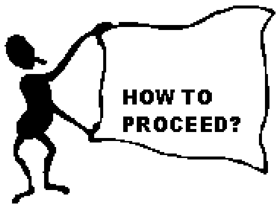
FIRST QUESTIONNAIRE

THE GOAL OF THIS QUESTIONNAIRE IS TO EVALUATE THE WORKLOAD COMPONENT LEVEL FELT DURING A SUB-SEGMENT, WITH THE CONFIGURATION PROPOSED (TACTICAL SCENARIO, SIMULATOR, KNOWLEDGE AND TRAINING, SYSTEM FUNCTIONS). YOU HAVE TO FOLLOW THE FLOW CHART TO DETERMINE YOUR FELT LEVEL.

FOR EACH COMPONENT



3- WORKLOAD ASSESSMENT QUESTIONNAIRES (WLAQ)



THE WORKLOAD ASSESSMENT QUESTIONNAIRES ARE SHARED IN 4 PARTS WHICH EXPRESS THE MAIN WORKLOAD COMPONENTS INVOLVED IN A HELICOPTER CREWMEMBER WORKLOAD. THESE 4 WORKLOAD COMPONENTS ARE:

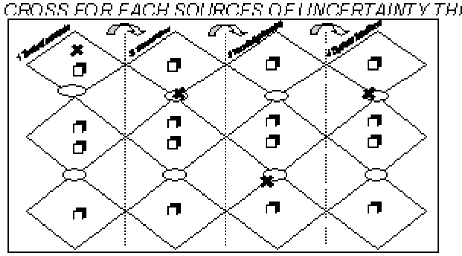
- ***MENTAL EFFORT,***
- ***TIME CONSTRAINT,***
- ***STRESS,***
- ***PHYSIO EFFORT.***

TWO KINDS OF QUESTIONNAIRES HAVE TO BE FILLED PER COMPONENTS (WITH AN ADDITIVE ONE FOR THE MENTAL WORKLOAD, EXPLAINED IN DETAIL INSIDE). THESE TWO KINDS OF QUESTIONNAIRES ARE THE FOLLOWING:

SECOND QUESTIONNAIRE

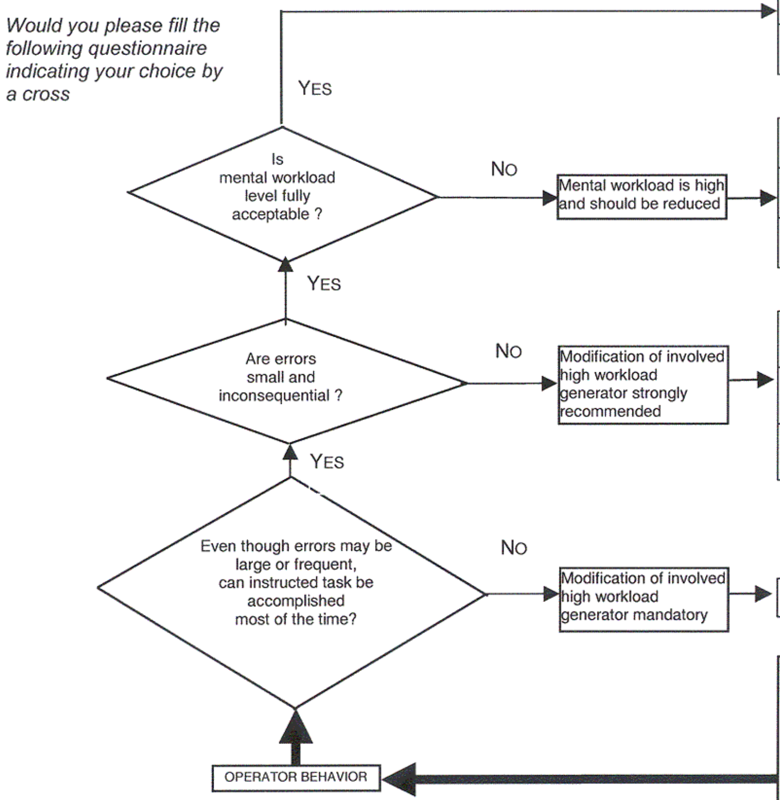
THE GOAL OF THIS QUESTIONNAIRE IS TO EVALUATE THE INFLUENCE OF UNCERTAINTY SOURCES ON YOUR ASSESSMENT OF THE WORKLOAD COMPONENT FOR THE SUB-SEGMENT. THE UNCERTAINTY SOURCES ARE: TACTICAL SCENARIO, SIMULATOR, KNOWLEDGE/TRAINING, SYSTEM FUNCTIONS. THESE INFLUENCE COULD HAVE LEAD TO ESTIMATE YOUR WORKLOAD COMPONENT IN A DIFFERENT WAY OF THIS WHICH COULD BE ASSESSED IN A REAL SITUATION.
YOU HAVE TO CROSS FOR EACH SOURCES OF UNCERTAINTY THE

FOR EACH COMPONENT

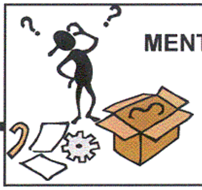


3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

A - WORKLOAD COMPONENTS LEVEL ASSESSMENT -



Difficulty level	Operator demand level	Crewmember feeling
Very easy, highly desirable	Operator mental effort is negligeable	
Easy, desirable	Operator mental effort is low	
Fair, mild difficulty	Moderate operator mental effort is required to perform the tasks	
Minor but annoying difficulty	Moderately high operator mental effort is required to perform the tasks	
Moderately objectionable difficulty	High operator mental effort is required to perform the tasks	
Very objectionable but tolerable difficulty	Maximum operator mental effort is required to perform the tasks	
Major difficulty	Maximum operator mental effort is required to bring errors to moderate level	
Major difficulty	Maximum operator mental effort is required to avoid large or numerous errors	
Major difficulty	Intense operator mental effort is required to accomplish task, but frequent or numerous errors persist	
Impossible	Instructed task cannot be accomplished reliably	



MENTAL EFFORT ASSESSMENT SCALE:

mental effort is intended to express the intensity of mental activity by means of quantifying the difficulties in finding information processing it and making decisions.

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3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

B- UNCERTAINTY SOURCE EFFECT ON WORKLOAD COMPONENT LEVEL ASSESSMENT -

Would you please fill the following questionnaire on uncertainty sources effect for the workload component ***MENTAL EFFORT*** *indicating your choice by a cross*

1 Tactical scenario

The proposed scenario was representative enough of a real tactical situation and allowed a **CORRECT** ☐ evaluation of the mental effort

OR

The proposed scenario could have been not representative of a real tactical situation, and so the mental effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The proposed scenario was not representative of a real tactical situation, and **I DON'T KNOW** ☐ its influence on the mental effort evaluation, either in a worse or either in a better way

2 Simulator

The simulator configuration was representative enough of the reality (ext. environment, cockpit, aircraft model) and allowed a **CORRECT** ☐ evaluation of the mental effort

OR

The simulator configuration could have not been representative of the reality (ext. environment, cockpit, aircraft model) and so the mental effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The simulator configuration not representative of the reality (ext. environment, cockpit, aircraft model), and **I DON'T KNOW** ☐ its influence on the mental effort evaluation, either in a worse or either in a better way

3 Knowledge/training

The knowledge and training was sufficient (system operation information/training level) and allowed a **CORRECT** ☐ evaluation of the mental effort

OR

The knowledge and training could have been not sufficient (system operation information/training level and so the mental effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The knowledge and training was not sufficient (system operation information/training level) and **I DON'T KNOW** ☐ its influence on the mental effort evaluation, either in a worse or either in a better way

4 System functions

The simulated system functions was representative enough of a real configuration and allowed a **CORRECT** ☐ evaluation of the mental effort

OR

The simulated system functions could have been not representative of a real configuration, being too much complicated, and so the mental effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The simulated system functions scenario was not representative of a real configuration and **I DON'T KNOW** ☐ its influence on the mental effort evaluation, either in a worse or either in a better way

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (MEUQ)

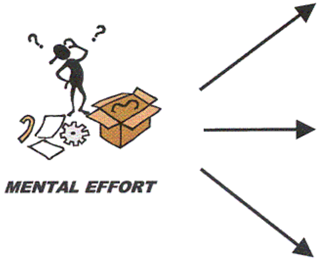
C - MENTAL EFFORT CHARACTERICS -

The goal of this questionnaire is to determine the nature of the mental effort during the sub-segment.

The mental effort is composed of 3 mental behaviors, not always used at the same level. These 3 mental behaviors are the following:

- ***reflex behavior:*** *application of predefined and fixed sequences of actions, automatisms,*
- ***procedural behavior:*** *selection and application of prepared procedures for wellknown situations, regulations,*
- ***cognitive behavior:*** *elaboration of new procedures from the available information, decisions.*

Would you, please, fill the following questionnaire indicating your choice by a cross expressing, within the mental effort, the level of each mental behavior felt during the considered sub-segment:



MENTAL EFFORT

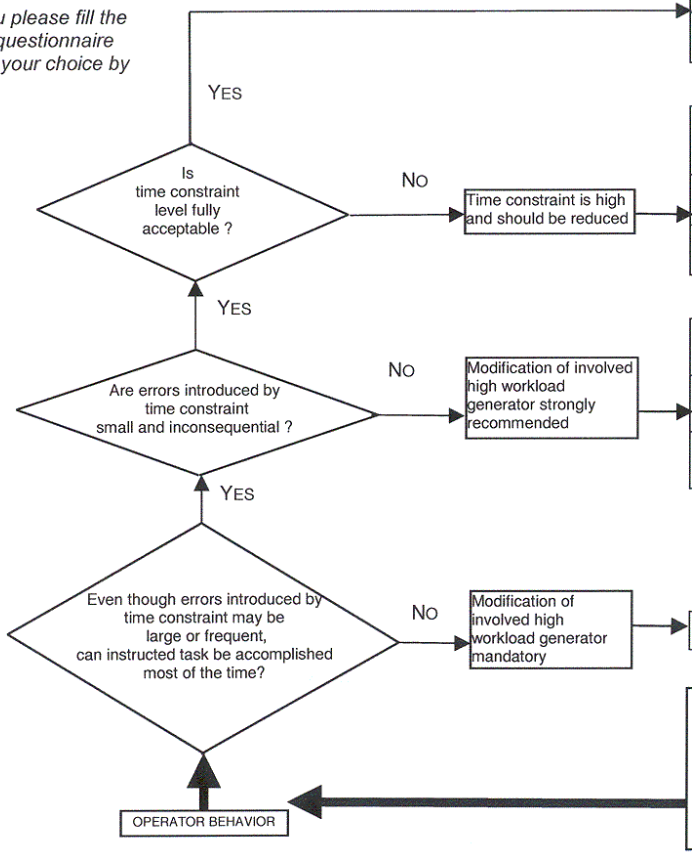
	+	+ +	+ + +
REFLEX BEHAVIOR			
RULES ***PROCEDURAL BEHAVIOR***			
COGNITIVE BEHAVIOR			

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

A - WORKLOAD COMPONENTS LEVEL ASSESSMENT -

Would you please fill the following questionnaire indicating your choice by a cross

Difficulty level	Operator demand level	Crewmember feeling
Very easy, highly desirable	Time constraint applied to operator is negligeable	
Easy, desirable	Time constraint applied to operator is low	
Fair, mild difficulty	Moderate time constraint is applied to operator to perform the tasks	
Minor but annoying difficulty	Moderately high time constraint is applied to operator to perform the tasks	
Moderately objectionable difficulty	High time constraint is applied to operator to perform the tasks	
Very objectionable but tolerable difficulty	Maximum time constraint is applied to operator to perform the tasks	
Major difficulty	Maximum time constraint is applied to operator to accomplish task, but bringing errors to moderate level	
Major difficulty	Maximum time constraint is applied to operator to accomplish task, avoiding large or numerous errors	
Major difficulty	Intense time constraint is applied to operator to accomplish task, but frequent or numerous errors persist	
Impossible	Instructed task cannot be accomplished reliably	



TIME CONSTRAINT ASSESSMENT SCALE:

time constraint is intended to evaluate the time-induced pressure generated by time allotted to complete task and the speed with which the tasks follow each other; this also identifies any slack periods.

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

B- UNCERTAINTY SOURCE EFFECT ON WORKLOAD COMPONENT LEVEL ASSESSMENT -

Would you please fill the following questionnaire on uncertainty sources effect for the workload component ***TIME CONSTRAINT*** *indicating your choice by a cross*

1 Tactical scenario

The proposed scenario was representative enough of a real tactical situation and allowed a

CORRECT ☐

evaluation of the time contraint

OR

The proposed scenario could have been not representative of a real tactical situation, and so the time contraint level evaluation was

HIGHER ☐

OR

LOWER ☐

than with a more realistic one

OR

The proposed scenario was not representative of a real tactical situation, and

I DON'T KNOW ☐

its influence on the time contraint evaluation, either in a worse or either in a better way

2 Simulator

The simulator configuration was representative enough of the reality (ext. environment, cockpit, aircraft model) and allowed a

CORRECT ☐

evaluation of the time contraint

OR

The simulator configuration could have not been representative of the reality (ext. environment, cockpit, aircraft model) and so the time contraint level evaluation was

HIGHER ☐

OR

LOWER ☐

than with a more realistic one

OR

The simulator configuration not representative of the reality (ext. environment, cockpit, aircraft model), and

I DON'T KNOW ☐

its influence on the time contraint evaluation, either in a worse or either in a better way

3 Knowledge/training

The knowledge and training was sufficient (system operation information/training level) and allowed a

CORRECT ☐

evaluation of the time contraint

OR

The knowledge and training could have been not sufficient (system operation information/training level and so the time contraint level evaluation was

HIGHER ☐

OR

LOWER ☐

than with a more realistic one

OR

The knowledge and training was not sufficient (system operation information/training level) and

I DON'T KNOW ☐

its influence on the time contraint evaluation, either in a worse or either in a better way

4 System functions

The simulated system functions was representative enough of a real configuration and allowed a

CORRECT ☐

evaluation of the time contraint

OR

The simulated system functions could have been not representative of a real configuration, being too much complicated, and so the time contraint level evaluation was

HIGHER ☐

OR

LOWER ☐

than with a more realistic one

OR

The simulated system functions scenario was not representative of a real configuration and

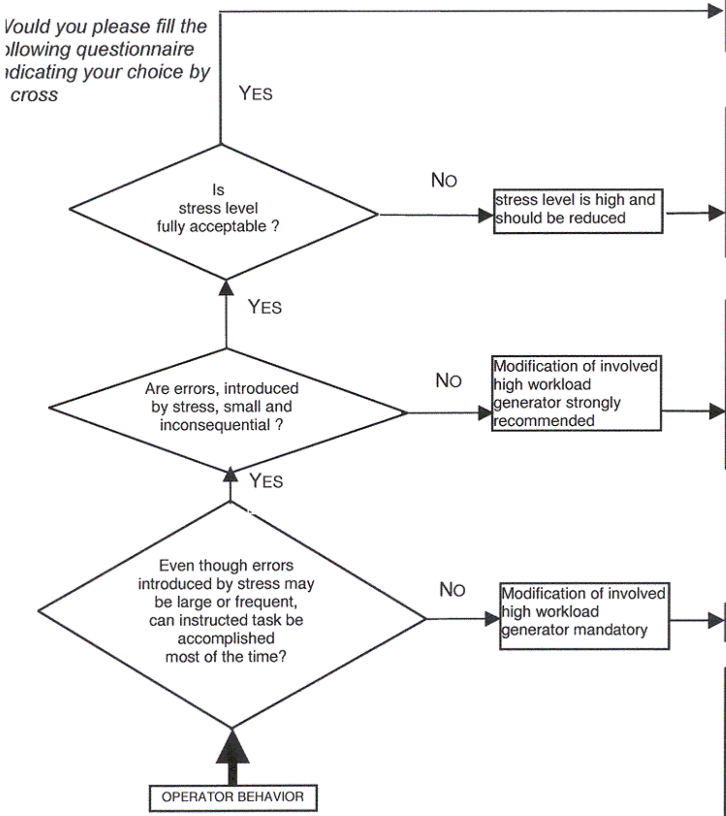
I DON'T KNOW ☐

its influence on the time contraint evaluation, either in a worse or either in a better way

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

A - WORKLOAD COMPONENTS LEVEL ASSESSMENT -

Difficulty level	Operator demand level	Crewmember feeling
Very easy, highly desirable	Stress applied to operator is negligeable	
Easy, desirable	Stress applied to operator is low	
Fair, mild difficulty	Moderate stress is applied to operator to perform the tasks	
Minor but annoying difficulty	Moderately high stress is applied to operator to perform the tasks	
Moderately objectionable difficulty	High stress is applied to operator to perform the tasks	
Very objectionable but tolerable difficulty	Maximum stress is applied to operator to perform the tasks	
Major difficulty	Maximum stress is applied to operator to accomplish task, but bringing errors to moderate level	
Major difficulty	Maximum stress is applied to operator to accomplish task, avoiding large or numerous errors	
Major difficulty	Intense stress is applied to operator to accomplish task, but frequent or numerous errors persist	
Impossible	Instructed task cannot be accomplished reliably	



STRESS ASSESSMENT SCALE:

stress is intended to express
a lack of confidence,
a feeling of subjective constraint
and nervous tension.

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

B- UNCERTAINTY SOURCE EFFECT ON WORKLOAD COMPONENT LEVEL ASSESSMENT -

Would you please fill the following questionnaire on uncertainty sources effect for the workload component ***STRESS*** *indicating your choice by a cross*

1 Tactical scenario

The proposed scenario was representative enough of a real tactical situation and allowed a

CORRECT ❐

evaluation of the stress

OR

The proposed scenario could have been not representative of a real tactical situation, and so the stress level evaluation was

HIGHER ❐

OR

LOWER ❐

than with a more realistic one

OR

The proposed scenario was not representative of a real tactical situation, and

I DON'T KNOW ❐

its influence on the stress evaluation, either in a worse or either in a better way

2 Simulator

The simulator configuration was representative enough of the reality (ext. environment, cockpit, aircraft model) and allowed a

CORRECT ❐

evaluation of the stress

OR

The simulator configuration could have not been representative of the reality (ext. environment, cockpit, aircraft model) and so the stress level evaluation was

HIGHER ❐

OR

LOWER ❐

than with a more realistic one

OR

The simulator configuration not representative of the reality (ext. environment, cockpit, aircraft model), and

I DON'T KNOW ❐

its influence on the stress evaluation, either in a worse or either in a better way

3 Knowledge/training

The knowledge and training was sufficient (system operation information/training level) and allowed a

CORRECT ❐

evaluation of the stress

OR

The knowledge and training could have been not sufficient (system operation information/training level and so the stress level evaluation was

HIGHER ❐

OR

LOWER ❐

than with a more realistic one

OR

The knowledge and training was not sufficient (system operation information/training level) and

I DON'T KNOW ❐

its influence on the stress evaluation, either in a worse or either in a better way

4 System functions

The simulated system functions was representative enough of a real configuration and allowed a

CORRECT ❐

evaluation of the stress

OR

The simulated system functions could have been not representative of a real configuration, being too much complicated, and so the stress level evaluation was

HIGHER ❐

OR

LOWER ❐

than with a more realistic one

OR

The simulated system functions scenario was not representative of a real configuration and

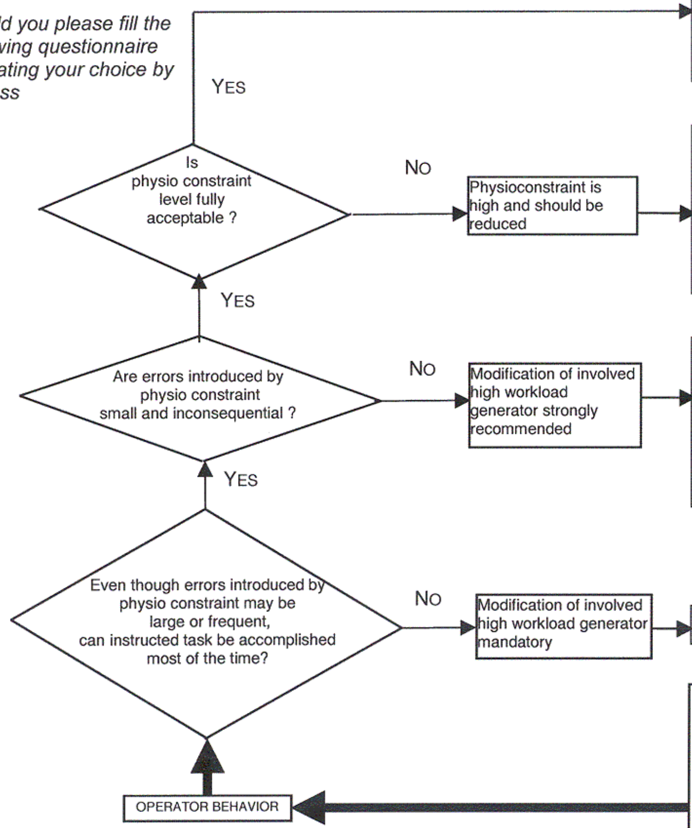
I DON'T KNOW ❐

its influence on the stress evaluation, either in a worse or either in a better way

3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

A - WORKLOAD COMPONENTS LEVEL ASSESSMENT -

Would you please fill the following questionnaire indicating your choice by a cross



Difficulty level	Operator demand level	Crewmember feeling
Very easy, highly desirable	Physio constraint applied to operator is negligeable	
Easy, desirable	Physio constraint applied to operator is low	
Fair, mild difficulty	Moderate physio constraint is applied to operator to perform the tasks	
Minor but annoying difficulty	Moderately high physio constraint is applied to operator to perform the tasks	
Moderately objectionable difficulty	High physio constraint is applied to operator to perform the tasks	
Very objectionable but tolerable difficulty	Maximum physio constraint is applied to operator to perform the tasks	
Major difficulty	Maximum physio constraint is applied to operator to accomplish task, but bringing errors to moderate level	
Major difficulty	Maximum physio constraint is applied to operator to accomplish task, avoiding large or numerous errors	
Major difficulty	Intense physio constraint is applied to operator to accomplish task, but frequent or numerous errors persist	
Impossible	Instructed task cannot be accomplished reliably	

PHYSIO EFFORT ASSESSMENT SCALE:
physio effort constraint is intended to evaluate the induced physical and psychological tiredeness sensation generated by cockpit equipments to complete task.

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3- WORKLOAD ASSESSMENT QUESTIONNAIRE (WLAQ)

B- UNCERTAINTY SOURCE EFFECT ON WORKLOAD COMPONENT LEVEL ASSESSMENT -

Would you please fill the following questionnaire on uncertainty sources effect for the workload component ***PHYSIO EFFORT*** *indicating your choice by a cross*

1 Tactical scenario

The proposed scenario was representative enough of a real tactical situation and allowed a **CORRECT** ☐ evaluation of the physio effort

OR

The proposed scenario could have been not representative of a real tactical situation, and so the physio effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The proposed scenario was not representative of a real tactical situation, and **I DON'T KNOW** ☐ its influence on the physio effort evaluation, either in a worse or either in a better way

2 Simulator

The simulator configuration was representative enough of the reality (ext. environment, cockpit, aircraft model) and allowed a **CORRECT** ☐ evaluation of the physio effort

OR

The simulator configuration could have not been representative of the reality (ext. environment, cockpit, aircraft model) and so the physio effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The simulator configuration not representative of the reality (ext. environment, cockpit, aircraft model), and **I DON'T KNOW** ☐ its influence on the physio effort evaluation, either in a worse or either in a better way

3 Knowledge/training

The knowledge and training was sufficient (system operation information/training level) and allowed a **CORRECT** ☐ evaluation of the physio effort

OR

The knowledge and training could have been not sufficient (system operation information/training level and so the physio effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

The knowledge and training was not sufficient (system operation information/training level) and **I DON'T KNOW** ☐ its influence on the physio effort evaluation, either in a worse or either in a better way

4 System functions

The simulated system functions was representative enough of a real configuration and allowed a **CORRECT** ☐ evaluation of the physio effort

OR

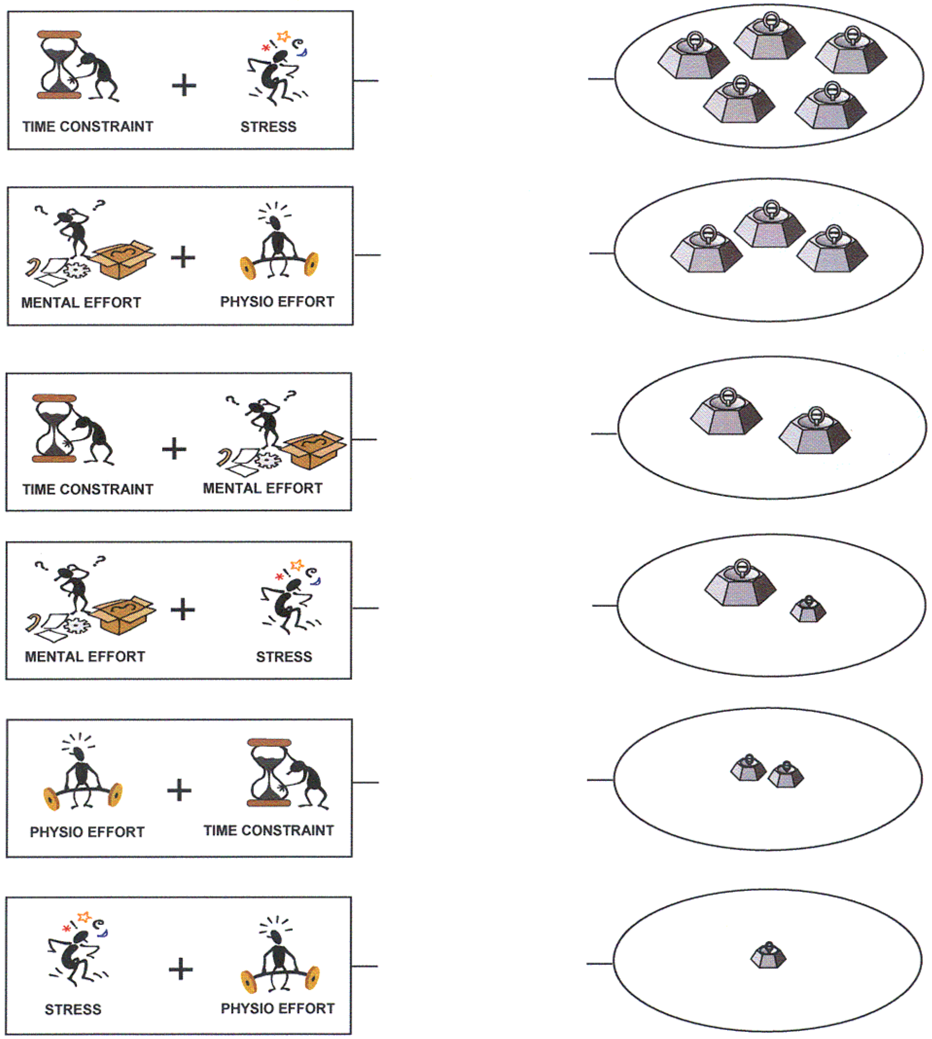
The simulated system functions could have been not representative of a real configuration, being too much complicated, and so the physio effort level evaluation was **HIGHER** ☐ OR **LOWER** ☐ than with a more realistic one

OR

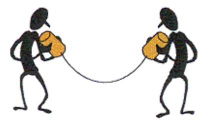
The simulated system functions scenario was not representative of a real configuration and **I DON'T KNOW** ☐ its influence on the physio effort evaluation, either in a worse or either in a better way

4- WEIGHTING FACTORS QUESTIONNAIRE (WFQ)

The goal is to classify each couple of workload components w.r.t. the weight felt during the sub-segment.
So, please link each rectangle (couple of components) to a single oval (weight):



Would you, please, answer to the following questions :

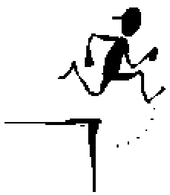
Were your mental activities mainly a management of unknown situations or a management of well-known situations?	*Did you perform activities which were not planned in your task allocation?*
 UNKNOWN SITUATION ❑ OR  WELLKNOWN SITUATION ❑	 EXTRA TASK ❑ Yes ❑ No

Was the time allocated well sized to reach the target of the phase?	*If you have spent more time than expected, please explain the need of additive time?*
 ON TIME ❑ Yes ❑ No	 ADDITIVE TIME NEEDED

DID YOU FEEL OVERLOADED DURING THIS SUB-SEGMENT?

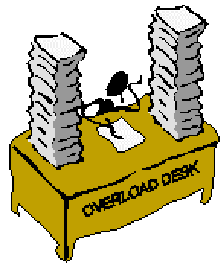
NO ❑

PLEASE, JUMP TO THE NEXT SUB-SEGMENT, IF ANY.



YES ❑

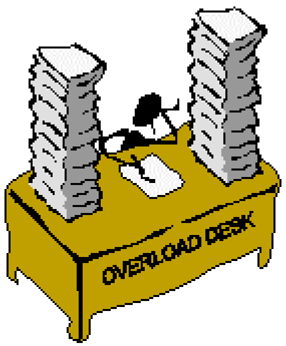
PLEASE, FILL THE EXTRA OVERLOAD QUESTIONNAIRE.



TRPH

EVALUATION DE LA CHARGE DE TRAVAIL PILOTE

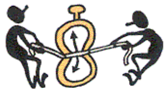
- DEBRIEFING -



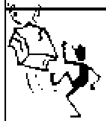
OVERLOAD QUESTIONNAIRE

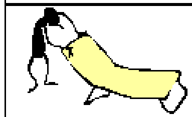
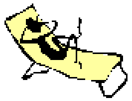
5- SEGREGATION QUESTIONNAIRE

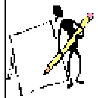
OVERLOAD QUESTIONNAIRE

Do you think that the tasks can be shared out differently between the crew members?	Do you think that the tasks assigned to the crew can be time-sequenced differently?
 Yes ❑ No ❑ *if yes, please substantiate*	 Yes ❑ No ❑ *if yes, please substantiate*

What were the critical mission and/or flight control phases?	*What were the related equipment?*
	

Is there a need to modify an equipment or a information presentation?	*Are essential functions lacking at equipments level?*
 Yes ❑ No ❑ *if yes, please substantiate*	 Yes ❑ No ❑ *if yes, please substantiate*

Does the system sufficiently support crew members mental basic actions?	*Does the system sufficiently support crew members reflex actions?*
 Yes ❑ No ❑ *if yes, please substantiate*	 Yes ❑ No ❑ *if yes, please substantiate*

DO YOU HAVE ANY OTHER COMMENTS OR SUGGESTIONS?


THE END

THANK YOU FOR YOUR CONTRIBUTION AND YOUR PATIENCE IN FILLING THESE QUESTIONNAIRES

UNCERTAINTY QUESTIONNAIRE (UQ)

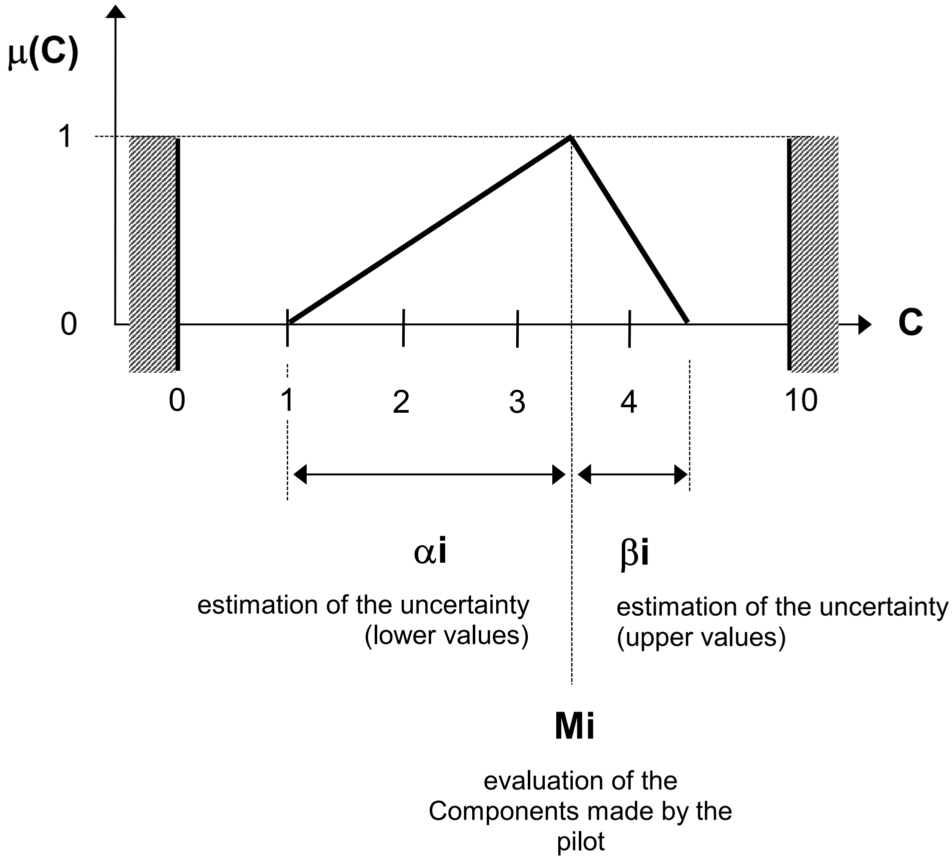
FUZZY LOGIC ESTIMATION

The level of uncertainty, associated to the evaluation of the components, is determined by :

- α_i = 0.5+ number of answers in {3; 4}
  limited such that : $(M_i-\alpha_i) \geq 0$
- β_i = 0.5+ number of answers in {2; 4},
  limited such that : $(M_i+\beta_i) \leq 10$

with:

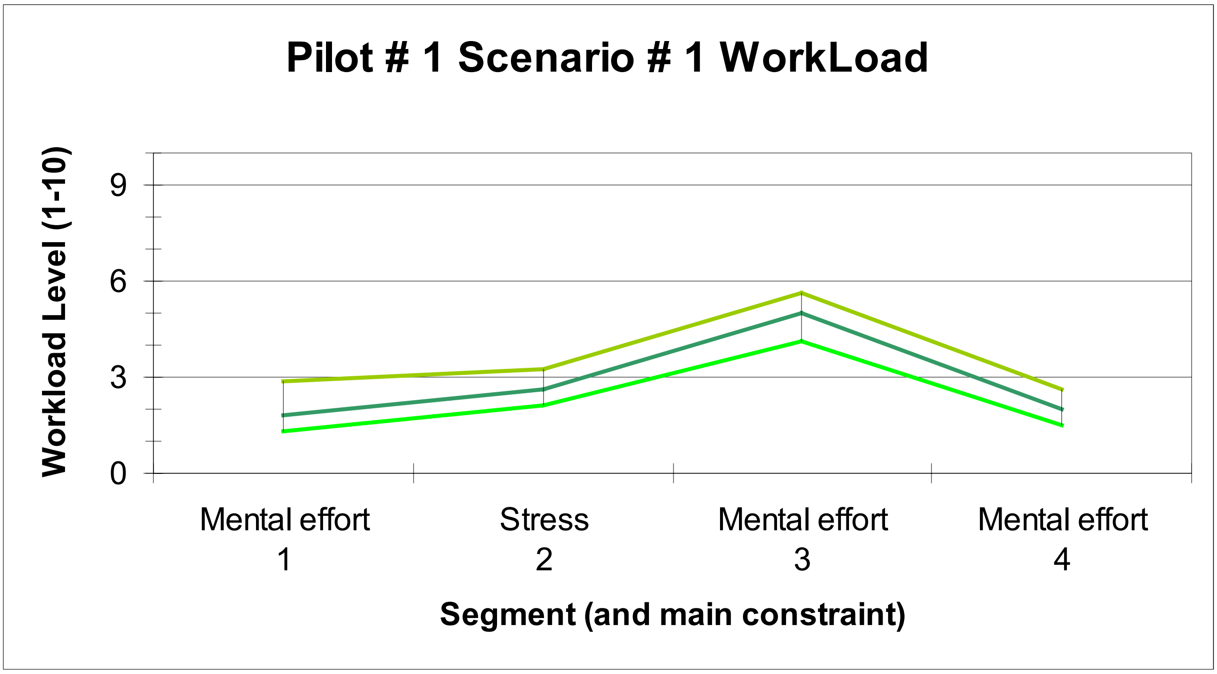
- CORRECT= 1
- HIGHER= 2
- LOWER= 3
- I DON'T KNOW = 4

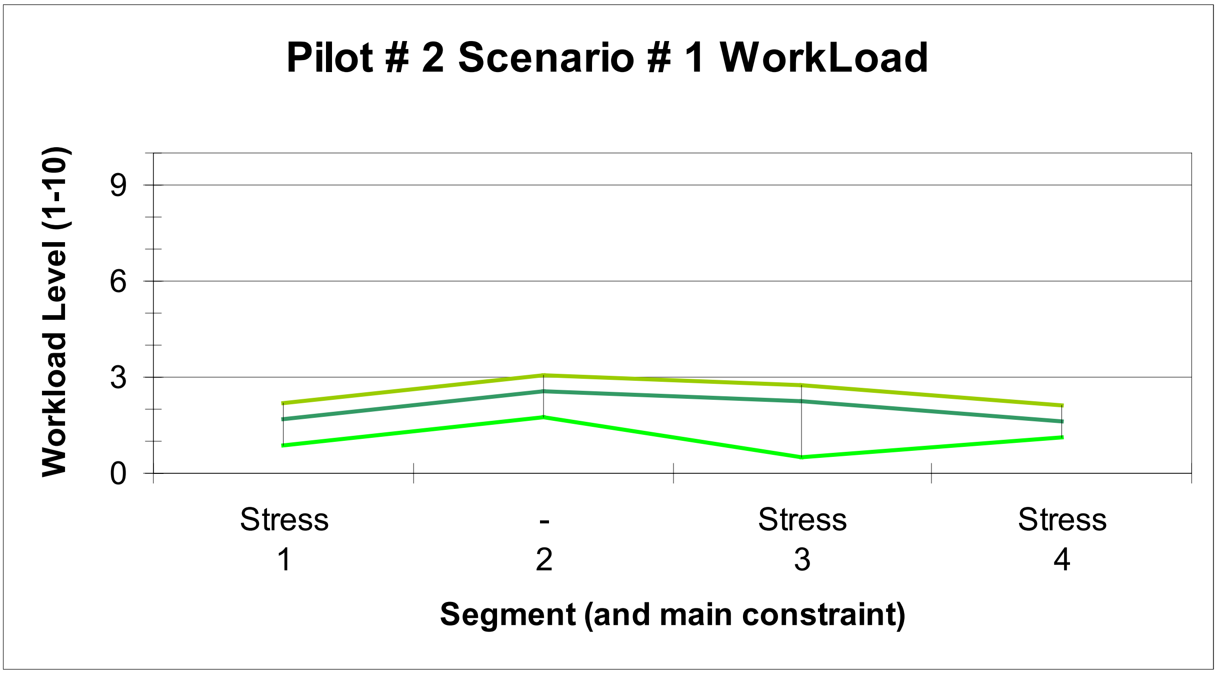


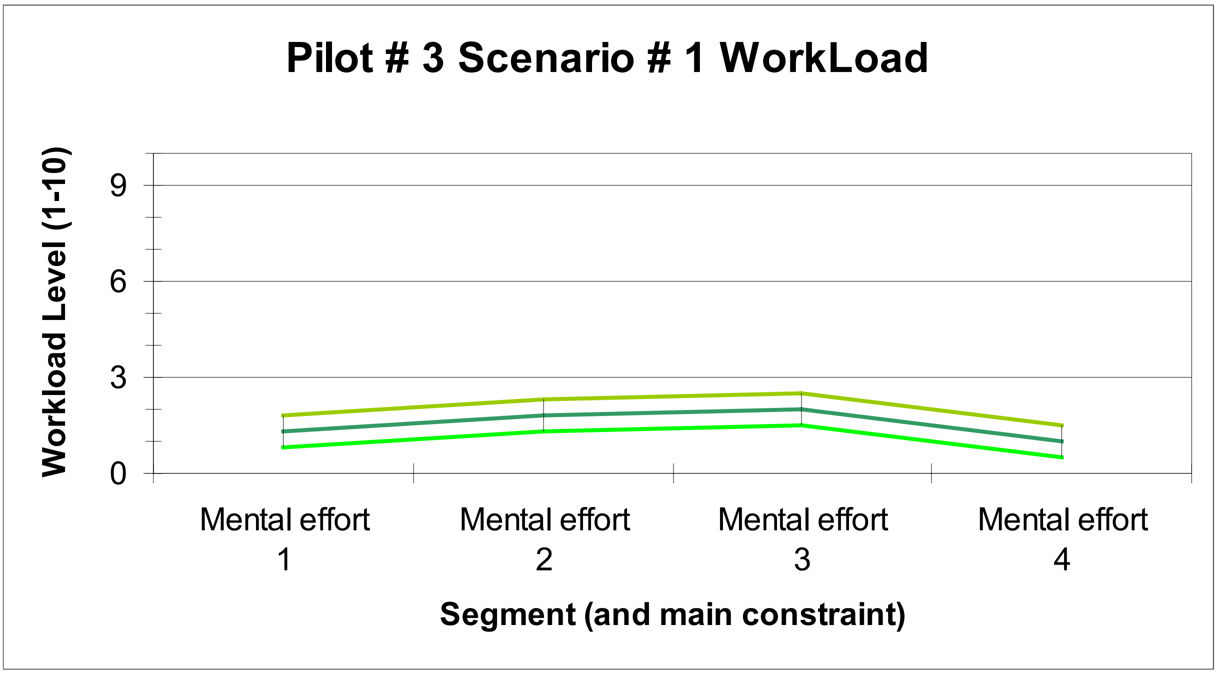
Then, the fuzzy quantity, describing the evaluation of the component C_i on the workload, is :

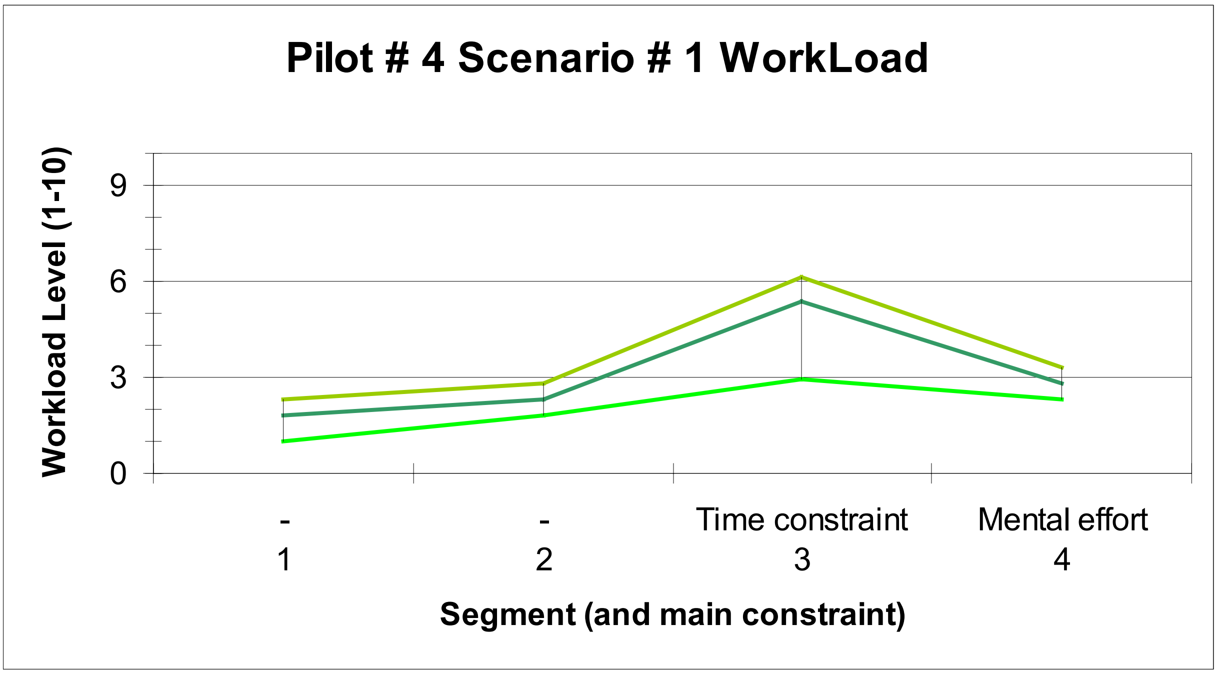
$$\boxed{WL(C_i) = (M_i, \alpha_i, \beta_i)}$$

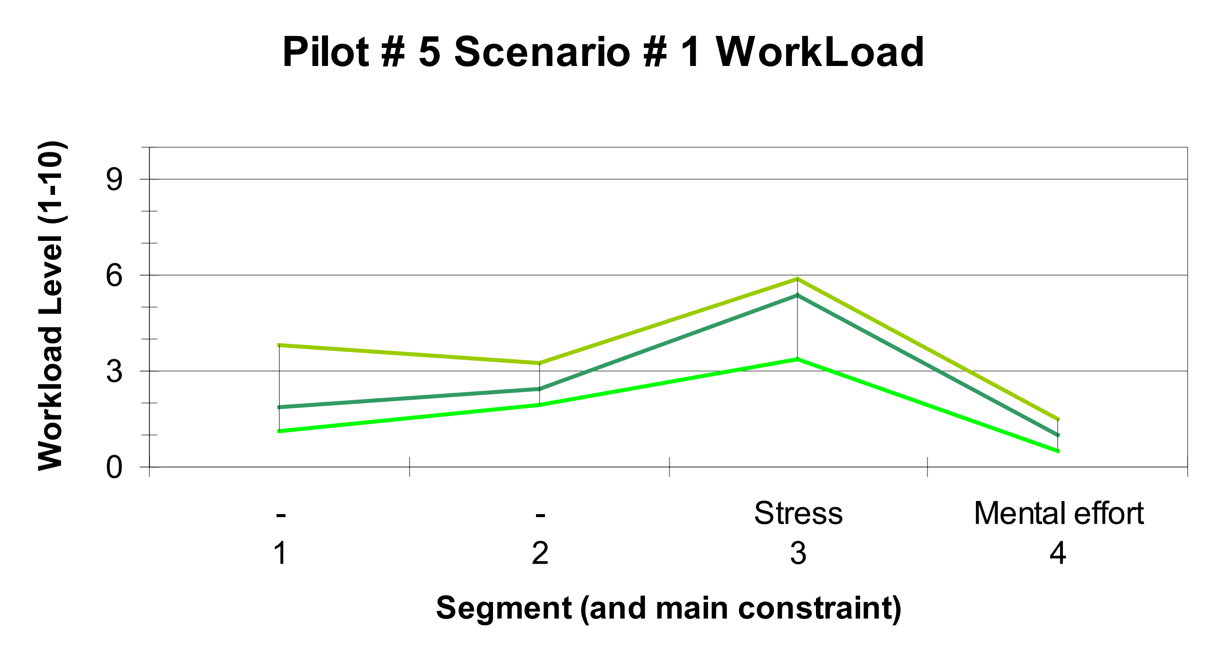
APPENDIX 4 : SUBJECTIVE EVALUATION OF THE WORKLOAD

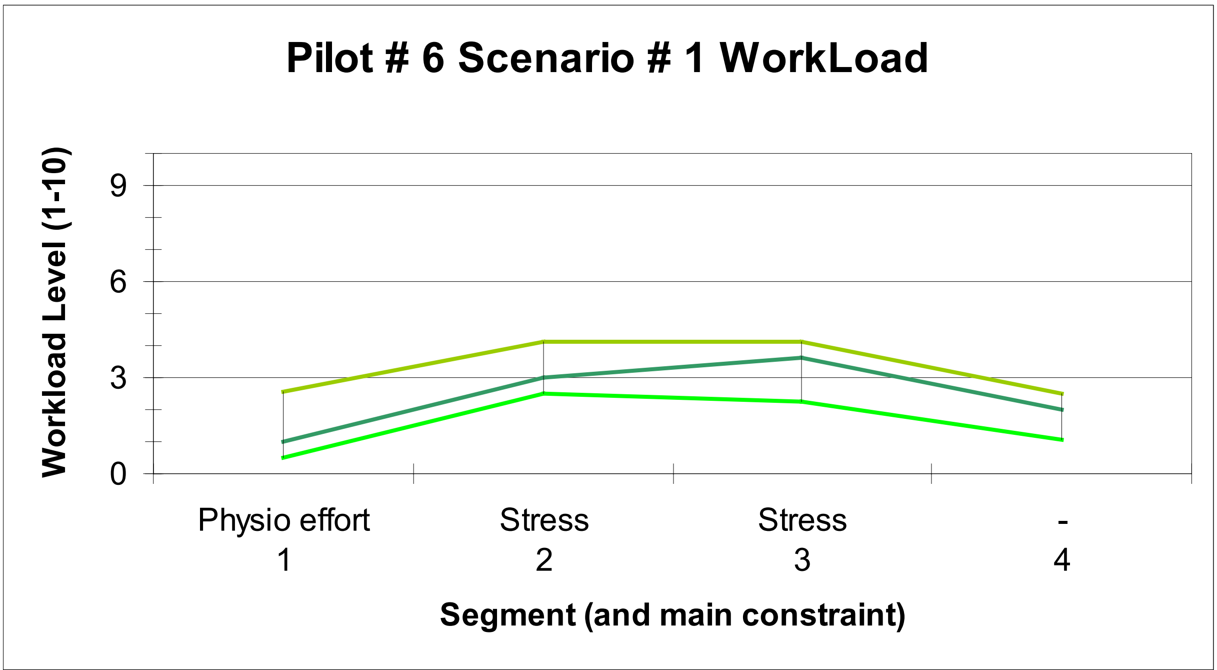


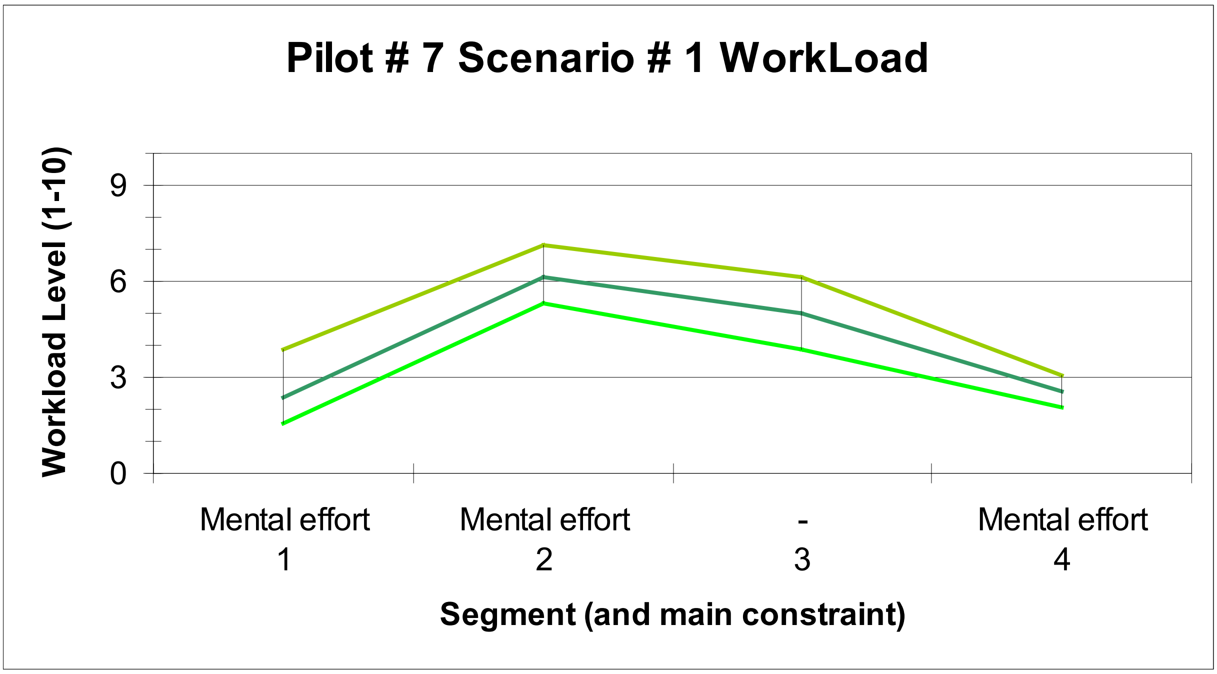



Pilot # 3 Scenario # 1 WorkLoad
Workload Level (1-10)
9
6
3
0
Mental effort
1
Mental effort
2
Mental effort
3
Mental effort
4
Segment (and main constraint)

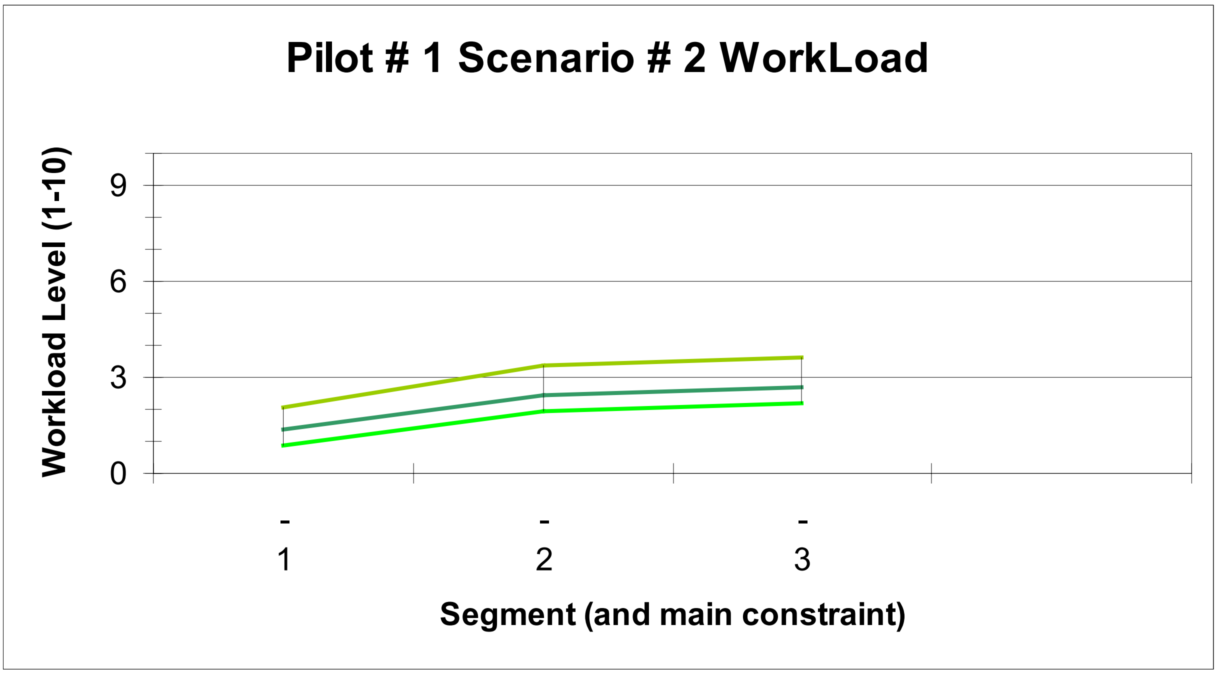

Pilot # 4 Scenario # 1 WorkLoad
Workload Level (1-10)
9
6
3
0
-
1
-
2
Time constraint
3
Mental effort
4
Segment (and main constraint)


Pilot # 5 Scenario # 1 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
-
2
Stress
3
Mental effort
4
Segment (and main constraint)

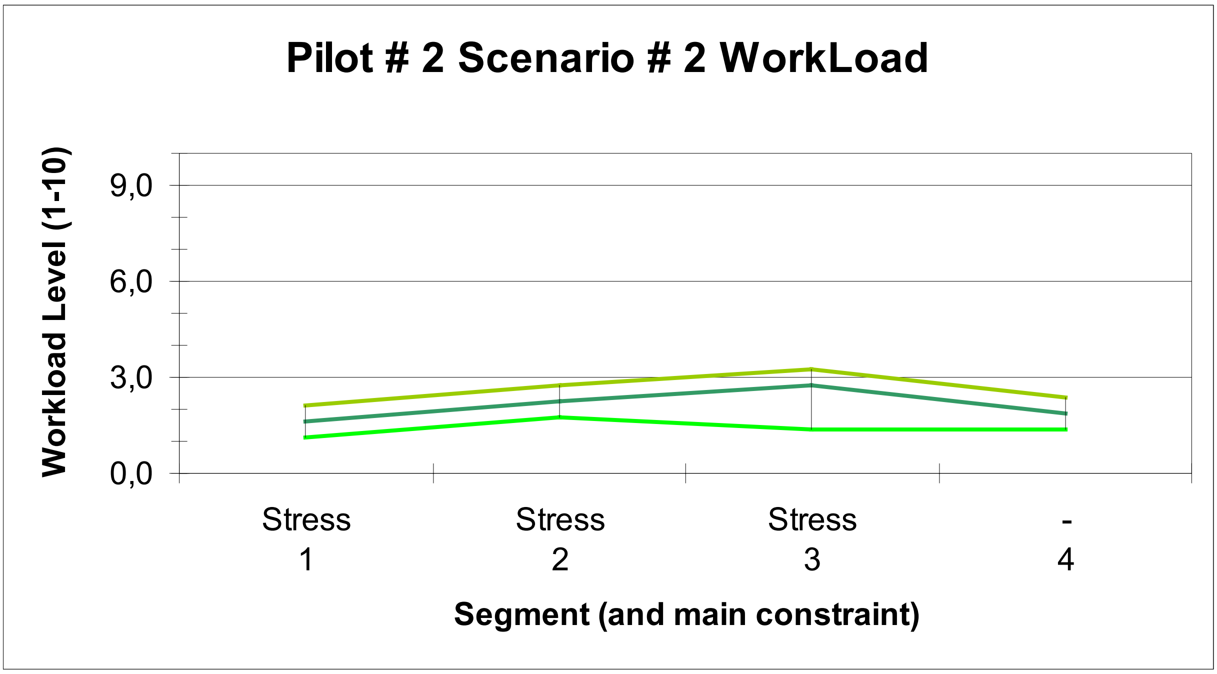

Pilot # 6 Scenario # 1 WorkLoad
Workload Level (1-10)
0
3
6
9
Physio effort
1
Stress
2
Stress
3
-
4
Segment (and main constraint)



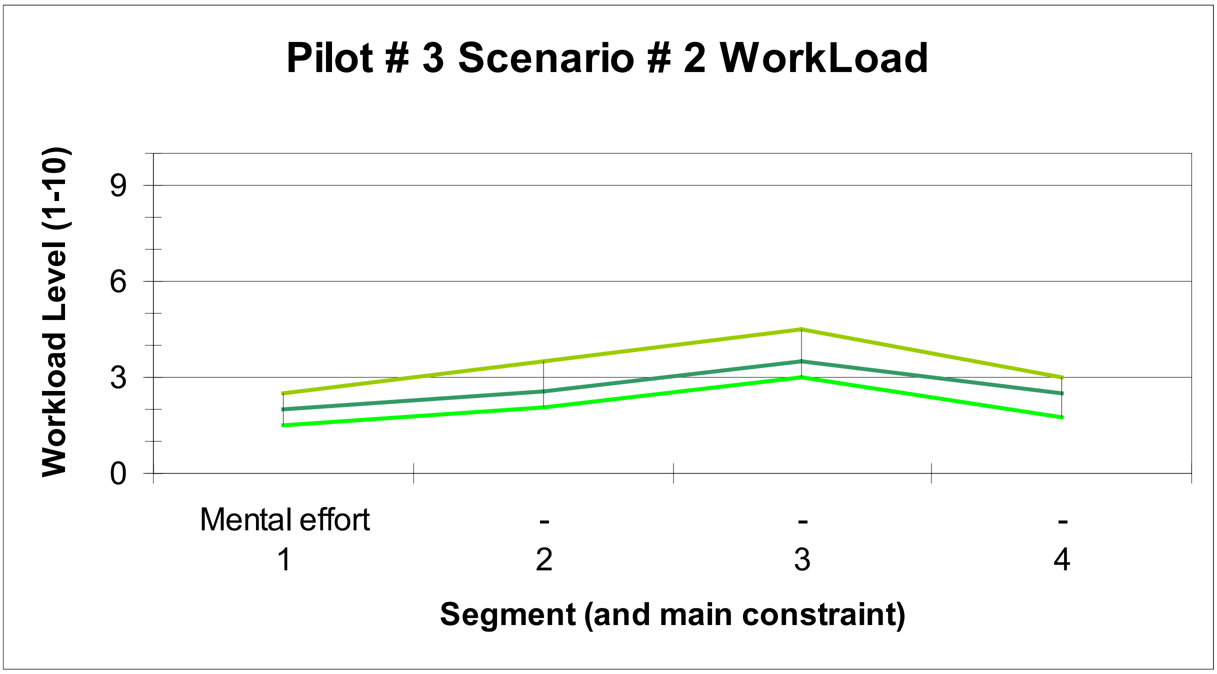
Pilot # 7 Scenario # 1 WorkLoad
Workload Level (1-10)
0
3
6
9
Mental effort 1
Mental effort 2
- 3
Mental effort 4
Segment (and main constraint)



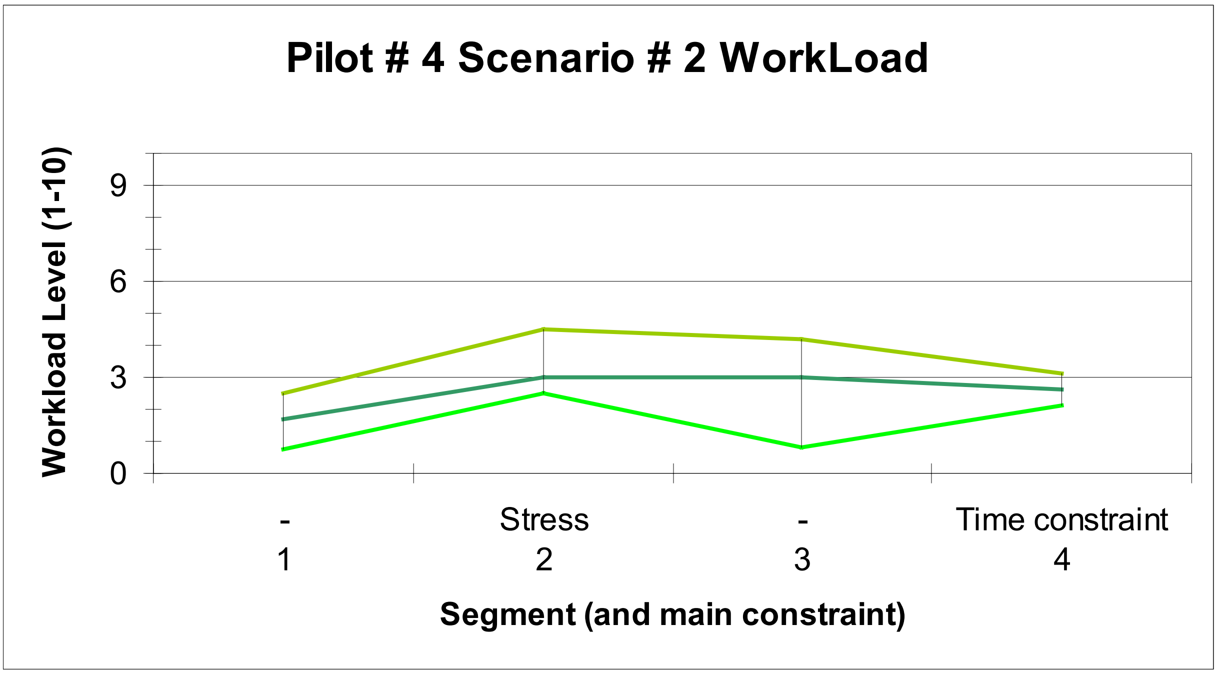
Pilot # 1 Scenario # 2 WorkLoad
Workload Level (1-10)
0
3
6
9
- 1
- 2
- 3
Segment (and main constraint)

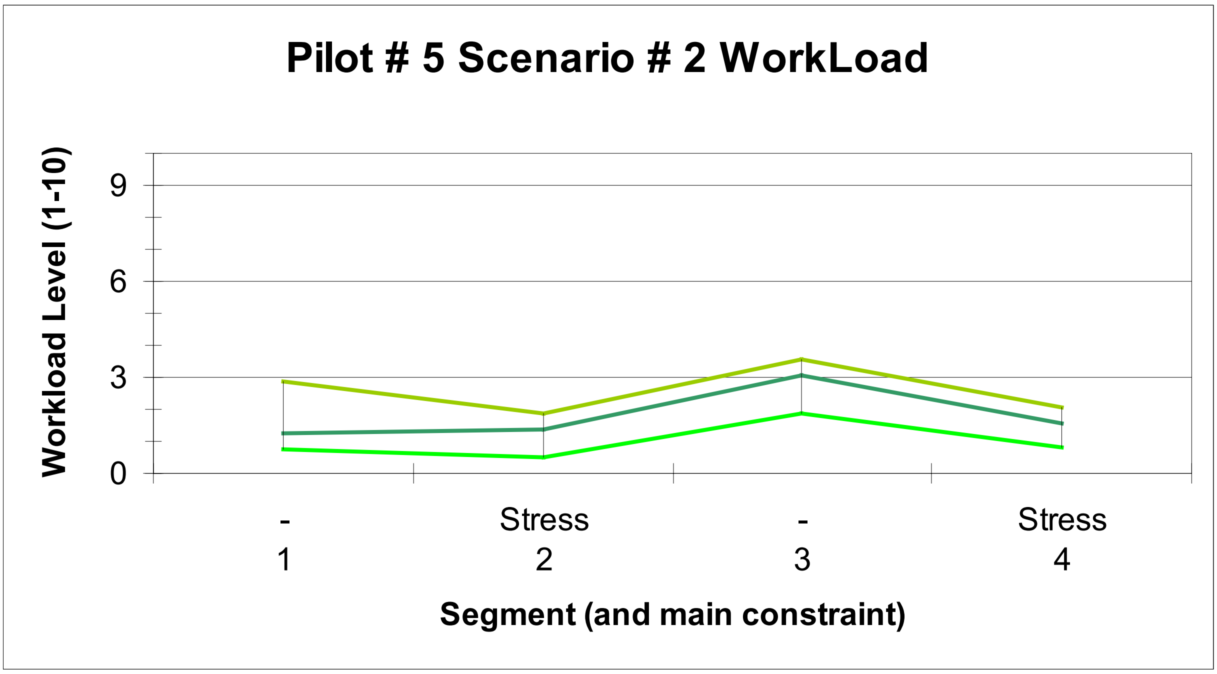


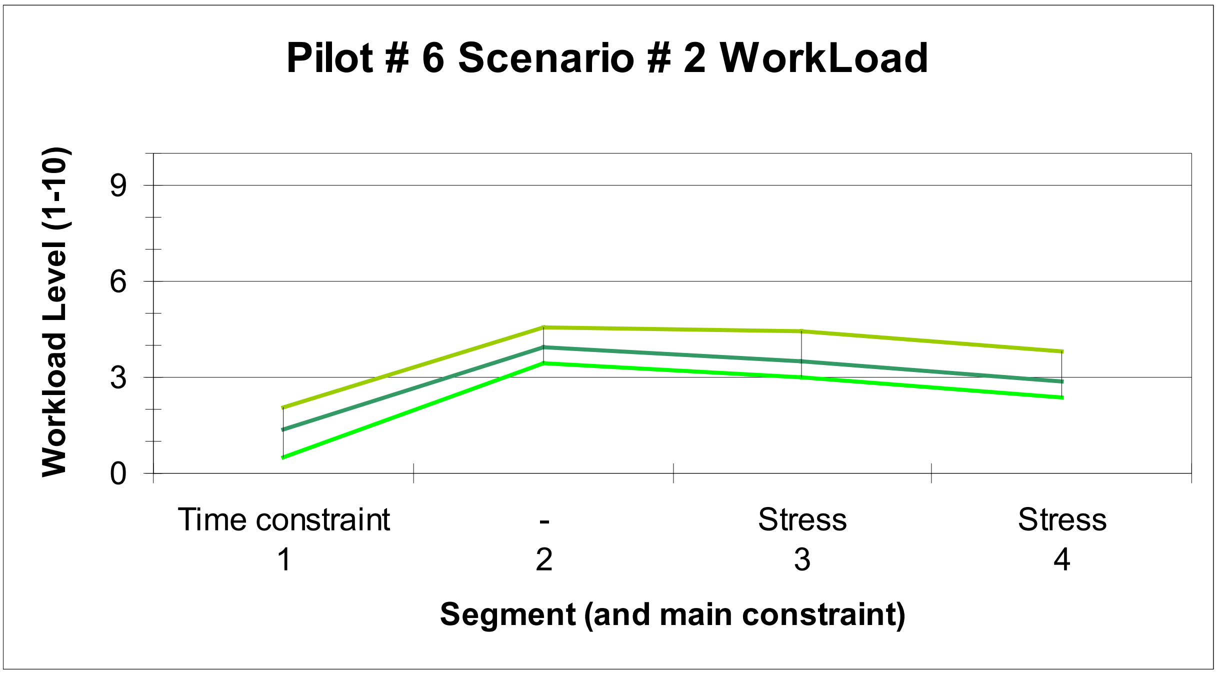
Pilot # 2 Scenario # 2 WorkLoad
Workload Level (1-10)
9,0
6,0
3,0
0,0
Stress 1
Stress 2
Stress 3
- 4
Segment (and main constraint)

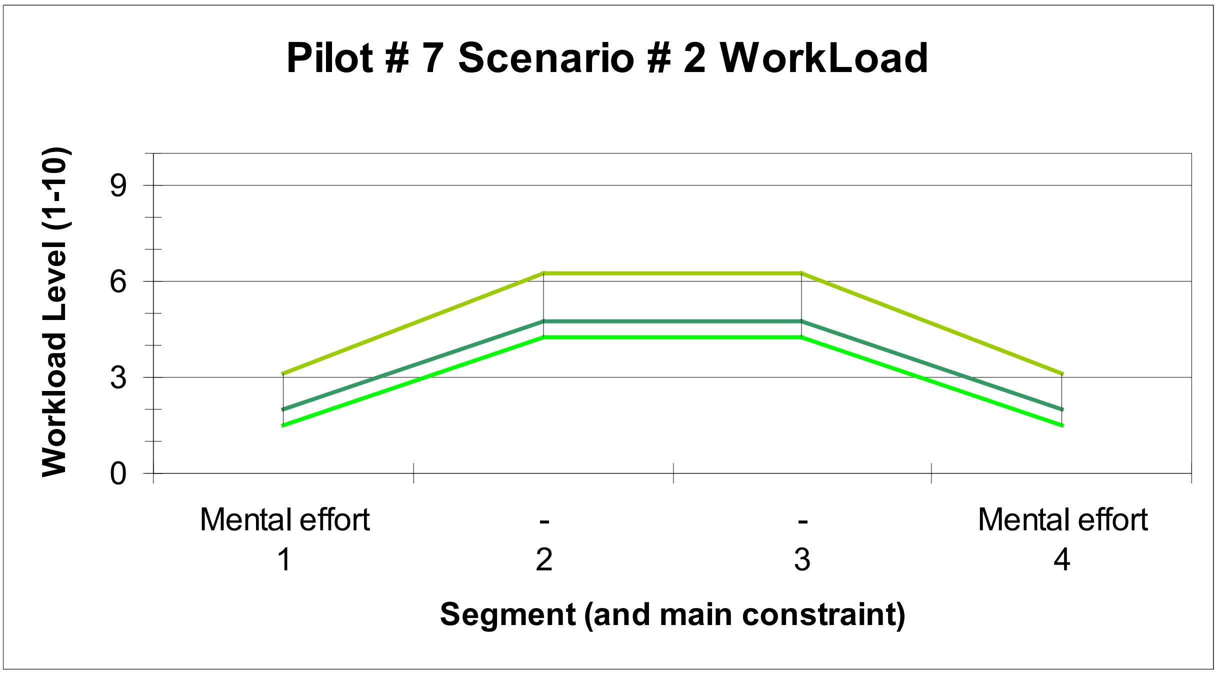


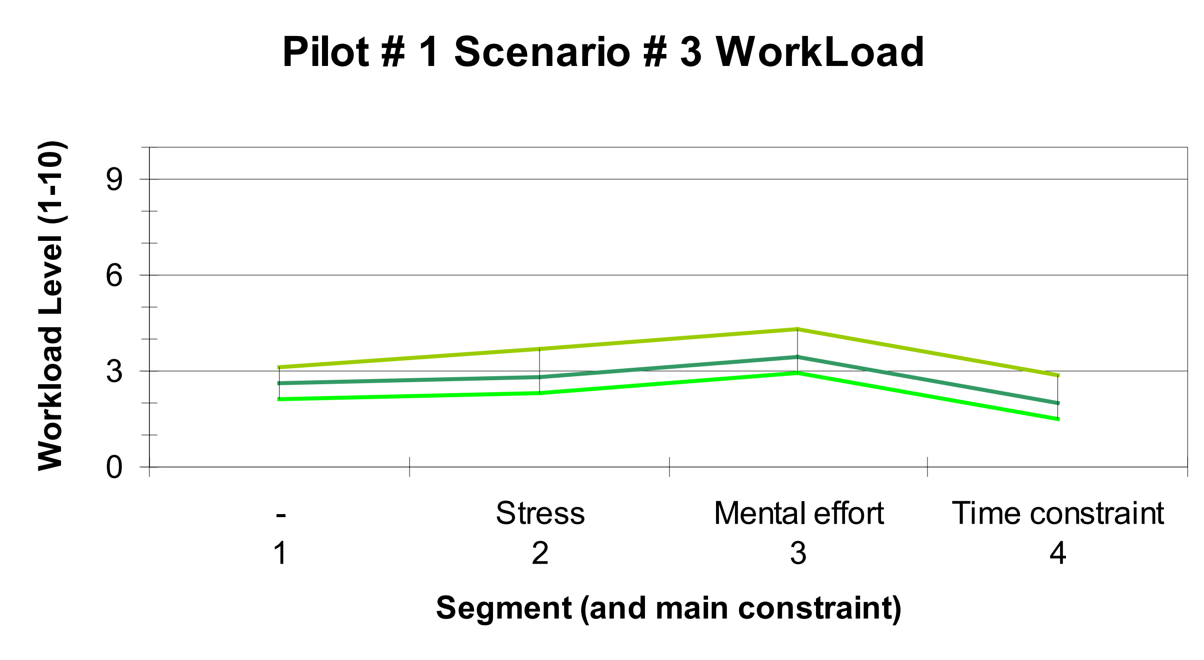
Pilot # 3 Scenario # 2 WorkLoad
Workload Level (1-10)
9
6
3
0
Mental effort 1
- 2
- 3
- 4
Segment (and main constraint)

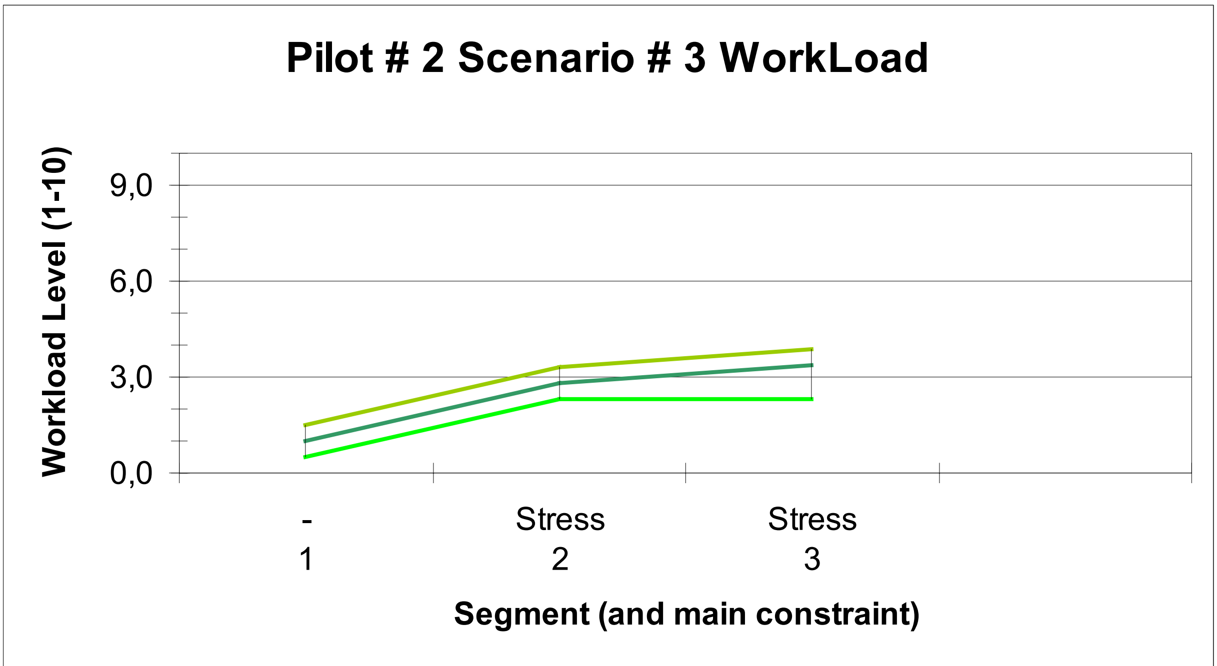

Pilot # 4 Scenario # 2 WorkLoad
Workload Level (1-10)
9
6
3
0
-
1
Stress
2
-
3
Time constraint
4
Segment (and main constraint)

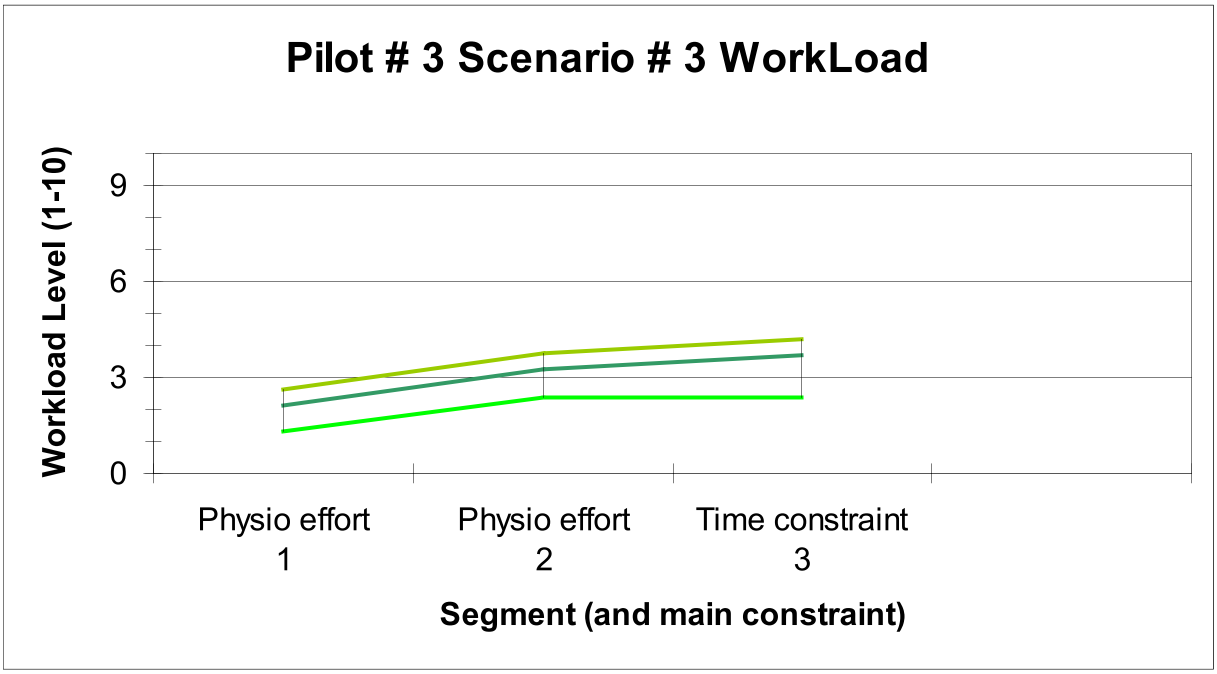

Pilot # 5 Scenario # 2 WorkLoad
Workload Level (1-10)
9
6
3
0
-
1
Stress
2
-
3
Stress
4
Segment (and main constraint)

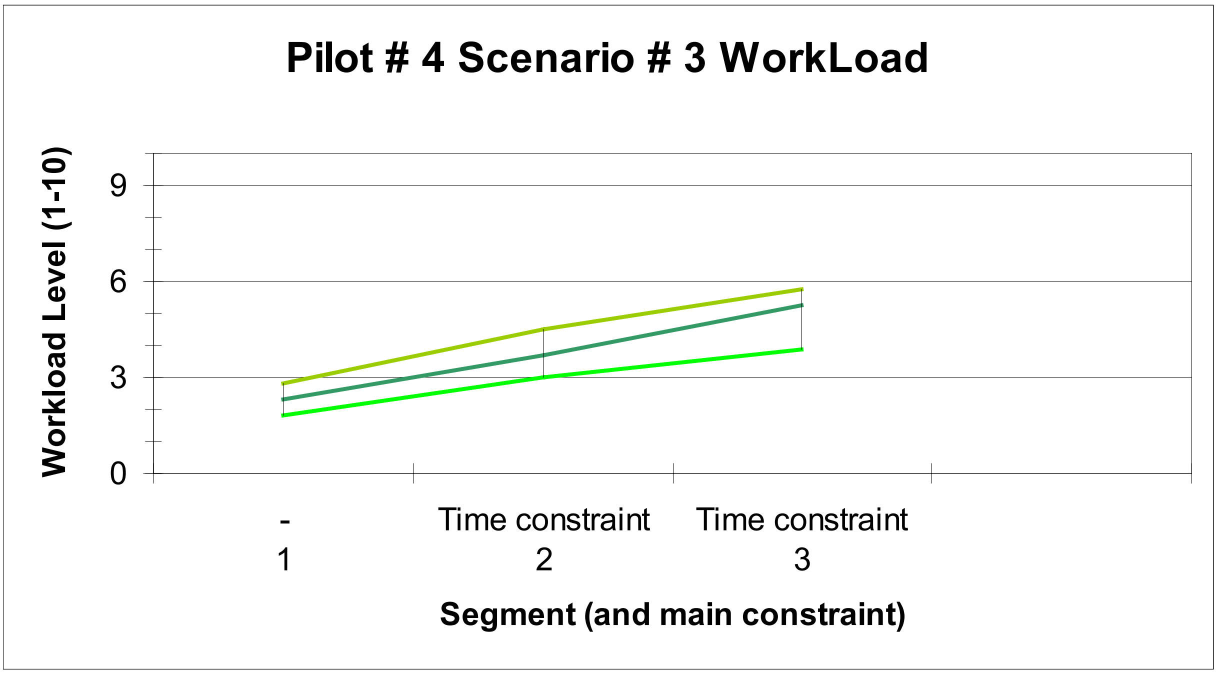

Pilot # 6 Scenario # 2 WorkLoad
Workload Level (1-10)
0
3
6
9
Time constraint
1
-
2
Stress
3
Stress
4
Segment (and main constraint)

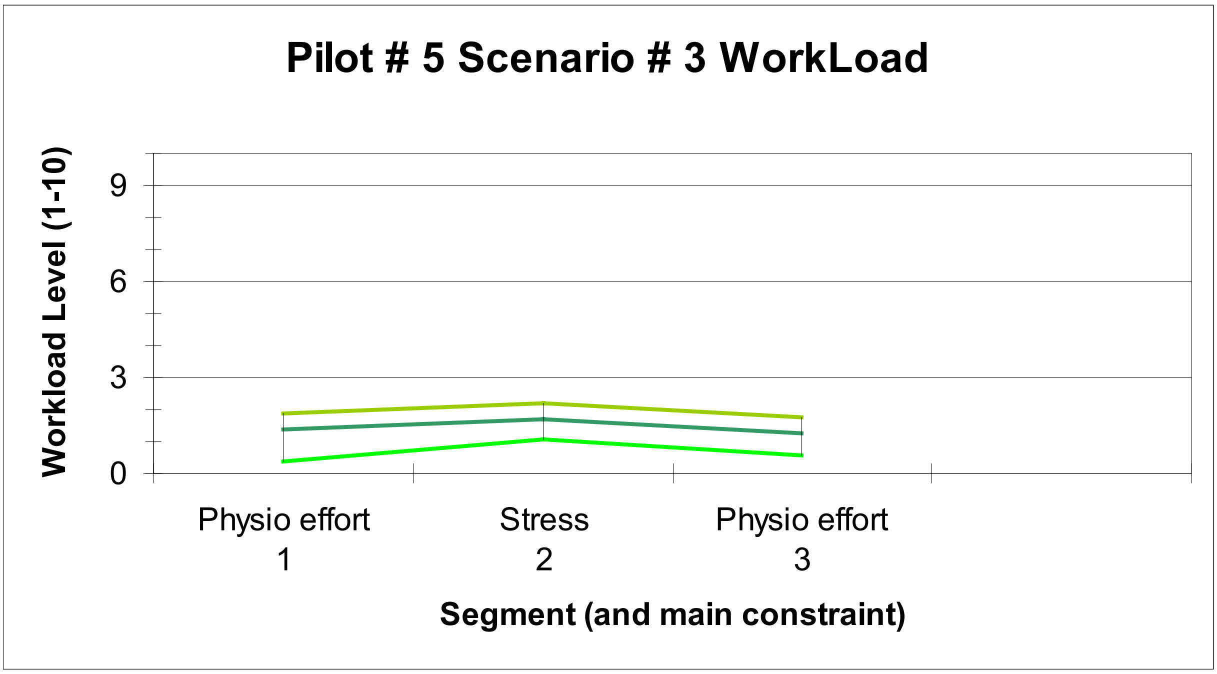

Pilot # 7 Scenario # 2 WorkLoad
Workload Level (1-10)
0
3
6
9
Mental effort
1
-
2
-
3
Mental effort
4
Segment (and main constraint)


Pilot # 1 Scenario # 3 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
Stress
2
Mental effort
3
Time constraint
4
Segment (and main constraint)

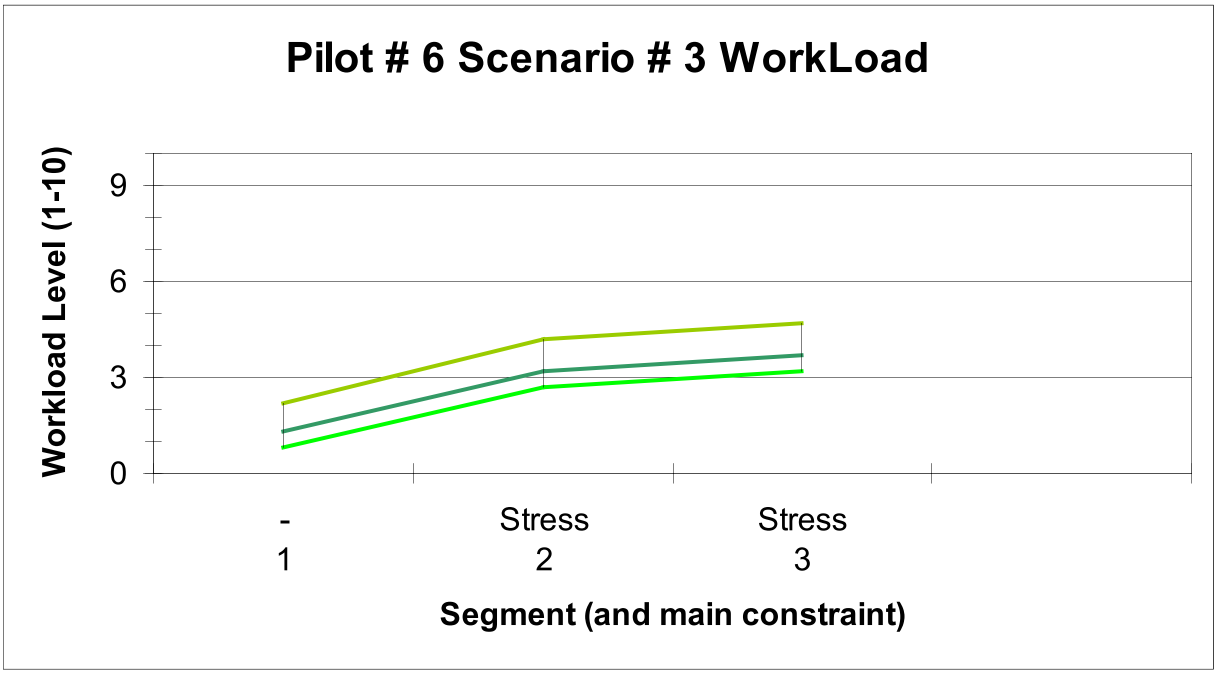

Pilot # 2 Scenario # 3 WorkLoad
Workload Level (1-10)
0,0
3,0
6,0
9,0
-
1
Stress
2
Stress
3
Segment (and main constraint)


Pilot # 3 Scenario # 3 WorkLoad
Workload Level (1-10)
0
3
6
9
Physio effort
1
Physio effort
2
Time constraint
3
Segment (and main constraint)

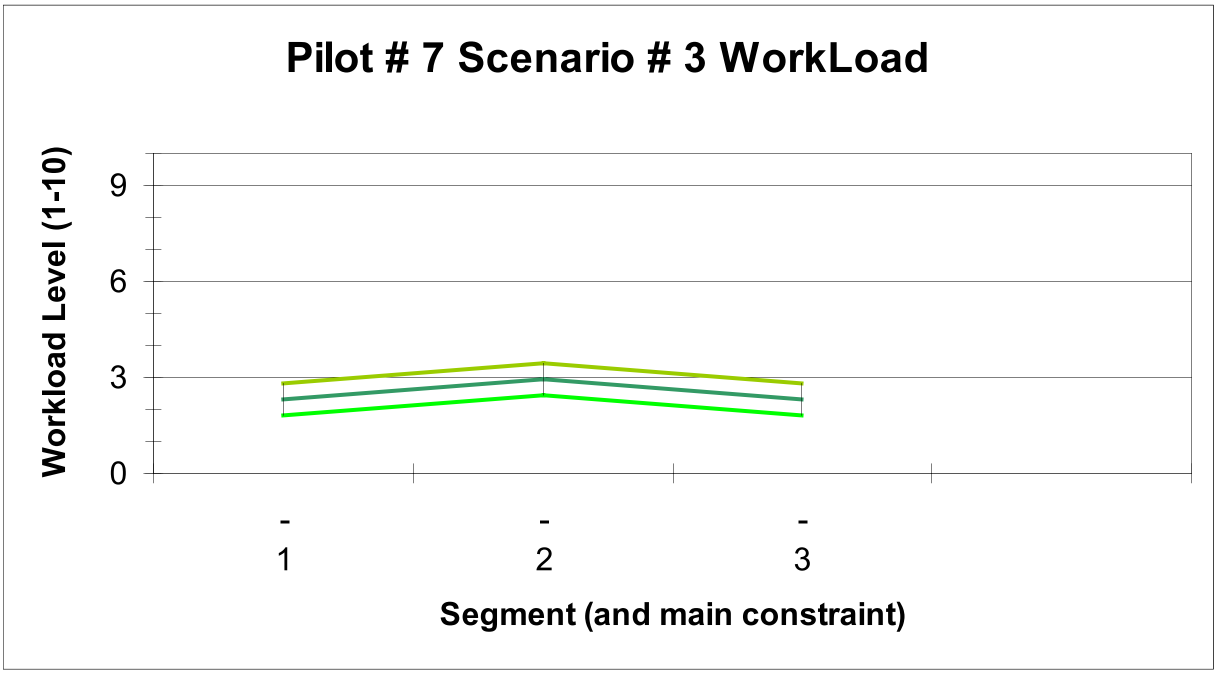

Pilot # 4 Scenario # 3 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
Time constraint
2
Time constraint
3
Segment (and main constraint)

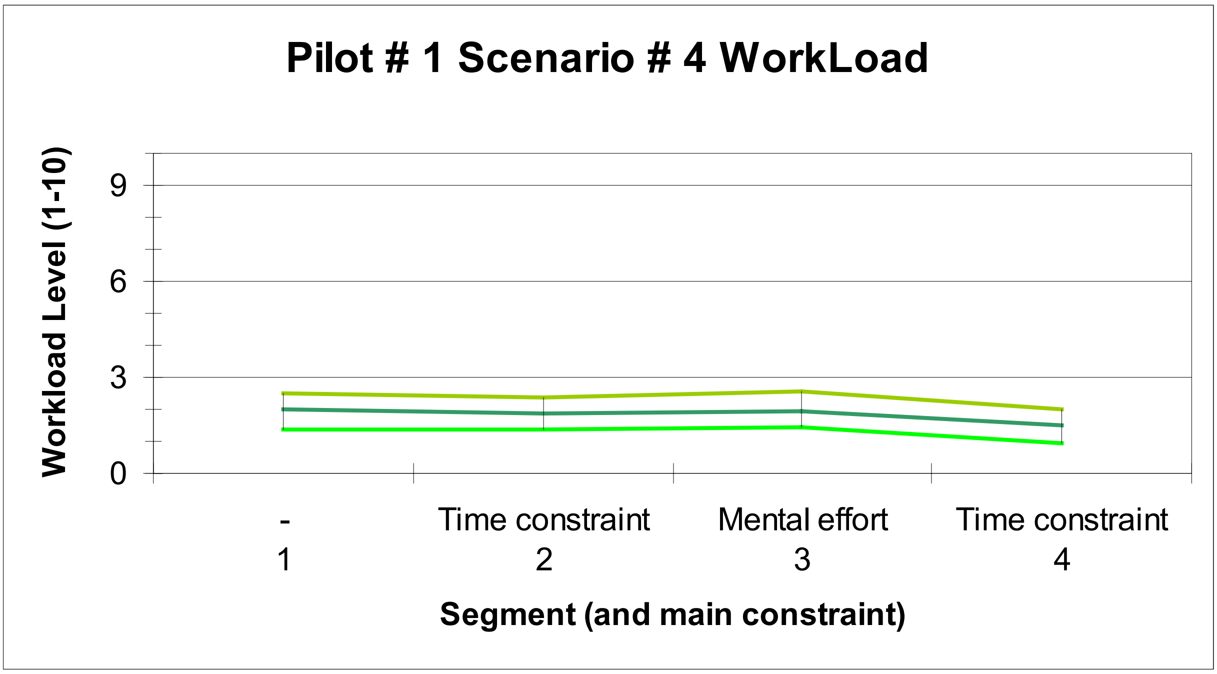


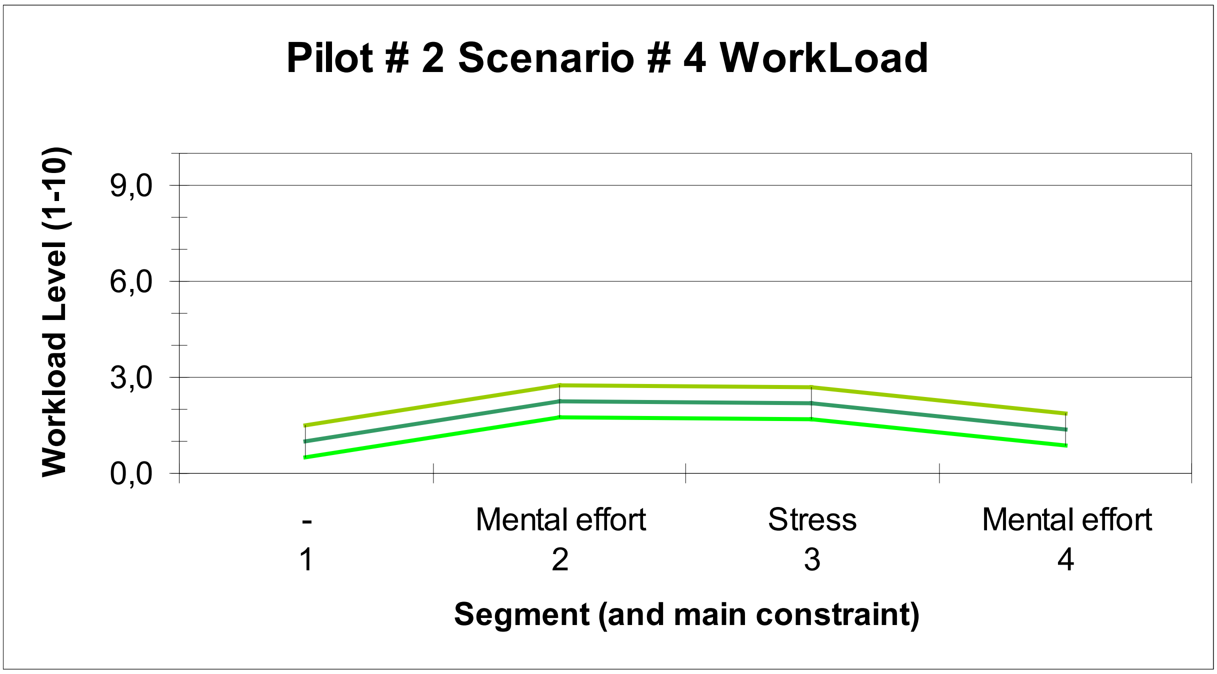
Pilot # 5 Scenario # 3 WorkLoad
Workload Level (1-10)
9
6
3
0
Physio effort
1
Stress
2
Physio effort
3
Segment (and main constraint)



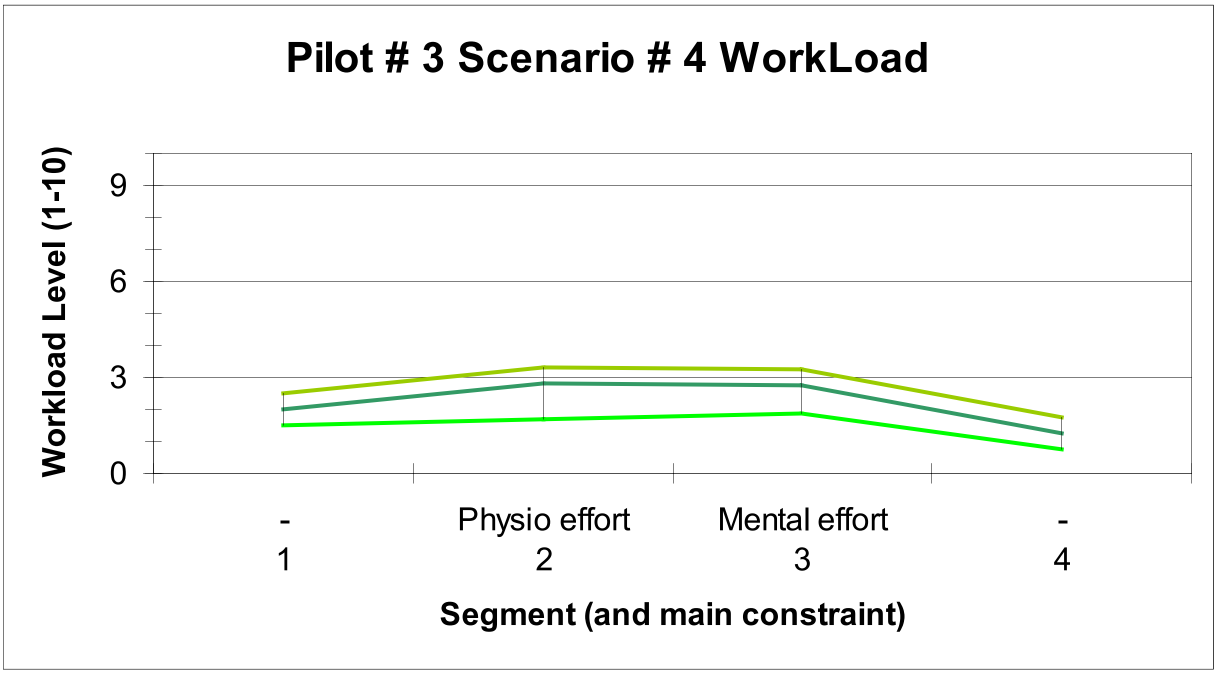
Pilot # 6 Scenario # 3 WorkLoad
Workload Level (1-10)
9
6
3
0
-
1
Stress
2
Stress
3
Segment (and main constraint)


Pilot # 7 Scenario # 3 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
-
2
-
3
Segment (and main constraint)

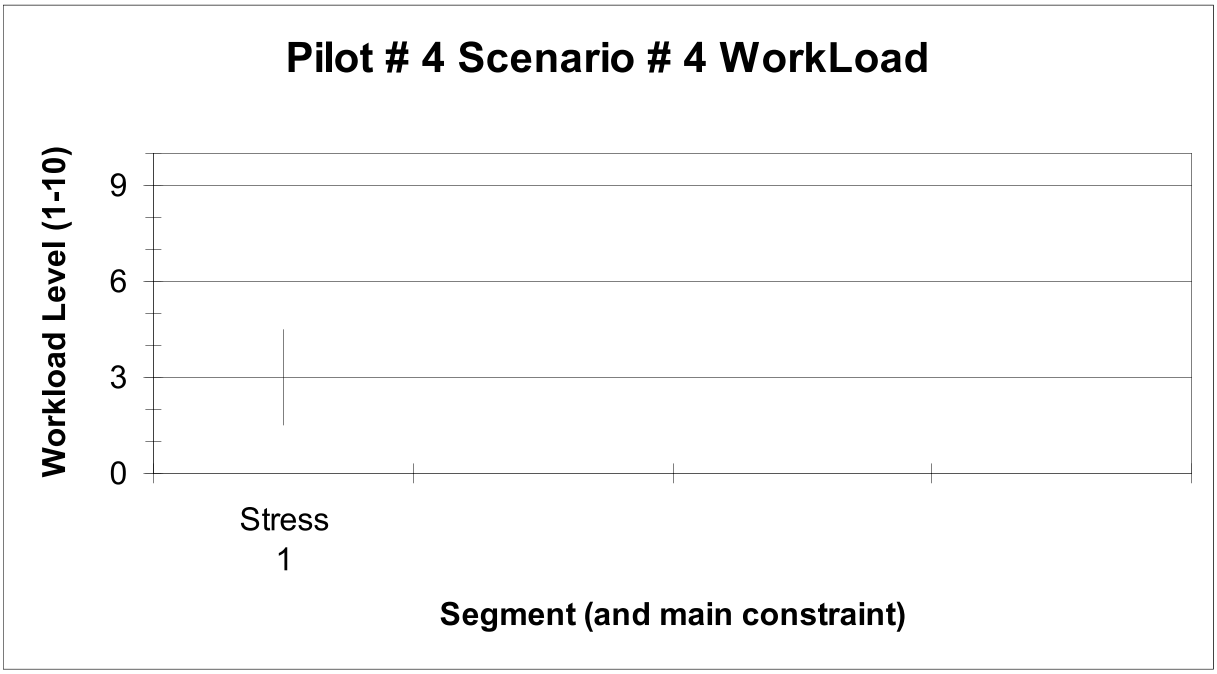

Pilot # 1 Scenario # 4 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
Time constraint
2
Mental effort
3
Time constraint
4
Segment (and main constraint)

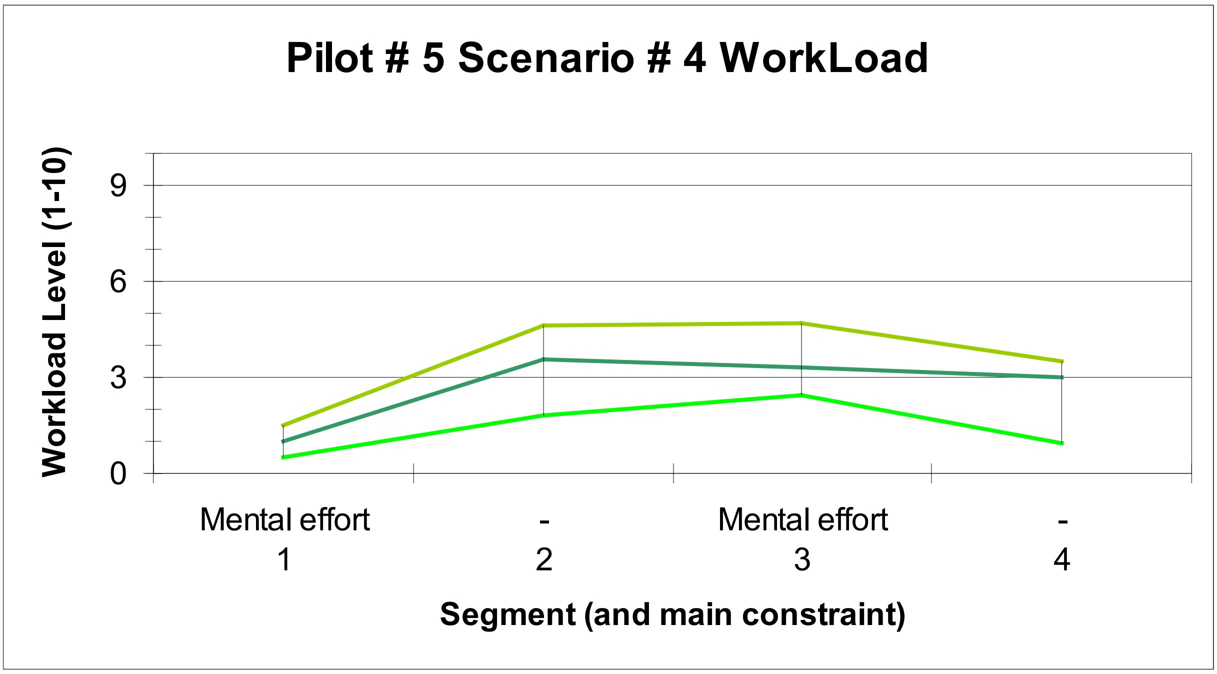


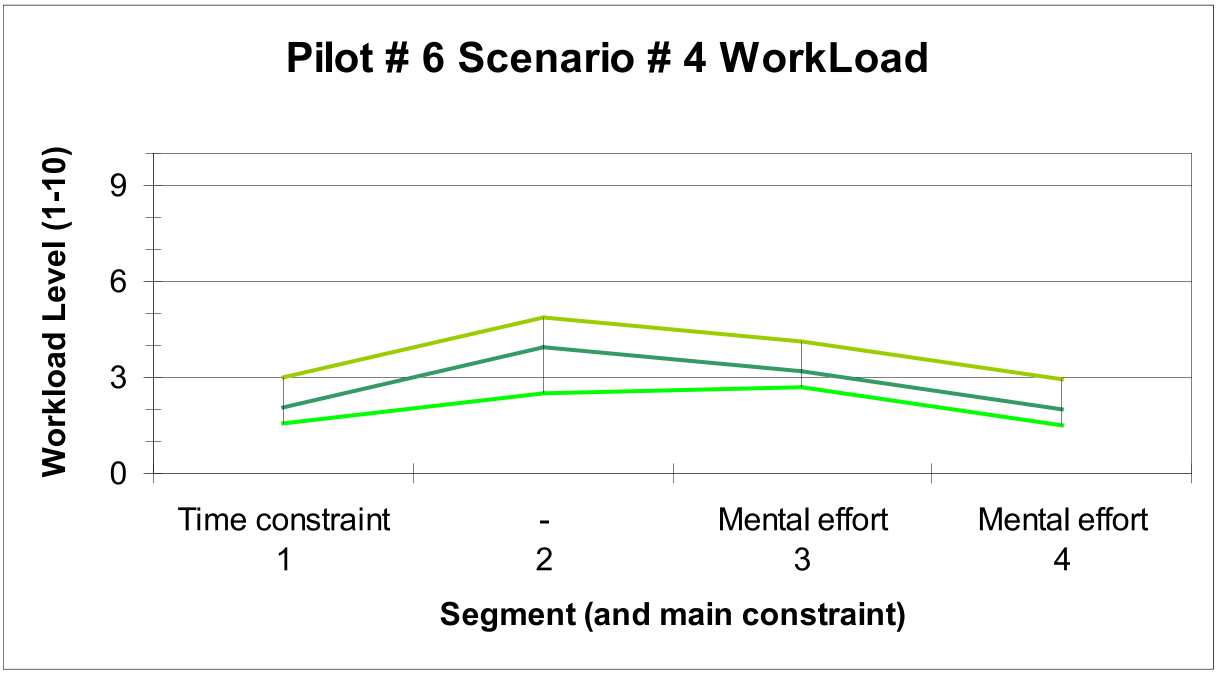
Pilot # 2 Scenario # 4 WorkLoad
Workload Level (1-10)
9,0
6,0
3,0
0,0
-
1
Mental effort
2
Stress
3
Mental effort
4
Segment (and main constraint)



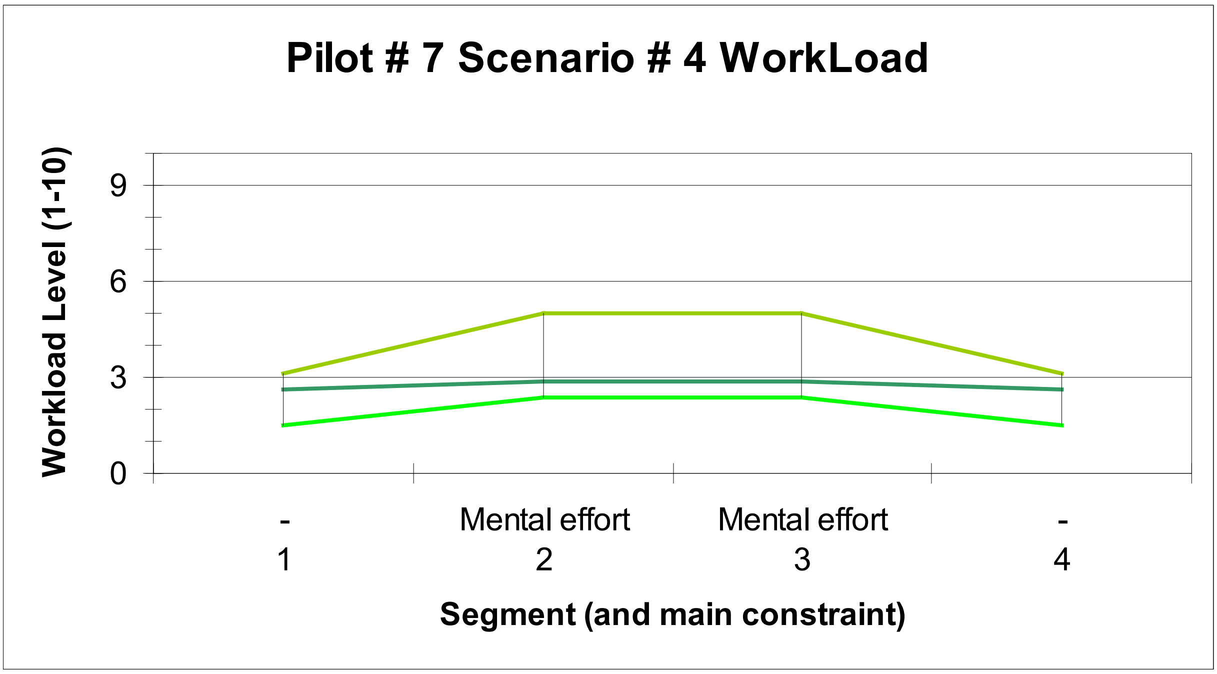
Pilot # 3 Scenario # 4 WorkLoad
Workload Level (1-10)
9
6
3
0
-
1
Physio effort
2
Mental effort
3
-
4
Segment (and main constraint)


Pilot # 4 Scenario # 4 WorkLoad
Workload Level (1-10)
0
3
6
9
Stress
1
Segment (and main constraint)

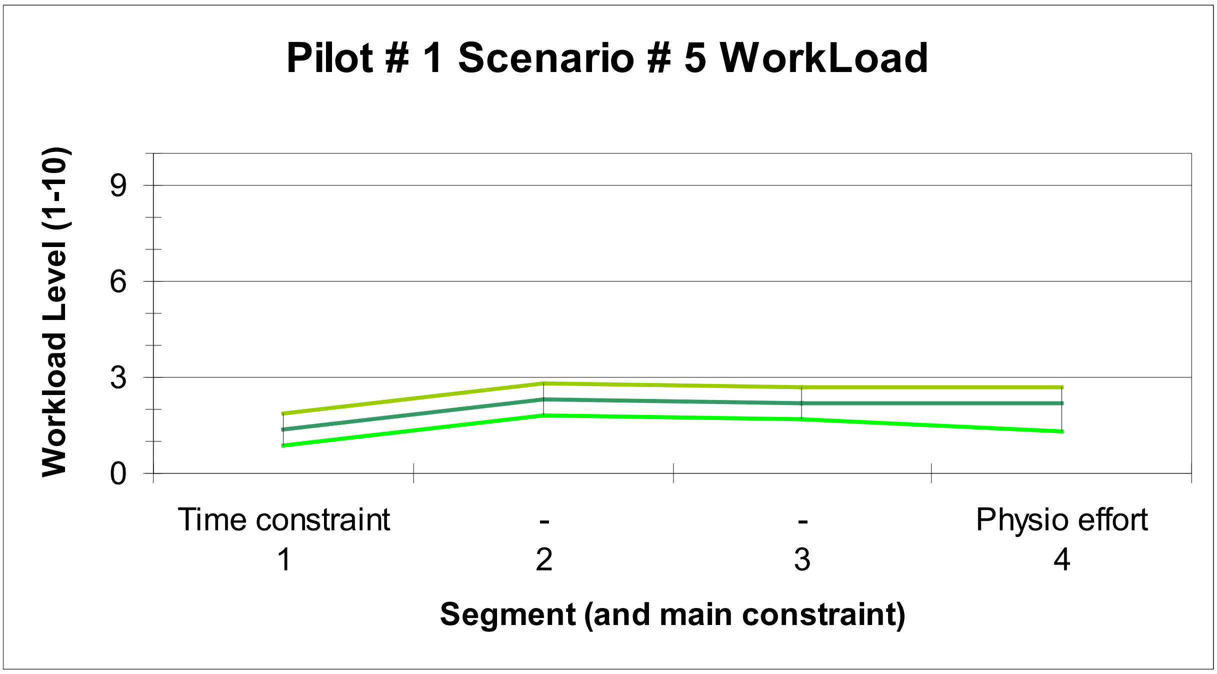

Pilot # 5 Scenario # 4 WorkLoad
Workload Level (1-10)
0
3
6
9
Mental effort
1
-
2
Mental effort
3
-
4
Segment (and main constraint)

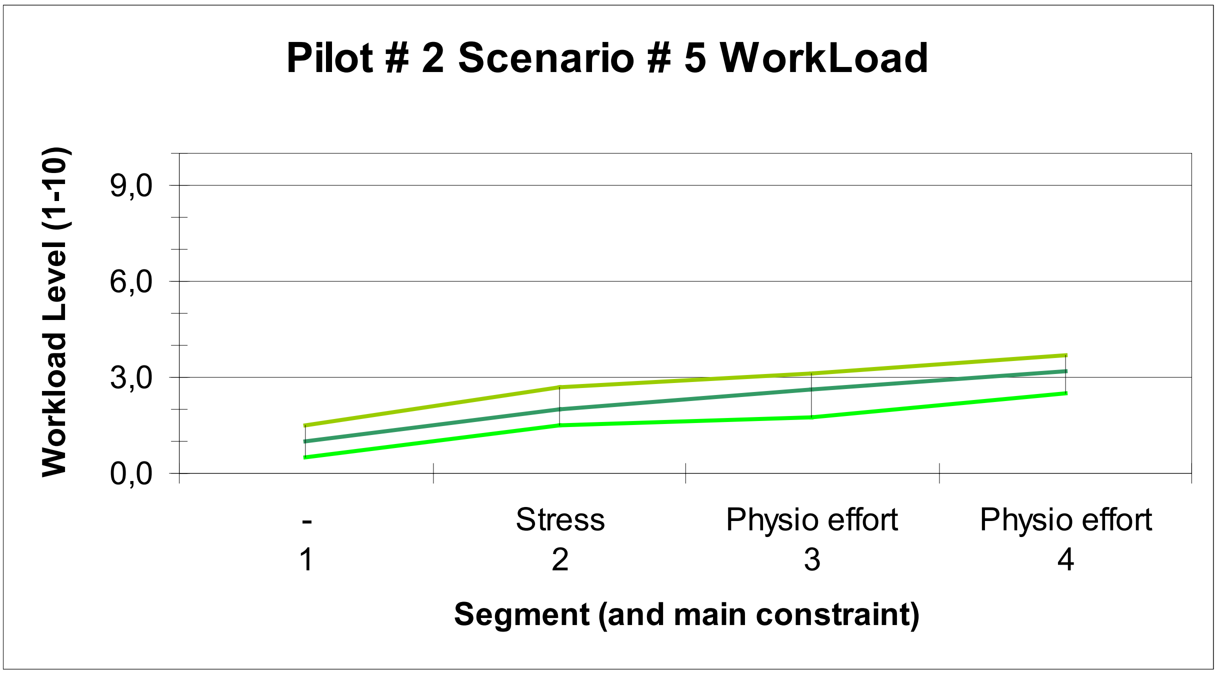


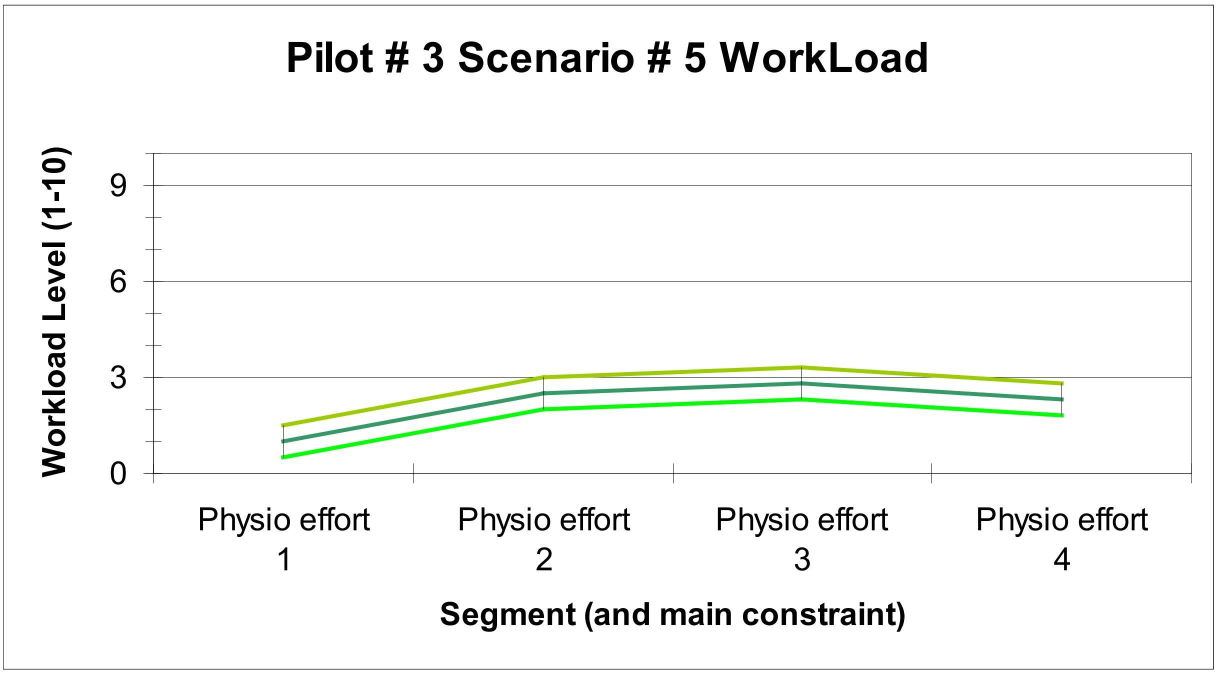
Pilot # 6 Scenario # 4 WorkLoad
Workload Level (1-10)
0
3
6
9
Time constraint
1
-
2
Mental effort
3
Mental effort
4
Segment (and main constraint)

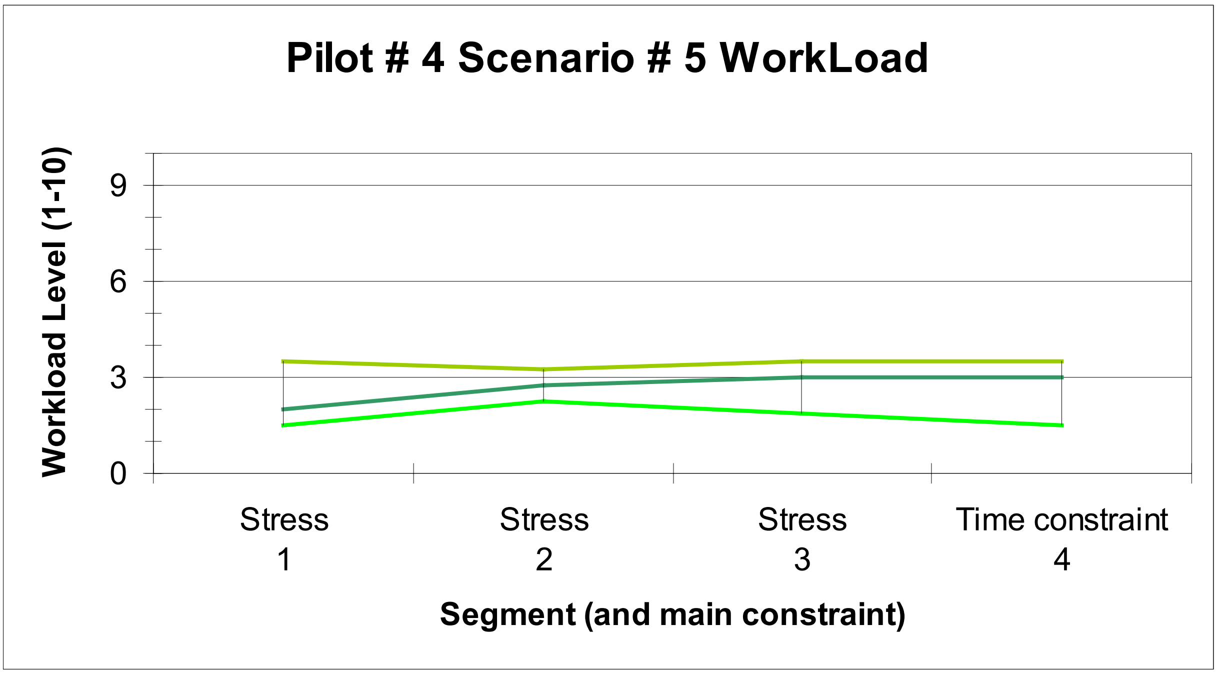


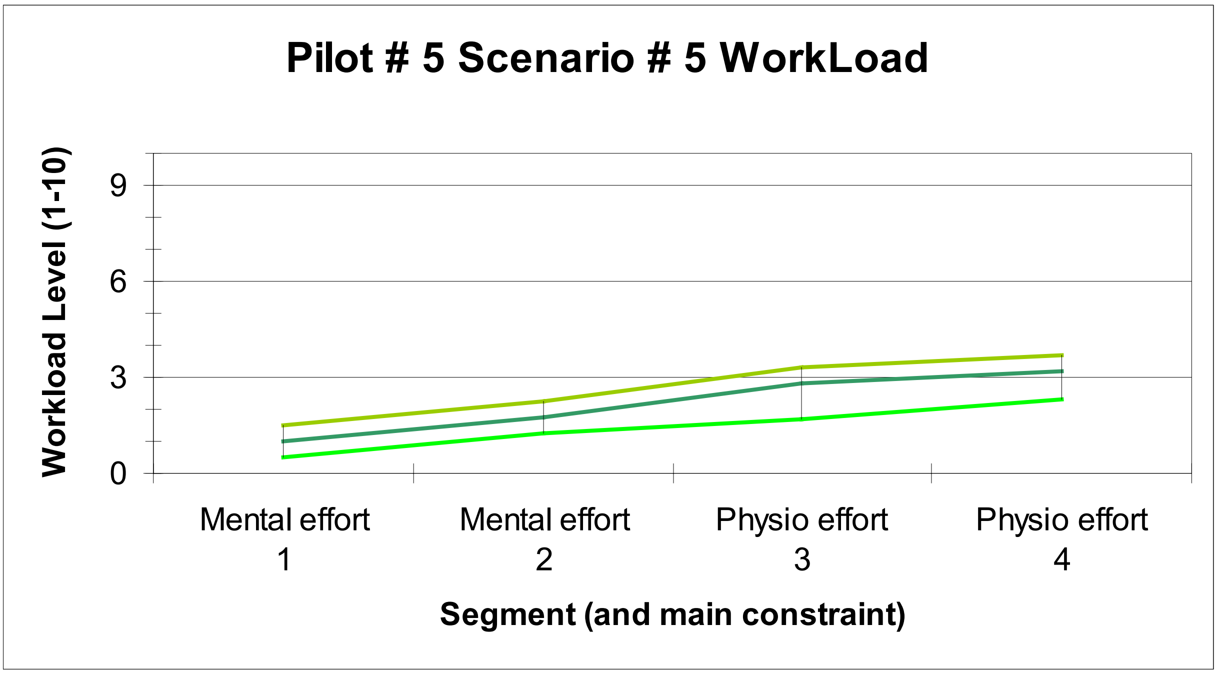
Pilot # 7 Scenario # 4 WorkLoad
Workload Level (1-10)
0
3
6
9
-
1
Mental effort
2
Mental effort
3
-
4
Segment (and main constraint)

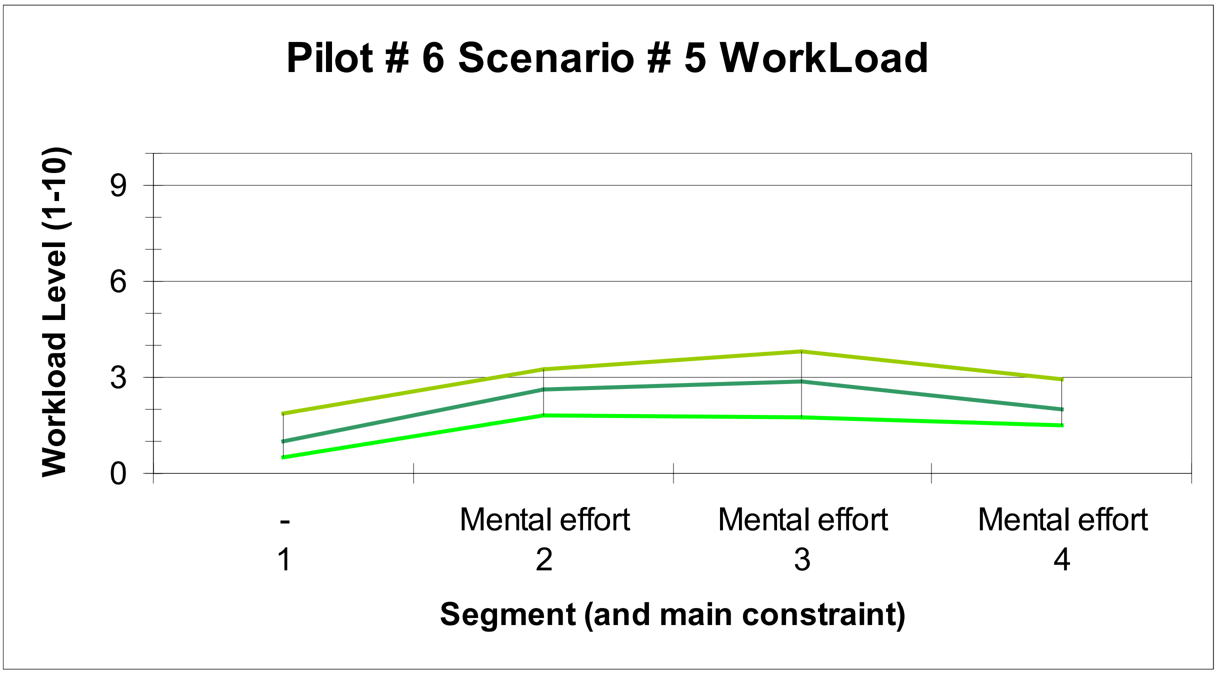

Pilot # 1 Scenario # 5 WorkLoad
Workload Level (1-10)
9
6
3
0
Time constraint
1
-
2
-
3
Physio effort
4
Segment (and main constraint)

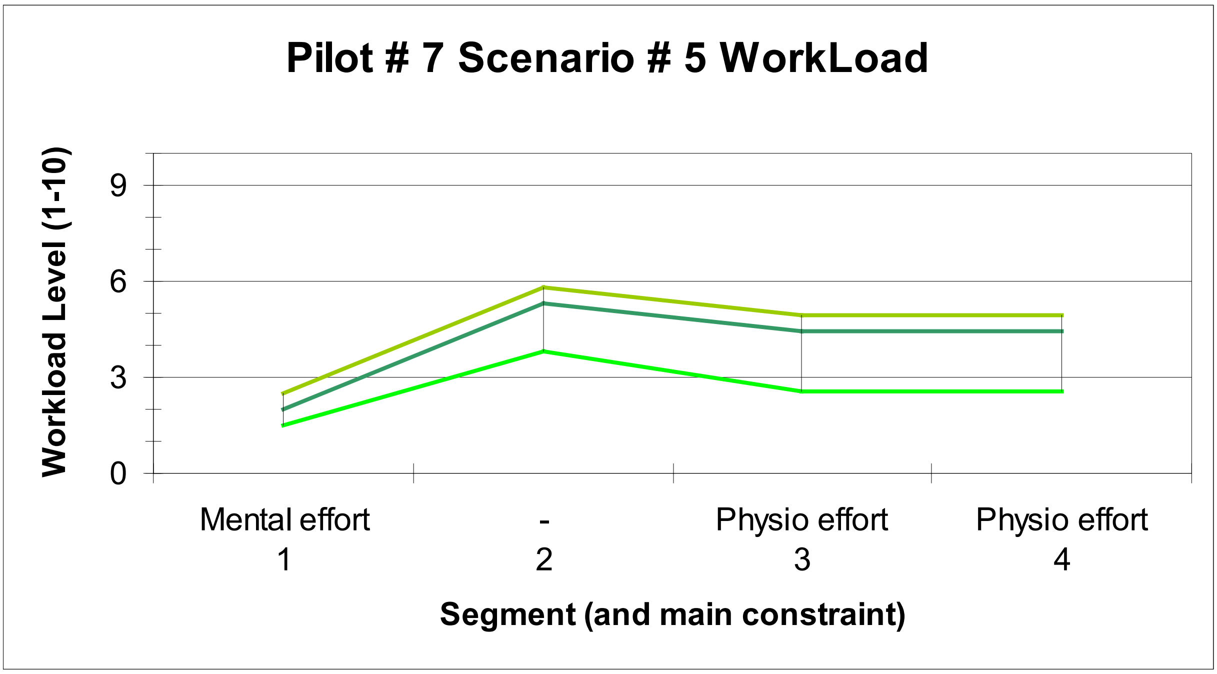

Pilot # 2 Scenario # 5 WorkLoad
Workload Level (1-10)
9,0
6,0
3,0
0,0
-
1
Stress
2
Physio effort
3
Physio effort
4
Segment (and main constraint)


Pilot # 3 Scenario # 5 WorkLoad
Workload Level (1-10)
0
3
6
9
Physio effort 1
Physio effort 2
Physio effort 3
Physio effort 4
Segment (and main constraint)


Pilot # 4 Scenario # 5 WorkLoad
Workload Level (1-10)
0
3
6
9
Stress 1
Stress 2
Stress 3
Time constraint 4
Segment (and main constraint)


Pilot # 5 Scenario # 5 WorkLoad
Workload Level (1-10)
9
6
3
0
Mental effort 1
Mental effort 2
Physio effort 3
Physio effort 4
Segment (and main constraint)


Pilot # 6 Scenario # 5 WorkLoad
Workload Level (1-10)
9
6
3
0
- 1
Mental effort 2
Mental effort 3
Mental effort 4
Segment (and main constraint)


Pilot # 7 Scenario # 5 WorkLoad
Workload Level (1-10)
9
6
3
0
Mental effort
1
-
2
Physio effort
3
Physio effort
4
Segment (and main constraint)