ORGANISME EMETTEUR	CLASSIFICATION	
eurocopter an EADS Company	SECRET MILITAIRE	SECRET INDUSTRIEL
	N/A	**N/A**

DIRECTION EMETTRICE : **OT**	LIEU D'ARCHIVAGE :
AUTEUR : **P. BOUDIER** — SIGLE : **OTSM/M**	VISA : — DATE : **11/12/2003**

SERVICE EMETTEUR
SIGLE : **OTSM/M**
NOM : **Y. BRUN**
VISA :
DATE : 8/01/2004

SERVICE CONTRIBUTEUR
SIGLE : **OTIS**
NOM : **S. BAILLY**
VISA : S. Bailly
DATE : 16/01/04

RESPONSABLE DE RECHERCHE
SIGLE : **OTRA/M**
NOM : **F. TOULMAY**
VISA :
DATE : 8/01/2004

VISAS D'ORIGINE DIRECTION EMETTRICE

VISAS D'ORIGINE AUTRES DIRECTIONS

SIGLE :
NOM :
VISA :
DATE :

SIGLE :
NOM :
VISA :
DATE :

SIGLE :
NOM :
VISA :
DATE :

TITRE

HELICOPTER FAILURES CORRECTION TIMES PHASE 2

SUPPLEMENT TO SUMMARY DOCUMENT

DIFFUSION (SIGLES)

INTERNE DIRECTION EMETTRICE		EXTERNE DIRECTION EMETTRICE	
DOCUMENT COMPLET	RESUME (Page 1 à)	DOCUMENT COMPLET	RESUME (Page 1 à)
OTS G. MILLON **OTSM/M Y. BRUN** **OTRA/M F. TOULMAY** **OTIS S. BAILLY**		**FFCC A. VISCONTI**	

EXTERNE EUROCOPTER

DGAC / SFACT R.E			

PROGRAMME	MARCHE N°	LOT N°	CAT. DIFFUSION	REF. BIBLIO.
RECHERCHE	**99.50.075**			

NOTION D'INDEXAGE	IND.	N° DOCUMENT	PAGE
Temps de reprise en main des pannes	**A**	**TNX 000 AR 488 E 03**	**1** / 25

MODIFICATIONS

IND.	PAGE(S) MODIF.	DATE	SUMMARY OF THE MODIFICATION	AUTHOR	VISAS RESP. SERVICE	AUTRES DIRECTIONS MARQUE
A	X	11/12/2003	NEW DOCUMENT	X	X	X

ABSTRACT

This document is a supplement to the summary report of project "Helicopter Failures Correction Times" phase 2, as defined in contract DGAC 99 50 075.

This document includes a theoretical study comparing the results of the Helicopter Failures Correction Times study, phase 2 indicated above and described in the summary report TNX 000 AR 421 E 03 with the reactions expected by the pilots under the same failure scenarios in former generation cockpits.
This additional study is a theoretical study based on Eurocopter's operational experience and on this study simulations (phase 2) dealing with the pilots' reactions in a new generation cockpit.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

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 Human 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	Visual Meteorological Condition
VMD	Vehicle Management Display
V_{NE}	Velocity Never to Exceed
WAT	Weight, Altitude, Temperature
WWWS	Windshield Washer Wiper

1 Introduction

The increasing automation of systems and the progress in helicopter technologies have modified pilot's work. The pilot has become both a supervisor and decision-maker, the basic tasks being handled by the systems.

This new role and the new interfacing capabilities have made it possible to redesign the man/machine interfaces for better summary of the helicopter 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 analyze 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 must allow for the new pilot's role.

The purpose of this survey was 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 survey, 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.

In the second phase of the survey, tests were conducted with a panel of 7 pilots. The analysis of these results demonstrated that the introduction of new cockpit technologies does not imply modification of the current regulations.

However, during the presentation of the results from the second phase analysis, it seemed worthwhile to compare the reactions recorded during these simulation sequences and those expected in former generation cockpits. This comparison forms the subject of this supplemental document.

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 summary documents of study phase 1 are:

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

The reference documents that are internal to the study second phase and used as intermediate reports, are:

- "Phase 2, Quarter 1" progress report – 16/07/2002 – Ref. OTSM/1074/2002 (SH)
- "Phase 2, Quarter 2" progress report -29/10/2002 – Ref. OTSM/1097/2002 (PB)
- "Phase 2, Quarter 3" progress report -20/01/2003 – Ref. OTSM/1010/2003 (BDR)
- Minutes of the meeting held on 03/12/2002 – Ref. OTSM/1011/2003 (BDR).
- "Phase 2, Quarter 4" progress report -10/04/2003 – Ref. OTSM/1048/2003 (BDR)
- Minutes of the meeting held on 23/05/2003 – Ref. OTSM/1071/2003 (BDR).

The summary documents of the study phase 2 are:

- “Helicopter Failure Correction Times - Phase 2 – Summary Document”– TN X 000 AR 421 E03 issue A

The present document is a translation of the French language document that remains the reference issue:

- “Temps de reprise en main des pannes hélicoptère - Phase 2 – Document de synthèse”– TN X 000 AR 420 F03 indice A

3 Scope of the Survey

3.1 Approach

Phase 2 of the Helicopter Failures Correction Times 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.
- Analyzing and summarizing the collected data in accordance with the methods selected on phase 1.

This description does not necessarily follow 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 collected data analysis.

3.2 Typical Configuration of a New-Generation Helicopter

This survey considered only one non-specific 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 compatible with JAR and FAR 29 regulations. This non-specific aircraft is equipped with a full glass cockpit, which includes a basic helicopter management system. It includes a digital automatic flight control system (fly-by-wire controls) and a full-authority digital engine control (FADEC).

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

3.3 Typical Configuration of a Previous Generation Helicopter

This comparative study is based on a non-specific aircraft. This aircraft is representative of helicopters of the medium/heavy twin-engine type (i.e. within the 6 to 10 metric tons range) manufactured by Eurocopter in the early 1980's. The cockpit of this non-specific aircraft is equipped with analog instruments and a central warning panel. The automatic flight control system is of the duplex analog type with possible addition of an optional 4-axis coupler for upper modes. The engine is controlled mechanically and/or by a duplex analog electronic device. The vehicle management is directly performed via engraved diagrams and indicator lights on the vehicle management panels.

3.4 Typical Configuration of a Former Generation Helicopter

This comparative study is based on a non-specific aircraft. It is representative of helicopters of the medium/heavy twin-engine type (i.e. within the 6 to 10 metric tons range) manufactured by Eurocopter in the early 1970's. The cockpit of this non-specific aircraft is equipped with electro-mechanical instruments and a central warning panel. The Automatic Flight Control System is a simplex electro-mechanical system with 4 independent axes. Engines are hydro-mechanically controlled.

3.5 Extent of the Survey

3.5.1 Failures

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

3.5.2 Simulator

Experimentation was 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 survey was 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 announcements, 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 aural warnings.

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

3.5.3 Comparisons

Data covered by this document are only compared on a theoretical basis.

In fact, all the simulations of phase 2 of the Helicopter Failures Correction Times survey involved a new-generation helicopter. The pilot's reactions under the same failure scenarios in former generation helicopters are therefore derived from Eurocopter operational experience, but were not experimentally measured with an experiment protocol in similar simulator.

4 Summary of Simulations To Be Performed

A more detailed description of the simulations performed during Phase 2 of the Helicopter Failures Correction Times survey are given in the summary report TN X 000 AR 421 E03.

4.1 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 AP altitude hold upon a barometric altimeter failure	Cruise in IMC conditions
5	Hardover on AFCS roll axis	Cruise in VMC conditions at low altitude

4.2 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.

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 the 2 FND symbologies - “HANDS ON” audio warning - Temporary illumination of “FCS” red warning light (meaning « hands on »)+ “FCS” and “AVICS” (amber) on CWP	- Cross check between both displays/stand-by instrument - Warning acknowledgement - Identification of display providing false information - MFD2 reconfiguration on IRS1 ** Automatic AFCS switch off*

4.2.1 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 avionic pages on the VMD and see that the IRS are indicated as being unreliable (amber). However, 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 analyzed 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 analyzed 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.

4.3 Failure No 2: Loss of Engine No 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.

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

4.3.1 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.

Only one pilot (pilot 1) decided to pursue 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.

4.4 Failure No 3: Reduction of Engine 1 Power

The partial reduction of engine 1 was selected for its « slowover » aspect 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.

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

4.4.1 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 of 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 pursue – and even accelerate – the landing, apart from one pilot who opted for a go-around.

4.5 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 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.

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

4.5.1 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 with the standby altimeter, as 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 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.

4.6 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.

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- “HANDS ON” audio warning	- Correction
- Temporary illumination of “FCS” red warning light (meaning « hands on »)+ “FCS” (amber) on CWP	- Correction with cyclic stick
- Warnings on FND - AFCS disengagement	
- FNDs reporting a roll movement to the right	
- movement of the external environment	

4.6.1 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:
  - 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 stabilizing the helicopter. They then used the VMD to analyze 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

5 Scenarios Applied to Previous Generation Helicopters

5.1 Failure No 1: Slow IRS 2 Drift

This failure is not to be considered on former generation helicopters since their artificial horizons are generally independent of the AFCS vertical indicator. In the case where the artificial horizons use the vertical information from the AFCS IRS's, this would be equivalent to the scenario occurring on new-generation aircraft.

Therefore, two cases will be considered: a pilot's artificial horizon drift or an AFCS vertical indicator drift resulting in a roll movement. In the latter case, the aircraft has to be provided with a simplex AFCS (or initiating a flight on a duplex AFCS with a failed channel).

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Nose-down and roll movements displayed on the pilot artificial horizon - If the failure is an AFCS failure and if it is not detected by the pilot, the AFCS switches off (with alert signal) when it can no longer follow its vertical indicator as the helicopter attitude becomes excessive.	- Correction - AFCS switch off - cross check of both 2 ADI / standby horizon - identification of the failed system; ● depending on the diagnosis, in case of a pilot's horizon problem: - AFCS reengagement - Monitoring of AFCS behaviour using standby horizon ● or (if AFCS problem): - manual piloting on roll and pitch axes

5.1.1 Scenario Sequence

The failure is initiated in a steady cruise flight in IMC conditions. The first sign of the failure is an artificial horizon that starts to deflect as if for the beginning of a turn.

Then the pilot has to recover manual control and observe his standby horizon so as not to blindly follow the indications of his main horizon.

If the pilot's horizon is defective, the AFCS can be reengaged, observing the attitude of the helicopter on the standby horizon. Otherwise, the pilot will have to pursue his flight by manual piloting on the roll and pitch axes using the cyclic stick.

5.1.2 Comparison

In contrast to the new generation helicopters, this failure poses two problems: the detection and the resolution of the failure.

In the former generation aircraft, the failure is not detected by the system but by the pilot. This is of no importance in the case of an horizon failure since the AP still maintains the aircraft horizontal. However, if the pilot is not attentive, this may lead to a hazardous situation in case of an AP malfunctioning. However, it can be pointed out that a former generation simplex AP is rather a stabilization aid (the pilot keeping full control of the helicopter) than an AP in its modern meaning. . It is therefore unlikely that the aircraft starts turning without being detected in this configuration.

In the event of an AP failure, correction is rather easy: the pilot can follow his instinctive reflex consisting in recovering manual control and stabilizing the helicopter using the indications of his artificial horizon. However, any pilot's horizon failure requires the pilot to check the standby horizon before attempting to recover from a situation perceived as an accidental turning. Nothing indicates that the 3 pilots who started to follow the failed horizon in the new generation aircraft would not have react in the same manner in this specific case.

To summarize, if the failure appears more complex in new generation aircraft since a same sensor can deliver information to several equipment items, this advanced system also helps the pilots in detecting the failure. Moreover, this system allows the aircraft to be reconfigured for piloting with the correct inertial reference source, thus reducing the workload compared with that required for standby horizon piloting in the former cockpits.

5.2 Failure No 2: - Loss of Engine 1

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

The failure is different depending on whether it occurs on a helicopter of the previous generation or an older helicopter. With the helicopters of the previous generation:

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION

- Drop of Ng, T4, torque and NTL of engine 1
- NG.DIFF. and PRESS.1 warnings (central panel), + ALARM warning light
- then, depending on the load release rapidity and on the collective pitch decrease rate:
  - PWR.1 warning (dedicated light)
  - NR.MIN warning (dedicated light + audio warning)
	- release of the sling load
	- Lower collective pitch to retain rotor NR, if needed
	- Accelerate (push cyclic stick forward) and control path (obstacle avoidance)
	- Switch engine No 1 off to prevent fuel supply

With the older aircraft:

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Drop of Ng and T4 of engine 1 - PRESS.1 warning (central panel), + ALARM warning light - then, depending on the load release rapidity, the application of emergency power and the collective pitch decrease rate: - NR.MIN warning (audio warning)	- release of the sling load - Apply emergency power - Lower collective pitch to retain rotor NR, if needed - Accelerate (push cyclic stick forward) and control path (obstacle avoidance) - Switch engine No 1 off to prevent fuel supply

5.2.1 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.

For helicopters of previous generation, this failure causes a red warning light « NG.DIFF » to illuminate on the CWP, rapidly followed by an « NR.MIN » warning since in these conditions, it is impossible to maintain the helicopter in stabilized single-engine flight.

The pilot is expected to relieve the helicopter by releasing the sling load; then the pilot can reduce the collective pitch so that the remaining engine power is sufficient to maintain the rotor rpm and a nose-down attitude is adopted to increase speed. Once the edge of the oil rig has been cleared, this acceleration can be facilitated by using the platform height above the sea. The pilot may also elect not to attempt to increase speed and to land directly. In fact, this alternative is not adopted because of the possible damage caused by the sling load release on the landing pad.

On aircraft of previous generation, the engine control system automatically switches to OEI mode, thus authorizing the use of the maximum contingency power. On older aircraft, correction of this failure is more delicate since the pilot must manually authorize the use of the maximum contingency power by the remaining engine governor.

5.2.2 Comparison

In spite of their different aspect, the warnings initiated by this failure are similar to those appearing in new-generation cockpits. Since the pilots have their hands on the controls and this failure is the most critical in these conditions (OGE hover at high aircraft weight), the reaction time would also have been rapid.

However, since the analog engine control system has a more limited response capacity than that of a FADEC, it is more likely to obtain a rotor rpm decrease than on new-generation aircraft, which would probably have alerted the pilots not complying with the procedure. The pilots would therefore have released the loads earlier.

On former generation aircraft, the requirement for applying emergency power (to authorize the remaining engine governor to use the maximum contingency power) would probably have increased the workload.

It can also be assumed that the absence of a synthetic power indicator on former generation aircraft, such as the FLI (First Limitation Indicator) currently installed on Eurocopter aircraft would still have increased the workload.

5.3 Failure No 3: Reduction of Engine 1 Power

The partial reduction of engine 1 was selected for its « slowover » aspect 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.

In this specific case, the failure is different depending on whether it occurs on a helicopter of the previous generation or an older helicopter. With the helicopters of the previous generation:

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION

- Progressive drop of Ng, T4, torque and NTL of engine 1
If not initially detected:
- NG.DIFF warning (central panel), + ALARM warning light
- then, when increasing collective pitch (e. g. executing a flare) :
  - PWR.1 warning (dedicated light)
  - NR.MIN warning (dedicated light + audio warning)
	- Attempt of manual control
	- Manual shutdown of failed engine 1;
	- Lower collective pitch to retain rotor NR, if needed
	- Decision to divert
	If not initially detected:
	- Land with reduced power or increase speed (pilot's decision)
	- Stop engine 1

With older aircraft:

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Progressive drop of Ng, T4, torque and NTL of engine 1 *if not initially detected, when increasing collective pitch (e. g. executing a flare) :* - NR.MIN warning (audio warning)	- Attempt of manual control - Apply emergency power - Manual shutdown of failed engine 1; - Lower collective pitch to retain rotor NR, if needed - Decision to divert *If not initially detected:* - Apply emergency power - Land with reduced power or increase speed (pilot's decision) - Stop engine 1

5.3.1 Scenario Sequence

When the failure is initiated, engine 1 slowly begins to develop less power than the power demand. This drop can be detected by a mismatch of the displayed engines parameters.

If no action is taken, the torque difference between the two engines reaches a threshold at which the NG difference warning is triggered by the monitoring logic. The failure is initiated so that this threshold is reached at the decision point.

Then, if the power demand becomes sufficiently high to decrease rotor RPM, the low NR and engine 1 power loss warnings are triggered In fact, in an analog control system of this generation, as long as the rotor RPM remains nominal, it is impossible for the monitoring system to know whether engine 1 loses power because of a failure or in response to an overspeed condition of engine 2.

In the case when the initial degradation has not been detected, the scenario is more hazardous on older aircraft since the control system is not able to output an engine failure signal. Therefore, when the NR warning is triggered during a flare execution, the pilot must analyze the reason of the lack of engine power, switch to emergency power mode and complete landing (or elect to perform a go-around) with a single engine. In practice, the priority in short final approach is to look outside the cockpit (controlling the flight path and the touchdown area), with additional workload due to night flight. It is therefore probable that the pilot will decide to complete the landing before analyzing the failure. This will result in "hard" landing.

5.3.2 Comparison

In this case, the pilot does not receive any warning before the decision point is reached. In former helicopters, the pilot does not even receive a warning before the rotor speed is decreased by a manoeuver.

It is therefore logic for the pilot to proceed with the landing. The only significant difference between new-generation helicopters and helicopters of the previous generation would lie in the better reactivity of the digital control system, slightly reducing the risk for hard landing. However, former helicopters are significantly more exposed to this risk since a pilot that would not have detected the engine prior degradation, would not be alerted before engine power becomes insufficient when executing the flare.

Should the pilot hear the warning before the decision point is reached or detect an initial drift of the engine parameters, the approach procedure would logically be interrupted although several options are proposed by the procedure. But during the simulations, it was seen that during night flights with a single pilot, searching for appropriate touchdown point increased the pilot's workload, thus making correct monitoring of engine instruments rather improbable.

Moreover, night landing with former aircraft on unprepared terrain requires the presence of a second crewmember for monitoring the vehicle and more particularly the engines.

5.4 Failure No 4: Slow Drift of Barometric Altimeter No 2 affecting the AP

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 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.

This failure is not to be considered on former generation helicopters. In fact, the AP is equipped with its own altimeter (whose indication is not visible by the crew), and this type of drift is generally due to an internal failure of the measuring instrument (e. g. leak in the barometric cell). However, in this study, priority will be given to a failure category rather than to a specific scenario. Even if this is not realistic, we will therefore consider that the concerned non-specific helicopter presents a failure mode inducing a common drift of both pilot's and AP altimeters, for example via static ports.

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Vertical speed indicator reporting a 100ft/min drift - Discrepancy between pilot and standby altimeters	- Correction - Altitude hold disengagement - transition to « standby static pressure »

5.4.1 Scenario Sequence

With the helicopter in steady IMC cruise flight, the altimeter that the AFCS is slaved to begins to drift, and an hypothetical common mode induces the same drift on the pilot's 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 with the standby altimeter, as 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 at its maximum.

5.4.2 Comparison

In this case of failure, there would be no reason for the pilots to react in a different manner than in new-generation cockpit.

In fact, the pilots always have to regularly check that their «Basic T» indications are consistent with those displayed on the standby instruments. However, it shall be noted that, to extend the scope of the survey to lighter aircraft or dual controls, a cross-checking function for pitot-static indications had been disabled on new-generation aircraft. Therefore, the latter is capable of informing the pilots of the presence of an altimeter problem. This function was not provided on former aircraft.

5.5 Failure No 5: Hardover On Roll Trim Actuator

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.

FAILURE DETECTION ELEMENTS	FAILURE CORRECTION
- Artificial horizons reporting a roll movement to the right - movement of the external environment; - *if required (depending on aircraft generation):* • Indication of AFCS failure (amber light) • AFCS disengagement warning	- Correction - Correction with cyclic stick - AFCS disconnection

5.5.1 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:

- movement of the external environment;
- the attitude indicators indicate rolling to the right;

Depending on the aircraft design, the AFCS can detect the failure, causing illumination of an AFCS failure amber warning light and disconnection of the AFCS (or at least of the roll channel) along with the corresponding alert signal.

The pilot is expected to immediately proceed to manual recovery and stabilization of the aircraft (if needed overriding the AFCS). After analysis of the failure, the pilot will switch off the AFCS and release the trim feel loads on roll axis, even cut off AFCS hydraulic pressure. Then, depending on the systems, the pilot can re-engage the other channels.

5.5.2 Comparison

In this case of failure, there are few reasons for the pilots to react in a different manner than in new-generation cockpits.

In fact, the failure results in a sudden movement of the external environment, felt as a very strong indication by all the pilots. The major difference lies in the existence, on new-generation helicopters, of a « hands-on » alert signalling the necessity for immediate manual recovery of the aircraft. This alert signal combined with the temporary illumination of a red light, increases the criticality of the situation. But in the scenario under study, in good weather conditions, it is probable that these indications are not needed by the pilots.

6 Conclusion

The results of this complementary study are consistent with the assumption that had originated the Helicopter Failures Correction Times survey, i.e.: on any advanced technology aircraft, the pilot spends less time flying the helicopter than managing the systems.

In fact, it can be pointed out that, for the scenarios retained in this survey, the failures obtained for new-generation aircraft are:

- a little more complex to analyze, due to the interconnection between the various systems, which can lead to several effects for a same failure depending on the exact configuration of the aircraft at the time of the failure occurrence;
- but more easy to detect thanks to the various monitoring functions achievable by this system interconnection, which allows the pilot to be informed directly by the system;

Moreover, the pilot can use the system as an aid for the failure diagnosis. He can often reconfigure the system so that the system operates in a virtually nominal mode. For example, upon an IRS failure, the pilot can display on his screeen the data of the valid IRS or the standby instrument instead of piloting the aircraft using this standby instrument which is not directly in the pilot's field of view.

Therefore, the pilot's role is changing. His tasks include less "conventional" vehicle control and monitoring actions and more system and configuration management operations. However, as previously demonstrated by the simulations performed for this survey, the warning and aid provisions in a modern system ensure pilot's failure correction times complying with the regulations established for former systems and even allow the risks related to the failure consequences to be reduced.