USAGE ANALYSIS, SLL DYNAMIC ASSESSMENT - METHODS, BENEFITS AND CONSTRAINTS

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OVERVIEW

Keeping a helicopter in the air isn't simply a matter of being able to afford the fuel bill. On-going maintenance is a vital consideration and the cost can be extremely high. Optimising maintenance costs without compromising safety is the focus of attention for the condition based maintenance project. Therefore, maintenance issues are in a constant state of improvement to meet the expectations of customers who are looking for increased profitability and fleet availability.

Maintenance optimisation requires the maximum exploitation of every part of an aircraft, to decrease the number of interventions and part replacements, while guaranteeing a very high level of safety. Rotorcraft manufacturers are now optimizing "on-condition" maintenance in order to avoid unscheduled maintenance, thanks to the implementation of appropriate monitoring tools.

This paper describes methodologies implemented in the general maintenance policy within Eurocopter. The development of an optimized and customized maintenance program is supported by relevant data recorded with on-board monitoring systems like HUMS (Health and Usage Monitoring System) or FDCR (Flight Data Continuing Recording).

Currently, the maintenance planning documents require parts' service lives which are defined during certification phase. The parts' service lives are determined under a hypothesis which considers rigorous operational conditions, and mechanical strength characteristics of the components. The estimation of these service lives could be improved through on-line monitoring of environmental and usage parameters.

The objective of the paper is to present the global end-to-end customized Service Life Limit calculation chain. The figure below describes the process:

The usage of the aircraft is determined using flight phase recognition software, which enables to associate every customer flight phase to a well-known flight configuration performed during development phase on a prototype equipped with loads measurement installation during Load Survey Campaign. Then every flight phase can be associated to a level of loads and mechanical damage per flight hour in the components. Knowing the real time damage of the parts enables to estimate the remaining service life of the component. Out of the evident benefit that could be earned in terms of helicopter availability for customers, this approach could also be an opportunity to optimize the sizing and thus the weight of rotor components. In addition, the paper present the result of a proof of concept on the EC225 offshore with an estimation of maintenance cost benefit and identification of main constraints. Eventually, this paper addresses the next issues to be solved in order to provide the customers with a fully certified, integrated and reliable device of usage based maintenance. In this approach, the vibration monitoring was used to confirm the prognosis made by the environment and usage data analysis. The purpose of this paper is to provide the required inputs for the definition of the future Usage management structure that will achieve customized maintenance planning adapted to the actual usage of the aircraft.

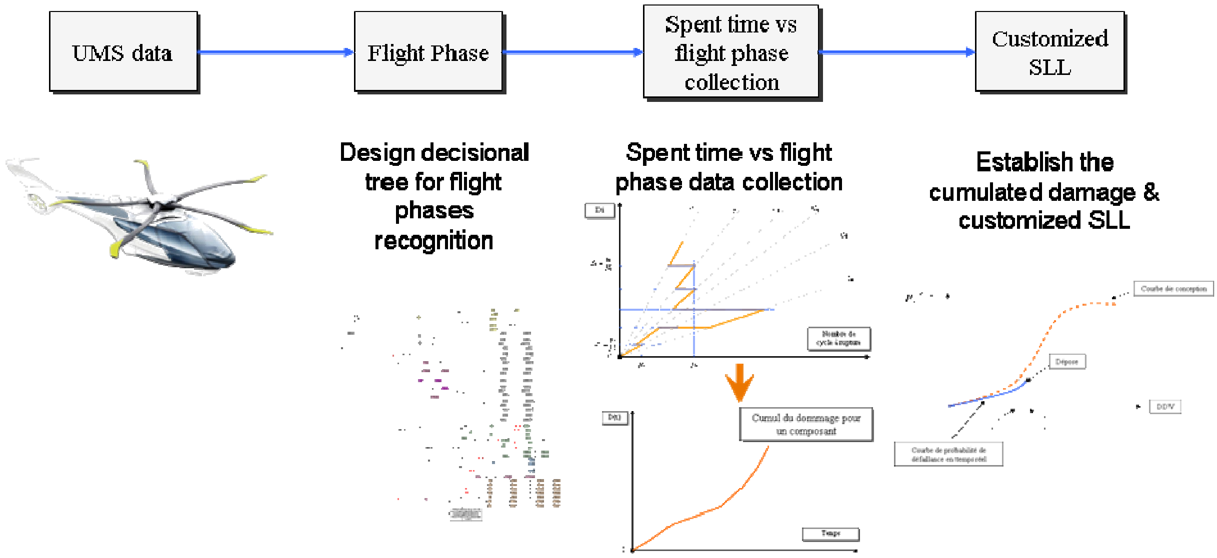

Figure 1. Service Life Limit calculation chain

1. USAGE DATA ANALYSIS

1.1. Objectives

The aim of usage data analysis is to provide information for maintenance optimisation process. For this goal, the Health and Usage Monitoring System (HUMS) data provides a good basis. HUMS equipped on EUROCOPTER helicopters provide aircraft state during flight through many parameters. With this data, analysis on flight stress on helicopter structural parts is possible. In this way, HUMS data are computed for complete assessment of aircraft usage, components damages and remaining useful lifetime prediction for individual component until hard time period expiration.

1.2. Concept description

The USAGE Function performs:

- Acquisition/collection of information from aircraft,
- processing of USAGE data,
- recording of USAGE data,
- display of USAGE data.

The USAGE function is fulfilled by two main parts:

- an on-board segment (airborne system) which monitors and records aircraft information during each flight, displays some of the data recorded and performs a few processing of the data
- an on-ground segment (ground infrastructure) which allows to collect all the information, processes and displays on ground after the flight results of USAGE algorithms.

The on-board segment is performed in the avionic system of the aircraft. At the end of the flight (or at any time considering the operational context), the collected aircraft information is downloaded to the ground infrastructure using the common aircraft data transfer means. If possible, this information is completed with other data such as aircraft configuration, logbook and maintenance operations history coming from customer Maintenance System and sent to EUROCOPTER for complete treatment.

The on-ground segment will consist of:

- a local ground station installed at customer level able to display and record immediate USAGE data post-flight. This local ground station will be used too as interface for data transfer to Eurocopter website.
- an internal ground infrastructure, based at Eurocopter and made of Information technology (IT) capabilities (servers, databases, web interfaces) in charge of collecting, computing and recording all the USAGE data and making restitution of USAGE algorithms results

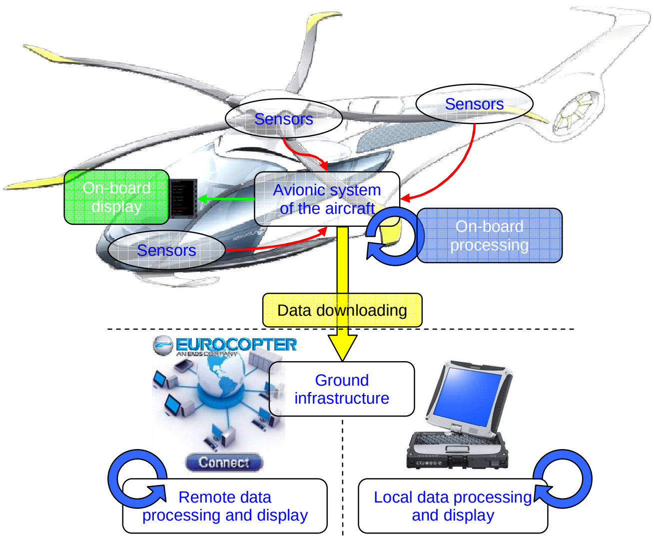

Figure 2. System overview

USAGE monitoring function needs as prerequisite, data collection on aircraft followed by data analysis & correlation on ground. It supposes ground station but also IT capabilities and performances able to collect automatically all customers' data at EUROCOPTER, to record them in adequate databases and to treat them according to specified USAGE function algorithms. Customers' data include flight data plus aircraft configuration and Maintenance system information.

In this paper, we will focus on a dedicated function inside USAGE, customized Service Life Limits (SLL).

2. CUSTOMIZED SLL CALCULATION CHAIN

This section presents an overview of the system to be used to determine the lifetimes of dynamic components associated to the real usage of the helicopter. Usage parameter data can be used to determine the time in each manoeuvre category (spectrum) for each HUMS-equipped aircraft. This spectrum will be combined with existing fatigue strength and certification load survey data to determine the amount of lifetime that has been used up in fatigue on critical parts.

This processing can be made by specially designed usage software on ground. At the moment, the processing of usage data was made at EUROCOPTER thanks to a data collection process.

2.1. Data collection

Data collection consists in two steps:

- collect data on-board with a data concentrator,

- download the operational data from customer to EUROCOPTER.

The data are generally concentrated on-board through the HUMS system. At the end of the flight, the data are downloaded in a ground means, like a ground station or server. Each day, the EUROCOPTER support team download data in EUROCOPTER server. The data are available for different algorithms for HUMS analysis.

2.2. Flight Phase Recognition (Pre-processing)

The calculation of the components lifetimes is performed during certification phase, considering a flight spectrum, defined as the expected but conservative use of the rotorcraft to be certified. This flight spectrum includes a set of flight phases, weights, Centre of Gravity locations, altitudes,… representing the different uses and possible manoeuvres of the aircraft associated with percentages of flight time.

The first step of this usage processing is the evaluation of the real flight spectrum made during the flight by the customer. Many papers present method and concept for this phase. Someone use neural network for this evaluation [1], other use a methodology based on rules [2]. For our case, we use both. For the manoeuvres easy to find, the processing uses a decision tree based on rules and for other learning methods:

- The rules were commonly defined by stress and aerodynamic departments.
- Learning methods are based on database created with helicopter simulator software in order to generate, after flight, mechanical parameters unavailable or not reliable.

The Flight Regime Recognition (FRR) process is not dedicated to track abnormal manoeuvres or exceedances, but rather to identify manoeuvres that could have an impact on lifetime.

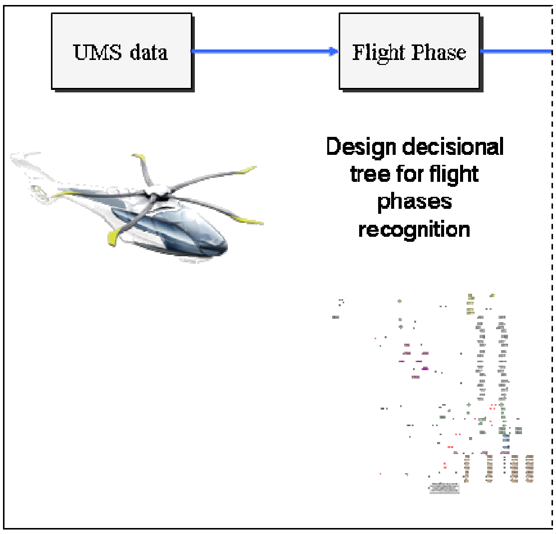

Figure 3. First step of the service Life Limit calculation chain

Damages per manoeuvre were defined following certification load survey campaign. It is a list of possible manoeuvres that can be flown during the operational life of the helicopter. The flight spectrum is the unique reference during the whole design and certification phases for which it is necessary to know the usage of the aircraft. For example, it represents 22000 possible combinations for EC225.

A list of the on board data measured parameters required for usage evaluations is presented in table 1. All the parameters in this list can be recorded in the aircraft on a removable memory card for post processing. Post processing will occur on the ground, using specially designed usage software through a web portal or a ground product.

N°	Parameters	Description	Unit
1	date day	date day	D
2	date month	date month	M
3	date year	date year	Y
4	time hour	time hour	H
5	time minute	time minute	M
6	time second	time second	S
7	NR	Rotor speed	%
8	P0	Static pressure	Bar
9	OAT	Outside temperature	°C
10	IAS	Indicator air speed	Kts
11	TRQ2	Torque engine 2	%
12	N12	Engine speed 1	%
13	N22	Engine speed 1	%
14	TOT2	Engine temperature 1	°C
15	AEO	Engine state	-
16	OEI_1	Mode	-
17	OEI_2	Mode	-
18	TRQ1	Torque engine 1	%
19	N11	Engine speed 2	%
20	N21	Engine speed 2	%
21	TOT1	Engine temperature 2	°C
22	FLIGHT	Position in flight	-
23	GROUND	Position on ground	-
24	TRAIN_STATE	State	-
25	ZB	Altitude barometric	ft
26	GAM_Z	Vertical acceleration	g

27	COLL PITCH	Collective control	%
28	LONG PITCH	Longitudinal control	%
29	LATT PITCH	Lateral control	%
30	YAW_CT_ANGL	Tail rotor total pitch	%
31	HEADING	HEADING	°
32	PITCH ATT	Pitch angle	deg
33	ROLL ATT	Roll angle	deg
34	R	yaw rate	deg/s
35	WEIGHT	Weight	Kg
36	MGBP	MGB Pressure	Bar
37	MGBT	MGB temperature	°C
38	ZRS	Radio altimeter	ft
39	PITCH RATE	Pitch rate	deg/s
40	ROLL RATE	Roll rate	deg/s
41	NMSGS	Ground speed	Knt/s
42	LONG_ACC	Longitudinal Acceleration	g
43	LATT_ACC	Lateral Acceleration	g
44	DRF_ANGL	Drift angle	deg
45	WIND_SPD	Wind speed	kts
46	WIND_DIR	Wind direction	°
47	LATT	GPS Latitude	-
48	LONG	GPS Longitude	-
49	ALTRATE	Vertical speed	ft/min

Table 1. Parameters list

The objective of the processing is to recognise flight phases in the customer flight data. Each manoeuvre is characterized by a 5 digit code. For example, F0IAG means "level flight standard at 100% of the MCP with a drift angle of 5° and at nominal rotor speed".

The table below is an extract of the flight phase catalog of the EC225.

A	APPROACH	1	NORMAL	0	STD	0	STD	E
		2	ON HEAVY SLOPE					K
		4	FLARE					G
		5	QUICK STOP					
L	LANDING	1	NORMAL	0	STD	0	STD	E
		3	ROLL					K
		4	AFTER COMPLETE AUTOROT					G
L	LANDING	2	ON SLOPE	C	COMBINED	0	STD	E
				R	RIGHT	A	6°	K
				L	LEFT	C	8°	G
				U	NOSE UP	E	10°	
				D	NOSE DOWN	G	12°	
S	SPOT-TURN	A	30°/S	R	RIGHT	1	MEAN STOP	E
		C	45°/S	L	LEFT	2	MAX STOP	K
		F	MAX					G
H	HOVERING	I	IGE	0	0 KTS	0	STD	E
		O	OGE	A	5 KTS	1	FRONT	K
				E	10 KTS	2	FRONT RIGHT	G
				I	15 KTS	3	RIGHT	
				M	20 KTS	4	REAR RIGHT	
						5	REAR	

Table 2. FRR codes

This code is completed by 3 digits characterizing the weight, centre of gravity location and the barometric altitude of the aircraft.

The result of the decision tree is a code at eight digits characterizing the manoeuvre.

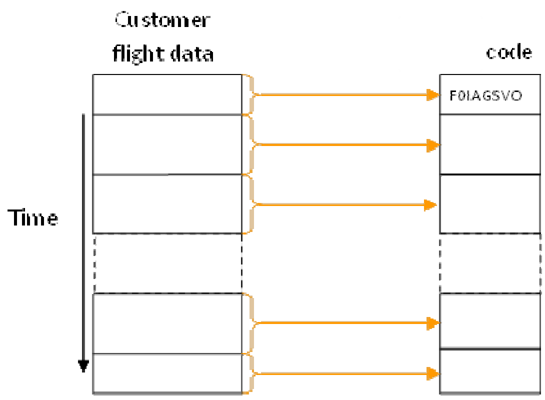

Figure 4. Customer flight data in code

Therefore, after this step, customer flight data is decomposed in several codes "flown". The second step is to associate a cumulated duration to each code detected by the decision tree, then to find the database load linked to each code.

2.3. Fatigue damage per manoeuvre

During certification phase, a dedicated flight load survey is performed in order to evaluate the flight loads and the number of load cycles for each manoeuvre. It will be then created for each code a file called "peak matrix".

In parallel, the demonstrated fatigue strength of each component will allow to determine damage per flight hour for each code.

F0IAG	manoeuver		
Begin time	140151	End time	140205
MR Pitch rod load			
Id	Static load	Dyn load	Ncycles / FH
1	100	1000	124
2	100	1100	96
3	100	1200	28
…	…	…	…

Figure 5. Typical "peak matrix"

2.4. SLL calculation

The lifetime of each component is derived by the calculation of the cumulated damage of all the manoeuvres really performed by the customer during a period.

At the end, the "customized" lifetime is the flight duration leading to 100% of cumulated damage.

As a consequence, the HUMS system can provide a real time computation of the remaining lifetime and damage level assessment through usage monitoring data (based on flight customer spectrum recording), by following this end-to end-chain.

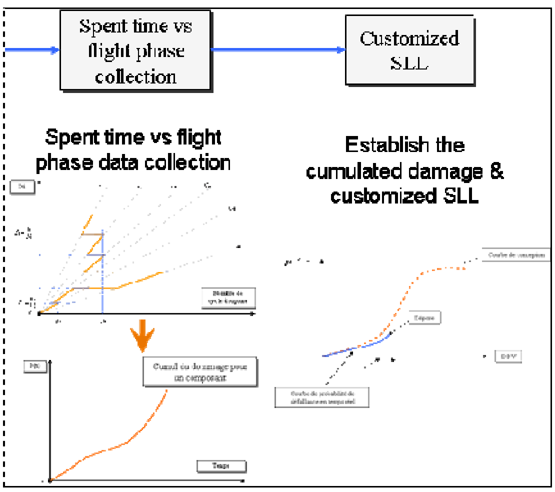

Figure 6. Service Life Limit calculation chain

The treatment needs different kinds of data:

- Aircraft data: information coming from embedded sensors and flight parameters. Those data are recorded in continuous during flight
- Maintenance data: all maintenance actions made on aircraft. This information is necessary to follow the "as maintained" configuration,
- Strength and material data: fatigue behaviour laws of each material used on components, fatigue strength (safe fatigue limits) demonstrated on all components, Flight test data: load and strain information recorded on aircraft during certification load survey campaign. This data is necessary to make the association between flight phases and part undergone stress.

2.5. Missing codes

By evidence, some flight manoeuvres required in load survey are not performed or some parameters are invalid.

Therefore, all theoretical code are not realised during flight test. We need to make an association between the recognised code and the available code in the flight test database. This step is called missing code management.

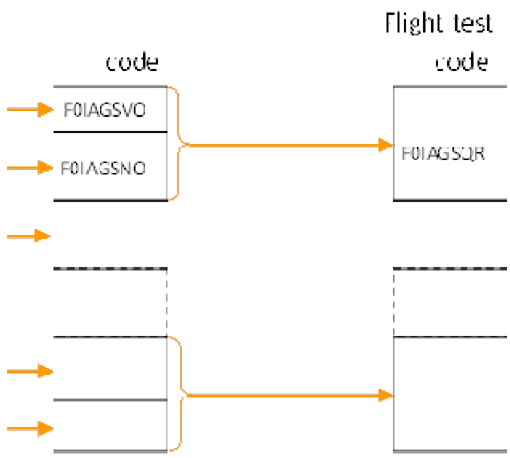

Figure 7. FRR

After the identification of the best code for the customer manoeuvre, the following step is to estimate the damage of the part for each recognised manoeuvre.

3. FATIGUE MANAGEMENT PROCESS, TEST AND RESULTS

A lot of papers present some cost-benefit analysis of the condition based maintenance process [3]. Other focuses on the discussion around the definition of the end-to-end process [4]. All these articles prove that the maturity of the HOW to make usage based maintenance is now well-known and agreed by the community. This paper presents the result of a test made on real operational data. The goal was to evaluate the impact of the usage based maintenance process and particularly the fatigue management process. In this way, an end-to-end chain was implemented at EUROCOPTER on operational data collected every day. The following sections present component selection and results.

3.1. List of selected item

The test was made on EC225 helicopter. We chose items function of:

- operational lifetime observed in our support and service department,
- sensibility to our theoretical flight spectrum,
- repair cost and price of the item.

The selected items are:

- Non rotating swashplate
- Rotating swashplate
- Tail Gear Box (TGB) wheel
- Tail rotor transmission shaft

3.2. Inputs used

We use for this test, flight files coming from EC225 in operation. The detail of the files use is:

- Number : 870 files (15/11/09 to 23/01/2011)
- 15 months
- Number of recorded hours : 2357H 44m 45s
- Number of flight hours : 1632H 59m 35s
- Number of MGB cycles : 2866 cycles

3.3. Results

Results obtained with flight spectrum algorithm described below, are presented in Figure 8.

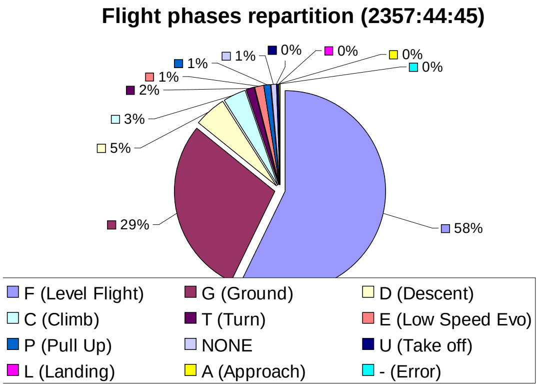

Figure 8. Flight spectrum

We can then compare this information with the flight spectrum of AC27 MG11.

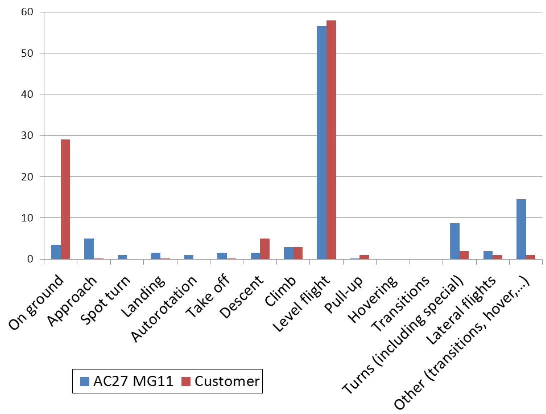

Figure 9. Flight spectrum comparison

We can notice that the time in level flight is similar to the time in the theoretical flight spectrum. We notice also that the operational time in turns, hover, transition, are less than the theoretical time.

These differences have an impact on the lifetime.

3.4. Benefit summary

We have computed results on the part lifetime using design method.

<u>Service Life Limit extensions:</u>

- Non rotating swashplate : x 2
- Rotating swashplate : x 1.5
- TGB wheel : > x10
- Tail rotor transmission shaft : > x10

<u>Weight:</u>

No detailed analysis has been led on weight impact in the frame of customized SLL process.

Nevertheless, weight impacts had been evaluated with regards to SLL targets. On the parts analyzed, the weight benefit between 20 000 FH and 10 000 FH had been evaluated to about 10%, which could lead to increase performances (payload, autonomy,…).

4. ON GOING SUBJECTS

Some on-going subjects are required on this topic for an integration of the customized Service Life Limit function in EUROCOPTER maintenance programme.

4.1. Configuration management issue

The customized SLL function is available if the operating time of the part is known. We need to implement a tool to follow all maintenance action made on aircraft. The objective is to detect "removal - installation" action to assign all good flight files for the customized SLL computing.

4.2. Certification and safety topics

Many certification and safety issues can be highlighted in relation with customized SLL process, typically:

- As lifetimes are part of the airworthiness limitation section of the Master Servicing Manual, the reliability of their determination shall be the same whatever the process used. In our case of an automatic process where the FRR and the data storage (on-board, then on ground station) are key points, the impact of the system failure and potential alternative methods shall be evaluated on the lifetimes.
- Some customers fly helicopters built with many optionals and/or extended flight domains, such as cargo sling, hoist equipment, ship deck landing, and/or icing conditions, cold weather, high altitude,… that have traditionally an impact on rotor loads. In this case, the customized SLL process shall be robust to these items and shall account for them.

5. CONCLUSION

Through this article, a complete loop of the customized SLL chain has been performed on real usage data collected during a period of more than 1 year on typical mission profiles.

It is demonstrated that the theoretical flight spectrum is well more conservative than the real usage of the helicopter. As a consequence, it seems that "classical" customers fly helicopters more developed for "exceptional" customers, leading to potentially oversized helicopter. In this frame, this customized SLL chain would allow adapting maintenance and SLL policies with real usage, and could help customer and crew to adapt piloting in an economic way.

Nevertheless, a large amount of work remains necessary to :

- Demonstrate that the "SLL reached" rate is in line with the expected benefits of such a process because it is clear that a low MTBUR component is not candidate to the customized SLL process.

- Consolidate the FRR algorithm reliability through more examples and dedicated tests.
- Consolidate the certification and safety issues because the impact of such a process on the concept of treatment tool is important. The end-to-end functional chain shall be compliant with DAL B. Such safety objectives need to set-up an adequate end-to-end system architecture (redundancies, safe back-up modes, error detection…) able to comply including the ground part based on COTS.

6. BIBLIO

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