

INSTANTANEOUS RELIABILITY AND GROUND RISK EVALUATION OF A ROCKET LAUNCHER WITH BLIND AND BALLISTIC PHASES

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Needs and Goal

- Flights over highly populated areas
- Loss of radio contact (blind area of trajectory)
- Eventual ballistic phases and re-ignition

- *Need for Ground risk minimization*
- *Need for adequate ground risk evaluation*
 - *Instant risk and resulting « footprint » if mission loss*
 - *Resulting risk for population*

Risk characterisation

– Footprint depends on

- instant position $M(t)$ $[X(t), Y(t), Z(t)]$ and speed $M'(t)$ $[X'(t), Y'(t), Z'(t)]$
- associated « *gaussian blur* »
- instant mission loss risk $h(t)$

– Ground damage depends on footprint through model $\psi(x,y,z)$ (e.g. *Electra*)

• *Resulting risk*

• $\int \psi[X(t), Y(t), Z(t)].h(t).dt$

• \int Mission

Goal is: evaluating $h(t)$

problem definition

Conditional probability of failure between t and $t+\delta t$:

$$\begin{aligned} & P\{\text{failure between } t \text{ and } t+\delta t \mid [\text{survival} \rightarrow t]\} \\ &= 1 - P\{[\text{survival from } t \rightarrow t+\delta t] \mid [\text{survival} \rightarrow t]\} \\ &= 1 - R(t+\delta t)/R(t) \\ &= [R(t) - R(t+\delta t)]/R(t) \end{aligned}$$

instant risk definition

instant risk for detected modes

$$h(t) = -d \frac{\{\ln[R(t)]\}}{dt} = -R'/R$$

instant risk for non detected modes

$$F'(T) = d[1 - R(T)]/dT = -R'(T)$$

problem definition

instant risk definition

Conditional probability of failure between t and $t+\delta t$:

$$\begin{aligned} & P\{\text{failure between } t \text{ and } t+\delta t | [\text{survival} \rightarrow t]\} \\ &= 1 - P\{[\text{survival from } t \rightarrow t+\delta t] | [\text{survival} \rightarrow t]\} \\ &= 1 - R(t+\delta t)/R(t) \\ &= [R(t) - R(t+\delta t)]/R(t) \end{aligned}$$

instant risk for detected modes $h(t) = -d \frac{\{\ln[R(t)]\}}{dt} = -R'/R''$

instant risk for non detected modes $F'(T) = d[1-R(T)]/dT = -R'(T)$

THEORETICAL MODELS AND TOOLS

NHPP PROCESS - ageing process and entropy

generalized Weibull distribution

$$R(T) = e^{-\left(\int_0^T g[C(t)] \frac{dt}{\theta}\right)^\beta}$$

ageing $V(T) = \int_0^T g[C(t)] dt$

entropy $\xi(T) = (V(T))^\beta = \left(\int_0^T g[C(t)] dt\right)^\beta$

THEORETICAL MODELS AND TOOLS

NHPP PROCESS - ageing process and entropy (generalized Weibull distribution)

$E = \text{Equivalent Missions} = (\text{total test entropy}) / (\text{Mission entropy})$

if k failures

$$C = 1 - R^E \sum_{j=0}^{k-1} [E \cdot \ln(R)]^j = 1 - \Phi(E, k, R)$$

$$f(R) = [\varphi(E, k, R)] = E * R^{E-1} \frac{[-E * \ln(R)]^{(k-1)}}{(k-1)!}$$

$$E(R) = \int_0^1 r \cdot f(r) dr = \frac{(E)^k}{(E+1)^k} \left[\int_0^1 \varphi(E+1, k, r) dr \right] = \left[\frac{E}{(E+1)} \right]^k$$

$$d\Phi/dH = \varphi(H) = E \cdot e^{-E \cdot H} (E \cdot H)^{k-1}$$

$$E(H) = \int_0^{\infty} H \cdot \varphi(H) dH = \left(\frac{k!}{(k-1)!} \right) \left(\frac{1}{E} \right) = \frac{k}{E}$$

THEORETICAL MODELS AND TOOLS

BINARY PROCESS

Pyrotechnics and other constant PO

P(1st defective strictly before k)

$$***= 1 - P(0 defective strictly before k) = 1 - R^{k-1}***$$

$$C = 1 - \left[\sum_0^{k-1} C_{n-1}^{k-1} R^{(n-1-j)} (1-R)^j \right] \quad C = 1 - \Psi(N, k, R)$$

total defective k > 0

$$R \cdot \psi(n, k, R) = \left(\frac{\binom{n-k}{n}}{\binom{n}{n}} \right) \cdot \psi(n+1, k, R)$$

$$E(R) = \frac{\binom{n-k}{n}}{n} = 1 - k/n$$

THEORETICAL MODELS AND TOOLS

Estimate and Confidence

Hypothesis Ho: $r < R$ (optimistic R estimate)

$$P\{e \text{ [non observed event]}\} = f(R) = 1 - \alpha$$

strictly decreasing monotonous function of R

\Rightarrow hypothesis rejected with α risk (confidence $1 - \alpha$)

usually: $e = \text{number of defectives} > \text{observed}$ (risk α)

*here: rank of k -th defective (**strictly before N or E**)(risk $\alpha' < \alpha$)*

\Rightarrow closer bound:

(2 parameters k, N (or E) marginal variation $\delta R / \delta N < \delta R / \delta k$)

$k > 0$; if zero, lower bound : 1st defective not before N

$$\Rightarrow C \geq 1 - R^N \text{ (success-run)}$$

THEORETICAL MODELS AND TOOLS

absorption process for non observed modes

Tests : N missions, 1 incident $R_{\mu} = 1 - 1/N$

\Leftrightarrow ***estimated reliability, for whole set of modes:
modes not observed are « absorbed » by observed mode
if 0 incident, lower bound $R_{\mu} \geq 1 - 1/N$***

\Leftrightarrow **lower bound for estimated reliability, for whole set of modes...then
for every mode !**

\Rightarrow ***if taken as estimate for each mode it would give
for whole set of k modes : $R(\text{all modes}) = (R_{\mu})^k$
...while demonstrated reliability is $R(\text{all modes}) = (R_{\mu})$***

MODE CHARACTERISATION AND HIERARCHY

Thorough technology analysis

Rex data, expertise

FMECA, CIL, ...



Critical

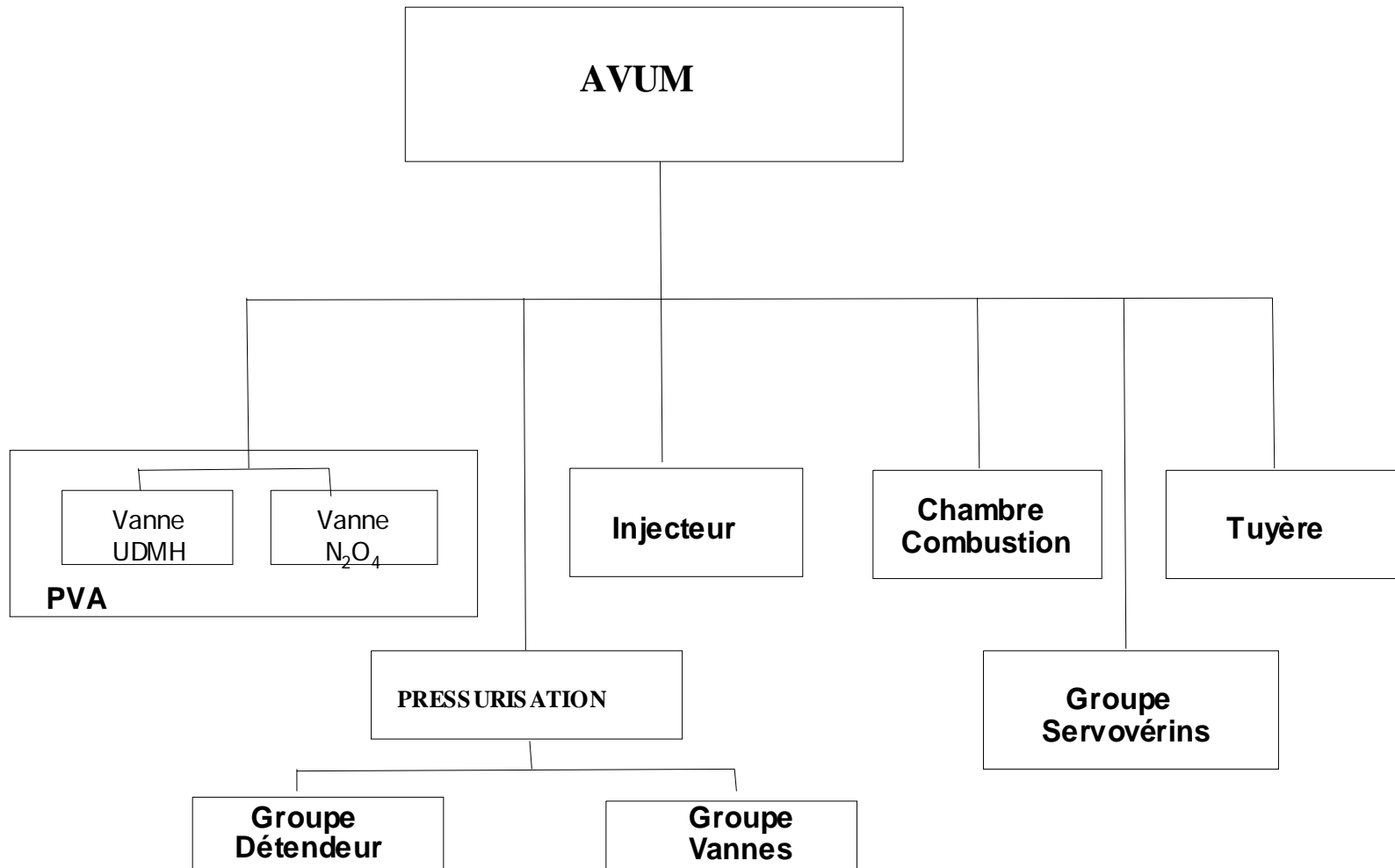
Major

minor

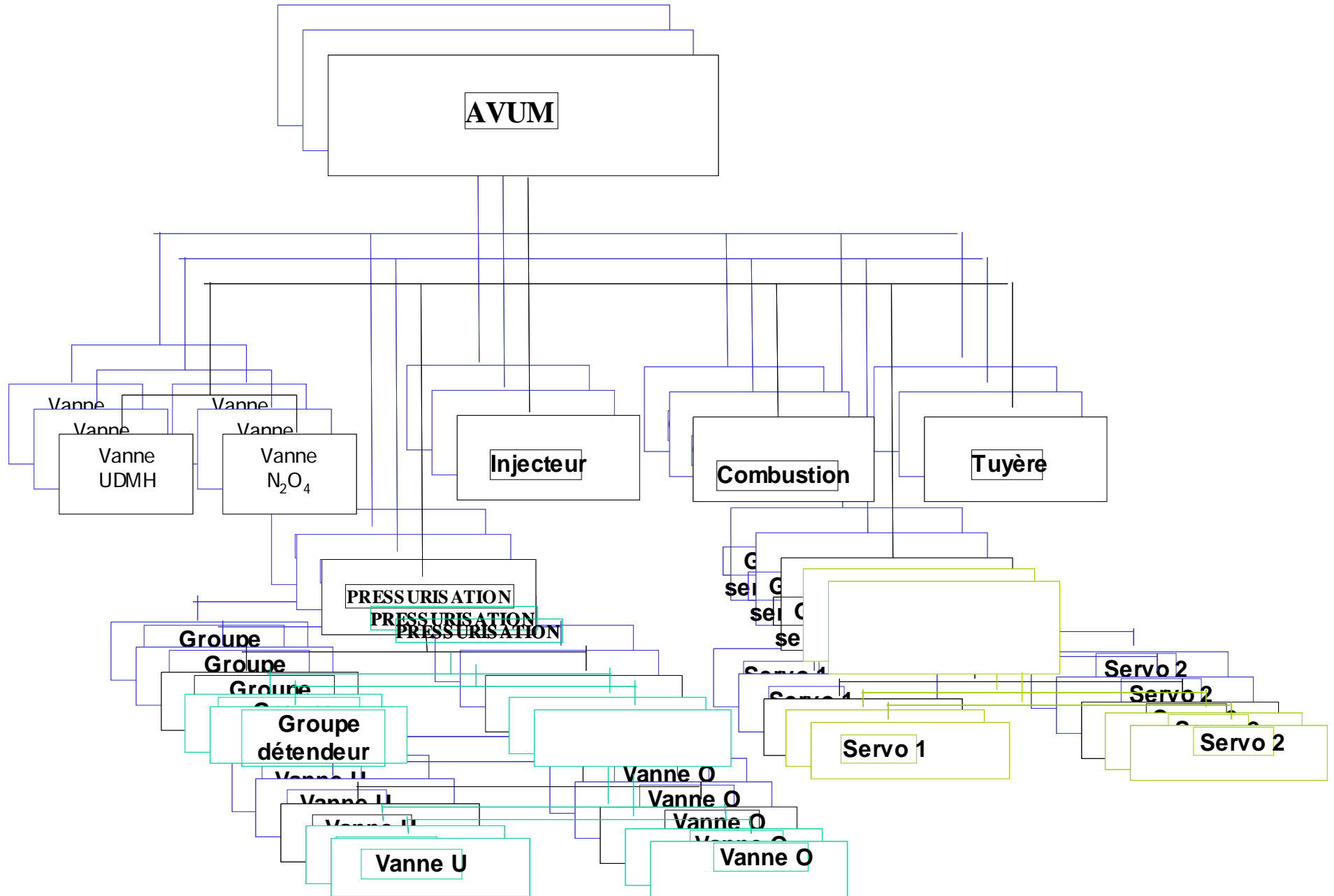
negligible (*generally implicitly « absorbed »*)

MARTA

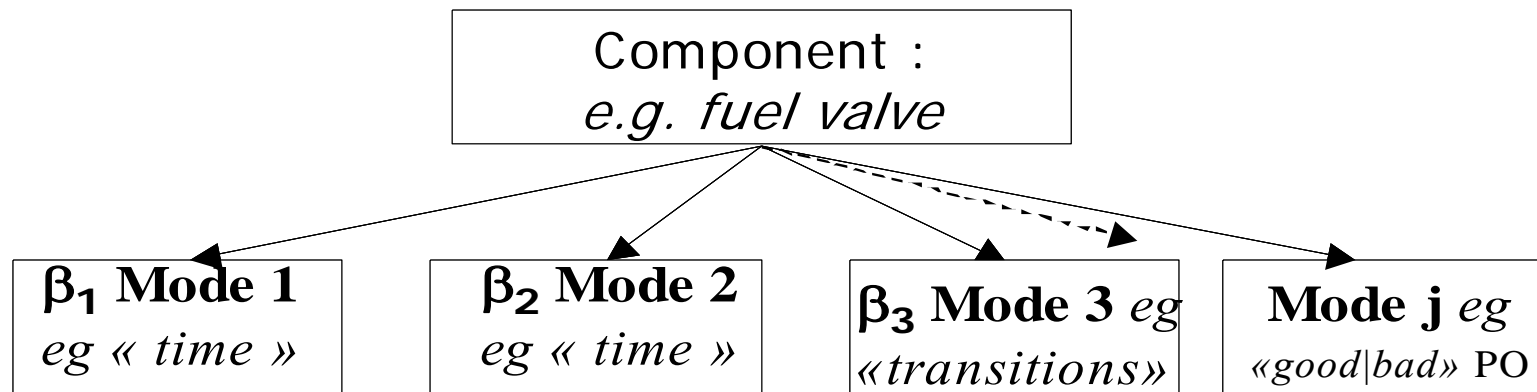
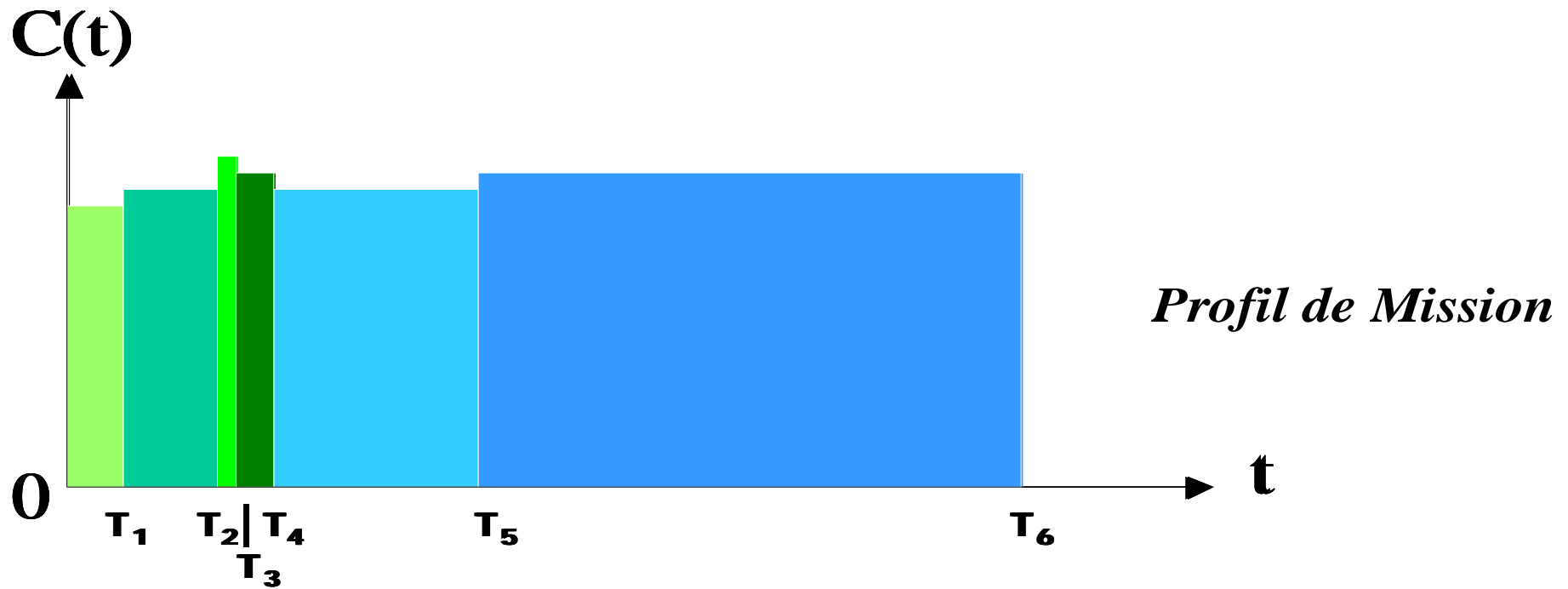
ARCHITECTURE:
ARBORESCENCE DE DESCRIPTION STRUCTURELLE



MARTA



MISSION et MODES



MARTA

Convolution above all modes

$$P(R) = \iint \dots \int \prod_{k=1}^n \frac{\partial \psi_k(r_k)}{\partial r_k} dr_k$$

$$R \geq \xi(r_1, r_2, \dots, r_n)$$

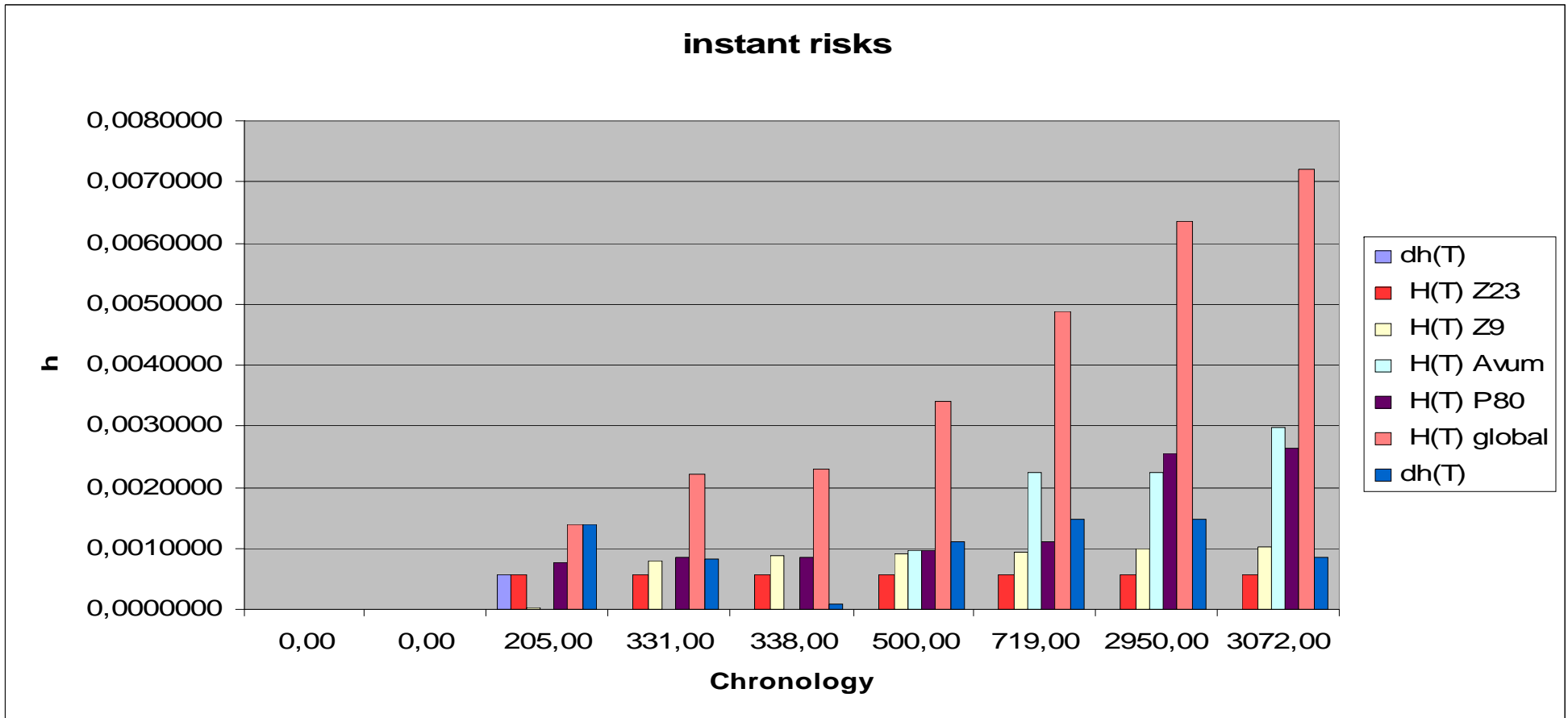
R domain defined by reliability function $\xi(r_1, r_2, \dots, r_n)$

Analytic quick tool

MRESpace/ESRIM/SF-2006 6/NT 00 04(2)				Simplified Analytic Model for VEGA								
Time line → 0 →												
Subsystem	LIII	Test Entropy (MEQ)	NI	no incident	1 incident	durée	Missin for mode	transitions	of	Transition weight	Ground ageing before T=0 for that mode	Mission ageing for NHFP
0												
Load												
0												
Fct battery OBB		34482	1	NA	34482	1	3072		2	0,5	0,0000000	0,0000E+000
OBC	(Mode 17/2-3 [t,1])	12345	1	NA	12345	1	3072			0,5	0,0000000	0,0000E+000
MFU	(Mode 12-2 [t,1]) e.g.	3077	1	NA	3077	1	3072		2	0,5	0,0000000	0,0000E+000
IRS/IN \$	All Modes	5182	0	5182	NA	1	3072			0,5	0,0000507	5,0710E-005
RACS	FCV (18-1 (N,2) e.g.)	590	1	NA	590	1	3072			0,5	0,0000000	0,0000E+000
P80: 1) TVC												
Battery TVC	Mode: all but autonomy	16393	1	NA	16393	1	108			0,5	0,0000000	0,0000E+000
IPDU/CM/PM	Mode: all	2439	1	NA	2439	1	108			0,5	0,0000000	0,0000E+000
EMA (electronics)	Mode: all	6024	1	NA	6024	1	108			0,5	0,0000000	0,0000E+000
SRM	low/short Thrust			NA	NA							
	Flexible joint fail.			NA	NA							
	Nozzle failure			NA	NA							
				5182	590							
P80 ignition (FO)	Launch delayed	1012800										
Other constant PO	Separation %	285714	1									
Other constant PO	RR ignition	3225800	1									
Other constant PO	RR (5/0 at least)	240000	1									
						MISSION, 1	MISSION, N			SMU+SRU λsu	7,735000E-003	
				Example		3072	2			GdBenign<T=0, Ro=	0,88901200000	
										RSASpyrochain P80	0,89720700000	
										ΔH=h _u t	7,1189E-004	
										F' pyrochain P80	3,179916E-003	
										P(launcher ground impact (P80 boost)	7,7222E-009	
										T (heure)	0,03	
						Notes :						
						Boost1+Boost						
						2 =						
						301+122+303e						

figure 1 : mode characterisation block

Simplified result example



P80 boost phase

$$= G(T) * 7.8 \cdot 10^{-9} < 0.078 \cdot 10^{-7} \text{ (as } G(T) \text{ is a probability)}$$

P80/Z23 separation phase

$$= g(t) * 0.87 \cdot 10^{-9} < 0.0087 \cdot 10^{-7}$$

Mode Characterisation and Hierarchy

Thorough technology analysis

Rex data, expertise

FMECA, CIL, ...



Critical

Major

minor

negligible (*generally implicitly « absorbed »*)

CONFIDENCE P{R}

(χ^2 compatible)

