Is Optimized Design of Satellites Possible?

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ABSTRACT: The design of satellites is most of the time a legacy of traditional architectures that are already flight-proven. This conservative view leads very often with over-specifications and misfit with the mission scope. In doing so, the space community prevents itself from thinking in the opposite way, that is to say to start from requirements and then to design the best optimized architecture. This paper proposes to study an innovative approach based on reliability optimization.

1 INTRODUCTION

1.1 *Overview*

Optimization of the satellite architecture is an interesting option in case of the development of a constellation, because the high number of satellites allows a return on investment for this effort.

As an example, we propose to study a simple micro-satellite of the Myriade type and to follow two consecutive steps: first, we will build a simplified model of the satellite internal architecture (platform only, not payload, in order to reuse our study results on various missions), taking into account all its main sub-systems:

- Attitude and Orbit Control
- Propulsion
- Thermal regulation
- Power supply
- On-board processing
- Telecommunications etc…

This may seem a difficult task, considering that satellites have a very complex architecture with a lot of different equipments and redundancies. However, it is possible to build a reliability model of the architecture of one satellite thanks to Reliability Data Blocks, markovian graph or matrix, Fault Trees and redundancies formulas. The reliability prediction of each function (composed of redundant equipments if necessary) is computed with standard exponential law hypothesis. The failure rates data sources are typical in-field performance lessons learned or results of analytic predictions but not real figure for confidentiality constraints.

Then, the second step will consist in applying optimisation techniques based on genetic algorithms and non-linear simplex on this reliability model in order to find the best trade-off between costs and performances. Innovative variant of architectures are expected compared to traditional design and the associated benefits in terms of costs will be evaluated, in relative compared to arbitrary prices used for the study.

1.2 *Methodology*

The reliability of the platform satellite model is computed thanks to markovian techniques associated to Fault-Tree, because each function is considered necessary to the good functioning of the satellite. Nevertheless, each function can include redundancies in itself.

The optimization technique is based on genetic algorithms. Faure et al (2006), Cabarbaye et al (2006).

The software tools are respectively SUPERCAB and GENCAB of the Cab Innovation company.

Based on a hybrid method associating Genetic Algorithms (Goldberg 1994), Differential Evolution (Feoktistov 2004) and nonlinear Simplex (Nelder Mead algorithm), the principle of this generic tool is illustrated by figure 4 (Cabarbaye 2003). Composed of various parameters (genes) of type real, integer or binary, the chromosomes are subjected to random mutation, crossings and differential evolutions (summation of a gene of chromosome with the difference between same genes of two other chromosomes). After selection, the best elements of the population can be improved at the local level by several steps of Simplex. This hybridization of total and local techniques, which can be possibly parameterized, allows making the tool robust to the diversity of the problems defined by the user on a sheet of spreadsheet. Thus the Differential Evolution will be generally more effective to treat a convex function but will present the disadvantage, for others, simultaneously to exploit the whole of genes.

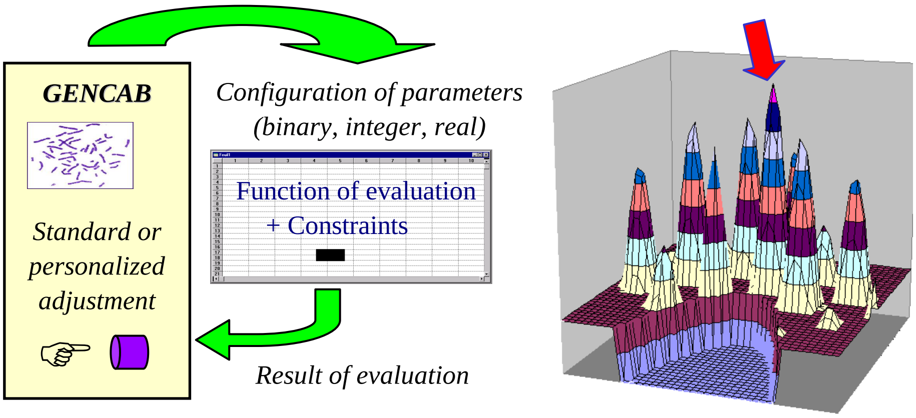

Figure 1. Principle of the tool

The genetic algorithm is then coupled with an evaluation algorithm based in that case, on Markovian and fault-tree process, allowing to compute the satellite reliability.

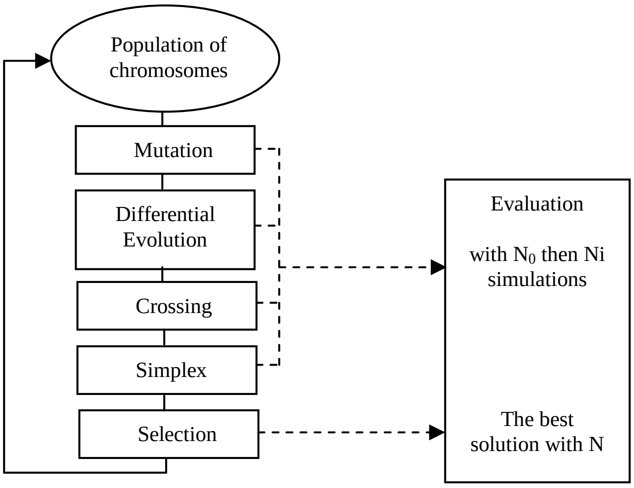

Figure 2: Coupling

2 RELIABILITY MODEL

2.1 *Main parameters*

The main parameters are in the satellite model:

- Equipments
- Failure Rate expressed in FIT (10^-9 failure per hour) in ON or OFF mode
- Number of equipments
- Kind of redundancy (active, passive or none)
- Rate of utilization

For each equipment, the reliability is computed for a time duration: we chose 5 years in this example. The reason why is that it is an interesting perspective to push the limit of this satellite platform that was initially intended to operate for 2 years maximum (but proved much superior in-field lifetime).

2.2 *Results for the series platform*

The reliability of the series platform at 5 years is evaluated to 0.6 approximately. See Table 1.

EQUIPMENTS	Failure rate ON (fit)	Nb	Kind of redundancy	Failure rate OFF(fit)	Utilization rate r (%)	Unit cost high quali. k€	Quality Level	Reliability T (years) = 5
Power Supply	**1000**		**serie**			100	1	0,95714537
Solar Array	100		série					0,99562958
Battery	230		série					0,98997657
	100		active 9/10					0,99916028
Potential SPF (Central Computer)	40		série					0,99824953
I/O 1	500		série					0,97833806
I/O 2	500		série					0,97833806
TM/TC - clock	100		passive 1/2					0,99998948
TM/TC - I/F	100		passive 1/2					0,99998948
TM/TC - I/F +FPGA	200		série					0,99127826
TM/TC - I/F Telemetry	100		passive 1/2					0,99998948
CPU- Flash Memory	**200**		active 2/3			10	1	0,99977312
CPU- FRAM	200		active 1/2					0,99992393
CPU - FPGA,T805,DRAM..	**300**		série			20	1	0,98694595
CV1 - DC/DC chain	500		passive 1/2					0,99974022
CV1 - PPU DC/DC	50		série					0,9978124
UCM	300		série					0,98694595
Memory component	70		série					0,99695992
S Band emitter	**800**		passive 1/2		2,00%	50	1	0,99998427
S Band receiver	1100		active 1/2					0,99778745
S Band antenna and filter	30	2	série					0,99737545
Solar Sensor	10	3	série					0,99868686
Gyrometers	800	3	**serie**			20		0,90021649
Propulsion	1500		série		1,00%			0,99286428
Reaction Wheels	500	4	**serie**			40		0,91612725
Magneto Torque Bar	10	3	série					0,99868686
Magnetometer	400		série					0,98263258
Star sensor (electonics)	1100	1	**serie**			50		0,95296224
Star sensor (optical head)	300	1	**serie**			20		0,98694595
X Band telemetry unit	500		série		2,00%			0,99741914
X Band antenna and filter	20		série					0,99912438
GPS	2000		**serie**			30		0,91612725
‍iscell. (Pyro,wiring,thermal regulatio	200		série					0,99127826
$	SATELLITE PLATFORM							0,58769724

Table 1. Reliability model of the generic satellite platform

3 OPTIMIZATION

3.1 *Objective*

It is interesting to check if the potential of this platform can be stretched to a Reliability of 0.8 at 5 years, in order to use it for more operational missions that require a much better availability.

3.2 *Rationale*

In the reliability model of the satellite platform, it is easy to spot the main contributors to the global unreliability.

Targeting these equipments, our objective is to improve their reliability thanks to:

- Redundancy
- Components quality level (associated with cost)

In that scope, the satellite platform configuration can be seen as a set of parameters, such as a chromosom, and the optimization algorithm will find the one that provided the smallest cost within the reliability target objective.

3.3 *Targets of the optimization*

For this example, and not for real data, the targeted equipments are:

- power supply system
- flash memory
- main processor
- S-Band emitter
- Gyrometers
- Reaction wheels
- Star sensor: main electronic + optical heads
- GPS

The genetic optimization will be applied precisely to the listed equipments in this respect:

- For active or passive redundancies (M among N), the number N will be optimized.
- The components quality level will be optimized. The following hypothesis are exposed in Table 2.

EQUIPMENTS	Failure rate ON (fit)	Nb	Kind of redundancy	Failure rate OFF(fit)	Utilization rate r (%)	Unit cost high quali. k€	Quality Level	Cost k€	Reliability T (year) = 5
Power Supply	3525		Passive 1/2			100	2	100	0,988223573
Solar Array	100		série						0,995629578
Battery	38		série						0,998336984
	119,2		active 9/10						0,998813186
PPU potentiel (OBC)	38		série						0,998336984
I/O 1 (OBC)	500		série						0,978338064
I/O 2 (OBC)	500		série						0,978338064
TM/TC - OCXO (OBC)	100		passive 1/2						0,999989481
TM/TC - PIC rep (OBC)	100		passive 1/2						0,999989481
TM/TC - I/F +FPGA (OBC)	200		série						0,991278257
TM/TC - PIC TMD (OBC)	100		passive 1/2						0,999989481
CPU- Flash Memory (OBC)	600		active 2/3			10	2	15	0,998016609
CPU- FRAM (OBC)	200		active 1/2						0,999923931
CPU - FPGA,T805,DRAM.. (OBC).	300		série			20	1	20	0,986945953
CV1 - DC/DC chain (OBC)	500		passive 1/2						0,999740224
CV1 - PPU DC/DC (OBC)	50		série						0,997812396
UCM (OBC)	300		série						0,986945953
Memory component (red)	70		série						0,996959918
S Band emitter	8300		passive 1/2		2,00%	50	3	20	0,998367749
S Band receiver	1160		active 1/2						0,997545902
S Band antenna and filter	20	2	série						0,998249534
Solar Sensor	9	3	série						0,998818099
GYRO	800	3	Passive 1/2			20		40	0,998024441
Propulsion	1524		série		1,00%				0,992750524
Reaction Wheels	500		Active 3/4			40		160	0,99726522
Magneto Torque Bar	7	3	série						0,999080623
Magnetometer	410		série						0,982202284
Solar sensor (electonics)	1110		Passive 1/1			50		50	0,952544932
Solar sensor (optical head)	324		Active 1/1			20		20	0,98590902
X Band telemetry unit	530		série		2,00%				0,997264496
X Band antenna and filter	20		série						0,999124384
GPS	1922		Passive 1/2			30		60	0,996324465
Miscell. (Pyro,wiring,thermal regulation)	174		série						0,992405743
$	PLATFORM							518	0,800278754

Objective: 0,8

EQUIPMENTS	Failure rate ON (fit)	Nb	Kind of redundancy	Failure rate OFF(fit)	Utilization rate r (%)	Unit cost high quali. k€	Quality Level	Cost k€	Reliability T (year) = 5
Power Supply	3000		Passive 1/2			100	2	100	0,99133358
Solar Array	100		série						0,99562958
Battery	230		série						0,98997657
	100		active 9/10						0,99916028
Potential SPF (Central Computer)	40		série						0,99824953
I/O 1	500		série						0,97833806
I/O 2	500		série						0,97833806
TM/TC - clock	100		passive 1/2						0,99998948
TM/TC - I/F	100		passive 1/2						0,99998948
TM/TC - I/F +FPGA	200		série						0,99127826
TM/TC - I/F Telemetry	100		passive 1/2						0,99998948
CPU- Flash Memory	600		active 2/3			10	2	15	0,99801661
CPU- FRAM	200		active 1/2						0,99992393
CPU - FPGA,T805,DRAM..	300		série			20	1	20	0,98694595
CV1 - DC/DC chain	500		passive 1/2						0,99974022
CV1 - PPU DC/DC	50		série						0,9978124
UCM	300		série						0,98694595
Memory component	70		série						0,99695992
S Band emitter	8000		passive 1/2		2,00%	50	3	20	0,99848139
S Band receiver	1100		active 1/2						0,99778745
S Band antenna and filter	30	2	série						0,99737545
Solar Sensor	10	3	série						0,99868686
Gyrometers	800	3	Passive 1/2			20		40	0,99802444
Propulsion	1500		série		1,00%				0,99286428
Reaction Wheels	500		Active 3/4			40		160	0,99726522
Magneto Torque Bar	10	3	série						0,99868686
Magnetometer	400		série						0,98263258
Star sensor (electonics)	1100		Passive 1/1			50		50	0,95296224
Star sensor (optical head)	300		Active 1/1			20		20	0,98694595
X Band telemetry unit	500		série		2,00%				0,99741914
X Band antenna and filter	20		série						0,99912438
GPS	2000		Passive 1/2			30		60	0,99602952
Miscell. (Pyro,wiring,thermal regulatio	200		série						0,99127826
$	SATELLITE PLATFORM							518	0,79605702

Table 3. Configuration resulting from the optimization

Objective: 0,8

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4 CONCLUSION

Facing the increase in the use of COTS technology, intrinsically more sensitive to radiations in the case of the micro-processors, one candidate solution is to implement more redundancies.

Towards an evolutionary model of satellites design: it might be the next cutting edge methodology for optimized design, based on reliability, costs or power consumption, mass etc…The optimized parameters have practically no limits, and the increase in computing power will allow to deal with models in which every parameter will be subject to optimization.

The techniques and the way of thinking exposed in this paper are currently being put into practice at the French Space Agency (CNES) on future project designs at satellite and system level: constellations (deployment and maintenance strategy), ground segment infrastructure (maintenance of repairable systems).

5 REFERENCES

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