SAFETY BY ZONAL ANALYSIS IN AIRCRAFT CONCEPTUAL DESIGN: APPLICATION TO S.A.v.E. PROJECT

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Abstract. The objectives of this work are the evaluation and the application of the Zonal Analysis methodology, which is typical of conceptual design context. The AeroSpace System Engineering Team (A.S.S.E.T) at the Department of Aerospace Engineering at Politecnico di Torino has developed a thorough knowledge in the field of safety analysis and conceptual design. The integration of these two aspects with the use of parametric 3D CAD, as presented in this work, shows the huge benefits in terms of cost-effectiveness and increased safety in the design of subsystems layout. The Zonal Analysis approach has been applied to the concept of a future MALE (Mid Altitude Long Endurance) unmanned aircraft, called S.A.v.E..
Keywords. Safety in installation, Safety Zonal Analysis, Bay, Risk, CAD, Fuel-cells, Digital Mock-Up

1 Introduction

The AeroSpace System Engineering Team at the Department of Aerospace Engineering of Politecnico di Torino has always been interested in the development of design methodologies which rate safety of the design at the highest level.
Unfortunately this target is particularly difficult to pursue during the early phases of the design, due to the still poor definition of the product. Moreover it is clear that removing defects (potential sources of dangerous events) as soon as possible has the relevant advantages of:

1) reduction of resources wasted in making choices that might be rejected in the next future;
2) higher probability of improving the final product, as the greatest part of the product characterization will be achieved in conceptual/preliminary design.

The main tool useful for System Safety Analysis is the FTA – Fault Tree Analysis and it is good practice to utilize it since we have a first architectural layout (i.e. Block Diagram at least at main equipments level); so we can check if the hypothesized system architecture is adequate to fulfill the safety requirement. Unfortunately the FTA is capable of capturing only functional Safety critical failure; in fact the FTA becomes inadequate when we start considering also the failures caused by the interaction between the installed equipments. The installation design is particularly important when

systems are characterized by a great number of equipments in a very reduced space. The density of components installed into a combat aircraft is a critical aspect as the closeness of the components/subsystems can cause extremely serious induced failures. As a matter of fact failures, that could be ignored from a functional perspective, could propagate to the close components and lead to a collapse of the whole system. Not taking into account this kind of failures may lead to wrong results in a preliminary analysis focused on functional aspects. The number of necessary redundancies could, for example, be underestimated or unexpected induced failures could arise.
While it is fairly easy to estimate the probability of functional failures, it is more difficult to assess the probability of induced failures. As far as the failures effects are concerned, it can be said that for both functional and induced failures the estimation is quite difficult. So far, classical Zonal Analysis techniques, which consist in a visual check carried out by all designers of the subsystems installed in the area under examination, have been developed and used on the basis of aircraft mock-ups and/or prototypes. The efficacy of the Zonal Analysis is assured by exchanging ideas arising among the working team and by check lists reporting all design criticalities available from the past experience. Recent progresses in 3D CAD SW tools offer now the advantage of using digital mock-ups to perform Zonal Analysis for safety studies. Considering that ASSET, in the past, devoted many efforts to develop Conceptual Design methodologies, based on 3D CAD [1], [2], [3], with the possibility of carrying out a preliminary Digital Mock-Up (called DMUCL Digital Mock-Up at Conceptual Level), the application of Zonal Analysis to DMUCL has been planned in order to face Safety criticalities due to installation even in early design phases, thereby greatly enhancing the ability to anticipate failures. An example of the DMUCL is shown in Figure 1; the main components of each system are virtually installed into the aircraft 3D-model.

Figure 1 - DMUCL of S.A.v.E. aircraft

The purpose of this paper is to present the results of the accomplishment of the preliminary safety analysis during the early phase of conceptual design, instead of performing it at installation level (Figure 2). This is possible thanks to a conceptual design methodology strongly integrated with 3D CAD tools, which has already led us to the implementation of Digital Mock-Up at Conceptual Level (DMUCL). The paper illustrates the Methodology and its application to a “Concept” of a future

MALE-Mid Altitude Long Endurance unmanned aircraft, named SAvE and shown in Figure 1. SAvE is the acronym for "System for UAV Advanced Alternative Energy". It is a research program, funded by Piemonte Regional Government and lead by Politecnico di Torino, in cooperation with ALENIA Aeronautica [4], [5].
The main goal of the SAvE project is to investigate innovative solutions for the onboard secondary power subsystem, where High Voltage DC Generation and Fuel Cells fed by H2 are taken into account. Considering also the aircraft long endurance (more than 30 hours of mission) and the airworthiness issue, the application of the Zonal Analysis methodology in the conceptual design phase seems particularly interesting.

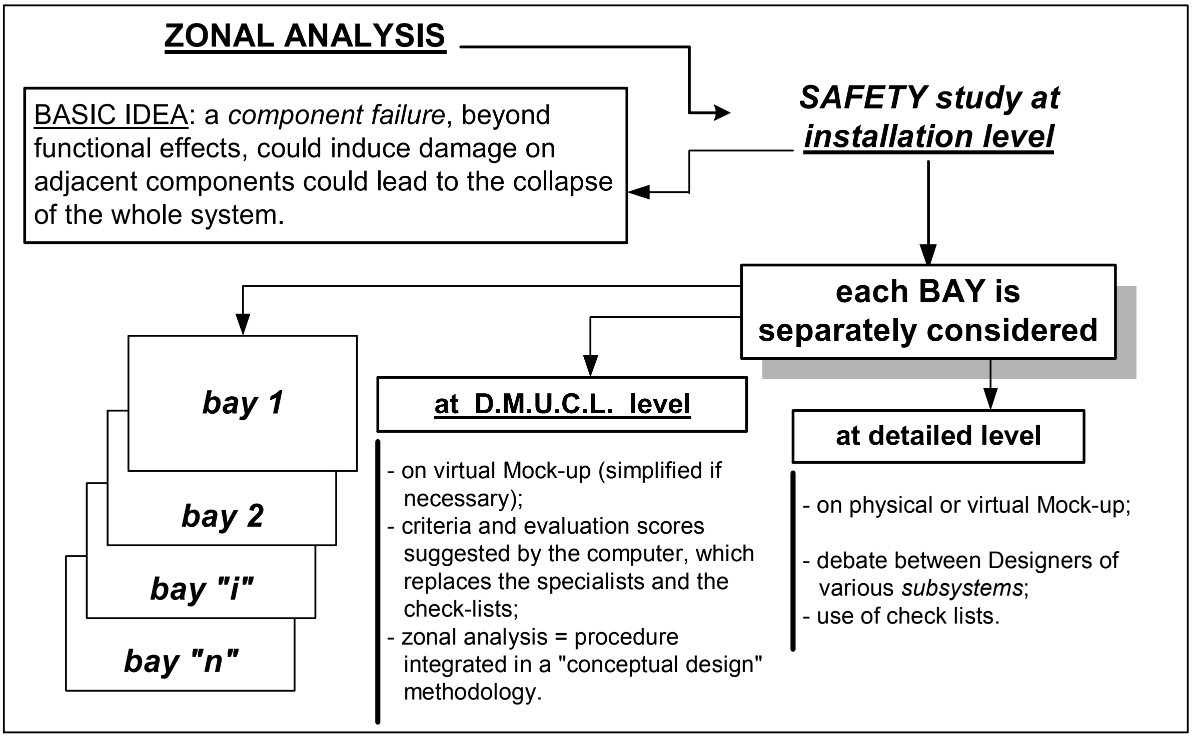


Figure 2 - Zonal Analysis at the traditional level of detail and in the context of Conceptual Design

2 Zonal Analysis at Conceptual Design Level

Let us shortly remind here our Conceptual Design methodology:

1. conceptual design at system level: definition of main aircraft characteristics (weight, thrust or power to weight ratio, wing surface, etc.) and estimation of other parameters (for example, zero-lift drag coefficient, subsystems weights, etc.) by means of algorithm based on analytical, statistical or empirical relationships integrated with drawing/modelling phases, performed thanks to 3D-CAD tools. The results of these first phases of design make it possible to estimate new characteristics of the aircraft (fuselage length, aspect ratio, etc), in order to verify performances and to assess effectiveness and cost.

2. Preliminary design at subsystem level: design of the main aircraft subsystems, including the preliminary definition of the structural layout. The typical sequence is:

a. definition of the block diagram with PFMEA (Preliminary/functional Failures Modes and Effects Analysis) and FTA analyses and 3D-CAD non dimensional models of subsystems' components;
b. sizing of components (thanks to the parametric features of 3D-CAD tools) by means of algorithms and/or simulations;
c. installation of the sized components in the airframe, thereby carrying out DMUCL.

The DMUCL has already been extensively applied and has proven useful in:
1. verifying the actual possibility of the airframe to contain all subsystems and check the right positioning of each equipment;
2. allowing a very accurate and easy estimation of the centre of gravity, geometrical quantities and tanks capacity: all these quantities are automatically calculated by 3D CAD software;
3. studying assembling procedures, accessibility for maintenance and safety analysis.

In Aeronautical Industries the "Safety Zonal Analysis" is usually performed with physical or digital mock-up support. In our case, due to the extremely early development stage, only the second method is applicable.

With reference to Figure 2, in traditional applications debates and brainstorming between different specialists and the extended use of check lists are the basic tools leading to complete the Zonal Analysis. The accomplishment of the Zonal Analysis in earlier development stages cannot be based on debates and brainstorming, as the specialists are not involved yet in the conceptual design phase.

Therefore a different computerized method becomes necessary to evaluate risks. The procedure presented in this work is characterized by the following steps:
a. subdivision of the aircraft in several zones, carried out through CAD by planar surfaces "cutting" the aircraft. It is possible to draw out information on equipments/modules, placed in different zones, from the previously defined DMUCL (Figure 3 and Figure 4) [6];
b. definition of the equipment/module risk level: this is performed by the designers through an "engineers' judgement", taking into account the following aspects:
   - ✓ probability of dynamic mechanical failures;
   - ✓ presence of fire sources;
   - ✓ presence of corrosive liquids;
   - ✓ presence of high pressure vessels or pipes;
   - ✓ presence of electrical devices;
   - ✓ equipment duty cycle.

   Each of the aforesaid aspects gets a score ("equipment risk score");
c. definition of the "zone risk level": this can be obtained by summing the equipments risk scores and the inherent bay risk score (obtained with a procedure similar to the previous one, which takes into account temperatures, vibrations and shock levels and probability of external hits of the bay);
d. definition of the "delta zone risk score" (Δ_{risk}), which is added to the previous sum. This score takes into account the induced risk due to the adjacent zones.

The whole procedure, used to perform the Zonal Analysis at Conceptual level [7], [8] is summarized in the scheme reported in Figure 5, that shows how the evaluation of "overall bay risk" can be obtained.
Table 1 illustrates an example of the coefficient evaluation necessary to carry out the procedure.

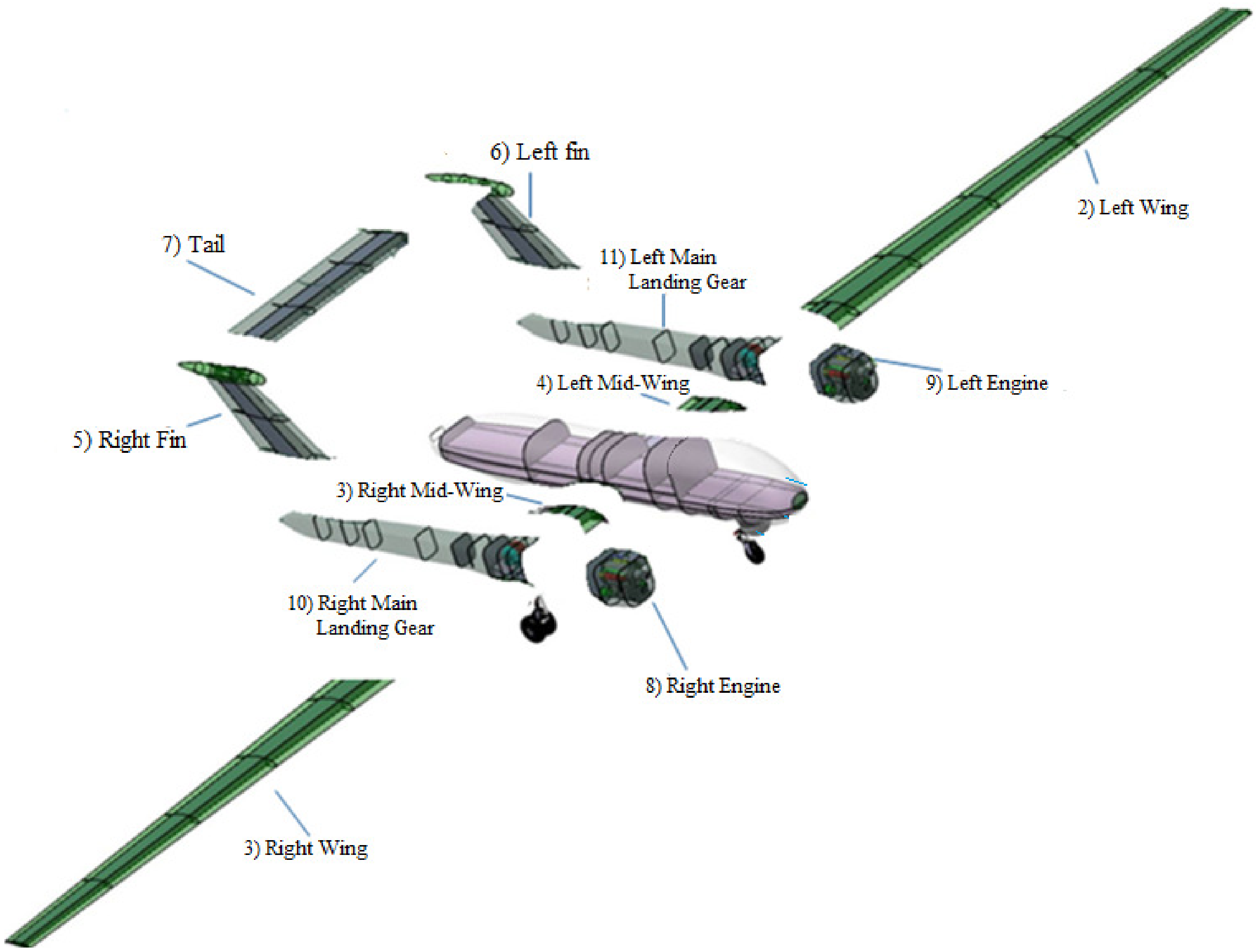


Figure 3 - Bays subdivision performed on a DMUCL (S.A.v.E. aircraft)

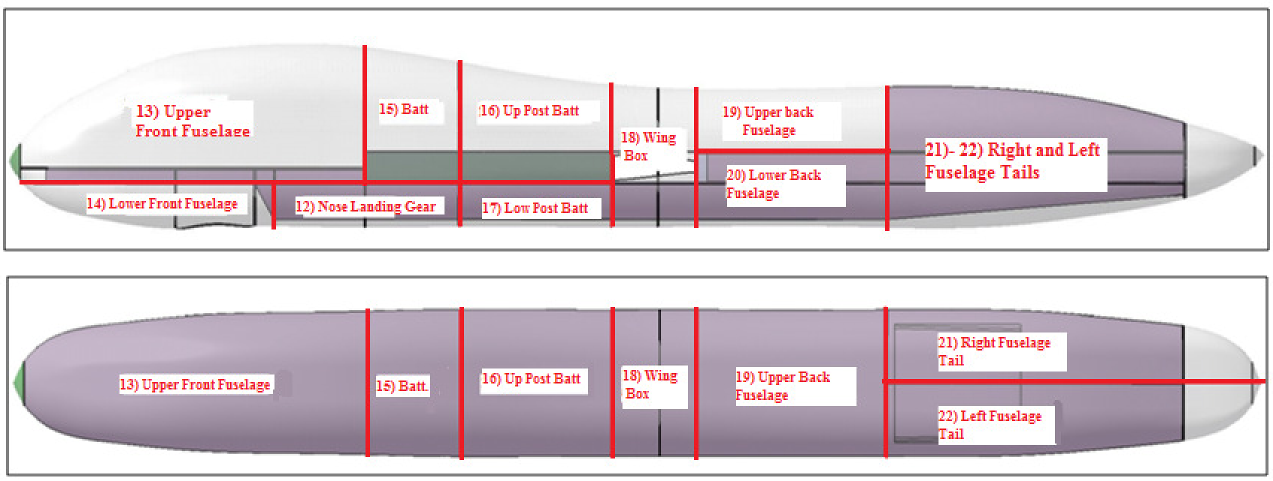


Figure 4 - Bays subdivision performed on a Fuselage DMUCL (S.A.v.E. aircraft)

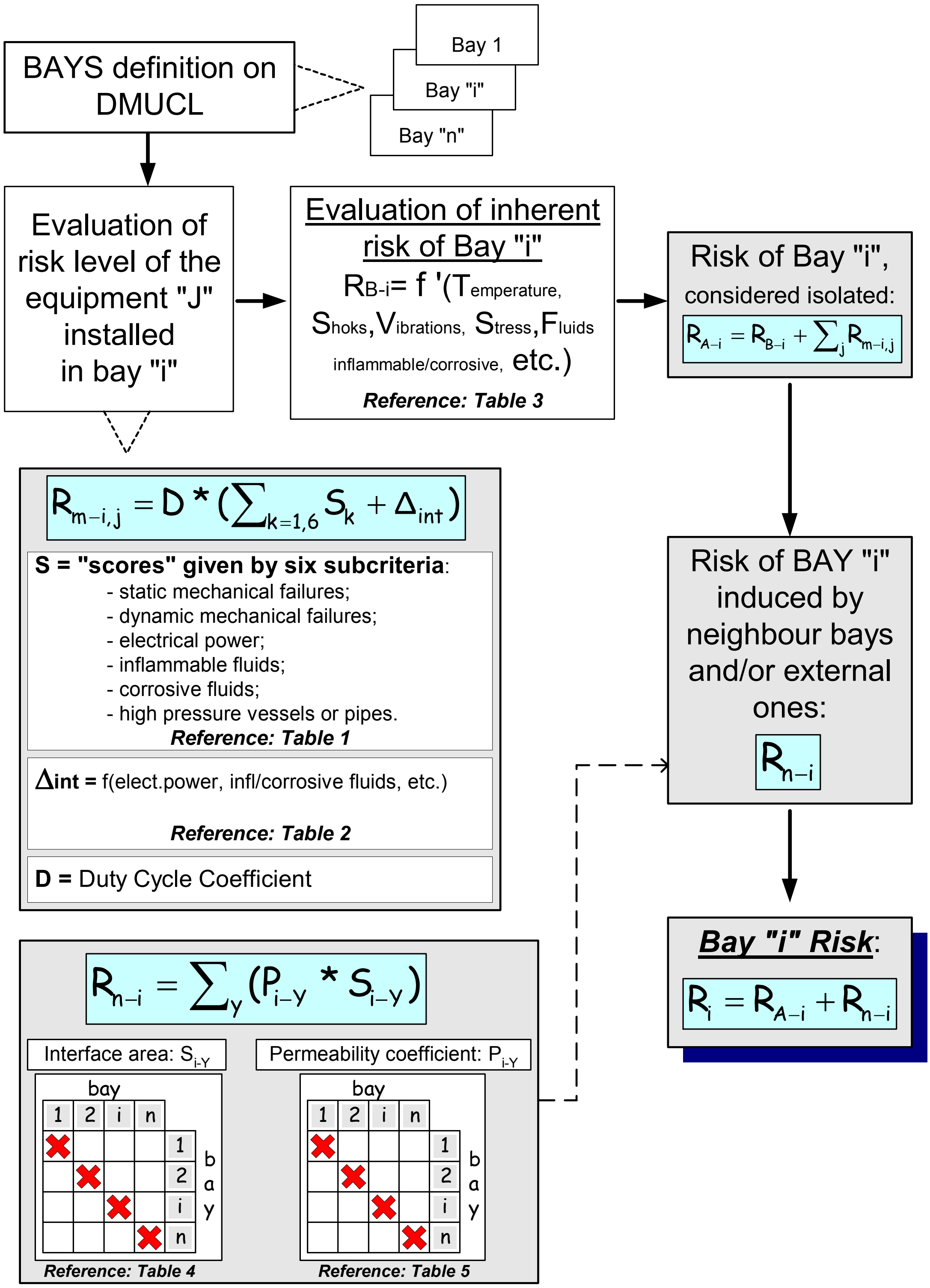


Figure 5 - Procedure to perform Zonal Analysis on DMUCL

Mechanical breakdown due to static failures	Thermal stress			Relative action				Forces or torques exchanged		
	None	Low	High	None	Rotation	Misc.	Friction	Low	Medium	High
	0	1	2	0	1	2	3	1	2	3

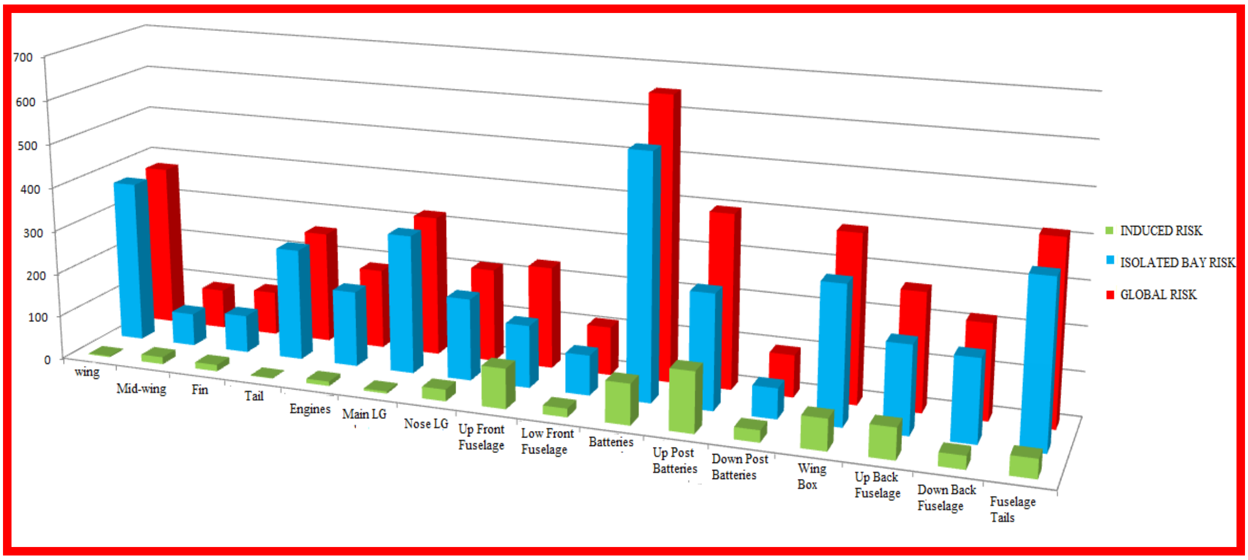
Table 1 - Example of coefficients evaluation

The final result of the procedure is therefore a score of "installation risk" for every bay constituting the aircraft. Please note that these scores do not have an absolute validity but they allow to visualize by comparison which bays have the highest "installation risk". The next application examples clarify this concept. The Zonal Analysis applied to DMUCL help the designer chose the right place where the various equipments can be installed, in order not to have bays with very high score and others with low score, as bays with a very high probability of generating failures due to installation have to be avoided, whenever possible.

3 Results and conclusion

The Zonal Analysis has been carried out for two different configurations of the S.A.v.E. aircraft: the first one is the conventional configuration, while the second is the one using fuel-cells for the Secondary Power subsystem. The visualisation by means of "Pareto plot" of the risk scores of the aircraft bays (each one with its own components) allows the designer to easily identify possible concentration of risks.

The Pareto plots for the two configurations are shown in Figure 6 and Figure 7



. Figure 6 - Pareto Plot for conventional configuration of S.A.v.E. aircraft

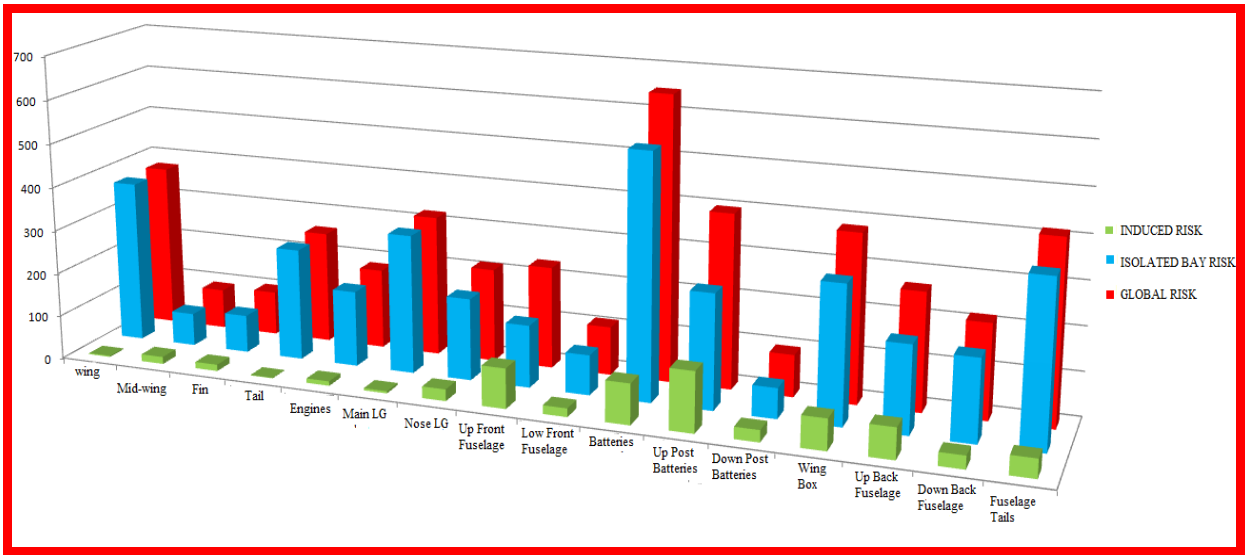


Figure 7 - Pareto plot for configurations with fuel cells of S.A.v.E. aircraft

Comparing the results shown in the previous figures, there are no changes in the risk scores of the bays, which do not have new installed modules or are not adjacent to the ones modified by the new configuration. The bays, which do not have new internal components but are neighbour of considerably modified bays, have an increase in induced risk. The bays containing fuel cells give an important contribution to the induced risk of the bays, which are adjacent to them: these bays run the major risks connected to safety.

According to the results evaluated in both configurations, the most critical bay is the battery one. In the conventional configuration this is due to the high number of batteries, while in the new configurations with fuel cells a lower number of batteries is installed but there are two hydrogen tanks, which become critical items for the safety of the aircraft.

So the installation of new modules with fuel cells gives advantages from an environmental friendliness viewpoint, but increases the risks connected to their presence.

	∑ Induced risks	∑ "isolated bay" risks	∑ global risks
Conventional	539	3063	3602
Fuel Cells	660	3747	4407

Table 2 - Evaluation of global risks

As shown in Table 2, risk scores for the new configurations with fuel cells, are all greater than the ones related to the conventional one. As for risks connected to isolated bay, which influences particularly the global risks, the score for fuel cells configuration is 20% higher than the conventional one; as previously said, this is due to a higher number of new installed modules and to the risk connected to the presence of hazardous gas like hydrogen. Besides, the new modules need to be fed by electrical supply and this affects particularly Zonal Analysis results.

In conclusion, quite obviously, high risk concentrations have to be avoided by changing the layout in the digital mock-up. Different new layouts will undergo again the procedure and the final results will give the designer information about:

- ✓ design's quality level reached;
- ✓ necessity of further improvement;
- ✓ indication of which areas offer the possibility of improvement.

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References

[1] S. CHIESA, M. DISCIUVA, D. CAMATTI, S. CORPINO, M. PASQUINO, "Utilizzo di CAD 3D parametrico per studi di configurazione e Digital Mock-up nel progetto concettuale", XV Congresso nazionale AIDAA Torino, Nov. 1999.

[2] S. CHIESA, D. CAMATTI, S. CORPINO, M. PASQUINO, N. VIOLA, "Affordable technological demonstrator for hypersonic flight", 4th International Seminar on RRDPAE, Warsaw, Dec. 2000.

[3] D. CAMATTI, S. CHIESA, S. CORPINO, G. LUDA DI CORTEMIGLIA, M. PASQUINO, "Maintainability and accessibility: logistics advantages by application of 3D CAD digital mock-up technique", SOLE Congress, New Orleans, Aug. 2000.

[4] M. BIRINDELLI, S. CHIESA, S. CORPINO, B. TRANCHERO, N. VIOLA **"**Alternative Energy Based Systems for Advanced Uav: The "S.A.v.E." Project**"** 26th ICAS Congress, Anchorage (Usa) October 2008

[5] S. FARFAGLIA, B. TRANCHERO, S. CHIESA, C. RAGUSA, G. SCAVINO, N. VIOLA "The SAvE project: hypothesis and investigation strategies for alternative energy based systems for MALE UAV" XX CONGRESSO NAZIONALE AIDAA - MILANO, ITALY, JUNE 29–JULY 3, 2009

[6] A. Borgese, D. Faggella, "CAD digital mock-up of S.A.v.E. aircraft", S.A.v.E. Program Internal Report, 2009

[7] S. Chiesa, D. Camatti, S. Corpino, M. Pasquino, G. Sembenini, "Safety by zonal analysis at a very early phase of system design", European international conference ESREL Congress, "Towards a safer world" Turin, Sept. 2001

[8] S. Chiesa, "Affidabilità, sicurezza e manutenzione nel progetto dei sistemi", C.L.U.T. Torino, 2008